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WASHINGTON, D. C., *September, 1892.*

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UNITED STATES GEOLOGICAL SURVEY

J. W. POWELL, DIRECTOR

CORRELATION PAPERS

NEOCENE

BY

WILLIAM HEALEY DALL

AND

GILBERT DENNISON HARRIS

WASHINGTON

GOVERNMENT PRINTING OFFICE

1892

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
U. S. GEOLOGICAL SURVEY,
DIVISION OF GEOLOGIC CORRELATION,
Washington, D. C., July 12, 1891.

SIR: I have the honor to transmit herewith a memoir by Messrs. William H. Dall and Gilbert D. Harris on the Neocene of the United States, prepared for publication as a bulletin.

The Division of Geologic Correlation was created for the purpose of summarizing existing knowledge with reference to the geologic formations of North America, and especially of the United States; of discussing the correlation of the formations found in different parts of the country with one another and with formations in other continents; and of discussing the principles of geologic correlation in the light of American phenomena. The formations of each geologic period were assigned to some student already well acquainted with them, and it was arranged that he should expand his knowledge by study of the literature and by field examinations of classic localities, and embody his results in an essay. The general plan of the work has been set forth on page 16 of the Ninth Annual Report of the Survey and on pages 108 to 113 of the Tenth Annual Report, as well as in a letter of transmittal to Bulletin No. 80 of the Survey.

The present essay is the fifth of a series, having been preceded by essays on the Carboniferous and Devonian, the Cambrian, the Cretaceous, and the Eocene, prepared severally by Messrs. Williams, Walcott, White, and Clark, and constituting Bulletins 80, 81, 82, and 83.

Besides assembling and systematically outlining the published material available for the correlation of the Neocene formations, the memoir makes important original contributions based on personal investigations by Mr. Dall in the field and in the laboratory. In respect to Florida these contributions are so important that it has seemed best to expand the chapter on that State so as to include practically all that is known of its geologic history.

While using freely the terms of the Lyellian classification of the Cenozoic, the authors are of the opinion that the correlation of individual American formations is impracticable; that all the present classifications and correlations are provisional merely; and that in the nature of the case it is not to be expected that even the major divisions of European Cenozoic classification can be paralleled with synchronous divisions in America. Their use of the terms Eocene, Miocene, and Pliocene is analogous to that defined by Huxley as homotaxial.

Very respectfully, your obedient servant,

G. K. GILBERT,
Geologist in charge.

Hon. J. W. POWELL,
Director U. S. Geological Survey.

OUTLINE OF THIS PAPER.

This paper, after discussing general principles connected with the study and description of the Tertiary or Cenozoic rocks and fossils contained in them, takes up the Neocene deposits of the United States in particular.

A chapter is devoted to a summary of what is known in regard to the Neocene of the eastern coast of the United States, each State in geographical order being separately considered, beginning at the north. The State of Florida, in regard to which much unpublished information was available, being entirely composed of Cenozoic rocks, and therefore as a type of such structure peculiarly interesting, is treated of in greater detail and more at length than in other cases. The part of this essay relating to the State of Florida is really a preliminary geological report on that State, of which the structure has hitherto been very little known. The important fact that until the Pliocene period Florida, so far as it was elevated above the sea, was an island separated from the mainland by a wide strait, is here first demonstrated. It is also shown that the strata are probably gently folded lengthwise of the peninsula, and that in the trough now occupied by the "lake region" of Florida in Pliocene time a large lake probably existed, to which the name of De Soto has been applied. The age of the remains of fossil vertebrate animals, which in south Florida are associated with the so-called "pebble phosphates," is here definitely determined.

After discussing by States the character and distribution of the Atlantic Neocene, a chapter is devoted to the consideration of the general geological movements and fluctuations of land, sea, currents, and water temperatures which appear to have been concerned in producing the characteristics described.

In like manner the Neocene geology of the Pacific Coast has been treated, and in addition to that of California, Oregon, and Washington, a synopsis of data relating to British Columbia has been included, together with a summary of what is known in relation to Alaska during this epoch. The latter discussion contains a large amount of material extracted from unpublished notes covering some fifteen years' study and exploration by W. H. Dall in the Alaskan region, and therefore adds materially to the sum of our knowledge in regard to that part of the United States.

The Great Interior region of the West is then taken up, and a summary of our knowledge in regard to its Neocene geology is brought together for the first time. While this is necessarily far from perfect, the very fact that such gaps exist will stimulate the collection of information to supply the missing links.

The essay closes with a list of names proposed for geological beds, groups, and formations in the American Cenozoic strata and a description of the data upon which the coloration of the general map is based.

THE NEOCENE OF NORTH AMERICA.

By William H. Dall and Gilbert D. Harris.

INTRODUCTION.

This paper has been prepared at the request of the Director of the U. S. Geological Survey as one of a series of essays on American geologic systems, with the view of presenting a summary of the state of our knowledge of the Neocene of the United States. This summary being needed by a stated time, it has been necessary to attempt only what could be done in a satisfactory manner within that period, rather than what might have been practicable with unlimited time at one's disposal. It will be understood, therefore, that absolute completeness, however desirable, was neither attained nor sought. It is believed, nevertheless, that reference has been made to all facts of serious importance within the scope of the paper as planned.

It will be understood, to begin with, that the scope of this essay is not intended to include matters lying within the field of paleobotany, vertebrate paleontology, or the vulcanology of the American Neocene.

To sketch, from researches into the literature, the extent and character of the Neocene deposits on the coasts and in the interior regions of the United States; to point out the sequence of the chief modifications, faunal and physical, of the regions concerned during the periods stated; to enumerate the names applied to geologic formations, beds, etc., included in the American Neocene; to refer to the chief sources of information bearing on the subject; and to indicate the work most urgently needed to be done in order to supply deficiencies in our knowledge;—these have been the objects kept in view.

It has been found impracticable at the present time to do more for the Interior region than to summarize the literature. Any attempt to correlate fresh-water deposits of limited extent with each other or with the marine beds laid down in the coast regions, presents such difficulties that authors differ greatly among themselves. The information, especially the knowledge of the fauna of these various beds, notwithstanding all that has been done and the extensive literature which exists, is extremely fragmentary and imperfect when the whole field is considered. It has been found impossible to map some formations of which the age is pretty well determined from the vertebrate fauna, for the reason that authors have frequently refrained from stating the exact provenance of the fossils which they have described.

The small scale of the map available for use in this connection has also tended to give this part of the present work a general rather than a detailed character. This, perhaps, would have been advisable at any rate on account of the imperfection of our present knowledge.

Time has not been available for researches into the literature of such extra-limital regions as Mexico, the Antilles, Greenland and the Dominion of Canada, which might very properly have been correlated with those relating to our own territory.

Nearly all the literature of importance in the general history of research into the geology of the Neocene of America has been referred to by footnotes in the course of this essay. This literature is hardly to be separated as a class by itself from the general literature of the American Cenozoic. The names of Say, Conrad, Lyell, Lea, and Rogers are eminent among those who have contributed most to the progress of knowledge in this direction, to say nothing of others who are still living. The same names would hold a similar preeminence in a discussion of the Eocene. To separate the history of research into the Neocene from the other geological investigations with which it was originally associated and is more or less firmly linked, has appeared a work of too little interest or importance to occupy time which could be otherwise profitably employed; and therefore it has not been attempted.

The character of the topography associated with the rocks of this series is referred to in the local discussions of particular regions. The rocks of the system, as a whole, have no such topographic distinctness from lithologically similar rocks of other epochs as would make it practicable to diagnose them without a knowledge of their fossil fauna. Indeed, one of the most necessary reforms in Cenozoic nomenclature is the elimination of such mineralogical designations as "White limestone", "Rotten limestone", "Lignitic", "Buhrstone", etc., for geological formations. However applicable they may be in describing single strata of a single section, the belief in their distinctiveness as applied to larger areas is responsible for much confusion. It has happened that strata ranging all the way from the Cretaceous to the Upper Miocene have been correlated and discussed as a single stratigraphic unit because they were all suitable for use in building chimneys. While this may be regarded as an extreme case, yet the principle is applicable to all the names above cited, and numerous others.

Publications like the present are useful much as are milestones on public roads. They show us approximately how far we have gone and suggest by implication how far we still have to go. Fully aware of the inevitable imperfections of the present summary, reflecting as it does both the imperfection of our knowledge and the limitations of those concerned in its preparation, the writers hope that its very faults may stimulate new and more thorough investigation leading to wider and more accurate knowledge of the rich and interesting system of which it treats.

From the perfection of its fossils and their close relationship to existing faunas the paleontology of the Neocene has for the biologist a unique interest. Nowhere is there a more perfect succession of fossiliferous beds of this epoch than on the Atlantic shores of the United States. We may therefore anticipate the inscription of a really epoch-making page in the history of organic evolution when the record of these faunas shall have been perfected.

As regards the division of labor between the senior and junior authors of this paper, it may be stated that the work of searching the literature and bringing together the scattered data relating to particular States or regions has been largely performed by Mr. Gilbert D. Harris. For the revision and correlation of this material and for the whole of the chapters on Florida, British Columbia and Alaska, and the general discussions embodied in the essay, Mr. Dall is responsible. The list of formations, which, short as it is, has cost much labor and correspondence with authors who have proposed the names, has been prepared by Mr. Harris, who has also prepared the chapter on the Interior region.

CHAPTER I.

GENERAL CONSIDERATIONS.

EARLY CLASSIFICATION OF AMERICAN CENOZOIC BEDS.

The original division of the Tertiary formations into Eocene, Miocene, and Pliocene by Deshayes and Lyell on the basis of the supposed percentage of living forms in their fossil contents was, early in the history of American geology, applied by Lea[1] and Conrad to the Cenozoic beds of the Atlantic coast.

The discrimination of the Chesapeake Miocene from the Eocene, as soon as the beds and fossils were studied, followed as a matter of course. The gap between them, which farther south is partly bridged by strata of the Tampa and Chattahoochee groups, sufficiently emphasized the distinction thus drawn. Lea, in the publication above cited, doubting whether any Miocene in the European sense had been observed in America, referred the Miocene of Virginia, Maryland and New Jersey to the "Older Pliocene" of Lyell, a term equivalent to Pliocene of our present notation; the "Newer Pliocene" being what we now term Pleistocene.

About the same time Conrad[2] had divided the Tertiary into Upper Marine (Miocene), Middle Tertiary (Eocene), and Lower Tertiary, following the system of Conybeare and Phillips; but in the second edition of his cited work (part 4, p. 36) he adopts the nomenclature introduced by Lea. Three years later[3] he substituted for "Older Pliocene" the term "Medial Tertiary" (p. VI) which he still regarded as the equivalent of Pliocene (cf. p. 45). The use of the term Miocene as applied to the American strata now known as such was established by Conrad in 1841, in a communication[4] to the National Institution of Washington,

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[1] Contributions to Geology, by Isaac Lea, Philadelphia: Carey, Lea, and Blanchard. 1833. 8°. pp. 227, 6, pl.; cf. pp. 18–21.

[2] Fossil shells of the Tertiary formations of North America, by T. A. Conrad, Philadelphia, the author, 1832, 8°. Introduction, pp. 9–14; 2d edition. Mar., 1835.

[3] Fossils of the Tertiary formations of the United States, Philadelphia: J. Dobson. 1838. 8°.

[4] Observations on a portion of the Atlantic Tertiary region. Proc. Nat. Inst., 1841, 2d bull., p. 177; published in 1842. Isaac Lea, in his Contributions to Geology, 1833, p. 158, places the "Upper Tertiary (Conrad) of Virginia" in apposition to "the Miocene of Lyell." In the same work, however, on page 211, he refers the fossils at St. Marys, Md., to the "Older Pliocene" of Lyell.

Conrad used the term Miocene in the first edition of the introductory part to the republication of No. 3, Fossil Shells of the Tertiary Formations, 1835, p. 36, in designation of that portion of the now so-called Miocene which outcrops at Stow Creek, N. J., Charlotte Hall, and Choptank River, Maryland, and is characterized by *Perna maxillata* Lam. In the second edition of this introduction these localities are placed among those of the Older Pliocene.

W. B. Rogers used the word Miocene as now understood April 8, 1841, before a meeting of the Association of American Geologists. See Silliman's Journal, 1841, volume 41, p. 175.

in which he gives a table of the supra-Cretaceous deposits of the Atlantic coast. In this the absence of the Pliocene between the Miocene or Medial Tertiary and the Pleistocene or Upper Tertiary is duly indicated. Similar conclusions were announced by Lyell[1] in 1842, as a result of which the nomenclature of the chief divisions of the American Cenozoic series was definitely fixed. The marine strata of the Atlantic coast, which are Pliocene as now understood, were first definitely referred to that epoch by Prof. Michael Tuomey in 1846. He found the percentage of living forms in certain beds of South Carolina to be nearly 50 per cent and, on that ground, referred[2] the Carolinian fauna to the Pliocene of Lyell. This fauna was afterward beautifully illustrated in the well known publication by Prof. Tuomey and Dr. F. S. Holmes.[3] It has since proved to be, as will be shown later, a mixed assemblage, containing numerous Upper Miocene species, together with others properly referable to the Pliocene.

Realizing the impracticability of a rigid application of the system of percentages employed by Lyell, Dana proposed[4] for the American epoch referred to the Miocene by Lyell and Conrad the alternative term "Yorktown epoch," and for the American Pliocene the term "Sumter epoch." In 1884 Prof. Heilprin prepared a convenient summary[5] and discussion of the existing knowledge of the Atlantic coast Tertiaries, in which he refers Tuomey's Pliocene to the uppermost part of the Miocene, leaving the question open as to the existence of genuine Pliocene on the Atlantic border. Assuming that the mixed assemblage of Tuomey was a natural fauna, this course was justified by the presence in it of several characteristic Miocene types.

In this publication Prof. Heilprin classified the Atlantic Miocene as follows:

(1) CAROLINIAN (Upper Atlantic Miocene), comprising deposits of North and South Carolina, equivalent to the Sumter epoch of Dana.

(2) VIRGINIAN (Middle Atlantic Miocene), comprising deposits of Virginia and of the "newer" group of Maryland, equivalent to part of Dana's Yorktown epoch.

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[1]Proc. Geol. Soc. London, 1842, vol. 3, pp. 735–742; also 1845, vol. 4, pp. 547–563.

[2]Final report on the Geology of South Carolina, 1846.

[3]Pliocene fossils of South Carolina, containing descriptions and figures of the Polyparia, Echinodermata, and Mollusca. Charleston, S. C., Russell & Jones, 1857. This fine work appeared in quarto in bi-monthly numbers, as follows: Nos. 1 to 6 in 1855, Nos. 7 to 15 in 1856, the title page and index and pp. i–xvi in 1857. Each number comprised two plates and accompanying text; Nos. 3 and 4, 5 and 6, 9 and 10, 11 and 12, 13 and 14 were double numbers. The total comprised pp. i–xvi, 152, and 30 leaves unpaged explanatory of the plates. Each number had a printed title on the cover, with date.

[4]Manual of Geology, by James D. Dana, Philadelphia: Bliss & Co. 1863. 8°. pp. xvi; 798; cf. pp. 506–507. The author remarks, in relation to the Lyellian percentages, "These proportions are not capable of general application. It is possible that beds in America containing all extinct species may be synchronous with those of Europe in which there are 10 or 15 species of recent shells. Moreover, not even the subdivisions in different parts of Europe can be made to correspond to these epochs; still they are convenient terms for Lower, Middle, and Upper Tertiary, and with proper caution may be used to the vantage of the science, op. cit., p. 506.

[5]Contributions to the Tertiary Geology and Paleontology of the United States, by Angelo Heilprin; Philadelphia, the author, 1884, pp. (vi) 118, 4° and map. This work is in part an expansion and reissue of articles previously published by the author.

(3) MARYLANDIAN (Lower Atlantic Miocene), comprising deposits of the "older" group of Maryland and possibly the lower Miocene beds of Virginia, equivalent to that part of the Yorktown epoch not included in the Virginian.

Prof. Heilprin further correlates the "Virginian" with the "Second Mediterranean" of the Austrian geologists, and with the faluns of Touraine. The "Marylandian" he correlates to a greater or less extent with the "First Mediterranean" and with the faluns of Leognan and Saucats (op. cit., p, 67).

In the course of explorations in Florida, undertaken at the instance of Mr. Joseph Willcox, of Philadelphia, a fine series of Pliocene beds on the Caloosahatchie was explored in 1886–'87 and identified as true marine Pliocene by Prof. Heilprin in an extensive report[1] on the expedition. This identification completed the series of the Atlantic Tertiaries, excluding all contested deposits.

Beds of all three divisions of the Cenozoic were early recognized on the Pacific coast of the United States,[2] and the fauna has been summarized by Gabb in the Paleontology of California, volume II, 1869, and more lately by Dr. J. G. Cooper.[3]

These notes comprehend the chief points of interest in the history of the nomenclature of the marine Neocene of the United States. That of the fresh-water beds and strata containing terrestrial vertebrates of the great Interior region is still in an unsettled and more or less contested state, as will be pointed out in detail later in this essay.

BOUNDARIES OF THE SUBDIVISIONS OF THE CENOZOIC.

Preserving to some extent the Lyellian nomenclature for the chief divisions of the Neocene of America, while rejecting the method of percentages upon which it was originally based, it seems advisable to substitute provisional definitions for the chief subdivisions in place of those we have discarded.

EOCENE.

The end of the Mesozoic in America was for the most part marked by such physical changes that on the Atlantic coast at least little difficulty has been experienced in determining the fundamental boundary of the Cenozoic. The presence of sundry species of nearly world-wide distribution, like *Venericardia planicosta*, enables a certain correlation between the Eocene of Europe, of eastern and of western America to pass unchallenged. During the Eocene, or, at all events, the latter part

[1] Trans. Wagner Free Inst. of Science, Philadelphia, vol. 1, Philadelphia, the Institute, 1887; cf. p. 31.

[2] Cf. Report on the Geology of the Coast Mountains and part of the Sierra Nevada by Dr. John B. Trask; legislative document No. 9, Assembly, session of 1854, Sacramento, B. B. Redding, 95 pp. 8°, 1854. See pp. 35, 39.

[3] Catalogue Inv. fossils of the western slope of the United States. San Francisco: Bacon & Co. 1871, vi, 39 pp. 12mo., printed on one side only, for labels. Also, continued in Seventh Ann. Rep. State Mineralogist, Cal. State Mining Bureau, Sacramento, J. D. Young, 1888; pp. 223–308.

of it, it is known that a fauna indicating warm temperate or subtropical conditions extended on the Atlantic coast nearly to the Hudson, and on the Pacific to Oregon. At the same time a more or less free communication between the Atlantic and Pacific oceans existed in the present Central American region. Toward the end of the Eocene a movement in elevation affected the equatorial and Gulf regions of the two Americas and the Antillean area between them. One result of this disturbance was the elevation of Yucatan and part of Florida above the sea and the serious diminution, though not complete closure, of the passages connecting the Atlantic and Pacific.

MIOCENE.

For present purposes, therefore, the Miocene may be defined as that period of geologic time which began with the culmination of a vertical movement which terminated the Eocene and first raised central Florida above the sea.

As might be expected from the vertical range of this movement, the greater part of the littoral invertebrate fauna perished in the change, only those forms belonging to deeper water surviving. Among the forms which seem to have suffered total wreck at this time several large foraminifers, *Orbitoides*,[1] (?) *Nummulites*, etc., are conspicuous.

A second and analogous vertical movement brought the Miocene to a close and appears to have been marked by the definite and permanent connection of the Eocene island of Florida with the mainland to the north and west, and probably by the union of North and South America.

The Miocene, as thus defined, is distinctly separable into two epochs, recognizable by their faunal facies.

The first or Older Miocene presents a warm-water fauna, the invertebrates being such as might, so far as temperature is concerned, have existed in the preceding Eocene. The warm temperate conditions exhibited by the supposed Miocene leaf beds of Greenland were perhaps synchronous with the spread of this fauna, which can be traced as far as New Jersey, the conditions there being then similar to those now exhibited in the vicinity of the Isthmus of Panama.

The second or Newer Miocene is characterized by the extension southward of a relatively cold-water fauna which took the place of the warm-water assemblage. This fauna extended to Florida and to the Appalachicola River.

The first period is typified by the Chipola beds and the second period by the Ecphora bed or the Chesapeake Miocene in general.

If the invasion of the cold-water fauna was consequent upon an elevation of the sea-bottom at the south deflecting off shore the gulf and equatorial currents and allowing a cold polar stream to find its way

[1] Mr. J. C. Purves states, on the authority of Rupert Jones, that *Orbitoides mantelli* extends "*jusq'au sommet du Miocène* de la Jamaïque."—Bull. du Musée Royal d'Histoire Naturelle de Belgique. Tome III, 1884, p. 290.

southward inshore, the changes which mark the inception of the Pliocene might equally harmonize with a subsidence such as is called for by the deposition of the Lafayette formation.

PLIOCENE.

The marine Pliocene of the eastern United States is marked by a return to the Floridian region of a warmer, chiefly Antillean, invertebrate fauna. Many of the Chesapeake species survived the change and still persist in the Gulf region, indicating that the change, though obvious and well marked, was not sudden or cataclysmal. That the subsidence which permitted this influx from the south did not separate the two Americas or Florida from the mainland, is proved by the appearance, in mid-Pliocene, of South American terrestrial vertebrates in great numbers on the shores of Florida, and also in the interior of the continent.

By common consent the Glacial Period is taken as closing the Pliocene epoch. Yet we may be confident that its end was gradually attained and there seems to be no obvious reason why the great Pliocene mammals might not long have enjoyed in Florida a peaceful existence, undisturbed by the northeastern ice sheet. The rocks show that no very great or very violent changes took place there, whatever may have happened on the borders of the Appalachian region.

The minor divisions of the Neocene of the eastern United States will be found discussed in another place.

GEOGRAPHIC PROVINCES OF THE AMERICAN NEOCENE.

The deposits of this age divide themselves naturally into three principal geographical, faunal and dynamic regions, each of which has, for physical reasons, a certain individuality.

These are the Atlantic and Pacific coast regions, offering marine fossils, and the Interior or terrestrial and fresh-water basins, offering an appropriate fauna and flora. At present we are unable to correlate the Interior with the Coast regions in any general and satisfactory way, but with the increase of our knowledge of the stratigraphy and of the vertebrate remains, it can not be doubted that this desirable result will be within our reach.

To what extent these regions, when sufficiently studied, will admit of being subdivided into more limited natural areas, is yet quite uncertain. In fact, few paleontologists of America seem to have fully grasped the principles upon which such subdivisions must be based. For this reason it is perhaps advisable briefly to consider them.

PRINCIPLES OF CLASSIFICATION.

Apart from purely petrologic characters the Cenozoic formations exhibit several dynamic types marked by special features which distinctly characterize them, but which are not to be regarded as evidence in discussing their time relations. These are:

(1) Marine sedimentary deposits, either littoral or deep water, characterized by the presence in either case of an appropriate fauna, and the greater or less amount of included terrigenous material which in deep-sea deposits may be entirely absent.

(2) Perezonal deposits; terrigenous, with a sparse fauna, if any, characteristic of the conditions of deposition, totally different from faunas of the preceding class, yet often absolutely synchronous with them.

(3) Lake beds of the interior; and, lastly,

(4) Subaerial and fluviate deposits.

All these varieties, corresponding to as many types of dynamic action, not only may have been, but must have been, in process of formation simultaneously. Every marine bed must have had its contemporary perezone, its river bottoms, its lake beds, its contemporary abyssal fauna, with all their intermediate phases or diversities.

From this it obviously follows that diversities in the fossil fauna of different beds do not, in the absence of stratigraphical evidence, necessarily indicate any want of geologic synchrony, unless the beds belong to a single dynamic type.

It is now in order to consider how far in beds of the same type faunal differences may be relied upon to indicate time relations. Where there is no aid afforded by the stratigraphy, identity of fauna may fairly be regarded as establishing a presumption of synchrony. Is the reverse true, as has generally been taken for granted?

In showing that it is only relatively true, we shall be establishing only what is admitted by all biologists. This might be thought unnecessary, but as a matter of fact paleontologists have seldom tested their conclusions by biological rules or even, if we may judge from the literature, indicated in any way their cognizance that such tests were applicable, still less that they were needed.

Taking any synchronous and continuous invertebrate fauna, such as exists on either coast of the United States, let us consider by what it is characterized, and to what influences its diversities are due.

Temperature is well known to be a potent factor in such cases. On the eastern coast of the United States we shall find that certain genera occur in cold northern waters as a characteristic feature of the fauna, and that as we trace their distribution southward they disappear from the coast absolutely, if they are littoral species, or, if they are not by their habits necessarily littoral, by following the isotherms into the cold water of the deeps. The limits of the endurance of the species are probably fixed by the capacity of the embryos. A very few degrees of cold below the normal at the time of spawning will absolutely prevent the development of embryos, and in a single generation may exterminate a whole species. A temperature inhibitory of their habitual food, whether plant or animal, may be similarly destructive. Equally tender species, which have a different spawning time, may escape if the depression of temperature is not too prolonged. Another way in which the existence of a species is affected through its embryos is connected with the specific gravity of the water. If the species like the common oyster should have embryos of less specific gravity than that of the water in which they are spawned, being free-swimming during the short embryonic period, they would float, and if unable to reach the bottom would perish for want of a place of fixation. Thus an oyster reef accustomed to slightly brackish water, by a small subsidence surrounding it constantly with pure sea water (in which the adults might flourish admirably, but through which the embryos could not sink to the bottom) might be wholly exterminated in one generation. From these illustrations the student will perceive that cataclysms are by no means necessary to exterminate or seriously modify a fauna. The tolerance in the direction of heat is apparently greater than that for cold, but this point has been less investigated.

As the sea currents greatly influence the sea temperatures, so those features of the shore which deflect or modify the course of currents indirectly affect the fauna. Cape Cod and Cape Hatteras more or less influence the direction of the polar current and Gulf Stream circulation. They are, consequently, landmarks indicating notable changes in the fauna. To Cape Hatteras, and perhaps still farther south, cold water creeps along the shore. Off shore a few miles, though the water is not deep, the influence of this current is not felt, and numerous West Indian species, unknown along the shore, flourish in abundance. In shore from them various northern species maintain a precarious foothold, so that an east and west line would cut two faunas, one of southern and the other of northern facies, yet absolutely synchronous and closely adjacent.

From the point of view of temperature, therefore, we note that a continuously distributed synchronous coast fauna of invertebrates is modified as regards its constituent organisms; (1) gradually, as the latitude; (2) suddenly, as by changes due to currents; (3) in bathymetric station, or depth inhabited, by tending to follow the isotherms into deeper water.

As we are considering only a shore fauna, or one which might exist between low-water mark and twenty fathoms, it is not necessary to consider the interesting series of influences peculiar to the station of deep-sea organisms.

In the matter of food there are modifications of distribution due to geologic structure of the bottom. On the Alaskan coast I have noted that the red seaweeds grow only where granite or syenite rocks occur. The green seaweeds occur with them and also on the sandstones. On the basaltic shores and bottoms only olive-colored algæ appear. The fauna associated with the latter is different from that which frequents the region of green and especially of red algæ. These differences appear not only among the phytophagous animals, but also among the carnivorous forms which prey upon them and those which use the beds of algæ merely as a refuge. If in the midst of basaltic areas were some small islets of granite, there inevitably, and only there, would the familiar species of the granitic or red seaweed area be found. Ordinarily abundance of food is manifested in the fine development and abundance of individuals rather than in any change in the number of species or the nature of the assemblage.

The influence of the mechanical character of the bottom has been more fully recognized by paleontologists than by others, partly because it is reflected in the fauna and partly because the matrix of the fossils itself brings the question directly under the eye even of the closet philosopher. Very much more remains to be learned in regard to the details of these influences, and this must perforce be left to the biologist who can study the matter in the field, since the conditions under which fossils are found rarely admit of the determination of all the factors in the problem.

TABLE OF ZONES, WITH CENSUS OF FAUNA.

It now becomes necessary to consider the general effect of those influences which may be summed up under the term "difference of latitude." This is best determined by an inspection of known recent faunas of which the following table will give a fair idea. The species which would be absent in a fossil state, such as Nudibranchs, naked cuttlefish, etc., have been eliminated. As mollusk faunas are the best known, and, whether recent or fossil, most characteristic, they have been chosen to illustrate the argument. The number of species contained in each fauna, the date and the authority for the enumeration, and the particular fauna referred to are stated in parallel columns. It is, of course, understood that these estimates are approximate only, some of the faunas being known less thoroughly than others, and the estimate of what constitutes a species differing with different naturalists. The estimates used here are, it is believed, rational and conservative, and, on the whole, are taken from much the same point of view, none of the absurdly exaggerated estimates which have been indulged in of late by certain amateurs having been admitted. The zones adopted in the table correspond approximately to the following ranges of the minimum temperature of the coldest winter month for the surface of the sea: boreal, to a range of from 32° to 40° F.; cool temperate, 40° to 60°; warm temperate, 60° to 70°; tropical, 70° to 80°. These figures are not exact, but our knowledge of the sea temperatures is too imperfect to justify other than round numbers. The fluctuations of the maxima at the same stations are, of course, much greater than the minima, but they do not have the same important relation to the welfare of the species.

Table showing the number of shell-bearing marine species of mollusks contained in recent faunas of different temperature zones.

Fauna.	Enumerator.	Date.[1]	Species.
1. Boreal zone.			
Greenland	O. A. L. Mörch	1875	180
Cape Cod to Cape Breton	A. E. Verrill	1879	277
Vineyard Sound (shallow)	A. E. Verrill	1871	177
New England Coast (abyssal)	A. E. Verrill	1888	296
Arctic Norway	G. O. Sars	1878	332
2. Cool temperate zone.			
Britain	J. G. Jeffreys	1870	436
France, Atlantic Coast	P. Fischer	1878	444
North and South Carolina	Kurtz and Bush	1885	305
Bermuda	Dall	1889	198
Japan	Lischke	1875	429
New Zealand	Von Martens	1885	439
Upper California	J. G. Cooper	1867	598
3. Warm temperate zone.			
Ægean sea	E. Forbes.	1840	405
Adriatic	S. Brusina	1866	536
Sicily	R. A. Philippi	1830	587
Cape of Good Hope	F. Krauss	1848	383
East Florida (abyssal)	Dall	1889	260
West Florida	Dall	1889	681
Isle of Réunion	Deshayes	1863	530
4. Tropical zone.			
Mazatlan, Mexico	P. P. Carpenter	1857	654
Panama	C. B. Adams	1852	517
Guadeloupe Island, W. I.	P. Fischer	1858	560
Cuba	A. d'Orbigny	1842	595
Suez	R. MacAndrew	1869	818
Average mollusk-fauna in the—			
Boreal zone			252
Cool temperate zone			407
Warm temperate zone			483
Tropical temperate zone			629

[1] Of publication of list.

Of these faunas it may be said that that of Greenland is extremely well known, but very sparse, other areas equally arctic having a much richer fauna as regards species. The other boreal faunas are also quite thoroughly known, unless we except the deep-sea fauna off the coast of New England. There is, therefore, no reason to suppose that the average for this zone is far from the truth.

Of the second, the British and French faunas are probably the best known of any in the world. The enumeration for the Carolinas is defective by underestimation to some extent. Bermuda has probably more species, but the variety of station is small and the fauna is more concentrated than any of the others cited. The others mentioned under this head, of which Upper California is the best known, may be regarded as fairly representative.

Of the warm temperate faunas that of the Adriatic is probably the most thorough; that of Sicily is old and perhaps somewhat deficient, but the lists of Mediterranean species have been of late years artificially expanded so as to have little value for scientific purposes, and it became necessary to go to the older literature to find an enumeration which should be comparable with the others used in this table. The east Florida deep-water fauna represents the number of species obtained from an examination of about a bushel of gravel from two or three casts of the dredge in about 300 fathoms off Fernandina. There were no large shells in the gravel, but it represents much such an assemblage of specimens as might be obtained from sifting an equal quantity of fine shell marl. The West Florida fauna includes some deep-water species which in that region appear in quite moderate depths, as well as the littoral species.

Of the tropical fauna cited, all probably err on the side of underestimation. That of Mazatlan is probably the best known. Doubtless there are localities in the Indo-Pacific region which would largely exceed any of the estimates above cited in a complete enumeration of their shell-bearing mollusks, but none of these seemed sufficiently authenticated to be worthy of citation, and for a discussion of the fossils of our Tertiaries they would not be especially relevant.

It will be noted that nearly all these citations are of faunas sufficiently diffused, or, rather, of areas sufficiently large to eliminate differences due to station within the 100-fathom line.

It is not probable that within the narrow limits of a single collecting spot or beach all the species of any cited fauna could be found, but in collecting fossils access to the original sea bed is so much facilitated and the possibility (as from our Neocene marls) of making a complete collection at any one spot so much more favorable, that it is quite certain that the fauna will be more adequately represented than any recent fauna could be by much more extended work. This is abundantly proved by recent collections made under the writer's direction in the southern marl beds, where the number of species collected in a single locality in each case closely approximates the average for the warm temperate zone above described. Peculiarities of station may limit a fauna to a comparatively small number of species, but in such a case the nature of the matrix and the specific assemblage will discover the reason when properly studied.

CONCLUSIONS FROM THE TABLE.

We may then conclude that that part of the average mollusk fauna which is capable of leaving traces in the shape of fossils, under conditions not greatly differing from those of the present day, if situated in the arctic or boreal region, would comprise about 250 species; in the cool temperate region about 400 species; in the warm temperate, about 500 species; and in the tropical region, not less than 600 species. In regions where the conditions have greatly changed, as for instance, in Greenland since the old Miocene, during a period corresponding by the character of its fauna and flora to a different temperature zone from that in which it is now classified, the fauna should correspond in number of species to that which would be normal to the temperature as it was, not as it is. To illustrate, if we could discover old Miocene marl beds with well preserved fossils in Greenland, they should contain a mollusk fauna of 400 species normal to the cool temperate zone, rather than of 180 species, as is normal to Greenland at present.

Allowing 150 species as equivalent to the boreal species not represented south of New York, we have on the eastern coast of North America, from the Rio Grande to the arctic regions, 1,772 recent species by actual count.[1] Summing up the averages of our table we find that for a coast extending from the boreal region to the tropics (allowing the tabular figures to be exclusive for each zone) we should have 1,771 species for the whole range. This coincidence is accidental, for the tabular figures are deficient in the enumeration of the deep-sea forms. Deducting from our actual enumeration of east North American forms those which appear to live exclusively in the deeps beyond 100 fathoms, we have left 1,364 species.

But the species credited to the zones are, as we know, not exclusive, many of them being included in more than one faunal zone. The difference between the 1,771 theoretically present along the whole line and the 1,364 actually enumerated may be approximately a measure of the overlapping. In this case we should have 1,364 species of potential fossil shells represented by the existing faunas from the Rio Grande to Greenland. If the present sea bottom were elevated the paleontologist who might examine the beds should find, according to the region which he searched, a number of species approximating to the number assigned to that region in the preceding table, provided his estimate of the differences which indicate a species did not differ essentially from ours.

As he proceeded southward he would find a change in the fauna. Species would drop out, but a large number would appear which he had not observed before. Where cold currents have crept along the shore he would find a sparser and more boreal fauna; yet traveling eastward on the continuous strata he would find the more numerous and chiefly different warm water fauna of the edge of the Gulf Stream in absolutely synchronous deposits.

An interesting confirmation of these views is found in the Ecphora marl bed of northwest Florida, a cold water fauna which was preceded and succeeded by a warm water fauna. In the same bluff collections show the much smaller number of species in the Ecphora bed.

It should be noted that in geological changes species of the warmer region are more likely to persist from one formation into another than

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[1] U. S. National Museum, Bull. No. 37. A preliminary catalogue of the shell-bearing marine mollusks and brachiopods of the southeastern coast of the United States, by W. H. Dall, Washington, 1889, 221 pp., 8vo, 74 pl. Cf. p. 176.

those of colder regions. This is accounted for by the greater liability to injurious changes in regions which may be buried in or torn up by ice or visited by exceptional winters, while the conditions in the south are less uniform, and the greater area of the tropics gives more chance for widely distributed tropical species to escape destruction from local changes of level or from volcanic activity. Small species have more chances of escape than large ones, being able to hide from enemies in crannies, and, as they offer less food, they are less attractive to hungry prowlers. Species inhabiting moderate depths are safer than those whose station is between tides, from the action of sudden elevation or the visitation of frost, fresh water or water charged with noxious gases, such as break out at intervals on the Florida coast and other shores built of porous lime-rock. Thus it happens that the forms in the recent fauna which can be traced back to the Eocene are all warm-water species of small size, living seaward from low tide as a rule. We should also expect to find, as we do find, that southern beds will contain a larger percentage of still living forms than northern beds of the same age.

The lesson which is to be learned from these facts is not obscure. It is, in brief, that in correlating the fossil contents of different strata with a view of extracting the geological information they can yield, it is necessary to contemplate the growth and evolution of the continent as a whole, to recognize the interrelation of the details, and especially the fact that they can not be scientifically treated by any method which assumes their isolation and fails to take account of the factors we have indicated.

Such treatment is less easy than the old-fashioned way of basing an elaborate discussion on supposed faunas of fifty or a hundred species, but it is capable of yielding results which will stand the test of time and will express with some approximation to accuracy the truths which are the province of paleontology.

The conclusion to which present study seems to lead is that which in the main derives each successive fauna, in an area of reasonable extent, from that which preceded it, though the imperfections of the record in most cases leave this to be inferred. In those rare cases where the record is not greatly interrupted (as in part of the Floridian region) the characteristics, in a general sense, persist from one bed to another. If, owing to changes in temperature, a fauna is replaced by one not related to it, as in the case of the Chipola and Ecphora Miocene beds, with the recurrence of the original conditions the original types show themselves again, as in the Pliocene marl of the Caloosahatchie.

In the above case the Ecphora bed, or Chesapeake fauna, can be traced northward whence it came; while the Chipola types, during their temporary extinction in Florida, were preserved in some undisturbed Antillean area and reappeared by migration in Florida when conditions favored. Both groups of species are essentially American and recall recent American types, just as the Neocene of southern Europe is of a genuine European type. In the imperfect state of our knowledge it is rash to speak of species common to them, but it is certain that there are more species common to the recent fauna referred to than have been yet recognized in their fossil remains. Occasionally a type appears which seems out of place and recalls some distant region where it still lingers, as in the case of *Batissa* of the Oregonian Neozoic, which now is known only from the Indo-Pacific region. But in this case, as in general, when the history of such groups is studied, it is found that *Batissa* is merely a slight modification of *Cyrena*, which is abundant, recent and fossil, in America; such a modification as might have been expected to occur sporadically anywhere where *Cyrena* abounded during several geological periods or was represented by numerous species.

It may be as well to add, for fear of misconception, that it is true that in older geologic epochs the differentiation of faunas and of zones of temperature was certainly less marked than in Neozoic and recent time, and the methods we have recommended for the latter are less applicable to the former. Still it is possible in some cases to trace special characteristics in successive faunas for long periods; as in the faunas of the Californian coast, where, from the Cretaceous to the recent period inclusive, every marine fauna has included a large species of *Nucula* (e. g. *Acila*) with strongly marked divaricate sculpture, a certain type of *Cancellaria*, of *Turritella*, and of *Natica*. Something of the same sort will probably be found true of the successive faunas of the north shore of the Gulf of Mexico.

DIFFICULTIES IN CORRELATING FAUNAS.

In correlating contemporaneous faunas which are geographically separate, it is but seldom that one may have the aid of many identical species. This is especially the case with shallow-water or littoral species of the tropical or warm temperate regions. From the polar regions, owing to the polar circulation and uniformity of conditions, certain species are, as it were, centrifugally distributed to several adjacent faunas. On account of the long persistency of analogous conditions near the poles these species have little value as indications of minor divisions of geologic time. It is rather by the parallelism in stages of development by homologous groups in widely separated regions that a correlation of the Neozoic beds of such regions may eventually be reached, if at all. On the other hand, we do occasionally find a widely distributed yet little modified form like *Venericardia planicosta* of the Eocene; and it is not improbable that more thorough study and careful comparison of Neocene faunas of different parts of the world may reveal a larger number of such species.

CONCLUSIONS.

The conclusions to which the above considerations point at the present time may be summarized as follows:

1. The final correlation of the different beds of Atlantic Neocene will depend on a rational study of their fauna, which is now too imperfectly known to form the basis of satisfactory conclusions.

2. Correlation of these beds with those of Europe is wholly impracticable at present.

3. Faunal division of the known fossil contents of the different formations would be at present premature.

4. While paleontology holds the key to the problems of local and comparative stratigraphy, yet no study of paleontology that neglects the broad and general stratigraphic changes which accompanied the development of the continental border as a whole is calculated to afford results of permanent value.

CHAPTER II.

SUMMARY OF OUR KNOWLEDGE OF THE NEOCENE OF THE ATLANTIC AND GULF COASTS OF THE UNITED STATES, CONSIDERED BY STATES.

SUBMARINE STRATA OFF NEWFOUNDLAND, AND SOUTHWARD TO CAPE COD.

Remains that have been supposed to belong to the "Miocene or Later Tertiary" formation, have been dredged from the Grand Banks off Newfoundland (lat. 44° 30′, long. 50° 15′), at a depth of 35 fathoms. Of these, *Cyprina islandica* only has been definitely determined.[1] At Banquereau, Nova Scotia, have been found *Fusus decemcostatus*, *Latirus albus?* and a species of *Furritella.* Again, on Georges Bank, at a depth of from 35 to 70 or more fathoms, fragments of rocks were dredged up, containing, among other things, *Isocardia* resembling *Cyprina islandica*, but differing in hinge structure; *Myatruncata*, *Solen americana*, *Cyprina*, *Natica*, *Venericardia*, allied to *V. borealis*, but with smaller ribs, and *Cardium islandicum.*

From these facts Verrill is led to infer that there is an extensive bed belonging to the Tertiary formation, which extends beneath tide from Cape Cod to the Banks of Newfoundland. Mr. C. H. Hitchcock[2] had a somewhat similar idea in mind when he wrote, "Possibly Sable Island off Nova Scotia and the Great Banks off Newfoundland may indicate the position of the place of these (Tertiary and Alluvium) Cenozoic deposits at the close of the Tertiary period."

MAINE.

Both Jackson and Hitchcock have mentioned the occurrence of Tertiary deposits in this State. The former says[3] that nearly all the river valleys below 150 feet A. T. are filled with marine deposits, and abound in marine shells, some recent, some extinct. At Kittery,[4] a deposit was found containing *Saxicava rugosa*, *Mytilus edulis*, *Macoma*, and *Astarte castenea.* A similar deposit was found at Lubec. These beds, however, are now regarded as Quaternary. Hitchcock at one time held[5]

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[1] A. E. Verrill: Am. Jour. Sci., October, 1878, 3d ser., vol 16, pp. 323–324.

[2] Geol. of New Hampshire, Chas. H. Hitchcock, 1877, vol. 2, p. 21.

[3] Maine State Geol. Report, No. 3, 1839, C. T. Jackson, p. xiii.

[4] New Hampshire State Geol., Final Report on Geology and Mineralogy, 1844, Chas. T. Jackson, p. 94.

[5] Prelim. Report on Nat. Hist. of the State of Maine (Geology, by C. H. Hitchcock), in "Agriculture and Geology of Maine," by the Sec. of Board of Agriculture, 1861, pp. 256–257.

that certain hematite breccias, found at Blackington Corner, belong to the Tertiary, since Miocene fossils had been found in similar material in Vermont.[1] Later, however, he asserts[2] the absence of all Cenozoic deposits northeast of Massachusetts.

NEW HAMPSHIRE.

Jackson[3] mentions the discovery of a Tertiary deposit of blue plastic clay in the southeastern part of Portsmouth, in which were found *Nucula*, *Sanguinolaria* (*Macoma*) and a few recent forms. Hitchcock, however, makes no mention of any such deposits in this State. Moreover, he implies by a statement in Vol. II of the Geology of New Hampshire that none such exist.[4] The stratum in question is doubtless of the same age as the Quaternary beds previously mentioned as occurring on the coast of Maine.

VERMONT.

In 1853 Prof. Edward Hitchcock gave[5] a description of a brown coal deposit at Brandon, Vermont, with an attempt to determine the geologic age of the principal hematite ore beds in the United States. Though figures of fossil plants are given from the above named locality, he seems to have drawn no conclusions from them as regards the age of the deposit; for he says,[6] in substance, that the Brandon deposit belongs to a Tertiary formation, for (1) it lies below the drift and is not consolidated; (2) it contains all the varieties of rocks of the Tertiary formation: white clay, variegated clay, water-worn beds of sand and gravel, carbonaceous and bituminous matter, iron, and manganese. Moreover, he states[7] that this deposit is probably Pliocene or newer Tertiary, for (1) it lies immediately beneath the drift, (2) is not consolidated, and (3) similar brown coal of Europe is of the newer Tertiary.

In Vol. I of the "Geology of Vermont"[8] the above statements are repeated together with those of other eminent specialists. J. P. Lesley[9] is quoted as opposing the idea that the deposit is of Tertiary age, maintaining that it represents simply a mass of disintegrated Paleozoic rock. J. W. Bailey,[10] after examining the fruits microscopically, concludes, or rather intimates, that one may be that of a palm. Leo Lesquereux[10] states that none of the species are living, hence it can not be

[1] Geol. of Vermont. In two vols. Published under the authority of the State legislature by Albert D. Hager, 1861. The "Scientific Geology" by Prof. Edward Hitchcock, vol. 1, pp. 226–240.

[2] Geol. of New Hampshire, 1877, vol. 2, p. 21.

[3] Final Rep. Geol. and Min., New Hampshire 1844, by C. T. Jackson, State geologist, p. 121.

[4] Geol. of New Hampshire by C. H. Hitchcock, 1877, vol. 2, p. 21.

[5] Mass. Report on Geol., 1853, by Edward Hitchcock, p. 22.

[6] Ibid., p. 31.

[7] Ibid., p. 33.

[8] Geology of Vermont. In two volumes. Published under the authority of the State legislature by Albert D. Hager, 1861, vol. 1, pp. 226–237.

[9] Ibid., p. 237–238.

[10] Ibid., p. 240.

Pliocene, and he likens the flora to that of "Oeningen, the upper lignitic bed of the Tertiary."[1]

In an abstract of an article by Mr. H. Carvill Lewis,[2] in which he treats of the iron ores of the "Brandon Period," this deposit is discussed in connection with others of a similar character in southeastern Pennsylvania. Feeling assured of the identity of the deposits in the two States, he concludes that the lignitic clays of Pennsylvania are probably Oligocene, though he suggests that they may be Wealden.

RHODE ISLAND.

Certain deposits of clay and sand in this State were once supposed by Jackson[3] to belong to the Tertiary system; but there seems to be no evidence recorded in support of his views.

The cliff of "plastic clay" on Block Island is probably composed of beds referred with some doubt to the Tertiary, by Mr. Aug. F. Foerste.[4] The beds are said to "lie at such an angle as to make their dislocation by mountain-building forces almost certain."

MASSACHUSETTS.

MAINLAND.

Various deposits of clay in this State were at one time considered by Hitchcock[5] to be of Tertiary age; but in his final report[6] on the geology of Massachusetts, he concludes that none of these clay deposits are of Tertiary age except "the plastic clay of Marthas Vineyard."

Though no undisturbed Tertiary deposits have as yet been positively identified on the mainland of this State, fossils recognized as Eocene species[7] have been found in bowlders in the drift on the east side of Cape Cod. These fossils[8] are found most abundantly about one-half mile south from Highland Light, where a bluff rises to a height of 150 feet. At this place the fossiliferous fragments are not found imbedded in the modified drift, but are scattered about on the slope of the bluff. Farther to the south, however, one mile south from the head of Pamet River, Mr. Warren Upham has observed them so imbedded; and hence he concludes that they were probably brought there by glacial action from a Tertiary deposit in the bottom of Massachusetts Bay.

[1] For distribution of the Brandon beds, see vol. 2 of the above report, map, p. 989.

[2] H. C. Lewis: Proc. Am. Assoc. Adv. Sci., 1880, vol. 29, p. 427.

[3] Rept. Geol. Survey R. I., by Chas. T. Jackson, 1839, p. 129. For distribution of these so-called Tertiary deposits see "Geological and Agricultural Survey of Rhode Island," 1840, by Chas. T. Jackson (map at end of volume).

[4] Bull. Geol. Soc. Am., 1890, vol. 1, p. 447.

[5] Mass. Geol. Surv. Report, 1832, vol. 1: Edward Hitchcock. See map (frontispiece).

[6] Op. cit., 1841, vol. 2, p. 360.

[7] W. O. Crosby: Proc. Bost. Soc. Nat. Hist., vol. 20, pp. 136–140, 1878; and W. Upham, Am. Nat. Sept. 1879, vol. 13, p. 562.

[8] *Venericardia planicosta* Lam; *Venericardia* probably *parva* Lea; *Venericardia alticosta?* Con., Young; *Ostrea* apparently *divaricata* Lea; *Ostrea* possibly *sellæformis* Con.; *Ostrea virginiana; Anomia* resembling *tellinoides; Plicatula* near *filamentaria* Con.; *Axinea staminea, Camptonectes, Yoldia, Corbula, Cardium, Natica, Turritella?*

DEPOSITS ON THE ISLANDS OFF THE MAINLAND OF MASSACHUSETTS.

The announcement of Tertiary deposits on Georges Bank has already been referred to.

NANTUCKET.

The next area to be considered, proceeding in a general southwesterly course along the Atlantic border, is the island of Nantucket.

This island has been made the subject of a special study by Shaler,[1] and as there seems to be no good reason for believing that any of its beds[2] are of Tertiary age, it need here receive but little attention. Nevertheless, since Shaler has suggested[3] the possible identity of the clays observed by Messrs. Desor and Cabot at Sankaty Head with those which occur on the southern shore of Chilmark, and since he has recently intimated[4] that the latter may be Pliocene, it may be well briefly to review the opinions that have been expressed in regard to the age of these clays by various scientists. In 1849 Messrs. E. Desor and Edward C. Cabot published in the proceedings of the Geological Society of London a letter written to Sir Charles Lyell[5] "On the Tertiary and more recent deposits in the island of Nantucket." The bed termed by these gentlemen "Tertiary" was probably seen by Mr. S. H. Scudder in 1874,[6] and it was considered by him to be of great thickness. He observes, moreover, that it contains no fossils, and dips strongly (17°) to the southwest. On account of the present superincumbent débris, Prof. Shaler failed to find, with certainty, the beds described by the foregoing writers. The fossiliferous post-Pliocene strata conformably overlying these clays have been fully discussed by Prof. A. E. Verrill[7] in the American Journal of Science.[8]

MARTHAS VINEYARD.

From the facts thus far obtained it appears that the deposits which form this island may be classified under the following heads, viz: Cretaceous, Miocene, Pliocene, Glacial, or Recent. Of these the last mentioned has by far the greatest areal distribution. In fact, there are but two localities where any considerable outcrops of the pre-Glacial deposits appear, viz: At Gay Head[9] and at Chilmark (or Nashaquitsa) cliffs.

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[1] Bull. U. S. Geol. Survey No. 53, 1889.

[2] Ibid., p. 15.

[3] Ibid., p. 34.

[4] Bull. Geol. Soc. Am., 1890, vol. 1, p. 445–446.

[5] Quart. Jour. Geol. Soc. London, 1849, vol. 5 (proceedings), p. 340. (For this reference see Bull. U. S. Geol. Survey, No. 53, 1889, p. 31).

[6] Am. Jour. Sci., 3d ser., 1875, vol. 10, pp. 364–375.

[7] Ibid.

[8] These have been referred to the Columbia formation by McGee. See Am. Jour. Sci., 3d ser., 1888, vol. 35, p. 450.

[9] N. S. Shaler: Report on the Geology of Marthas Vineyard. Seventh Annual Rept. U. S. Geol. Survey, 1888, p. 327.

Cretaceous.—Though the gorgeous colored clays, sands, and lignites at Gay Head and Chilmark cliffs have been regarded by various writers as Cretaceous,[1] Eocene,[2] Miocene,[3] and even Alluvium,[4] it now appears that they can not all belong to one and the same system, but that at Gay Head at least two different ages are represented. Omitting, therefore, all details relating to the lower or Cretaceous[5] portions of these bluffs, suffice it to say that at Gay Head these beds[6] are more or less folded and faulted, but have a general northeasterly dip of from 15° to 50° or even[7] 90°, having the so-called Miocene superimposed conformably, whereas at Chilmark cliffs[8] an anticlinal axis causes the beds to have a northeasterly dip of from 15° to 25° east of the axis, and a southwesterly dip of from 20° to 45° west of the same, while the Miocene beds are wanting.[9]

Miocene.—Very little evidence has been brought forth to prove the existence of Miocene deposits on this island; nevertheless, that there are Tertiary deposits of a horizon "above the base of the Eocene and below the summit of the Miocene"[10] can scarcely be doubted.

Near the northern end of the section at Gay Head[11] there is a series of beds, comprising brown and greenish clays and sands, which have commonly been termed "Greensand." Beneath or to the south of these are sands, clays, and lignites of the Cretaceous,[12] as well as others of doubtful horizon, while above and to the east-northeast are the so-called Pliocene[13] sands.

This Greensand deposit has furnished the greater part of the animal remains that have been mentioned in connection with this locality.

The Testacea, sharks' teeth, etc., mentioned by Edward Hitchcock in his Final Report[14] on the Geology of Massachusetts are scarcely characteristic enough to be of any particular value in determining the age of this series.

The statements of Lyell[15] are somewhat more definite, yet by no means conclusive. The fossils he enumerates are as follows: A tooth of a seal allied to *Cystiphora proboscidea;* a skull of a walrus

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1 Wm. Stimpson: Am. Jour. Sci., 2d ser., 1860, vol. 29, p. 145.

2 Ed. Hitchcock: Reports on the Geology of Massachusets, 1832, 1833, and 1841.

3 Chas. Lyell: Am. Jour. Sci., 1st ser., 1844, vol. 46, pp. 318–320.

4 F. J. H. Merrill: Trans. N. Y. Acad. Sci., 1885, vol. 4, p. 79.

5 D. White: On Cretaceous Plants from Marthas Vineyard. Am. Jour. Sci, 3d ser., Feb. 1890, vol. 39, pp. 94–101, pl. 9.

6 N. S. Shaler: Tertiary and Cretaceous deposits of eastern Massachusetts. Bull. Geol. Soc. Am., vol. 1, pp. 443–452, pl. 9.

7 Seventh Annual Rep. U. S. Geol. Surv., 1888, p. 331.

8 Ibid., p. 327, Fig. 59.

9 Mr. D. White, of the U. S. Geol. Survey, has very recently furnished us with specimens of Greensand from this locality containing sharks' teeth, crab remains, fragments of shells, etc., similar in every respect to those of the Greensand of Gay Head.

10 See Bull. Geol. Soc. Am., vol. 1, p. 446.

11 U. S. Geol. Survey, 7th Ann. Rep., 1888, p. 329.

12 Bull. Geol. Soc. Am., 1890, vol. 1, pp, 445–446.

13 U. S. Geol. Survey, 7th Ann. Rep., 1888, pp. 329–332.

14 Vol. 2, p. 432, pl. xix, figs. 16, 17, 18, 1841. The fossil "Testacea" here figured are casts of a *Venus*, *Tellina*, and *Turbo*.

15 Lyell: Am. Jour. Sci., 1st ser., 1844, vol. 46, pp. 318–320.

somewhat different from any living species; bones of a whalebone whale and of a bottle-nosed whale (*Hyperoodon*); shark teeth, some of which were like those found in the Miocene, near Evergreen, on the right bank of the James River; two crustaceans; casts of a *Tellina*, allied to *T. biplicata*, and one allied to *T. lusoria;* casts of a *Cytherea*, resembling *Sayana;* three casts of a *Mya*, one of which bears a close resemblance to *M. truncata*.

The numerous remains of Cetacea of the genera *Balæna* and *Hyperoodon*, the author contends, are adverse to the supposition that the bed is Eocene, while such fossils abound in the Miocene of America.

In 1863, Dr. William Stimpson[1] discussed the crab remains in these beds, and found them generally referable to two types. One of these, *Archæoplax signifera*, a new genus and species, he describes and figures; but, on account of its distant relationship to other crabs, recent and fossil, it gives no clew in regard to the age of this deposit.

Other Tertiary deposits of doubtful age—later Miocene or Pliocene.—Between Gay Head and Indian Hill there is a series of deposits which resemble lithologically the various beds at Gay Head, but whose fossil contents are unknown. Shaler has estimated[2] the thickness of this series at no less than 15,000 feet. This estimate, however, was made under the supposition that between the localities mentioned above the northeasterly dip is constant and equal in amount to that at Gay Head. This supposition, it appears, must be somewhat in error, for in a later publication[3] he represents the Cretaceous and Tertiary in a section from the valley of Tisbury River to Vineyard Sound as having a northwestern dip of at least 45°.

Nothing more definite than what is implied in the preceding statements is known regarding the distribution of this series.

The series of deposits termed by Shaler[4] the Weyquosque, Nashaquitsa or Chilmark series is typically exposed at the bluffs on the southwestern coast of the island which bear these various names. Beds resembling lithologically those at Gay Head are imperfectly disclosed[5] near the base of these cliffs at certain stages of erosion. The Weyquosque series rests unconformably upon these beds[6] and is entirely different in its physical characters. Its various deposits consist of gray and blue clays and whitish sands, and in the latter are occasional hypogene pebbles. There are no traces, however, of the red and white sands and the lignites so characteristically exposed at Gay Head. The total thickness of this series has been estimated[7] at over 1,500 and possibly over 2,000 feet. On account of the absence of organic remains the geological horizon of these beds is unknown. Shaler[8] is inclined to refer

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[1] On the fossil crab at Gay Head: Bost. Jour. Nat. His., 1863, vol. 7, pp. 583–589, Pl. xii.
[2] U. S. Geol. Survey, 7th Ann. Rep., 1888, p. 332.
[3] Bull. Geol. Soc. Am., 1890, vol 1, p. 451, Pl. ix, Fig. 1.
[4] N. S. Shaler: U. S. Geol. Survey, 7th Ann. Rep., 1888, p. 340.
[5] Ibid., p. 327.
[6] Ibid., p. 320.
[7] U. S. Geol. Survey, 7th Ann. Rep., 1888, p. 341.
[8] Ibid., p. 320.

them to the Tertiary system on account of their various small contortions and plications, as well as their general inclination, which often amounts to 15°. These dislocations show evidences of such mountain-building forces as have not been displayed in this region since the close of Tertiary times.

These deposits are mainly confined[1] to the limited areas to the south and east of Menemsha and Squipnocket ponds, though several small patches of apparently similar material have been noted around the northern border of the island. Moreover, there are reasons[2] for suspecting that the lower clays of Nantucket,[3] others on No Man's Land, and possibly certain others in Duxbury may belong to this series.

NAUSHON.[4]

Immediately to the northwest of Marthas Vineyard is the island of Naushon, composed for the most part of reddish and yellowish sands, with occasional water-worn pebbles. The surface of these great arenaceous deposits is worn into forms characteristic of glacial erosion and is strewn with glacial débris. The time of their deposition may, therefore, be supposed to antedate the last glacial period, though to what extent is unknown. Similar deposits, however, have been noted about the shores of Marthas Vineyard, which lie unconformably upon the upturned edges of the Weyquosque series. Shaler is inclined to believe that these sands are more nearly related to the deposits of the glacial age than to those of the preceding series.

NEW YORK.

LONG ISLAND.

Both Hitchcock[5] and McGee[6] have mapped the southern portion of this island as belonging to the Neocene or post-Eocene Tertiary. Very few facts, however, have been given in proof of this view. The island is little more than a glacial moraine, a mass of débris, both unmodified and in every stage and form of modification. Judging from the character and position of the brown and red plastic clays of Huntington and Gardiners Island, Mr. Merrill[7] has been led to surmise that they may be of Tertiary age. The paleontological evidence brought forward in support of this view consists of a shark tooth, which might indicate an Eocene or Miocene period.

If the reported find of an *Exogyra costata*[8] between Brooklyn and Flatbush be authentic, there would seem to be little doubt as to the

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[1] U. S. Geol. Survey, 7th Ann. Rep., pl. xx, opp. p. 308.
[2] Ibid., p. 341.
[3] Ibid., and Bull. 53, U. S. Geol. Survey, 1889, p. 34.
[4] U. S. Geol. Survey, 1888, 7th Ann. Rep., pp. 342–343.
[5] Geol. map of the United States, compiled by C. H. Hitchcock, 1866.
[6] Ibid., W. J. McGee, 1884.
[7] F. J. H. Merrill: Ann. N. Y. Acad. Sci., 1886, vol. 3, p. 356.
[8] Cozzen's Geol. History of L. I., 1843, p. 51.

existence of Cretaceous beds on this island. Between these bedsand the Columbia[1] and glacial deposits above, Tertiary deposits do perhaps exist.

NEW JERSEY.

Though very few localities have yielded fossils characteristic of the Miocene beds, there is good reason to suppose that such beds are extensively developed in the southeastern portion of the State.

Their northern limit can not be accurately determined,[2] on account of the superincumbent superficial deposits, but it may be supposed to extend in a general way from Asbury Park, southwest, to the mouth of Salem Creek; south of this line none but Miocene and Quaternary deposits appear.

Topography.—That portion of the State included within the limits referred to above consists, for the most part, of level, sandy plains covered with forests of pine. The streams meander through flat valleys and are usually bordered by impenetrable swamps of white cedar, often miles in extent. The sea and Delaware Bay shores are fringed by an intricate network of creeks and are broken by numerous bays.[3] In this section of the State there are but two considerable areas whose mean elevation exceeds 100 feet above tide. The more northerly of these occupies the western part of Ocean County, together with a portion of Woodland township in Burlington County. It contained two points which respectively rise to the height of 208 feet above tide, the one 4 miles northwest of Cedar Bridge, the other 3 miles southwest of Shamong Station, called Applepie Hill.[4] The more southerly elevated area occupies the southeast central portion of Camden and Gloucester counties, together with the central portion of Salem and the extreme northern part of Cumberland counties. The highest point in this area is 2 miles north of Berlin, on the line between Camden and Burlington counties, where an altitude of 214 feet A. T. is attained.

These two more elevated areas are separated by a marked depression which extends across the State in a northwesterly direction from Great Bay to Burlington. Along this line of depression the watershed between the Delaware River and ocean systems of drainage is very low,[5] reaching a minimum of 85 feet A. T.

THE MIOCENE MARLS.

In the southwestern part of the State the erosive action of Stow Creek has exposed the upper portion of a bed of gray marl containing typical Miocene fossil remains. It is from this horizon that the fossils enu-

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[1] Am. Jour. Sci., 3d ser., 1888, vol., 35, pp. 383, 453, 455, et seq.

[2] Cope states (Proc. Phila. Acad. Nat. Sci., 1872, p. 14) that a thin stratum of loamy sand containing terrestrial vetebrate remains of the Miocene period overlies the Eocene marl on Shark River.

[3] Geol. Survey N. J., Ann. Rep., 1887, p. 18.

[4] Geol. Survey, N. J., 1888, vol. 1, Topog. Magnet. Clim., p. 170.

[5] Geol. Surv. N. J. (Geo. H. Cook, State Geol.), 1888, vol. 1, p. 170.

merated in various publications as "from Jericho and Shiloh, near Bridgeton, N. J.," are obtained.

The Shiloh marls.—A visit made by W. H. Dall in June, 1888, to the classic locality at Shiloh and its vicinity, afforded the following observations:

Section at Shiloh, New Jersey.

6 inches vegetable mold.
10 feet drift gravels rather fine and sandy.
2 feet yellow marl.
2 to 3 feet black marl.
8 to 10 feet shell marl.
Blackish sand not marly and of unknown depth.

Above the barren black sand which underlies the marls are three distinct successive unconformable marly strata, locally known as the "Shell marl," the "Black marl," and the "Yellow marl."

The lower stratum, or Shell marl, when moist, as it lies in the bed, is blackish, becoming grayish green when dry, with numerous rolled fragments and broken pieces of white fossil shells scattered through it. With these fragments are occasional perfect valves or complete specimens of ***Turritella***, ***Astarte***, ***Crassatella***, and ***Balanus***, with occasional sharks' teeth and other vertebrate remains.

The upper surface of this bed is very irregular, with small and large rounded hummocky hillocks separated by lower areas or channels, the whole bearing evidence of having been deposited in disturbed water subject to strong and irregular currents.

Above the Shell marl and unconformably filling its cavities is the Black marl, destitute of fossils and clayey or unctuous to the touch. The layer of this is two or three feet thick and its upper surface is worn into irregular rounded lumps, like that of the Shell marl surface below, but not conformably to the latter.

Above the Black marl is the Yellow marl, also destitute of fossils for the most part and unconformable with the surface below it. It is less unctuous than the Black marl, but rather greasy, of an orange brown color and does not average over two feet in thickness. It is sometimes absent in spots or indicated only by a narrow yellow line, and also has an irregularly worn, lumpy surface.

About 10 feet of sandy drift gravel, capped with some 6 inches of vegetable mold, overlies the marls.

The areas in which these marls occur are patches of comparatively limited extent, not indicated by any surface features, so that exploration is always required to determine whether there is any marl under a given field or not. The succession of the beds at Marlboro, Shiloh, and Jericho was essentially the same in all the pits and sections examined.

The appearance and contents of the beds strongly recall the condition of the sea bottom off Hatteras at the present day, where Miocene and

Pliocene sharks' teeth are being mixed with those of recent species and Miocene fossil shells come up in the dredge with living forms. The turbulent and irregular whirls and currents which are characteristic of the sea off Hatteras were paralleled in the waters in which these marls were laid down, and the genera represented in the latter are the same as those of the recent shells dredged off Hatteras.

It may be added that the ferruginous matter, to which the Yellow marl owes its color, sometimes settles to the bottom of the stratum and forms a thin hard layer over the upper surface of the Black marl below it. The latter is occasionally absent, so that the Yellow marl rests directly over limited areas upon the surface of the Shell marl bed.

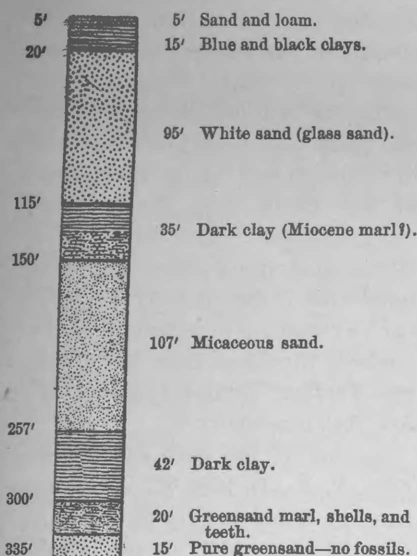

FIG. 1.—Section of artesian well at Winslow, Salem County, N. J.

The area in which these marly deposits are found is very limited. Its most northerly portion now known is about 3 miles north of Shiloh, whence it extends in a narrow belt in a southwesterly direction to a point about 1½ miles southwest of Jericho. The average thickness of the beds has been estimated[1] at from 10 to 15 feet, though, on account of the undulations of both upper and under surfaces, these figures must be understood as only approximate. The nature of the formation beneath the marl is not well exhibited in the vicinity referred to by Prof. Cook. Immediately above it, he states, there lies a bed of Black marl, varying in thickness up to 6 feet; upon this in turn rests a yellow earthy deposit of from 1 inch to 3 feet in thickness; above the latter appear the surface gravel and sand. The order of superposition, however, is not constant on account of the absence of some of the above-mentioned strata or the interpolation of others.

The stratigraphic relations of this bed to others of presumably Tertiary age can best be seen by referring to the section of the artesian well at Winslow, Salem County.[2] (See Fig. 1.)

The bed termed "Miocene marl" in this section is probably the same that appears on the branches of Stow Creek.

Its thickness is here represented as being 35 feet when taken in connection with the clays above. Beneath this there is a deposit of "micaceous sand" 107 feet thick, that appears not to have been identified at any place on the surface. Below this stratum of sand there is a

[1] George H. Cook: Geol. of N. J., 1868, p. 296.
[2] See Geol. N. J., 1868, pp. 291-292.

deposit of "dark clay," evidently identical with the "astringent clays" of later reports.[1] The "Greensand marl, with white shells and teeth," below the "dark clay," is evidently the Eocene marl bed that appears at the surface about Deal and Shark River in Monmouth County.

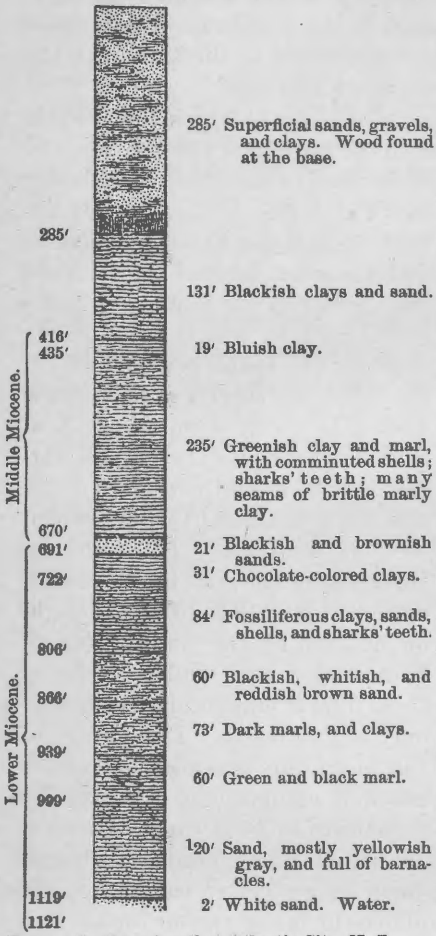

FIG. 2.—Section of well at Atlantic City, N. J.

Above the "dark clay," that rests immediately upon the "Miocene marl" is a stratum of "Glass sand" 95 feet thick. This sand forms the surface rock of no less than one-fourth of the whole Tertiary portion of the State. South of the valley of Mullica River it is for the most part obscured by later deposits, except along the valleys of the Great Egg Harbor and Maurice rivers. North of Mullica River the strips of Glass sand alternate with those of later deposits, each extending in a general southeasterly direction from the Cretaceo-Tertiary boundary line to the low Atlantic shore.

Section of the well at Atlantic City, N. J.—In 1886-'87 a well was sunk at Atlantic City to the depth of 1,150 feet, which proved beyond all doubt the general and wide distribution of Miocene deposits in this part of the State. The section[2] here given (Fig. 2) is compiled from an article by Mr. Woolman in the Proceedings of the Philadelphia Academy of Natural Sciences. Many fossils were obtained from the borings of this well[3], but unfortunately the depths from which they respectively came were not recorded, with perhaps three exceptions, viz:

Turritella plebeia came from a depth of 450 feet.

Corbula elevata came from a depth of 730 feet.

Perna maxillata came from a depth of 800 feet.

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[1] See Rept. of 1886, Geol. Surv. N. J.

[2] Lewis Woolman: Proc. Phila. Acad. Sci. for 1887, pp. 339–341.

[3] Prof. Angelo Heilprin identifies the following species: *Anomia* (prob. *ephippium*), *Arca centenaria* *A. subrostrata*, *A.* (*idonea?*), *A.* (*lienosa?*), *Artemis* (*acetabulum*), *Astarte compsonema*, *A. abrupta*, *A. perplana*, *A. thomasii*, *Cardita granulata*, *C. arata*, *Crassatella melina*, *Corbula idonea*, *C. elevata*, *Cardium* (prob. *laqueatum*), *Cytherea*, *Discina lugubris*, *Donax* (*variabilis?*), *Fulgur*, *Lucina trisulcata*, *Mactra lateralis?*, *M. ponderosa*, *Mytiloconcha incurva*, *Mytilus incrassatus*, *Mysia*, *Natica catenoidea*, *Nassa trivittata*, *Nucula obliqua*, *Ostrea*, *Pecten madisonius*, *P. humphreysii*, *P. vicinaria*, *Tellina subreflexa*, *T. declivis*, *Turritella cumberlandiana*, *T. æquistriata*, *Turbinella woodii*. Also shark teeth, barnacles, etc.

The division of that portion of the section below 400 feet into "Middle" and "Lower" Miocene is said to be based upon "paleontological evidence," but the propriety of the division is certainly questionable while so little is known in regard to these deposits.

A second well was drilled in 1888, on which Mr. Woolman has given some notes[1] in regard to the diatoms and Foraminifera. These occur in a series of clay beds, separated by sand beds, the whole aggregating 250 feet in thickness and extending from a depth of 387 feet to 638 feet. The clays contain diatoms in abundance, though they are almost absent from the sand. Samples from 406 feet and 550 feet are especially rich. About 100 species have been catalogued by C. H. Kain. Nearly all the forms occurring in the diatomaceous outcrops of Maryland and Virginia have been recognized, except two or three regarded as characteristic of the outcrop near Nottingham, Maryland, on Lyons Creek. Mr. Woolman regards these diatomaceous beds as belonging collectively to the Miocene, though referable to various separate horizons, of which that at Nottingham is probably the lowest.

Five forms of Foraminifera were found at 435 feet and fifteen forms at 1,125 feet, those of the upper horizon recurring in the lower level, and all practically the same as species described by d'Orbigny in 1840 from the Miocene clays of Vienna, Austria.

A *Nonionina* is now the common recent foraminifer in the Atlantic City sands, an ounce of which has been computed to contain 18,000 specimens. This, which is almost the only form now found on the New Jersey coast, does not occur in the samples obtained from the wells.

CENOZOIC SANDS.

Above the so-called "glass sand"[2] of this State there is a deposit of coarse white sand of more than 100 feet in thickness, which forms the base of the highest hills southeast of the marl belt. It may be seen in the Hominy Hills east of Freehold, and also in Apple Pie, Bear Swamp, and Governors Hills, as well as in the high ground of the plains, and especially near Lakewood and in the Forked River Mountains. This deposit Prof. Cook[3] has classified as Tertiary, though for want of paleontological evidence its geological horizon is not known with any degree of certainty.

Above this deposit of coarse sand, a series of beds of blue or light colored clays[4] may be seen at Winslow, near Wheatlands, Mount Misery, Vineland, Millville, and elsewhere. Whether these beds are Upper Pliocene or Pleistocene is uncertain. Resting unconformably over all these beds is a deposit of "yellow gravel." This is presum-

[1] Microscopical Bulletin of Queen & Co., Phila., Dec., 1888, vol. 5, No. 6, p. 41.
[2] Geol. Surv. New Jersey, Ann. Rep. for 1886, by Geo. H. Cook, p. 133.
[3] Idem.
[4] Idem.

ably post-Pliocene[1] and will accordingly receive no further attention here.

Dip.—By calculations based upon the depths at which the various marl beds were found[2] in the "Ocean Grove" well, together with the position of their respective outcrops, it has been found that the dip of the Tertiary beds here represented is about 25 feet per mile in a southeasterly direction. From various observations and calculations Prof. Cook[3] concludes that the dip in the southern part of the State varies from 20 to 40 feet per mile in the same general direction as stated above.

PENNSYLVANIA.

In accordance with the results of the most recent and trustworthy investigations, there appear to be no deposits belonging to the Tertiary system in this State. But since certain clays, lignites, ores, gravels, and conglomerates have been supposed by various authors to belong to this system it may be worth while briefly to consider the reasons that have led to these suppositions, together with those by which they have been opposed.

Cenozoic gravels.—At an average distance of 5 miles from the Delaware River, in the vicinity of Philadelphia, roughly parallel to it, there extends a prominent gneissic elevation, termed by Lewis[4] the "upland terrace." Within this terrace, and resting upon its slopes there is a deposit of gravel, termed[5] "fossiliferous gravel" by the same author, and identified by him with the "yellow gravel" of New Jersey.[6] This he regards as "probably of newer Pliocene age,"[7] drawing his conclusion from facts substantially as follows: Unlike the Quaternary gravels and clays this deposit is not limited in extent, but occurs all along the Atlantic seaboard of the Southern States. It is therefore of oceanic origin. It is characterized by small water-worn pebbles of quartz and quartzitic rocks. There are also occasional pebbles of flint and fossiliferous hornstone and chert. It contains no bowlders, and its pebbles nearly all have a water-worn, eaten appearance. The great amount of erosion it has suffered and the decomposed state of the beds upon which it lies point to the conclusion that it is an ancient deposit of marine origin, made during a submergence in preglacial times. The glacial drift overlies and is consequently more recent than this yellow gravel. To these various arguments it is only necessary to say that they are equally applicable to the beds of the Columbia formation;

[1] Geol. Surv. N. J. Ann. Rep. for 1886, p. 133; see also McGee's article on the Columbia formation in Am. Jour. Sci., 3d ser., 1888, vol. 35, pp. 383, 452–453, etc.
[2] Geol. Surv. N. J. Ann. Rep. for 1883, p. 19.
[3] Geol. Surv. N. J. Ann. Rep. for 1886, p. 129.
[4] H. C. Lewis: Jour. Frank. Inst., 3d ser., May, 1883, vol. 85, pp. 359–372.
[5] Proc. Phila. Acad. Sci. for 1880, p. 267.
[6] Geol. Surv. N. J., Ann. Rep. for 1886. p. 127.
[7] Jour. Frankl. Inst., 3d ser., May, 1883, vol. 85, pp. 370–371.

and that, according to Lewis's own statement, this deposit is but a continuation of the "yellow gravel" of New Jersey, whose post-Tertiary age has already been proved.

Back of the upland terrace there are isolated patches of two surface deposits, which from their elevated position and peculiar lithological characters are evidently more ancient than the gravels just described. In 1878 Mr. Lewis[1] named these deposits the "Branchtown clay" and "Bryn Mawr gravel," noted the identity of their contained bowlders, and assigned them to a Tertiary period.

In subsequent discussions[2] he seems to have discarded the first-mentioned name, but discusses the "Bryn Mawr gravel" in great detail, giving its peculiar lithological characters and geographical distribution, and reiterated his views as to its Tertiary age. The antiquity of the deposit, as stated above, is proved by its elevated position and its lithological characters, entirely different from the Columbian and Glacial formations below. Nevertheless, these arguments would be equally applicable to pre-Tertiary or even pre-Cretaceous deposits; so that, with no other evidence to the contrary, there appears to be no reason for doubting McGee's identification[3] of this "gravel" with his "Potomac formation." It is, however, worth while to note that Lewis[4] finds that "a precisely similar formation caps some of the hills in New Jersey. On top of the hill at Mount Holly, N. J., is an identical conglomerate of gravel, similar in appearance and composed of the same materials as the formation in Pennsylvania. The conglomerate has the peculiar ferruginous glaze already noticed. It here overlies Cretaceous marls and sands."[5]

Iron ores and lignites, supposed to be of Cenozoic age.[6]—The stratigraphy of the various "Tertiary" lignitic and iron-ore deposits of southeastern Pennsylvania, especially of Montgomery County, has been carefully studied by Mr. Lewis, who has found them severally of the Bryn Mawr gravel horizon,[7] or stratigraphically beneath it.[8] Owing to the probable age[9] of this gravel, these lignites and ores will not be discussed here.

DELAWARE.

Geographical distribution of Cenozoic deposits.—The Cenozoic as well as the older deposits in this State are covered to such an extent by the Columbia[10] formation that their geographical distribution is as yet but

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[1] Proc. Phila. Acad. Sci. for 1880 pp. 268–272.

[2] Ibid., p. 277, 288, 289. Jour. Frankl. Inst., 3d ser., May, 1883, vol. 85, p, 371.

[3] Am. Jour. Sci., 3d ser., 1888, vol. 35, p. 130.

[4] Jour. Frankl. Inst., 3d ser., May, 1883, vol. 85, p. 372.

[5] Recent observers have informally expressed the opinion that these gravels would prove to be Lafayette.

[6] Proc. Acad. Nat. Sci. Phila. for 1880, vol. 32, pp. 281–291.

[7] Ibid., p. 288.

[8] Ibid., pp. 288–289.

[9] Upper Jurassic; Am. Jour. Sci., 3d ser. 1888, vol. 35, p. 138.

[10] The "Delaware gravels" and "Estuary sands" of Chester. See Am. Jour. Sci., 3d ser., 1885, vol. 29, p. 36. The "Lower clays" of "recent (post-Tertiary) origin.' Booth, Mem. Geol. Surv. Del., 1841, p. 94.

indefinitely known. According to the interpretation of Mr. F. D. Chester,[1] the boundary line between the Cretaceous and Cenozoic systems extends across the State in an ENE. and WSW. direction, passing in its course about 3 miles south of Middletown. From this line south as far as Murderkill Creek a belt of Miocene clays occupies the whole width of the State, just beneath the Columbia formation. Still farther to the south the pre-Columbia sands and clays are, according to the same author,[2] presumably of "later Pliocene" age.

Judging from the general trend of the Tertiary outcrops in adjacent States, it seems probable that the foregoing statements approximately represent the truth, provided only that the "glass sand" of New Jersey and this State be regarded as Pliocene, a supposition for which there appears to be no paleontological evidence.

Stratigraphy.—The uppermost layer in the Cretaceous system is, according to Booth,[3] a sandstone or conglomerate which separates the fossiliferous sands below from the Yellow clay formation of the Appoquinimink hundred above.

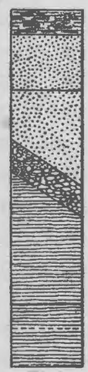

FIG. 3.—Section of well near Blackbird, New Castle County, Del.

The last-named formation consists for the most part of yellow clay,[4] though beds of coarse gravel and bluish and whitish clays are not uncommon. Not far from Blackbird, on the north bank of a creek of the same name, a well was dug to the depth of 15 feet and a boring made 7 feet deeper. A section is given in Fig. 3 of the various beds passed through, together with their respective thicknesses.[5] The Yellow sand contains numerous particles of green sand, and hence has been supposed to be derived from Cretaceous deposits. Not far from the same locality fragments of silicified wood are frequently seen, which belong, perhaps, to the genus Pinus.[6] No other fossils seem to have been noted in this "Yellow clay formation."

Just how much of the section here represented Mr. Chester would consider Miocene and how much Columbia[7] is a difficult question to settle; yet, from his brief characterization of the Miocene bed of this State, it may be presumed that at least the lowest 4 feet of the boring penetrates into Miocene clay.

Farther to the south, along the branches of Old Duck Creek[8], perhaps 4 miles below Smyrna, a stratum of blue clay appears, proved to

[1] Proc. Phila. Acad. Nat. Sci., 1884, p. 240. Map.
[2] Ibid.
[3] James C. Booth: Memoir of the Geological Survey of Delaware, Dover, 1841, pp. 53, 88.
[4] Ibid., p. 89.
[5] Ibid., p. 90.
[6] Mem. Geol. Surv. Del., 1841, p. 89.
[7] Cf. McGee. "Delaware Gravels" of Chester's nomenclature.
[8] Mem. Geol. Surv. Del., 1841, p. 81.

be of Miocene age by the fossil shells it contains. The clay is mixed with white sand in such proportions as to crumble without difficulty, when dried, to a leaden gray, pulverulent mass. In some instances the upper layer of this stratum consists of a ferruginous sandstone, averaging a foot in thickness, and abounding in casts of shells. Among these have been noted[1] *Venus alveata*, *V. inoceroides*, *Nucula lævis*, *Myoconcha incurva ?*, *Pecten madisonius*, *Mactra*, *Cardium*, and *Serpula*. The blue argillaceous layers below contain casts of apparently the same genera and species. The thickness of the whole stratum is known to be at least 12 feet; and, like the Miocene clay of New Jersey, becomes somewhat arenaceous in its lower parts. Above it reposes a bed of reddish yellow sand, passing at times into a similarly colored clay and capped by a gravelly layer cemented into a conglomerate by oxide of iron, while this in turn is covered by a light, loamy soil. The order of superposition, together with the thickness of the various strata, is represented in Fig. 4.

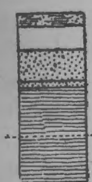

FIG. 4.—Section at Wales's mill-dam, near Smyrna, Del.

Farther to the southwest, near the headwaters of Choptank Creek, a blue clay has been observed[2] at "Smith's mill," rising a few feet above tide, differing in no respect from that on Old Duck Creek except in the absence of fossils. It is also overlain by a yellow gravel sand and loam and capped by gravel. This clay, according to Booth, appears to be continuous with Miocene clays lower down the Choptank, and it may therefore be a continuation of that at Old Duck Creek.

For several miles southward from these creeks the substratum of clay[3] observable in nearly all the streams seems to be without fossil remains. On Jones Creek, east of the Statehouse[4] the clay rises a little above water level and appears to be of a general yellowish color, though streaked with a few white seams. Upon it rests a reddish gravelly loam 8 or 10 feet thick, and upon this in turn a yellowish sandy loam 4 or 6 feet in thickness. The greatest known thickness of the Yellow clay stratum (15 feet) was obtained by a boring near the junction of Tydbury branch and Jones Creek. The yellow sand at the bottom, however, may be only a subordinate bed in the clay. The accompanying section (Fig. 5) represents graphically the sequence, character, and thickness of the above-mentioned deposits.

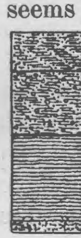

FIG. 5.—Generalized section on Tydbury branch and Jones Creek, Kent County, Del.

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[1] Mem. Geol. Surv. Del., 1841, p. 81, 82. *P. madisonius* is on Dall's authority.
[2] Ibid., p. 83.
[3] Ibid., pp. 91–94.
[4] Ibid., p. 92.

It is evident from the statements of Chester[1] that he regards this stratum of clay as a continuation of the fossiliferous deposit on Old Duck Creek. Booth[2] is inclined to think it stratigraphically above this deposit, and below that of Murderkill Creek to be described hereafter.

Little is known definitely regarding the dip of the various Tertiary and Quaternary deposits of this State, but upon general principles it has been assumed that there is a general low dip toward the southeast.[3] The observations of Booth,[4] however, tend to show that the city of Dover is located in a general depression of the subjacent strata. The slight northern dip for some distance southward from Dover tends to prove that the stratum of clay under consideration merges into the blue fossiliferous clays of Murderkill Creek.

Along the confluents of this creek, in the neighborhood of Frederica, the Miocene is again fully developed, abounding in fossil remains. A typical section of the representative beds of this vicinity was obtained at "Springmills" by Booth,[5] which is here represented graphically (Fig. 6). "The uppermost stratum is loose sand, below which is a ferruginous conglomerate of sand and pebbles, 1 to 2 feet thick; next a brownish yellow sand, containing a large portion of oxide of iron, 3 feet, at the bottom of which is a thin layer of gravel; still lower a light gray, somewhat argillaceous sand, partially indurated, and abounding with casts of shells, from which the carbonate of lime has been wholly removed and sometimes replaced by a thin coating of brown oxide of iron, excepting in one instance, in which a part of a single shell remained; its thickness is from 3 to 6 feet; below it is a stratum of hard ironstone, 1 foot; and the lowest stratum visible is a blue clay similar in every respect to that of the Northern Tertiary (at Old Duck Creek), consisting of more or less white sand imbedded in a highly tenaceous blue clay and abounding in impressions of the same shells that characterize the upper white sand. The hardest shell-casts are found in the ironstone, and among these we recognize a large scallop shell, probably the *Pecten madisonius*. A boring made to the depth of 5 feet below tide-water offered no variation in the nature of the blue stratum."

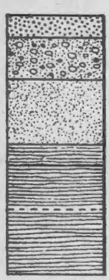

FIG. 6.—Section at "Springmills," Frederica, Kent County, Del.

The series of sands and clays termed Pliocene by Chester,[6] occupies

[1] Proc. Phil. Acad. Nat. Sci. for 1884, p. 240.
[2] Mem. Geol. Surv. Del. 1841, pp. 91, 93.
[3] Ibid., p. 93, and Proc. Acad. Nat. Sci. Phila. for 1884, p. 240.
[4] Ibid., pp. 92-93.
[5] Ibid., p. 86.
[6] Proc. Phil. Acad. Nat. Sci. for 1884, p. 240.

that portion of the State to the south of Murderkill Creek. That some of the sand beneath the Columbia formation may represent the Glass sand of New Jersey seems very probable; but, admitting this, their Pliocene age, as before stated, is not proved for want of paleontological evidence. Booth[1] includes all these beds under "Recent Formations."

MARYLAND.

The terms Eastern Shore and Western Shore have been used to designate those portions of the State lying respectively to the east and west of Chesapeake Bay. For the sake of convenience and perspicuity, the Miocene deposits of these two divisions will here be considered separately.

EASTERN SHORE MIOCENE.

According to Mr. Uhler[2] the southeastern boundary of the Eocene in this part of the State begins "near the head of the Andover branch of Chester River, next the Delaware line,[3] and extends, in an interrupted order, west of southwest past Sudlersville, Churchill, and Centerville, and, taking in Kent Island, crosses to Chesapeake Bay."

Several characteristic Miocene fossils have been found at Easton, on Treadhaven Creek.[4] The southern limit of the Tertiary series has been defined[5] as extending from near the head of the Little Choptank eastward to the Delaware line. The evidence upon which this limitation is based is wholly lithological and very unsatisfactory.

WESTERN SHORE MIOCENE.

On this side of the Chesapeake the southeastern boundary of the Eocene is said[6] to begin at the mouth of West River; thence it passes in a general southwesterly direction, above Lower Marlboro, to near Ludlows Ferry on the Potomac. To the south of this line the peninsula is mainly composed of Miocene beds, overlaid by the Columbia formation.[7]

The knowledge hitherto acquired in regard to the Miocene of this state has been obtained almost exclusively from examinations made along the low banks and escarpments of Chesapeake Bay and the Patuxent and Potomac rivers. In the following discussion, the formation as it appears along the above-mentioned bodies of water will be considered as constituting three sections, extending from the Eocene

[1] Mem. Geol. Surv. Del., 1841, p. 94.

[2] Trans. Md. Acad. Sci., 1888, p. 30.

[3] At "Wye," doubtless the modern Wye mills in the extreme northern part of Talbot County, Prof. J. W. Bailey found the "Infusorial Stratum" of Rogers "with all its usual characteristic species." Am. Jour. Sci., 2d ser., 1851, vol. 11, pp. 85–86.

[4] Second Bull. Proc. Nat. Institution, 1841–'42, p. 176, Proc. Acad. Nat. Sci. Phil. for 1880, p. 25.

[5] First Rept. of State Agric. Chemist, Md., 1860, p. 44, map.

[6] Trans. Md. Acad. Sci., 1888, vol. 1, p. 30.

[7] Am. Jour. Sci., 3d ser., 1888, vol. 35, p. 380, 383, 449.

on the north to the Pleistocene beds on the extreme end of the peninsula.

Section along the west shore of Chesapeake Bay—In accordance with Conrad's observations,[1] the northernmost outcrop of Miocene deposits along this section is that near Fair Haven, Anne Arundel County.[2] The bluffs in this vicinity generally rise to the height of about 50 feet above tide, while their continuity is interrupted by numerous valleys of bayward-flowing streams. The lowest stratum, level with the tide, is composed of clay, containing a layer of *Ostrea percrassa*, *Vola humphreysii*, and various other species. The top of this stratum is about 5 feet above the level of the bay. Above is a light-colored clay, containing great numbers of siliceous casts of small shells, chiefly Turritellas; to this succeeds a whitish clay without fossils.

Section at Fair Haven, Anne Arundel County, Md., after Conrad.[3]

Feet.	Character of strata.
50	Whitish clay.
	Bones of cetacea.
3	Clay, with siliceous casts of marine shells, and fragments of bones.
5	Clay, with *Ostrea percrassa* and *Vola humphreysii*.

This locality is "interesting from the occurrence of joints which traverse all the strata without interruption, and which were evidently produced by the same cause as those in Paleozoic formations.[4]"

About 20 miles south of Fair Haven ("near Col. Blake's"[5]) the escarpment is at least 150 feet high. At its base the clay stratum is replete with a species of *Tellina*, and above this, at about 6 feet elevation, there is a thin stratum of *Ostrea percrassa*. The upper portion of the cliff consists of sand and clay, apparently destitute of fossils. At a point a few miles farther to the south ("Capt. Hance"[6]) a small stream has worn a channel in the bank and exposed the beds of a mixture of sand and clay, in general very incoherent, with numerous fossil remains. Its elevation is but a few feet above the level of the bay. From it Conrad cites thirty-seven species of Mollusca.[7] Three or 4 miles farther to the

[1] Second Bulletin, 1841, Proc. Nat. Inst., p. 181.

[2] Prof. J. W. Bailey discovered (Am. Jour. Sci., 2d ser., 1849, vol. 7, p. 437) the "Infusorial stratum" of the Lower Miocene, at Herring Bay, on the west coast of Chesapeake Bay.

[3] T. A. Conrad, Second Bull. Proc. Nat. Inst., 1841-'42, p. 181.

[4] Ibid.

[5] Ibid.

[6] Ibid.

[7] Ibid.

south (Capt. Beckett's[1]) there is another vertical cliff, perhaps 35 feet in elevation, whose basal portion is formed of a brown mixture of sand and clay, and contains the same fossils as those found at "Capt. Hance's"; above, the fossils occur, but less frequently; then succeeds a 20-foot stratum of sands and clays apparently without fossils; above, and resting on this, is a stratum of quartzose sand, very incoherent and filled with shells, among which are *Dosinia acetabulum*, *Discina lugubris*, and *Pecten madisonius*.

Cliff near "Capt. Beckett's," Calvert County, Md. [2]

Feet.	Character of strata.
5	Sand, without shells.
3	Sand, with innumerable shells.
20	Mingled sand and clay, without fossils, or very rare.
3	Same as below; less numerous.
4	Sand and clay, with a group of shells like that at Hance's.

From this place to the mouth of the Patuxent, escarpments containing Miocene fossils are numerous. It is not, however, till Cove Point is rounded that they have received any scientific investigation. In the vicinity of Cove Point, both Conrad[3] and Clark[4] have noted the occurrence of cetacean bones; and between this point and the mouth of Patuxent River each has noted the occurrence of a great number of fossil mollusca. Concerning the geology of this section between the mouths of the Patuxent and Potomac no observations seem yet to have been recorded.

Section along the Patuxent River.—On the Calvert County side of the Patuxent River, about three-quarters of a mile below Lyons Creek, an abrupt bank rises to the height of 44 feet.[5] In the lower portion typical Eocene materials and fossils appear, while in the upper part there is a stratum of diatomaceous earth, or "Tripoli," about 3 feet thick. From this point to Hollands Cliffs, 2½ miles below Lower Marlboro, the upper surface of the Eocene approaches nearer and nearer the level of the river, while the stratum of Tripoli increases to a thickness of 30 feet. This in turn is here overlain by a slightly ferruginous sand, about 6

[1] T. A. Conrad, 2d Bull. Proc. Nat. Inst., 1841–'42.
[2] Ibid, p. 182.
[3] Ibid., p. 183.
[4] Johns Hopkins University, Circ. No. 65, April, 1888, p. 3.
[5] P. R. Uhler: Trans. Md. Acad. Sci., 1888, pp. 22, 23.

feet thick, holding an abundance of Miocene shells, *Perna maxillata* and *Ostrea percrassa.* At a short distance above Coles Creek, Miocene blue sandy clay appears.

Miocene beds very similar to these have been noted by Conrad at some distance away from the river, but which can be most conveniently discussed in this section. At Huntington[1] in the northern part of Calvert County, about 4 miles east of the river, he found *Perna maxillata* at the bottom of the race-way excavation, in a quartose sand, above which rests a "blue marl, with shells similar to the group at Captain Hance's. Three miles from here, at the bottom of a ravine, great numbers of *Perna maxillata* and *Discina lugubris* are imbedded in a lead-colored clay. At Charlotte Hall,[2] between the Patuxent and Potomac Mr. Conrad found *Perna maxillata* at the bottom of a ravine, in a matrix of sand, above which rested a 30-foot bed of "diluvial."[3]

Returning again to the Patuxent river,[4] at a point not far from Benedict where the cliffs are very high, their upper portions are formed of an arenaceous fossiliferous bed some 15 or 20 feet in thickness; beneath this, as is known from observations farther down the river, are *Perna maxillata* beds. Two or three miles farther down the river the arenaceous bed becomes thinner, is filled with *Scutella alberti*, is overlain by a thin bed of *Ostrea virginica*, and beneath it, to the water's edge, is a bed replete with *Perna maxillata.* Six miles farther to the south ("at the landing of Dr. Gilliams") the *Scutella* rock reaches the water's surface. At a distance some 12 miles from Benedict a range of cliffs begins that continues to the mouths of the Cuckold and St. Leonard's creeks. Near the base of the bank, at the mouth of the last-mentioned creek, a rock appears which resembles in its lithologic character the *Scutella* rock before mentioned, and is characterized as follows: "This rock has originally been a stratum of coarse sand, full of fragments of *Balanus proteus*, mixed with many whole specimens of the same, and of *Pecten madisonius*, which abounds on the upper surface." Much of the sand has been washed out, and the remainder of the stratum has become cemented by carbonate of lime and oxide of iron. It is a very porous rock, with an exceedingly craggy or irregular surface.

Resting upon this is a stratum of fine, siliceous sand, cemented by carbonate of lime, in which are imbedded innumerable casts of *Perna maxillata*, with many *Pholas ovalis.* At the mouth of Cuckold Creek, on the opposite side of the river, these fossiliferous beds appear at the water's edge, but on account of the southeastern dip they soon disappear beneath stratigraphically higher deposits. To the northward they extend along the range of cliffs referred to above.

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[1] 2d Bull. Proc. Nat. Inst., 1841, p. 183.

[2] Jour. Acad. Nat. Sci. Phila. 1st series, 1830, vol. 6, p. 212.

[3] In Cope's article "Vertebrate Fauna of the Miocene period," etc., Proc. Acad. Nat. Sci. Phila., for 1867, pp. 138, 139, a list of about 50 species of molluscan forms is given from near J. T. Thomas's residence, not far from the Patuxent River; Charles County, Md., Conrad's identifications.

[4] 2d Bull. Proc. Nat. Inst., 1841, p. 183–184.

For some distance toward "Point Patience," from St. Leonard's Creek, the Balanus rock appears along the shore. When last seen it rises to a height of 6 feet above the water, overlain by a stratum of friable sand 4 feet thick; then follows a bed of gravel a foot thick with an occasional pebble, and the highest stratum consists of a clay without fossils 7 feet thick.

Section along the Potomac River.—A short distance above the mouth of Port Tobacco Creek the Eocene deposits grade upward into drab clayey sands. Near Ludlows Ferry this sand is overlaid by diatomaceous earth as on the Patuxent. That the Miocene series extends along the banks of the Potomac from this point to St. Marys river can not well be doubted, but unfortunately this region has never been examined by a geologist.

In the right bank of St. Marys River, near the water's edge, innumerable fossils are exposed. Here it is that Conrad and others have made extensive collections. According to Conrad the stratigraphy of this bank near the mouth of the river is as follows:[1]

Section on St. Mary's River, Maryland.

Feet.	Character of strata.
10	Mixed sand clay, without fossils.
2	Sand and clay, with the same shells as below.
5	Lead-colored clay with, 3, group of shells as given in the lists, 2, veins of *Turritella plebeia, 1, Panopæa.*

From the fragmentary, comminuted state of the shells and from the occurrence of separated valves, Mr. Conrad concludes that this deposition was made near enough to the sea beach "to be influenced by the currents along the shore, or perhaps by the undercurrent of the surf, during the prevalence of violent tempests."[2] Some of the large univalves are most common in the arenaceous stratum, but none are limited to it. The eastern bank of the river presents a cliff of nearly the same elevation, 15 or 20 feet. The clay rises about 3 feet above tide, containing the same group of shells which prevails on the opposite shore. Near the southern end of the cliff the fossils disappear, having been converted into masses of selenite, many of which are 12 inches in diameter, and which are profusely imbedded in the clay near the level of the beach.

The predicament in which Conrad leaves the stratigraphy of the Miocene beds of this state is very remarkable. From his study of the Chesapeake section he is led to conclude[3] that the beds in the northern

[1] 2d Bull. Proc. Nat. Inst., 1841, p. 185.
[2] Ibid., p. 186.
[3] Ibid., p. 176.

part of the section are contemporaneous with those of the souther that, in fact, they extend horizontally along the coast line. Strong contrasted with these statements are those referring to the stratigrap of the Patuxent River section. In several places he refers to the dip along this river carrying beds beneath those of higher formations to the south and causing them to rise toward the north.[1] The followi diagram is a graphical representation of the ideas conveyed in his text.

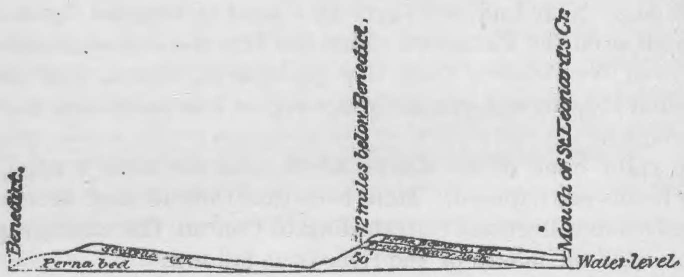

FIG. 7.—Section along the Patuxent, after Conrad.

Chesapeake group.—Heilprin has endeavored to show, chiefly by paleontological evidence, that there are two well defined divisions in the Miocene formation of this state, as well as in others to the south.

That the fossiliferous beds exposed in the northern part of the Miocene area of the peninsula are stratigraphically lower, and hence older than those of the southern part, is probably true. One would accordingly expect to find a larger number of recent species in the southern beds than in the northern ones; this Heilprin has shown to be the case. But there is no evidence characterizing two or any other particular number of subdivisions. It is for the present better to regard them as a continuous series of beds, in which some species keep dropping out and new ones appearing, instead of two distinct groups of deposits. The finding at St. Leonards Creek in the same bed of what have been regarded as fossils typical of the lower and upper beds respectively[2] goes far toward proving a continuity of deposition in the Miocene as represented in this state from the base to the uppermost deposits. For this series of beds the name of Chesapeake formation has been proposed by Darton.[3]

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[1] 2d Bull. Proc. Inst., 1841, p. 184.

[2] W. B. Clark: The Johns Hopkins Univ. Circ. No. 65, 1888, p. 3; and T. A. Conrad: 2d Bull. Proc. Nat. Inst., 1841, p. 184. Recent collectors have found *Perna maxillata* and some other species to be by no means confined to or characteristic solely of the older beds. See also discussion of the Chesapeake group under "Florida" of this essay. Darton is of the same opinion.

[3] For a discussion of the nomenclature of this series see under "Chesapeake group" in the section devoted to Florida.

Cf. Darton, Bull. Geol. Soc. Am., vol. 2, pp. 431-450. This publication was issued after the present work was practically complete. Mr. Darton has found the Chesapeake formation to be much more extensively developed in some parts of Maryland than earlier writers had supposed.

POST-MIOCENE DEPOSITS.[1]

From observations made on the Chesapeake and Potomac, Conrad concludes that the upper Tertiary borders the lower part of the peninsula from near the mouth of Town Creek, on the Patuxent, to a point on the Potomac about half way between St. Marys River and Brittains Bay.

The most common fossils of this formation[2] are *Ostrea virginica*, *Mytilus hamatus*, *Pholas costata*, and *Arca transversa*. Some of the species retain their colors and nearly all are known to exist in a living state. Heilprin does not state his reasons for regarding this formation as belonging to the Pliocene epoch, but he probably relies on the presence of a few supposed extinct species.[3] McGee seems to regard it as synchronous with the beds of Delaware, containing several recent species, which Chester, tracing them inland, found to be continuous with the Delaware gravel.

VIRGINIA.

For our knowledge of the Neocene beds of this State we are mainly indebted to the labors of W. B. Rogers and T. A. Conrad. The latter described or identified molluscan forms from nearly all the more important exposures, while the former by a series of investigations, extending from 1834 to 1841, examined and described in detail the stratigraphy and lithology of this as well as other formations in the State. The work of Rogers[4] will therefore form the basis of this brief discussion, though the material has been rearranged and, in some instances, slightly modified for the sake of clearness, and to bring it into harmony with the results and methods of more recent investigations.

The final disappearance of the Eocene formation with its gentle dip eastward may be roughly defined as on a line extending in a southerly direction from Mathias Point on the Potomac, past City Point on the James, to the North Carolina line. To the east, the state is traversed by numerous large rivers, from whose banks our knowledge of the Tertiary deposits has been chiefly derived. Of these, the four most important are the Potomac, Rappahannock, York, and James. Sections along each of these will now be considered, beginning with the most northern.

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[1] Upper Tertiary formation, Post-Pliocene period, Conrad, 2d Bull. Proc. Nat. Inst., 1842, pp. 187–188. Post-Pliocene (Pliocene?), Pleiocene, Heilprin, Proc. Phil. Acad. Nat. Sci. for 1880, pp. 21–23.
Columbia formation, McGee, Am. Jour. Sci., 3d Ser., 1888, vol. 35, p. 449.

[2] Jour. Acad. Nat. Sci. Phila., 1st ser., 1830, vol 6, pp. 205 et seq.; also 2d Bull. Proc. Nat. Inst., 1841, pp. 187–188.

[3] This fauna should be reexamined. The congregation of species as identified by Conrad is in general of a type resembling the present or a slightly colder water fauna, but it is remarkable for the presence of *Gnathodon* or *Rangia cuneata* Gray, which is now confined to the brackish estuaries of the Gulf of Mexico.

[4] Most conveniently consulted in the octavo reprint of [his] papers on the Geology of the Virginias, New York, Appleton, 1884, pp. xvi, 832, with many maps and illustrations.

RIVER SECTIONS.

Section along the southern bank of the Potomac.—As before stated, the Eocene beds disappear beneath the waters of this river not far from Mathias Point, but their contact with the beds known to be of Miocene age is nowhere shown. The reddish and yellowish clays incumbent on the Eocene just above the point disappear just below it, and the "shore becomes low and retiring."

We are left, by the statement of Rogers,[1] somewhat in doubt as to the exact distance down the river from Mathias Point to the first appearance of the Miocene, but it is certain that beds of this age do appear four miles above the mouth of Chantilly Creek, Westmoreland County.[2]

A bluish sandy stratum 5 feet in thickness here appears in the face of Stratford cliff at an elevation of about 50 or 60 feet above tide. This is filled with numerous and well preserved specimens of *Perna maxillata* (small size), *Turritella plebeia*, *Mactra modicella*, *Arca idonea*, and other large shells. This bed dips gradually to the east and at a distance of a mile and a half below its first appearance it is but 15 feet above the river. Nearer the mouth of Chantilly Creek[3] the fossils exist only as impressions in a blue sandy clay matrix that occupies the base of the bluff to a height of from 50 to 70 feet. The species here noted were *Pecten madisonius*, *Venus mercenaria*, *V. cortinaria*, and *Mactra modicella.*

Chantilly cliffs, situated below the mouth of the creek of the same name, form, according to Rogers,[4] a continuation of the Stratford cliffs just described. The fossiliferous stratum rises from the water's edge to a height of 25 feet. It contains few Pernas, but Mactras and Pectens are abundant.

Still farther down the river, at Cole's Point, on the south side of the mouth of the Lower Machodoc, a low bluff appears "which is prolonged for about 1½ miles down the river at a pretty uniform elevation of 14 feet. A few paces below the point the following strata occur:

1. A layer 2 feet thick, consisting of a bright yellow mixture of sand and clay, abounding in shells of various kinds, among which are *Perna maxillata*, *Ostrea compressirostra* [as identified by Rogers], *Venus mercenaria*, *V. Cortinaria*, *V. paphia*, *Isocardia fraterna*, *Pecten madisonius*, *P. jeffersonius*, *Pectunculus pulvinatus*, *Corbula inequale*, and *Turritella variabilis*.

2. Next a layer 6 feet thick, composed of mottled ferruginous sand with a small admixture of clay, containing no shells, but abundant markings, as if shells had once been present in great numbers.

3. A band of iron sandstone 3 inches thick, and

4. A dark mold, extending to the top.

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[1] Geology of the Virginias, p. 422, 1884.

[2] Ibid., p. 428.

[3] Dr. Leidy mentions the occurrence of *Balæna prisca* and *Crocodilus antiquus* with *Pecten jeffersonius* in Westmoreland County, Virginia, Proc. Acad. Nat. Sci. Phila., vol. 5, p. 308.

[4] Geology of the Virginias, 1884, p. 429.

In proceeding down the Potomac the yellow marl is seen gradually rising higher in the bank. A stratum of blue marl lying beneath it next comes in view, and this continues along the base of the bank extending some distance out upon the beach, until the shore sinks into a low sandy flat at Ragged Point.[1]

By this it would seem that the general southeasterly dip is here reversed, at least for a short distance. Similar reversions will be frequently referred to in connection with the sections along the rivers farther to the south.

Farther to the southeast, in Northumberland County, Miocene fossils occur in the banks of Hull Creek about 2 miles above its mouth. The lowest stratum here exposed consists of a ledge of ferruginous rock, containing immense numbers of *Perna maxillata*, with *Venus* and *Pecten*, firmly cemented together. The bed is 2 feet thick. Above it rises a stratum of yellowish sandy clay of the same thickness, abounding in *Perna maxillata* in a very friable condition. Incumbent on this is a 10-foot bed of light blue marbled clay, capped by course diluvium.

From the foregoing detailed description of what is recorded of the various Miocene exposures along or near the southern bank of the Potomac it may be seen that the stratigraphy of the section is as yet almost wholly unknown.

Section along the Rappahannock River.—The Eocene strata finally disappear beneath the level of this river[2] not far from the mouth of Chincoteague Creek. The bluffs, such as border the river in this vicinity, give place to low sandy shores farther down the river, as did those on the Potomac at Mathias Point. No Miocene outcrop has been definitely mentioned above Belmont, Lancaster County. Here the cliffs are made up of heavy beds of clay and sand, overlain by the ordinary diluvium and resting upon a stratum of soft ferruginous sandstone. No fossils are mentioned up to a distance of 1½ miles below this place. Here a rocky layer is met consisting entirely of shells, converted into brown oxide of iron, situated at the base of the cliff. This continues in the same direction for a distance of 1¼ miles. The following is the order of the strata composing the bank at a point near its eastern termination:

1. Six feet of diluvium.
2. Five feet of sand.
3. Ferruginated shelly rock, 4 feet thick, with the same shells as in No. 4.
4. Blue marl, containing numerous *Venus, Natica,* and *Oliva,* extending beneath the base of the bluff into the water.

Below this, and within a short distance of Curratoman River, marl beds occur below the level of the flats, consisting chiefly of a peculiar elongated variety of *Ostrea virginica.*

Below the mouth of the above-mentioned river may be seen, extending from half a mile to 1 mile above Cherry Point, a cliff which consists of the following strata:

1. Ten feet of diluvium.
2. Ferruginous sandstone.

[1] Geology of the Virginias, p. 430.
[2] Rogers: Geology of the Virginias, p. 422.

3. A bed of partially decomposed *Serpula*, containing few other fossils, 1 foot thick.

4. Chocolate colored clay, with vast numbers of the *O. virginica* referred to above, 3 feet thick.

5. Blue clay marl, extending from beneath water level to a height of 3 feet.

Miocene marl, clay, and shelly rock continue at intervals from here to Mosquito Point, below which the shores become flat and sandy. Here, as well as on the Potomac, there is a slight syncline, causing a reversal of the direction of the dip near the most eastern exposures of the two sections. The finding of marl with characteristic Miocene fossils near Kilmarnock indicates[1] "the prolongation of the Miocene strata to the very extremity of the peninsula." Finally, it must be admitted here, as in the case of the section along the Potomac, that the stratigraphic relations of the various beds exposed are as yet wholly unknown.

Section along the York River and its tributaries.—Though there may be a few Miocene outcrops along the Mattapony, the northern fork of the York River, none seem to have been recorded by Rogers in any of his various publications. But on the Pamunkey, the southern fork of the York River, numerous sections have been made in the vicinity of and above Piping Tree[2] that show the Eocene beds overlaid by those of Miocene.

At the place just referred to the strata taken in a descending order as follows:

		Ft.	In.
Miocene.—	1. White friable sandy clay, containing fossil impressions	10	0
	2. White sandy marl with broken shells		6
	3. Ferruginous stratum, abounding in casts, and occasionally containing the shells themselves		6
	4. Thin band of black pebbles		
Eocene. —	5. Dark greensand stratum, no shells	4	0
	6. Rocky shell of cemented shells of *Ostrea sellæformis*		6
	7. Dark greensand stratum, with small shells	2	0
	Total	17	6

The precise point at which the Eocene finally disappears "occurs at Northbury,[3] and directly opposite at the plantation of Dr. Charles Baxton."

From this point bayward no references of any importance are made to Miocene beds until a point is reached about 6 miles above Yorktown, termed by Rogers[4] "Jones's Plantation." At this place the shelly stratum similar to those nearer Yorktown is overlain by a thin and interrupted layer of a siliceous rocky mass, "approaching in its porous character and harsh, gritty texture to the nature of the buhrstone of France. Associated with this is a more compact rock, containing some carbonate of lime, with much silex, and exhibiting very perfect casts

[1] Rogers: Geol. of the Virginias, p. 433.

[2] Geol. of the Virginias, p. 53.

[3] Ibid., p. 51.

[4] Geology of the Virginias, p. 38.

and impressions of *Pecten*, *Cardium*, etc. Over these strata is the usual layer of ironstone, and the general aspect of the upper bed is somewhat ferruginous."

From Kings Creek to Wormleys, numerous Miocene beds are exposed in the banks of the river. These were examined in a cursory manner by Rogers and described in his first annual report of 1835.[1] More recent investigations by G. D. Harris, of the U. S. Geological Survey, have shown that the stratigraphy is by no means so simple as Rogers's description would imply, but that there are numerous local anticlines and synclines together with lines of uncomformability. Following, then, our more recent investigations, these various beds may be described as follows: Between Kings and Filgates creeks a bluff rising to the height of from 15 to 30 feet may be seen extending along near the margin of the river. The lower portion, to an altitude of from 10 to 20 feet, is composed of a grayish sandy marl, literally packed with large bivalve shells, of which those in the lower part are mostly *Pecten jeffersonius*, while above, *Venus tridacnoides*, *Venus rileyi*, *Ostrea disparilis*, *Pectunculus subovatus*, and *Dosinia acetabulum* prevail. Here, too, various forms of *Crepidula* as well as *Fissurella* are abundant; *Striarca centenaria* is occasionally met with. Below Filgates Creek, and extending over a mile toward Yorktown, is the famous Bellefield Cliff, from which great numbers of fossils have been obtained. Its lower portion is mainly composed of gray fossiliferous marl, save in one instance where a local syncline carries the marly portion beneath tide level, and the incumbent (Columbia?) clay bed alone forms the bluff. The other irregularities of the upper surface of the Miocene seem to be due to two causes, viz, erosion and disintegration. The effect of the first is plainly seen at the southern extremity of the bluff, near the mouth of Indianfield Creek. Here the marl bed slants abruptly beneath tide level, and is overlain by loamy sand. Nothing in the lamination of the marl indicates that this incline of the marl bed is due to dip; and, from the wholly different character of the incumbent material, it is evident that the marl suffered extensive erosion before the latter was deposited upon it. The effects of the second cause of irregularity, i. e., disintegration, are plainly marked by sinks wherever the marl owes its rigidity to calcium carbonate, and is overlain by no impervious layers. They are formed in somewhat the following manner: Surface water that possesses slightly acid properties percolates through the overlying sand till it reaches the bed of marl. Its calcium carbonate is attacked and dissolved. The water thus charged passes into subterranean veins and is at length discharged into the river. The rigidity and part of the component material of the marl being removed, it gradually sinks down in the particular locality thus acted upon till finally great holes or channels are formed in the marl, filled, of course, with the residuum of disintegration and the overlying sands.

[1] Geology of the Virginias, p. 37, 38.

The sides of the cavities are often very irregular, sometimes perpendicular, and sometimes even overhanging.

The diagram below (Fig. 8) shows the general features here mentioned. That these cavities were not produced by the denuding action of water upon the surface of the marl before the overlying sands were deposited (as suggested by Rogers)[1] is proved beyond all doubt, considering the comparative softness of the marl; by (1) the perpendicularity or even overhang of the walls; (2) their great depth (being in some instances at least 10 feet); and (3) the material with which they are filled. This is evidently a marly product, from its color and ingredients,[2] though the fossils it once contained are wholly obliterated.

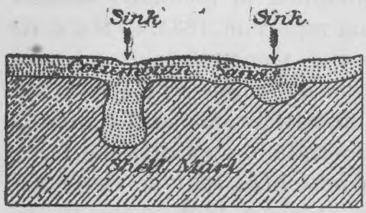

Fig. 8.—Diagram showing cavities in Shell marl filled with sand, near Yorktown, Va.

Marked examples of irregularities thus formed can be seen in the Bellefield cliff west of the bed of blue clay, as well as in the bluff already described that extends from Filgates to Kings Creek.

At the western extremity of the Bellefield cliff "the marl" rises to a height of at least 17 feet, and forms nearly the whole perpendicular height of the bluff. It is here a gray sand full of fairly well preserved fossils. These are essentially the same as those mentioned above, with a greater abundance of *Dentalium*, *Murex*, *Natica*, and numerous smaller forms. The great abundance of huge *Pectens*, extending along the base of the cliff for perhaps one-eighth of a mile, is one of its most pronounced features. Just west of the local syncline before mentioned a marked change takes place in the appearance of the marl. The shells are often finely comminuted and cemented together by calcium carbonate. Though large *Pectens* are very abundant at the base of the cliff, they do not occupy it to the exclusion of all other forms as they do farther west. In this cemented fragmentary rock, a few specimens of *Perna maxillata* were found.

All along in this portion of the Bellefield cliff the lamination of the marl is very oblique. To this structure Rogers refers in his report for 1835,[3] likening it to "appearances described by Lyell and others as existing in the Crag of England." The angle of lamination varies, sometimes amounting to 30° but generally not over 20°, and sometimes closely approaching zero; the direction is approximately east.

The Miocene, as exposed in this cliff to the east of the local syncline, contains fewer fossils than do the more western beds just described; it consists of a yellowish sandy marl, without the peculiar, regular, and well defined oblique lamination. It contains numerous remains of Cetaceans.

[1] Geology of the Virginias, 1884, p. 32.
[2] Ibid., p. 31.
[3] Ibid., p. 35, 39.

The same marly bed appears in the right-hand bank of Indianfield Creek at its mouth, though it is here but 5 feet above the water level and soon passes entirely below it. It reappears in low cliffs toward Berrys Landing, but contains few well preserved fossils.

Judging from the steep westerly dip in the strata well exposed in a bluff about 200 yards below Berrys Landing, it is probable that the marl we have been describing is at this place wholly or mostly absent, and that the strata exposed here represent a lower horizon. The fauna is widely different, though containing many of the larger forms already mentioned; the abundance of *Astarte symmetrica*, *A. concentrica*, *A. abbreviata?* *Lucina crenulata*, *Gouldia lunulata*, etc., is here quite noticeable. *Diplodonta acclinis*, too, puts in an appearance at this place. In a second bluff, about one-half mile below Berrys Landing, the same beds are exposed, though higher up in the bluff, owing to the western dip. They are at least 15 feet thick, and as they appear in cliffs nearer Yorktown they rise higher and higher and become fragmentary and consolidated into a rock of considerable hardness.

In the extensive cliff that stretches along the shore from about a mile above Yorktown, the beds just mentioned can be seen for but a short distance at the western extremity. The fossils soon disappear and the sands become mingled with those of the Columbia formation above. Below it, at this place, however, there is a bed of gray marly matter 14 feet thick, containing few fossils. Still below this, and reaching to the water's edge, is a stratum of blue marl whose upper portion is often stained brownish by iron oxide. In its upper portions *Dosinia acetabulum* and *Panopæa reflexa* are fairly abundant, but are very tender and fragile; below, in the more purely blue portions, *Yoldia limatula*, *Cytherea sayana*, *Pandora crassidens*, *Mactra delumbis* *Solen*, *Tellina*, *Scaphilla*, *Dentalium*, *Cadulus*, etc., are very common, but owing to the softness of the shelly material, a perfect specimen can rarely be found. Near the Yorktown end of this cliff these fossils are replaced by *Crepidula*, *Pecten*, *Venus*, etc., and the marl becomes more arenaceous and of a yellowish gray color. Beneath it, at the eastern extremity, about half a mile above Yorktown, another fragmentary bed appears containing *Pecten jeffersonius* and other large bivalves. This is the top of a series of fragmentary rocks which appear in bluffs to a point at least 1 mile below Yorktown. The fragmentary structure is a more or less variable and local feature, being developed, as a rule, more commonly near the lower portion of the cliffs. The fossils in this series include nearly all that have been mentioned as occurring in the beds between Yorktown and Kings Creek, except, perhaps, those characteristic of the blue clay or *Yoldia limatula* bed. About one-half mile above Temple Place this fragmentary series is underlain by a stratum of blue clay marl, very similar in character to the *Yoldia limatula* bed. Its thickness is not far from 5 feet on an average; its color becomes brownish upon long exposure. Just above Temple Place the base of this bed may be seen, appearing in detached patches along the top of the marl and just beneath the Columbia sands. It is here about 25 feet above tide, thus giving a westerly dip of about 25 feet in one-half mile. The fragmentary series in the meantime disappears, its various members, having been brought up to a height of 25 or 30 feet by this westerly dip, have all been planed down to this height by pre-Columbia erosion. Immediately under the 5-foot stratum of blue clay appears a stratum 10 to 15 feet thick, literally packed with *Crepidula.* Inasmuch as this genus is so abundantly represented throughout the whole of the upper portion of the Miocene, this bed is most easily identified by *Striarca centenaria*, which it contains in great abundance. The usual representatives of *Ostrœ*, *Venus*, *Pectunculus*, *Pecten*, *Fulgur*, etc., are fairly abundant. Owing to the westerly dip its lowest layers are brought up to the Columbia sand a short distance below Temple Place. The superior hardness of this rock to the one below is very manifest just above Temple Place, where it protrudes beyond or overhangs the underlying bed. This last, though mostly hidden, appears to extend perhaps a quarter of a mile below Temple Place, is probably 12 feet thick, and contains few well preserved shells. The bed just beneath this is slightly more argillaceous and contains *Turritella alticosta* in great abundance. When the Miocene finally disappears, about half a mile below Temple Place, it presents the section described by Rogers[1] as at Wormleys Creek, though its component parts are by no means so separate and distinct as one might imagine from his description. The marl bank is here only about 8 feet high. Farther to the east it is absent, the bluffs being formed wholly of Columbia sands.

Section along the James River.—The Eocene finally disappears beneath stratigraphically higher formations three-quarters of a mile below the mouth of Powells Creek, but the Miocene extends back, in detached areas, over the Eocene for some distance west of this point, and even appears in and about Richmond. Near that city Rogers first discovered the existence of an "infusorial stratum" in Virginia.[2] Its relations to the adjoining Eocene and Miocene beds are typically presented in the principal ravine on the west side of the valley of Shockoe Creek.[3]

		Feet.
1. Sandy stratum of mottled gray and yellowish brown clay, vegetable impressions and prints of *Pecten.s*	MIOCENE..	14
2. Greenish brown and lead colored less sandy clays, with vegetable impressions	MIOCENE..	6
3. INFUSORIAL STRATUM		20
4. Lead colored heavy clay of a greenish tinge		3
5. Brownish black, containing a few prints of fossils and a large amount of carbonized vegetable matter, to which the color of the stratum is owing		5

[1] Geolo gy of the Virginias. 1884, p. 37.

[2] *Procamelus virginiensis* Leidy, was found in this vicinity. It is described by Leidy, vol. 1, U. S. Geol. Survey Terr., 1873, p. 259, Am. Nat., 1886, vol. 20, p. 621.

Regarding this species Dr. Leidy informs us that he has modified his original opinion that it belongs to *Procamelus* and now thinks it "more nearly related to the living *Auchenia*" (Nov., 1890). Its stratigraphic position can hardly be regarded as definitely ascertained.

[3] Geology of the Virginias, 1884, p. 453.

	Feet.
6. Lighter colored bed, with yellowish blotches, and streaks, very friable even when moist, being more sandy than the succeeding. A few impressions .... EOCENE..	8
7. Dark olive and bluish stratum, tenacious while moist but becoming mealy and of a grayish tint when dry, and in that condition showing an efflorescence of gypsum upon the surface. Impressions of *Cardita*, etc .... EOCENE..	4
8. Felspathic sandstone, Upper Cretaceous	4

Rogers includes the infusorial deposit in the Miocene Tertiary. It rests either upon or but little above the top of the Eocene,[1] is composed largely of diatoms, and contains occasional casts of Miocene shells.

From Richmond down the James River for some distance Miocene beds are occasionally seen lying upon the Eocene. After the latter dips beneath tide level, the banks of the river present no point of particular interest until the vicinity of Williamsburg is reached. The cliff at Kings Mills is abrupt and has a height varying from 20 to 45 feet above the water. The strata of shells extend along the river with slight interruptions, when the cliff sinks nearly to the level of the water for a distance of between 2 and 3 miles, and they are found in a somewhat similar order of superposition for some distance inland. Their general direction is horizontal, but the outline of any one is frequently very irregular. This irregular outline is particularly remarkable with the beds of *Chama* which are very thick at some points, and then thin out rapidly and again thicken. A detailed account of the Miocene and Quaternary beds at King's Mills will be found on p. 36 of the Geology of the Virginias.

At Days Point, the most eastern exposure of marl immediately on the southern bank of the James River, at a short distance above the mouth of Pagan Creek, the shelly stratum that first emerges from the beach, consisting of the overlying bed of ferruginous marl, is seen gradually rising to a higher level as we ascend the river. A quarter of a mile above, and in a direction northwest from the point at which the marl first came in view, we see the blue stratum beginning to show itself beneath the other, and soon, with a gentle slope rising to the height of several feet above the base of the river bank.[2]

Here, as in the various exposures on Pagan and Nansemond rivers, the yellow ferruginous upper marl layer is often fragmentary and cemented together at the top.

The only remaining point of interest to be considered in connection with this section is one on the north bank at the mouth of the river, namely, Fortress Monroe. Here an artesian well was sunk to the depth of 907 feet, penetrating Miocene, Eocene, and Cretaceous strata. The infusorial stratum was encountered at a depth of 558 feet below the parade ground, and the base of the Miocene Rogers considered to be between the depths 577 and 583 feet. The importance of these determinations will be discussed elsewhere.

Cenozoic district south of James River.—But little detailed descrip-

[1] Notes from Macfarlane's Geological Railway Guide, 1879. Reprint in Geology of the Virginias, 1884, p. 725.

[2] Geology of the Virginias, 1884, p. 258.

tion is given by Rogers of this district. The line of contact between the Tertiary and older rocks passes in a general way, meridionally south from Richmond. But in its course it presents most complex sinuosities.

Indeed, islands and peninsulas of the sandstone (secondary) are met with some distance eastward of the general boundary, while inlets of the Tertiary strata are seen penetrating beyond it to the west. Thus on a branch of the Appomattox just above the fork near Broadway, on a meridian several miles to the east of that of Petersburg these layers of coarse and fine sandstones and conglomerates are seen lying horizontally, one upon the other, forming a cliff about 50 feet in height, while in the vicinity of Petersburg the greenish sandy strata of the Eocene are found.[1]

South of this place "no unequivocal indications of the continuation of this lower member of the Tertiary series can be found."[2] The Miocene and later formations therefore abut directly upon the primary rocks to the west.

High up along the Nansemond River, and along the Blackwater, Nottoway, and Meherrin, as well as their branches, a striking constancy is remarked in the position of that portion of the series of marl deposits called the blue marl, the lowest of the series as exposed in this and other parts of the area occupied by the Miocene Tertiary of the State. * * * This stratum may be seen skirting the water line in a slightly undulating band and rarely rising to the height of many feet above the stream. In the southern portion of the tract this feature is most uniformly displayed, while near the James River a decided rise of the strata may be seen as we trace them westward. * * * The general parallelism thus maintained between the plane of the marl and that of the rivers throughout most parts of the southern tract distinctly indicates a gentle declination of the marl in a southerly direction or that in which the Blackwater, Nottoway, and Meherrin flow, and indeed it might with some reason be maintained that the sloping of these beds in that direction, as well as the comparatively unyielding nature of the tenacious clays of which they are principally made up, have exerted an important agency in determining the drainage in that direction, as well as preventing the streams from forming a deeper channel than is furnished a few feet below the upper surface of these beds.[3]

In Norfolk and Princess Anne counties diligent inquiry, aided by shallow borings at several places, has been made along the canal and feeder and at other points within the Dismal Swamp, but no unequivocal deposit of marl has yet been found excepting in the vicinity of the Great Bridge in Norfolk County and 4½ miles northeast of Suffolk near the western margin of the swamp. Of these the latter consists of blue marl, identical in character with the upper portion of that formation west. The former was of more ambiguous character, and owing to the small number of species obtained, its exact horizon in the Miocene could not be determined.[4] However, in 1889, Prof. Shaler obtained a small collection of fossils in the northern part of the Dismal Swamp, immediately below the vegetable soil, containing 29 species of which 24 are known in the recent state and, of the others, one is known only from the Caloosa-

[1] Geol. of the Virginias, 1884, p. 261.
[2] Ibid., p. 262.
[3] Ibid., p. 256.
[4] Ibid., p. 257.

hatchie Pliocene and the 4 remaining extinct forms are common to the Miocene of Maryland and Virginia, and the Pliocene of Florida. This would indicate a position, if not Pliocene, at least very high up in the Miocene system.

GENERAL CONSIDERATIONS.

Rogers's generalized section[1] along the James River, from Primary to Quaternary rocks, is as follows:

A-B. Represents the beds of sand and gravel, usually lying immediately below the soil, which from their oblique position and the general coarseness of the materials, indicate a deposition under the influence of strong currents. This overspreading the region extensively, and evidently due to some general cause, is properly to be regarded as *Diluvium*.

B-C. Horizontal beds of sand and clay, prior to the diluvium and partially and sometimes entirely removed at the time of its deposition.

C-D. Upper portion of the yellow marl—a conglomerate of fragments containing in its lower parts nearly entire but water-worn shells.

D-E. Lower portion of the yellow marl—shells contained in a friable sand, and near the bottom is a tenacious clay; numerous species above, *Mactra modicella* almost exclusively beneath.

E-F. Upper blue marl—a blue clay of fine texture; rich in *Mactra modicella;* shells becoming more varied as we descend.

F-G. Lower blue marl—a more sandy material, abounding both in number and variety of its shells.

G. Thin band of pebbles, separating the Miocene from the Eocene Tertiary.

G-H. Eocene on the James River—clays and sands usually of a grayish tinge, containing shells and their impressions, often presenting a considerable proportion of green sand and some gypsum.

H-I. Sandstone formation—deeply channeled above, before the deposition of the Eocene.

I-K. Granite and other Primary rocks, upon which the sandstone rests.

There seem to be two discrepancies in Rogers's views of the stratigraphy of the Miocene: first, the supposition that these strata everywhere preserve such horizontality as is stated by this author is opposed by the finding of the infusorial stratum which crops out at the surface near Richmond, at a depth of 558 feet below the surface at Fortress Monroe; second, not all the blue marl exposed at the base of the bluffs along the principal rivers can be considered as belonging to a lower bed in the Miocene formation. These beds of a bluish clayey marl are frequently interpolated in grayish and yellowish marl beds, as has recently been proved in the case of those exposed about Yorktown. Again, the borings from the Fortress Monroe well do not show the Upper Miocene as consisting of yellow marl and the lower of blue marl.

That the blue marl nearly always appears at the base of the bluffs instead of higher up is due to the fact that when the dip brings the stratum up from the lower part of the bluff it is so weathered and oxidized that it loses its characteristic blue tinge and is not readily dis-

[1] Geology of the Virginias, 1884, p. 264.

tinguished from the ordinary yellow marls, except by careful examination of its dips and fossils.

It is probable that nearly the whole of the Miocene of the state when better known will prove to belong to the beds of the Chesapeake group.

PLIOCENE ROCKS.

The uppermost Miocene or lower Pliocene fossils found by Shaler in the marl of the great Dismal Swamp have been already referred to, (p. 64), and, if Pliocene, appear to form the first recognized fauna of that age in the state. But if the conclusions of McGee be correct, this horizon is well represented by a perezonal formation, that first makes its appearance on Potomac Creek and expands rapidly toward the south. Its distinctive characteristics, geographical distribution, and probable age will appear from the appended quotations, from the description given by McGee,[1] who applied to it the name (since replaced by the term Lafayette) of the Appomattox formation.

THE LAFAYETTE FORMATION.

Character and distribution.—Near the summits of the bluffs overlooking the Rappahannock River from the southward a mile or two west of Fredericksburg, a distinctive, stratified, orange-colored, sandy clay is found reposing upon Potomac sandstone, from which it is readily distinguishable by its greater homogeneity, the more complete intermingling of its arenaceous and argillaceous materials, its more regular stratification, and its more uniform and predominantly orange color. It is as readily distinguishable from the Columbia deposits, on the other hand, by its vertical homogeneity, its comparatively regular stratification, its distinctive color, and its greater range of altitude, extending, as it does, from tide-level to the highest eminences of the Piedmont escarpment between the Rappahannock and Roanoke. At Fredericksburg the deposit is commonly thin and confined to limited isolated areas, especially at the higher levels, and it appears at but a single locality (Potomac Creek) north of the immediate valley of the Rappahannock; but it rapidly increases in thickness and continuity to the southward. About the confluence of the Ny, Po, and Ta Rivers it forms the surface over a meridional zone fully 10 miles wide. It is well exposed in the bluffs of the Tapony, along which it reposes on the fossiliferous Eocene, and in the bluffs of the Mattapony and the Anna rivers, as well as over the intervening divide, it is the prevalent surface formation, maintaining the characteristics exhibited at Fredericksburg, save that it is frequently gravelly. In the vicinity of Richmond it is occasionally exposed toward the summits of the river bluffs, but is there less conspicuous than the subjacent Miocene, Eocene, and Potomac deposits, while still farther southward it continues to thicken and expand.

The distinctive orange-colored sand and clays of the formation are typically exposed on and near the Appomattox River from its mouth to some miles west of Petersburg. A mile below Petersburg they are found at tide-level in the river banks. In the eastern part of the city they appear overlying the fossiliferous Miocene beds midheight of the bluff; and at the "Crater," a mile and a half east, in the railway cuttings in the southwestern part, and on the upland, 2 miles west of the city, they occupy the highest eminences. The zone of outcrop here is at least 30 or 40 miles wide. As at Fredericksburg, the deposit is a regularly but obscurely stratified orange-colored clay or sand, sometimes interbedded with gravel or interspersed with pebbles. Perhaps the best exposure is at the "Crater" (a pit formed by the explo-

[1] Am. Jour. Sci., 3d ser., 1888, vol. 35, p. 328.

sion of 8,000 pounds of powder in a mine carried by Federal engineers beneath a Confederate fort July 13, 1864). Here the principal material is a dense, tenaceous clay, orange, gray, pink, reddish, and mottled in color, plastic yet firm when wet, and so hard and tough when dry that medallions stamped from it as souvenirs are as durable as rock; indeed, the well known strategic measure to which the "Crater" is due was rendered successful by the firmness and tenacity of the clay through which the entire mine was excavated save where it barely touched the subjacent fossiliferous glauconitic sands of the Miocene. At Butterfield's bridge, in the southwestern part of Petersburg, the railway cutting exposes some 20 feet of plastic clay (like that found at the "Crater"), pebbly and sandy clay, and cross-laminated clayey sand, all predominantly orange-colored, in alternating beds, and it is noteworthy that here, as at some other points, flakes and lines of white, plastic clay, similar to those of the Potomac arkose, are occasionally included in the formation.

The formation continues to thicken and expand south of the Appomattox River, until it forms the surface everywhere in the vicinity of the fall line, save where it is cut away by erosion or concealed beneath the Columbia deposits. * * *

In the brief inland margin of the Appomattox formation, as exposed north of Roanoke river, is a moderately regularly stratified sand or clay, with occasional intercalations of fine gravel, generally of pronounced orange hue and without fossils; it reaches a thickness of probably 50 to 100 feet and forms the predominant surface formation over a zone 40 or 50 miles wide on the Roanoke, but attenuates and narrows northward, finally disappearing at Potomac Creek, 4 or 5 miles north of Fredericksburg; and although it appears to thicken seaward it soon disappears beneath tide level and newer deposits.

Stratigraphic relations.—At Fredericksburg the formation reposes, sometimes unconformably and again without visible unconformity, upon the lower member of the Potomac, and like relations are frequently exhibited in the vicinity of Richmond and Petersburg; in the bluffs of the Tapony generally, and of the Pamunkey, 2 or 3 miles north of Hanover court-house, it rests unconformably upon fossiliferous Eocene beds; at the "Crater" and at a number of other localities in the vicinity of Petersburg it rests without visible unconformity upon fossiliferous Miocene beds; in the western part of Petersburg it lies directly upon the Piedmont crystallines; 2 miles northeast of Bellefield it can not be clearly demarked from the fossiliferous Miocene. * * *

The formation is overlain only by the alluvium of small streams, æolian sands, etc., on the broad plain between Petersburg and Weldon, by occasional accumulations of wave-washed débris derived from its own mass in the extensive Quaternary terraces prevailing in its area, and by the characteristic clays, sands, and gravels of the Columbia formation in the vicinity of the larger streams.

Taxonomy.[1]—No fossils have thus far been found in the Appomattox formation, except at Meridian [Mississippi], where Johnson has found it to contain well preserved magnolia leaves apparently identical with those of trees now growing in the same vicinity. Its stratigraphic position, unconformably below the Pleistocene and unconformably above the (probably) Miocene Grand Gulf formation, indicates an age corresponding at least roughly with the Pliocene.

The formation represents a considerable part of a more or less vaguely defined series of deposits variously called "Orange sand," "Drift" or "Quaternary," "Southern drift," etc., by many geologists; but since this vaguely defined series included not only the Appomattox, but also the basal gravel beds of the Pleistocene loess, parts at least of the Cretaceous or Jurassic Potomac (Tuscaloosa) formation, and other deposits of various ages, none of the old designations can be retained without material modification in definition. It therefore seems wise to extend the term applied to the formation in the region in which it was first studied and clearly defined.[2]

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[1] Am. Jour. Sci., 3d ser., 1890, vol. 40, p. 33.

[2] See discussion of the nomenclature farther on and also in the list of formations.

NORTH CAROLINA.

In this state, as in Virginia, two entirely distinct classes of deposits have been included in the Tertiary system, viz, the marine and the peri-zonal. Those of the first class include both Eocene and Miocene beds, and are exposed along river bluffs, in ditches, wells, etc., for a distance sometimes not less than 75 miles inland from the ocean.

MIOCENE ROCKS.

Chesapeake formation.—The Miocene has a much greater horizontal extent than the Eocene, and is thicker, reaching sometimes as much as 20 feet or more and averaging about 5 to 8 feet in thickness. It is less continuous than the Eocene according to Kerr, and often exposed in small and disconnected patches. Yet it is probable that its continuity has really been underestimated, since Clark regards it as forming a tolerably continuous sheet over Eocene and Cretaceous alike. Its distribution is perhaps best ascertained by consulting Kerr's map, prepared to illustrate his report for 1875.

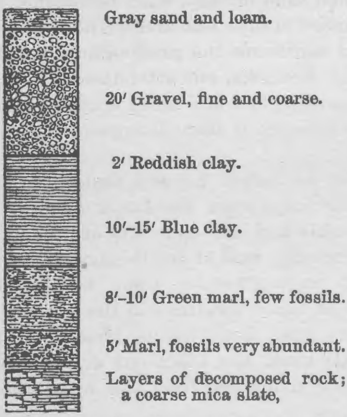

FIG. 9.—Section on Roanoke River, North Carolina.

The Miocene strata, consisting mainly of various colored marls, are generally exposed on the south side of the large rivers and on the north slopes of the divides or swells of land between the rivers. This formation thickens, deepens toward the northern border of the State, the beds being much thicker on the Tar and Roanoke than on the rivers farther south. They are in fact of such thickness here as to conceal both the Eocene, if it exists, and the Cretaceous, with a few local exceptions. The shell beds are rich in fossils, which are often in very perfect preservation.[1]

The principal exposures along a few of the more important rivers will now be considered, beginning with the most northerly.

Chowan River and its tributaries.—At Murfreesboro, on the south side of the Meherrin, there are numerous small gorges, excavated by streams in beds of sand, at whose base a stratum of Miocene marl is distinctly exposed. From these, fossils shells, especially *Ostrea* and *Pecten*, have been washed out in great profusion.[2] Other limited exposures have been noted farther down the same river.[3]

Roanoke River.—A section given by Emmons in his report for 1852,[4]

[1] Rep. Geol. Survey N. C., by W. C. Kerr, 1875, vol. 1, pp. 149-151.
[2] J. T. Hodge: Am. Jour. Sci., 1st ser., 1841, vol. 41, p. 333.
[3] W. C. Kerr: Rep. Geol. Survey N. C., 1875, vol. 1, frontispiece.
[4] Op. cit., p. 67.

probably from the vicinity of Halifax, is here represented diagrammatically (Fig. 9). The marl beds are probably of Miocene age. Another limited exposure of beds of this age is represented near Palmyra on the map accompanying Kerr's report of 1875.

Tar River.—Beginning in Nash County, 5 or 6 miles above Rocky Mount, we find the shelly marl at intervals as far down as Washington.[1] The marl from a locality 4 or 5 miles above Rocky Mount is more or less consolidated and breaks up into masses. Both the brown or red and blue varieties are here noted, the former of which is a little stronger in calcium carbonate than the latter. "The appearance of granite and syenite at Rocky Mount has produced a series of falls in the Tar River; and sometimes the marl is found resting immediately upon those pyrocrystalline rocks." It is more or less sandy, with its upper portion filled with small shells, while below are large scallops and clams (*Venus tridacnoides*). Upon this rests a stratum of sand and rounded pebbles, which is 10 feet thick.

Marl appears at Tarboro at many points, sometimes on the river banks and sometimes in the banks of creeks. Sections of the marl and its accompanying strata, shown in Figs. 10 and 11, have been compiled by Prof. Emmons.

FIG. 10.—Section on Tar River, North Carolina.

FIG. 11.—Section on Tar River, North Carolina.

The marl is intermixed with coprolites, a few bones, and water-worn pebbles, mostly at the bottom of the bed.[2] There is the same tendency to consolidation as at Rocky Mount, and at other places on the Neuse and Cape Fear rivers. The same shells are found in it comprising large Pectens (*Pecten madisonius*), *Venus tridacnoides*, and two or three species of *Pectunculus*. Marl beds appear in numerous places along the river as far down as Washington, notably at Sparta and in the vicinity of Greenville. In each bluff there is usually but one bed, and it varies somewhat in thickness, though apparently averaging from 7 to 8 feet.[3]

Neuse River.—The principal localities on this river where the Miocene marl is well exposed are about Goldsboro and Newbern; at the former place the bed is from 12 to 15 feet thick, and consists of shells imbedded in a green marly clay. At the latter, beds have frequently been brought

[1] Emmons's Rep. Geol. Survey, N. C., 1852, p. 51.
[2] Ibid., p. 55.
[3] Emmons, Geol. Surv. N. C., 1852, pp. 62-64.

to light by accident in various favorable spots, thus proving a fairly general distribution of the Miocene in this vicinity. In 1858, Emmons[1] published the following diagram (Fig. 12) to show the relations of the shell marl to the white Eocene beds of the Neuse.

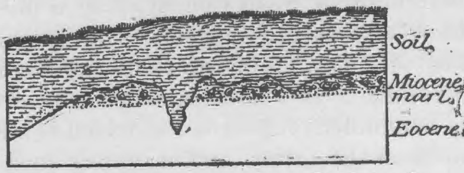

FIG. 12.—Section on Neuse River, North Carolina.

Cape Fear River.—The recent investigations of Prof. W. B. Clark[2] along this stream have thrown some light on the way in which the Neozoic beds of this state have been laid down. The Eocene, according to this author, "occupies wide basins or hollows within the Cretaceous."

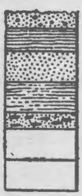

FIG. 13.—Section on Cape Fear River, North Carolina.

FIG. 15.—Section at Brown's Landing, Cape Fear River, North Carolina.

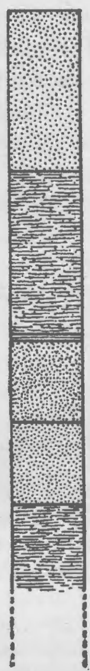

FIG. 14.—Section above Brown's Landing, Cape Fear River, North Carolina.

"Widely extended over Eocene and Cretaceous alike is an incoherent shell marl that may be referred to the Miocene." The rise and decline of the shore line, of a character and extent sufficient to produce this arrangement of deposits, is briefly discussed. He dwells also at some

[1] Rep. Geol. Surv., p. 87.
[2] Bull. Geol. Soc. Am., vol. 1, 1890, p. 537-540.

length on the commingling of the Cretaceous and Eocene faunas near Wilmington, and the occurrence of *Exogyra costata* in Miocene beds, observed by Emmons in 1858,[1] and since confirmed and explained by Stanton in 1891.

Kerr represents,[2] on the geological map accompanying his report for 1875, the Miocene formation as extending along the right flank of this river valley at least 20 miles above Elizabethtown. According to Emmons,[3] "The first [marl] beds which appear upon the river are about 10 miles above Elizabethtown in Bladen County." It here presents three varieties: viz, sandy, argillaceous, and cemented. Just below Elizabethtown, perhaps half a mile, a marl stratum from 2 to 3 feet thick is exposed in the bank on the south side of the river. Fish teeth, coprolites, bones, and rounded pebbles are frequently found at the base of the stratum.[4] The marl with its associated strata are shown in Fig. 13.[5]

"Below Elizabethtown, in Bladen County, the marls continue to be exposed at intervals. One exposure is at Walkers Bluff, 9 miles below Elizabethtown. It is the highest upon the river. It presents a steep escarpment, which consists of different colored sands, with a thick layer of shelly marl."[6] One mile above Browns Landing, or 11 miles above Black Rock, the following beds may be seen:

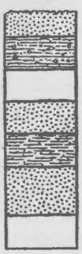

FIG. 16.—Section at Black Rock, Cape Fear River, North Carolina.

"At Brown's Landing, 10 miles above Black Rock, there are numerous distinct beds. In arrangement they belong to two distinct dates: First, the upper, which is Miocene, and the lower, which is probably Eocene."[7] The beds here exhibited are shown in Fig. 15.

Below the shell marl horizon there are at least 60 feet of sand and clay beds considered by Emmons[8] to be of Eocene age, though they may prove to belong to the Miocene.

The shell bed itself contains *Exogyra*, *Belemnites*, and coprolites which were derived from the Cretaceous formation. At Black Rock[9] the beds shown in Fig. 16 occur.

The bed of shell marl represented is, according to Emmons, identical with that at Browns Landing, and here it rests directly upon the Greensand, while there at least 60 feet of sand and clay intervene.

[1] Geol. Surv. N. C., 1858, p. 85. His locality was Browns Landing, Cape Fear River. The mixture is entirely mechanical.

[2] W. C. Kerr: Rep. Geol. Surv. N. C., 1875, frontispiece.

[3] Rep Geol. Surv. N. C., 1852, p. 44.

[4] Ibid, p. 46.

[5] Emmons: Rep. Geol. Surv. N. C., 1858, p. 86.

[6] Emmons: Rep. Geol. Surv. N. C., 1852, p. 47.

[7] Emmons: Rep. 1858, p. 84.

[8] Rep. Geol. Surv. N. C., 1858, p. 85.

[9] Ibid., pp. 81-85.

In the vicinity of Wilmington, Mr. J. T. Hodge made a collection of Miocene fossils, which were identified and published by T. A. Conrad in 1841.[1] Kerr maps a limited Miocene area in this district, but makes no reference to it in his text.

Lyell, in writing of the Eocene limestone, states[2] that "on the shore at the town of Wilmington it is 12 feet thick, covered with a shelly Miocene deposit 6 feet thick."

Mr. Stanton, of the U. S. Geological Survey, also found Miocene beds at this place during a visit made in 1891. They contain the ordinary fossils of the Chesapeake group, like the Yorktown beds of Virginia.

Natural Well, Duplin County.—There is one more Miocene locality in this state that deserves special mention on account of the extensive collection made at that place by Mr. Hodge. This he designates[3] as the "Natural Well," of Duplin County, North Carolina. The sink, so called, is a circular basin, partly filled with water, with steep banks presenting the following section:

Section at Natural Well, Duplin County (after Hodge).

Feet.	Character of strata.
3-4	Soil, loam.
4	Shell marl.
6-8	Tough blue clay.
	Blue sandstone.

The marl consists entirely of shells and fragments of shells, with a small proportion of fine white siliceous sand, more or less discolored by peroxide of iron. The shells are mixed together in great profusion, are soft and friable, and show signs of having been massed together by strong currents. Conrad enumerates about 80 species from this locality.

This locality has recently been visited by Mr. Frank Burns, of the U. S. Geological Survey, who reports the "well" or sink to be situated in the midst of a hard-wood "hammock" covering a few acres. The surrounding country is low and level. The whole seems to be underlain by the shell bed, the commoner Miocene fossils fairly paving the bottom of the small rivulets, ditches, and streams over a radius of several miles. The section at the sink shows 10 feet of reddish sandy clay covering the marl bed, which on the west side of the sink is about 5 feet thick. The sink known as the "Natural Well" is one of several

[1] Am. Jour. Sci., 1st ser., 1841, vol. 41, p. 344.
[2] Geol. Journ., 1845, vol. 1, p. 431.
[3] Am. Jour. Sci., 1st ser., 1841, vol. 41, pp. 335-343.

which are grouped in this vicinity. It appeared to Mr. Burns to be about 200 feet in diameter, circular, and with perpendicular sides rising about 30 feet above the water, which is popularly supposed to be bottomless. On the west side part of the bank has caved in so that, on the bank thus formed, the water can be reached. On the south and east sides of the well the superficial loam diminishes to some 4 or 5 feet in thickness and the marl bed to about the same number of inches. Below them on all sides is a tenacious bluish clay mixed with sand, which at the time of Mr. Burns's visit extended under water to a depth of 4 feet, where it rests upon the sandstone of Hodge's section. Much of the marl has been removed for use as a fertilizer and good specimens of fossils are now rare. But better exposures of the marl can be found in the immediate neighborhood of Magnolia, a village about 2 miles northeast from the well. On the farm of Mr. Strickland, 1½ miles northwest from Magnolia, the same bed afforded better preserved fossils than at the well, while on the farm of Mr. Hollingsworth, 2 miles northeast of Magnolia, the marl is cemented into a comparatively solid rock, hard enough to burn for lime.

Mr. Burns obtained a very large collection from the vicinity of Magnolia and the well, but the fauna appears to be remarkably similar to that of the beds at Yorktown, Virginia.

Vertebrate remains.—Bones of six cetaceans, one Sirenian, and *Mastodon obscurus* Leidy, beside a large number of fishes, have been enumerated by Prof. Cope[1] from the Miocene of North Carolina.

Submarine beds.—Among the dredgings made on the coast of the Carolinas in 1885 by the U. S. Fish Commission, were hauls at the following stations:

No.	Latitude.		Longitude.		Fathoms.	General location.
	°	′	°	′		
2595	35	8	75	5	63	22 miles ESE. from Cape Hatteras.
2596	35	8	75	10	49	17 miles ESE. from Cape Hatteras.
2615	33	45	77	25	18	27 miles ESE. from Cape Fear.
2616	33	43	77	31	17	25 miles ESE. from Cape Fear.
2617	33	37	77	36	14	25 miles SE. from Cape Fear.
2619	33	38	77	36	15	Do.

In the gravel brought up at these stations were numerous Miocene fossils, mostly in a worn condition, including about twenty species of shells and nearly as many fishes, among which Prof. Cope recognized *Galeocerdo egertoni* Ag., *Nemipristis serra* Ag., and a *Lamna* known to be Miocene. The indications are that a considerable part of the submarine plateau extending eastward from the shores of the Carolinas is composed of rock of Miocene age.

[1] Rep. Geol. Surv. N. Carolina, vol. 1, 1875. Appendix B, by E. D. Cope, pp. 29-52, pls. 5-8.

PLIOCENE ROCKS.

Lafayette formation.—This formation belongs to the second class of deposits into which the Tertiary system of this state is divided—i. e., the perezonal.

In the eastern central part of North Carolina the formation[1] is notably variable and heterogeneous over the thinly covered eastern extension of the Piedmont crystallines, now culminating in the continental projection of Cape Hatteras (which has been during past ages an even more conspicuous geographic feature than to-day), and its features are evidently connected with the proximity of the crystalline strata. Thus, at Wilson there is the usual partition into several regular and rather heavy (2 to 5 feet) strata, the usual orange hue, and the usual distribution of quartzite and quartz pebbles either throughout the several strata or in bands or pockets; but the lowermost stratum exposed in the northern part of the town is largely composed of arkose, slightly rearranged and sparsely intermixed with fine quartz pebbles, and there is some admixture of arkose in the superior layers. Then, half a mile south of Wilson a 9-foot railway cutting displays the usual heavy and moderately regular bedding, and the usual hues both in weathered and unweathered strata, while the lowest exposed bed (4 or 5 feet thick) is made up of interlaminated gray or white clay and orange or reddish loam, the clay being fine and plastic, the loam rather sandy and massive within each lamina, and the laminæ sensibly horizontal and ranging from an eighth of an inch to half an inch thick for the clay, and quarter of an inch to an inch or more for the loam. Both of these exceptional aspects of the formation are exhibited in various exposures in this region; both resemble in some measure characteristic aspects of the Potomac formation seen in eastern Virginia, and it is significant that the Potomac is not found here (probably by reason of removal through degradation), that crystalline rocks approach and in the immediate vicinity reach the surface, and so that the Appomattox probably rests immediately upon the eastward extension of the ancient Piedmont crystallines.

Nearer the coast the formation is frequently exposed in railway cuttings and displays the features characteristic of the contemporaneous deposits north of the Roanoke, save that the orange tints are less pronounced and mixed with browns and grays in some strata, that the bedding is thinner and more pronounced, and that the pebbles are small and rare. It is significant that the aspect of the formation here approaches that displayed by the phosphate-bearing Pliocene beds of the South Carolina coast.

The latter, it may be added, are also of a perezonal nature.

Marine Pliocene.—While it is highly probable that marine Pliocene strata were deposited along the shores of this state at the same epoch as those known to exist farther south, yet their presence in that part of the state now above the sea has never been demonstrated. A very considerable addition to our knowledge will be required before it can be definitely stated that such beds are totally absent from the Atlantic border of the state, where it is by no means unlikely that they may have been confounded with beds of the Chesapeake group, as in South Carolina, and for the same reason.

SOUTH CAROLINA.

At present the literature on the geology of South Carolina indicates that there are two classes of deposits or formations which, though

[1] McGee: Am. Jour. Sci., 3d ser., vol. 40, pp. 19-20. Appomattox is the name used by McGee in this article.

widely differing from each other in all paleontological, lithological, and structural features, are, nevertheless, both regarded as having been laid down in Neocene time. The one consists of "a series of predominantly orange-colored, nonfossiliferous sands and clays, resting unconformably upon Miocene and older formations, and unconformably overlain by the Columbia formation."[1] This McGee regards as a southern extension of his Appomattox (=Lafayette) formation, and assigns to it "an age corresponding at least roughly with the Pliocene."[2] It will be described hereafter.

NEOCENE MARLS.

The other consists of isolated patches of marl,[3] filling depressions in the underlying Eocene or Cretaceous strata.

Mineralogically this marl[4] differs from that of the Miocene beds in Virginia in that it contains a much greater percentage of calcium carbonate. Paleontologically the difference is equally marked; for both Tuomey[5] and Heilprin[6] maintain that the proportion of recent to extinct species is more than double that in the Miocene of the Old Dominion. These facts led Tuomey, in 1846, to refer[7] the beds in question to the Pliocene rather than the Miocene, a view which was reasserted in Tuomey and Holmes' "Pliocene Fossils of South Carolina,"[8] though Holmes,[9] Ruffin,[10] Lyell,[11] and Conrad[12] had previously regarded them as Miocene. More recently Dana[13] has seemingly followed Tuomey's interpretation, though he substitutes the name Sumter for that of Pliocene. Heilprin[14] correlates these with the North Caroliana Miocene beds, and styles them "Carolinian" or "Upper Atlantic Miocene." Since the discovery[15] of undoubted Pliocene deposits in Florida with their abundant and characteristic fauna it has become possible to state with certainty that some of the South Carolina forms are typical Pliocene species. Dall concludes that these marly patches probably consist for the most part of Miocene material that has, in some places, a certain mechanical admixture of true Pliocene forms incorporated subsequently to their original deposition.

In South Carolina, as in North Carolina, paleontologists have been

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[1] Am. Jour. Sci., 3d ser., 1890, vol. 40, p. 15; ibid., 1888, vol. 35, p. 328.

[2] Ibid, p. 33.

[3] M. Tuomey: Geol. S. C., 1848, p. 171; Agric. Surv. S. C., by E. Ruffin, 1843, pp. 27-28; Contr. Tert. Geol. and Paleont. U. S., by A. Heilprin, 1884, p. 21.

[4] M. Tuomey: Geol. S. C., 1848, p. 171; E. Ruffin, Agric. Surv. S. C., 1843, p. 29.

[5] Geol. S. C., 1848, p. 183.

[6] Contr. Tert. Geol. and Paleont. U. S., 1884, pp. 51-53 and 60-61.

[7] Geol. of S. C., p. 171.

[8] Op. cit., 1857, p. 9.

[9] Notes on the Geol. of Charleston, S. C., Am. Jour. Sci., 3d ser., 1849, vol. 7, p. 191.

[10] Agric. Surv. S. C., 1843, p. 27.

[11] Quart. Jour. Geol. Soc. Lond., 1845, vol. 1, p. 413.

[12] Medial Tert. Intr., 1843, p. 5.

[13] Dana: Man. Geol., 1863, p. 506.

[14] Contr. Tert. Geol. and Paleont. U. S., 1884, p. 66.

[15] Trans. Wagner Free Inst. Sci. Philadelphia, 1887, 1890, vols. 1, 3.

confronted with a difficulty arising from the alleged coexistence in the same beds of fossils mollusks elsewhere characteristic of different formations. In the fine work on the Pliocene of South Carolina by Messrs. Tuomey and Holmes, both Miocene and Pliocene species are included, with the result that, by some authors, the whole fauna has been regarded as Miocene, and by others, including the writers of the work in question, as Pliocene. Both conclusions rest on the assumption that all the species referred to have been derived from the undisturbed matrix of a single horizon, although collected at a number of different localities. This assumption appears insufficiently supported by the facts, since no critical stratigraphic investigation of the beds in question has ever been made, and especially no researches directed to the solution of this particular series of discrepancies. It may, however, be assumed that no very obvious, if any, stratigraphical differences exist, since otherwise it would seem as if they must have compelled recognition before now. The shell marl, from which the fossils in question have been derived, in part, at least, exists as patches of relatively small extent occupying shallow depressions in older deposits, which, as well as the marl and the superincumbent sands, are unconsolidated, loose, and liable to more or less shifting. The action of the torrential rains which annually visit this region, the influences at work in subaerial denudation, freshets, and floods, as well as the earthquakes which occasionally disturb the soil, offer means not at all inadequate to the confusion of thin, superficial, incoherent strata of similar constitution already in contact with one another; at least to an extent which would make it extremely difficult to recognize any distinction of age or stratification on a casual examination. There is, of course, no reason why in this state, as elsewhere, some species originating in the Miocene should not persist to the Pliocene, or even to the present fauna, essentially unchanged, as they are known to do in Florida, for instance. If this were all, no question need be raised as to the synchronous existence of species which have been collected from these beds. But this is not the real question; on the contrary, it is entirely beside the point. What we find in the supposed fauna of Messrs. Tuomey and Holmes is an aggregation of species of which some have (both north and south of the state) a definite stratigraphical position in certain Miocene beds, where they have never been found associated with certain others as in the South Carolina deposits. These others, again, are known to be mutually associated in beds of Pliocene age, from which the above-mentioned Miocene types have never been collected. Lastly, the known order of development, deduced from the succession of these forms in regions where, as in Florida, the stratigraphical succession is unquestioned, complete, and distinct, is violated by their alleged contemporaneous existence in a locality so nearly adjacent. The annexed tables illustrate the kind of discrepancies alluded to.

I. South Carolina species exclusively belonging to the Miocene (Ecphora zone) in Florida, North Carolina, Virginia, and Maryland.

Scaphella trenholmii, Fla., N. C., Md.
Mitra carolinensis, Fla., N. C.
Fasciolaria rhomboidea, Fla., N. C., Va.
Fasciolaria sparrowi, Fla., N. C.
Fulgur incile, Fla., N. C., Va., Md.
Ecphora 4-costata, Fla., N. C., Va., Md.
Cypræa carolinensis, N. C.
Arca centennaria, Fla., N. C., Va., Md.

II. South Carolina species exclusively belonging to the Pliocene or later in Florida:

Mitra lineolata.
Fasciolaria gigantea.
Fasciolaria distans.
Pisania auritula.
Astyris lunata.
Arca rustica.
Janira hemicylica.
Ostrea raveneliana.

These tables are given as illustrations merely, and comprise conspicuous and characteristic members of the particular faunæ. With a single exception they are of large size and distinctive appearance. With a better knowledge of the Tertiary fauna a complete list of such species would probably be a long one, but we have taken only those which happened to be conspicuous and thoroughly investigated. Now, it seems to the writer[1] that the supposition that the so-called Pliocene of South Carolina represents a mechanical mixture of species of two horizons, is more in harmony with what is known and with paleontological experience than the view that these species, elsewhere diversely distinctive, are, in this locality and for this occasion only, biosynchronous. At least it would seem as if the onus probandi lies with those who would claim a nominally transitorial character for these beds.

The Great Carolinian ridge.—Another fact bearing directly on this question is the lesser Pliocene and Pleistocene change of level in South Carolina. The level of the Columbian (Quaternary) perezone above the sea is here less elevated than it is either north or south of South Carolina. The off-shore deep sea soundings show that the sea bottom rises in an east-west general direction off that state, so that the Gulf stream flows up and over a hill or ridge transverse to its course. This indicates a relatively stationary axis or wide fold here (for which in this essay the term Great Carolinian ridge has been used), over which the Miocene beds are thin because it was not greatly depressed, and the following Pliocene beds also may be supposed to have been extremely thin, a state of affairs, considering the incoherence of the beds, which would greatly have facilitated subsequent confusion of the fossils and mixture of the material beds.

Stratigraphy.—These fossiliferous deposits are mainly confined to the northeastern part of the State. In Horry district slight exposures were noted by Tuomey on Little River; better ones were seen along the

[1] W. H. Dall.

Waccamaw, for some distance from Conway borough. At Potters Landing and at Harpers the strata appear as follows:

Feet.	Character of strata.
30-40	Yellow sand.
8-12	Yellow fossiliferous marl.
8	Cretaceous beds.

On the right bank of the river, not far from Nixonville, the beds as exposed stand thus:[1]

Feet.	Character of strata.
30	Loose sand and clay.
10	Marl.
2	Cretaceous. *Exogyra costata.*

From these and other less important exposures on the Waccamaw Tuomey enumerates 47 molluscan species, 21 of which he regards as recent.

In the southeastern part of Marion County several marl beds have been noted in the banks of or near the various rivers by which this district is crossed. The most easterly of these[2] is exposed on the Marion road, 2 or 3 miles from Galovants Ferry on Little Peedee River. It is 6 feet in thickness, is laid bare for a distance of 100 yards, and contains *Pecten eboreus*, *Ostrea virginica*, and *O. disparilis*. On the Great Peedee three localities are worthy of special mention, viz, Witherspoons Bluff, Giles Bluff, and Godfreys Ferry. At the first of these marl is seen rising from the water's edge, in a bed 10 feet thick, the upper portion of which is more siliceous than the rest. *Modiola ducateli* and *Panopæa reflexa* have here been identified. At Giles Bluff[3] the marl bed is from 8 to 10 feet thick, and is underlain by Cretaceous deposits at least 20 feet thick. The lower part of the marl is soft and of a light ash color, and contains fine specimens of *Pecten mortoni*. Above the structure is coarser, of a ferruginous color, and made up principally of casts of shells, among which *Chama congregata* predominates. The

[1] M. Tuomey, Geol. S. C., 1848, p. 173.
[2] Ibid., p. 175.
[3] E. Ruffin gives the thickness of the Miocene at this place as 12 feet and the underlying Cretaceous bed 14 feet.—Agric. Surv. S. C., 1843, p. 24.

upper, firmer portion of the marl is again seen at Godfreys Ferry,[1] which is its southern limit on the Peedee.

Leaving the river and proceeding toward Darlington Court-House, marl occurs at wide intervals and is rarely exposed except in artificial excavations. Immediately about the village localities are quite numerous. The marl is usually found in the beds of creeks and their branches, though sometimes met in digging wells. Above it are superficial incoherent beds of sand, clay, and the accumulating organic matter of swamps. The most important exposure in this vicinity is that at "Col. Ervin's," on a small stream one mile east of the court-house. The marl is here 10 feet in thickness. The fossils are in a fine state of preservation, and, owing to extensive excavations that were being made at the time of Tuomey's visit to this locality, he was able to make an excellent collection. This assisted him materially in his conclusions in regard to the age of these marl deposits. In a southwesterly direction from Darlington, as far as the Black River, in Sumter County, numerous exposures of marl may be seen; one of these has yielded [2] fragments of deer horns, together with *Gnathodon* and *Cyrena;* from another a tusk of *Mastodon* has been reported.[3] Below Eutaw, in St. John Berkeley, marl [4] is dug from pits for agricultural purposes, though there are no natural exposures. From these, Tuomey has obtained *Ostrea disparilis*, *Pecten septenarius*, *Venus rileyi*, and *Ecphora quadricostata*. Again, at Grove,[5] on the left bank of Cooper River, the Miocene marl has been cut into during the construction of a canal. This marl is lithologically like the Eocene, and can be distinguished only by its fossil remains. Very similar to this marl bed is one on Goose Creek;[6] the latter, however, is somewhat more ferruginous and harder.

On the Edisto, [7] below Givham's Ferry, *Ostrea disparilis* and other fossils of this formation have been detected.

In the vicinity of Oakley Inlet, Georgetown District, Ruffin [8] collected "*Venus rileyi*, *V. alveata*, *Corbula inequale*, *Arca limosa*, a variety of *Ostrea virginiana*," and others, all in an excellent state of preservation. They were evidently thrown up by the waves and "must have formed part of a submarine bed of Miocene marl, which still exists and perhaps has always remained under the sea." Moreover, a shark's tooth "precisely similar to those of large size found in the Miocene of Virginia" was "drawn up by an anchor from the bottom of Charleston harbor, in water 45 feet deep, off Fort Sumter."

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[1] Ruffin states that the Miocene marl has a visible thickness of over 25 feet above water the and on Cretaceous marl was seen beneath it.—Agric. Surv. S. C., 1843, p. 24.

[2] Geol. S. Car., M. Tuomey, 1848, p. 177.

[3] Ibid p. 178. These remains are hardly Miocene in character.

[4] Ibid p. 178. This deposit, on the other hand, is characteristically Miocene.

[5] Ibid p. 179. Lyell mistook this for Eocene: Quart. Jour. Geol. Soc., 1845, vol. 1, p. 432.

[6] For the history of the discovery of this deposit, see Ruffin's Agric. Surv. S. C., 1843, p. 28.

[7] Geol. S. C., M. Tuomey, 1848, p. 179.

[8] Agric. Surv. S. C., 1843, p. 34.

PLIOCENE ROCKS.

Lafayette formation.—This formation, as has already been stated, consists of a perezonal series of predominantly orange-colored, non-fossiliferous sands and clays, resting unconformably upon Miocene and older formations, and unconformably overlain by the Columbia.

Unfortunately, little has as yet been published concerning the geographical distribution, thickness, lithological features, etc., of this formation in South Carolina. McGee says in substance that it forms a terrane 40 or 50 miles wide on the Roanoke, thence extends southward in a broad zone at first widening but afterward narrowing with the encroachment of the overlapping coast sands upon its area, quite across the Carolinas.[1] Hypsographically it extends from an elevation of from 25 feet to 650 feet above tide[2] level. South of the Roanoke[3] it is subject to local variations in its lithological and stratigraphical features. In some instances it approaches in appearance the phosphate-bearing Pliocene beds[4] of the South Carolina coast, into which it perhaps merges.[5] He says:[6]

Another distinctive but hardly distinct aspect of the formation is extensively displayed in central South Carolina, notably about Columbia. Here the usual moderately-regular and rather heavy but always inconspicuous bedding of the formation is displayed; but the prevailing colors are richer and darker than in other parts of the terrane, commonly ranging from orange red to chocolate brown. Moreover, certain of the strata exhibit a peculiar mottling (which is better displayed farther southward); certain other strata exhibit a distinctive cross-stratification defined by gray or white plastic clay in laminæ, irregular sheets, and lines of pellets; the various strata are more uniform in composition than in the north, consisting rather of loam than of sand and clay in alternating beds, and the deposit as a whole takes on a solid, massive, and rock-like appearance, and gives origin to a distinctive topography. So conspicuously diverse in color, texture, and habit of erosion are the prevailing formations of central South Carolina that over thousands of square miles the surface is popularly divided into "red hills" and "sand hills"—the former representing the Appomattox, the latter the southern interfluvial phase of the Columbia formation.[7] The distribution of pebbles in this vicinity is especially interesting; northeast of the Congaree River, on the line of the Richmond and Danville Railway, pebbles are rare to within 2 miles of the present water way; there they suddenly increase in abundance, and in some sections within a mile from the river form a considerable and sometimes the principal part of the deposit; while south of the river they quickly become rare, being abundant only within a mile or less of the river bluffs. The pebbles are predominantly of quartz, though partly of quartzite, and comprise a few gneissoid fragments. They range in size from two and a half

[1] Am. Jour. Sci., 3d ser., 1890, vol. 40, p. 28.
[2] Ibid., p. 30.
[3] Ibid., p. 19.
[4] Ibid., p. 20.
[5] Ibid., p. 33.
[6] Ibid., p. 20.
[7] This expression needs modification to avoid misconception. The "red hills," as above used, means merely the superficial debris rearranged from the subjacent formations; the same is true of the "sand hills." The "red hills" and "sand hills" formations of South Carolina local usage are the red Buhrstone (or Claiborne Eocene) beds of Tuomey and the white siliceous Buhrstone which lies below it. The material derived from them and used in the Lafayette and Columbia perezones is that to which the words of McGee relate.

aches downward. Commonly they are accumulated in lines or pockets, sometimes at the base of the formation; but a few also occur disseminated throughout the ill defined strata.

About the fall line on the Santee River system the Appomattox (Lafayette) loam is in part overlain unconformably by the Columbia formation, though it has been severely degraded; and in an admirable section on the Richmond and Danville Railway immediately east of the state house, where both upper and lower contacts are displayed, the Appomattox rests unconformably on the Potomac. Farther up river the Appomattox rests directly upon the Piedmont crystallines, which here give origin to residuary products of dark red and brown color, and so the origin of the exceptionally rich hues of the formation in this region are not difficult to trace.

As our note (p. 80) shows, there is a liability to misconception in the language of McGee's account of the deposits included in the Lafayette formation. He seemingly includes in it beds of much greater age than that to which the Lafayette can be referred. But we understand that his intention was to indicate, as part of his Lafayette, only that superficial portion of these older beds which has been rémanié by the perezonal forces at a later time.

GEORGIA.

The distribution of the Tertiary deposits of this state is still but imperfectly understood, and the information brought together here, though fuller than elsewhere published, is still only roughly approximate.

MIOCENE.

Altamaha grit.—Descending the Ocmulgee River from Hawkinsville, Pulaski County, the main body of the country rock composing the bluffs along the river is the Orbitoides or Vicksburg limestone, often silicified and occasionally surmounted by a still more cherty layer, corresponding to the foraminiferal beds which form the culmination of the Eocene in Florida. These rocks rise to some 80 feet above the river, and at House Creek, Willcox County, are covered by a thin sandy bed containing the same silicified oyster shells, and presenting much such a petrologic character as the Hawthorne beds of Florida. Below this point the bluffs recede from the river but near the middle line of Coffee County appear again, exhibiting at Rocky hammock the first example on the river of a formation to which the name of Altamaha grit may be applied. The preceding notes are from observations by Mr. Frank Burns, of the U. S. Geological Survey, but the first reference we have found to this formation is by Loughridge[1] who describes it as follows:

Included between the Savannah River and the Atlantic and Gulf water divide, there seems to have been once formed a large shallow basin, which is now filled with a sandstone composed for the most part of coarse angular grit and clay partly cemented with silica, and resembling in character the Grand Gulf sandstone of the Gulf states. The area is marked on the map by the deep green color of the pine barren region, whose soil overlies the formation. The rocks have a slight dip to the southeast, have been traced by Capt. M. T. Singleton for 60 miles along Oconee River, and he estimates the thickness to be 200 feet.

[1] Dr. R. H. Loughridge: The Cotton Product of Georgia, in Tenth Census, vol. 6, part II, pp. 15, 16.

Outcrops have been observed in Irwin, Dodge, Ware, and other counties. Paramore hill, in the western part of Screven County, is of this sandstone, which has a thickness of 50 feet or more. Its grains of quartz are partly clear and translucent and partly white and opaque, and the rock is highly aluminous.

The southern limit of the sandstone is apparently at the edge of the second terrace, near the coast and along the Satilla River north of Okefinokee swamp, but the formation (represented by blue clays underlying the sandy land) extends probably still farther southward, including in its area the country near the Florida line, between Allapaha River on the west and the ridge on the eastern side of the swamp, a part of the main Atlantic and Gulf water divide of the state.

In order to define more closely the limits of this formation and determine, if possible, its age, Mr. Frank Burns, of the U. S. Geological Survey, was requested to follow the river from Hawkinsville to the point where it emerges from the highlands upon the flats of the Coastal plain. This point is approximately marked by the Atlantic Coast Railroad, as the last bluff of the grit is only a few rods above the bridge across the Altamaha River at Doctor Town, the piers of the bridge resting upon a newer formation.[1] Between Rocky hammock and Doctor Town all the bluffs (which are mostly on the right bank of the river) are composed of the grit, somtimes extremely hard and flinty and at others more disposed to crumble, but always composed of angular grains of slightly worn quartz mixed with more or less clay as a matrix and with water-worn quartz pebbles. The Altamaha grit is well exposed in these bluffs, which sometimes, as at Tillmans Ferry, Tatnall County, reach an elevation of 70 feet above the river, the beds being nearly horizontal or dipping slightly to the south and east.

The soil above them is sour and sterile, the decomposed quartz grains allowing the finer vegetable mold or any applied fertilizer to leach away rapidly. The district under which they occur has the local name of the "wire-grass section," and from an agricultural standpoint has only its healthfulness to recommend it. It is but sparsely settled and has few attractions.

These grits are obviously of a perezonal nature and represent, for the Georgian embayment, the operation through the agency of the southeastern drainage of Georgia of the same forces and analogous circumstances, to those which on the borders of the Mississippi embayment produced the Grand Gulf perezone. Though the contact with the oyster-bearing Hawthorne beds of House Creek was not observed by Mr. Burns, there can be little doubt that the latter are overlain by the grit where they join, and that the grits which contain no fossils except a little silicified wood are consequently of Miocene age. Seaward from them marine Miocene beds of the Chesapeake series were doubtless laid down, since Conrad records the washing up on St. Simons Island of a specimen of *Ecphora*.[2]

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[1] Mr. Burns learned that in digging for the foundations of these piers a bed of marine shells was cut through about 20 feet below the surface. At Jesup, not far west on the railroad, at 20 to 23 feet, an artesian well passed through a bed of oyster shells, below which was only yellow sand, and the well after being driven 500 feet without reaching water was abandoned. These shell beds are probably Pliocene or Pleistocene, but without much labor could not be reached at the present time.

[2] Proc. Acad. Nat Sci., Phila., 1852, vol. 6, p. 199.

Chattahoochee group.—Rocks of this age are known to occupy at least a narrow strip along the southern border of the southwestern tier of counties, being probably more or less continuous with the belt of Hawthorne beds observed by Burns on the Ocmulgee River and regarded by him as extending over a considerable area to the southwest. A large silicified coral, similar to those found in the clay of the Hawthorne beds in Alachua County, Florida, was, according to L. C. Johnson (letter of May 11, 1885) obtained by State Geologist Little at Thomasville, Georgia. Very recently from Barrows and Campbell Hill, Decatur County, Georgia, in the vicinity of Bainbridge, Prof. R. Pumpelly has forwarded specimens of silicified corals belonging to the same species as those found in the Hawthorne beds of Florida, together with fragments of rock containing fossils of the Chipola marl.

The latter, according to Prof. Pumpelly, come "from broken-up siliceous beds in the great mass of clays which are the residuum of the shrinkage by dissolution of, I think, a great thickness of strata." "Underneath them is limestone" belonging to the Vicksburg group, containing *Orbitoides mantelli* and *Pecten poulsoni*, in place at Russells Spring on the Flint River.

This evidence confirms the former existence of Miocene sediments, forming the link between Altamaha grits and the Miocene of the Chattahoochee River in Florida, which bordered on the north the Miocene strait connecting the Georgia embayment with the Gulf of Mexico. These sediments have here, as in many other places, disappeared under the solvent influence of percolating waters; leaving only the harder fragments, silicified fossils, and insoluble clays to indicate their presence. Subsequently, probably in early Pliocene time, the processes which formed the La Fayette perezone have rearranged to some extent the residual materials of the older Miocene rocks without, apparently, transporting them from their original site.

Jacksonboro limestone.—A locality near the northeastern border of the state has recently afforded evidences of Miocene strata apparently belonging to a horizon near that of the Chipola series. Near the confluence of Brier Creek and Beaver Dam Creek, which together form a tributary of the Savannah River, and 3 miles below Jacksonboro, Scriven County, Georgia, is a stratum of limestone containing very numerous casts of shells and occasionally a silicified specimen, on the whole not unlike the Tampa limestone. This stone was formerly burned for lime. It was visited by Lyell,[1] who referred to it on several occasions and supposed it to be of Eocene age. This locality was recently visited by Prof. W. B. Clark, who found the quarry and ruins of the kiln spoken of by Lyell. An examination of the material collected there showed the presence of *Strombus chipolanus ; Fissurella* like *Marylandica; Infundibulum perarmatum* Con?; *Xenophora humilis ;* a *Cerith-*

[1] See Lyell, Proc. Geol. Soc., vol. 3, pp. 735, 742; vol. 4, pp. 547, 563, and reprints of the same papers in Quart. Jour. Geol. Soc., 1845, vol. 1, pp. 413 and 429.

ium, much like *C. hillsboroensis;* a species of *Vertagus*, recalling one from the Caloosahatchie Pliocene; *Capulus*, like one in the Tampa silex beds; *Bulla petrosa? Pecten septenarius*, a small *Macoma* like one from the Tampa silex beds; a *Cardium* and an *Ampullina*, resembling the Chipola species, besides a number of forms which might be Eocene or later, but had a Miocene aspect. There were, as in the Chipola beds, several forms known from the Upper Eocene, such as *Eburna sp.*, *Serpula sp.* The section here showed 5 feet of ferruginous sand and over 12 feet of compact marly rock with fossils. Until a more thorough examination and study of the species has been made the matter can not be said to be finally settled, but at present the presumption is obviously in favor of the early Miocene age of this deposit, from which Lonsdale has described[1] several corals collected by Lyell. The uppermost fossiliferous layer at Shell Bluff, while probably Eocene, presents indications of a modification of the fauna in the direction of that following it in the Miocene epoch. *Cerithium, Cardium*, and *Yoldia* closely resembling *Y. limatula*, were found by Prof. Clark in Richmond County west of Augusta, in a pit at McBean, on the land of R. W. Knight. A similar silicified layer was observed by Frank Burns capping the softer Vicksburg along the Ockmulgee River between Hawkinsville and House Creek.

PLIOCENE ROCKS.

Marl beds.—Two very different deposits in this state have been referred to the Pliocene age. The one is described by Loughridge as follows:

The Savannah region along the coast, which occupies the first terrace at an elevation of from 10 to 15 feet above tide-water, is assigned to the Pliocene formation. Marls or shell beds of this age are found on the Savannah River near the Effingham and Chatham County lines. On Satilla River a white marl bed outcrops at Burnt Fort, the head of tidewater, which is mostly devoid of fossils. In the sand and clay beds of the coast region in Glynn, Chatham, and other counties have been dug up the remains of gigantic quadrupeds, such as the mastodon, and along its borders are buried stumps of cypress and other trees still standing upright.

The Lafayette formation.—This, according to McGee, forms "the most conspicuous terrane of central Georgia, where it stretches from the fall-line to the inland margin of the coast sands all the way from the Savannah to the Chattahoochee.[2] It is in this state that the formation appears best developed. "At many points it overlaps far upon the Piedmont crystallines. On the seaward side of the fall-line it is unquestionably overlapped in turn by the pine-clad sands of the Columbia formation over many thousand square miles. It evidently reaches a considerable thickness, perhaps 100 feet or more." Good exposures may be seen at Augusta, Green's Cut, Munnerlyn, Sun Hill, and especially at Macon, where it is typically developed. "Above the

[1] Quart. Jour. Geol. Soc., 1845, vol. 1.
[2] Am. Jour. Sci., 3d ser., 1890, vol. 40, p. 28.

reach of modern alluvium, and above the vaguely defined and poorly exposed 'second bottoms' it forms the prevailing surface;[1] and in every street and suburban road, in every storm-carved runnel and road-side gulley, and in every cutting of the seven railways radiating from the city its materials are exposed." Here it displays its usual orange-yellow and orange-red tints, its cross-bedded structure, and its indefinite and irregular stratification. Here, too, near the fall-line the formation abounds in small pebbles, arranged in lines, accumulated in pockets or disseminated throughout the deposit. At Macon, as at Columbia, the Appomattox (Lafayette) is intercalated between the Columbia and Potomac formations. It is noteworthy that although the Appomattox (Lafayette) and the Potomac are here, as elsewhere, strikingly unconformable, they sometimes merge so completely that no line of demarcation can be drawn with precision. Of these three formations, the finest southern exposures may be seen just below the falls of the Chattahoochee in the villages of Girard and Lively, Alabama, opposite Columbus.

Vertebrate remains.—In the American Naturalist, 1878 (vol. 12, p. 129), it is stated that Prof. Little, director of the geological survey of Georgia, has accumulated a valuable collection of the vertebrate fossils of the state, of Cretaceous and Tertiary age. Among these there have been identified the dinosaurian *Hadrosaurus tripos*, and the turtles, *Taphrasphys strenuus* and *Amphiemys oxysternum*, a new genus and species related to *Adocus*. Mr. Loughridge, of the Survey, also discovered a very fine specimen of that rare propilurid, *Peritresius ornatus*.

FLORIDA.

INTRODUCTORY.

The state of Florida presents the most complete succession of Tertiary and post-Tertiary fossil-bearing strata of any part of the United States. These have been but little disturbed by orogenic movements, exhibit but trifling uncomformities, and present numerous interesting cases of the survival of forms from one horizon to another, thus illustrating in the most forcible manner to the biologist the uniformity of conditions under which the beds have been laid down.

Perhaps no other region on our coast presents so many instances of Miocene species still existing in the deeper waters off its own shores. Nowhere else can the problems of descent with modification during Cenozoic and later time be so well studied in the fossil and recent faunas.

For these reasons, since Florida offers a sort of standard, with which it may be convenient to compare the Cenozoic beds of other parts of the coast, and also because much unpublished material pertinent to the occasion is in the writer's[2] possession, the description of Floridian geol-

[1] Am. Jour. Sci., 3d ser., 1890, vol. 40, p. 22.

[2] For the portion of this essay relating to the state of Florida W. H. Dall is solely responsible.

ogy has been more fully detailed than in the case of either of the other states referred to in connection with this essay. The peculiarity of certain processes, such as erosion by solution and deposition by chemical rather than by gravitative energy, which have played such an important part in the geology of the peninsula, the simplicity of its petrographic character, originating almost solely from oceanic, chiefly organic sediments; and the total absence of certain forms of action, conspicuous, if not overshadowing all others, in most other parts of the continent; all these things render the geology of Florida especially interesting.

In offering here and there a working hypothesis in explanation of sundry problems, the writer would explain, once for all, that these hypotheses are provisional, that he fully appreciates the defectiveness of our knowledge and anticipates the necessity, with further knowledge, of much revision and correction. Nevertheless, he believes that facts, like beads, can be better appreciated strung on the thread of even a working hypothesis than when merely incoherently aggregated.

All the facts at present gathered tend toward the conclusion that the Floridian peninsula is a region where geological action has been gentle, slow, and very uniform; where elevations and depressions, if sudden, have been slight in vertical range and symmetrical over considerable areas; where the total elevation has probably not been very much greater than at present, in post-Cretaceous time; and where organic sediments in the main, have been the building material. The changes in the rocks have been almost exclusively due to chemical rather than mountain-building forces, and have repeated themselves in rocks of each successive epoch by methods which can be studied in actual operation at the present moment.

TOPOGRAPHY OF THE FLORIDA PENINSULA.

Foundation of the peninsula.—The shore lines of the peninsula of Florida very imperfectly indicate its fundamental topographic relations. To understand those it is necessary to study a chart, such as that accompanying this volume, or a model which exhibits the submarine topography of the adjacent seabottom as well as the subærial modeling of the land surface. On grounds which are more fully discussed in another section of this essay, I am disposed to believe that the present peninsula rests on a much more extensive foundation of Eocene limestone, mostly of Vicksburg age, forming a plateau which formerly extended from the southeastern margin of the continent to the Cuban and Bahaman region and possibly to Yucatan. The deeper channels which now separate the Floridian part of this plateau from the Antillean and Yucatan areas are probably, as Agassiz has suggested, due to scour exerted by the Gulf stream as its flow became restricted by the gradual elevation of the land, though there is some evidence in favor of faulting in this connection. The material, as originally deposited, consisted almost wholly of siliceous and calcareous remains of marine invertebrates, which at the period when the scour was initiated may well have been in a comparatively soft or incoherent condition, as much of the Vicksburg limestone still remains. The attrition of the siliceous particles and harder calcareous fragments, contained in the uppermost layers and transported by the tremendous energy of the current, would have formed a sand blast capable of almost any amount of cutting, and more than equal to the task which has been performed in the Florida strait and its northern extension under the Gulf stream.

Folds of the strata.—In considering the topography of Florida it has been customary among geologists and others to speak of the "central ridge," "elevated axis," and in the latest contribution to the subject[1] Prof. Shaler regards Florida as "formed of lowlands rising as a broad fold from the deep water on either side to a vast ridge, the top of which is relatively very flat, there being no indication of true mountain folding in any part of the area." In an extremely wide and general sense it is of course true that the peninsula forms a great fold, but in the ordinary and literal meaning of the words this description conveys an inaccurate idea of the structure of the region.

ORIGIN, CHARACTER, AND DECAY OF ROCKS.

Before endeavoring to give an idea of the topographic structure, as observed by the writer, it will be well to consider the material of which the peninsula is composed and its behavior under the conditions to which it has been almost invariably subjected.

The materials hitherto observed in the peninsula of Florida, and of which the rocks are for practical purposes exclusively made up, are lime, clay, and silex, with occasionally a little oxide of iron, all materials which at the present moment are being copiously deposited in the bed of the ocean.[2] In Florida, for the most part, they may be assumed to have been derived from organisms or sediments transported to the spot by the sea. From organic agencies, operating since part of the peninsula has been raised above the sea, have been received sulphuretted hydrogen, carbon dioxide, and phosphoric acid, which, in a state of solution or chemical combination with rainwater, have energetically acted upon the rocks.

The Eocene lime rocks were deposited over a vast area of the sea

[1] The Topography of Florida, Bull. Mus. Comp. Zool., 1890, vol. 16, No. 7.

[2] At a depth of 600 feet, in boring the artesian wells for the Sub-Tropical Exposition at Jacksonville, Florida, two years ago, a thin stratum of greenish clay was struck which contains numerous extremely fine particles of mica. These particles were, of course, derived from the continent to the northward, the rocks with which the clay was associated in the wells, being of the Chesapeake group or newer, cold water, Miocene. This clay much recalls the clay associated in many places farther north with the fossils of this age. The bed which contains it is the only stratum reported from the peninsula part of Florida, and yet brought to the writer's notice, which might not have been derived from the material of which the peninsula has been built up. Pebbles of crystalline rock from the St. Augustine well and the small particles of volcanic rock of Antillean origin, in the marls of Southern Florida may be considered as exceptional exotics. Most of the latter probably reached Florida attached to drifting seaweed or the spongy floats of *Lepas fascicularis*.

bottom, instead of a narrow strip, as in the case of sediments directly derived from antecedent dry land. To the broad and even manner in which they were spread out and the fact that subaerial erosion has on the dry land of Florida proceeded rather by processes of solution than by comminution and transportation of the material comminuted, we may ascribe the feebleness of those evidences of lateral thrust and vertical flexure which on most coast regions are so forcibly exhibited. Nevertheless, flexures are not entirely absent, as was pointed out by the writer on another occasion,[1] even in the later deposits of the southern part of the peninsula, where, in the section exposed on the banks of the Caloosahatchie River, gentle folds with their axes generally parallel with the trend of the peninsula, continually succeed one another between Lake Okeechobee and the Gulf of Mexico.

Effects of solution on the topography.—From Eocene times until the present day the modification of the rocks has proceeded through a series of constantly recurring similar changes. The silica derived from organic remains has been taken up by percolating waters and redeposited in the form of sheets, strings, and nodules of flint, chalcedony, or chert, or as a cement holding together with extreme tenacity the other minerals of the particular stratum concerned. The "gravels" referred to in the description of peninsular Florida rocks are the waste of these siliceous products comminuted by wave action or left loose by the solution of their associated carbonate of lime and rounded by attrition on each other. Much of the sand of Florida is derived from the same source, excluding the shore sands of the eastern coast. Occasional minute particles may be found which seem to have had a volcanic origin, and which are doubtless derived from the volcanic region of the Antilles. The decay of organic, largely vegetable, matter carried by rain into the interstices and subterranean passages of the porous lime rock produces the sulphuretted waters, which are found all over the peninsula. These sometimes find an exit on the seashore and are often so strongly charged as to destroy life in all organisms with which they come in contact over hundreds of square miles of coast. To these or to analogous forces acting on the lime rocks may be ascribed the formation (as at Dunellon on the Withlacoochee) of extensive beds of gypsum or sulphate of lime. In a similar way the action of rain water on beds of guano or the daily ejections of great rookeries of birds in some cases, or on other decaying animal matter in other cases, has carried phosphoric acid into the subjacent porous lime rock in such a way as to result in the modification of numerous extensive beds of ordinary limestone or marl into more or less phosphatized lime rock, much of which is available for fertilizers. The presence of the organic material and the porosity of the rock beneath it have alone been in question here, as rock of all ages, from the Eocene up, has been subjected to similar influences in Florida with analogous results.

It is probable that the beds commercially most valuable are comprised

[1] Geology of Florida: Am. Jour. Sci., 3rd ser., 1887, vol. 34, p. 168.

within more limited geological confines, but essentially the same agencies have been at work up to the present moment, though with varying degrees of energy and very different quantitative sources of supply.

By the constant slow circulation of the fresh water derived from the atmosphere and contained in the porous rock, like water passing through a stone filter, a circulation incited by gravity and relieved by the outflow of myriads of springs, the salt which might have been entangled in the original sediments appears to have been almost wholly removed from the Florida rocks.

Most of the limestones contain more or less clayey matter, but occasional beds of clay occur of such magnitude as to suggest a different origin, perhaps from river sediments transported from a distance, or other sources which can not with our present knowledge be satisfactorily determined.

The general structure of the peninsula seems to indicate a succession of moderate longitudinal folds which are more accentuated in the north, and which, like those mentioned as observed on the Caloosahatchie, trend with the general trend of the peninsula. The evidence points quite strongly to the existence of two principal anticlinal folds, of but very moderate height, it is true, but high compared with the average level of the peninsula and to which its most remarkable topographic features are due. The highest and oldest of these folds is also the most western and consists chiefly of Eocene limestone. The eastern fold is somewhat narrower and lower and formed of Miocene rocks. The features of the latter are obscured by superficial sand deposits.

The peculiar solutionary method by which erosion is chiefly carried on in Florida results in unfamiliar topographic minor details. The broader features often recall that peculiar facies of the English "downs," which is due to analogous causes. The "lumpy" rounded character of the superficial sandhills is very confusing to the eye and effectively masks the long and gentle curves of the strata. Only when a water level, as along a stream, offers a direct means of comparison does one recognize the fact that these apparently horizontal rocks are really bent.

Good exposures of this sort are, unhappily, rare in Florida, and but little of the country is visible under its carpet of semitropical vegetation or even more delusive blanket of sand. For proof of the existence of the greater flexures recourse must be had to another method. It is obvious, if the strata look horizontal wherever we are and if one finds by a series of levels that the supposed level surface really describes a series of ridges, that at least a probability is established for the proposition that the strata are also flexed.

PROFILES FROM LINES OF RAILWAY LEVELS.

From series of levelings executed for railway surveys in Florida I have prepared the following profiles. It may be stated in advance that the leveling is probably of a rough and ready character, not to be depended upon for the registration of minute differences and in some cases having rather uncertain connection with the level of mean tide, here taken as zero. Yet for considerable differences of level and for general relations of altitudes to each other it may be presumed to be accurate enough for our purposes, even if the absolute altitudes are not determined with great exactitude.

These represent, respectively:

I. Profile from the ocean at San Pablo Beach east of Jacksonville westward 110 miles to the Suwanee River, reduced to the parallel of north latitude 30° 15′. (Fig. 17.)

This shows the Atlantic drainage, part of the gulf drainage, and

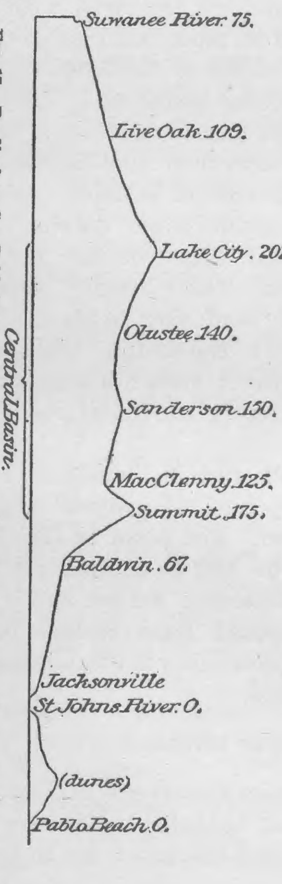

FIG. 17.—Profile from San Pablo Beach, Duval County, westward to the Suwanee River, Florida.

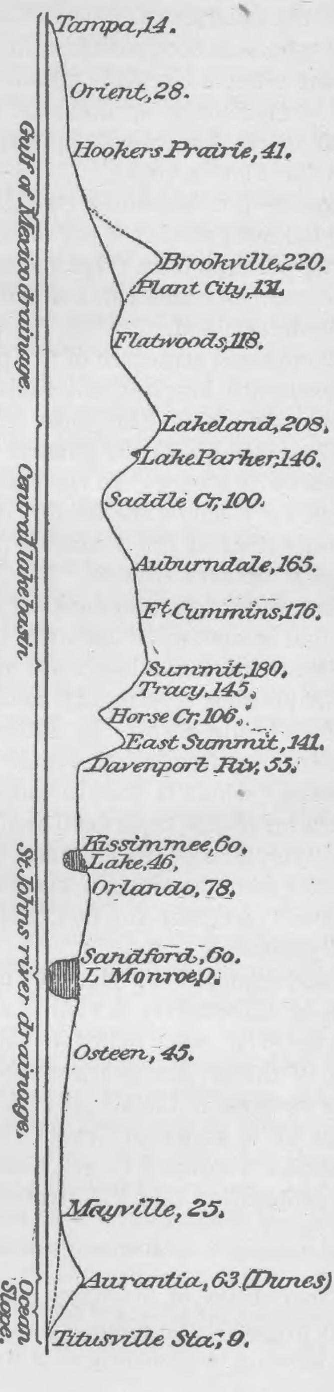

FIG. 18.—Profile across Florida from Indian River, Brevard County, to Tampa Bay.

what I have termed the Central Lake basin between the two principal anticlines, cut nearly at right angles, not far from its northern extreme. The levels were furnished by the officers of the Florida Railway and Navigation Company to the geographer of the U. S. Geological Survey.

II. A similar east and west profile reduced to the parallel 28° 30′, from the sea level at the inlet called Indian River west to the Gulf at Tampa Bay, from levels of the South Florida Railway Company. (Fig.18.)

This profile cuts the "central basin" near its southern third, and the third anticline west from it is clearly brought out. This profile is less right-angled to the anticline axes than the northern one (I), because the peninsula trends more easterly as we go south, but it is reduced from a profile almost exactly right-angled to these axes, and the difference on the scale used is unimportant. Southward from this region the general surface of the peninsula becomes lower and the elevation of the anticlines less and less marked.

III. A northeast and southwest profile from Fernandina on the Atlantic coast to the Gulf near Cedar Keys, 110 miles, from the Savannah, Florida and Western Railway leveling. (Fig. 19.)

This profile shows the Atlantic and Gulf slopes, the Central basin, and the third anticline near Archer, cutting the region traversed at an angle of 45° with the two previous lines.

IV. A north-south profile reduced by rectangular coordinates to the meridian of 82° west Green-

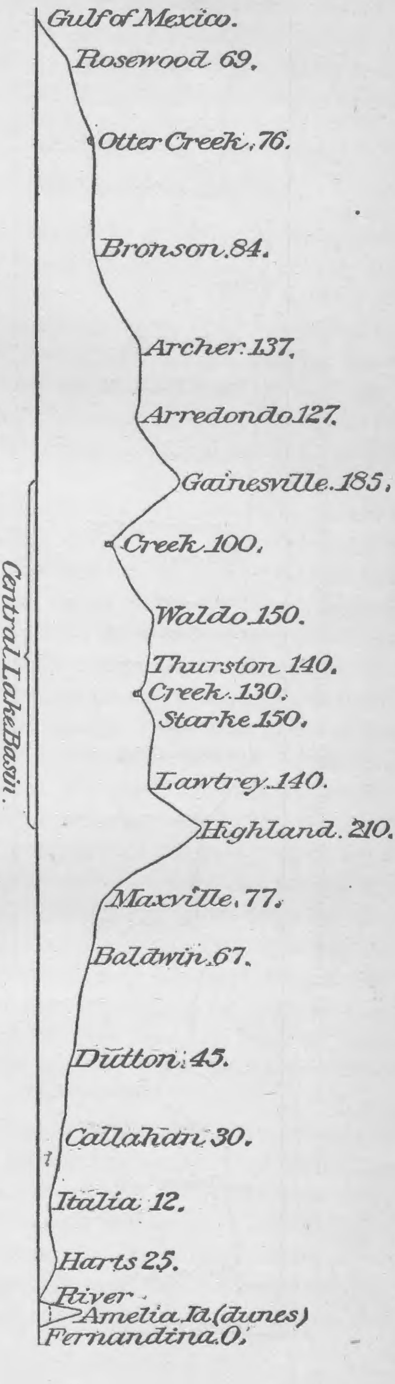

FIG. 19.—Profile across Florida from Fernandina, Nassau County, to a point near Cedar Keys, Levy County.

wich, from Callahan near the northern boundary of the State 180 miles south to Plant City, on the southern division of the Florida Railway and Navigation Company's road. (Fig. 20.)

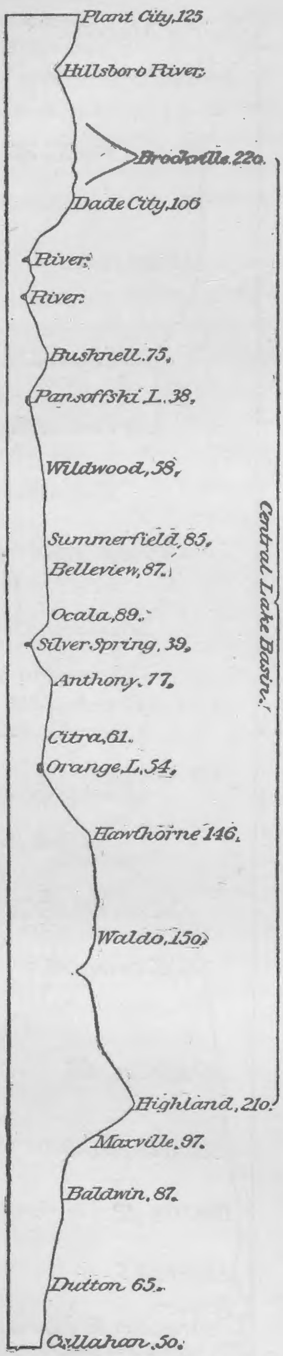

FIG. 20.—Profile from Callahan, Nassau County, to Plant City, Hillsboro County, Fla.

This profile cuts the region at an angle of 90° with sections I and II, but is somewhat oblique to the geologic axis. It leaves Callahan on the Atlantic slope, crosses the eastern anticline obliquely from Highland to Hawthorne, thence traverses the Central basin for 80 miles, rising on to the western anticline at Dade City. Between Dade City and Plant City, which last place is supposed to be on the second western anticline, there is an apparent dip into a shallow synclinal trough, but the data for this part of the road represent only the height at stations, and not the continuous profile, and its features can not be given with precision. Brookville, which is apparently on the third anticline, is indicated, but is outside the profile.

It will be admitted that these profiles unitedly testify to the existence of a ridge or height of land between the St. John's drainage area and that of the central lakes, and of another between the central area and the Gulf drainage, while there are indications of a third ridge, near to and parallel with the last, which for a certain distance shortens up the Gulf drainage streams, confining them to a narrow belt, though cut itself by the few larger rivers. An inspection of a properly constructed map, showing the railroads, will show how little modification has been needed in coordinating the railway lines with the straight lines of the sections. The sections cut the region in three different and opposed directions, yet all the profiles tell the same story. I shall therefore consider myself justified in assuming that the peninsula does exhibit a folded structure, and that there are two chief lines of elevation, and probably others, besides the minor flexures which have been observed farther south. The distribution of the lakes and rivers of the peninsula confirms this view, if confirmation is needed.

CENTRAL LAKE REGION.

It would perhaps be more strictly accurate to denominate the great syncline of the peninsula as a central trough rather than a central lake basin. The elevation which separates the central lake region from its natural continuation, the Kissimmee drainage area, Lake Okeechobee, and the Everglades, is probably not very great. Nevertheless, there are geological reasons for supposing that the northern area now dotted with innumerable lakes, marshes and sinks was at one time occupied by one or more large bodies of water, of which the existing lakes are mere remnants.

Lake De Soto: sand knolls.—This lake or lakes, which for convenience of reference may be called Lake De Soto, would then have occupied a relation to the existing land much like that which Lake Okeechobee holds to the southern part of the peninsula at present. The peculiar sculpture of the small sandy knolls or elevations occupying much of the central region, and which Shaler has compared to kames, might have been more or less due to the movement of the waters consequent on changes which finally resulted in the drainage of the area in question.

These knolls or hillocks appear to be more characteristic of the central basin. On the highlands they are absent or merged into the irregularities which appear on the surface of the country rock as the result of solution and decay. They are chiefly composed of the yellow sand, and as a rule the irregularities of their profiles do not reflect any elevations or depressions of the rocks below them. The sand hills, however elevated or irregular, rest on a relatively level surface of limestone, a fact confirmed by the experience of well-drivers all over southern Florida, as well as by the reports of the prospectors who bore for phosphates. More investigation is necessary before the idea that the form of these knolls is due to the action of currents of water can be regarded as established.

Over a large part of northern Florida a striking characteristic of the country arises from the singularly porous and incoherent character of the limestones (especially of the Vicksburg and early Miocene age) which form the country rock. When this rock is Eocene it is usually of a creamy white color, containing molluscan fossils, sometimes as complete shells, but more frequently as impressions in the saccharoidal carbonate of lime. Mingled with them, and sometimes forming almost the whole body of the rock, are enormous numbers of *Orbitoides mantelli*, heaped loosely upon each other.

If the rock is post-Eocene it is generally of less purity, containing more aluminous matter, but still whitish and porous, though without the discoid Orbitoides fossils. In either case it is easily cut when fresh, hardens when exposed to the air, and is pervious to water. In regions where it comes to the surface there are no small brooks and few streams. Rain sinks into it as into dry sand; the solution of the softer portions results in "sinks" or natural wells, sometimes of large size and often with perpendicular walls. These constitute a real danger to a wanderer who goes aside from the beaten tracks, as their apertures, from the size of a post hole to that of an amphitheater, are unmarked by anything which would serve as a warning; they are often of great depth and almost always contain water. The water sinks until it comes to a more dense stratum or the sediment it carries clogs the pores of the limestone beneath it. Then it flows in the direction of least resistance, forming underground brooks or tolerable streams whose course may be marked by a long line of sinks. If sawdust be thrown into one of these it presently appears on the water in the next below, and so on. The sinks above the stream gradually enlarge in the direction of its flow, the intervening portions remaining as "natural bridges," the number of which is extraordinary. In other places the drainage of a limited area runs toward a central point, where it is lost in the bowels of the earth. When the rainfall at some seasons of the year exceeds the capacity of this passage to carry away, a shallow lake appears, of a temporary nature, which is gradually drained off at drier seasons. Sometimes the funnel becomes permanently obstructed, and the lake remains and spreads until some new outlet appears. I have seen lands formerly used for growing cotton, and covering hundreds of acres, which had become permanently flooded in this way.[1] Fish abound in the sinks, and subterranean passages for their use evidently exist in profusion.

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[1] In illustration of these remarks the following quotations about one of the largest of the temporary lakes have an interest. The first is from the Providence Journal, September 14, 1891.

"A LOST LAKE.

"A curious spectacle was to be seen on the outskirts of Gainesville, Florida, recently. Alachua Lake, from 10 to 15 miles in length and covering some 40,000 acres of land, is no more. On its banks were lying thousands of dead fish, dead alligators floated ghastly in pools of black water, and the atmosphere was heavy with noxious gases. Men and boys were there in throngs with hoes and rakes, dragging to shore hundreds of fish which had sought the pools for refuge. The waters were fairly alive with their struggles for existence. Except for a small stream known as Payne's Creek, flowing from Newman's Lake into the Sink, the two main basins of the Sink, and a few stagnant pools, no water is now to be seen where a few years ago steamers were plowing their way. This is the second time since 1823 that a similar occurrence has taken place. At that time the bed of the lake was a large prairie—Payne's prairie—having in it a body of water called the Sink and a small creek. In 1868 heavy rains filled up the prairie, but the water disappeared after a short time and the prairie was again dry land. In 1873, after a series of heavy rains, the Sink overflowed and the creek swelled to the dimensions of a lake. During several years the waters increased till a larger lake was formed, and for fully fifteen years sufficient depth of water stood over the prairie to allow of small steamers. Dur-

When the porous lime rocks are covered with the clayey layers of the later Tertiary or the more coherent and impervious limestones of the early Miocene, or when the process of silicification has been carried on to such an extent as to render the upper layers of the porous lime rock impervious, a wholly different surface topography results. Instead of circular marshes and rows of "sinks" in which all the surface water is lost, one sees brooks and rivulets with their accompanying effects upon the landscape. It also seemed to the writer that the difference was to some extent reflected in the appearance of the vegetation.

NORTHWESTERN FLORIDA.

At the northern part of the peninsula the topography merges into that of the foothills of western Georgia and Alabama, or borders on the great cypress swamps of eastern Georgia.

At the west, in the vicinity of the Appalachicola River, Mr. Burns, of the U. S. Geological Survey, reports finding the Miocene hills, at a point 8½ miles below Bristol, terminating in a sharp cliff or bluff over 60 feet high, from the foot of which a flat plain extended seaward without interruption. An examination of the river banks to a locality known as Riccos bluff showed unfossiliferous horizontal beds of bright-colored sandy clays, everywhere covered with a thin layer of white sand. This break in the topography is a marked feature of this part of the State and is said to extend for many miles, preserving a general parallelism with the shores of the Gulf, and doubtless marking an ancient shore-line.

SOUTHWESTERN FLORIDA.

The shores of the Gulf of Mexico in the state of Florida north of Punta Rasa are chiefly sandy, or, near the rivers, sometimes formed of a chalky mud. But as far as known this stratum is usually of no great depth, being chiefly a superficial covering to beds of the country rock.

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ing the last two years, however, the waters have been gradually lowering, and about four weeks ago they commenced going down with surprising rapidity, the lake falling about 8 feet in ten days, until now nothing is left of Alachua Lake but the memory of it. The Sink is considered the cause of this change. There is evidently an underground passage connected, and for some reason not understood this underground passage has been acting as a drain until all the water in the lake has been drawn off."

The second is taken from the Washington Evening Star of September 19, 1891:

"The Star recently printed an account of the disappearance of Alachua Lake in Florida, a lake that was so well established that a steamboat line was maintained on it. A U. S. Geological Survey party has been engaged at work in that region. A member of this party, Mr. Hersey Munroe, who is now in the city, gave an interesting account of the lake, or rather the ex-lake, to a Star reporter. 'Alachua Lake,' said Mr. Munroe, 'is situated in north latitude 29° 35′ and west longitude 82° 20′ in Alachua County, Fla., and 2 miles south of Gainesville, the county seat. The lake was formerly a prairie, known as Alachua prairie before the Seminole war during 1835–'37. It has since been named Paynes prairie, after King Payne, an old Seminole chief of an early day. The prairie was a great grazing spot for the Indians' cattle and later was used for a like purpose and for tillage by the whites, some fine crops of corn and cotton being grown. The prairie lands are immense meadows, covered by the finest grass, interspersed with clumps of beautiful oak trees and palmettoes. These lands are subject to inundation during the summer season. Hatchet Creek rises 3 miles north of Gainesville and flows in every direction of the compass for a distance of 10 miles, emptying into Newmans Lake, a beautiful sheet of water covering 10 square miles.

The latter extend seaward, sometimes forming extensive oyster banks near the shore through which navigation can be carried on only in small boats and by troublesome and intricate channels, when away from the main navigable outlet of each particular stream.

The sands are derived from the siliceous contents of the country rock and are frequently more or less bound together by the deposition of lime held in solution, forming a sort of coquina. Much of the shore, especially to the south and the extreme west, is defended by sandy keys formed at the neutral line of tide and land drainage, and offering much-needed facilities for coast navigation in small craft suited to these shallow waters. The sea-bottom, level as a floor to all appearances, inclines gently to the west and south, and for miles from the beach attains only a very moderate depth.

It might have been anticipated that the detritus, especially the fine sediment brought down by the Mississippi, would be conspicuous in the bottom deposits of the gulf in the direction of the prevailing currents. The soundings and samples of bottom obtained by the U. S. Coast Survey and the Fish Commission show that this is not the case. The terrigenous sediments (except at the immediate shore) extend eastward but a little way off the Floridian coast. The line indicating the change in the bottom from mud to organic limy sediments approaches the shore to the westward of Appalachicola, in the vicinity of St. Andrews Bay.[2] That this limitation of the fresh-water deposits is not a modern thing is shown by the almost identical range of the Grand Gulf beds of Hilgard on the ancient shores of the Gulf of Mexico. A reason for it may perhaps be found in the tendency, so well known, of a saline solution to precipitate the sediment contained in fresh water when the two liquids are mixed. The mixture of the two fluids in the gulf may

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'HOW THE LAKE WAS FORMED.

'The overflow from Newmans Lake forms a large creek named Prairie Creek, which wended its way through Paynes prairie to Alachua Sink, one of the curiosities of the State. There the waters found their way into a subterranean passage. Visitors, to have their curiosity gratified by seeing what the effect would be to have logs thrown into the sink, were the probable cause of the overflow of Paynes prairie. The logs would float out to the center of the sink, whirl around in a circle and suddenly disappear. This choking of the outlet to the waters of Prairie Creek caused the overflow and made a sheet of water sufficient to float small steamers and other craft.

'One steamer in particular had a splendid freight traffic, during the vegetable season carrying shipments of vegetables from its wharf on Chacala pond across Alcahua Lake to the mouth of Sweetwater branch, the nearest point to Gainesville, the principal place for shipment north. After the overflow and the forming of a lake it was christened Alachua Lake. This name has been decided upon by the United States Board on Geographic Names. Alachua Lake is 8 miles long, east and west, and in one place 4 miles in width, north and south, covers 16,000 acres, and the average depth is from 2 to 14 feet deep.

'LOWERING FOR SEVERAL YEARS.

'For several years the lake has been gradually lowering. The elevation of the water above sea level as given by the Savannah, Florida and Western Railroad some years ago is 64 feet. By accurate levels run by one of the topographical parties of the Geological Survey working in this section during the winter of 1890–'91 the elevation of the water was found to be 58 feet, thus showing that the lake had been changing elevation; and about two weeks ago I was informed that Alachua Lake had disappeared entirely, that only small pools remained and the usual amount immediately around the sink.'"

[2] Three cruises of the Blake, vol. 1. p. 286, Fig. 191.

then be supposed to be complete at any point where all the mud has been precipitated.

EASTERN COAST OF FLORIDA.

On the eastern coast of Florida toward the north we find a narrow margin composed of the coast sands, between the abrupt margin of the country rocks and the sea, and extending under the sea eastward for a distance from the shore in north latitude 30° of more than 50 miles The source of these sands is thus explained by Shaler:[1]

During the glacial period a very large amount of arenaceous material was contributed to the sea in the region north of Cape Hatteras. The general trend of the shore of this part of the continent is from the northeast to the southwest, while the prevailing direction of the wind is from the east. The result is that, so far as impelled by the waves, this sand works down along the coast shelf to the southward. Whenever it comes upon the beach and remains within control of the waves the southward movement is quite rapid. A very large amount of this sand is continually pouring round Cape Florida.

Undoubtedly this view of Prof. Shaler is quite correct, except that the operation of the forces mentioned is not necessarily postglacial. No doubt at various times more or less of the sand has been derived from the siliceous rocks, like the Altamaha grits or the buhrstone, of the Atlantic slope, all the way along its border. Artesian borings show that the formation of the sand, its position along the coast, and its general character have been pretty uniformly maintained throughout the whole of Cenozoic time; and while, no doubt, a large addition was made to the common stock of Atlantic sands during the glacial epoch, yet this was merely an incident in the history of operations which had been going on ever since the Cretaceous period, or at least ever since the Atlantic border assumed approximately its present form and trend.

On the northern part of the east coast of Florida the dry sandy border is quite narrow and largely consists of narrow, long islands where the sand has been elevated into dunes which reach a height in some cases of more than 50 feet, but which, owing to the torrential summer rains and rapid growth of vegetation in this semitropical clime, have generally lost the sharp wind-carved sculpture of dunes formed in a drier climate and have become more or less covered with vegetation. Inland the surface sands, whatever their origin, are usually much thinner, often only a few feet, and I have seen records of no boring which revealed the existence of over 20 feet of sea or white sand, while this I suspect to be very exceptional. References have been made to much greater depths away from the coast, but I have not seen any satisfactory proof of the correctness of such estimates. The average depth in sandy places in Alachua County seems to be between 6 and 20 feet. These figures refer solely to the superficial siliceous sea sands and not to the yellow sand proper or to the interbedded calcareous sands of Tertiary age.

[1] Shaler, Topography of Florida, p. 149.

PEREZONAL FORMATIONS.

There seems to be an absence, in geological nomenclature, of a term to indicate the region between the neutral zone where sediments are dropped in the sea near the beach and the point where subaerial erosion terminates. If we regard the land above the base level of erosion in the light of an earth-glacier, more or less liquefied by the action of water and discharging into the sea, the region I refer to constitutes the terminal moraine.

The "coastal plain," or coast peneplain, in so far as it has reached the base level, forms part of it; the beaches another part; the region between the beach and the neutral zone (generally marked by a bar or shoal) a third part. Yet the whole has a certain unity. It is subject to the operation of special forces which are forever at work. In the absence of great changes of level it might happen that the same region or area might remain, so to speak, ground as between upper and nether millstones by the erosive and marine forces for a period covering several geologic epochs. Such instances can be cited. The grist of this great mill is ground over and over, its waste is constantly supplied; it may contain the relics of several periods of geologic time. The greater portion of it will be unfossiliferous, the fossils preserved will be terrestrial or brackish water rather than marine. It will border on the sea, but its marine fossils where action is energetic will be rolled, worn, and triturated, out of recognition for the most part. Here and there a limited fauna will be preserved in lagoons or on oyster banks. It will happen that the material concerned in such areas may abut on synchronous beds containing an abundant fauna, but, owing to the lines on which the forces work, the synchrony will often be very difficult to prove.

Yet such deposits may extend about a whole continent with recognizable features derived from the forces which have been concerned in its formation. Almost everywhere it will be composed of the débris of other formations often lying directly upon them and containing some of their fossils in the rehandled material. When a special area has been subject for a short time to the forces exerted and by a change of level has been removed from the zone referred to, a mixture of the fossil fauna of subjacent beds will be almost certain to be included in the resulting formation. I believe that we have on our Atlantic border several formations widely extended and of this nature and the relations of which, owing to the reasons above indicated, are and are likely long to be in dispute. For the specific belt or margin, in which the above-mentioned forces are active, and in whose characteristics the results of such forces are individualized I would propose the name of perozone.[1] I believe that the clearer recognition of special dynamic genesis as well as of the continuity inherent in the process, apart from important changes of level, which is implied in the adoption of a special term for the result

[1]From *peresus*, worn or wasted, and *zone*.

will be useful in our geological discussions. The thing itself has always been known, and its genesis more or less clearly understood, but its individuality at any stated epoch has, in the absence of a special name, not always been clearly exhibited or appreciated. The perezone will be for the seacoast analogous to, though not identical with, the peneplain of interior basins. The perezone of east Florida, so far as it is above water, is very narrow and becomes still narrower as we go southward. We are indebted to Prof. Shaler[1] for information which shows that a living coral reef borders the shore of the peninsula as far north as Gilbert's bar, 12 miles above Jupiter Inlet; that a former reef probably extended as far north as Mosquito Inlet, above Cape Canaveral, and that from Titusville on Indian River south to the head of Biscayne Bay an elevated beach of coquina defends the lowlands behind it. This beach is elevated some 20 feet above its original position. It presents a steep escarpment with indications that part of the cutting which formed it took place during the process of elevation, sea caves and other reentrants existing in the cliffs at a considerable height above the present plane of the sea and separated from the latter by a barrier of drifting sands. Southward from the head of Biscayne Bay as far as the parallel of Old Rhodes Key this reef of coquina is continued as an elevated coral reef with a height at Cocoanut Grove of 22 feet and a width of about 2 miles. To the whole barrier Prof. Shaler gives the name of the Miami Reef. It has suffered considerable loss by corrosive action and is honeycombed by subterranean water passages. He says:

The effect of this reef on the drainage of Florida is very great. Although the rivers at many points have found their way across the elevation, either by subterranean streams or through the low points of the barrier, it serves to retain the land waters, and to bring into the condition of swamp a large part of the peninsula. The St. Johns River and the extensive swamps in which it heads are in good part determined by the existence of this barrier.

In a less complete way the waters of Lake Okeechobee and of the Everglades to the south of it are prevented from finding a path to the sea by this natural wall. Thus, at Cocoanut Grove, Biscayne Bay, the waters of the Everglades at a distance of only 3 miles from the shore in their time of lowest level lie 16 feet above high tide. In the rainy season they often rise to such an altitude that they pour over the reef where it is less than 20 feet in height. * * * The rivers which flow over this part of the reef come down to the sea level over a series of rapids formed upon the harder layers of the reef, and thus the full escape of the Everglade's waters is prevented. In the region more to the north, the entanglement of the vegetation about the head waters of the streams likewise hinders the escape of the marsh waters.[2]

THE EVERGLADES.

The region of the Everglades has received but little examination in recent years. Prof. Shaler examined the southeastern margin as above cited. Mr. Joseph Willcox in the winter of 1887–'88 made a determined effort to penetrate into the region with a view of determining the char-

[1] Topography of Florida, pp. 148–150 and map.
[2] Ibid., pp. 143–144.

acter of the rocks. Whitewater Bay lies a few miles north of Cape Sable, and Mr. Willcox with his party, on a small craft drawing less than 2 feet of water, made many attempts to enter it without success, spending six days in the endeavor to find a navigable channel. They entered several passes between the islands and penetrated 10 or 12 miles east of the latter in several places, but found the water too shallow to proceed. Except sand bars thrown up by the waves no land was seen in this vicinity which was not covered at high tide. All the land consisted of muddy mangrove islands, the trees being much larger than any seen farther north. Where the tide runs rapidly between the islands it scours out channels 8 to 12 feet deep with a floor of hard rock, of which it was found impossible to get specimens. Except in these channels the bay is quite shoal, and covered with calcareous mud.

At the north end of Lostmans Key they entered the river of the same name and succeeded in penetrating 12 or 15 miles inland. No hard ground was seen except near the mouth of the river, and the highest land at the latter place was not over 3 feet above high tide. Wide, shallow bays, with muddy bottom interspersed with low, muddy mangrove islets comprised the whole scenery. The boat frequently grounded and was obliged to wait for the rise of the tide. A small fresh-water stream was finally reached, the current of which had scoured a channel 4 to 6 feet deep, with a rough, hard rock bottom, fragments or which were broken off. It consisted of large masses of Polyzoa more or less completely changed into crystalline limestone, the cavities filled with crystals of calc-spar. The rock is very hard and compact. The only mollusk or other organic matter, except the Polyzoans, which was discoverable in it was a single valve of the *Chione cancellata*, which is still found living in those waters and has existed there without perceptible variation since the early Miocene. Four or five miles within the margin of the Everglades no dry land was seen; only soft, wet soil, none of it a foot above the level of the water. From the top of a tree nothing could be seen to the east but a vast extent of such marsh land, which is said to be covered with water during the rainy season of summer and early autumn. Lostmans River is sometimes mapped as the Chittahatchee, and it enters the sea behind the Ten Thousand Islands in north latitude about 25° 30′.

Allens Creek, emptying into Walaka Inlet, an arm of Chukoliska Bay, was also visited. At a point 8 or 10 miles east from the Gulf of Mexico the party were able to land on soft, wet soil a little higher and drier than that at the head of Lostmans River. A third of a mile eastward from the head of the creek specimens were obtained of a few rocks which project above the soil. They presented molds of recent shells with the interior filled with calc-spar, and an occasional *Pecten dislocatus* or *Ostrea virginica* still retaining its shell structure. The cavities between the shells were filled with hard, coarsely crystalline limestone. The rock was not coquina modified, but looked more like a fossilized oyster reef. It contained no corals, and was obviously Pleistocene. The rock formed the base of small islets of drier soil amid the marsh, on which islets grew pine trees. The marsh, apart from these islets, is probably entirely submerged in the rainy season.

Another attempt was made to reach the interior by Corkscrew Creek, about 15 miles southeast from Punta Rasa. About 8 to 10 miles from the gulf was attained. The banks of this creek are dry pine land, rising 8 or 10 feet above the sea. The rocks here are the hard, ringing Eolian limestone, with recent land shells, perhaps a local equivalent of the yellow sand, such rocks as are found on both sides of the peninsula in many places and are of extremely recent origin.

The observations of Mr. Willcox thus appear to indicate, which indeed the known circumstances would have led us to expect, that no coral reefs have occupied this region. The outpouring of fresh water and mud must have rendered the region unsuitable for such animals, probably for a very long period, perhaps since the Gulf stream has occupied its present channel.

The deposit upon which the Everglades immediately rest, in this part at all events, is a recent organic limestone probably based on the Tertiary rocks which, farther north, are elevated above the sea. For it we may provisionally adopt the name of the Everglades limestone.

THE KEYS.

Of the structure of the keys, which has been exhaustively treated by Agassiz, it does not seem necessary to speak in this place. It may, however, be pointed out that much of the limy deposit of the area behind the reefs and defended by them is probably the result of the deposition of lime originally held in solution and precipitated by chemical action rather than of mechanically transported sediment.

It may be added that the large rivers represented on most maps as flowing out of the Everglades to the southwest have no existence in fact, as such. The streams in the dry season are all small, and most ot the outflow seems to be over the whole surface, which, during the rainy season, near the sea is totally submerged.

STRATIGRAPHY OF FLORIDA.

EOCENE ROCKS.

Vicksburg group: The Orbitoides limestone.—It has already been explained that the foundation of the peninsula, as far as known, is laid in a limestone belonging to the Vicksburg epoch, which, for uniformity and brevity, will be referred to here as the Orbitoides limestone, from the characteristic *Orbitoides mantelli*, which is found throughout the formation, associated with a variety of other foraminifera, *Pecten perplanus* Morton and *P. poulsoni*, as the most obvious and abundant fossils. The older name, Orbitolite limestone, by changes in nomenclature of the foraminifera has now become misleading.

Over a large part of the northern central portion of Florida the Orbitoides limestone forms the country rock, often rising to the surface or lightly covered with a thin coating of wind-blown sand or sandy soil. Its exact extent is not determinable at present, owing to the fact that it has been more or less confounded with later rocks of similar appearance and lithologic character but containing a different fauna. It varies in character, much of it as previously described, being loose and friable in texture when first excavated, porous and pervious to water. Other portions are much infiltrated with silex, which is deposited in smaller or larger masses or which is calculated to render a considerable portion of the rock cherty and extremely hard; others again contain a certain proportion of clay, as the Lake Worth borings show, the rock then being compact and impervious. As early as 1849 this rock was observed by Prof. J. W. Bailey, U. S. Army, who noted its character in several publications.[1] He found it in diggings from a well at Piles, a settlement 40 miles west of Palatka, on the road to Tampa, and noticed it at several points intervening between Palatka and Tampa. It has been noted by Prof. Eugene A. Smith[2] in Jackson County, in the northwest; also farther east, under a thin coating of Miocene deposits, at Live Oak (109 feet above tide), and possibly at Lake City (202 feet) the highest elevation on this line in northern Florida, whence it is believed to extend southward in the interior of the State to a point near the Hillsboro river not far from Richland, Pasco County.

The opinion of the older geologists that the country rock of the peninsula of Florida is essentially a southward prolongation of the Eocene limestone of Georgia was for a time obscured by the theories of coralligenous growth suggested by the observations of Agassiz and Le Conte on the keys and the extreme southeastern margin of the peninsula. To Smith in the paper above cited we are indebted for a substantial rehabilitation of the older theory, with modifications due to greater knowledge. But later observations again oblige us to modify to some extent the range assigned by Smith to this limestone, as it has become evident from the observations of Langdon, Heilprin, Willcox, Dall, Aldrich, Neal, Stanton, and others that beds of several distinct ages have been confounded in the general estimate. It is impracticable with the data yet printed to determine exactly at how many of Smith's localities the country rock belongs to the Orbitoides horizon. Some of them, doubtless, will eventually be shown to be of later age, as will be indicated later in this summary. Only those where no doubt seems to exist will be specified here. In Alachua County it is widespread, having been observed by Smith and Dall at Gainesville and westward to and about Archer, though in many places overlain by solutionary residuum, remnants or even beds of later age but moderate thickness. It

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[1] Smithsonian Contr. Knowl., 1850, vol. 2, No. 8, p. 19; Am. Jour. Sci., 2d ser., 1851, vol. 2, p. 86. He speaks of it as the "white Orbitulite limestone."

[2] Am. Jour. Sci., 3d ser., 1881, vol. 21, pp. 299, 300.

had been identified at Silver Spring, 6 miles east from Ocala, by Le Conte, as early as 1861,[1] and subsequently the observation has been confirmed by Smith. Specimens of this rock have been collected by Willcox at Martin station, Marion County, about 8 miles north of Ocala, where the rock is very cherty; and at Jarves's Spring, on the southern border of Pasco County; at Fort Foster, on the North fork of the Hillsboro River, where, as in many other places, relics of the old Miocene beds overlie it. Several of the localities referred to by Heilprin must remain for the present on the doubtful list, but among them should hardly be counted the islet at the mouth of the Homosassa River, from which Mr. Willcox obtained the *Pygorhynchus* (*Ravenelia*) *gouldii* Bouvé, a small echinoderm originally described from the buhrstone (ante-Claibornian) of Georgia. If the identification be correct, which I do not doubt, one would hardly expect this species to appear in the so-called "Oligocene."

The thickness of this formation is very considerable in Florida. At Salt Mountain, in Alabama, excluding the still doubtful "coral-limestone" of Smith and Johnson and the "Jackson" beds below the Orbitoides limestone, the latter has a thickness of only 140 feet. But in northern Florida, west of Gainesville, according to reports from L. C. Johnson, artesian borings have started at the surface in the "Vicksburg," and have been drilled over 350 feet without finding any other rock or reaching the clayey layer of the Orbitoides rock (which is impervious) so as to obtain any water. On the eastern side of the peninsula, much farther south, at Lake Worth, an artesian well, after passing through a mass of talus in which the recent coquina was sometimes overlain by Miocene rubbish, etc., finally reached the solid Orbitoides rock at a depth of 1,000 feet, and penetrated it without finding any change for 212 feet, when, abundance of water having been obtained, the drilling was pushed no farther. In the Jacksonville well, though carried to a depth of 900 feet, the Eocene rocks were not recognized and perhaps not reached, offering a strong contrast to the well at Charleston, where they were encountered at a depth of 60 feet and penetrated for a depth of 330 feet before the Mesozoic strata, were attained. At St. Augustine, south-southeast from Jacksonville, the Vicksburg limestone was encountered at a depth of 212 feet, and the boring was still in them when it ceased at about 1,278 feet.

Nummulitic beds, Ocala limestone (*Oligocene of Heilprin*).—Among the rocks which until recently were not discriminated from the Orbitoides limestone, and which appear in central Florida directly and conformably to overlie the latter, though no one has described their contact, is a yellowish friable rock containing many foraminifera, conspicuous among which are two species of Numulites, *N. willcoxii* and *N. floridana* Hp. This rock was first brought to notice by Mr. Joseph Willcox, and to Prof. Heilprin we owe a description of it which discriminates

[1] Am. Jour. Sci., 2d ser., 1861, vol. 21, pp. 1–12.

between it and the Vicksburg or Orbitoides rock. The rock was early recognized as Eocene, though not discriminated from the earlier beds. It is best displayed at Ocala, Florida, where it forms the country rock, and has been quarried to a depth of 20 feet without coming to the bottom of the beds.

Dr. John Le Conte, in 1861,[1] speaking of the portion of the peninsula about Ocala, says that it is "composed of a mixture of sand and shell limestone, probably of Eocene age." Four years later Conrad[2] refers to some fossils from the Ocala limestone received by Prof. Cook of New Jersey. He specifies *Glôbulus (Natica) alveatus*, *Venericardia prima* and *Dosiniopsis alta* as belonging to the Eocene of California, Maryland, and New Jersey, and refers the formation to the epoch of the New Jersey Shark River Eocene marls. Mr. Willcox has since visited the quarry at Ocala and rediscovered some of these species, as well as *Aturia alabamensis* and a number of other Eocene species, most of which are common to the Vicksburg limestone as far as identified, and others to Lower Miocene rocks, such as those of Tampa and the Chipola beds.

The original discovery of the Nummulitic stratum, by means of which it was discriminated from adjacent beds, was made by Mr. Willcox at a clearing known as Loenecker's, on the Cheehowiska or Chassahowitska River, where it occurs in fragments more or less enveloped in a Pleistocene sand rock containing recent land and fresh water shells. Since then Mr. Willcox has obtained the rock in place 15 miles northeast of the original locality, from the shore of Waccassee Bay, near Cedar Key, and also from the banks of the Wacassassa River, Levy County; from a "sinkhole" at Pemberton's Ferry on the Withlacoochee River, about 10 miles eastward from Brookville, and also at Bayport, Hernando County, and at various places about Ocala. Prof. Wetherby has also sent specimens from a well 5 miles southwest of Gainesville, Alachua County, and Mr. L. C. Johnson reports it from an old Confederate iron furnace 3 miles northwest of Levyville, Levy County[3], where it is only 20 feet thick, and is covered with a bed of bog-iron ore formerly worked. Pemberton's Ferry is the most southern point at which it has been recognized at the surface, but at Bartow, Polk County, it occurs covered by about 6 feet of later strata.

Miliolite limestone.—A rock observed on the Homosassa River by Prof. Heilprin is practically horizontal and rises 2 or 3 feet above the water at low stages of the water, on the left bank of the Homosassa at "Wheelers" about 1 mile above the river mouth. It has also been collected by Neal 6 miles southwest from Lake City. It is a tough limestone, full of foraminifera, mostly belonging to the *Miliolidæ*, for which Prof. Heilprin proposes the name of Miliolite limestone. Its distinctness from the other foraminiferal limestones of this region is hardly established as yet.

[1] Am. Jour. Sci., 2nd ser., vol. 31, p. 11.
[2] Proc. Acad. Nat. Sci. Phila. for 1865, p. 184.
[3] SE. ¼ Sec. 28, T. 11 S., R. 15 E.

From what precedes it will be noted that the Nummulitic beds occupy, as far as known, a very limited area from the vicinity of Gainesville on the north to Pemberton's Ferry on the south, extending from Ocala westward nearly but not quite to tide water. These rocks, Nummulitic, Miliolite, etc., as regards most of their fossil contents are hardly to be separated from the Orbitoides limestone and must certainly be regarded as forming part of the Vicksburg group.

The layer of siliceous foraminiferal Eocene, overlying the typical Orbitoides limestone, which has been recognized by Burns in Pulaski County, Georgia, at Hawkinsville, and southeastward across the remainder of the local Eocene belt; and by Dr. Neal in a similar situation at White Springs, on the Suwanee, in Hamilton County, Florida, is with little doubt the analogue and representative in these localities of the Nummulitic and Miliolitic areas of central Florida.

It may be added that vertebrate remains belonging to the cetacean genus *Zeuglodon*, or, possibly, to *Squalodon*, were discovered by Mr. Willcox in the Nummulitic rock of the Ocala quarry, thus adding another indication of the close faunal relations of the Nummulitic with the preceding post-Claiborne beds.

There is little doubt of the correctness of Prof. Heilprin's contention that these rocks are the analogue of the so-called Oligocene of the West Indies and of northern Europe. But, while this may be admitted, the propriety of regarding the group or series as constituting a distinct epoch, equivalent to or analogous in value to the Eocene, Miocene, or Pliocene epochs, which would be inferentially granted by adopting for them the term Oligocene, is a very different matter, and in Florida receives no justification from the paleontological evidence.

From Dr. J. C. Neal, of Lake City, Florida, we have specimens of the uppermost rock stratum at Branford, on the Suwanee. It is interesting as being of a character not common in Florida, namely, an extremely fine grained, pulverulent sandstone, apparently chiefly composed of particles of organic silica in a state of very feeble cohesion. It contains impressions of very numerous foraminifera and of a small *Pecten*, perhaps *P. perplanus* Morton, and should probably be referred to the horizon of the Ocala limestone or Nummulitic beds, though of a different lithological character from the beds of that age hitherto known.

In the foregoing brief account of the Floridian Eocene the writer may, perhaps, somewhat have overstepped the limits assigned to him. But, for a clear understanding of the Neocene series in this region it seemed necessary to do this, and the recapitulation of matters elsewhere treated of by Prof. Clark, will have done no harm, while its presentation in this connection seemed indispensable.

MIOCENE ROCKS.

Chattahoochee group: Ocheesee beds.—The Miocene rocks of Florida present, lithologically and petrographically, a series entirely analogous to the calcareous, siliceous, ferruginous, phosphatic, and clayey beds of the Eocene, but with a greater variety of strata in the same thickness. This indicates less uniform conditions and probably more numerous changes of level. In this respect the Miocene of Florida presents a contrast to that of the Antilles, where, according to Cleve,[1] the Miocene was a period of calm, regular deposition, without notable orographic disturbances, though such disturbances have left distinct traces in the Eocene strata and were again experienced in post-Miocene time.

Another feature which is noteworthy, even with our present imperfect knowledge, is the restricted area of many particular beds, which in some sections attain a considerable thickness, while other sections, without indicating uncomformities, show no traces of these special strata.

In 1887 Langdon[2] observed a group of beds on the Chattahoochee River overlying the Orbitoides limestone at a point 9 miles above River Junction, or Chattahoochee, and traced it southward by the river to Ocheesee and Rock Bluff, 17 miles below the railroad bridge at River Junction, where it dips below the Miocene beds, which are exposed at Alum Bluff, 8 miles farther down the river. At Ocheesee there were visible above the water 5 feet of creamy white granular limestone with obscure fossil corals, surmounted by 10 feet of greenish yellow unfossiliferous argillaceous limestone. At Rock Bluff 30 feet of limestone, in strata of varying purity, are exposed. These limestones are slightly phosphatic, and by disintegration afford a rich black loam characterized by the growth of *Torregia taxifolia*, the so-called "stinking cedar." The beds as a whole are more siliceous and argillaceous than those of the Orbitoides limestone, and were estimated by Langdon to have a total thickness of 250 feet, who referred them to the newest member of the Eocene or the oldest of the Miocene, under the name of the "Chattahoochee group." The same rocks were observed by Mr. Burns, of the U. S. Geological Survey, in the adjacent portion of Decatur County, Georgia; at a locality on the railroad 3 miles east of the bridge over the Chattahoochee River, Florida;[3] and below the Chipola marl, near Baileys Ferry, Chipola River, westward from Alum Bluff, Langdon obtained from these beds a large *Pecten* and an oyster resembling the recent *Ostrea virginica*. Burns, at the locality mentioned, obtained a small number of fossils, among which were 22 species identifiable with those of the Tampa Miocene, including ***Pyrazisinus cornutus***, ***Cerithium hillsboroensis***, ***Potamides transecta***, ***Conus planiceps***, ***Natica amphora***, ***Lucina hillsboroensis***, ***Cardita serricosta***, ***Venus staminea***, ***V. cancellata***, ***V. penita***, ***Cytherea nuciformis***, ***Cyrena vesica***, and ***Orbitolites floridanus***. Three or four other species were identical, or probably so, with Chipola species and two were not known, a *Tagelus* and *Solen*. There were also obscure corals and one *Echinus*. The condition of

[1] Agassiz, Three Cruises of the Blake, vol. 1, p. 109; and Kong. Svenska Vetensk. Akad. Handl., 1871, Bd. ix, No. 12.

[2] Am. Jour. Sci., 3d ser., 1889, vol. 38, p. 324.

[3] Here his collection was made.

these fossils is poor, but they are sufficiently identifiable in all the cases above specified to speak with confidence, and in most of them with certainty.

From the general trend of this limestone, its considerable thickness on the Chattahoochee and Appalachicola rivers, and its numerous sink-holes, ponds, and natural bridges about the Chipola River, it (and not the Orbitoides limestone, as was supposed by Smith and others) is doubtless the country rock over a considerable part of northwestern Florida.

In the vicinity of Tampa, especially in the rock forming "the bed of the Hillsboro River," Heilprin, in 1886, discovered *Cerithium hillsboroensis* in large numbers.[1] This rock is variable in character, but all the specimens I have seen of it are friable and of a creamy yellow, or even somewhat ferruginous tint. The mass originally collected by Heilprin, which I have examined, is chiefly filled with the molds of this *Cerithium.* Specimens subsequently obtained from Magbeys Springs and submitted to me by Mr. Willcox, and others personally collected, undeniably belong to the Tampa limestone, though most of its fossils are identical with some of those above cited as collected by Burns from the Chattahoochee limestone. Although no one has yet established the existence of a Miocene rock under the Tampa silex beds or described their contact, yet there can be little doubt that such a rock should underlie the Orthaulax bed (by which name, for clearness, I shall hereafter denominate the Ballast Point silex bed proper) at Tampa, just as the Chattahoochee limestones underlie the Chipola marl at Alum Bluff. In other words, the equivalence of such a rock, if it exists, with the fossiliferous stratum of the Chattahoochee group from which Burns obtained his fossils must be conceded, as well as the reference of both to an older horizon than the Orthaulax bed, which is thereby implied. Thus the truly Miocene character of the Chattahoochee group is established.

But these beds do not everywhere represent the lowest member of the Miocene system. Of the artesian boring at Tampa, which would have given us the succession and thickness of the rock, unfortunately no data are preserved.

Hawthorne beds.—From the unpublished reports of L. C. Johnson, of the U. S. Geological Survey, it is gathered that in the interior a different or rather a more comprehensive succession of beds is the rule. In 1885 the writer was able to confirm by personal observation in Alachua

[1] The account given by Heilprin is extremely obscure. He speaks of the "hard siliceous blue rock, charged with Cerithium," which appears at Ballast Point and along the banks of the river. But the hard blue rock of the silex beds does not contain *C. hillsboroensis;* the species with which it is charged is Prof. Heilprin's *Pyrazisinus campanulatus.* and the rock from which he described and figured his *C. hillsboroensis* (as is evident on an examination of the specimen) is neither "hard" nor "blue," though in places the bed is, like nearly all the Floridian limestones, more or less permeated with silex. In Heilprin's Cerithium rock, which is probably a phase of the Tampa limestone, the shells are represented by molds. In the silex bed proper they are represented by siliceous pseudomorphs, among which five years' work of a half a dozen good collectors has so far revealed not a single specimen of *C. hillsboroensis.*

County the presence of beds of phosphatic rock, more or less broken up and inclosed in a younger matrix overlying the Vicksburg limestone at the "Devil's Millhopper," near Gainesville, and afterward to observe remnants of the rock in place on the hilltops near Archer and Arredondo, as well as the presence on top of the Orbitoides limestone, where the latter formed the surface of numerous silicified pseudomorphs and fragments of fossils belonging to the phosphatic rock above mentioned.

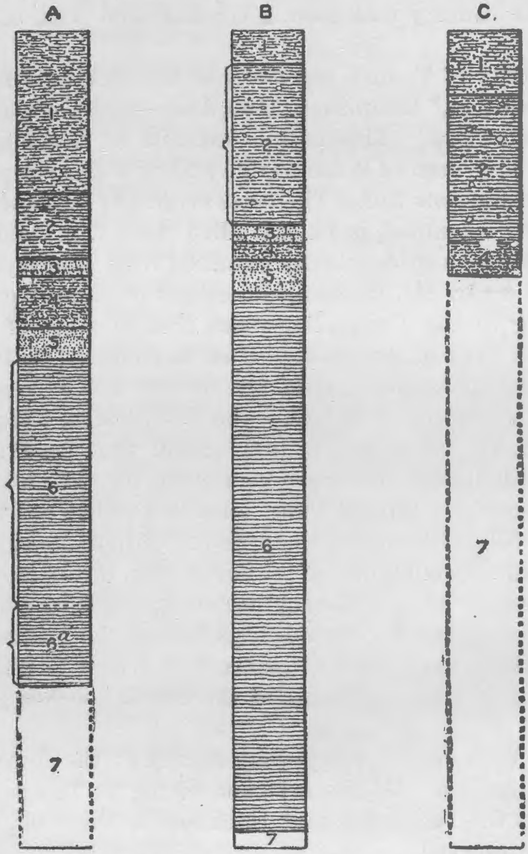

FIG. 21.—Sections in Central Florida, illustrative of Hawthorne beds. A, Nigger Sink; B, Newnansville well; C, Sullivan's hammock. 1, surface sand and loam; 2, phosphate rock; 3, soft sandstone; 4, ferruginous gravel; 5, sand or sandstone; 6, greenish yellow clay; 6a unexposed; 7, Vicksburg rock.

The latter at the time of my visit was being quarried and ground up as a fertilizer at Hawthorne, where the beds have a considerable thickness. For this reason I referred to these beds in my unpublished report as the "Hawthorne beds," and to the chief facts of their occurrence in a paper read before the National Academy of Sciences in 1887.[1] This name will therefore be adopted here for convenience in reference to the beds about to be described. Johnson has obtained several clear sections illustrating these beds, which are here graphically reproduced.

[1] Am. Jour. Sci., 3d ser., 1887, vol. 34, p. 164.

Mr. Johnson finds that the greater part of the phosphatic deposit at the Devil's Millhopper and to some extent at Hawthorne has been washed away and the rest more or less broken up. A natural sink in the midst of the phosphatic area, Downing's field, near the Natural Bridge of the Santa Fe River, Alachua County (Sec. 18, T. 7 S., R. 18 E.), affords a good section (A). This place is locally known as "Nigger sink," and the Vicksburg limestone has been reached by a well hole in the center of it. Above the well the lower 10 feet of the wall of the sink is hidden by talus, but is believed to be clay of a greenish yellow color, 30 feet of which rises above the talus, covered by a four-foot layer of firm, hard sand, almost a sandstone, and this by a sandy ferruginous layer of clay and gravel containing an oyster, like *O. virginica*, reproduced in chalcedony. This ferruginous layer, which will be referred to here under the term ferruginous gravel, seems to appear in many different sections, with its oyster and silicified corals. It also occurs in Georgia. Above it is a layer 2 feet thick of soft sandstone resembling the phosphatic rock in appearance. Covering this is a bed of sand and clay 8 feet thick containing fragments of all sizes, from a few pounds to a ton in weight, of the phosphatic rock and its large, silicified coral heads. These last, when they appear on the surface as around Archer, from the solution of the phosphatic matrix are popularly known as "fossil stumps" or "nigger heads." They are large masses of chert or chalcedony, often hollow, retaining on the surface more or less obscure indications of the original coral structure. Above this stratum come the surface sand and loam, here about 20 feet thick.

At a well near Newnansville (section B) another section was obtained by Mr. Johnson. Here 70 feet of the greenish clay overlies the Vicksburg rock, but otherwise this resembles section A, except in the following particulars: The ferruginous bed is only 2 feet thick, and 3 feet above it comes a bed 8 to 20 feet thick of solid phosphatic rock in place, with but little alluvium over it. For some distance north and east of the well this rock forms the surface of the hill. At Sullivan's hammock (Section C), 5 miles east of Mixons, in the same region, the cherty Vicksburg rock mixed with clay seems to begin immediately under the ferruginous stratum, which is surmounted by the phosphatic rock covered under a moderate depth of loam. Near Archer the phosbatic rock remains here and there on the hilltops as remnants, directly on the Orbitoides limestone, the greater portion having been dissolved away by rain and percolating water, as is also the case in Decatur County, Georgia. A similar rock with the characteristic coral heads occurs near Pasco County near the point where the South Florida Railway crosses the the North fork of the Hillsboro River, and also 1½ miles northeast from Jarve's Spring, in the same vicinity. At De Leon Springs, on the St. Johns River near Lake Helen, Volusia County, Mr. T. H. Aldrich reports a bed of well preserved Chipola fossils overlying phosphatic rock doubtless of this same horizon. The water table reached by the artesiah borings near Lake Worth at a depth of about 900 feet—which 100 feet below gives place to the Orbitoides limestone—is probably formed by the impervious clays, gravel, and phosphatic rock of this group of beds, which here and in other places is covered by beds of pervious sand.

A ferruginous bed, with oysters, directly overlies the Nummulitic bed near Levyville, Levy County. At Magnesia Springs, near Hawthorne, the water comes out from under the phosphatic rock and brings with it numerous specimens of the silicified oysters which lie in the mud at the bottom of the springs. Specimens have also been received by the U. S. Geological Survey from Live Oak, Suwanee County, and Lake City, Columbia County, in the northern part of the state, where, according to Johnson, the same phosphatic rock occurs. This information has been confirmed by specimens subsequently forwarded by Mr. Stanton and Dr. J. C. Neal, of the Florida experiment station at Lake City. We are indebted to Dr. Neal, for data showing the character of the Miocene deposits in that vicinity, and along the Suwanee River between Hamilton and Columbia counties.

At White Springs on the Suwanee the following section was obtained:

		Feet.
I.	Gray soil, sand, and humus	2
II.	White sand	4
III.	Clay with silicified corals and oyster (Hawthorne beds)	6–8
IV.	Indurated clayey rock (Hawthorne beds ?)	2
V.	Clayey sand-rock, rather fine grained and soft	4
VI.	The same, somewhat coarser and harder	8–10
VII.	Sand rock of coarser sharp grains, coated and cemented together with white limy matter	4–6
VIII.	Foraminiferal Eocene top-rock (Vicksburg) indefinitely below.	

The silicified corals of bed III are sometimes 20–60 pounds in weight and along the river when dislodged from the clay often wear immense pot holes in the softer lime rocks. Miocene sharks' teeth and fragments of bone also occur in the clay. Under bed VIII, when it is tilted up, as occurs in various places along the river, is found the older Orbitoides limestone of the Vicksburg group.

In a sink 4 miles north of Lake City the following section was observed:

		Feet.
I, II.	Sand and sandy soil	5
IV.	Indurated clayey rock	2
VII.	Lime cemented sand-rock	8
VIII.	Foraminiferal Eocene (indefinitely down).	

Two miles south of Lake City:

		Feet.
I.	Sandy soil	2
III.	Clay, with corals and oysters	20
VII.	Lime cemented sand-rock	3
VIII.	Foraminiferal Eocene (indefinitely below).	

Near the southern boundary of Columbia County, at Fort White, the rocks are gently folded and the surface has been more or less worn into basins containing phosphatic breccia of the older lime rocks, which are themselves under these basins of phosphate slightly phosphatized in their upper portions. Here, owing to the fact that the Miocene and Foraminiferal Eocene (Miliolite) beds have been more or less broken up by the action of water dissolving or wearing away the softer parts, the Orbitoides limestone sometimes immediately underlies the breccia in the basins and in other places the basins are composed of the Miliolite limestone. Beds VI, VII, and VIII, of the above series are more or less silicified, or when broken up the resulting breccia contains numerous angular fragments of chert.

The Suwanee strait.—The argillaceous deposits which are comprised in the Hawthorne beds appear to have been laid down toward the southern margin or the Suwanee strait, which separated the continental border from the Eocene and Miocene islands representing Florida at that epoch. Farther to the north and west the rocks indicate deeper water, contain less clay, and have a much more abundant and characteristic Old Miocene fauna. The data which have conclusively shown this were obtained by Mr. T. W. Stanton, of the U. S. Geological Survey, since much of this paper was in manuscript, and are detailed at another place. The northern border of the strait appears to have been the site of deposition of a different, more siliceous material, which resulted in the formation of the beds elsewhere referred to as the Altamaha grits of Georgia.

Old Miocene phosphatic deposits.—These rocks were among those referred by Johnson to his Waldo formation,[1] though the typical exposure at Waldo belongs to the newer or Chesapeake Miocene.

There is no doubt that the sources of phosphoric acid, through the existence of which the phosphatic rocks of Florida were made possible, were not confined to any one epoch. Rocks of unmistakably recent (Pleistocene) origin, containing sometimes remains of man, often reveal perceptible quantities of phosphoric acid on analysis. On the other hand, the leaching process to which the rocks are subjected from the semitropical rainfall has carried the precious substance into the Eocene limestones when they were adjacent and of a nature to absorb and retain it. Mr. Darton has collected unmistakable Orbitoides rock, which is mined for fertilizer and presents a large percentage of phosphoric acid, while much of the richest phosphate rock is of Pliocene age.

But when all these allowances are made the fact remains that certain lower Miocene strata below the Chipola beds, though not the richest in phosphoric acid, yet, as far as known, are more generally phosphatic than any other single group of rocks in the state, and that this condition is to some extent characteristic of them.[2] The following table will

[1] Am. Jour. Sci., 3d series, 1888, vol. 36, p. 234.

[2] Cf. George W. Hawes on a phosphatic sandstone from Hawthorn, in Florida. Proc. U. S. Nat. Mus. for 1882, pp. 46–48.

exhibit our understanding of the relations of the different beds considered as a whole, up to the base of the Chipola beds.

Miocene, Chattahoochee group	Ocheesee beds	Cerithium rock (Tampa)?. Chattahoochee limestone.
	Hawthorne beds	Water-bearing sands. Phosphatic oolite. Ferruginous gravel. Greenish clays.
Eocene, Vicksburg group	Nummulitic beds	Miliolite limestone. Ocala limestone.
	Vicksburg beds	Coral limestone (Salt hill)?. Orbitoides limestone (Vicksburg). White limestone (Jackson).

It is of course understood that these beds are never all present in any one section, and when their respective faunas become known parts of some of them will perhaps be found to overlap. While much of the fauna of the upper beds of the Chattahoochee group survives into later strata, and no marked unconformity has been shown to exist at the base of the Chipola, yet the lithologic and faunal differences appear sufficiently well marked to retain, at least for the present, the Chipola beds in a group by themselves.

Tampa group: Tampa, Chipola, and Alum Bluff beds.—Tampa Bay was the theater of the earliest identification of Miocene rocks in Florida, those of Conrad [1] in 1846. In the same year and journal in which Conrad's account was made public Prof. John H. Allen [2] briefly but accurately characterizes the rocks of the region about Tampa City, discriminating the siliceous rock (Orthaulax bed) and the Tampa limestone, and assigning them to their true relative situation, stratigraphically. His account in this particular is better than Conrad's and more clear and correct than anything since published, previous to the investigations of the U. S. Geological Survey in 1887. But, like others who have made brief explorations in Florida up to a recent period, he did not discriminate between the lithologically similar surface limestones of Florida elsewhere, and his observations are accurate only for the region above mentioned.

The Miocene rocks of Florida above those forming the Chattahoochee group and below the upper fossiliferous bed at Alum Bluff, I include in the group, which from their oldest known typical exposure, I name the Tampa group. This may be divided into three sets of beds, the Chipola beds (including the Sopchoppy limestone, the Orthaulax bed, Bailey's "infusorial earth," the White Beach sand rock, and the Chipola marl or lower bed at Alum Bluff); the Tampa beds (including the Tampa limestone) and the Alum Bluff beds, or unfossiliferous sand and clay strata intervening between the Chipola marl and the upper fossiliferous bed at Alum Bluff. The latter belongs to the Upper Miocene, or Chesapeake group, similar to that of South Carolina, and the later beds of North Carolina, Virginia, and Maryland.

[1] Am. Jour. Sci., 2d ser., 1846, vol. 2, pp. 36-48; 399-400.

[2] Ibid., vol. 1, pp. 38-42.

The following sections will illustrate the succession as observed at different localities:

Alum Bluff.	*Tampa.*	*Manatee River.*
Yellow unfoss. sand, 70 feet.	White sand, 6 to 24 inches.	White sand, (?)
Lignitic sand, 10 feet.	Yellow sand, 6 to 36 inches.	Yellow sand, (?)
Ecphora bed, 30 feet.	Pliocene breccia, traces.	
Alum Bluff beds, 15 feet.	Tampa limestone, 10 to 15 feet.	Ecphora bed, 24 to 36 inches.
Marl (Chipola), 5 feet.	Orthaulax bed, 6 to 10 feet.	Orthaulax bed, (?)
Chattahoochee limestone (?)		

At Ballast Point, Tampa, while repeating the researches of Conrad and others, the following notes were taken by the writer in the winter of 1886–1887: [1]

The Orthaulax bed.—The rock rises but a few feet above the beach. Two layers may be distinguished, especially by their fossils, for the rocks are so broken up that the superposition of the newer layer here is less clear than I found it farther inland. The older rock is composed of a limestone, which in some places is so impregnated with silex as to form an almost pure flint; and at other spots retains its limy character, or is decomposed into a marl of peculiar tenacity. In many places the marl occurs in pockets surrounded by or covered with chert. In other spots it forms the greater part of the bank, and in this condition was termed by Bailey "infusorial earth;" but, however different in character, the chert and marl are merely parts of one stratum which has been subjected to different chemical processes in its different parts, and not to two strata or beds. In the chert the fossils, of which the rock is full, have disappeared, leaving cavities from which their forms may be reproduced by molding in gutta-percha. In the marl they have also disappeared, but in favorable spots the smaller ones are represented by more or less perfect pseudomorphs of subtranslucent silex, reproducing every detail of the original shell. The larger ones, such as heads of coral, retain their outward form, but are usually mere shells with an interior of botryoidal chalcedony, often of great beauty. The fauna of this bed has been elucidated by Heilprin and to some extent by the writer. It is characterized especially among other things by the presence of the singular Stromboid genus *Orthaulax*, for which reason I have called it the Orthaulax bed. The more usual expression "Tampa silex bed," owing to the presence of silex in other beds of different age near Tampa, is less explicit and desirable.

This stratum was also recognized by Conrad[2] in the bed of a rivulet a few miles up the Manatee River, "near the shore of a creek having a very narrow entrance, but which widens above, and about 1½ miles up contracts again, then expands into a beautiful basin with tables of rock bordering the shore. * * * Above this is a buff-colored lime-

[1] Am. Jour. Sci., 3d ser., 1887, vol. 34, pp. 165, 166.

[2] Ibid., 2d. ser., 1846, vol. 2, p. 45.

stone without organic remains, about 1 foot thick. This spot is the limit of tide water." He also traced the same rock to the rapids or falls of the Hillsboro River about 9 miles above its mouth, as Allen also did, as well as later explorers. This locality is 14 miles or so northward and eastward from Ballast Point and Mr. Burns has collected the silicified fossils at various intermediate points along the bay shore. I found the same rock and fossils on Six Mile Creek at the head of navigation, near Orient station, about 6 miles to the eastward of Tampa, on the South Florida Railway. At Ballast Point the fossils are chiefly marine, but there is a certain admixture of land shells which becomes more pronounced toward the top of the bed, indicating a gradual increase of the adjacent land area during the deposition of the bed. Finally, in some places on the upper surface, nothing but land shells are found, showing that, at last, it became dry land, at least in certain spots.

These land shells are all of extinct species, allied more nearly to those of the West Indies than to the present fauna of the Southern States. A small bulimoid shell has been, I think incorrectly, referred to the Pacific genus *Partula*, which it somewhat resembles, as observed by Conrad forty years ago. But it is probably more nearly related to certain recent bulimuli of the North American, Antillean and South American recent faunas. The same rock, beside extending northward to the head of Hillsboro Bay, crops out on the other side of the peninsula which separates the latter from Old Tampa Bay. Specimens of the fossils were collected here by Mr. Burns. It extends up the Hillsboro River at least as far as the rapids, while silicified corals are reported from a point 25 miles above the mouth of the river at the crossing of the Florida Central Railway, in Pasco County, which may be of the same age. Siliceous fossils of the same character are reported to have been collected at Clearwater on the Gulf coast of Hillsboro County, west of Old Tampa Bay, and it is not improbable that the same rock occurs at the mouth of the Pithlachascoötee River, Pasco County, somewhat farther north, a specimen of *Pyrazisinus* having been collected there by Heilprin. A specimen of the *Orthaulax* has been collected by Matthew Hooper on the shore of Sarasota Bay, showing that the same bed exists there.

White Beach sand rock.—A little farther south, again, in the northern and western extreme of the Little Sarasota Bay is a locality known by the name of White Beach, which was visited by Messrs. Willcox and Heilprin in 1886 and by Mr. Willcox and the writer the following year. It consists of an outcrop of rock which rises two or three feet above high water. It is a yellowish limestone, much waterworn and covered in places with a thin layer of recent sand rock. It contains distorted molds of many species which can not be recognized, but in some places these molds have become filled with a pseudomorph in lime of the original shell. These pseudomorphs are gradually exposed by the action of the sea on the rock, and afforded about forty species of molluscan fossils, besides several corals and corallines. The rock did not show any foraminifera, though several of the species of shells are identical with those of the orbitolite stratum of Tampa.[1]

While all the species collected here have not yet been determined, about half of them have been studied sufficiently to show their near equivalence to the *Orthaulax* bed of Tampa and the Chipola marl bed of Alum Bluff. Several peculiar species are common to them and several others to the Antillean Miocene. On the whole, while the White Beach fauna is too imperfectly known for dogmatism, it would seem probable that it does not greatly differ from that of the *Orthaulax* bed, is certainly to be included in the Tampa group, and may possibly be a little younger than either of the beds above mentioned. More thorough study has shown that the first impression, that this horizon is not far removed from the Caloosahatchie Pliocene, is untenable, since we now know that the whole of the Chesapeake group, at least, must intervene between the two horizons.

The White Beach bed is covered with a thin coat of Quaternary indurated sand containing recent land shells, and extremely hard.

This is the most southern point, so far, at which Miocene strata have been observed to crop out in Florida; but on Shell Creek, a tributary of Peace Creek, in about latitude 27° north, draining into Charlotte Harbor, Mr. Willcox found a specimen of *Vasum haitensis* Sby., which is a shell described from the Antillean Miocene, and probably, if correctly identified, indicates the presence of beds of the Tampa group in this vicinity.

I have referred to the presence of *Orbitolites floridanus* Conrad in rocks of the Chattahoochee group. It is also found silicified, though not abundant, in the *Orthaulax* bed from which Prof. Heilprin supposed it to be absent.

Bailey's infusorial earth.—To return to the Tampa section: it is to be noted that at one point on the bay shore between Ballast Point or Newman's Landing and the mouth of the Hillsboro River the marl associated with the siliceous fossils, forming a phase of the *Orthaulax* bed, rises above the beach to an estimated height of 10 feet. Here Mr. Burns, of the U. S. Geological Survey, Col. Bartholomew, of Tampa, and others have collected fine series of silicified fossils. At this point Prof. J. W. Bailey, U. S. A., discovered what he regarded as a bed of infusorial earth resembling that of Virginia in its lithologic character. Of this he says:[2] "Directly on the shore of the bay I detected a highly interesting stratum of fossil marine Diatomacea or Infusoria. It is exposed for at least a quarter of a mile, and from 5 to 10 feet of its thickness may be seen. In its external characteristics (whiteness, lightness, fissility, etc.) it has some resemblance to the infusorial

[1] Dall, Am. Jour. Sci., 3d ser., vol. 34, p. 167.
[2] Microscop. Obs. Smithsonian Contr. Knowl., 1850, vol. 2, No. 8, p. 19.

strata of Virginia, but is much more indurated, so that although it is easy to show that it is made up of the remains of Diatomacea, spicules of sponges, etc., it is difficult to isolate and determine the individual specimens. This infusorial earth, like that at Petersburg, Va., changes in a singular manner to a salmon color when exposed to the vapor of turpentine or Canada balsam." This bed has not, as far as we know, been examined since Prof. Bailey's visit, and in order to determine its position, stratigraphical and lithological, it was visited by the writer in January, 1891.

The most marked exposure is locally known as Conklin's Bluff, and is situated on the western shore of Hillsboro Bay, about a quarter of a mile above a long wooden pier belonging to a Mrs. Chapin, and a mile and a half north of Ballast Point. It is a steep bank 6 or 8 feet above high-water mark, and is the only place on this shore between Ballast Point and Tampa which at all corresponds to Bailey's description. The land along this shore is mostly low and the beach soft and muddy or sandy, but there are a few places where the *Orthaulax* bed rises above high-water mark. The rock is like that at Ballast Point. The shells are often represented by molds in the chert, but there are pockets of putty-like marl which contain the siliceous pseudomorphs and small nodules of chalcedony.

Bailey's white bed consists of a deposit of this marl, which elsewhere occurs in pockets in the harder rock, but here for a few hundred feet appears in sufficient quantity, by itself, to be regarded as a bed. Some of the material is pretty hard, but all of it is fissured vertically and horizontally into a profusion of angular fragments. The lower layers are the hardest and rest on siliceous rock of the *Orthaulax* bed, of which this must be regarded as merely a very local phase. At this place the marl is nearly destitute of fossils. The few which occur are nearly all small branches of coral; much of it has no fossils. The lower part is of a gray or pale green hue, bleaching when dry, as in the upper layers, to white. It also becomes softer and more fragmentary. It is penetrated by roots to a depth of 2 feet, and a piece large enough to form a good specimen can be found only low down in the bed, and then in drying will break into numerous fragments. The average thickness of the bed may be 3 feet, the maximum 6 to 8 feet. In one place it is covered by a thin layer of æolian sand rock discolored by iron oxide. The strata along this beach are gently waved; the places where rock appears above high-water mark are the summits of these waves, which seem to trend in a northwest and southeast general direction. This marl is one of the highest of the waves, and farther back from the shore is covered by the Tampa limestone, according to reports of residents. There seemed to be no recognizable dip.

It will be noticed in Bailey's list of species collected that he mentions only three or four from this deposit, all of which are also found living over a great part of the Atlantic coast, and especially in Florida, around the roots of plants growing in wet places. The deposit does not seem to be properly infusorial in character, though doubtless containing, like other marl, a few such organisms. It is really a siliceous marl formed by a decomposition of part of the rock which originally constituted the *Orthaulax* bed. An analysis, according to Prof. F. W. Clarke, shows the following composition:

Silica	70·78
Alumina and iron	11·33
Lime	2·18
Water and loss	15·71
	100·00

This indicates the material to be little different from the yellow sand, which, like it, is probably a residual product of the disintegration of indigenous lime rock of organic origin which has lost most of its lime by solution.

An examination of some of this marl by Mr. Lewis Woolman, the well known student of microscopic organisms, did not reveal a single diatom, though specimens doubtless occur in certain portions of the deposit as observed by Bailey.

The Tampa limestone.—A second stratum, which appears obscurely at Ballast Point and with clearness at other localities, overlying the *Orthaulax* bed, was first clearly described by Allen in 1846. He observes:

The first layer of solid rock beneath the soil is a stratum of limestone; it is hard and white, has an earthy texture, and appears to have resulted from comminuted and decomposed shells. The surface of this rock is exposed in several places in the vicinity of Fort Brooke; about 2 miles north, near the Hillsboro River; 4 miles west, on the shore of the bay; and 6 or 7 miles east, in the banks of a small stream.[1]

This rock I have named the Tampa limestone. It was observed by Heilprin,[2] who noted in it the great abundance of the Orbitolite described (under the name of *Nummulites*) by Conrad in 1846. But in Heilprin's text it is more or less confused with a supposedly different rock which he regarded as underlying the *Orthaulax* bed. An examination of the rock in the Hillsboro River from Tampa to the falls shows that what he mistook for the *Orthaulax* bed was merely a cherty layer of the Tampa limestone, that rock being characterized by an abundance of *Cerithium hillsboroensis* in this vicinity, and everywhere overlying the *Orthaulax* bed. The following notes on this rock were made by the writer in 1887.[3]

Above the stratum above described [*Orthaulax* bed] is a layer from 1½ to 10 feet thick, of a limestone free from silex and pretty uniform in character. The fossils are mostly represented by external molds; but a few, and particularly an orbitolite described by Conrad, and probably identical with one now living at moderate depths on the Floridian coast, retain their shell structure.

This rock underlies the town of Tampa, where wells are dug through it, and water obtained at a depth of 10 feet or less. It is probable that the more compact cherty

[1] Am. Jour. Sci., 2d ser., 1846, vol. 1, p. 38.
[2] Trans. Wagner Inst., 1887, vol. 1, p. 61, ¶ 2.
[3] Am. Jour. Sci., 3d ser., 1887, vol. 34, pp. 166-167.

stratum underlies it here and forms a water table. The same rock occurs 7 miles northeast of Tampa in wells, and also on land belonging to Mr. Lapenotiére of Tampa (SE. ¼, Sec. 14, T. 29, R. 19), near Orient Station. Its upper surface is about 14 feet above Six-Mile Creek, near by, and about 25 feet above the water in the harbor of Tampa, at the railroad wharf, according to recent surveys. Its exact thickness here I was not able to determine. I was informed that the same rock occurred on the Manatee River above Braidentown. Still farther to the south and west I observed it about 1 mile from Sarasota village, on the road from Braidentown, in the gulley of a small rivulet about a half mile from the shore of the bay.

There is an outcrop of rock at Bowleys Creek, emptying into Sarasota Bay, about 8 or 9 miles northwest of Sarasota and about 2 miles from its mouth. This can be reached only by boat at high water, and is then a foot or two below the surface. I visited it and succeeded in getting some fragments with prints of two species of *Pecten* and one of *Ostrea*, with traces of a *Spondylus*, all of which are represented in other Miocene localities. The rock was covered with Quaternary beds of indurated sand containing recent shells in a semifossil condition.

The same rock appears to crop out at Belleview, Marion County, and Bayview, on Old Tampa Bay, where specimens were collected by Willcox.

The known area of the Tampa limestone, and that which is probably to be assigned to it, from the information in our possession, is nearly the same as that of the *Orthaulax* bed; but as yet we know very little about the geographical extent of either. These rocks are usually much corroded on their upper surface, through the action of carbon dioxide and rainwater, and are covered with from a few inches to several feet of sand, loam, and humus.

A section on the bank of the Hillsboro, near Lapenotiére's Spring, generalized from variations observed in the near vicinity, gives the following succession:

Thickness.	Character of strata.
6 to 36 inches	Humus, yellow sand, etc.
10 to 15 feet	Tampa limestone.
7 inches to 10 feet	Orthaulax bed.

Total elevation above the level of mean tide at Tampa, about 25 feet.

The Cerithium rock of Heilprin.—In January, 1891, the writer visited Tampa for the purpose of settling some lurking doubts excited by discrepancies in previous accounts of the stratigraphy of the "Cerithium rock" and Tampa limestone. The writer has never seen the so-called Cerithium rock underlying the *Orthaulax* bed, though analogy with the Alum Bluff section would seem to call for it. Heilprin distinctly affirms its existence in such a position, but his language would seem to indicate a confusion in his mind of the rock holding *Pyrazisinus* with that containing *Cerithium hillsboroensis*. His description of the rock would seem to apply to the former, but his reference to the species particularizes the latter.

A trip up the Hillsboro River about 12 miles, in a skiff, examining every outcrop of rock in the banks from Tampa to the rapids, resulted as follows: The *Orthaulax* bed is clearly and unmistakably below the Tampa limestone, but nowhere could any rock below the *Orthaulax* bed be observed; the stratum itself rarely rises more than 2 or 3 feet above the water. The Tampa limestone everywhere covers the *Orthaulax* bed, and reaches a maximum thickness of 25 to 30 feet. The two strata appear to be gently waved in a northwest and southeast direction, the Hillsboro River cutting these waves transversely, as a rule. There appear to be about half a dozen such waves between Tampa and the rapids, where the *Orthaulax* bed rises about 6 feet above the river and forms its bed for a short distance. In the *Orthaulax* bed there are many species which have not been found in the Tampa limestone, but I have found comparatively few, mostly minute, species in the Tampa limestone, except *Cerithium hillsboroensis*, which are not represented in the *Orthaulax* bed.

Along the river the summits of the anticlines bring up the Tampa limestone and less commonly the *Orthaulax* bed above the water at the shore. Between the anticlines the Tampa limestone sinks out of sight and is covered by swamp. In intermediate places it forms the bed of the river, and perhaps from some such place Prof. Heilprin's *Cerithium* was collected. The lower layers of the Tampa limestone are silicified or cherty in many places, but still remain yellowish. This part of that bed can be distinguished from the *Orthaulax* bed chiefly by color and by the absence of the characteristic *Orthaulax*, *Pyrazisinus*, and other fossils of the older stratum.

In the city of Tampa good exposures of the limestone were obtainable at the city waterworks (with which Magbey's Spring is now incorporated) and at a quarry where the rock is excavated for road metal. Here the rock is at least 20 feet thick. The lower part has few fossils. Those of the upper part are in the form of molds. *Natica amphora* and *Venus penita* are particularly abundant; *Cerithium hillsboroensis* not rare in the upper part. The upper surface of the beds, which is covered by a yellowish loamy sand, is wave-worn with Lithodomus borings, lumpy and irregular. The outer crust is harder than the rock below. The yellow sand contains occasional phosphatic nodules and fragments of bone. It descends into the fissures and depressions of the limestone and averages 2 or 3 feet in thickness, covered by the usual layer, 3 to 6 feet thick, of white siliceous sea sand.

From these observations it appears that, while the existence of a *Cerithium* rock under the *Orthaulax* bed is a priori probable, sufficient evidence of its existence is still to be collected, and the rock identified as such by Heilprin may very possibly have been a portion of the Tampa limestone.

The Sopchoppy limestone.—Specimens of a very soft limestone containing numerous imprints of shells and many fragments of vertebrate ribs and other bones were exhibited in 1890 at the Subtropical Exposition at Jacksonville. These were stated to be from Sopchoppy, Wakulla County, near the Okloconee River. This locality is not easily accessible, but through the kindness of Mr. J. C. Hodge some of the rock was obtained for examination. It proved to contain Conrad's orbitolite and about thirty species of shells, most of which are common to the Chipola marl or the *Orthaulax* bed. No sign of *Orthaulax* or *Pyrazisinus* was noticed, but the horizon is probably not far from that of the Chipola marl.

Mr. Burns was informed that a mass of limestone of this character extends from the river near Sopchoppy to the Gulf coast eastward of the mouth of the river, and this may belong to the Chipola beds, like the specimens examined. This, however, remains to be definitely determined.

Other localities of limestone belonging to the Tampa group, but of which the fauna is too little known to determine the exact horizon, are Sulphur Spring Ferry, Suwannee County (L. C. Johnson); Johnson's Limesink, Levy County, and a 50-foot well near the capitol building in the city of Tallahassee. These are represented by specimens in the National Museum collection.

In the endeavor to determine the extent of Miocene deposits in the line of the Suwanee Strait between the Miocene Florida islands and the continental border of the same epoch, an examination of the rocks along the line of the railroad from Tallahassee to Lake City was kindly undertaken, in the intervals of other work, by Mr. T. W. Stanton, of the U. S. Geological Survey.

Mr. Stanton notes that the country around Tallahassee is hilly and rolling and the surface covered with red sandy clay (referred to the Appomatox by McGee), which forms the soil and is the only material to be seen in the cuts on the railroads and wagon roads.

In a ravine 2 miles west of the town were found a large number of masses, 2 feet thick, of hard, white siliceous limestone, which do not form a continuous bed, but occur in soft gray argillaceous sand 8 feet thick, unconformably overlain by the red sandy clay referred to, which here, together with the surface soil, forms a layer 3 to 10 feet thick. This rock recalls that observed by the writer at Bowleys Creek, Sarasota Bay, and like it contains *Pecten* and *Ostrea* and other old Miocene fossils.

One mile west of this place, on the farm of G. H. Meginnis, Mr. John E. Davids has dug a shaft 60 feet deep in search of phosphate rock. This well is said by Mr. Davids to pass through—

	Feet.
1. Surface soil and red clay	10–12
2. Light green clay	14
3. Green clay, with fragments of shell	2
4. Fine white sand, with a little clay and some fragments of hard sandstone	16
5. "Soft phosphate"	9
6. "Hard phosphate"	10

Nos. 5 and 6 contained irregular fragments of rock, said to be phosphatic and apparently an altered Miocene limestone; some fossiliferous fragments of that age in the field near by were said to have come from an old well.

At Lloyd, a station 18 miles east from Tallahassee, all the streams of the neighborhood flow northward and disappear in sinks. At the station a rock said to be phosphatic was struck at the depth of 20 to 25 feet in digging a well. This is overlain by clay, in which, at the depth of 8 feet, was a bed of large oyster shells.

Two and a half miles east of Lloyd a large creek called the Miccosukee Drain flows from a lake of the same name and sinks into the limestone. The latter appears to be Tampa limestone, with abundance of *Orbitolites floridanus* Con., and other fossils; it is about 10 feet thick, and contains more or less cherty matter. Similar rock was exposed at a sink 1½ miles south of Lloyd, resting on greenish clay. Five miles southwest of Lloyd the country becomes less flat and the red clay again appears on the higher ground. It also is seen near Monticello.

South of the railway, at Weelaunee, Jefferson County, on Bailey's plantation, a Miocene limestone with the characteristic fossils occurs in a bed about 3 feet thick, which has been quarried for lime. It is covered by about 2 feet of surface soil, and the upper part is fragmental. At the farmhouse, which is on a hill a mile away, a well 100 feet deep has recently been dug, from the lower third of which much rock of the same sort has been taken. Phosphatic rock, probably of the same age, has been found at a third point, in low ground, on the same estate.

The Suwanee River is crossed by the railroad just east of Ellaville, and a light yellowish limestone is exposed here in the banks of the river. Mr. Stanton was unable to stop at this point, but specimens collected there by L. C. Johnson, and now in the National Museum, show that the rock is probably Tampa limestone.

Nine miles east from Ellaville on the railroad is a "rock cut," where 4 feet of Miocene limestone and calcareous clay is unconformably overlain by 4 feet of red and yellow clay. The limestone is of the Tampa beds, and contains the usual molluscan fossils, represented by rather imperfect casts, which have been more or less filled with crystals of calc-spar. The ground is comparatively high at this point, though the surface is more level and the hills lower than at Tallahassee or Monticello.

These observations and collections of Mr. Stanton are of much importance, since they confirm, by unimpeachable evidence, the Miocene insulation of central Florida, which had been regarded as probable by the writer previously, chiefly on theoretical grounds.

Taken in connection with the observations of Mr. Burns on the Altamaha grits of Georgia, they show that the passage between Florida and the mainland, here termed Suwanee Strait, and now occupied by the Okefinokee and Suwanee swamps and the trough of the Suwanee River, was a wide, and even in Miocene times a moderately deep, body of water, the general trend of which did not differ much from that of a line drawn from Savannah to Tallahassee, and which had a probable width of more than 50 miles.

Chipola marl.—This bed contains the lower marl bed of Langdon's section. Owing to a lower stage of the water at the time of his visit, and more detailed study of Alum Bluff by Mr. Burns, he was better enabled to determine its thickness and discover a considerable westward extension of its area.

At Alum Bluff the Chipola marl bed is about 5 feet thick and well characterized by a species of *Orthaulax* (*O. gabbi* Dall), different from *O. pugnax* of the bed at Tampa, and also from that originally described by Gabb from the Miocene of Santo Domingo.

At Baileys Ferry, on the Chipola River, an affluent of the Appalachicola from the west, the Chattahoochee beds are overlain by a stratum of yellowish calcareous sand containing well preserved fossils, identical with those at Alum Bluff, but in much better condition. The same bed is reported by Aldrich over phosphatic rock at De Leon Springs. It, or its analogue, exists in the Miocene rocks of Santo Domingo, from which Sowerby and Gabb have described so many species. Similar beds exist in Venezuela, Curaçoa, Trinidad, Barbuda, Anguilla, Haiti, Jamaica, and probably in Cuba. They have numerous species in common with the Chipola marl and the Orthaulax bed of Tampa, the differences not being greater than the faunal differences between the cited localities at the present day. Some of the interesting forms first described from this rich fauna, like *Bothrocorbula*, are absent from the immediate vicinity of the present coast, but still exist, living, in the greater depths off shore.

The White Beach bed has afforded 40 species of molluscan fossils; the Tampa Orthaulax bed about 165; the Chipola marl about 400 species, part of which have been determined. Sixty species have been enumerated from the Tampa limestone, of which more than one-half are known to be common to the Orthaulax bed. It should be added that, as one might expect from its position in the column and relations to the subjacent Eocene, these rocks contain a certain number of Eocene species which afterward die out. A few small specimens of *Ostrea sellaformis* (*O. divaricata* Lea) appear in the beds, as well as a certain number of Vicksburg fossils, and nearly the whole Chattahoochee fauna, as far as yet known, reappears in the Chipola beds.

Alum Bluff beds.—Over the richly calcareous rather ferruginous, Chipola marl at Alum Bluff we find a total change of material and a total disappearance of the fauna. There are from 5 to 15 feet of gray siliceous sand and a little clay, without fossils, while above that a radical change of fauna is revealed by the fossils of the Ecphora bed.

To these transition strata I would apply the provisional name of the Alum Bluff beds, until such time as fuller information shall be available. That they represent in the series at Alum Bluff a period of important changes of level and probably of sea temperatures, and no inconsiderable portion of geologic time, is hardly open to dispute.

Chesapeake group.—For the Miocene strata extending from Delaware to Florida, but best developed in Maryland, Virginia, and the Carolinas during the Yorktown epoch of Dana, including a large part of Heilprin's Marylandian, Virginian, and Carolinian, I propose the name of the Chesapeake group. On this noble bay and its estuaries, forming the greater part of the Patuxent, York, and James rivers, these beds are displayed in all their breadth, and the Chesapeake waters may almost be said to be inclosed in rocks of this group. I have been unable to use Heilprin's names, as they have never been recognizably defined so that one might say, from a knowledge of the fossil fauna, such and such a bed is "Virginian" or "Carolinian;" neither am I convinced that these names correspond with precision to any definite geologic facts.

That there is a gradual change in the fauna from the older beds to the newer ones may very probably be the case; but no careful stratigraphical evidence has yet been combined with such a statement of the fossil fauna of each stratum as to put the matter in a sufficiently clear light for intelligent discussion, still less for geographical apportionment. That the lowest beds of Shiloh, New Jersey, and perhaps some of those elsewhere, correspond to the Tampa group there is some reason to su spect; but even here revision and comparison of the species comprising the fossil fauna is necessary before positive conclusions can be safely drawn.

For the strata bordering on the Chesapeake in Maryland and Virginia which belong to the Miocene, Darton has proposed[1] the name of the Chesapeake formation. This term as used by him is equivalent to "Miocene" as heretofore understood in these states, and is the stratigraphic homonym of the chronologic "Yorktown epoch" of Dana.

The term *Chesapeake group*, as independently suggested, here includes as typical Darton's Chesapeake formation and also all other beds belonging to the same horizon and containing the same general fauna on the Atlantic and Gulf coasts of the United States.

The Carolinian Miocene is presumably closely analogous to the Ecphora bed at Alum Bluff, and represents the later beds of that epoch, but the terms Carolinian and Sumter, as heretofore used by most authors, involve assumptions which seem dubiously true, and for that reason I am unwilling to adopt either term. As originally used by Dana they were chronologic, and not stratigraphic terms.

It is obvious from what has preceded that the term Middle Miocene is inappropriate if used to denote what seems to be the culminating series of Miocene deposits on our Atlantic coast, as is done by Heilprin under the assumption that what I regard as the mixed Neocene of

[1] Mesozoic and Cenozoic formations of eastern Virginia and Maryland, by N. H. Darton, Bull. Geol. Soc. Am., May 1891, vol. 2, p. 443. This use of the name was not known to the writers of this essay until the essay had been practically finished.

South Carolina is a homogenetic deposit. Consequently I am obliged to bring in a new term, which shall have no ambiguity in its meaning, and in which I intend to include all the marine Miocene of eastern America possessing a fauna newer than that of the Tampa group, and of which such species as *Ecphora quadricostata*, *Fusus equalis*, *Perna maxillata*, *Mactra congesta*, and the great Miocene Pectens are illustrative members. It is quite possible, when this group of beds has been properly investigated, that an opportunity may arise for subdividing it. At present, however, no satisfactory data exist warranting such subdivision; even the upper limits of the oldest Virginian fauna, in terms of stratigraphy, are entirely unknown.

The Chesapeake group is represented over a very wide area in Florida, if the scattered observations already made can be regarded as indicative of its extension. Borings on the eastern coast of Florida and in the St. Johns valley indicate that there the beds of this group in some places attain a thickness of at least 500 feet.

The Ecphora bed.—At Alum Bluff the group is represented by what I have termed the Ecphora bed, of gray marl, with over 100 species of fossils many of which are common to North Carolina, Virginia, and Maryland. It has a thickness here of 30 feet or more. One mile west of Baileys Ferry, on the Chipola River, the same bed appears with the same fossils and probably a somewhat greater thickness. Mr. Burns also traced it along the hills east of the Appalachicola River from about 5 miles above Bristol to a point 8 miles below that place, thus giving the outcrop a breadth of at least 13 miles, while along the Chipola he believes it may attain fully 20 miles. L. C. Johnson, of the U. S. Geological Survey, has made a small collection from what is probably the western extension of the same bed, 5 miles east of De Funiak Springs, in Walton County; and on the branches of Shoal River above Crestview, in the same general direction, he reports marl with abundance of fossils, which are likely to prove of the same age.

To the eastward of the Appalachicola River for some distance no observations are on record.

At 15 miles west from Tallahassee Mr. Joseph Willcox recently found a bed of white marl containing *Mactra congesta*, *Lucina crenulata*, *Corbula dietziana*, and *Dentalium attenuatum*, which clearly belongs to the same group. Johnson reports an extensive deposit of marl in the vicinity of Tallahassee.

Jacksonville limestone.—At Jacksonville, Florida, in Duval County, in the excavation made for the city waterworks, a porous, slightly phosphatic, yellowish rock, derived from indurated calcareous sand, was discovered.[1] It contains numerous molds of fossil shells belonging to the newer Miocene fauna. The same was apparently exposed on Black River, Clay County, and Preston sink, 3 miles north of Waldo, Alachua County, where *Pecten jeffersonius*, *Carditamera arata*, etc., were obtained.

[1] E. A. Smith, Min. Res. U. S. for 1885, p. 251.

West of Jacksonville, at Live Oak, Suwanee County, and Lake City, Columbia County, specimens of fossils were obtained which may prove to belong rather to this than to the Chattahoochee group of beds.

The borings at Jacksonville passed through what appears to have been this rock for nearly 300 feet. East of Jacksonville, at St. Augustine, similar borings were prosecuted when *Venus rileyi*, *V. permagna*, and *Arca limula* were obtained at a depth of 208 feet, while at 224 feet the characteristic fossils of the Vicksburg appeared.

Farther southward, at Rock Springs, near Zellwood, Orange County, Smith[1] obtained from a limestone bluff at least 10 feet high *Pecten madisonius*, *Venus alveata*, *Venericardia granulata*, *Carditamera arata*, *Mytiloconcha incurva*, *Cardium sublineatum?* and *Oliva literata?* which indicated decisively the Upper Miocene age of the outcrop. About 150 miles farther south an artesian boring near Lake Worth reached the Vicksburg rocks at a depth of 1,000 feet. This well was evidently bored through deposits, in part at least, of the nature of talus, since if the depths at which the specimens were obtained above the Vicksburg were correctly stated (which is open to grave doubt), several very remarkable inversions of Tertiary rock and recent coquina occurred. However, at an indeterminate point between the surface and 1,000 feet below it a few Upper Miocene fossils were obtained, including a *Corbula* and *Dentalium attenuatum*, so abundant in the Ecphora bed. This is valuable chiefly as indicating the southernmost point where beds of the Chesapeake group are known to occur on the Atlantic shore.

Manatee River marl.—In the western portion of the peninsula a few localities are known for beds of this age. At Rocky Bluff, on the right bank of the Manatee River, a few miles above Braidentown, Heilprin[2] found *Pecten madisonius*, *P. jeffersonius*, *Venus alveata*, *Perna maxillata*, *Arca incongrua*, and other Upper Miocene species. The so-called "bluff" is a ledge of rock, 2 or 3 feet above the water level at the time of his visit, which consisted of a basal white marl and yellowish sandstone and an overlying siliceous conglomerate. The latter, which is probably Quaternary, is almost entirely deficient in organic remains. The marl is "densely charged with them." It is probably from more westerly submarine strata belonging to this series of beds that was derived the *Ecphora* collected by Dr. Stearns in 1868-'69 on the beach of Long Key. At one time I was inclined to refer this specimen to the silex beds,[3] but subsequent study of the stratigraphy has led me to renounce that idea, since the *Ecphora* belongs to a later horizon, similar to that of the Manatee River stratum. Further search showed, according to Prof. Heilprin, that the marl at the Manatee River locality "thinned out and disappeared after a short distance, but the yellow sand rock, largely honeycombed and containing much fewer fossils, many of them identical with the forms of the marl, continued up the

[1] Am. Jour. Sci., 3d ser., 1881, vol. 21, p. 302.
[2] Trans. Wagner Inst., 1887, vol. 1, p. 13.
[3] Trans. Wagner Inst., vol. 3, p. 125.

river to the farthest point reached by us." (Op. cit., p. 13.) Prof. Heilprin does not state whether the marl was above the yellow stone or sand rock or below it, or whether he regards the latter as simply another aspect of the bed elsewhere preserved in the shape of marl. But if the yellowish rock was below the other, as the context seems to indicate, it might be identical with the Tampa limestone found both north and south of this locality at no great distance. However, this supposition is rendered doubtful by the fact that in a similar rock which occurred in the banks of Phillips Creek, flowing into Sarasota Bay, Prof. Heilprin found casts of *Pecten madisonius*, *P. jeffersonius*, and *Arca idonea?* beside others which appeared identical with fossils of the Manatee River rock. The bed on this creek rises at intervals to 2 or 3 feet above the water. The fossils are in the form of molds or impressions and poorly preserved. At one or two points near the mouth of Phillips Creek this rock is seen to be overlain by 2 or 3 feet of compact coquina composed of triturated fragments of the recent shells of the coast. At Whittakers, a point a few miles south of Hunters Point, in the northern part of the bay, a similar rock was noted, but without recognizable fossils. These imperfect data indicate the most southern extension of the Chesapeake group which has yet been determined on the western edge of the Floridian peninsula.

GENERAL DISTRIBUTION OF THE FLORIDIAN MIOCENE.

The notes herewith given indicate that the older Miocene rocks surround more or less completely the original Eocene island or nucleus of the peninsula on the northwest, southwest, south, east, and northeast. On the north and northwest they exist over a large area only in patches indicative of greater original extension, the connecting deposits having been removed by solution or erosion over much of this area. On the west they are for the most part submerged, the Eocene, except in the river valleys, reaching to the Gulf coast.

In the De Soto basin they are overlain by Pliocene and Pleistocene beds, but appear again in the eastern anticline, the mass of which, if our information may be relied upon, is probably mainly composed of Miocene rocks, of which the older series east of the ridge dips rapidly under the newer rocks, reaching a depth of probably more than 600 feet at the present eastern margin of the peninsula.

In the western part of the State, near the Appalachicola River, the formations succeed each other regularly; the Eocene, old Miocene, Newer Miocene, Pliocene, and Pleistocene appearing one after another as one passes from the State boundary south to the Gulf. The near approximation of the depressions occupied by the great Suwannee and the Okeefinokee swamps, and the beds of Miocene known to exist on the highest part of the watershed between them, point toward a submersion in Miocene time of much of this region and the insularity of the area above the sea to the southward.

During the Chesapeake epoch northeastern Florida must have been deeply submerged and over five hundred feet of rocks belonging to the Chesapeake group were laid down in this embayment. A deposition of strata of this age went on along the whole Atlantic border at least as far south as Lake Worth, though at present buried over much of this coast by Pleistocene deposits. Newer Micocene in the northern half of the peninsula appears on both sides of the older Miocene ridge. In the central basin and to the south it is buried under Pliocene or later beds; in the southwest a single small patch is known; in the west it must necessarily exist, if at all, underneath the waters of the Gulf outside of the older Miocene, a supposition to which the washing up of *Ecphora* on Long Key lends a certain plausibility. The preservation of its shell structure indicates that the bed from which it came was under the sea, since no beds of Miocene rocks are known in this part of Florida, where rainwater has access to them, which retain the natural structure of their shell-fossils. On the other hand salt water does not erode or dissolve the fossils in the same way, because at moderate depths it does not contain carbon dioxide in sufficient quantity.

The Grand Gulf beds enter the State only in its northwestern extreme as far as known, and more information is urgently needed.

The appearance of mammalian bones in the Sopchoppy limestone indicates the preservation of remains of warm-blooded vertebrates considerably older than those of the Alachua clays on the Peace Creek Pliocene bed. It is likely that these bones are sirenian or cetacean, but too little is yet known to hazard any conclusions upon them. It is probable that the bones from the clays near Wakulla, which have achieved popular notoriety, are of later origin, perhaps Pliocene; but here, again, our information is deficient.

PLIOCENE DEPOSITS.

Terrestrial fauna, the Alachua clays.—Later in this essay I shall endeavor to indicate all that is known to date of writing of the marine Pliocene beds of Florida, but there is another formation to be spoken of which has been referred by some authorities to the Upper Miocene, though regarded by others as late Pliocene or even Pleistocene. This comprises the deposits of clay containing bones of extinct mammalia which, in my report to the Director of the U. S. Geological Survey in 1885, I termed the Alachua clays.

These clays occur in sinks, gullies, and other depressions in the Miocene, Upper Eocene, and later rocks of Florida, especially on the western anticline in the higher portions of Alachua County, and along the banks of many of the rivers and streams. They appear in Alachua County to have been subjected to denudation after deposition, so that only those portions protected by their depressed position in cavities or gullies of harder rocks remain undisturbed. The clay is of a bluish or grayish color and extremely tenacious, so that it is most difficult to discover remains imbedded in it. Dr. J. C. Neal was among the first to notice these remains and brought them to the attention of geologists in 1883. To his exertions and those of later collectors is due most of our knowledge of the mammalian fauna contained in them. The clays occur in patches, usually in depressions, but occasionally in short ridges whose lateral buttresses of limerock have disappeared through the dissolving agency of rainwater and carbon dioxide. These deposits are believed by Dr. Neal to have a definite relation to the margins of the ancient De Soto Lake which occupied more or less the synclinal trough eastward from the westward anticline. The rather limited opportunities for observation which the writer enjoyed in 1885, while examining these clays, did not show anything to antagonize this view of Dr. Neal, which, however, requires more evidence to receive definite acceptance.

The appearance of the bones suggests that the animals were mired and then torn to pieces by predatory carnivora. Ashes and burnt clay were found under some of the bones at Hallowell's ranch, but there is no evidence of any human agency in this. The fire was probably due to lightning, an every-day occurrence in Florida at the present time. The longitudinal splitting of the long bones sometimes observed may often be the result of the penetration and growth in the hollow of the bone of roots which might afterwards decay and leave no sign. I have observed roots penetrating the bones on several occasions.[1]

Among the localities to be noted are: In Alachua County, Mixon's farm, 10 miles south and 1½ miles east of the railway station at Archer; Hallowell's place, 10 miles north and 2 miles west of the station; a pond about one-fourth of a mile from the station; another in the vicinity of Mixon's, 2 miles northwest of the first; a ditch about 2½ miles west of Gainesville; a spot where the railway crosses the Santa Fe River, near Gainesville; 1 mile north of Gainesville, on the Newnansville road, in a ditch dug for a mill race; and Owen's, nearer the town. Other localities are: Clay Landing, on the Suwanee River, near Fort Griffin, Levy County; Rocky Creek (old Tampa Bay), Hillsboro County (*Bison latifrons*); Philipps' quarry, Ocala, Marion County.

At Arcadia, on Peace Creek, Manatee County, and some points on the upper Caloosahatchie River, Monroe County, and also in Wakulla County, similar remains have been found, associated with phosphatic gravel or nodules in the beds of streams, which has been segregated from the material of the banks by the action of the water much as in the South Carolina Pliocene or Pleistocene, where vertebrate remains are associated with nodules of phosphate of lime sufficiently rich to have resulted commercially in an important and well known industry.

In the case of the South Carolina remains, as it appeared to have been of late conceded that they are derived to a greater or less extent from geological horizons outside the limits set for this essay, though at one time supposed to be of Pliocene age, we have not attempted to consider them. But, in the case of the Floridian vertebrate fossils, more doubt has been raised by the fact that one, at least, of our most

[1] Dall, Am. Jour. Sci., 3d ser., 1887, vol. 34, p. 165.

distinguished vertebrate paleontologists has repeatedly asserted his belief in their Miocene or Pliocene age, though they have by others been referred to the Pleistocene, like most of those from South Carolina.

For this reason it has seemed desirable to state the facts upon which these different opinions are based, as understood by experts in vertebrate paleontology.

The specimens from the Alachua clays identified by Dr. Leidy are of the following species:

Rhinoceros proterus *Mastodon floridanus* *Megatherium* sp. *Auchenia major* *Auchenia minor* *Auchenia minima* *Cervus (virginianus?)* *Hippotherium ingenuum*	From Archer.
Rhinoceros proterus *Mastodon floridanus* *Hippotherium ingenuum* *Hippotherium plicatile* *Auchenia major*	From Mixon's, 10 miles east from Archer.
Elephas columbi *Equus fraternus* *Auchenia minima* *Machairodus floridanus*	From Ocala, Marion County.

The following specimens have been obtained from a bed which extends for miles along the banks of Peace Creek, Manatee County, near Arcadia.

Tapirus americanus.
Elephas columbi.
Mastodon sp. (not *M. floridanus*).
Hippotherium ingenuum.
Equus fraternus.
Bison americanus.
Cervus virginianus.
Megalonyx jeffersonii.
Chlamydotherium Humboldtii.
Glyptodon sp.
Hoplophorus euphractus.
Manatus antiquus.
Priscodelphinus sp.
Emys euglypha.
Trionyx sp.
Eupachemys sp.
Testudo crassiscutata.
Alligator mississippiensis, and a variety of fish remains, including teeth of *Carcharodon*, *Galeocerdo*, *Myliobatis*, etc.

From the Pliocene beds of the Caloosahatchie were obtained:

Bison latifrons.
Elephas columbi.
Equus fraternus.

In regard to the equivalence of this fauna, assuming it to be all of one epoch, which is still to be determined, Dr. Leidy writes that he has not yet come to any final conclusion, but thinks there are no species identical with those of the Loup Fork horizon. The three forms of

Auchenia according to him "seem to belong to *Palæolama*, founded by Gervais on remains from the Pampean formation of Buenos Ayres." A specimen once obtained from Virginia, and at that time referred to *Procamelus*, Dr. Leidy now thinks "more nearly related to the living *Auchenia*." In regard to the latter Prof. Cope states that its stratigraphical provenance is doubtful, and it can not be positively stated that it came from the Miocene of Virginia, as was once supposed.

In regard to the remains from the Alachua clays, Prof. Cope furnishes the following note:

The vertebrate fauna [referred to] presents a mixture of species and genera which are found in the West in two different horizons, viz, the Loup Fork and Equus beds. This may be seen by the following table of comparisons:

Loup Fork.	*Florida.*	*Equus Beds.*
	Glyptodon petaliferus Cope.	*Glyptodon petaliferus* Cope,
	Chlamydotherium humboldtii Lund.	*C. humboldtii* Lund.
Machairodus catocopis Cope.	*Machairodus floridanus* Leidy.	
*Rhinoceros (Aphelops) fossiger** Cope.	*Rhinoceros (Aphelops) proterus** Leidy.	
Rhinoceros (Aphelops) malacorhinus Cope.	*Rhinoceros (Aphelops) longipes* Leidy.	
Hippotherium occidentale Leidy.	*Hippotherium princeps* Leidy.	
	Equus major De Kay.	*Equus major* De Kay.
	*Mastodon floridanus** Leidy.	*Mastodon serridens** Cope.
*Pliauchenia vulcanorum** Cope.	*Pliauchenia major** Leidy.	
	Pliauchenia media Leidy.	
*Pliauchenia humphreysiana** Cope.	*Pliauchenia minor** Leidy.	

A few of the other described species do not throw any light on the question of age. Those marked with an asterisk are not yet shown to be distinct from the corresponding species of the other horizons. It thus appears that six species are allied to or identical with as many of the Loup Fork horizon of the West, while four are characteristic of the Equus beds of the East, of Texas and of South America. The epoch they represent is then probably between the two.

It would be presumptuous to attempt to decide so recondite a matter in the presence of two such experts as Drs. Leidy and Cope, but it will not be amiss to point out that both their conclusions, though differing somewhat, agree in referring the epoch of the Floridian mammals to a period related to the Equus beds or Pampean formation, and perhaps somewhat earlier.

The relations of the clays to the Pliocene Lake De Soto, if Dr. Neal's hypothesis be confirmed, and the presence of some of the species in the undoubted Pliocene of the Caloosahatchie and the Pliocene age of the Peace Creek beds, all point in the same direction, and, while the determination of the precise epoch of the deposition of these remains in the clays may be regarded as still a desideratum, we may be permitted to conclude with some confidence that at least they are not Miocene.

Peace Creek bone bed.—In view of the differences of opinion in regard to the age of the mammalian remains of Florida, the writer, in January, 1891, decided to visit the Peace Creek region, believing that there an opportunity might be found for observing an interstratification of the marine beds with those containing the mammalian remains, and that thus the age of the latter, relatively to the marine beds, might be positively settled, at least as far as the Peace Creek bed is concerned. This anticipation proved to be well founded, and the visit was completely successful in its object.[1]

Some account of the condition and relations of the earlier Pliocene strata and their geographical distribution in Florida will follow under the head of Marine Pliocene beds. For the present it is only necessary to state that the "pebble phosphates" of Peace Creek are derived from the reduction into gravel of (1) a phosphatized and altered lime rock, and (2) of fragments of bones, teeth, and other vertebrate remains, which generally, in addition to the phosphate of lime they naturally contain, have been subjected to the same conditions as the lime rock above referred to, on which they originally lay or in which they were more or less imbedded.

Arcadia marl.—In the case of the Peace Creek bed the phosphatized rock in or over which the bones are situated is exposed in the bank of the river, in situ, near the mouth of a brook known as "Mare Branch," which enters Peace Creek from the east, about 6 miles north of Arcadia. The same rock is also visible along the branch, at several points, but there it is generally at or below the surface of the water in the branch and less easily inspected.

At the edge of Peace Creek the section exposed was as follows:

		Feet.
1. Humus and white sand		1½– 6
2. Yellow sand		6 –10
3. Peace Creek bone bed, phosphatized rock with bones (about)		1
4. Arcadia Marl	Yellowish sandy marl, to water's edge	3
	The same, under water (about)	3 – 6

The sandy strata above are the two beds of siliceous and argillaceous sand common to a great part of the peninsula. Varying in thickness along the creek the two, combined, will average about 12 feet in thickness.

The phosphatized rock is a calcareous sand rock, originally light colored, but here blackened, or of various shades of gray or dark brown; it contains numerous imprints of shells in rather poor preservation, but which exhibit several distinctively Pliocene species, such as *Arca rustica*, *Turritella apicalis*, *T. perattenuata*, and *Cardium floridanum*, besides a large number of forms which are to be found over a wider range. No trace of any characteristic Miocene species was to be found, though several species appeared which are common to both Miocene and Plio-

[1] For facilities extended, information furnished, and various other courtesies, the writer is indebted to numerous gentlemen, resident or interested in the region, and especially to Maj. M. T. Singleton and President M. F. Knudsen, of the Peace River Phosphate Company, of Arcadia; Mr. G. W. Land and Mr. J. H. Tatum, of Bartow; Mr. F. J. La Penotière, of Tampa, and Mr. James Willcox and Supt. I. T. Beeks, of Orlando.

cene, as well as the recent fauna of the region. I have no doubt that this is the same rock which was obtained by Mr. Alonzo Cordery, with the shell impressions much better preserved, a little farther north from the Charlie Apopka River (secs. 2 and 3, T. 36 S., R. 25 E.), where, however, it is not phosphatized.

I do not hesitate to refer this rock to the older Pliocene, a horizon somewhat lower than that of most of the Caloosahatchie beds, but containing a nearly identical fauna as far as it goes.

The mammalian bones at this point appear to lie on this stratum, and where it is broken up, as is most commonly the case, are mingled with its fragments and blackened in the same way. The fish remains are found lower down as well, but I found no evidence of any mammalian bones in the marl below the phosphatic rock. On a low point of beach where the bank showed the best exposure of the rock, the shore was blackened with fragments of the rock, mixed with an astonishing number of pieces of bone, largely fragments of ribs. Nothing could more clearly indicate the great number of the animals which found a final resting place here.

The marl which underlies the thin bed of phosphatic rock comprises a putty-like mixture of lime and sand, with minute phosphatic pebbles, a few small shark's teeth, and obscure prints of *Ostrea*, *Spondylus*, and other bivalves.

This marl, when exposed to the air, away from the water, rapidly hardens, sometimes forming a very hard and brittle rock, which splinters and rings almost like chert under the hammer. Nothing was observed in it to cause a doubt of its belonging to the Pliocene series.

The pebble phosphates of Peace Creek are derived almost exclusively from the worn fragments of this dark-colored rock and its associated bones.

Oyster marl.—At a point on the west bank of Peace Creek, 3 miles below Mare Branch, and about the same distance north from the bridge at Arcadia is an old landing, generally known as Singleton's Landing, just below which is a low flattened point of the bank called by Maj. Singleton Shell Point. This point would be covered at the stage of high water, but at the time of my visit presented the following section:

	Feet.
1. Humus and white sand	3–5
2. Yellow sand (indurated)	3
3. Oyster marl (in part subaqueous)	2–4

This oyster marl is the remnant of an old oyster bed containing the same oysters, barnacles, and Pectens, which abound in the Caloosahatchie beds. It is unmistakably later Pliocene and occurs with the same stratigraphical relations over a wide area of the Peace Creek drainage. Near Zolfo Springs it overlies the phosphatic stratum, but everywhere contains material, such as bones, phosphatic pebbles, casts of older Pliocene shell fossils, etc., derived from the beds below it.

In this way we have finally fixed the position of the Peace Creek bone bed, between an older Pliocene rock below and a newer Pliocene bed above, thus settling its Pliocene character beyond question. The Pliocene age of other beds containing similar fossils, such as the Alachua clays and the river phosphate deposits of other parts of Florida, as well as Georgia, South Carolina, etc., may reasonably be inferred from the preceding conclusion, though it must not be forgotten that in the solution or denudation of beds of different horizons their harder contents, such as bones and teeth, would remain associated in a heterogeneous assemblage, offering in some cases problems which greater knowledge than we have at present is required to solve.

Pliocene lake beds: Lake De Soto.—The whole question of the existence of a Pliocene lake or series of lakes, is obviously at present in a hypothetic stage, yet such evidence as there is points strongly in this direction.

The trough-like form of the peninsula, the present existence of at least two principal aggregations of small lakes in the axis of this trough, and of the analogic Lake Okeechobee, illustrating the same geologic processes in action on the same line farther south; the kame like mounds and ridges of the yellow sand, erected on the relatively level floor of this trough and molded as if by aqueous action, the existence of what appear like marginal beds of clay, as suggested by Dr. Neal—all these facts seem very suggestive.

The northern focus of this supposed ancient lake area would seem to have been in the vicinity of Orange and Santa Fe lakes; the southern focus somewhere near lakes Harris and Apopka; the area thus roughly indicated being now drained by the Withlacoochee, Oklahwaka and Santa Fe rivers. A watershed divides this area from the Kissimmee basin to the south. In harmony with Dr. Neal's theory of the marginal clays, we find this watershed marked in many places by a stiff, red clay, which is cut through by the railroad at Bartow Junction and at many points along the line between Bartow Junction, Lake Haines, Haines City (one of the highest points), and Kissimmee.

The Kissimmee basin, centering about Lake Hamilton and now connected by canal with the Okeechobee system, illustrates a second stage or duplication of the features we have referred to in connection with the more northern area. It is now drained to the south and west, and would seem, from its lesser elevation, never to have attained the solidarity and importance as a fresh-water area which we are inclined to claim for the De Soto basin.

In Lake Okeechobee and its surroundings, with the clayey deposit which is so characteristic of the fields of "sawgrass" by which it is encircled, we seem to have an exponent of the processes which, at an earlier period, characterized geologic action in the more northern basins.

Sand mounds of the Lake Region.—It must especially be noted in considering these supposed lake basins that the mounds and ridges, chiefly of yellow sand, which diversify the present land surface, do not reflect, as a rule, any similar irregularities of the rocks beneath. One of the geologic features most strongly insisted on by the well drivers and prospectors for phosphate, of whom the writer interviewed so many, is that the rocks below these bodies of sand are practically horizontal. In order to reach the rock on one of these sand hills, one must bore through practically the entire height of the hill, while near one of the depressed lakelets at a short distance away the rock will be found correspondingly close to the surface. This, of course, does not refer to the more general changes of level offered by the gently rising main anticlines of the peninsula and their intermediate synclinal depressions.

The form of the mounds of yellow sand, if referable to current action, would seem to indicate that the main lowering of the water in these ancient basins, though brought about, in all probability, by slow and gentle changes of level in the land, finally took place with some suddenness, as by the removal of some barrier of sand or clay which up to that time had held the waters in confinement at a higher level. Here again our information is too scanty to justify dogmatism.

PHOSPHATIC DEPOSITS.

General features of the beds.—Although the presence or absence of phosphoric acid in combination with the lime rocks of Florida is a chemical and accidental rather than stratigraphical phenomenon it would seem, in view of recent economical developments, advisable to include some notice of the manner in which this combination presents itself. The remarks here offered must be regarded as merely provisional and preliminary, as a thorough investigation of these deposits by the U. S. Geological Survey has already been organized, but from which we can hardly expect results in time to be utilized for the purposes of this essay.

Notes on the phosphatic beds would seem perhaps to be as properly in place here as anywhere in this paper, since, though the process of phosphatization has doubtless been more or less active since the first elevation as an Eocene island of any part of Florida above the sea, yet those deposits which are of most commercial importance seem to have been formed in Pliocene time, or at all events, subsequent to the deposition of the older Miocene and Pliocene rocks, and are certainly anterior to the later marine Pliocene beds.

While the association of Pliocene bones and teeth with the phosphatic lime rock either bedded or in pebbles is very general, it is merely accidental. The bones occur in many localities where the rocks are not phosphatic, and phosphatic rocks are by no means invariably bone-bearing. The natural phosphate of lime included in the fossil bones has no necessary connection with the phosphoric acid combined with the associated lime rock. In some cases, as on Peace Creek, it is obvious that a bed of rock over which bones were more or less scattered has been subjected to influences which have added phosphoric acid and a little iron to both bones and rock simultaneously.

In all cases it seems reasonable to conclude that the extraordinary supply of phosphoric acid which appears in certain localities, and makes the beds commercially valuable, has been derived entirely from organic sources, probably in the shape of rookeries of birds or seals or other gregarious animals, whose dung afforded the acid in question. This material was very probably carried into the subjacent porous lime rock nearly as fast as it was deposited, since there is no reason for doubting that Florida has always been a rainy region during certain portions of the year.

The local character of such rookeries would determine the local occurrence of phosphate rock, whose irregularities in this respect are notorious. The different forms under which the phosphates now present themselves would result from the different constitution of the rocks upon which the rookeries were originally situated; the difference in elevation and dryness or accessibility to occasional incursions of brackish or salt water; the existence or nonexistence of some subterranean water table in the particular localities; and subsequent solutionary or erosive action upon the rocks thus modified. The material of such rocks rearranged into later strata would preserve a certain proportion of phosphoric acid, even though no subsequent additions of that substance were received by the new beds. A tendency under certain circumstances for the phosphatized lime to concentrate in nodules, or as shells over harder nuclei, is very marked. In this process it would seem as if the traces of iron in the rocks followed and joined with the phosphoric acid, since these nodular concretions are almost invariably darker colored than the rest of the rock, and, when subjected to river action, frequently become blackened by the resulting chemical action on the contained iron.

As argillaceous veins or sheets in the lime rock would check the percolation of the rain-water bearing phosphoric acid and give it more time to act on the lime about it, it occurs that the accumulation of phosphatic matter is apt to be larger in the vicinity of such clayey material.

To their generally rather impervious and argillaceous character is probably due the generally phosphatic character of the Hawthorne beds, which has been previously referred to.

The phosphate-bearing rocks of Florida may, without reference to their chemical constitution, be provisionally classified by their outward appearance under several heads. It may be premised that the phosphatization of a rock seems to tend to obliterate the fossils in it, especially when the latter are in the form of casts. Rock well known to contain usually abundant fossil impressions, in places where it is thoroughly phosphatized will hardly present any trace of organic remains, other than bones, if the latter are present at all. Phosphatization increases the hardness and insolubility of lime rock; the most phosphatic portions are the hardest, other things being equal. Therefore, in the natural attrition of river gravels, originally derived from phosphatic rock, the mechanical action of the current on the gravel segregrates the more valuable (harder) portions, wearing away the less phosphatic and softer parts, and thus naturally accomplishes a result for which no suitable machinery is likely to be devised. To this is due the uniformity in quality and high average of the "river" or "pebble phosphates," now extensively mined in south Florida river beds by a process of dredging and screening.

Floridite and phosphorite.—There are two main varieties of phosphatic rock in Florida. One, which so far seems to be exclusively confined to the area of the old Eocene island on the western anticline, has been produced by the modification of rocks belonging chiefly to the Vicksburg or nummulitic group. The phosphatic rock of Florida is chemically an impure massive apatite which has been called phosphorite and the Dunellon variety floridite.[1] The latter is generally soft, pale yellow or white in color, light in proportion to its bulk, amorphous in fracture, uniform in texture, and presents no traces of organic remains, even when the nummulitic rock of which it is a modification was originally little more than a mass of foraminifera. The segregation of this mineral in masses by itself seems quite as likely to be the result of chemical as of any other circumstances, and specimens in which the original organic character of the rock has not been entirely obliterated are sufficiently common. It would be unreasonable to suppose that large masses of guano could accumulate under the circumstances which are known to have existed in Florida. Neither the dry climate nor the impervious substratum, one or the other of which would have been necessary to the preservation of guano as such, were present in the locality where the floridite occurs. It seems likely, however, from the geologic and geographic distribution of this mineral, that its genesis was not entirely unconnected with the elevated site, free drainage, and notably absorbent rock which the old Eocene island afforded. This area must have been dry land most of the time since the older Miocene epoch, since no deposits of later date occur upon it except in connection with the supposed Pliocene lakes, or along the channels of the rivers.

Other phosphates.—The other forms of phosphatic rock, which may be grouped under the general term phosphorite, are usually modifications of the Miocene or older Pliocene limestones. They comprise:

1. *Lime rock phosphatized in place*, a variety that is not abundant and often seems rather barren in phosphate of lime. (Ex.: Hawthorne beds, bed of Peace Creek.)

2. *Fragments of phosphatic rock united in a softer, geologically later, limy matrix, itself not phosphatic.*—This variety is hardly more valuable

[1] E. T. Cox, in Am. Naturalist, Dec., 1890, vol. 24, pp. 1185–1186.

though more common than the preceding, and is apt to be uneven in character. (Ex.: Devil's Millhopper at Gainesville.)

3. *Segregated gravel or pebbles of phosphatic rock united as above by a softer matrix.*—This having been subjected to a natural process of selection by mechanical forces is of a better quality than the unworn conglomerate (No. 2) and therefore more valuable. The same hard pebbles have been in many cases repeatedly consolidated in a matrix of softer lime, released from it by the action of water and reconsolidated into a later bed, a process which it would seem will only cease with the complete destruction of the pebbles by wear. (Ex.: Yellow marl of Peace Creek and the Alefia River.)

4. *Nodular phosphate rock*, produced by the alteration and rearrangement of the lime rock particles into concretionary phosphatic nodules, united by a softer matrix of less phosphatic lime. This variety occurs in masses or bunches of great irregularity, though often individually rich. This is the "rock phosphate" of many of the prospectors. The lime is often deposited over cavities in the rock in a drusy layer. The nodules are so poorly united by the softer matrix that a large mass can often be rubbed into a sort of gravel between the hands. A machine has been invented for doing this and segregating the nodules. Owing to a want of uniformity in percentages of phosphoric acid and the very irregular distribution of the larger masses in the soil, the prospects for the utilization of this variety of phosphates seem somewhat less promising than for the floridite or the "pebble phosphate" deposits. This variety appears to be more widespread in Florida than any other and occurs in rock of every age from the Eocene up. The nodules or pebbles which it contains, though similar in shape, are not the same as the phosphate pebbles obtained from the river beds of the Alefia and Peace Creek and are very much less uniform in quality. (Ex.: Some Bartow rock phosphates.)

5. *Gravel or sand, itself not phosphatic, but coated with and united by a phosphatic matrix.*—This variety is not uncommon, and is said occasionally to have a local value as a fertilizer. The matrix appears to be derived from the disintegration of antecedently phosphatic rock. These oolitic, sometimes pisolitic, rocks are usually of very recent formation, often Pleistocene. (Ex.: Rock Island, Lake Monroe.)

6. *Pebble phosphate.*—This results from the action of rivers upon the other varieties of rock, reducing them, as well as any bones or teeth they may contain, to gravel. The hardness and value of contained phosphate, being relatively proportional in a general way, the older gravels will contain, on the whole, the best material, which is usually derived from varieties 1 and 2 and their associated vertebrate remains. The pebbles are screened and dried, after being dredged from the river bottom by a centrifugal pump. They are then exported for conversion into soluble phosphates for fertilizers. Examples of this variety may be found in the river deposits of almost any part of Florida, but especi-

ally, as far as we know at present, such rivers as the Alefia and Peace Creek. Rivers in which the banks are composed of material geologically later than the older Pliocene do not afford the pebble phosphates, and the richness of others in this variety of the mineral will doubtless be found to be measurably connected with the development of old Pliocene strata along their banks.

River phosphates.—In an article on the "Phosphate Beds of Florida" Prof. Albert R. Ledoux[1] speaks of the phosphatic nodules with which the Peace Creek remains have been stated to be associated, and states that "in appearance and composition this phosphate differs very little from the South Carolina material. They are identical" (op. cit., p. 176). He also notes that "the Florida deposits may be divided into two distinct classes, one, 'the river deposits,' almost resembling in quality and manner of occurrence the South Carolina beds, and the other [floridite] totally different." The deposits of the first class, beside those above mentioned on Peace Creek, include others in Wakulla County, in the north, several points on Tampa Bay, the basin of the Alefia River, and even in the vicinity of Fernandina. Many years ago the officers of the U. S. Coast Survey called attention to the occurrence of such phosphatic nodules and vertebrate remains in the outlets of several of the western creeks and rivers of the State, but they attracted little attention except as curiosities. Experts representing the Charleston phosphate interests are said to have reported that, owing to the difficulty of access and expenses attending the collection of the material from these deposits, the South Carolina article need not fear any very immediate competition from this direction.

At present, however, the Charleston interests are investing largely in this region, and numerous other companies have secured territory which they are either working or about to develop. At one place, Zolfo Springs, the principal corporation concerned in the business not only gets out the "pebble phosphate" and prepares it for exportation, but manufactures soluble phosphates for local use as fertilizers.

It forms no part of the writer's plan to detail the commercial development of these interests, which, moreover, is so rapid in its progress that any account in this place would become obsolete before it could be made public. At the time of writing, however, it may be desirable to state that the production of dry phosphatic gravel from Peace Creek, dredgings is estimated to be about two hundred and fifty tons a day A rather full account of the business in Florida, from its economic side, by Dr. J. Shrader, has recently been issued by the Courier-Informant newspaper office at Bartow, Florida.[2]

As we ascend the Peace Creek drainage system toward its head the pebble phosphate, in the beds of streams comprising the system, naturally becomes less abundant in proportion to the smaller size and

[1] Eng. and Mining Jour., Feb. 8, 1890, vol. 49, page 175.

[2] Florida. The Underground Wealth and Prehistoric Wonders of Polk and De Soto counties. Bartow. 1890. 34 pp. 8°.

inferior mechanical efficiency of these streams. Hence, in the peripheral portions of the basin attention has been chiefly directed to the varieties of phosphatic rock which, lower down, have been subjected to the segregative action of wear by the current. On the other hand, on the Alefia River it would seem from the few data accessible that the lower part of the basin cuts through old Miocene rocks, while the upper part is situated in a newer Miocene or older Pliocene area. Consequently the deposits of pebble phosphate in this basin are richer at some distance above the mouth of the river than they are in its lower reaches.

Floridite deposits.—These deposits are described by Prof. Ledoux as follows:

At present, for a description of the new discovery, we can confine ourselves to the Gulf counties south of Wakulla and north of Tampa. There seems to be also a gradual concentration towards a center well defined and whose area at this writing may be defined by a circle whose diameter is 30 miles and whose center is near Hernando, in Citrus County. This includes Dunnellon on the north and Floral City on the south and is roughly bisected by the Withlacoochee River from southeast to northwest. * * * In this area it seems that almost anywhere a pit or auger will reveal phosphate. In no pit or opening that I visited in that section did I find it entirely absent. * * * The phosphate is found at varying depths below the surface, sometimes within 2 feet and sometimes 10 or 12 feet down. In sinking a pit it is sometimes difficult to tell where the clay ends and the phosphate begins; they shade into each other, at times gradually, at other times the clay is entirely absent, the sand being the only thing between the surface and the valuable mineral. When wet they are dark or light yellow, but usually a dazzling white when dry. The thickness of the beds is very variable. There is nothing to indicate it on the surface; it may be a few inches, or 10, 12, or 16 feet of solid mineral. * * * Prof. W. P. Frost states in a description of the Dunnellon field that "I myself saw an auger bored 16 feet into this stuff without going through it; it remained of the same consistency throughout, perfectly smooth and free from grit. * * * The natives, who are ignorant men, not knowing the value of the material, testified that they had seen wells dug 60 feet through this material to reach water-bearing strata." He estimates for the Dunnellon field that 3,000 acres (out of 13,000) are underlaid by the mineral, which occurs in ridges and pockets, running by his analyses 50 to 65 per cent and averaging between 55 and 60 per cent.

Prof. Ledoux personally observed material of a somewhat different sort occurring in Citrus County, a mile southeast of Rutland post-office, where, by sinking pits, phosphate in numerous nodules or masses, not in place, was discovered in the sand, making up fully one-third of the material excavated below a depth of 3 or 4 feet from the surface. These masses were of a yellow color and quite hard. These would seem to resemble the material at the Devil's Millhopper, elsewhere referred to as composed of fragmentary masses of the phosphatic Miocene rocks of the Hawthorne beds.

It is impossible for the most experienced person, according to Prof. Ledoux, to tell by the eye alone the difference between the white carbonate of the lime or phosphate, or between the calcareous clay and cream-colored phosphate.

He calls attention to the necessity of discriminating, in analyses, between the sand and clay mechanically mixed with the phosphate of lime and the chemical silicates and phosphates of alumina, which are commercially worthless.

A surface indication, which is considered of value by some experts as pointing to the presence of phosphates below the soil, are masses of flint or siliceous rock protruding from the surface. "The area of the beds is sometimes defined from curious bowlders and masses of a hard phosphate rock, white or yellowish white, which has stood weathering remarkably, and which is quite rich in phosphate."[1]

It may be premature to venture on an opinion of the age at which the phosphoric acid so marvellously preserved in these beds was deposited on the soft calcareous rocks which have furnished the lime. It may not be amiss, however, to point out certain facts which apparently have a bearing on this question. The phosphatic character of the Hawthorne beds would indicate that the source from which this phosphoric acid came was later than the deposition as lime rock. The rocks of the Chattahoochee group afford very nearly the soft and absorbent surface which would best appropriate the valuable element from fresh or rain-washed excreta, such as we may imagine were the source of the Florida phosphates.

At the upper part of the Orthaulax bed, which overlies the Chattahoochee group at the southern edge of the phosphate area, the presence of a large land-shell fauna (initiated in the last days of the Eocene Ocala beds) shows that a considerable area had by that time become dry land with fresh-water ponds and knolls elevated above any tide. This land must largely have presented a surface of the Eocene nummulitic or Miocene Chattahoochee group rocks, and would afford an admirable locality for rookeries of birds or other guano-producing creatures. The character of the land fauna of the Orthaulax bed shows that it was derived from the south and not from the north, and the dry land of Florida may have borne to the Miocene continent much such a relation as the Bahamas islands and lagoons do to the present peninsula of Florida.

It seems, then, as if the facts pointed toward a more or less continuous deposition of phosphoric material between the older Miocene and newer Pliocene epochs, which was absorbed by the subjacent rocks and which, preserved there in large masses, has furnished to later, even to actually forming, rocks in Florida the more or less evident traces of phosphoric acid which many of them present and which can hardly have been wholly derived from more recent sources of supply.

MARINE PLIOCENE BEDS.

The discovery of genuine Pliocene fossiliferous beds in south Florida is of comparatively recent date. It may be said, indeed, to date from the time when the Okeechobee Canal Company endeavored to extend the area of the rich hammock land about the lake by reducing its area.

[1] Ledoux, op. cit., pp. 176, 177.

The latter was to be brought about by cutting drainage canals, and the explorations of the upper Caloosahatchie necessary to this end brought some intelligent people to a point where they could not avoid seeing the remarkable fossil shells of which the banks are so full. Some reference to this had appeared in a popular article[1] in one of the magazines, and among the earliest modern explorations recorded was that of Engineer J. L. Meigs in 1879. But the scientific exposition of these beds begins with the report by Prof. Heilprin of the results of the party led by Mr. Joseph Willcox and fitted out with the cooperation of the Academy of Natural Sciences and the trustees of the Wagner Free Institute of Science, of Philadelphia, in 1886. This report was printed in the first volume of the Transactions of the Institute, published in 1887. In the winter of 1886 and 1887 Mr. Willcox revisited the locality in company with the writer, and a third time subsequently. A description of the fauna of these beds has been begun in the third volume of the Wagner Institute's Transactions.[2]

Older marine Pliocene beds.—More recent observations by the writer and others have resulted in showing that between the epoch when these beds were deposited and a subsequent similar, vastly more extended, but probably not vertically great depression, there was a time when a moderate elevation brought large areas above the sea, when the thin sheet of newer or Chesapeake group Miocene, which had been laid down about the island of Eocene rocks formed by the western anticline of the peninsula, was more or less eroded, when the northern part of the median syncline was perhaps occupied by the Pliocene lakes, or Lake De Soto, and when the innumerable Pliocene vertebrates wandered over the hummocks or left their bones in the tenacious mud of bogs or on the marshy borders of lagoons.

The marine beds of the Pilocene, which were laid down before this time of elevation, in the main, as far as examined, do not show any marked difference in the invertebrate fauna when compared with the newer or Caloosahatchie beds. This similarity of fauna is in itself strong evidence in favor of the moderate character, both in duration and vertical range, of the changes of level referred to. A very large area in central and southern Florida was probably covered by this older marine Pliocene. There appear to be traces of it at Clay Landing and other points on the lower Suwanee River, and it is not unlikely that the whole great Suwanee swamp region may be underlaid by it, as well as the De Soto lake area. There are traces of it in the rocks of the upper Alefia, but farther to the west and north, on the Hillsboro, so far as known, if any of this rock was deposited it has since been removed. I incline to the belief, however, that the Hillsboro region, from its relation to the great western anticline, was not depressed below

[1] Which the writer of this essay read at the time and remembers, but has since been unable to trace.

[2] Contributions to the Tertiary fauna of Florida by W. H. Dall. Part I, Pulmonate, Opisthobranchiate and Orthodont Gastropods. Aug., 1890. 4°, 200 pp., 12 pl.

the sea during this part of the Pliocene. The "pebble phosphates" of the upper Alefia, like those of the Peace Creek basin, are, as far as yet observed, entirely of this rock, and on the Alefia researches hitherto made have failed to find the subsequent marine Caloosahatchie Pliocene represented. The writer has traced the older rocks in question up the Peace Creek basin to Bartow, where in one place it lies in a stratum only 3 or 4 feet thick over a knoll of Eocene nummulitic rock, but in general is of much greater, yet undetermined, depth; the phosphate rocks of the vicinity of Lakeland appear to be of this age. That it underlies the lake beds of the De Soto basin is probable from indications afforded by borings for phosphate near Tavares, in the very focus of that basin. The last traces on the northeast disappear at Orlando, just beyond which the Miocene makes its appearance on the rise of the eastern anticline.

To the south, along Peace Creek, this series of beds is covered by the newer marine Pliocene, at least as far as Zolfo Springs, but at Fort Meade the later beds would seem from report to be absent. The northern margin of the Caloosahatchie beds would therefore seem to lie somewhere between these two points. On the Charlie Apopka River (Secs. 2 and 3, T. 36 S., R. 25 E.) the older rock is abundantly represented. It has not been phosphatized, and, therefore, presents its fossil impressions in much sharper and better state than along Peace Creek; whether it is overlain by newer Pliocene on the Charlie Apopka is not yet known. On the Caloosahatchie and all the great southern region, owing to the very small elevation of the land, it is not known to crop out anywhere, the base of the Caloosahatchie beds themselves being below the level of the sea as far as yet known. It has, however, been dredged up from the channel of Tampa Bay at a depth of some 40 feet, while harbor improvements were in progress.

Caloosahatchie beds (Floridian of Heilprin).—As the Caloosahatchie beds are the original and typical exposure of the newer Floridian Pliocene, our description of that formation will best be opened by an account of the beds observed by the writer on that river in February, 1887, when accompanying Mr. Joseph Willcox.

Prof. Heilprin[1] has informed us that the level of the bottom of lake Okeechobee will average about 10 feet above the sea level, or is composed of a plain having 7–15 feet of elevation, with a depth in the greatest observed depression of 22 feet, but an average of less than half as much water over it in a dry season. Lake Hickpochee, between Okeechobee and the head of the Caloosahatchie River, now connected with both by canal, is supposed by Prof. Heilprin to have practically the same level as Okeechobee. The canal, where it leaves Lake Hickpochee to the west, on its way to connect with the Caloosahatchie, is stated by Prof. Heilprin to be 20–22 feet above the sea level. He states that this is "about 11 feet above the base of operations near

[1] Trans. Wagner Inst., Vol. I, p. 41.

Fort Thompson." If this is intended for the water level, as the context indicates, it is probable that Prof. Heilprin was misinformed, as the depth of the river, considering the character of its bed and the volume of water, by no means corresponds to a fall of nearly a foot to the mile. It is not improbable that there has been some confusion between the height of the land, which varies considerably, and the level of the stream.

The Caloosahatchie River, in the proper sense of the word, begins at the northeastern extreme of the long estuary which bears the name, some distance above the town of Myers.

The banks at first are extremely low and screened by thickets of mangroves, which only disappear when the water becomes perfectly fresh. The land appears nearly level. As the river is ascended a close scrutiny shows that it cuts through a succession of gentle waves, gradually increasing in height, inland, whose crests would show a general parallelism with the direction of the peninsula of Florida, or transverse to the average course of the river. Near the headwaters of the river these waves of elevation rise above the level of the river at low water, to a height of perhaps 12 feet at most, and their individual length from one trough to another may average about one-quarter of a mile. Though insignificant as flexures, they are interesting as showing that a lateral as well as a vertical thrust has attended the movements of the rocks in this part of the State, a fact which has been questioned.

The greatest elevation studied by us extends for several miles between the sites of the old forts Thompson and Denaud. At the former point the canal from Lake Okeechobee enters the river, its bed being a compact silicified rock, which had to be blasted out. The succession of the strata is perfectly uniform, though the amount of their fossilferous contents varies.[1]

Just below the rapids at Fort Thompson the following section was obtained:

	Inches.
1. Vegetable mold and sand	18
2. Indurated sand with fresh-water shells, post-Pliocene	8
3. Mixed marine and fresh-water shells, post-Pliocene	6
4. Pliocene Planorbis rock, to the water's edge	15

The Planorbis rock which forms the lowest member of this section is the hard rock which was blasted in making the canal; it reaches a thickness of 3 feet or more and overlies the so-called "*Venus cancellata* bed," or upper stratum of the Caloosahatchie marls. In previous reports no strict discrimination has been made beween the Quaternary fresh-water indurated sand rock (No. 1 of the preceding section), which is the youngest of all and found widely spread over the peninsula, and the Pliocene Planorbis rock, which contains only extinct species or recent species also common to the Pliocene marl. I suppose that the "fresh-water limestone" which Heilprin refers to (op. cit., p. 33) as forming the bed rock of the canal is practically the Planorbis rock (more or less inclusive of the later rocks lying upon it as above), and this, according to Captain Menge, has been traced eastward a considerable distance; disappearing about 3 miles west of Lake Hickpochee at a depth of 5 feet 2 inches below the level of the surface of the water in the canal. It probably extends much farther eastward, and has

[1] Dall, in Am. Jour. Sci., 3d ser., vol. 34, p. 168.

been found by one of Mr. Eldridge's associates near the eastern coast of Florida, in about the latitude of the southern end of Lake Okeechobee.

The same compact limestone, with the same species of *Planorbis*, etc., occurs near Hillsboro Bay, Tampa, and has been dredged in large masses from the channel by which the harbor of Tampa is entered. This shows a very wide extension of this deposit, the two localities being some 90 miles apart in a direct line.

Two miles below the point where the last section was taken, the following section (Fig. 22) was measured on the south bank of the Caloosahatchie:

1 18″. Sand and humus.
2 18″. Indurated yellow sand; no fossils.
3 2′. Sandy marl; *Venus cancellata* bed, with *Bulla*, etc.
4 3′. Compact marl.
5 18″. Sand and marl.

FIG. 22.—Section on the south bank of the Caloosahatchie River, Florida.

Nos. 3, 4, and 5 are Pliocene, the upper layers probably Quaternary.

A third measurement of the south bank, about 4 miles above Daniel's place, afforded the following section:

	Inches.
1. Fine white siliceous sand	18
2. Vegetable soil, with some sand; shows black	12
3. Sandy marl, with *Venus cancellata;* shows gray.	
4. Hard, eroded rock, with the same fossils; shows grayish.	
5. Soft yellowish marl, with the same fossils as No. 3, but more lime and less sand and many worn siliceous nodules. Total (3, 4, and 5)	66

The three lower layers grade into each other petrographically and have the same fossils, without exception. They belong to the Pliocene series.

Practically the same set of beds, measured about two miles and a half below the western end of the canal, gave 18 inches humus and sand over the same depth of indurated yellow sand without fossils, below which are 2 feet of sandy marl with *Bulla striata*, *Venus cancellata*, and a multitude of *Planorbis* and *Physa;* then 3 feet of compacter marl, with a great many marine fossils and comparatively few fresh-water shells, the deposit containing irregular nodules, lumps, and strings of silicified material, often extremely hard, and in which the fossils are often represented by mere molds. Below this, which is the chief fossiliferous stratum, lies a foot and a half of sand and marl, with few fossils and many fragments and worn siliceous fragments against which the water dashes. This stratum in other places is consolidated to a tolerably compact rock; and the fossil bed above it to a flinty chert. The chert shows manifest indications of having been worn by the action of the waves, and one of my specimens shows a boring bivalve still intact in its burrow in one of the protuberances of this layer. In other places fossil oyster-banks, corresponding to the oyster marl of Peace Creek, could be clearly seen, but nowhere any coral reef, though small isolated heads of coral were not uncommon. The intermixture of fresh-water and marine shells is characteristic of the whole deposit, though the upper stratum contains proportionally many more fresh-water individuals.

The upper siliceous Planorbis rock was by the writer,[1] as well as by Prof. Heilprin, supposed to be Quaternary until the fossils were studied.

[1] Am. Jour. Sci., 3d ser., vol. 34, p. 169.

But careful study made on the spot showed that the supposed post-Pliocene age of the so-called "Venus cancellata bed" was an error, due to the fact that layers of *Venus* (*Chione*) *cancellata* Linné, of Quaternary age, are very common in Florida, and sometimes in the Caloosahatchie region overlie the Planorbis rock.

In this connection it may be stated that *Chione cancellata* is known from the Chipola Old Miocene marls, in no respect differing from recent specimens, and that it has continued as a conspicuous member of the Florida fauna (except during the epoch when the Ecphora beds were being deposited) up to the present day. It is a warm-water shell and extended in abundance farther north during Chipola times and the newer Pliocene than during the period when the beds of the Chesapeake group were being deposited or at present. The last-mentioned periods were and are relatively cooler and the two former relatively warmer, judging by the fauna. The species has never been entirely absent and at the present day reaches as far north as Hatteras, in the warm-water area. It is also a shallow-water shell, living chiefly between tides when the climate is mild enough, and its abundant presence with *Bulla* is indicative of a formation laid down in quite shallow water. The *Bulla* has in recent times also receded southward, probably for similar reasons.

The marls of the Caloosahatchie contain a large number of species, of which a fair proportion, perhaps 15 per cent, are supposed to be extinct; many of the others are known only from deep water. How many of the so-called extinct ones, like *Amusium mortoni*, will turn out to be still living when the deeper waters of the Floridian coast are thoroughly dredged remains to be seen. A number of the species appear to be more nearly related to shells known from the Asiatic or Californian coasts of the Pacific than to the shells of adjacent waters. But these apparent relations depend a good deal on our ignorance of what the deep waters of the Gulf really contain. In their curious partial silicification these beds afford an interesting parallel to those of Ballast Point, and show that similar action has been going on since Miocene times on this coast.

The age of the Caloosahatchie beds is more clearly Pliocene than that of any others which have been so called on our eastern coast. The time has not yet arrived, nor is our knowledge sufficient to enable us to decide finally as to the chronologic relation of all of these terrestrial and marine Pliocene beds to each other. But without reference to their minor chronology the geological history of the Caloosahatchie marls is clearly stated in their structure.

The assemblage of species on the whole, in the principal stratum, is such as one might expect to find in water from 20 to 50 feet in depth, judging by what we know of living mollusks. Mixed with these are a certain number of shallow-water forms which may be supposed to have flourished as the water became shoal by elevation of the sea bottom. There were lagoons of fresh water and probably short streams emptying into the sea, and in time of flood sweeping their fresh-water population out on to the shoals, where it perished. Part of the bottom became elevated nearly to the surface, oyster banks were formed on it, and the compacter parts became water-worn. The absence of shells, like *Litorina* and *Nerita*, seems to indicate that the dry beaches were muddy or sandy rather than rocky. In the course of time elevation so shoaled the water that only species like *Venus cancellata* and others able to live between tide marks could remain. This portion of the formation constitutes the so-called *Venus cancellata* bed, though neither of its component species is peculiar to it. Finally, the area became cut off almost entirely from the sea and occupied more or less by fresh-water ponds in which the pond snails multiplied in myriads. Drifting sea sand has buried these and in its turn has been covered with a thin coat of humus in which the pine, palmetto, and a host of scrubby plants make a fairly successful fight against the invasion of civilization.

The history of Ballast Point seems to have been much the same in Miocene times, except that there the land seems to have risen sufficiently to enable true air-breathing land snails to become abundant. On the Caloosahatchie they are extremely rare, only one or two specimens having turned up among the thousands of fresh-water snails. On the other hand, if Ballast Point rose higher, it was afterward depressed lower, so that several feet of marine orbitolite rock could be formed over it. On the Caloosahatchie the thickness of the marine strata over layers of the Planorbis rock did not exceed 6 inches.

As it may be supposed that the admixture of fresh-water forms with the marine forms has been due to mechanical mixture after fossilization, which in certain places, where the marl is penetrated by roots from above, might have occurred, I will add in concluding that the same mixture occurs in the interior of the most flinty chert bowlders. It is curiously paralleled by the mixture found in material collected by the U. S. Fish Commission, in some of the inner lagoons of the Bahamas, where a similar series of geological changes may be supposed to be at this moment in progress. Among the fresh-water species is a large *Cyrenella*, a genus recently found by Hemphill living in a South Florida marsh. It has not been before known from the United States, was originally described from Senegal, and subsequently from Porto Rico.

No coral rock or coral reef formation was anywhere observed, though isolated small heads of coral are moderately common in some parts of the Caloosahatchie marl.

The uppermost strata of the Pliocene beds begin to appear above the level of the river at low water (during the dry season) about 24 miles due east from the shore of Charlotte harbor, and they dip to the eastward out of reach about 30 miles farther east. Their total measured breadth here is thus at least 30 miles and includes the whole of the elevated land between Lake Hickpochee and the point on the river above mentioned. In this distance there are not less than twenty visible but very gentle folds of the strata in the direction of the trend of the peninsula.

That these beds extend much farther north and south there can be very little doubt, though our information so far is fragmentary. The most northern point at which they have been actually observed is in the banks of a small stream crossed by the railroad a short distance north of the depot at Zolfo Springs.

On the Caloosahatchie the strata may be divided into oyster-reef marl beds, conchiferous or Turritella marl, and layers of sand; which intergrade without distinction and have no invariable succession, but always grade into the shallow-water fauna at the top,[1] which is overlain by the Planorbis rock, and this in turn by post-Pliocene deposits which are seldom of great thickness.

Near the north end of Charlotte harbor a small creek comes in from the east called Alligator Creek. Here Mr. Willcox found an extension of the Caloosahatchie beds. The banks are about 12 feet high, the upper half being pure sand; the lower half contains fossils of Pliocene age, mollusks, barnacles, and flat Echinidæ. They differ from the Caloosahatchie deposits in being in pure sand instead of marl as a matrix. The upper half of the fossiliferous stratum shows the shallow-water fauna, with its usual partial admixture of strictly Pliocene extinct species. Some parts of the bed are united by siliceous cementation into a hard rock.

A little farther north Peace Creek enters Charlotte harbor above Punta Gorda. The banks of this creek are low for some distance, but Prairie Creek, which enters the estuary from the east, has a south fork, known as Shell Creek, a short but navigable stream which heads among Pliocene beds. The banks are higher here than on the Caloosahatchie, being 25 feet at the highest point, but the difference is chiefly of unfossiliferous marine sand 12 feet deep. Then comes about 2 feet of shallow water fauna with some Pliocene species, below which is a hard limestone stratum 2 or 3 feet thick, beneath which is a bed of conchiferous marl, like that of the Caloosahatchie. There are slight differences in the fauna, such as might be expected at points 20 miles apart.

The Myakka or Miacca River comes into the Charlotte harbor from the northwest parallel with the Gulf coast, and its estuary is nearly at right angles to that of Peace Creek.

Here Mr. Willcox found a bed of lime rock at the sea level with uncharacteristic species poorly preserved. Above the lime rock are beds of shell marl considerably mixed with sand. In this deposit was collected about forty species of shells, of which about 10 per cent were

[1] There are Pliocene beds of *Venus cancellata* and *Bulla striata*, and post-Pliocene beds chiefly composed of the same two species. For this reason the name "Venus cancellata bed" for the shallow water part of the marine Pliocene is unfortunate, though very natural to anyone who has seen it. It will always require careful examination to determine to which series a bed of *Venus cancellata* should be referred, and some confusion has already occurred from taking the Pliocene age of such a bed for granted. To distinguish the Pliocene and Pleistocene beds of this kind the latter might be called, from their most abundant fossil, the *Bulla striata* marls.

extinct Pliocene species. This bed seems to have fewer extinct species than the Caloosahatchie marls and may be regarded as a little younger, perhaps corresponding to the Planorbis rock, which seems to be absent on the Myakka.

Along Rocky Creek, which falls into Lemon Bay near Stump Pass, in about latitude 26° 55′ west from the Myakka, a bed of *Venus cancellata* rises to about a foot above the water, or in many places forms the bed of the stream. It is probably the upper shallow-water layer of the Pliocene, as *Cerithidea scalata* Heilprin, a Pliocene species, has been found near by on the beach of the bay.

On Peace Creek there are no banks high enough to afford a section and no trace of Pliocene yet observed up to 3 miles above Fort Ogden.

Farther north, on Peace Creek, the Caloosahatchie beds appear at Shell Point, 3 miles above Arcadia, as previously described;[1] and I was informed that the same bed occurs on Joshua Creek, near Nocatee, and at a point on Peace Creek 6 miles below the works at Arcadia, between that place and Fort Ogden. The same oyster bed is conspicuous in the banks of a small stream just north of the railroad station of Zolfo Springs. This stream, a feeder of Peace Creek from the east, has cut quite a deep gully, and the oyster bed occurs in the vertical sides about 2 feet, or possibly less, above the water when the latter is low, as in January, when I observed it. Above the oyster bed the elevation cut by the stream is composed of some 20 or 25 feet of yellow sand, with a foot or two of the white sand covering it. Some portions of the yellow sand here, as at Shell Point, are quite indurated and stand vertically like rock. The section can be well observed from the railway culvert.

Considerably east of Peace Creek beds of marl containing "large clams" have been reported to Mr. Willcox as occurring on the banks of Arbuckle Creek. Something of the same sort on the Kissimmee River, near Fort Kissimmee, was mentioned to me by prospectors at Bartow who had visited that locality. Both these marl beds are likely to prove to be Pliocene.

The slight tilting of the plane of the peninsula caused by the rise of the eastern border and a presumed equivalent depression of the Gulf coast opposite is indicated by the manner in which the Pliocene beds disappear west of the Tampa Old Miocene. The washing and dredging up of newer Miocene and Pliocene fossils along this shore may indicate the continued existence of beds of both ages under the adjacent waters of the Gulf rather than wash from the existing shores.

Cerithidea scalata has been found on the shore of the Gulf near Casey's Pass, 17 miles northwest of Stump Pass, and near the entrance to Little Sarasota Bay, 6 or 7 miles farther in the same direction, which would indicate the presence somewhere in that vicinity of the Pliocene marl.

Finally, the presence of large fragments of older marine Pliocene and

[1] See under the head of "Oyster marl," p. 132.

of the Planorbis rock in the channel at Port Tampa, Hillsboro Bay, before referred to, carries the Pliocene nearly 50 miles farther to the northwest.

These data would indicate the original presence of the Caloosahatchie beds over a distance on the western part of the peninsula, roughly speaking, of 100 miles northwest by 50 miles southeast. On the eastern coast of Florida no marine Pliocene has yet been identified, and the first point where the characteristic species have since been recognized is in South Carolina, where a number of them are found and have not been discriminated from the Miocene of the Chesapeake group. Still farther north one of the species appears, with a few other extinct forms, in the marl which has been found underlying a part of the Great Dismal Swamp, in southeastern Virginia.

Recent observations by Heilprin[1] seem to indicate the presence of late Pliocene rock over a considerable area in Yucatan. A few, four or five, Caloosahatchie species are, according to Prof. Heilprin, recognizable in the limestone of the Yucatan plains, but, judging from the list given, the fauna must have been at the very top of the Pliocene series, and none of the most characteristic Pliocene species occur in it.

PLEISTOCENE AND RECENT DEPOSITS.

While it does not strictly enter into the scope of this essay to discuss the Pleistocene series, for the sake of completeness in connection with the description of the Florida region a few notes on the later strata of the peninsula are appended.

The beginning of Pleistocene time is generally taken as marked by the Glacial Epoch. Recently Spencer,[2] Upham,[3] and others have postulated an elevation of the land north of the Gulf of Mexico "for a short time" to a height of "not less than 3,000 feet," in the endeavor to account for the Glacial Epoch.

Without expressing any opinion as to the possibility of such an uplift farther north, the writer desires to put on record here the reasons why such an uplift in Florida seems to him incompatible with the observed facts:

1. It is inconceivable that such an uplift and downthrow should have taken place at the end of the Pliocene without some dislocation and disturbance of the rocks, which would be conspicuously shown in the geology. But the most conspicuous feature of Florida geology is admitted to be the absence of any such dislocations.

2. It is inconceivable that rocks of the incoherent character which make up the peninsula of Florida, subjected to the torrential rains of their semitropical rainy season, should have been elevated to 3,000 feet above the sea without the carving out of canyons and the sculpturing of the topography in an unmistakable manner. The river beds would

[1] Proc. Acad. Nat. Sci. Phila. for 1891, pp. 141–143.
[2] Bull. Geol. Soc. Am., vol. 1.
[3] Am. Geologist, vol. 6, No. 6, Dec., 1890, p. 329.

have been worn to great depth, and, if subsequently filled, the filling would be heterogeneous.

But the absence of any such cutting is self-evident, the rivers often flow over undisturbed Pliocene beds of shell marl and are mostly too shallow for anything but small boats.

The larger part of the St. Johns River, which might appear to form an exception, is simply an elevated perezonal lagoon. This has become the channel of a drainage which is in no way related to the deposit of talus over which it now flows. In the so-called Indian River we see such a lagoon which has not yet been so elevated.

3. The scouring of the surface due to the steeper gradient would have left undisturbed, under the summer rains, no totally incoherent beds. They would have been carried off and redeposited at the perezone everywhere.

But it is well known that such incoherent beds exist undisturbed in every part of Florida, and represent, as a whole, rocks of every series from the Eocene up.

4. The carving referred to would have made canyons in the gulf plateau (now submarine, then dry) west of Florida indicative of the course of each of the Florida rivers which would be more or less evident in the present submarine contours.

Nothing of the kind is visible in the contours, though soundings in the gulf by the Coast Survey and Fish Commission vessels have been remarkably numerous and made with the greatest care and the best modern methods and instruments.

5. The elevation of the coast suddenly and for "a short time" to such a height would obviously have exterminated the whole marine shallow water and shore fauna, except such as lived elsewhere at a great distance, and, after the succeeding subsidence, might have immigrated to Florida. But there are a number of local species originating in the Miocene, peculiar to Florida, which live in shallow water and have preserved their continuity intact to the present moment, and there is no such preponderance of Antillean types in the present fauna as would have resulted from an immigration, possible (in the assumed circumstances) only from this direction.

Lastly, it may be pointed out that the hypothesis, so far as it relates to the Florida region, mainly rests on two unproved assumptions, either of which being shaken, will let the whole structure fall. The first of these is that submarine valleys must have been cut when the bottom was dry land. The second is, that the submarine valleys which are actually known to exist, and which have been miscalled "canyons," were necessarily cut at the end of Tertiary time.

That the first assumption is untrue every hydrographer knows, and everyone who has studied the Gulf Stream knows what a scour it exerts on its present bed at a depth of 3,000 feet.

The second assumption may or may not be true, but there is no evident reason why the valleys in question may not date from the Cretaceous quite as reasonably as from a later date. The slope, with reentrants, which the contours exhibit off the mouth of the Mississippi, the whole of which must be taken into account in any fairly constructed hypothesis, is visible in the contours at a depth of at least 9,000 feet, a height to which no one has yet ventured to elevate the Gulf of Mexico.

The collateral arguments by which this hypothesis has been supported (I speak with regard to the Florida and Gulf region) are in several instances based on error. For instance, Mr. Upham states[1] that "several low passes from ocean to ocean are found in the Lake Nicaragua region, on the isthmus (of Darien) and in the Atrato River district to the south, at heights from 133 to 300 feet above the sea level." These figures will bear a good deal of revision with the data at present available. Again, Dr. Maack is quoted in behalf of the Pleistocene age of fossils collected by him on the Atrato divide, "the lowest elevation of which was found to be 763 feet." (Op. cit., p. 396). The Doctor, in his report,[2] calls these beds "later" or "latest Tertiary," and speaks of the species as being "all living up to the present time." Unfortunately for the value of this report, Dr. Maack was a vertebrate paleontologist, unacquainted with invertebrate fossils or recent shells in the American fauna, and incompetent (even if he had been in a normal mental condition) to give any valid judgment on such a question. The unfortunate state in which his explorations left him is well known, and would render it necesssary to reexamine any conclusions which might be based on his opinions. On the other hand, we have the judgment of a good geologist and active paleontologist, the late W. M. Gabb, who examined Dr. Maack's fossils and regarded them as Miocene[3] and as including many species in common with the Miocene of Santo Domingo, which belongs to the lower Miocene, analagous to the Tampa Orthalaux bed. The Pleistocene fossils collected by Dr. Maack were obtained from an elevation of only 150 feet, 10 miles inland from Panama. I am able to state from an examination of the specimens at the Museum of Comparative Zoology, that all the fossils from the higher elevations on the Panama section are Miocene or Eocene. The explorations for the canal have shown that the ridge of greatest elevation is composed of azoic rocks, of which the age is uncertain, but probably not later than the end of the Eocene.

In this connection may be cited the observations of Everman and Jenkins,[4] who discuss at length the opinoins which have been held in regard to the mutual relations of the fish faunas of the east and west

[1] Am. Geol., vol. 6, No. 6, p. 339.

[2] Reports of Expl. for a ship canal, Isthmus of Darien, Washington, Navy Dept., pp. 155-175, 1874, fide Upham, Am. Geol., vol. 6, No. 6, p. 396.

[3] Proc. Am. Philos. Soc., 1872, vol. 12, p. 572.

[4] Proc. U. S. Nat. Mus., 1891, vol. 14, No. 846, p. 126.

coasts of Central America and Mexico, especially bearing on the hypotheses of a recent water way connecting them. They show how the original view that the two faunas contain a large percentage of identical species has faded away with a more thorough knowledge of the facts, so that at present only 5½ per cent of the species are regarded as common to the two coasts, excluding species of general distribution in the tropics.

These authors then announce as their conclusion in regard to the question at issue:

> Our present knowledge, therefore, of the fishes of tropical America justifies us in regarding the fish faunæ of the two coasts as being essentially distinct, and that there has not been, at any comparatively recent [geological] time, any water way through the Isthmus of Panama.

The contact of the marine Pleistocene with the Planorbis Rock has already been described in connection with the section (p. 143) taken nearest to the end of the canal on the Caloosahatchie.

There are multitudes of localities where such beds are visible, mostly at elevations not far from the present water level, and indicating a small elevation, with possibly a smaller subsequent depression since they were deposited on the western side of the peninsula, while on the east there has been a slow, somewhat intermittent elevation, which has amounted in the total to not less than 20 feet above the present sea level in the cases where it is lowest, and possibly nearly as much more in some localities. Without definite proof of the fact, it looks as if there had been in Pleistocene time a tilting of the peninsula on its north and south axis, attended with some gentle folding of the strata, as seen on the Caloosahatchie; the eastern coast with its reef, as described by Shaler, having been tilted up, the western coast having sunk a little less; the difference having been taken up in the crumpling of the strata.

Among the localities where the marine Pleistocene is best developed on the western coast may be mentioned: Rocky creek near Stump Pass, Lemon Bay, (Willcox) overlaying the Pliocene; Phillip's Creek at the head of Little Sarasota Bay; North Creek emptying from the east into the same bay; these beds contain a large number of species, all known to be living on the coast. It is also found on top of the Miocene at Rocky Point, Old Tampa Bay, and in considerable masses near the mouth of the Manatee River.

RECENT ROCK FORMATION.

The process of rock formation is going on in a more obvious manner than would be expected along the Gulf shores of western Florida. There is a general opinion frequently expressed by Floridians, in conversation, to the effect that between Tampa and the Keys coquina rock is to be found at only one place, the mouth of the Little Sarasota Pass. But this idea is certainly erroneous, as at every projecting point of the Keys along the Gulf shore which we visited we found traces of this rock, though often not visible above the water, and frequently composed more of sand grains than of shell, so that it looks much like wet loaf sugar. It is doubtless being formed at many points along the Gulf shore, though in small quantities in each place, and not at all in the lagoons and harbors.

Another species of rock which strikes an observer as curious is in process of formation by immense compact colonies of *Vermetus* (*Petaloconchus*) *nigricans*, which raise the orifices of their minute blackish tubes to several inches above low-water mark, and in some of the larger bays have formed extensive reefs. The animal has been supposed to be a worm, belonging among the *Serpulæ*, but the writer was able to determine its proper place by an examination of the soft parts. This rock rarely occurs in a strictly fossil state, though the species is found in the Caloosahatchie Pliocene. It is locally known as "worm-rock," and many of the "rocks" described by the natives of this region as cropping out along the seashore turn out on examination to be of this kind.

There are three other sorts of rock of which the formation appears to be still going on. One is more or less indurated sand, which was observed at Myers; also near St. James city on Pine Key; on South Creek, where it was found in the banks under the usual layer of sand, and close to the landing wharf at Sarasota, on Big Sarasota Bay. It is very widely spread over the state near the sea, its absence being rather the exception. It sometimes contains the fragments of other older rocks, as in a matrix, an example of which was noted by Prof. Heilprin on St. John Island, at the mouth of the Cheeshowiska River. This rock is usually rather soft and contains recent land and a few recent marine shells. In other places, as at St. James City, it becomes extremely hard and compact, ringing under the hammer and almost destitute of fossils. A thin layer of it, from a mere film to 3 inches thick, marks the upper surface of the much older outcrop at White Beach, Little Sarasota Bay. This may prove to be identical with what I have called the Yellow sand.

A second variety of rock is formed by springs containing iron in solution, which are numerous along the main shore, as in both Sarasota bays. This water consolidates the gravel, sand, shells, etc., over which it passes, into something resembling coquina, but in which the fragments of shell, etc., are united together by a cement of limonite. A spring near the estate of Judge Webb, at Osprey, has thus affected a considerable part of what appears to be an Indian shell-heap; and among the shells, etc., in the rock may be detected fragments of pottery. Specimens showing this were brought home, and it is probable that the human remains discovered by Judge Webb near Osprey and by Prof. Heilprin in Sarasota Bay,[1] which are replaced by a pseudomorph of limonite, though older, are of a similar origin.

[1] Leidy, in Trans. Wagner Inst., 1889, vol. 2, pp. 10–11.

In a softer stratum overlying that rock and apparently nearly of the same period of deposition were found *Venus mortoni*, *Pecten dislocatus*, *Strombus pugilis*, *Fasciolaria tulipa*, *Fulgur perversus*, and *Melongena corona*, all recent species in the same region. Some specimens forwarded by Mr. Willcox, who obtained them with some additional human remains from the same locality, appeared to be indurated sand rock of the variety first described. It contained a mixture of recent marine and land shells all common in the vicinity to-day.[1]

Other human remains in which the bones have been solidly silicified have been forwarded from the vicinity of Little Sarasota Bay to the Smithsonian Institution by Judge John G. Webb, of Osprey. They are doubtless Pleistocene and are contained in an indurated sand rock, tinged with iron oxide, and existing several feet below the surface at a considerable distance from the bay. These remains, though Pleistocene, are doubtless very ancient. It is probable no part of the world has afforded so many specimens of human remains in a truly fossil state as the peninsula of Florida.

The third variety of rock referred to occurs along the upper St. John River and about Lake Monroe. This is a sand rock in which each grain is coated with a pellicle of lime, giving the mass an oolitic appearance. In this rock, on Rock Island in Lake Monroe, Pourtalès and Wyman found the fossil remains of man which created so much excitement some years ago. The rock also contains recent land shells, but no marine fossils were observed. Rock of this character has been formed in Florida from the Miocene up. Some of the phosphatic rock of northern Florida is a variety of it, in which the limy envelope of the grains contains a certain amount of phosphoric acid.

The deposits lately formed and apparently now forming in the region of the Everglades have been already described (p. 100) in the remarks on the topography of the peninsula. They are partly organic and partly chemical in their origin. To the latter fact may perhaps be ascribed the exceptionally crystalline character which some of the Everglades limestone exhibits and which, so far, has not been duplicated elsewhere in the state.

The Yellow sand.—Very little observation is necessary to recognize over the greater part of the peninsula of Florida, away from the seacoast, two well marked varieties of sand. These differ in color, in texture, in mineral constituents, in the thickness of their beds, and in geological significance. The lower of the two beds or deposits is moreover, as a rule, where undisturbed, sharply discriminated from that above, and they are practically unconformable.

The Yellow sand, as the lower deposit may be called, forms the main mass of the sand hills and ridges of the central and southern part of Florida. These ridges and hillocks stand on the Neocene rocks below like hay ricks on a field, not reflecting the character of the surface

[1] See Leidy, Trans. Wagner Inst., Dec., 1889, vol. 2, pp. 9–12.

beneath them. They are rounded above, seldom show much, if any, evidence of stratification, and their upper surfaces are often slightly indurated or formed of a thin crust stained with peroxide of iron. The mass of the sand, like the rocks from which it was derived, is of a yellowish color, varying from pale straw color to yellow brown. It is sometimes 50 feet thick and seems to be perfectly uniform. A good example is afforded by the well near the schoolhouse at Lakeland, which after reaching this sand, which is covered by about 3 feet of white sand, continues in the former for many feet, until water is reached, the sand seeming perfectly homogeneous and uniform. This sand when closely examined seems largely crystalline and looks gritty, yet when rubbed between finger and thumb wastes away to an impalpable powder without any gritty feeling. When wet it has a loamy appearance and when dry runs with less facility than sea sand. It is chiefly composed of organic silica in an extremely fine state of subdivision and of fine residual clay, such as might result from the leaching away of the lime from almost any of the organic lime rocks of Florida. The sand is frequently indurated, as at Rock Lake, a mile and a half from Orlando, where the shores show what looks like a vertical border of waterworn rock. This can, however, be scratched with the finger nail, though hard enough to retain vertical faces of several feet in height. When subjected to the action of water it becomes brown, or even dark brown, probably from the small percentage of iron contained in it.

As a rule the sand hills are without fossils, but the upper layers may contain recent land shells or fragments of lime rock from older formations. The æolian sand rock or indurated sand, previously referred to as common near the sea coast, and containing recent shells in a more or less fossilized state, may very likely prove to be only a phase of the Yellow sand, but the best typical exposures of the latter are somewhat removed from the sea.

The Yellow sand appears to be indigenous and may date from the Lake period. At all events it is such a material as might result from the action of fresh water on the indigenous lime rocks. If the original sand is as old as the Pliocene, the portions of it now containing recent marine shells have, of course, been rearranged. For that part containing land shells the fossils offer no criterion of age. The whole question of its age and origin can be answered only by means of further study and investigation.

The analysis of some of this sand from a depth of about 40 feet in the Lakeland well, according to Prof. F. W. Clarke, afforded the following result:

Silica	80·39
Alumina and iron	15·03
Lime	1·22
Water (about)	3·36
	100·00

The absence of grittiness is probably due in part to the presence of so much clay and in part to the minuteness of the particles of silica. We may imagine that if one of the ordinary soft limestones of Florida was deprived of its lime and the organic silica which it contains remained in its original state of division, the residue would, in general, much resemble the clayey sand above described.

The White sand.—Above the Yellow sand almost everywhere on the peninsula of Florida may be observed an unconformable layer of snow-white sand. This is often grayish from a mixture of vegetable matter, but where the beds are thick or the sand has been washed by rain it is of a brilliant white, and often gives to large areas the aspect of being covered by a heavy fall of snow.

Unlike the Yellow sand, this stratum is seldom of great thickness. Leaving occasional dunes along the Atlantic border out of account, it is seldom seen more than 6 feet in thickness on level ground, and the hillocks formed by it rarely exceed 20 feet in height. Indeed, this height is extremely rare in the writer's experience. Nearly all the knolls, when cut by the railroads, show that their mass is composed of the Yellow sand and is only coated by the White sand.

This sand is mainly siliceous, sharp, and gritty, with a small admixture of lime particles. On the sea coast it is sometimes indurated or cemented into a rock which looks like wet loaf sugar. As the main superficial stratum of the peninsula, it contains vegetable matter, recent land or marine shells, pieces of coquina, etc., in many places; but in its nature is essentially a sea sand. It has been largely distributed by the wind, which never ceases in Florida, and to whose steady alternation of sea and land breezes is probably due the uniformity with which the White sand has been scattered.

In the transportation of glacial sands from the north, the silica, being the hardest component, would survive longest; hence the almost purely siliceous character of these sands from the southern extreme of the coast down which they travel. The indigenous silica is usually discolored. The glassy character of these White sands indicates a more northern origin.

The White sand is often absent from elevated surfaces exposed to the wind, but a close scrutiny of adjacent hollows will almost invariably disclose traces of it.

It has been suggested that the White sand, as here described, is merely the upper portion of the Yellow sand, from which the clay and iron have been leached out by the action of the weather. But, while the upper surface of the Yellow sand may in some places have been bleached in this way, the White sand here described appears to be distinctly unconformable to the underlying Yellow Sand and entirely independent in its distribution and bedding.

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SCHEME OF THE FLORIDIAN CENOZOIC ROCKS, APPROXIMATELY IN THE ORDER OF THEIR DEPOSITION.

EOCENE.

Vicksburg group	Vicksburg beds [1]	White limestone (Jackson).*
		Orbitoides limestone (Vicksburg).
		? Coral limestone (Salt Hill).*
	Nummulitic beds	Ocala limestone (Nummulitic).
		Miliolite limestone?
		Floridite phosphatic rock.

NEOCENE.

Warm-water fauna; older Miocene.

Chattahoochee group	Hawthorne beds	Greenish clays.
		Ferruginous gravels.
		Phosphatic oolite.
	Ocheesee beds	Water-bearing sands.
		Chattahoochee limestone.
		? Cerithium rock (Tampa).
Tampa group	Chipola beds	Orthaulax bed ?=Shiloh, N. J., marls.
		Chipola marl.
		Sopchoppy limestone.
		White Beach sand rock.
		? "Infusorial earth."
	Tampa beds	Tampa limestone.
		Chert of Hillsboro River.
	Alum Bluff beds	Sands and clays.

Cold-water fauna; newer Miocene.

Chesapeake group	? Patuxent beds	Ecphora beds.
	? St. Marys beds	Jacksonville limestone.
Grand Gulf group	Fayette beds*	Mississippi clays.
		Lignitic sandstone and sands.
		Gnathodon beds.
		Altamaha grit.

Pliocene.

Lafayette group*	Lagrange beds	Orange sand.
Floridian group	De Soto beds	Arcadia marl.
		Peace Creek bone bed.
		Alachua clays.
	Caloosahatchie beds	Oyster marl (Peace Creek).
		Turritella marl.
		Venus cancellata bed.
		Planorbis rock.

PLEISTOCENE.

Yellow sand.
Bulla striata marls.
Æolian sand rock (with *Homo*).
Coquina.
Vermetus rock.
Everglades limestone.
White sand.

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[1] Some strata, here marked with an asterisk, are inserted for completeness in this table, though their presence in the Florida series can not yet be demonstrated.

THICKNESS AND DIP OF THE STRATA.

Little is known of the dip of the rocks in Florida. In the northern part of the State, from the constantly greater depth at which water-bearing strata are found in artesian wells as one goes southward, a moderate southerly dip has been frequently assumed. In the south the dips follow the curves of the gentle folds of the strata. On the east coast it is questionable whether the great depth of the Eocene at the Lake Worth well is due to its steep eastward dip, or to a coastal erosion more or less masked by incumbent talus. The probabilities seem in favor of the latter view.

The thickness of the Pleistocene beds in Florida may be generously estimated in assigning it a maximum of 100 feet anywhere on level ground.

The Caloosahatchie beds will not much exceed 25 feet, and as much more would be a liberal allowance for the De Soto beds.

The Appomattox is not yet positively known to cross the northern boundary of the State, though it is stated to have been traced to Mobile Bay by L. C. Johnson, and McGee believes he has recognized it around Tallahassee.

The thickness of the Sopchoppy limestone is unknown, as the rock is known only by specimens, and the locality has not been visited by any geologist.

The existence of the Grand Gulf group in Florida is probable, but not yet sufficiently proved. The lignitic sand at Alum Bluff, perhaps of this age, is only about 10 feet thick. The Gnathodon bed discovered by Johnson is presumably of no great thickness.

The Jacksonville limestone and associated beds are about 500 feet thick at that point, but only about 200 feet at St. Augustine; the Ecphora bed at Alum Bluff only about 30 feet. On the Manatee River the bed corresponding in age to the Jacksonville rock is only 2 or 3 feet thick.

The Alum Bluff beds at the original locality are 15 feet thick.

The Tampa beds can hardly claim a greater allowance than 30 feet, and the Chipola beds perhaps half as much more.

For the Ocheesee beds Langdon has allowed 250 feet, while we may assign a maximum of 125 feet for the Hawthorne beds.

The total thickness of the Neocene rocks of Florida may be estimated to be less than 1,000 feet as a maximum, which agrees very well with the discovery of the Vicksburg beds at 1,000 feet deep in the Lake Worth artesian well. Over most of the peninsula these beds will not exceed one-quarter, and in many places one-tenth, of the maximum above noted.

The Eocene has been penetrated to 1,066 feet in organic limestone at St. Augustine without reaching the base of the Vicksburg beds. There is no reason to doubt that the Eocene will rival the Miocene in thickness, and perhaps exceed it, in Florida, as in most other States.

ALABAMA.

GRAND GULF GROUP.

In this State two very distinct formations are assigned a Neocene age. The older of these[1] consists of a fossiliferous deposit observed some 20 miles northwest of Mobile bay, and forms probably an eastern extension of the "Grand gulf" of Mississippi. Farther to the north and east, along the Tensaw River in west Baldwin County, the researches of Artemas Bigelow[2] have brought to light the existence of a sandstone formation which, in one locality not over "a rod square," contains "abundant but very obscure impressions of shells, apparently all bivalves." This, Dr. Hilgard[3] surmises, may belong to the "Grand Gulf" group, and, if so, may afford a clew for determining its age by paleontologic evidence.

The geographical distribution of this formation in Alabama has not yet been carefully investigated; but the southern extension of the Vicksburg group would of necessity confine it to a small area in the extreme southwestern part of the State.[4]

LAFAYETTE FORMATION.

The second and more recent formation is composed of perezonal sands, clays, gravels, etc., regarded by McGee as belonging to his "Appomattox formation" (since called Lafayette). A few of its more interesting and typical outcrops in this State were recently discussed before the Geological Society of America (December 27, 1889),[5] and are here given in abstract: At Girard, opposite Columbus, Ga., and at Tuscaloosa the unconformability of this formation with the "Columbia" above and the "Potomac" below is very marked. At the former "the distinctive cross bedding outlined in the laminæ of clay or lines of pellets of the same material is exceptionally conspicuous," and the pebbles are larger, more abundant, and less waterworn than usual. At the latter locality the pebbles are small, slightly waterworn, and comprise "cherts, siliceous dolomites, and a rather unimportant element of quartzite, but no true crystallines." At Cottondale, 7 miles east of Tuscaloosa, this formation and the Potomac intergrade. To the north of Eutaw it becomes sandy and friable, like the underlying Cretaceous, while to the southwest, where it occupies scattered patches upon the Rotten limestone, its clays and sands are intermingled with calcareous particles. Finally, the "Appomattox" appears between St. Elmo and Grand Bay, in the extreme southwestern corner of the State. It here consists of "undulating bosses, knolls, and plateaus rising above and evidently protruding through the sand." These remnants of ancient topography consist

[1] Johnson in Litt.
[2] Am. Jour. Sci., 2d. ser., 1846, vol. 2, pp. 420-421.
[3] Ibid., 1867, vol. 43, pp. 40,41.
[4] See Bull. U. S. Geol. Survey, No. 43, 1887. Map of Ala., opp. p. 134.
[5] Published in full in Am. Jour. Sci., 1890, vol. 40, pp. 23-26.

of regularly and rather heavy bedded loams, sands, and clays, commonly orange-hued, but weathering to darker reds and browns, and evidently represent a somewhat erratic phase of the Appomattox; erratic in (1) the complete assortment of the material, (2) its fineness, (3) regularity in stratification, (4) lack of cross-bedding.

It will be noticed that here the Appomattox approaches very near to the coast, while its altitude above tide is reduced at Grand Bay to but little over 25 feet. The comparatively high banks of Mobile Bay[1] doubtless owe their origin to this formation, though it is covered by more recent deposits. The small elevation of this deposit here and its undisturbed condition afford a strong confirmation of the view, elsewhere expressed (p. 141), that the present northern Gulf coast and the peninsula of Florida have not been subjected to any great disturbance of level, either of elevation or depression, since the Pliocene epoch.

Shell beds of Mobile County.—D. W. Langdon, of Cincinnati, Ohio, has recently called attention[2] to the fact that overlying certain "recent" shell beds on Mon Louis Island and making the surface soil throughout Mobile County are series of cross-bedded sands and loams, usually very light colored and devoid of clay or pebble beds. These beds are about 15 feet thick, and are quite similar to the beds of sandy loam found in the western part of the city of Mobile. McGee has determined these last-named loams as belonging to his Appomattox group, and should his identification prove correct it would change the age of the Appomattox (Lafayette) to a more recent date than he now seems to suppose.

"It establishes, however, a further extension inland than that marked by the present coast line and a fluctuation in the elevation of the floor of the Gulf in post-Tertiary times, which fact is believed to have not been previously noted."

The small shells belonging to recent species, which were examined by Dall, from dredgings in Mobile Bay, and which are supposed to have been derived from the "shell beds" above referred to, can not be regarded as settling the age of the deposit. Many of them are found in Miocene marls and range upward into recent seas. A fuller collection from this shell bed will be required to determine its position in the system.

MISSISSIPPI.

In this state, as in Alabama, two very different formations have been assigned a Neocene age. The older of these, the "Grand Gulf," was named by Wailes[3] from the place of its typical outcrop on the Mississippi, and was described at length by Hilgard in his "Report on the

[1] M. Tuomey, Second Biennial Rept. Geol. of Ala., 1858, p. 148.
[2] Am. Jour. Sci., 3d ser., 1890, vol. 40, p. 238.
[3] Agric. and Geol. of Miss., by B. L. C. Wailes, State Geologist, 1st Rep. 1854, p. 216.

Geology and Agriculture of the State of Mississippi" (1860). The following pages therefore consist of a brief generalization of the facts there presented, together with those brought to light by more recent investigations.

THE GRAND GULF FORMATION.

This underlies the greater part of the State south of a line passing in a general way through Vicksburg, Raymond, Byram, Brandon, Raleigh, and Waynesboro, or, in other words, south of the Vicksburg formation.

At their line of contact the Vicksburg and Grand Gulf rocks consist almost throughout of lignito-gypseous, laminated clays, passing upward into more sandy materials; they are not sensibly unconformable in place, but while the Vicksburg rocks at all long exposures show a distinct southward dip of some three to five degrees, the position of the Grand Gulf strata can rarely be shown to be otherwise than nearly or quite horizontal, although in some cases faults or subsidences have caused them to dip, sometimes quite steeply, in almost any direction.[1]

The superior durability of the arenaceous deposits of this formation over those of the Vicksburg series has caused a well marked ridge running diagonally across the state along their line of contact. This falls off abruptly to the north,[2] but descends very gradually toward the gulf.

All, or at least the greater part of this formation, is characterized by the presence of gypsum and salt and generally also magnesian salts.[3] This is the case with many of the solid sandstones, which, upon exposure to the weather become covered with a saline efflorescence. These sandstones frequently contain small concretions of iron pyrites, which oxidize and swell when the rock is exposed to the air, sometimes breaking up large blocks in this way. Carbonate of lime is a rare ingredient, and the deposits containing it are always quite limited.

In the northwestern part of its development in Mississippi, i. e., northwest of a line drawn from Fort Adams to Raleigh, this formation abounds in sandstone and arenaceous deposits, but to the southeast of this line it consists almost exclusively of clays.

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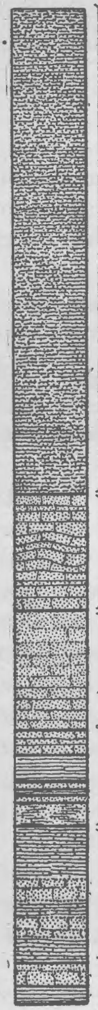
[1] Hilgard, E. W.: Am. Jour. Sci., 3d ser., vol. 22, p. 58.
[2] Ibid., p. 59.
[3] Agric. and Geol. Miss., 1860, pp. 147, 148.

At Grand Gulf the following section occurs:[1]

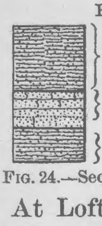


No.	Feet.	
12	60 to 70	Calcareous silt of the Bluff formation, forming the hilltops. (Loess.)
11	14	"Grand Gulf sandstone," in ledges 10 inches to 2 feet in thickness; stratification often discordant and curved.
10	15	Gray sandy material, sometimes soft sandstone, with an argillaceous cement; alternating with harder ledges, 6 to 10 inches thick, of friable, whitish sandstone.
9	2½	Solid whitish sandstone, of good quality.
8	2½	Greenish gray clay, with veins of $CaCO_3$.
7	1	Soft white sandstone.
6	½	Grayish yellow pipeclay.
5	1	Dark gray, brittle sandstone.
4	3	Gray, semiindurate clayey sand.
3	17	Gray and yellowish sands and clays, semiindurate, interstratified.
2	3	Semiindurate gray sand.
1	2	Greenish gray clay, with veins of $CaCO_3$.

FIG. 23.—Section at Grand Gulf, Mississippi.

The characters of the minor divisions of this section are very changeable, so that 50 yards away the lower portion of the section especially might appear very differently. It is only the upper bed (No. 11) that possesses the peculiar structure which characterizes the "Grand Gulf sandstone," viz, grains of pellucid quartz, containing rather coarse sand, imbedded in an opaque white, enamel-like mass of silex, which forms quite half of the bulk of the rock. This peculiar rock has been observed in several localities in this vicinity, but toward the interior of the State it is replaced by ordinary siliceous sandstone, sometimes compact but more often friable, with alternating layers of even softer material, such as sands, clays, lignites, etc.

North of Terry, about a half a mile, Meyer[2] obtained the following section of this formation:



Feet.	
10	Light sandy clay.
7	Sandstone, hard above, softer below, containing small nodules of green clay or corresponding cavities.
5	Green sandy clay.

FIG. 24.—Section one-half mile north of Terry, Mississippi.

At Loftus Heights, Fort Adams, Wilkinson County, the Grand Gulf rocks appear at the base of the exposure as follows:[3]

[1] Hilgard: Agric. and Geol. of Miss., 1860, p. 148.
[2] Meyer, Otto: Am. Jour. Sci., 3d ser., 1886, vol. 32, p. 20.
[3] Hilgard: Agric. and Geol. Miss., 1860, p. 150.

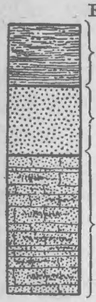


FIG. 25.—Section at Loftus Heights, Fort Adams, Mississippi.

In the northwesterly part of the Grand Gulf area silicified wood, especially that of the palm, is by no means rare; lignite, too, is fairly common in the more argillaceous beds. The latter contain also "impressions of fresh-water, bivalves" in a few instances, as cited by Meyer,[1] and a cast of *Unio*, from Stonington Station, Clairborne County, Miss., is in the National Museum collection.

To the south and east of the line before referred to as separating the arenaceous from the argillaceous areas of the Grand Gulf formation, there are but few if any compact sandstone beds to be found, though the clays contain various proportions of friable sand.

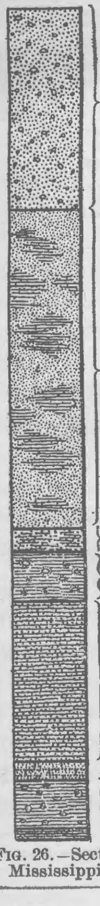


FIG. 26.—Section at "Barnes's white bluff," Marion County, Mississippi.

The color of these clays is various, though usually of a lighter shade than those of the "Northern Lignitic;" blue, white, and even green shades are not uncommon. They contain lignite, pyrite, potash, soda, magnesia, and some times calcium carbonate. The last named ingredient is notably rare except at one point, viz, "near Mr. Ben. Barnes's place, Secs. 2 and 35, T. 4 and 5, R. 12 E., Marion County." It was here that Hilgard[2] found the "chelonian bones" that have been so often cited as the only fossil vertebrate remains found in this formation. A section of the various strata in this immediate vicinity is given by Hilgard (Fig. 26).[3]

The 6-foot bed containing carbonate of lime (No.

[1] Meyer, O.: Am. Jour. Sci., 3d ser., 1886, vol. 32, p. 25.
[2] Hilgard: Agric. and Geol. of Miss., 1860, p. 151.
[3] Ibid., p. 179.

5) has been used to a limited extent as a fertilizer, and is often called "marl."

Another excellent exposure of these clays may be seen on Strong River, Simpson County, Sec. 6, T. 10, R. 20 W. At this place a local western dip of 15°–20° gives an exposure of about 110 feet, although the outcrop is nowhere over 40 feet high. "The materials here contain abundant vestiges of leaves, but so poorly preserved as to be generally unrecognizable; the only form made out with certainty was a fragment of fan-shaped palm-leaf."[1]

On the Chickasawhay and Pascagoula rivers Hilgard found[2] but few outcrops of the Grand Gulf formation. The most northerly of these, 2 miles south of Winchester, Wayne County, is of the highest importance on account of the well preserved lignitized trunks of trees found on the spot where they grew with their roots imbedded in the ancient soil. Successive layers of leaves are to be seen covered by thin sheets of whitish sandy clay. The whole is covered by about 20 feet of Orange sand.

Section at Sam. Power's, near Winchester, Mississippi.

Feet.	Inches.	Character of strata.	No.
18	....	Yellow sand with pebbles in its lower portions (Orange sand)	5
....	18	White sand with nodules of pipe clay	4
....	1	Black clay with leaves	3
3	....	Grayish white sand with vestiges of leaves on stratification lines	2
5	....	Bluish sandy clay, with roots and trunks of *Cupuliferæ, Coniferæ, and Palmæ*	1

Gnathodon bed in Greene County.—Though Hilgard examined this region more or less closely to the Gulf shore, we owe to L. C. Johnson the discovery of a very important bed in Sec. 27, T. 1, R. 7 W., Greene County (not far from Vernel), which contains an abundant lamellibranch fauna[3]. The bed, which we have called the Gnathodon bed, consists of a brownish clayey sand, packed with a small undescribed species of *Gnathodon*, while *Mactra lateralis* Say, of the existing southern type, and an oyster of gigantic proportions, resembling *Ostrea titan* of the west coast, are by no means uncommon. It is probable that these

[1] Hilgard: Agric. and Geol. of Miss., 1860, p. 151. Similar leaves were obtained by Burns from the lignitic sand bed above the *Ecphora* bed at Alum Bluff, Florida.

[2] Agric. and Geol., Miss., 1860, p. 153, and Am. Jour. Sci., 2d ser., vol. 2, p. 401.

[3] See specimens in U. S. Nat. Mus.

beds[1] may represent the same horizon as do the obscure bivalve impressions of Baldwin County, Ala., discovered by Mr. Bigelow fifty years ago.[2]

The Grand Gulf group has usually been regarded as Miocene, since it lies above the Eocene Vicksburg group and passes beneath the "Coast Pliocene." It is so considered by McGee, who regards[3] as probably Pliocene the superincumbent Orange sand which forms part of his Lafayette. Hilgard, however, in one of his more recent contributions to the subject,[4] says: "Clearly the Grand Gulf rocks alone represent on the northern borders of the Gulf the entire time and space intervening between the Vicksburg epoch of the Eocene and the stratified drift," the latter of which he regards as Quaternary. In the same article he estimates its thickness as not over 250 feet.

It is obvious that the Grand Gulf formation constitutes a typical perezone, bordering the lower part, at least, of the great Mississippi embayment, the landward portion consisting of the sandy beach formation on or near which grew palmettos, swamp cypresses, and pines; where tortoises wandered; where there were occasional lagoons of which the water was not muddy enough to destroy all the oyster embryos, and where the mud-loving *Mactra lateralis* and *Gnathodon* found a congenial retreat. Seaward the terrigenous deposits from the Mississippi drainage were laid down in argillaceous strata, which, like those laid down by the same great river to-day, contain hardly a trace of organic life.

The lignitic sand, with impressions of palmetto leaves, which occurs above the *Ecphora* bed at Alum Bluff, seems likely to represent the eastern feather-edge of this formation. If this be so, the age of the upper part and later condition of the Grand Gulf perezone would be not older than the latest Miocene. This supposition harmonizes with the presence of *Mactra lateralis*, which is a Pliocene and recent rather than a Miocene species.

Parallelism of later terrigenous deposits.—An interesting fact in this connection is the almost complete parallelism of the present extension, at the bottom of the Gulf of Mexico, of the terrigenous deposits from the Mississippi Valley drainage with that of the Grand Gulf group as at present understood. The present deposits of mud cease[5] at a point a little westward of the Appalachicola River mouth on the one hand, and on the other, in the vicinity of Vera Cruz, Mexico. The coarser material forms an inner band, while the finer silt borders it to seaward, just as do the sandy and clayey beds of the Grand Gulf. The latter, however, was deposited for the most part in relatively shallow water, and contains material more coarse than anything which at present is being laid down off the Gulf coast.

[1] Johnson in his MS. reports to the U. S. Geological Survey names this fossiliferous bed, with other adjacent strata, the "Pascagoula Group."

[2] Artemas Bigelow, Am. Jour. Sci., 2d ser., 1846, vol. 2, pp. 419-422.

[3] Am. Jour. Sci., 3d ser., 1890, vol. 40, p. 32.

[4] Eug. W. Hilgard, Am. Jour. Sci., 3d ser., vol. 22, p. 59.

[5] Agassiz: Three cruises of the Blake, 1888, vol. 1, p. 286, chart 191. See also Coast Survey Report for 1880.

THE LAFAYETTE FORMATION.

The second and more recent formation in this state which has been assigned a Neocene age is a continuation of the series of cross-bedded gravels, sands, and clays, termed by McGee the Appomattox (more lately Lafayette) formation (Orange sand partim of Hilgard).

This formation, according to McGee, characterizes the greater part of the surface of this State. Its thickness and constituent materials depend very largely upon the ancient topography and lithological features of the beds upon which it was deposited. It generally prevails over the terrane of the Potomac formation "despite the considerable altitude and high local relief, save in the valleys of the largest rivers." Over the less elevated terrane of the Eutaw sands it is more frequently and more widely cleft by drainage ways, and its remnants are thinner; over the next newer formation (the Tombigbee chalk), which lies flat and low, the greater part of the Lafayette has been carried away from northeastern Mississippi to beyond the Alabama River, so that it is commonly represented only by isolated belts and irregular patches which, as Smith has shown, most frequently lie on the northern slopes. Over the terrane of the Eufaula sands, in which the local relief again increases, the remnants of the Lafayette quickly increase in number and expand until the formation once more forms the prevailing surface on the uplands, though the Cretaceous deposits are laid bare along most streams and form the prevailing lowlands. Over the eight or nine lower Eocene formations into which the Lignitic of Hilgard has been divided by Smith and Johnson, and among which clay is the predominant material, the Lafayette still further expands until it forms almost the entire surface, highland and lowland alike, save in the valleys of the larger rivers. Still farther south lies the great siliceous deposit of the middle Eocene, commonly known as Buhrstone—the Choctaw buhrstone of Smith; its rocks are the most obdurate of the entire Neozoic series within the Gulf slope, and so its general surface is elevated and sculptured into a complex configuration of pronounced relief and sharp contours; yet, despite these conditions so exceptionably favorable to degradation, the Appomattox frequently maintains its integrity over considerable areas. Beyond the hill-land of the Buhrstone lies the lowland formed by the predominantly calcareous newer Eocene formations—the Claiborne, Jackson, and Vicksburg—over which the Lafayette is again trenched by almost every water way and reduced to ragged remnants only more extensive than those overlying the Tombigbee chalk; but upon the silico-argillaceous terrane of the Grand Gulf the remnants once more expand until they form the greater part of the surface, save along the larger water ways, as about Hattiesburg in central Mississippi.

In short, the formation is generally preserved over loamy and clayey terranes, much more seriously invaded by erosion over sandy terranes, and largely degraded over calcareous terranes.[1]

[1] McGee: Am. Jour. Sci., 3d ser. 1890, vol. 40, pp. 29-30.

The thickness of this formation is obviously extremely variable. Perhaps the greatest known thickness is at the University of Mississippi where, from well-borings, it was found to be somewhat over 200 feet.[1]

Regarding the position of this formation in the geological scale, McGee makes[2] the following statements:

No fossils have thus far been found in the Appomattox formation except at Meridian, where Johnson has found it to contain well preserved magnolia leaves apparently identical with those of trees now growing in the same vicinity. Its stratigraphic position, unconformably below the Pleistocene and unconformably above the (probable) Miocene Grand Gulf formation, indicates an age corresponding at least roughly with the Pliocene.

Hilgard has constantly maintained that his "Orange sand" (a more comprehensive group than the Lafayette) belongs to the Quaternary age. He finds in it fossils from the Silurian rocks up, but none which he regards as characteristic of the deposit itself. Its distribution, local characteristics, probable origin, and so forth, are discussed at great length in his report on the Agriculture and Geology of the State of Mississippi.[3]

These difficulties and the conditions of occurrence indicate that the Lafayette formation is perezonal in its nature and that its deposition is due to a depression of the surface which occurred after the Grand Gulf had been laid down and which was followed at a later time by an equivalent elevation. These movements may have been synchronous with the slight depression during which the middle Pliocene beds of South Florida were laid down. But in the latter region the vertical movements were slight, while north of the Floridian region their range was evidently much greater.

LOUISIANA.

The two formations that characterize the Neocene Tertiary in Alabama and Mississippi appear likewise in Louisiana.

GRAND GULF GROUP.

East of the Mississippi River, the seaward argillaceous phase of the Grand Gulf formation presumably extends some distance into this State; yet thus far we fail to find that any outcrop has been noted. Hopkins states in a general way[4] that it "reaches the strata of the Bluff period, in about township 4 or 5 south, on both sides of the river," and so he represents it on his "Preliminary Geological Map of Louisiana." The artesian well at New Orleans, sunk[5] to the depth of 630 feet, failed to reach this formation or even the "Orange sand."

[1] E. W. Hilgard: Agric. and Geol. Miss., 1860, p. 6.

[2] Ibid., p. 33.

[3] Op. cit. pp. 5-46. See also Am. Jour. Sci. 2d ser. 1866, vol. 41, p. 311. Ibid., 3d ser. 1871, vol. 2, p. 398.

[4] Louisiana State Univ. Rep. for 1870, containing 2d Ann. Rep. Geol. Surv. La., by Dr. F. V. Hopkins; p. 18.

[5] Rep. on the Geol. Miss. Delta, by E. W. Hilgard, in the Rep. of the Chief of the Engineer Corps U. S. A., to the Secretary of War, 1870.

West of the Mississippi no Grand Gulf rocks appear for some distance, owing to the breadth of the "bottom lands" along the Mississippi and its great tributaries. They reappear, however, on Sicily Isle, near Harrisonburg, Catahoula Parish, and between this point and Sabine River occupy a large triangular area, as shown by Hopkins's map, and as minutely described by him in his First Annual Report of the Louisiana State Geological Survey, in 1869.

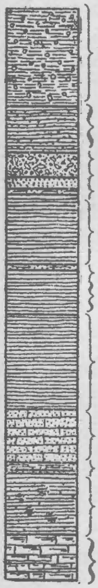


FIG. 27.—Section at Harrisonburg, La.

Here, as in Mississippi, the northerly portion of this formation is characterized by a predominance of arenaceous material, producing a series of escarpments[1] that break down abruptly on to the marine, calcareous Eocene, whereas,[2] towards the south, argillaceous matter predominates and the descent toward the Gulf is barely perceptible. In general, the Grand Gulf rocks of this State are the exact homologue of those in Mississippi. To illustrate, a section is here given of the various beds exposed at Harrisonburg.[3]

In some localities, however, a very white clay is not uncommon, which, owing to its general appearance, has usually been termed "chalk." The following section represents its stratigraphic relations[4] at the "Chalk Hills," Sec. 6, T. 10 N., R. 5 E.

[1] 2d Ann. Rep. Louisiana Geol. Surv., 1870. F. V. Hopkins in La. State Univ. Rep., 1871, pp. 18–20.
[2] Hilgard, E. W.: Am. Jour. Sci. 3d. ser., 1869, vol. 2, p. 397.
[3] 1st Ann. Rep. Louisiana Geol. Surv., 1869, F. V, Hopkins in La. State Univ. Rep., 1870, p. 99.
[4] Hopkins, F. V.: 1st Ann. Rep. Louisiana State Geol. Surv., in La. State Univ. Rep., 1870, p. 100.

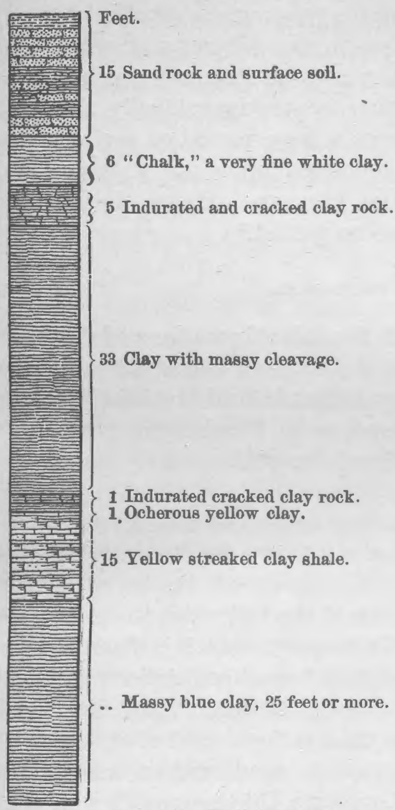


FIG. 28.—Section at the Chalk Hills, La.

Pure white shales are not uncommon. These, together with the "chalk," become very noticeable in the "Fayette beds" of Texas.[1] Calcareous matter, too, is more abundant in this State than in Mississippi, while it is far less so than in Texas. Anacoco prairie,[2] in the southwestern part of Sabine Parish, and the so-called "black land spots," are produced by the outcropping of "marl" beds.

The thickness of this formation can not be ascertained with any great degree of accuracy from surface estimates, owing to a lack of continuity in its constituent strata; nevertheless, Hopkins has estimated[3] that near Harrisonburg it is about 182 feet thick, while south of Cloutierville and on the Bayou Kisatchie it may be 325.

"The strata are generally nearly horizontal, but many places show slight southeast dips. The disturbances, though noticeable enough where the hills are high, as at Harrisonburg, are by no means as great as in the older members of the Tertiary."[4]

The absence of this formation at Kirkman's, and the Louisiana Oil Company's well, on the west fork of the Calcasieu River, is somewhat remarkable, since Port Hudson, Orange sand, Vicksburg, and Cretaceous groups were penetrated in one if not in both wells.

On this point Hilgard remarks:[5]

The rocks of the Grand Gulf age should have appeared in these profiles directly beneath the drift materials, but nothing has been found resembling them in the least, and since, of all the Tertiary groups, this one is the most persistently uniform in its lithological character, its absence might be taken as proved—it having, doubtless, been removed through the agency of the drift currents.

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[1] Penrose: 1st Ann. Rep. Geol. Surv. Texas.
[2] Hopkins, F. V.: 2d Ann. Rep. Louisiana State Geol. Surv., etc., p. 20.
[3] 2d Ann. Rep. Louisiana State Geol. Surv., etc., p. 19.
[4] Hopkins, F. V.: 1st Ann. Rep. La. State Geol. Surv., etc., p. 101.
[5] Hilgard, E. W.: Final Rep. Geol. Reconn. Louisiana, 1873, p. 41.

Although Hopkins found[1] no fossils in this terrane capable of specific determination he follows most writers on the subject and attributes to it a Miocene age. This view he believes to be strengthened by the following considerations: The formation is stratigraphically above the Eocene. Its upper surface evidences a long period of aerial erosion before the drift (Quaternary) was deposited upon it. This period directly before the Quaternary was the Pliocene. Hence the formation itself was laid down during the Miocene period.[2]

LAFAYETTE FORMATION.

Overlying the Grand Gulf and all the older formations of this State, save where their beds are highly calcareous,[3] is a deposit of water-worn pebbles, sands, and clays termed by Hilgard[4] and Hopkins[5] "Orange sand" or "Drift." Its thickness here, as in Mississippi, is extremely variable, but increases generally toward the gulf.

Thus at Carolina Bluffs it is about 50 feet thick, at Grand Écore and Harrisonburg about 25 feet thick, and in the cuts on the Shreveport and Marshall Railroad it is seen to vary from a few feet to a few inches, as it follows the double contour of the ancient and present hills.[6]

In Kirkman's well, on the West Fork of the Calcasieu River, it is over 96 feet thick, and in the Louisiana Oil Company's well it is about 174 feet.[7]

A few slight outcrops of this formation have been noticed on Weeks and Petite Anse Islands, near the gulf border. These are indeed somewhat erratic, since generally in the southern part of the State the Port Hudson group overlies the Orange sand with a considerable thickness of deposits; e. g., at the Louisiana Oil Company's well above cited, the Port Hudson group is 160 feet thick; in the Kirkman's well, 354; at New Orleans[8] no Orange sand was encountered at a depth of 630 feet.

Not knowing how much of this formation will ultimately be classified as "Lafayette," we forbear from discussing it more in detail.

TENNESSEE.

LAGRANGE GROUP.

As yet we are unable to state with certainty whether there are any deposits in Tennessee that can properly be classified as Neocene, but inasmuch as McGee[9] has recognized the Lagrange group of Safford[10] as

[1] 1st Ann. Rep. Geol. Surv., etc., p. 100; 2d Ann. Rep., pp. 20–21.

[2] Hopkins, F. V.: 2d Ann. Rep. Louisiana State Geol. Surv., 1870, in Rep. La. State Univ., p. 21.

[3] Am. Jour. Sci., 2d ser., 1869, vol. 48, p. 334.

[4] Suppl. and Final Rep. Geol. Reconn. State of La., 1873.

[5] Hopkins: 1st Ann. Rep. Louisiana State Geol. Surv., 1869, p. 104.

[6] Hopkins: 2d Ann. Rep. Louisiana State Geol. Surv., 1870, p. 23.

[7] Hilgard, E. W.: Suppl. and Final Rep. Geol. Reconn. Louisiana.

[8] Hilgard, E. W.: Rep. to the Chief of Engineers, U. S. A., Gen. A. A. Humphreys, on the Geol. Age of the Miss. Delta, 1870.

[9] W. J. McGee: Orally.

[10] Jas. M. Safford: Am. Jour. Sci., 2d ser., 1864, vol. 37, p. 369.; and Geol. Tenn., 1869, p. 424.

belonging to the Lafayette formation it will here be briefly noticed. This group occupies more than a third of the entire surface of west Tennessee; it includes a belt about 40 miles wide, which runs in a north-northeasterly direction through the central portion of this division of the state. As seen in bluffs, railroad cuts, gullies, and in nearly all exposures, it is generally a great stratified mass of yellow, orange, red, or brown and white sands, presenting occasionally an interstratified bed of white, gray, or variegated clay. It often contains vegetable matter, trunks of trees, lignite, etc. It is typically exposed at Lagrange, where a section 100 feet in height may be seen.

Safford assumed the thickness of this group to be 600 feet. He, moreover, supposed it to dip slightly to the west, and to underlie his "Bluff Lignite." The incorrectness of the latter supposition has recently been pointed out by Loughridge,[1] who holds that the Porter's Creek group (Flatwoods) and the "Bluff Lignitic" are really one and the same formation "as shown in the bluff of the Ohio on the Illinois shore at Caledonia, as well as by the continuity of the belt on the east, north, and west of the Purchase region."

No fossils except the remains of plants have been obtained from this group.

Among the fourteen species of fossil leaves obtained by Lesquereux from near Somervillle and Lagrange, three only were identified with living forms.[2] In 1861 he expressed the opinion that they probably belong to an upper Miocene horizon.[3] Safford, however, still classifies this group as Eocene Tertiary.[4]

KENTUCKY.

LAGRANGE GROUP.

The Lagrange group of Safford (Lafayette formation) is found well developed in that portion of this State lying between the Tennessee and Mississippi rivers,[5] where it occupies a broad belt passing north and south through the central and western part of this region, and lies, as it were, in a deep trough in the Lignitic deposits (Bluff Lignitic or Porters Creek group of Safford). It is generally covered by Quaternary deposits, yet is frequently met with along the courses of streams, in cuts, wells, etc. It consists of light colored, cross-bedded sands and white pipe clays, the former of which predominate, are usually fine, nonmicaceous, and sometimes variously colored, while the latter are frequently highly gypsiferous.

Loughridge,[6] though strongly inclined to regard these beds as "lowest of the Quaternary stratified drift," nevertheless places them provisionally in the Tertiary, though above the Eocene division. From

[1] R. H. Loughridge: Geol. Surv. Kentucky. Jackson Purchase region (F), 1888, p. 41.
[2] Geol. of Tennessee, 1869, p. 425.
[3] Am. Jour. Sci., 2d ser. 1864, vol. 37, p. 370.
[4] Am. Geol. Railway Guide; Jas. Macfarlane, 1890, p. 401.
[5] R. H. Loughridge: Report on the Jackson Purchase region (F), Geol. Surv. of Kentucky, 1888, p. 53.
[6] Ibid., p. 52.

the specimens of fossil leaves sent by him from Boaz station, Graves County, to the U. S. Geological Survey,[1] Lesquereux made[2] five identifications, viz, *Ficus multinervis* Heer, *Laurus californica* Lx., *Sapindus falcifolius* Al. Br., *Quercus* cf. *cuspidata* (Rossm.) Ung., *Quercus neriifolia* Al. Br. These are all extinct species, but they render no great aid in the determination of the age of their horizon, though they perhaps do indicate a preglacial age.

Thus far this group has yielded no other fossils. Its stratigraphic and lithologic characteristics are well defined in Loughridge's report on the Jackson Purchase region, while its geographical distribution is shown on an accompanying sheet.[3]

ILLINOIS.

Tertiary sands and clays.—A Tertiary series of stratified "sands and clays of various colors" is mentioned by Worthen[4] as best developed in Pulaski County, though found to some extent in Alexander and Union counties. Whether any part of them will be found to belong to the Lafayette formation can not at present be determined. There seems to be no ground for supposing that any other Neocene deposits exist in this State.

MISSOURI.

A series made up of clays, sands, and iron ores, more or less indurated, extends in bluffs skirting along the bottom lands from Commerce, Scott County, westward to Stoddard, and thence south to Chalk Bluff, Arkansas. No fossils have been found in these beds, but Swallow[5] has referred them provisionally to the "Tertiary" without attempting to designate the subdivision.

TEXAS.

Considered from a genetic standpoint, there are three very distinct groups of post-Eocene Tertiary deposits in this state, viz, (1) the brackish-water Fayette (Grand Gulf) beds, (2) the perezonal Lafayette formation, (3) the interior lake deposits. These will be considered in the order mentioned.

GRAND GULF GROUP.

In 1871, Prof. E. W. Hilgard presented to the geological section of the American Association for the Advancement of Science[6] a "Geological Map of the Mississippi Embayment," illustrative of an article "On

[1] Geol. Surv. Ky., Jackson Purchase region, 1888, p. 56.
[2] Proc. U. S. Museum, 1888, pp. 11, 12.
[3] See Map No. 1, accompanying Geol. Surv. Ky. (F), etc.
[4] Geol. Surv. Ill., vol. 1, 1866, pp. 44-46 and pp. 417-423.
[5] G. C. Swallow: Proc. Am. Assoc. Adv. Sci., 1857, vol. 11, II, p. 2-3, and Parker, "Missouri as it is in 1867," p. 123.
[6] See the proceedings, vol. 20, map opp. p. 222.

the Geological History of the Gulf of Mexico." On this map the Grand Gulf group was represented in Texas as occupying a belt of varying width, just inland from the Port Hudson, from the Sabine River to Camargo on the Rio Grande. The correctness of this partly hypothetical distribution was proved by Dr. R. H. Loughridge,[1] who eight years later, while making a reconnaissance of the state in connection with the agricultural investigations of the Tenth Census, noted the occurrence and character of this formation at Trinity on Trinity River; at Chapel Hill and Brenham, Washington County; at Lagrange, Fayette County; near Cuero, De Witt County; and from hearsay traced its extension through Live Oak and Duval counties to Rio Grande city on the Rio Grande.

In 1889 Mr. R. A. F. Penrose, jr., published "A preliminary report on the geology of the Gulf Tertiary of Texas, from Red River to the Rio Grande," in the first annual report of the geological survey of Texas, wherein he designates[2] the formation under consideration "The Fayette beds," though acknowledging their equivalency to Hilgard's "Grand Gulf."

This report describes in detail the characters of these beds as they crop out along the Colorado, the Brazos, and the Rio Grande.

Colorado River section.[3]—In going down the river, the first typical exposure of Fayette beds is seen in a bluff at the mouth of Barton Creek, though low clayey banks appear some distance above. The various strata at this point appear as follows:

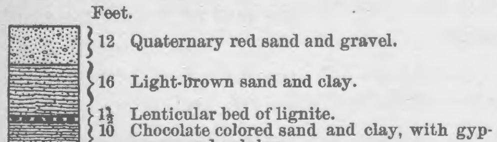

FIG. 29.—Section at mouth of Barton Creek, Colorado River, Texas.

The whole formation is much faulted and jointed, and dips 2° to 5° southeast. Farther down the river the so-called "Chalk bluffs," 12 and 6 miles above Lagrange, respectively, contain about the same material, though the proportion of white clays and sands, or those that become white, is so great as to give the exposures a chalky appearance. Gypsum, sulphur, and lignite are common at both of these bluffs. The latter, however, is characterized by numerous leaf impressions, especially in its lower portion.

Four miles by river, above Lagrange, is "Palm Bluff," about 100 feet high. Its upper 30 feet is composed of sand, in places hardened into

[1] Census Reports of 1880, vol. 5, p. 679.
[2] Op. cit., p. 47.
[3] Ibid., p. 52.

a friable sandstone. This is composed of sharp siliceous grains, sometimes coarse, the size of mustard seed or larger. Many impressions of palm or palmetto leaves as well as silicified stems and trunks are found in this sand. Toward the middle of the bluff clays and calcareous seams appear; the lower portion is covered by detritus.

Lagrange Bluff, 2 miles below the town, is the most southerly exposure described. It is very similar to Palm Bluff. State Geologist Dumble, however, has noted the occurrence of Fayette sands as far south as Wharton, Wharton County.

Brazos River section.—The Fayette beds first make their appearance on this river near the mouth of the Little Brazos. Here a slight rapid is formed by their cross-bedded indurated sands. The same water green and chocolate colored clays, with sands, lignites, and silicified wood appear on this river as on the Colorado. Sulphur Bluff, 9 miles below Moseley's Ferry, in the eastern part of Burleson County, contains the following bed:

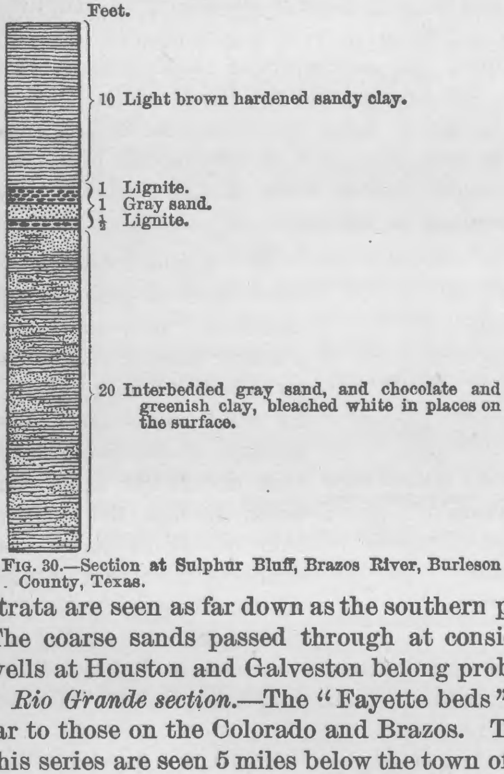

FIG. 30.—Section at Sulphur Bluff, Brazos River, Burleson County, Texas.

Still farther down the river, at points respectively 8 and 3 miles above the mouth of Yegua Creek, similar bluffs of clays, sands, and lignites appear. About 2 miles below this creek, a low bluff occurs, capped with a coarse sandstone containing fragments of silicified wood, small shark teeth, and worn pieces of bones one-half to 2 inches long. A mile and a half below this a hill rises 100 feet above the river bottom that closely resembles the Lagrange Bluff. Similar strata are seen as far down as the southern part of Washington County. The coarse sands passed through at considerable depths in artesian wells at Houston and Galveston belong probably to this formation.

Rio Grande section.—The "Fayette beds" on this river are very similar to those on the Colorado and Brazos. The first undoubted beds of this series are seen 5 miles below the town of Roma; though it is possible that certain strata above this place as far as the Rio Salado and Carrizo should be included here. Light sea-green clays, containing many impressions of leaves, predominate at first. Three miles below these clays are overlain by 15 feet of sandstone, with concretions, fragments of silicified wood, and a few broken pieces of oyster shell. Rio Grande city is situated on a bluff of hard white clay, which probably represents the sea-green clays of the Fayette beds, and has become indurated by exposure to heat in a dry climate. The most southern exposure of Fayette sands is at Hidalgo, Hidalgo County.

Such, then, are a few of the more important characteristics of the Fayette beds as seen along the banks of three great rivers. To the east of the Brazos Mr. Penrose's observations seem not to have extended. Between this river and the Colorado he notes briefly the topography, flora, and general features of the soil. Between the Colorado and Rio Grande he cites the observations of Loughridge.

Among the various inferences he has drawn from his study of the Fayette beds are the following: (1) The minimum thickness of these strata is 350 feet and probably nearer 400. (2) The lower part of the series is clayey and sandy; often hard, producing rapids in the water courses and a comparatively broken surface along the northern line of outcrop. Higher up in the series clays predominate, then suddenly the sands assume predominance and chiefly make up the upper half of the formation. (3) There is far more calcareous matter in these beds than in the Grand Gulf of Mississippi or Louisiana. (4) The clay at the base of the series is much thicker than in those States. (5) There are no indigenous fossil remains in these beds. The fragments of oysters, sharks' teeth, etc., appear to have been washed in from subjacent formations.[1] (6) The formation is continuous, occupying a bed often 60 or even 100 miles wide, from the Sabine to the Rio Grande.

If Mr. Penrose's measurements of dip be reliable the formation may prove to be considerably over 400 feet thick, since the general amount of dip along the Colorado and Brazos seems to be about 2° or 3° to the southeast.

Lafayette group.—Penrose has noted the occurrence of gravel deposits high up on the banks of the Brazos, Colorado, and Rio Grande, where they are from 1 to 15 or more feet in thickness. They contain limestone, flint, quarts, silicified wood, jasper, chert, etc., and are presumably the Texan representative of Hill's "Plateau gravel" in Arkansas,[2] though they seem to be more confined to the large water courses, their only representatives on the hills being a few scattered pebbles. To what extent these may be included in the Lafayette formation remains for future investigation to determine.

LAKE BEDS OF THE INTERIOR.

We believe there can be no doubt that during later Tertiary times the broad sheets of fresh water that flooded the plains of the West extended southward well into the State of Texas. Such has been the opinion of those who have studied the lake deposits of this period, though their observations were mainly confined to the regions farther north, in Kansas, Colorado, Nebraska, and Dakota.

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[1] Exception must be taken to this rule if we include among the Fayette beds the beds about Roma in which the numerous specimens of *Ostrea georgiana?* are found, and also the "*Meretrix*" found by Buckley in the central part of Washington County. Cf. Buckley's First Annual Report, p.63.

[2] Ark. Geol. Surv., Ann. Rep., 1888, vol. 2, p. 35.

"Mr. Robert T. Hill has made brief mention in three short papers of a very interesting fact concerning the age of the Staked Plains, and the extent of the fresh-water Tertiary formations of the West eastward into the Texas region. The whole of the great mesa known as the Llano Estacado and some of the basins of the trans-Pecos region, near El Paso, are composed of sandy loams, grits, and pebbles of this formation. This area in western Texas and eastern New Mexico extends in places eastward to the one hundredth meridian, and is a direct continuation southward of the same formation in Kansas and Nebraska. Its southern limit on the Rio Grande is near Del Rio, and the whole area, which is as large as New England, has been colored Cretaceous and Jurassic upon previous maps. The formation has afforded fossil bones in various places, but these, as yet, have been unstudied. It rests unconformably upon the Comanche series, the Jura-Trias, and the various rocks in the mountain ridges. Everywhere at its base it affords an abundant supply of well water, which has proved of great value to the settlers who are now rapidly locating on the Staked Plains. The Fort Worth and Denver road traverses the formation from Clarendon to Tascosa, and the Texas and Pacific from Sweetwater to the Colorado valley, and thence westward. This additional knowledge upon the former extent of the great inland lakes of Tertiary times is important, in that it nearly doubles the areal extent hitherto acknowledged, and enables us to locate the narrow continental divide between the Gulf of Mexico and the Tertiary lakes with greater accuracy. Dr. Otto Lerch has corroborated the extent of these beds in a recent article on the Concho country in the *American Geologist* for 1890.[1]"

Hill gives the thickness of these beds as between 100 and 300 feet. He styles them the "Staked Plains formation."[2]

Farther south, in Washington, Bastrop, and Navarro counties, many osseous fragments have been found in digging wells from 20 to 50 feet deep. Some of these Dr. Leidy[3] has studied, described, and referred to the "Miocene" or "Pliocene," generally, however, to the latter, or to the horizon of the extensive deposits of Niobrara and Little White rivers and Bijou Hill. The identification of *Hipparion speciosum*, *Procamelus occidentalis*, and *Merychippus insignis*, may be regarded as indicative of this horizon; *Rhinoceros meridianus*, according to Leidy, "presents much the general aspect of the Mauvaises Terres fossils of White River, Dakota, with which it is probably of contemporary age."[4]

[1] Am. Nat., 1891, vol. 25, p. 49. The "three short papers" referred to in this quotation are as follows: (1) Notes on the Geology of Western Texas: Bulletin Texas State Geol. Soc., Sept., 1888; (2) Topography and Geology of Texas Region: Pro. Am. Ass. Adv. of Sci., 1889, and (3) Classification and Origin of the Chief Geographic Features of the Texas Region: Am. Geol., 1890, vol 5, pp. 9, et seq. In these, however, we fail to find some of the points made in the above quotation.

[2] Am. Geol., 1890, vol. 5, p. 28.

[3] U. S. Geol. Surv. Terr., vol. 1, "Fossil Vertebrates," 1873, pp. 247, 248, 258, and Jour. Phila. Acad. Nat. Sci., 1869, (2) vol. 7, pp. 219, 229, 402.

[4] Jour. Phila. Acad. Nat. Sci., 2d ser., 1869, vol. 7, p. 229.

These fossils are generally found in a calcareous sandstone formation, the extent of which is unknown.

Southwestern Texas, especially Nueces County, has furnished numerous vertebrate remains that have been referred to the widely distributed Equus beds. Of these Cope[1] has described or identified five species of *Equus*, two of *Mastodon*, one of *Cistudo*, and one of *Glyptodon* (*G. petaliferus*).[2]

Concerning the distribution of the first-mentioned genus, Cope remarks:

> Of the five species of Equus of southwestern Texas, four have been found in the Pliocene of the valley of Mexico, and one is peculiar to the Pacific coast and basin of North America. Of the characteristic species of the eastern United States, *E. fraternus* and *E. major* the former only has been found.

The latter, however, Leidy[3] has reported farther east, in Hardin County, "from an asphaltum deposit and from a stratum of clay beneath, * * * associated with the remains of *Mastodon* and other extinct animals."

[1] Am. Nat., Dec., 1885, vol. 19, pp. 1208–1209, and 1888, vol. 22, pp. 345–346.
[2] Compare this fauna with that of Peace Creek, Florida. (See discussion of that State.)
[3] U. S. Geol. Surv. Terr., 1873, vol. 1, p. 244.

CHAPTER III.

GENERAL CONSIDERATIONS ON THE LATER ATLANTIC TERTIARIES.

CORRELATION OF AMERICAN AND EXOTIC NEOCENE.

Having completed the historico-geologic summary of the epoch assigned to us, in its relation to the political divisions of the eastern United States, it has seemed desirable to consider briefly the formations, their genesis, and their relations to the present continent as a whole.

It may be premised that our present knowledge of the Neocene faunas of North America is so far from being thorough or complete that it is entirely inadvisable to attempt in this place any correlation of American and European stratigraphical units in the Neocene. Carpenter[1] called attention to the relations which he believed to exist between the recent fauna of the Californian coast and that of the British Crag, and the writer, in common with Pourtalès, Jeffreys, and others, has indicated[2] a certain community of species which exists between the fauna of some of the Pliocene beds of southern Italy and that now living, off shore, near our southern and southeastern coasts. In a general way it is supposed, though as yet hardly demonstrated, that the American invertebrate faunas exhibited in Cenozoic and especially post-Eocene strata lag behind those of the transatlantic region in their development up to a given stage. From this it would seem as if the strata called Pliocene in south Europe might be older than those denominated by the same term in America, at least in part, or at all events that it can not be reasonably assumed that they were wholly synchronous.

CLASSIFICATION BY LYELL AND DESHAYES.

The attempt of Lyell, following Deshayes, to classify the Cenozoic strata in three categories, according to the percentage of living forms represented in them by fossils, I have stated[3] to be at the present time on the face of it impracticable, illogical, and misleading. It was origi-

[1] Suppl. Rep. British Assoc., 1863, p. 682.

[2] Bull. Mus. Comp. Zool. Reports on the Molluska of the "Blake" Expeditions, by W. H. Dall; 1881, vol. 9, No. 2, and 1886, vols, 12, Nos. 6 and 18, 1889.

[3] Am. Jour. Sci., 3d ser., 1887, vol. 34, p. 162.

nally a working hypothesis, based on the assumption that species are and always have been definite entities, about the individuality of which there could be no reasonable doubt in most cases, and which could therefore be appropriately used for numerical calculations. If this assumption were justified the rest would logically follow as a matter of course. There is no doubt that Lyell's hypothesis has been of great use in settling early Neozoic nomenclature, and has generally hitherto been applied in a manner to which little exception could be taken. But the old conception of the mathematical individuality of species has passed away, never to return, and the numerical estimates based upon it are no longer practicable in the absence of any method of determining the personal equation of different paleontologists in their estimates of what constitutes a species.

That this personal equation is in some cases a very large one, all workers are now well aware; and that it is subject to decided changes during the career of any single student is a matter of common observation. Furthermore, the specific contents of the best known faunas are subject to material enlargement from time to time, and, no matter what estimate of specific limits be in use for the time, the percentages can not remain uniform. The increase of our knowledge of geographical and bathymetrical distribution of organic beings has proved that discrepant faunas now exist simultaneously in closely adjacent regions, and that similar faunas are by no means necessarily synchronous.

The Lyellian nomenclature has, however, become an integral part of geological literature and classification. There is no good reason, as yet, why it should be disturbed. The formations originally designated by it will continue to retain their names; not because of their alleged percentages of living species, whether accurately determined or not, but because they are stratigraphic entities which have been so named and which are now recognized by those names and characterized by a recognizable assemblage of organisms.

The classification retaining these names is no longer numerical, but stratigraphic and developmental, and the formations classified under a given name are, for the writer at least, not necessarily synchronous, except where stratigraphically continuous, or synchronic only in a very wide and general sense.

It is believed that American geologists are well agreed that the minor subdivisions of the systems can not in America at present be subjected to any rigid parallelism with the minor subdivisions of other lands, and that the difficulty of correlation increases with the differences of latitude and distance. Concurring in this opinion, theoretically and practically, no attempt at such correlation has been attempted by the writer within the geological limits assigned to him.

The southeastern extremity of the United States, on the whole, presents that series of Cenozoic deposits which appears to have been laid down with the least disturbance and local denudation and the greatest vertical stratigraphic continuity of any within our geographic limits. For this reason, though our knowledge of it is still regretably imperfect, I have used the geological succession of this region as a provisional type or standard by which that of more distant portions of the country might be measured and discussed. The provisional nature of this standard must be emphasized; it is a working hypothesis, nothing more, though based upon facts more or less certainly determined.

GROWTH OF THE CONTINENTAL BORDER.

The growth of the borders of the continent has been ably discussed by Alexander Agassiz, who gives[1] conclusive reasons for supposing that in later Mesozoic time the Gulf of Mexico was connected with the Pacific Ocean across the continental divide of the present day, and therefore that some portion of the equatorial current of the Atlantic swept across wide regions now occupied by dry land and mingled its waters with those of the Pacific basin.

That this connection persisted into Eocene time there is excellent paleontologic evidence, combined with indications that the connection became less and less intimate and perhaps terminated with the Eocene. Cleve has shown[2] that powerful volcanic action was in progress in the West Indian region during the deposition of its Cretaceous strata, which are there the oldest fossiliferous rocks. To more or less synchronous disturbances of level, unaccompanied, however, by violent action of a Plutonic character, may be ascribed the unconformity, stratigraphic and faunal, which serves as the bench mark for the beginning of Neozoic time along the greater part of our Atlantic border. That in the Antilles these disturbances continued with less energy during the Eocene period, the Eocene strata, where they remain, bear evidence.

By inspection of a general geological map of the eastern United States it will be observed that the coasts along which the early Tertiary sediments were laid down, with the exception of the peninsula of Florida and the deep Mississippi gulf, reaching to southern Illinois, roughly approximate to those of the region at present, the discrepancy due to the existing belt of Tertiary rocks being least at their northeastern extreme, near the mouth of the Hudson, and greatest on those shores confronting the Gulf of Mexico. This generalization holds good if to the shore lines of the map we add the submarine areas necessary to fill out the true continental area, except that the region where the Tertiary belt is narrowest is then slightly further south, off Cape Hatteras, from which it gradually widens both northward and southward.

Agassiz holds, very justly, that modern researches have shown that, to such an immensity of prolific life as existed in the sea in which the Eocene limestone of Vicksburg age was laid down, the presence of a

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[1] Three cruises of the Blake. Boston, 1888. I, Chapters III–VI.

[2] K. Svensk. Vetensk. Akad. Handl., 1871, Bd. IX, No. 12.

vigorous marine current, bringing food and fresh supplies of oxygen, must be regarded as necessary. In the greater freedom of the warm equatorial currents and the wider sweep of their branches possible at that epoch he finds the needed factors supplied. Judging by modern faunas we conclude that the water in which these limestones were deposited may not have been very deep; certainly similar organisms flourish at present in waters not exceeding 500 feet in depth, and often much less. There can be little doubt that the sea bottom gradually and quietly sank under its load, the bottom preserving an approximately similar distance from the surface of the sea, rather than that these organisms were the means of filling up a depth of water originally equal to the final thickness of the deposit.

THE EOCENE ISLAND OF FLORIDA.

In the Floridian region the survey of the sea bottom shows an immense triangular plateau which unites Florida, the Bahamas, and Cuba, and extends from the northern end of the Bahamas toward Hatteras, as another portion of the same platform does to the westward of Florida, with a breadth equal to that of the present peninsula. Artesian borings in western Florida leave little room for doubt that the mass of this great platform (as well as of the similar plateau which includes Yucatan and its reefs) was laid down during the "Vicksburg" period of the later Eocene; that the surface, in part now deeply submerged, was once more nearly level and covered with comparatively shoal water, and that the channels which now divide Florida from Cuba and the Bahamas, though possibly initiated by fracture of the earth's crust, were chiefly cut out by a scouring process exerted by the ocean currents. Toward the end of the Eocene it is certain that the process of elevation had proceeded far enough to raise above the sea part of the summit of the western anticline of Florida, if not of both of the great Floridian anticlines, and that, during the deposition of the Nummulitic beds, this elevation (probably in the form of a chain of islets) had continued long enough for these islets to acquire a land-shell fauna as far south as about latitude 29° north. The absence of the Nummulites from the top rock of the Eocene beds farther north, between the soft Orbitoides limestone and the Chattahoochee group of rocks, is probably a purely faunal difference, as the Nummulitic beds appear to have an exact equivalent in the siliceous layers of the uppermost Georgia Eocene. Whether this be the case or not, it would seem as if in this region the Miocene was ushered in by a moderately evident stratigraphic change which is more vividly reflected in the discrepancies of the fauna than in unconformities of the rocks. The Nummulitic and Miliolitic limestones of central Florida appear to be restricted to very limited areas, and perhaps represent purely local faunal conditions which promoted the multiplication of these foraminifera toward the close of the Vicksburg epoch. The fact that nearly all the molluscan fossils of the typical

Vicksburg or Orbitoides limestone persist unchanged into the Nummulitic, and that no stratigraphic break is known between them, makes strongly for this view. The existence in the Ocala Nummulitic beds of well developed pulmonate land shells, identical in species with those which abound in the upper part of the older Miocene of the same region shows that a certain area of dry land had here appeared which was sufficiently elevated to be beyond the reach of the tide. It is now certain that the dry land of central Florida held toward the shore line of the main continent at that time much such a relation as the Bahamas at present hold to Cuba and Florida.

At the end of Eocene time the continental shoreline appears to have bordered the Atlantic in a generally northeast and southwest direction from the Hudson to the Chattahoochee. Omitting the North Carolinian projection and the Floridian peninsula, the present Atlantic coast retains a general parallelism with that which existed during the Eocene between these two rivers. There was a well marked indentation in southeastern Georgia, while from the vicinity of the Chattahoochee the shore rounded to the west, northwest, and north, forming the eastern coast of the great Gulf of Mississippi (as the embayment may for convenience be denominated) which extended to the meeting of the Ohio and Mississippi rivers in the region now constituting the southern extreme of the state of Illinois. From this vicinity the shore extended in a southwesterly direction, without striking irregularities, to the Rio Grande. At the culmination of the Eocene a movement of elevation seems to have taken place, which, without any destructive dislocation raised this shore to an extent which gave the continental margin a notable addition to its area. In conformity with what would have been expected from the hypothesis of Prof. Agassiz, the most important additions in point of area were to the southwest and on the shores of the Gulf of Mississippi. The area between the central Florida banks and the mainland was not elevated above the sea, though doubtless made much more shoal. Thence northeastward the dried Eocene border gradually narrowed, becoming a mere ribbon beyond North Carolina and reaching its vanishing point at the estuary of the Hudson.

THE GREAT CAROLINA RIDGE.

Broad off the chief mass of the southern Appalachians, in the direction of the northwest-southeast axis of South Carolina, there exists an elevated ridge of perhaps very ancient origin, and whose extension may be seen in the contours of the sea bottom far off the coast. That it is fundamentally of pre-Tertiary rocks is probable from the fact that the power of the Gulf Stream has been insufficient to cut a passage through it, and that mighty current therefore pushes up and over it. That the ridge has long been elevated may be gathered from the fact that the base of the Eocene upon it is reached at Charleston, S. C., in less than 400 feet below the present surface,[1] while to the south, at Lake Worth, on the eastern edge of the central Floridian area, the base of the uppermost member of the Eocene has not been reached at 1,300 feet. That the fluctuations of level of this ridge have been less than occurred either north or south of it may be inferred from the extreme thinness of the Neocene strata and the relatively slight elevation of its quota of the Pleistocene Columbian perezone, as reported by McGee.

CONTACT OF EOCENE AND MIOCENE.

The character of the contact at the surface of the Eocene and the Miocene is too obscure and insufficiently known, as yet, between Florida and the Carolinas; too much denuded, as in South Carolina, or more or less rémanié, as at some localities in North Carolina, to give clear evidence as to the conditions at the epoch of change. But we learn from Rogers[2] that in Virginia the Miocene Tertiary is separated from the Eocene below it by a band of pebbles or coarse sand, sometimes cemented into rock by iron peroxide. Excepting this thin band of comparatively coarse material (probably due to the acceleration of erosion by the slight elevation which closed the Eocene) there is no evidence of physical violence having intervened between the close of the Eocene and the commencement of the Miocene deposits. None of that trenched and channeled character of surface conspicuous on the pre-Eocene sandstones is here met with, but the smooth and unbroken level of the Eocene after receiving the pebbly band referred to was evenly covered by the successive Miocene strata. Yet the change in the fauna was almost complete, the Eocene species disappearing with perhaps only one or two exceptions, and a far greater variety of Miocene forms taking their place. Rogers concludes that there can be no doubt that some important physical revolution intervened at the end of the Eocene, for the distinct evidence of which we are, perhaps, to look to other and more distant regions.

The elevation of the ridge connecting North America and South America, if not so as to constitute an absolutely complete barrier, yet so as to turn the course of the equatorial current exclusively to the Atlantic, seems to furnish an abundantly sufficient cause and to be in harmony with the known facts, even if to be regarded as still insufficiently established.

In southwestern New Jersey an examination of the older Miocene marls shows them to have been laid down in a district subjected to the energetic and tumultuous action of conflicting currents, presenting almost exactly such a facies as does the material dredged off the similarly agitated area seaward from Cape Hatteras, North Carolina, at the present day. The meeting of northern currents with the Gulf

[1] Section of Charleston artesian well to accompany the report by Prof. James Hall, in the City Yearbook for 1884.

[2] Geol. of the Virginias, 1884, pp. 266-267.

Stream, which now takes place near Hatteras, may at that time have occurred between the Potomac and the Hudson.

WARM AND COLD WATER MIOCENE.

With the elevation which closed the Eocene and added so broad a margin to much of the continent, an acceleration of erosion over the whole area elevated was necessarily begun. The different branches of the equatorial current no longer able to escape in the direction of the Pacific must have been turned northeastward. In the deeper channels, as between the Floridian banks on the one hand and those of Cuba on the other, a scour must have been inaugurated which cut a fair way for the waters through the loosely aggregated organic sediments of the Eocene epoch. According to Cleve[1] the Miocene epoch in the southern and eastern Antilles was a time of continuous quiet and continuous gentle sedimentation with a profusion of animal life. On either side of Cuba, however, active submarine erosions must have been in progress. North of the Floridian banks it was probable that the water was too shallow to admit of the passage of any considerable current. The character of the Miocene strata and their contained fossils bears evidence in favor of this supposition. The increased sedimentation of terrigenous matter in the Gulf of Mississippi wafted eastward by the northern branch of the equatorial current (analogous to that now known as the Gulf Stream) and deposited on these shallows is probably responsible for the argillaceous character of the older Miocene beds of this region, which also, over a considerable region, carry a fauna appropriate to shallow and muddy waters. This fauna and that of the immediately succeeding beds in Florida is strongly Antillean in type, as might be anticipated on shores washed by strong currents from the West Indian region. A few Antillean species (e. g., *Cumia woodii* and various species of *Volutidæ*) penetrated the northern waters even as far as New Jersey. At no succeeding epoch do we find such tropical or semitropical littoral mollusks extending northward to such a distance from their present range. This fact may authorize the suspicion that the newer leaf-beds of Greenland and other parts of the Arctic sea, indicating a time when walnuts ripened on shores which now support the burden of the Inland ice-sheet, if really Miocene as has been claimed, may have been contemporaneous with the warm-water Old Miocene above described.

It is not improbable that, with the increasing elevation of northern Florida, in the absence of the present southward extension of the peninsula, and with the probable synchronous elevation of the Great Carolinian ridge, above described, a change was inaugurated. In the presence of such modifications of the coast, necessarily involving a modification of the direction of its flow, it may be surmised that the

[1] K. Svensk. Vetensk. Handl., 1871; Bd. IX, No. 12; Agassiz: Three cruises of the *Blake*, vol. 1, p. 109.

course of the Gulf Stream in the main was gradually turned more off shore than before or at present, and that, concurrently, there arose a greater opportunity for the influx of a cooler northern current inshore in a southerly direction. To this may be ascribed the development of the succeeding newer Miocene fauna, characteristic of the beds of what has been called in this essay the Chesapeake group, chiefly developed in Virginia, Maryland, and North Carolina. The preceding Eocene fauna, as well as the Old Miocene, was southern, or, at least, one which might nowadays be expected in fairly warm waters. The influx of colder northern waters, brought about as above suggested, might exterminate almost the whole of such a fauna by being too cool for the development of the invertebrate embryos, even in so widespread and adaptable a creature as the common oyster. Brooks has shown that a fall of a few degrees in the temperature of the water at spawning time will prevent the survival of the embryos subjected to it.[1] It is not necessary to postulate a very cold or Arctic current, only a current less warm by a certain amount than the antecedent sea temperatures. In this we might find an explanation of the phenomena noted by Rogers. This is the more likely because in the Floridian region, where the waters must have continued to be fairly warm, we find a very considerable percentage of Eocene species surviving into the Miocene beds. The change from clear sea water to that containing a considerable amount of clay and other sediments would induce much such a change in the fauna as we actually find in the northern Floridian region.

The Chesapeake fauna seems to have crept gradually southward. Profusely developed in the Chesapeake region, it becomes more sparse as we follow the beds southward where the temperature of the water would be less rapidly and completely changed. The difference is noticeable in North Carolina and still more so in South Carolina, as pointed out by Tuomey, Heilprin, and others.

The deposition of the older Miocene about the Florida islands or banks was accompanied by an increase in the area of land and a probably very slow and gentle elevation. With this was developed a profuse land-shell fauna, while the fresh-water lakes, which took the place of former marine lagoons, afforded a synchronous fresh-water fauna.

Subsequently to this the extended islands of the Florida banks became the seat of enormous rookeries of birds, seals, and other animals. The fresh guano supplied by these, washed by the constant rains, penetrated the porous organic limestones of which the land was composed, and thus was secured that precious store of phosphoric acid which is now bringing wealth to the owners of Floridian lands. The reception of the guano must have been after the deposition and elevation of the old Miocene strata, because they are the most generally and consist-

[1] The adult animal flourishes well in San Francisco Bay in spite of the low temperature of the water, but no one has ever succeeded in propagating the eastern oyster there. This is an excellent example of the far-reaching effect on a fauna of small differences of temperature.

ently phosphatic of any of the Floridian strata. But the underlying Eocene rocks received their share, and when the latter, as in the most elevated places, formed the top rock, no Miocene intervened. From the rehandling of detritus from the Miocene and Pliocene beds is probably derived the minuter proportion of phosphate of lime which is occasionally found in the newest of Floridian limestones.

At the end of the period of elevation, which characterized this epoch in Florida, an equally gentle and probably moderate depression followed. Over the area near Tampa, where the land shells had flourished, 15 or 20 feet of marine limestone was laid down; though all the land was not submerged, for a few land shells, such as love sea beaches, are found in this limestone to the very top. The marine fauna is largely mingled with species common to the rocks of the period of elevation. On the northern border of the Gulf of Mexico then existing and the southern sea margin of Georgia, this period was marked by sediments of erosion; in the Floridian region by organic sediments faunally connected with those which had preceded them. This fact, with others which might be noted, points toward an orographic independence of the central Floridian region, which is very noteworthy when contrasted with the interrelations in orogenic growth of the continental beds, and their much greater vertical fluctuations which seem to be indisputable.

Invasion of the Chesapeake fauna.—At the conclusion of the operations by which the sediments of the Tampa group were laid down, a very marked change took place, analogous to the change noted by Rogers in Virginia between the Eocene and Miocene faunas. Whether the small depression noted in Florida was synchronous with a greater one northeastward, or whether some other factor must be invoked to account for the facts, it is, at all events, certain that the shores of Florida, east and west, those of the northeastern part of the Gulf of Mexico, and those of the Georgia embayment, whether still continuous with the gulf or not, experienced a wholesale invasion by the fauna of the Chesapeake group. This, in connection with the evidence of depression on the mainland shore of the gulf at the same period, indicates that the northern cooler inshore waters for a time were able to penetrate even to the Gulf of Mexico, bringing the northern fauna with them. However brought about or explained, this change, from the older to the newer Miocene, is the most marked and extensive mutation which is traceable in the fossil invertebrate faunas of the Floridian and Gulf region, after the Eocene, in the whole of Neocene time.

Our present information permits us to assert with positiveness that, after the end of the older Miocene, the Floridian banks and their associated islands remained still insulated from the continent to the northward. All the facts that we have point toward such an insularity accentuated by orogenic independence. That an elevated region, from which detritus is constantly being transferred seaward to the base level of erosion, must submit to fluctuations of level in the portions most affected by such transfers of material, seems almost certain. If to this be added occasional vigorous orogenic action, then to distinguish in local stratigraphic records the changes due to general continental movement from those to be ascribed to more local causes, becomes very difficult. That more or less constant changes did take place on the continental border there is abundant evidence.

On the other hand the broad and level Floridian banks, built of organic sediments, could not have been subjected to transferrence of large bodies of detritus in such a fashion. The peculiar character of the rocks, elsewhere more fully described, led to erosion by solution instead of attrition; and the whole surface, in a general way, suffered equally; so that the factors were wanting which would bring about changes like those occurring locally on the continental border. To this in great part may be ascribed the apparent freedom from minor fluctuations presented by central and southern Florida. To general continental movements the mass of the banks would seem to have responded in some degree, but much less energetically than the continental border nearer the centers of disturbance. In the Georgia embayment, at that time the Atlantic entrance of a broad and shallow strait connected more or less directly with the Gulf of Mexico, a considerable mass of sediments was laid down during the Chesapeake period. At Jacksonville, which represents a point toward the southeastern portion of the embayment, about 400 feet of Miocene limestone, apparently of this age, has been drilled through in artesian wells. This would seem to represent a deposit formed in only moderately deep water, while that on the west coast of the Floridian banks and the north shore of the Gulf of Mexico did not reach any such thickness. Farther south, at St. Augustine, the deposit reached less than 200 feet. On the continental shore, to the northward, 30 or 40 feet seems to be the extreme thickness yet observed there.

It is notable that on the continental shore the bluish gray matrix and grayish white color of the fossils of the Newer Miocene agree exactly with those of the Chesapeake region, while the deposits containing the same fauna on the insular Floridian area partake more of the color and texture of the other beds of which that area is composed.

GRAND GULF PEREZONE.

The drainage of the continent entering the Gulf of Mississippi then as now brought with it abundant sediment, clay, sand, and gravel. These would have contributed not merely to the general shallowing of the gulf but also to a deposit along the neutral zone where the tides and currents of the Gulf of Mexico, dominated by the Gulf Stream, introduced a disturbing factor into the circulation and dispersion of the brackish and muddy waters of the estuary. The termination of the Chesapeake invasion, through changes of level accompanied by changes of water temperature, which seems probable, if accompanied by an upward movement on the south, would harmonize well with the formation of a brackish water perezone at the time indicated.

The estuarine sands and clays doubtless began to be laid down at a much earlier time and through the Chesapeake period served as a barrier to westward migration of the Chesapeake fauna. The elevation which terminated the deposition of the Chesapeake beds on the shores of the Gulf of Mexico was probably that which definitely united the Florida banks with the continental margin adjacent to them, and may have begun while those beds were still forming, as seems to have been the case in part of the region included in Central America. A striking illustration of the elevation which terminated the Miocene is afforded by the little state of Costa Rica, as described by the late Dr. William M. Gabb, who says:

The geology of Costa Rica is extremely simple, the formations being few and the structure with but few complications. The greater part of the rocks are sedimentary, of Tertiary age, the remainder being eruptive, of comparatively recent origin. The oldest sedimentary rock, that which makes up nearly all of the interior mountain chains and in all probability underlies all of the great plains, is of Miocene age. It is pushed up into steep dips in the mountains of Talamanca by an intrusion of granitic rocks, which have been laid bare by denudation, falls into gentle undulations in the lower hills and becomes level on the flat ground. Bordering this on the coast are small deposits of later age. Near Moen, on the railroad, between there and Limon, there is a deposit of clay of Pliocene age, abounding in fossils.

The granitic rocks are confined to an irregularly shaped, long, narrow mass, which has been intruded after the deposition of the Miocene, forcing the central portion up to a height of nearly 12,000 feet, the lowest exposure of the granite being no less than 3,000 feet above the sea.

Volcanic rocks form a prominent feature of the geology of Costa Rica, breaking through and often covering the Miocene sedimentary beds. Dikes of porphyritic material are common. A large part of the mountainous region is of volcanic origin.

The communication between the Atlantic and Pacific in the region of Costa Rica was interrupted in the Pliocene or subsequent to the deposition of the mass of the Miocene strata.[1]

On the Chattahoochee we have, overlying the Ecphora bed, a thin stratum of lignite-bearing sand with impressions of palmetto leaves. Within 50 miles westward from this river, in an area still geologically unexplored, we have the eastern termination of the formation known as the Grand Gulf group, characterized by clayey and sandy or siliceous sediments bearing fossil wood and particles of lignite, a few oysters and other brackish or fresh-water shells, and impressions of palms or palmettos. Whether the lignitic sand of Alum Bluff represents the thinned-out eastern margin of the Grand Gulf beds or not, it is not improbable that it may. The definite cutting off of any exit for the currents from the Gulf of Mexico north of the main body of the Florida banks must have confined those waters to much such a field as they at present occupy. It is therefore by no accidental coincidence that we find the modern terrigenous deposits of the Mississippi drain-

[1] Gabb, W. M.: MS. Report on the Geology of Costa Rica, in archives of the U. S. Geological Survey. See also Am. Jour. Sci., 3d ser., 1875, vol. 9, pp. 198, 320.

age, on the northern floor of the gulf, parallel to and coinciding in east and west extension with the Grand Gulf perezone.

The elevation which brought these beds to the surface and insured the silting up of the Gulf of Mississippi was not necessarily very great in vertical extent. It perhaps coincided with some depression to the north, since there we find beds representing Grand Gulf silts laid down upon a basis of fragmentary limestone derived from Vicksburg Eocene beds below[1] and with no trace of the Miocene which, to the southward, intervenes between them.

That the formation of the Altamaha grits of the Chesapeake beds and of the Grand Gulf beds was to some extent synchronous can hardly be doubted and would accord with the fact that over both the latter in the gulf region and over the Chesapeake beds in Virginia is laid down, according to McGee, Johnson, Hilgard, and other authorities, a single great perezonal formation. There is no doubt that directly in contact with the Grand Gulf beds in the Gulf States and with the Chesapeake group in Virginia lies the formation variously recognized under the names of Lafayette or Orange Sand of Hilgard,[2] Lagrange of Safford, or Appomattox of McGee. If the Grand Gulf sedimentation went on for any great interval of time after the conclusion of the Chesapeake beds it would seem inevitable that something should be found above the Chesapeake group in the north and below the Lafayette to correspond with that interval; which, so far as we are informed, is not the case.

LAFAYETTE PEREZONE.

The Lafayette from McGee's investigations, which are more comprehensive than any antecedent studies of the formation, consists of sediments of erosion derived chiefly from subjacent or closely adjacent rock masses. The distribution of these sediments corresponds with the inner margin of the coastal plain from Virginia southward and around the southern end of the Appalachian uplift, marginating the Gulf of Mississippi. Though not yet traced in the field, it is undeniable that this formation must have traversed Arkansas, Louisiana, and Texas in the same perezonal form as on the east of the Mississippi gulf. It or its remains will be found there on proper investigation.

The formation is more or less colored with iron oxide, which characterizes it almost everywhere. It is narrow in Virginia and North Carolina, where it is said to reach between 100 and 200 feet in thickness. As it traverses the region of the Great Carolinian ridge it widens and doubles or trebles in thickness. To the south it becomes thinner again until it crosses the main axis of the Appalachian uplift, where again it is said by McGee to reach a thickness of 450 to 550 feet, thus presenting the peculiarity of being thicker over the ridges and thinner along

[1] L. C. Johnson in Am. Jour. Sci., 3d ser., 1889, vol. 38, p. 213.

[2] Barring some not very important subtraction of Tuscaloosa beds.

the flanks of the highlands. It has few fossils, except those derived from other formations. Such as are autogenous are chiefly like those of the Grand Gulf beds, fragments of lignite and leaf impressions. Its material is largely cross-bedded or obscurely stratified, and consists chiefly of sands and clays with occasional stream gravels. Its lowermost portion is not greatly elevated above the sea; on the authority of L. C. Johnson it is said to reach tidewater in Mobile Bay; while in the Gulf of Mississippi and on a large part of the Atlantic coast it is supposed to average 25 to 50 feet above the level of the tide, reaching an extreme basal elevation of 150 feet at some localities in Virginia and the Carolinas.

The immense mass of material which would seem to constitute this formation must, to some extent, have been laid down in water. The relation of the local beds to the local older beds show that the erosion was not violent, though it may have been long continued. The characteristics assigned to it would seem to necessitate a subsidence of some 500 or 600 feet of the whole continental Atlantic and gulf border, the reconstitution of the Gulf of Mississippi, and a long-continued period of moderate erosive processes. To account for the absence of a marine fauna in any part of it would seem difficult, unless it be assumed that the subsidence and sedimentation were synchronous and practically so equal as to keep this sandy perezone in the condition of a fresh or brackish water estuarine formation from its inception to the succeeding period of elevation.

The Floridian region south of the Suwanee strait still seems to have been exempt from the experiences of the region north of it, to which view the close approximation of the Lafayette to the sea level on the northern shores of the gulf would seem to lend a further shade of probability. The organic limestone of the peninsula at any rate would afford no such sediments as constitute the Lafayette beds, and even if erosion took place it would assume a different form and the results would possess none of the continental characteristics. If the northern part of Florida was during Lafayette time again depressed it may be that a part of the arenaceous covering which now envelops it was received at that time, affording material for subsequent rehandling up to the present moment. In any case in Florida the depression was moderate in amount and gentle in its progress and reaction, so far as we can judge from the recorded data in the region concerned. The continuity of the marine fauna of the coasts was not greatly interrupted. The bulk of the Chesapeake fauna had disappeared, but many forms had become permanently acclimated and still persist. This is especially the case with a number of the largest bivalves, which would be particularly liable to extinction by any sudden elevation of the coast, even if it were of but moderate vertical extent. With this evidence we may safely conclude that the change of level was gradual. Whether the disappearance of the newer Miocene beds from a large part of the Carolinian region was due to causes connected with this period of elevation, or to those of a subsequent epoch we are not in a position to decide. Perhaps the latter is the most probable surmise. The changes which followed the Lafayette sedimentation can not yet be clearly discerned except in special details.

It is certain that the elevation which resulted in or followed the end of the operations connected with the formation of the Lafayette, added considerably to the area of southwestern Florida and probably dried out the Gulf of Mississippi and the Georgian embayment.

PLIOCENE DEPOSITS.

The marine Pliocene fauna which succeeded the Chesapeake Miocene, was of a more tropical character than that of the latter, and its members indicate clearer water and a greater abundance of food. The presence of numerous corals lead to the inference that the motion of these waters, perhaps part of the Gulf Stream, was felt more strongly; as it might be if by the elevation its exit-way had become more straightened.

This fauna, as I have elsewhere urged, reached South Carolina and perhaps even to the southeastern extreme of Virginia, but nowhere do the deposits containing it seem to have reached more than a few feet of thickness. In South Carolina it would seem as if a subsequent denudation had removed the greater part of the little which was deposited.

In Florida the accessible evidence points toward an extensive development of fresh-water ponds or lagoons in which species of ***Planorbis***, ***Physa***, and ***Vivipara*** multiplied to a remarkable degree. The evidence of a certain proportion of such ponds in close proximity to the sea, from a very early period in the marine Pliocene, is definitely established. The gradual change in the character of the marine fossils from below upward in the beds shows that a gradual shoaling of the water took place, probably from a slight motion in elevation of the land, until the species proper to a moderate depth were replaced by those characteristic of muddy shallows and tidal flats, and finally by an exclusively fresh-water fauna. The latter condition was not attained without some trifling fluctuations, which may, however, merely represent temporary inroads of the sea after exceptional storms upon lagoons which, under ordinary circumstances, were filled with fresh water.

It seems reasonable to associate the epoch of the Planorbis rock of southwestern Florida with that of the great Lake De Soto or the several large lakes which seem to have occupied the medium syncline of the peninsula a little to the northward. The last evidences of the Pliocene are comprised in the relics of the lakes and the silicification of the Planorbis rock.

Before the termination of the marine Pliocene deposits the permanent connection of the peninsula with the continent was accomplished and the lowlands invaded by a host of large vertebrates. The rhinoceros, the wild horse, the llama, the Columbian elephant, the mastodon, the glyptodon, and various enormous tortoises wandered along the shores of the lakes and through the marshes, while the saber-toothed tiger lay in wait. To what extent, if any, this fauna was affected by the glacial epoch of the north is unknown, but there would seem to be no reason why these animals should not continue to flourish in the warm marshes of Florida, notwithstanding the presence of an inland ice sheet in Pennsylvania and the Ohio valley. The subsequent depression of much of the continental border, during which the Columbia sands of McGee were laid down, may perhaps be as fairly regarded as a reaction corresponding to a northern rise after a melting of the first ice sheet has relieved the north from its weight as in any other way. But here we are wandering, so far as the southern Atlantic border is concerned, in a maze of hypothesis.

What we know is that before the deposition of the marine Pliocene strata of south Florida was ended (whether synchronous with other strata elsewhere called Pliocene or not) the invasion of these vertebrates began; that their remains lie below marine Pliocene strata as well as under the whole belt of superficial sands (in Florida and inferentially also in South Carolina), imbedded in the Alachua clays or associated with remnants of older phosphatic rocks in the Peace Creek phosphate beds and the Carolinian marls; that at a later time a general, though slight, depression of the peninsula began, without any obvious change of plane from the previous general horizontality, or any general change of fauna among the invertebrates, except the extinction of a number of the largest and most striking species of mollusks, chiefly gastropods. The great lakes perhaps were emptied; but their trough was apparently not filled with salt water, which encroached chiefly on the seaward margins of the peninsula and of the Atlantic coast northward. In Florida beds of incoherent marl and sand were deposited containing nothing but recent species. Farther north the discrepancy in vertical motion during such changes, when compared with that of Florida, is again manifested; on the whole increasingly so, as we go northward, excepting over the great Carolinian ridge.

At last the reaction came, and Florida rose again apparently about as much as it had been depressed, but with indications of a slight tilting or inequality which elevated the Atlantic border with its reefs more than the gulf shores. Since then the work of geologic forces has been chiefly exerted in the building of coquina and vermetus rock, in the solidification of æolian sandstone and battered coral reef, in the formation of modern oolitic rock, and the slow cementation of loose material by iron oxides. Waste has gone on in the old way by the slow and gentle processes which lead to solution and decay; and growth, chiefly by chemical precipitation of dissolved lime carbonate, by organic sediments and by wind-blown or sea-tossed sands.

The details of these processes, briefly and in many cases but provisionally indicated here, are for the future. Perhaps in no way better than by such an attempt to sketch their broader outlines can be made plain the imperfections of the record and of our knowledge of it.

TABLE SHOWING THE VERTICAL RANGE OF THE NEOCENE FORMATIONS OF THE ATLANTIC COAST.

Eocene.	Miocene.			Pliocene.			P. P.	Formations.
	L	*M*	*U*	*L*	*M*	*U*		
					—			Alachua clays.
	—	—						Altamaha grit.
		—						Alum Bluff beds.
					—	—?		Appomattox formation.
				—	—			Arcadia marl.
—	—	—	—	—	—	—		Atlantic group.
					—	—		Caloosahatchie beds.
		?—	—					Carolinian.
	—?							Cerithium rock.
	—	—						Chattahoochee group.
	—							Chattahoochee limestone.
			—					Chesapeake group.
	—	—						Chipola beds.
		—						Chipola marl.
				—	—			De Soto beds.
			—					Ecphora bed.
			—					Fayette beds.
	—							Ferruginous gravel.
				—	—	—		Floridian.
			—	—?				Gay Head series.
		—						Gnathodon bed.
		?—	—					Grand Gulf group.
			—					Grand Gulf sandstone.
—	—	—	—	—	—	—	—	Gulf group.
	—							Hawthorne beds.
		—						Infusorial earth.
		?—	—					Infusorial stratum.
			—					Jacksonville limestone.
					—			Lagrange group.
		?—	—					Marylandian.
	—	—	—					Mississippi clays.
					—?			Nashaquitsa series.
						?—	—?	Naushon series.
	—							Ochesee beds.
					—	—		Orange sand group.
	—							Orthaulax bed.
					—			Oyster marl.
			—?					Patuxent beds.
				—	—			Peace Creek bone bed.
			—					Perna beds.
						—		Planorbis rock.
	—							Shiloh marls.
	—							Sopchoppy limestone.
			?—					St. Mary's beds.
			—	—	—	?		Sumter beds.
		—						Tampa beds.
	—	—						Tampa group.
		—						Tampa limestone.
					—			Turritella marl.
						—		Venus cancellata bed.
			—					Virginian.
			—					Waldo formation.
					—?			Weyquosque series.
	—	—						White Beach sand rock.
						?—	—	Yellow sand.

CHAPTER IV.

SUMMARY OF OUR KNOWLEDGE OF THE NEOCENE OF THE PACIFIC COAST OF THE UNITED STATES AND CANADA, CONSIDERED BY STATES.

CALIFORNIA.

The geology of the State of California is still very imperfectly known, so much so that a general view of it is at present impracticable. The details here given are gathered from various sources, the most important of which are the reports published by Prof. J. D. Whitney, late State geologist, and those associated with him on the survey of the State; and subsequent researches by various members of the U. S. Geological Survey. The State mining bureau has recently issued a petrographic and geologic map of California, which, however, presents but little that had not been previously made known. The earlier reports by Trask, Antisell, and others were chiefly economic, and much of their information is of a general character, but they have been occasionally referred to in default of more specific data. The compilation which follows is derived almost exclusively from the literature, and for the reasons above given it can not appear otherwise than fragmentary.[1] There is some reason to suspect that much of the fossil fauna referred to as Pleistocene by Gabb, in his Paleontology of California, may prove from the number of extinct species included in it, analogous rather to what has been regarded as Pliocene on the Atlantic border, or that, as at Santa Barbara, species from two horizons have been confounded. It will be understood that in referring to various formations, as Miocene or Pliocene, the compilers accept no responsibility beyond that of correct statement of what has been recorded by others, except where otherwise indicated.

THE GREAT VALLEY OF CALIFORNIA.

California west of the one hundred and eighteenth meridian west from Greenwich, consists essentially of a great valley extending 450 miles northwest and southeast, with an average width of about 50 miles,

[1] It is known that the same type of geologic structure extends for some distance south of the boundary between the United States and the Mexican territory of Lower California. In the vicinity of Todos Santos Bay 50 miles south of the boundary, Cretaceous, Miocene and Pleistocene fossils have been collected, but nothing referable to the Eocene. The Miocene fossils are largely silicified, appear on the surface not far above the sea level, and belong to the same epoch, apparently, as those which have been collected in the vicinity of San Diego, California. Cerros Island also affords Miocene fossils, in a sandstone.

walled in on the east by the high and rugged Sierra Nevada, on the north by the Siskiyou Mountains, and on the west by the less elevated Coast ranges which at the south recurve toward the southwestern spurs of the Sierra. The valley of California, drained by the Sacramento and San Joaquin rivers, has a single outlet, the Golden Gate, the entrance of San Francisco Bay. This divides the Coast ranges into two groups, which are most conveniently taken up separately. The Coast Range, composed of a large number of small folds having a trend generally parallel with the coast, incloses here and there a number of small valleys, reproducing in miniature the topographic type of the great valley. Along much of the coast the mountains come close to the shore, and the sea is bold-to, so that there are neither harbors nor even landings.

The region east of the one hundred and eighteenth meridian is largely arid and partakes, except near the coast, of the character of the adjacent desert or semidesert region of Arizona and Nevada.

Recent changes of level.—All the evidence indicates that this region has undergone remarkable changes of level and orogenic activity at a very recent geologic period. There is no doubt that since the end of the Pliocene, part of the coast of San Diego County, for instance, has been at a level 600 feet lower than at present.[1] Farther north much greater fluctuations are reported. The Santa Barbara Channel separates by 25 miles from the mainland, a group of islands which in early Pleistocene times were connected with the mainland and afforded pasturage for the mammoth. Since man first made his appearance in this region the whole topography of the country has suffered material change to an extent unparalleled, so far as known, in any other part of the world. In spite of all this the submarine topography is so abrupt, immediately off the coast, that the continuity of the invertebrate fauna has been relatively but little interrupted by these violent physical changes, and quite as large a number of recent species appear in the Miocene fauna as one would expect to find in regions of very much less disturbance.

Before proceeding to take up the highlands in their order, a few notes may be recorded in regard to the great interior valley. They are derived from the experience of Mr. Jerome Hawes, of Stockton, California, whose specialty has been for many years the boring of artesian wells for water, oil, or natural gas. No one else has so thorough a knowledge of the underground conditions of the valley of California.

According to Mr. Hawes,[2] in boring in the valley away from the foothills, the strata exhibit great uniformity everywhere. They consist of clays and sands, the beds of clay becoming thicker as one bores deeper, and the beds of sand, usually 6 to 8 feet, remaining unchanged, so that the proportion of clay gradually increases, sometimes reaching 100

[1] Dall, Proc. U. S. Nat. Mus., 1878, vol. 1, p. 3.

[2] Verbal communication to W. H. Dall, in August, 1890.

feet without a break in the bed. The layers appear perfectly horizontal. Gravel is rare. In the city of Stockton, in the very center of the valley, at a depth of about 100 feet, there is a layer of which the pebbles reach the size of cobbles. At the well in the yard of the courthouse, in the center of the city, this layer is 58 feet thick, and also at the Hawes gas well; but, laterally from a line drawn between these two it diminishes in thickness and runs out to a few feet at a distance of a few blocks from this axis. From this down to about 1,400 feet there are merely alternating layers of clay and coarse sand. At about 1,400 feet there is more gravel with rounded pebbles, usually not exceeding $2\frac{1}{2}$ inches in diameter, mostly quartz or clay porphyry, and often with a thin black coating of iron oxide. The greatest depth yet bored is about 2,100 feet, but no rock has been reached at that depth. At 1,100 feet the water begins to be somewhat saline, and contains magnesia, sodium chloride, some borax, traces of petroleum, and bubbles of gas. At 1,400 feet there is less salt, so that it is hardly perceptible to the taste, but there is more borax, and the water has a temperature of 90° or thereabouts. Below the gravel it becomes more saline again. It is not potable below 1,100 feet. Stockton, it may be stated, is but little above the level of the sea, the influence of the tide being felt there in the river daily.

Twenty miles east from Stockton, at the edge of the foothills of the Sierra, at a depth of 200 feet the drill struck a layer of water worn granite cobblestones in a volcanic matrix. After boring through this over 100 feet, gravel and sand as in the valley were reached, and no more rock was found when drilling ceased at a depth of 900 feet.

According to Mr. Hawes the gravel is traceable to the Sierras. The sand and clay from the Sierra side is different in texture and color from that on the Coast Range or western side of the valley. But on the west, after boring through about 500 feet of Coast Range detritus the drill comes to Sierra gravel and thereafter continues in it, showing that the latter underlies the Coast Range talus.

At the southern end of the valley the flow of water is purer, more powerful and more profuse than in the northern part. The decrease northward is so gradual that Mr. Hawes supposes the artesian water of the valley proceeds more from the south than from any other direction.

No fossils have been found in the valley borings and only once when boring at the edge of the hills. Small twigs and particles of wood are occasionally brought up, but no large pieces. The harder nodules of the clay are sometimes perforated with holes about half an inch in diameter like the tunnels of some animal. These sometimes have a limy coat internally.

The indications of these data are that the valley as an estuary is older than the volcanic conglomerate and than the present elevation of the Coast ranges; that its bottom has been depressed below its original level either by mountain-building forces or by subsidence; that deposition first from the Sierras and subsequently also from the Coast ranges has gone on continually and without any notable tilting of the deposited material; that the ejection of the volcanic conglomerate did not interrupt the general detrital action which is still going on; and, lastly, that during this period the valley has for the most part maintained a perezonal character, not supporting marine life nor affording favorable conditions for the existence of fresh water shells. Much of it is doubtless filled with deposits of Pliocene age, if not even older, though the superficial portion of course belongs to the most recent times. The sandy and gravelly layers are covered with a rich blackish loam in great part of vegetable origin and very fertile. This is most abundant and thickest away from the hills, near which it gradually disappears giving place to more barren detrital soil, or even to basaltic rock or volcanic conglomerate almost bare of soil.

This valley in later Mesozoic time was occupied by an arm of the sea, and this condition was maintained to some extent at least as long as to the latter part of the Miocene. The marginal marine beds beginning with those referred to the Chico have been much broken up, eroded, and contorted, as a result of the physical changes which have taken place. At the northern end of the valley, where the Mesozoic sea washed the base of the Siskiyou schists of that epoch, something of the old state of things can be made out.

Near Redding, along the line of the railroad between that town and the station called Middle Creek, the valley begins to widen, showing its floor to be composed of irregular edges of the upturned schists laid bare by the floods which annually pour down the canyon of the upper Sacramento. They are more or less covered by coarse reddish gravel, containing many rather large cobbles. One-third of the way from Middle Creek station to Redding the schists come to an end and against them unconformably abut the somewhat crumpled sandstones of the Chico, mostly a good deal tilted, dipping to the south and west, and containing characteristic Upper Cretaceous fossils.

Over these lie a 10 or 12 foot stratum of gray sand with enough clay in it to give the mass stability. This bed is certainly Neozoic. It is remarkably uniform in texture, free from pebbles or other fragments, and shows no fossils. Though crumpled, it is less disturbed than the sandstones below it, and, on the whole, more horizontal. Half a mile of it is visible in the section. Conformably over it lie the same coarse gravels which farther north overlie the schists and which in some places have been incorporated with volcanic outflows, forming a sort of conglomerate very common around the valley. The lava flows which have brought this about are probably to a large extent Pleistocene.

The elevation of the Coast ranges has taken place to a certain degree since the beginning of the Miocene, but it is by no means probable that this was its first elevation. On the contrary, they are largely based upon schistose ridges, like the Siskiyous, which are of older origin, but which are still imperfectly known.

A large part of the Coast ranges is formed of fossiliferous Miocene sandstones more or less altered, contorted, and tilted up. On these at high altitudes are frequently found marine Pliocene and even Pleistocene fossils. The fluctuations and changes of level which have characterized the coast of this region since the beginning of the Neozoic, as the fossils prove, can hardly be realized except by the observer in the field, and any attempt at description would read like vagaries of a vivid imagination.

Notwithstanding their comparative youth, the valleys of the Coast ranges are not unlike the great valley of California on a minor scale. A few notes on the Livermore valley[1] will serve to illustrate their general features.

THE LIVERMORE VALLEY.

The Livermore valley is the largest valley of the Coast Range north of Mount Hamilton, and unlike most of the valleys of this range is well watered, agriculture requiring no irrigation, the rainfall amounting to some 12 inches per annum. The entire watershed is discharged into San Francisco Bay through Niles Canyon by the so-called Alameda Creek. Within the valley are a large number of branches of this creek, each draining a smaller valley or canyon of its own.

Of these the southeasternmost is the Arroyo del Viaje, or Valle, which discharges by a permanent stream into a small rounded basin, from which there is a narrow passage into the Livermore valley proper. Here the hills are composed of gravelly strata covering Miocene sandstone. The lower layers, near or in the bed of the creek, are composed of river pebbles, mixed with worn and broken Miocene fossils; oysters, *Venus*, *Tapes*, and other bivalves predominating, crushed together with many smoothly worn quartzite pebbles. The rock is very hard and the material obviously is the compacted result of the mixture of stream gravels with beach worn marine fragments. The strata are a good deal contorted, but those above lie conformably upon them. The dip is entirely variable, but preferentially eastward to some 30°.

A mile or two up the canyon one meets contorted schists, much crushed and cut in every direction by larger and smaller veins of quartz and jasper. These veins furnish the pebbles found in the later sandstone and clayey strata, together with cobbles composed of the harder water-worn fragments of the metamorphic schists. The sandstones lie unconformably on and against the schists, somewhat as at Redding. Their lower layers as described are full of fragments of shell but none in their natural shape, condition, or position. The upper layers vary in composition, but are more largely sandy and with numerous sandy concretions surrounded with thin layers of iron oxide and here and there traces of vegetable remains, but offering very few pebbles and practically destitute of fossils. The layers vary in thickness, yet the fluctuations appear

[1] Made by W. H. Dall in September, 1890.

to succeed each other with something like regularity. The upper beds are frequently pale greenish or whitish where weathered, or a little blue internally. They weather easily, and fragments exposed to the air gradually slack up into loose sand. Here and there are clayey layers or lenticular masses which intercept the infiltrated iron and are often very hard. The uppermost beds as a rule seem rather more horizontal than those below, as if the series had been deposited while changes of level were in progress.

Above the rocks, lying unconformably upon their eroded edges, is a layer (5 to 10 feet thick) of clayey soil full of pebbles of all sizes up to cobbles, mixed with weathered concretions from the underlying sandstones. The beds of the brooks are full of gravel and pebbles which were first derived from the schists, but which have been utilized more or less in all the subsequent strata and may have been washed out from any of them.

The talus of the steep hills is often composed almost wholly of this gravel, the finer materials having been carried away. The above description of the Miocene rocks of this particular locality will give a very fair idea of the Miocene beds as they appear in many places in the State; the differences chiefly arising from the greater or less amount of disturbance which the strata have suffered, or the more quiet and even sedimentation originally possible in some more favorable localities free from the influence of streams and surf.

The more level floor of the valley away from its borders is largely composed of brown loam, derived from the uppermost clayey layer above referred to, mixed with vegetable soil. Farther north there is in the valley and on many foothills a very deep layer of the so-called "black adobe," a black clayey loam, which is extremely fertile, but which in wet weather forms an almost impassable mire and in dry weather shrinks, forming deep vertical cracks running in all directions.

The Miocene sandstones of this vicinity attained a thickness of several hundred feet. Near the mouth of the Tessajara Canyon the stream cuts deeply into the level plain, affording a good section. The material derived from the adjacent hills is deposited in nearly horizontal layers covered with 5 to 10 feet of black adobe. Worn fossils derived from the adjacent sandstones are sparsely scattered through the alluvium. As the traveler goes from the hills toward the middle of the valley the land is seen to be more and more fertile. As he approaches the schists it becomes less and less fertile, until it is practically barren.

The Arroyo Mocho is next northeast from the Arroyo del Valle, and most of the rocks are tilted sandstones; but about 9 miles from Livermore, on the crest of the ridge, as the road runs, the schists make their appearance at an elevation of about 1,800 feet. They are much contorted, and graduate upward into a clayey rock containing much iron, which has been ground for paint. The mineral springs of Agua Vida, 10 miles from Livermore and 1,750 feet above the sea, issue from the schists.

The above notes will convey some idea of the character of the California valleys, and it now remains to recapitulate the information we have been able to compile in relation to the distribution of the Neocene rocks.

For this purpose it is necessary to take up the various sections of the State in some regular order, and the following arrangement has been adopted: The coast ranges are divided into those north and those south of the Golden Gate, and the different short ranges which make up this assembly are successively referred to, passing in a general way from north southward.

Then follow notes on the southern border of the State and the Santa Barbara Islands, and lastly the Sierras with their foothills and the region of the Auriferous gravels, Death Valley, and the rest of the desert region to the south and east.

STRATIGRAPHY—COAST RANGES.

DIVISION NORTH OF THE GOLDEN GATE.

But little is known respecting the distribution of the Tertiary series on the western side of this range to the north of San Francisco Bay. It appears that the most northern outcrops of marine Neocene rocks have been found in Humboldt County; Cooper[1] has catalogued various molluscan species from Eagle Prairie, Danger Creek, and Eel River in this county, and has assigned them a Pliocene age. At Eagle Prairie, near the town of Rio Dell, both Miocene and Pliocene are reported. Still less is known regarding the geology of Mendocino County, though the existence of Tertiary deposits here may be inferred from Whitney's general statement: "The great bituminous slate formation, of Tertiary age, extends through California, from Los Angeles as far north as Cape Mendocino."[2]

Farther to the south, in Sonoma County, Gabb[3] cites several molluscan forms as coming from "Russian River" and "Santa Rosa," while Whitney generalizes on these localities as follows:[4]

> The valley of Petaluma extends through to Russian River, being separated from that of Santa Rosa Creek by hills so low that the divide can hardly be recognized. This valley is in the direct line with the Tertiary strata of the Contra Costa hills, and is probably an excavation in that belt, with metamorphic Cretaceous and eruptive rocks on both sides.

Between Petaluma and the entrance of Tomales Bay the surface is generally depressed. The rocks exposed are mainly metamorphic, upon which here and there in mere patches rest, unconformably, sandstones of Tertiary age. The latter are well exposed at Estero San Antonio,[5] about 3 miles north of Tomales. Here the sandstone is soft yellow, with some hard, blue, calcareous nodules, and forms a bluff 250 or 300

[1] J. G. Cooper, M. D., 7th Ann. Rep. Cal. State Min. Bureau, 1888, pp. 223–308.
[2] J. D. Whitney, Geol. Survey Cal., Geol., 1865, vol. 1, p. 117.
[3] Gabb, W. M.: Geol. Survey Cal., Pal., 1869, vol. 2, pp. 69–110.
[4] Whitney, J. D.: Geol. Survey Cal., Geol., 1865, vol. 1, p. 108.
[5] Ibid., pp. 83–84.

feet high. Fossils are numerous and are classified by Gabb as Miocene.

To the west and south of Tomales Bay, in Marin County, beds of sandstone, presumably of this age, occur, resting nearly horizontally upon granite.[1] At White's Gulch the sandstone is overlain by white argillaceous slates, resembling the bituminous and infusorial strata of Santa Cruz and Monterey.

Near Suscol,[2] Napa County, the prevailing Cretaceous rocks are often hidden by volcanic material. Between the two, especially at the place just mentioned, sedimentary Tertiary rocks intervene, whose distribution is as yet but little known.

Finally, near the head of Pleasant Valley, the Cretaceous rocks are frequently covered by layers of volcanic ash, interstratified with gravel, conformable throughout, with a slight dip to the east. "They appear to be of Pliocene age, and identical in most respects with the sedimentary-volcanic beds to the north of Kirker's Pass.[3]

Of one area, that north of the Napa Valley and east of the Mayacmas Range, at an elevation of 1,310 feet above the sea, we are fortunate enough to have a special geological study by Dr. George F. Becker, of the U. S. Geological Survey.[4]

No Miocene strata have been detected in this region, and Dr. Becker inclines to the belief that during the Miocene this was a land area.

Cache Lake beds.—An extensive area, of which the limits have not been precisely ascertained, is occupied by fresh-water sediments, to which the name above cited has been applied. The body of water in which these were laid down overlapped the area at present occupied by Clear Lake, with which Dr. Becker shows its geologic history has been continuous.

These beds consist, first, of conglomerates carrying pebbles of metamorphic rock identical with that which underlies them, and of pyroxene andesite, which can not be discriminated from that of the adjacent "Chalk Mountain;" secondly, of sand beds, and, thirdly, of argillaceous and calcareous deposits. For the most part, the strata are little compacted and may be reduced to powder in the hand, but there are frequently nodular masses which are consolidated to firm rock. * * * Occasionally considerable areas of sandstone fully solidified are met with. The impression conveyed by the prevalent distribution of the more extended and irregular hardened masses is that they represent the local action of cold calcareous or siliceous waters upon the surrounding rock, an action which if sufficiently prolonged would result in the complete petrifaction of the whole series of beds.

The Cache Lake beds have been subjected to comparatively little disturbance. They are tilted at angles varying from about 10° to about 40°, but the inclination seldom changes rapidly, and there is very rarely anything which can be regarded as contortion. Within the area of the map, too, no faulting was traced, though more or less important disturbances of this nature occur near Chalk Mountain and

[1] Whitney, Geol., 1865, vol. 1, p. 84.

[2] Ibid., pp. 102-3.

[3] Ibid., p. 106.

[4] Monographs of the U. S. Geological Survey, vol. XIII, Geology of the quicksilver deposits of the Pacific slope, Washington, the Survey, 1888, 486 pp., 4°; and atlas, folio, cf., pp. 233-290.

on the north fork of Cache Creek, east of the map limit. The thickness indicated by measuring the strata, perpendicularly to the planes of stratification, is very great—some thousands of feet. I confess myself unable either to comprehend this or to ignore its significance. There is certainly no confusion between these beds and others of marine origin, since fresh-water shells were found in them at widely separated horizons; but the accumulation of several thousand feet of sediment in any lake except one of vast dimensions seems an impossibility. A careful search was made for faults without finding any. The probabilities, however, seem to me in favor of the supposition that these really exist, but thus far have escaped detection. Even on this assumption I believe it impossible to reduce the estimate of this deposit below 1,000 feet.[1]

The fossils found in these deposits comprise some vegetable remains, fresh-water shells identical with species now common to the region, and a few bones referred by Prof. O. C. Marsh to the horse, camel, and elephant or mastodon. Prof. Marsh's report seems to show conclusively that they are not Pleistocene, and they must therefore represent the close of the Pliocene.

The beds are extensively eroded, and near Cache Creek have been terraced. On and near the north fork of the creek they are covered unconformably by a deposit of gravel usually 50 feet or less in thickness.

This is somewhat obscurely stratified, unconsolidated and has been tilted, though less than the underlying lake beds. It presents no strata in which there would be any hope of finding fossils, and its origin is not certain. It may possibly represent the very last stages of Cache Lake, or, as seems to me more probable, the earliest river deposits after the close of the Cache Lake epoch.[2]

These beds are to a considerable extent overlain by andesitic eruptives and basalt. The former lie conformably upon the lake beds and the latter have been more or less metamorphosed, apparently rather through the action of hot water or springs than by any direct contact with heated lava. Similar results are noticeable where the basalt has come in contact with the lake beds. The metamorphosed deposits yield a red soil full of white masses of calcareous material which is said to be very fertile.

The later andesite overlies the Cache Lake deposits and also underlies the Clear Lake sediments. As previously noted, the vertebrates of the lake beds are Pliocene, while the amount of erosion and relation to the modern sediments show they are upper or later Pliocene. The date of the eruption is thus fixed at about the close of the Pliocene epoch.

The eruptions of basalt of the Clear Lake region were greatly inferior in volume to those of andesite, even more so than would appear from an inspection of the map, as owing to the fluidity of these lavas the layers are thinner. These rocks are regarded by Becker as entirely Pleistocene, resting as they do unconformably upon the uplifted Cache Lake beds.

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[1] Becker, op. cit., pp. 239 et seq.
[2] Op. cit., p. 241.

DIVISION SOUTH OF THE GOLDEN GATE.

Valley of San Francisco Bay.—In volume VI of the Pacific Railroad reports Prof. Newberry[1] gives the following section, obtained somewhere along the southern shore of San Pablo Bay, though its exact location is unfortunately not stated:

FIG. 31.—Section along southern shore of San Pablo Bay, California.

The fossiliferous strata are said to contain *Pecten pabloensis* Con., *Pecten nevadensis*, a *Mactra, Natica, Nucula, and Tellina.* All have an eastern dip of from 30° to 35°.

This is probably the same locality referred to by Whitney[2] in discussing the post-Tertiary deposit about Benicia. He says:

> Similar beds, with oysters, were observed on San Pablo Bay between Point Pinole and the Embarcadero; at this locality the beds containing oysters, which rest horizontally on upturned strata of the Tertiary, are elevated twenty-five feet above the level of the water in the bay.

In another place the same author states[3] that the Rodeo Valley marks the limit of the Cretaceous, going west from Martinez, and that here it is succeeded by comformable Tertiary strata, all dipping southwest.

Southeast from San Pablo Bay, a series of elevations, commonly known as the Contra Costa Hills, extends into Alameda County, where it blends into the Monte Diablo Range. Its northern portion is made up for the most part of Miocene sandstone, often highly fossiliferous,[3] and along its southwestern margin more or less thoroughly metamorphosed. The dip of the strata in this region is to the northeast. The localities most frequently quoted by Gabb[4] as furnishing molluscan remains are "Walnut Creek" and "San Pablo," though one specimen at least is cited "from the hills back of Oakland."

A short distance south of the pass between Oakland and Lafayette, rocks of uncertain age[5] occur, and form the central part at least, of this series of elevations until it merges into the Mount Diablo Range. Whitney is inclined to refer these to the "Cretaceous"[6] from the fossiliferous contents of bowlders apparently derived from them.

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[1] Explor. R. R. route from Sacramento Valley to Columbia River; Pacific R. R. reports, 1855, vol. 6, part 2, pp. 13–14.

[2] Whitney Geol. Survey Cal., Geol., 1865, vol. 1, p. 102.

[3] Ibid., p. 12.

[4] Geol. Survey Cal., Pal., 1869, vol. 2.

[5] Geol. Survey Cal., Geol., 1865, vol. 1, p. 17.

[6] Ibid., p. 18.

To the southeast of Martinez, Gabb found the "Cretaceous" and "Tertiary" formations occupying a syncline, as follows:

FIG. 32.—Section from near Pacheco to the Canyon del Hambre. Length, 4 miles. *a*, Lower Cretaceous, dipping southwest; *b*, Upper Cretaceous, dipping northeast; *c*, brown sandstone, without fossils; *d*, fine grained gray sandstone, with a few Tertiary fossils; *e*, Tertiary sandstone, containing *Ostrea titan*, etc.; *b'*, Upper Cretaceous sandstones, with numerous fossils; *f*, nonfossiliferous sandstones; *a'*, Lower Cretaceous sandstones, in low hills 1 mile north of Pacheco, containing numerous fossils.—Geol. Surv. Cal., Geol., vol. 1, p. 14.

Mount Diablo Range.—About 15 miles south from Martinez is the lofty summit of Mount Diablo. The central portion of this eminence is composed of metamorphic, probably Cretaceous rock, while flanking it on all sides rest unaltered stratified deposits. These are tilted, but otherwise little disturbed. To the north both Cretaceous and Tertiary beds appear (according to the California Geological Survey) and present no marked unconformability.

The Miocene series consists chiefly of beds of sandstone heavy bedded at base, resting upon siliceous deposits of uncertain age, and grading upward with apparently no interruption into thinner and more fossiliferous deposits, referred by Gabb to the Pliocene. The latter are particularly well exposed near the east end of Kirkers Pass, whence so many Pliocene forms have been cited.[1]

Resting upon these are beds of stratified volcanic materials several hundred feet thick to the west of this pass, often dipping at angles of 25°, 30°, or even 50°. To the southeast they form a series of rounded and bare hills, stretching along near the edge of the San Joaquin plains.

A special study of the geology of the vicinity of this mountain has recently been published by Mr. H. W. Turner[2] of the U. S. Geological Survey.

According to Mr. Turner, the Miocene beds are largely coarse gray sandstone containing *Ostrea titan* Con., with Pectens, and Echinoderms and conglomerates containing pebbles of rhyolite, quartz, and metamorphic rocks. The Pliocene strata of the same region contain marine fossils and also fossil leaves, silicified wood, and hornblende-andesite tufa and pebbles. The marine fossils have been collected at three localities, viz, Kirkers Pass on the north, the Railroad ranch reservoir on the south, and Corral Hollow, about 25 miles southeast of the mountain.

In the finer layers at Kirkers Pass there are also numbers of fossil leaves, wood, etc., which have been described (Proc. U. S. Nat. Mus.,

[1] Geol. Survey Cal., Pal., 1869, vol. 2; Geol., 1865, vol. 1, p. 32.

[2] The Geology of Mount Diablo, California. Bull. Geol. Soc. of Am., March, 1891, vol. 2, p. 383–414, pl. 15. Rochester, the Society, 8°, with a supplement on the Chemistry of the Mount Diablo Rocks, by W. H. Melville.

vol. 1, p. 35, 1889) by Lesquereux, who considered them Pliocene. Leaves from Corral Hollow were referred to the Miocene by Lesquereux, but were regarded as Pliocene by Prof. Whitney, in which opinion Turner concurs on stratigraphical evidence.

The Tertiary strata discussed by Turner are regarded by him as conformable with each other and with the Chico beds of the same region, though the Pleistocene deposits are thought to be unconformable.

The Tertiary rocks are greatly tilted, and in some places reversed so that, as in a section east from Tessajara Creek to Lone Tree Valley the Tejon and Chico beds overlie the Miocene.

South of Mount Diablo, the Miocene forms a high ridge some miles in extent, which subsides toward the south, giving place to the Amador and Livermore valleys.[1] Connecting the latter with the valley of California is the Livermore pass, which crosses the Monte Diablo range at right angles. The rocks here exposed are soft Tertiary sandstone, dipping to the west of the ridge in a southwestern direction, while on the opposite side this dip is reversed.

From this pass southward along the Monte Diablo range, these Tertiary deposits extend apparently without interruption as far at least as Corral Hollow; they extend to altitudes of 2,400 to 2,500 feet above the sea, are often much dislocated, and in some places contain the large *Ostrea titan*[2]. North of "Camp 61" impressions of leaves and silicified wood have been noted in beds referred by Whitney to the Pliocene. For some distance to the south of this "hollow" Cretaceous rocks give an abruptness of outline along these hills to near the mouth of Orestimba Canyon, where they fall away and are overlain by more yielding Neozoic deposits. The latter near the eastern end of the canyon appear to lie conformably upon the Cretaceous, and to dip eastward toward the San Joaquin at an angle of 45°.[3] From this point southward along the eastern slope of the Monte Diablo range very little is known regarding the character and distribution of the Neozoic series till the vicinity of New Idria is reached.

Nevertheless, it seems to be generally agreed that such deposits do exist,[4] though to what extent is unknown, owing to the development of overlying Quaternary deposits, and the limited number or entire lack of observations. Near New Idria, Gabb[5] identified several molluscan species and referred them to the Miocene.

Whitney[6] states in this connection:

> The road from Griswold's to New Idria keeps along pretty near the line between the Tertiary unaltered rocks and the metamorphic Cretaceous. Large masses of the former are seen in the hills on the eastern side dipping at an angle of 45° to the

[1] Geol., Survey Cal., Geol., 1865, vol. 1, p. 33.
[2] Ibid., p. 38.
[3] Ibid., p. 44.
[4] See Pac. R. R. Rept., vol. 7, pt. 2, Geol. by Thos. Antisell, pl. I, fig. 1. and map at the end of pt. 2; also vol. 5, pt. 2, Geol., by Wm. P. Blake, map at end. See also Trask's Rept. for 1854, pp. 28–29.
[5] Geol. Survey Cal., Pal., 1869, vol. 2, and Geol., 1865, vol. 1, p. 57.
[6] Geol. Survey Cal., Geol., 1865, vol. 1, p. 57.

north and northeast. * * * Everything indicates a considerable widening of the Tertiary belt, forming the eastern edge of the chain, as we proceed southward, and the mass of these sandstones appear to dip toward the plain of the San Joaquin.

Hilgard reports abundant well preserved marine (Pliocene?) fossils in unconsolidated sand on the eastern slope of the range along the road leading from Bakersfield to San Luis Obispo.

Having traced the Neozoic deposits along the eastern slope of the Monte Diablo Range, a few words must be added in reference to similar deposits upon the opposite side. Beginning, therefore, at the locality where this range merges into the Contra Costa hills, whose geology has already been discussed, we find here, as farther to the northwest, a ridge of more or less metamorphosed Miocene sandstone[1] extending along the eastern border of the valley of San Francisco Bay. Its southeastern extension has been traced some distance beyond the latitude of San José mission; its dip is toward the northeast, often at a high angle; it is often thoroughly metamorphosed in one locality and entirely unaltered close by it; its fossils, though numerous, are in a bad state of preservation.

Farther to the south, in the river valley above Tres Pinos, immense detrital deposits have been noted by Whitney which may belong to the Pliocene.[2] They fill the valley for 10 or 12 miles, are unconsolidated and unfossiliferous.

Santa Cruz Range.—This range has been but little explored from a geological standpoint; but its general structural features have been ascertained, and may be stated as follows:

From the Golden Gate, metamorphic beds, mostly Cretaceous, extend to the southeast through northeastern San Mateo and southwestern Santa Clara counties; in the latter they form a lofty ridge, occasionally rising into such summits as Mounts Bielawski, Umunhum, and Bache. Their northeastern slopes exhibit several patches of Neozoic rocks, of which material their southwestern slopes are almost wholly made up.

The New Almaden district has been carefully studied by Dr. George F. Becker,[3] of the U. S. Geological Survey. Here upon the metamorphic rocks lie some areas of soft Miocene sandstones of a yellowish color and containing a good many poorly preserved fossils. They are considerably disturbed, lying unconformably on the metamorphic rocks, of which they contain fragments. There also exists along the border of the Santa Clara valley a small quantity of conglomerate, composed of metamorphic pebbles imbedded in an arenaceous matrix, which is similar to the Miocene sandstone. According to Becker (op. cit. p. 313) this rock may be a remnant of Miocene, but more probably represents

[1] Geol. Survey Cal., Geol., 1865, vol. 1, p. 51-52.

[2] Ibid., p. 54. In his Auriferous Gravels, Whitney states without any qualifications that they are Pliocene; op. cit., 1879, p. 21.

[3] U. S. Geological Survey, Monograph, 1888, vol. 13, Geology of the quicksilver deposits, chapter x, pp. 310-318.

Pliocene, though it would, in the absence of positive evidence, be rash to map it as such.

A long and tolerably regular dike of rhyolite, a light yellow, tufa-like substance, hardly distinguishable at a distance from the sandstones, was discovered in the northern part of the district by Dr. Becker. He regards this rock as certainly post-Miocene, for if it had been earlier it must have shown the effects of the post-Miocene uplift. As a rule the rhyolites of the Pacific slope are, as pointed out by Richthofen, younger than the andesites. If this rhyolite is younger than the andesites of Mount Diablo and Napa County, it is Pleistocene, but there is no direct evidence that this is the case. On the whole the probabilities are that it is recent or late Pliocene, but all that is certain is that it is not older than the Pliocene. All the quicksilver deposits of the district occur along a rather simple fissure system, which was probably formed at the time of the rhyolitic eruption, to which Becker also attributes the genesis of the ore.

Farther to the west, a high range of granite hills[1] may be seen, beginning near Santa Cruz and stretching away to the northwest nearly to the Pescadero Creek. Still nearer the coast,[2] extending from Santa Cruz to a point 3 miles northeast of Spanish Town is a belt of bituminous slate, containing interstratified beds of sandstone and narrowing rapidly in going northward.

Going southward from San Francisco, the first deposits met with which are probably of Tertiary age are found along the seacoast from near Lake Merced to Mussel Rock.[3] They consist of a bluish sandstone, resting unconformably on metamorphic strata below and overlain by unconformable Pleistocene deposits. Upon the evidence of the fossils they contain, these have been assigned to the Pliocene. Gabb, moreover, has mentioned several species from "near San Francisco" and "12-Mile House below San Francisco" as belonging to a Pliocene horizon.[4]

Farther to the south, both Pliocene and Miocene forms are cited by this author from Half Moon Bay. The regular belt, however, of bituminous Miocene shale, begins at a point 3 miles northeast of Spanish Town where it caps a mass of granite.[5] No fossils of any particular value for determining the horizon of this bed were found here, yet from lithologic resemblance and structural position, they belong with little doubt to the Miocene belt well developed farther south.

In a section from San Mateo to Half Moon Bay at Spanish Town, Whitney found[6] that west of the granitic axial ridge there is a low ridge of friable sandstone, dipping to the west at an angle of 40 degrees.

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[1] Geol. Survey Cal., Geol., 1865, vol. 1, p. 72–73.
[2] Ibid., pp. 74 and 75.
[3] Ibid., p. 79.
[4] Geol. Survey Cal., Pal., 1869, vol. 2, p. 79.
[5] Geol. Survey Cal., Geol., 1865, vol. 1, p. 74.
[6] Ibid., p. 75.

Proceeding toward the coast, this dip is reversed, with a pitch of 50 degrees which diminishes all the way toward Spanish Town, and finally it is nearly horizontal on the seashore. The character of the rock also changes, becoming more and more argillaceous toward the bay. These beds probably belong to the Miocene series, since they are in line with the bituminous shaly belt referred to above, though characteristic fossils have so far been found only in the immediate vicinity of Half Moon Bay. Nevertheless, Whitney remarks,[1] "the fossils found in the strata show that they belong to the Miocene."

The same formation has been seen well developed along the trail from Pescadero to Searsville; near the latter place the occurrence of *Ostrea titan* has been noted among other molluscan forms.[2]

At Pigeon Point a gray compact sandstone appears, which, upon paleontological evidence, has been referred to the Miocene.[3] Another sandstone occurs just north of New Year's Point ranch house, which, according to Gabb, should be referred to a Pliocene horizon.[3] Bituminous shales have again been seen along Scott's Creek,[3] and again at Santa Cruz.

Upon the northeastern flank of the metamorphic region, mentioned above, there are several local exposures of Cenozoic deposits, all of which have been classified as Miocene.[4] Of these the more important are: (1) A patch on the ridge from Mine Hill to Mount Umunhum, and (2) those in the vicinity of McCartyville.

Gavilan Range.—This is in trend only a southeastern continuation of the Santa Cruz Range just described, being separated from it only by the valley of the Pajaro River. In its northern part it is well separated from the Monte Diablo Range, on the east by the San Juan and San Benito valleys, and from the Santa Lucia Mountains on the west by the Salinas.[5]

In the valley of the Pajaro Whitney has observed the bituminous belt of shale[6] so frequently referred to, as well as Miocene sandstone. Antisell makes no reference to shales, but reports the "basal rock" to be "felspathic granite" upon which the sandstone rests, though their juncture has not been observed. These sandstones form in the vicinity low foothills of the Gavilan Range. In them Antisell notes the occurrence[7] of *Venus pajaroana*, described by Conrad and referred to the Miocene Tertiary. Whitney remarks:

> Portions of the formations are fossiliferous; but all the shells found were in such a bad state of preservation that little or nothing could be made of them. There is not much doubt, however, that these rocks form a part of the Miocene Tertiary, so extensively developed in the Coast ranges.[8]

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[1] Geol. Survey Cal., Geol., 1865, vol. 1, p. 75.
[2] Ibid., p. 72.
[3] Ibid., p. 73.
[4] Ibid., p. 67–68.
[5] Ibid., p. 159.
[6] Ibid., p. 165.
[7] Pac. R. R. Rept., vol. 8, pt. 2, p. 37.
[8] Geol. Survey Cal., Geol., 1865, vol. 1, pp. 159–160.

To the south, near the trail from Canyon San Juan to Natividad ranch, these rocks become metamorphic. Finally, Antisell has given a somewhat hypothetical section,[1] extending due east from Point Pinos to San Joaquin Valley, which, of necessity, crosses this range still farther to the south. The Gavilian Range is here represented as being made up of (1) a central axis of "orthose granite," flanked on either side by (2) metamorphic limestone, which in turn is overlain by (3) "Dosinia sandstone."

Little is known regarding the geography or geology of this range along its southern extension; it is assumed, however, to blend into the Monte Diablo Range in the vicinity of San Lorenzo. The foothills that are found along its western margin, just to the east of the Salinas River, are said by Antisell to extend southeastward to the mission of San Miguel, making their entire length 80 or 90 miles. Their lithological character and stratigraphic relations are the same throughout as represented in the section referred to above.

Finally, molluscan forms have been collected in the Estrella Valley, which Conrad referred to the Miocene—an opinion in which Gabb concurs.

Sierra de Salinas.—This chain of hills, so named on the Pacific Railroad maps, begins a little northwest of Monterey and extends in a southeasterly direction to the confluence of the San Antonio and Salinas rivers. Its structural features are given very differently by Whitney and Antisell in their respective reports, while the statements of Trask and Marcou are too general to be of service here, the former designating it as "an extensive group of the serpentine formations."[2]

Whitney[3] has described at considerable length the geology of the immediate vicinity of Monterey in his report of 1865 (pp. 160 et seq.).[4] Suffice it to say that this region shows all stages of metamorphism in its rocky material, and that the junctions of the granitic masses with the Miocene slates and conglomerates are well exposed.

Extending east from Monterey, and flanking the Palo Escrito Hills (such being the name applied to the northern part of the Sierra de Salinas) on the north is a series of sandstones and conglomerates several hundred feet in thickness, which dip more or less to the north and northeast, and in places are quite fossiliferous. "These rocks appear to belong to the upper division of the Miocene." Between the mission of Carmel and Monterey the Palo Escrito Hills consist of unaltered bituminous slate, light in texture and containing some fossil remains.

By these Whitney[5] determined the age of this formation so extensively developed throughout the Sierra de Salinas. They belong to the

[1] Pac. R. R. Rept., 1857, vol. 7, part 2, Geol., pl. 1, fig. 1.
[2] John B. Trask; Assemb. Doc. No. 9, 1854, "Rept. on Geol., etc." p. 21.
[3] In Pac. R. R. Rept., 1856, vol. 5, part 2, pp. 180 et seq. Blake has also described this vicinity.
[4] For description infusorial strata in this vicinity see Proc. Phila. Acad. Sci., 1855, vol. 7, pp. 328-331.
[5] Geol. Survey Cal., Geol., 1865, vol. 1, p. 154.

Miocene. This confirms the speculations of Blake[1] and Conrad published nine years before.

Farther to the southeast, in the vicinity of mission Soledad, the rocks on the east side of this chain are nearly all metamorphic, "consisting chiefly of mica slate, in places interstratified with gneiss, while the western slope is made up partly of metamorphic rocks and partly of unaltered bituminous slate." Still farther in the same direction, between the San Antonio and the Salinas, the rocks consist almost exclusively of bituminous slate.[2]

In general it appears, from the remarks of Whitney, that these beds have on the whole a northeastern dip, though they are often much folded and broken and dip, locally, in various directions.

Santa Lucia Mountains.—This chain of mountains rises suddenly from the ocean level at Point Carmel and extends in a southeasterly direction parallel to the coast for over 100 miles without a single break. Much of it rises abruptly from the sea. It has been very little explored. It is known, however, to have a granitic axis from the outcrops along the coast from the point just mentioned to El Sur and from bowlders of

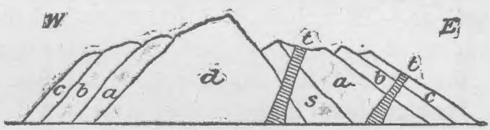

FIG. 33.—Section near San Miguel, California. *d*, central axis, felspathic granite; *a*, *b*, *c*, sandstones (*c*, the *Dosinia* bed); *s*, serpentine; *t*, dikes of felspathic (augitic) trap.

this material washed down from its heights into the San Antonio and Nacimiento rivers. Resting on the granite is a Cenozoic sandstone (probably Miocene) and very extensively metamorphosed. Stratigraphically above this, as may be seen on the Carmelo and the Arroyo Seco rivers, rest thick deposits of bituminous slate. These continue southeastward and are well developed along the Nacimiento, some 6 or 8 miles from its mouth. They in turn are here overlain by a group of rather soft sandstone, sometimes calcareous, with a thickness of over 1,000 feet. These beds are fossilferous in places, containing species of *Pecten* in particular abundance. Among these the Miocene *P. pabloensis* is most common.

This sandstone is probably the one referred to by Antisell in his "Section of Antonio Hills," from which Conrad describes four species of *Dosinia*. Unfortunately nothing more definite is given regarding the locality of this section than that it is "near the mission San Miguel." Such being the case it seems scarcely exact to apply to it the name "San Antonio Hills," since they, according to Whitney, are found only

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[1] Pac. R. R. Rept., 1856, vol. 5, part 2, p. 182, and Appendix, p. 317.

[2] Geol. Survey Cal., Geol., 1865, vol. 1, p. 150.

at some distance below, viz, near the mouth of the San Antonio River. The section, however, is given in Fig. 33.

Farther to the south, in the Santa Margarita Valley, a quartzitic sandstone has been observed, which contains oysters and pectens, and on Atascadero ranch the fossils are supposed to be Pliocene.

Deposits supposed to belong to the bituminous slate formation have also been observed here. Fig. 34 shows the structure of the Santa Lucia Mountains, between Santa Margarita Valley and San Luis Bay.

Another section apparently somewhat farther to the south is given by Antisell. (See Fig. 35.)

The continuity of this range to the southeast has not been traced with certainty far beyond San Luis Obispo, yet it may perhaps be regarded as blending into the Sierra San Rafael.

To the east of this range Antisell has described at some length his "Sierra San José" as extending from the Margarita Valley to the "mountain mass of San Emidio. It has a granitic axis, which is flanked with serpentine, slates, conglomerates sandstone," etc.[1] Along the western borders of the Santa Lucia Range, a series of so-called "buttes"[2] are found which are very sharp in outlines, being made up of trachyte and trachytic porphyry, as well as metamorphic sandstone and serpentine.

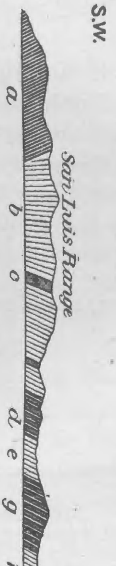


FIG. 34.—Section from Santa Margarita Valley to San Luis Bay. Horizontal scale same as perpendicular. Length, 16 miles. *a*, San Luis Bay; *b*, San Luis Range, of slate; *c*, limestone bed, with fossil oysters; *d*, serpentine and metamorphic rock of north base of San Luis Range; *e*, *f*, sandstones underlying the San Luis Valley; *g*, serpentine butte, southeast of the town; *h*, *i*, *k*, metamorphic rocks, with the serpentine belt (*i*) intercalated in them; *l*, serpentine at the base of the Santa Lucia Range; *m*, unaltered slates, dipping north; *n*, fetid limestone; *p*, serpentine; *q*, slates in Santa Margarita Valley, dipping north.—Geol. Surv. Cal., Geol., vol. 1, 1868, p. 144.

FIG. 35.—Section of Santa Lucia Range somewhat south of Fig. 34. Perpendicular scale exaggerated. *w*, veins of asphalt, passing through the bituminous group of San Luis Obispo Valley; *t*, trappean and augitic rock; *c*, serpentine layers; *a*, granitic rock.—After Antisell.

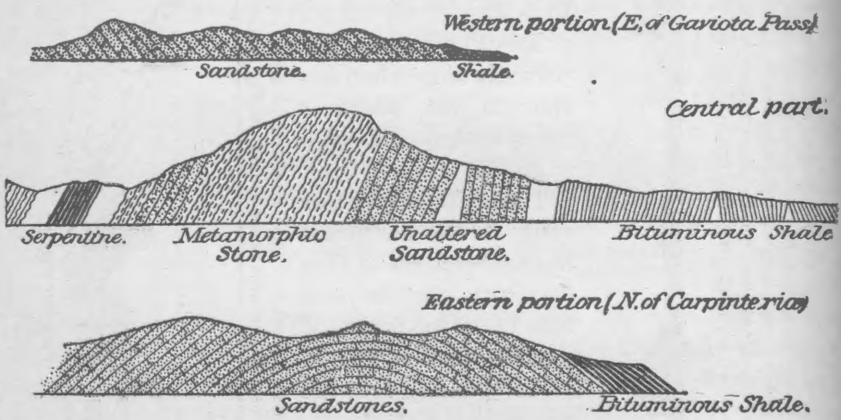
[1] Pac. R. R. Rept., 1857, vol. 7, part 2, pp. 47 et seq.
[2] Geol. Survey Cal., Geol., 1865, vol. 1, p. 139.

Southwest of the San Luis Valley a low chain of hills separates the valley from the ocean. To this Whitney has given the name "San Luis Range."[1] Its structure may be seen in his section given above (Fig. 34). It often contains vast quantities of *Ostrea titan.*[1]

This region is one in which the influence of both the northwest-south-east trend of the mountain ranges already described, and the east-west trend of the ranges about to be described, are quite apparent. The result is a general complication of the stratigraphy.[2] It is almost wholly unknown.

Santa Inez Mountains.—This is a well defined mountain chain, geographically speaking, and one whose structure is simple and fairly well known. It consists chiefly of Miocene sandstone and shale, as do the ranges of the San Rafael, Cuyames and others in the region of complicated stratigraphy to the north.

The following three sections will suffice to show the structure of this range:



FIGS. 36,[3] 37,[4] 38.[5]—Sections across the Santa Inez Mountains.

The asphaltum and bituminous substances of such common occurrence along the shore of the Santa Barbara channel at the base of the Santa Inez Range, have received much attention from Dr. Antisell, as may be seen from Chapter XVI, in volume VII of the Pacific R. R. Reports, as well as from his work on "Photogenic Oils."

There is another interesting feature of the geology of the coast of this region, and that is the development in some localities, especially in the vicinity of Santa Barbara Mission,[6] of Pliocene deposits which lie unconformably upon the upturned edges of the bituminous slate series.

[1] Geol. Survey Cal., 1865, vol. I, p. 140.

[2] Ibid., pp. 110, 111.

[3] Ibid., p. 135. For a detailed description of Gaviot Pass, see vol. 7, Pac. R. R. Rep., pt. II, chap. 10, pl. 4.

[4] Ibid., p. 129.

[5] Ibid., p. 128.

[6] Ibid., p. 130. For Conrad's description of the Miocene and its fossils at this locality, vide Proc. Phila. Acad. Nat. Sci., 1855, vol. 7, pp. 267 and 441.

They are often fossiliferous; their stratigraphic relations may be illustrated by the following section:

FIG. 39.—Section from the Pacific to the Santa Inez chain, at Santa Barbara. Distance about 3 miles. *a*, *b*, Pliocene and Pleistocene strata; *c*, bituminous slate, much contorted; *d*, bituminous slates and fine grained sandstones; *e*, sandstone, dipping south.

Tulare Valley.—Before proceeding further with remarks on the Neocene formations as they are found in the ranges and plains near the ocean, it seems well to refer briefly to some deposits of this age, found some distance to the northeast, at the head of Tulare Valley.

Between the eastern terminus of the Santa Inez Mountains and the Tulare valley, the geologic as well as geographic features are little known. Antisell's section (Fig. 6, Pl. IV, Pacific R. R. Reports, pt. 2, Vol. 7), from San Buenaventura to Cañada de las Uvas, may perhaps serve to give a general idea of the stratigraphy along this line, yet allowance must be made here as elsewhere for the tendency of this author to classify among igneous rocks many which later surveys would lead us to regard as metamorphic.

FIG. 40.—Section at San Emidio Canyon. Length, 10 miles. Horizontal and vertical scales nearly equal. *a*, granite, mica slate, and metamorphic rocks; *b*, Cretaceous sandstones and shales; *c*, nonfossiliferous sandstones; *d*, Miocene sandstones; *e e*, Tertiary sandstones without fossils; *f f*, horizontal deposits of gravel; *g*, Tulare plain.

San Emidio Canyon.—Along San Emidio Canyon, to the north of Mount Pinos, Tertiary deposits are developed as follows:[1]

"The belt of Tertiary extends along the flanks of the mountains eastward for about 20 miles from San Emidio Canyon, passing out into the plain, and terminating in a range of hills to the northwest of the mouth of the Cañada de las Uvas." West and northwest of this canyon "a wide belt of Tertiary rocks may be seen skirting the coast ranges and worn into rounded hills, which are generally barren." "A spur runs out into the plain to the west and northwest of Buenavista Lake, and widens out near Paso el Roble, extending down the valley as far as the eye can reach."

Many of the sandstone beds, presumably Cenozoic, are nonfossiliferous, while others contain a great number of fossils, though generally in a poor state of preservation. The whole group must have considerable thickness, since it is said to dip northward at an angle of 60° or 70° for about 2 miles. The up-

[1] Geol. Survey Cal., 1865, vol. 1, p. 189.

per members "consist of sandstone and conglomerates, the latter abundant and coarse, and appearing to be more recent than Miocene; they are probably of Pliocene and post-Pliocene age. All these are disturbed and upturned, to the very mouth of the canyon."

FIG. 41.—Section across the Santa Monica and Santa Susanna ranges, extending northwest from the plain of Los Angeles. Length 40 miles.

Not far from the region under consideration, viz, near Cañada de las Uvas, the granitic axes of the Sierra Nevada and the Coast Range appear to unite,[1] and extend thence in a southeastern direction, forming the backbone of the San Gabriel, the San Jacinto, the subordinate ranges to the west of the latter, and of the great San Bernardino Range to the east. It should be borne in mind, however, that these minor granite upheavals were not synchronous, so that they may represent several distinct periods of disturbance resulting in the apparent blending of the two more important ranges.

San Gabriel Range.—Passing southeastward from the Cañada de las Uvas,[2] the first presumably Neocene deposits met with are found about the base of the San Gabriel Range.[3] They consist of immense masses of sandstone and conglomerate, penetrated in some instances by granite dikes, and often turned up at a very high angle in almost any direction. The metamorphic rocks of this range are referred by Whitney to the Cretaceous.

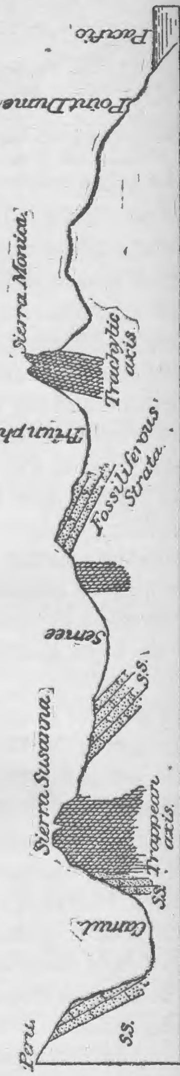


FIG. 42.—Section across the "Sierra" Monica and Santa Susanna ranges, extending northward from Point Dume.

[1] From this locality southward into Lower California Antisell calls this range "The Cordilleras." Pac. R. R. Rept., vol. 7, pt. 2, p. 87, 1857.

[2] For a geological map of the region about these passes, see Blake, Pac. R. R. Rept. 1856, vol. 5, pt. 2 p. 197.

[3] Geol. Survey Cal., Geol., vol. 1, pp. 171 et seq.

The topography about this range is evidently little known, for the authorities give widely varying accounts of its relations to the different sierras in this region. Whitney regards it as continuous with the Santa Susanna and Santa Monica ranges on the west.[1]

Santa Susanna and Santa Monica ranges.—The structural features of these two mountain ranges, especially the last mentioned, are fairly well known. The main characteristics are shown in the sections given in Figs. 44 and 45. The first, after Whitney,[2] is across their eastern portion, while the second, taken from Antisell,[3] is farther to the west, extending northward from Point Dumel.

These sandstones and shales belong for the most part to the Miocene. Gabb, however, has referred a certain deposit, north of the east end of the San Fernando valley, to the Pliocene.[4] To this age also are referred certain conglomerates at the opposite or western end of the valley. Here a low transverse range of hills seems to connect the Santa Susanna and the Santa Monica ranges. They are made up for the most part of Miocene shales and sandstones, some of which are highly metamorphosed, while on the hills north of Cayeugas ranch there are beds of light colored sandstone containing numerous Pliocene fossils. In and around the San Buenaventura or Santa Clara valleys the light colored, bituminous shales are extensively exposed. These and the region about Los Angeles have been studied with some care by Antisell in reference to the "bituminous effusions" already referred to.[5] The geology about Los Angeles is briefly described by Whitney.

Cordilleras.—Under the head of "Geology of the Cordilleras," Antisell has given a few general remarks on the geology of the granitic range under consideration, between the San Gabriel Mountains and the Lower California boundary line. None, however, materially assist in working out the character and extent of the Cenozoic deposits of this region. Whitney has devoted several pages to Santa Ana and Temescal ranges in the first volume of his report. Both these ranges are found to have axes of granite, with more or less metamorphic material, referable, perhaps, to the Cretaceous; and near the Santa Ana River thick deposits of coarse sandstone and conglomerates are found, with imperfect Tertiary shells supposed to be Miocene.

A geological map of the coast range, from the San Gabriel Mountains south to the boundary line of Lower California, is given by Blake in his report on the geology[6] for 1855. This shows the distribution of "Tertiary and detritus" about the borders of the Colorado desert and

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[1] Geol. Survey Cal., Geol., 1865, vol. 1, p. 171.

[2] Ibid., p. 121.

[3] Pac. R. R. Rept. 1857, vol. 7, part 2, Geol., pl. iv, fig. 5.

[4] Geol. Survey Cal., Geol., 1865, vol. 1, p. 121. (Is this the locality whence Gabb cites so many Pliocene specimens? See Pal., vol. 2.)

[5] Pac. R. R. Rept., 1857, vol. 7, pt. 2, Geol., chapter xvi, and "Photogenic Oil."

[6] Rept. P. R. R. Exped., 1856, vol. 5, pt. 2, map opp. p. 228.

along the western slope of the range in question, i. e., between it and the Pacific Ocean.

San Diego region.—From specimens collected at San Diego by this expedition, Conrad was led to infer[1] that some phase of the Miocene series may here be represented. In a subsequent volume[2] he repeats the same impression, though making it perhaps slightly more definite.

In 1874, W. H. Dall published in the proceedings of the California Academy of Sciences[3] a list of 69 molluscan forms, which were obtained from a depth of 140 to 160 feet in a well sunk at San Diego. Concerning these forms he remarks:

> On an examination of the list it will be seen that of 69 species only three are strictly Miocene, while many are reported by Gabb as extending from the Miocene to the present epoch. * * * The age of the deposit, in general terms, may be taken as Pliocene.

From various localities in this vicinity, as Pacific Beach, False Bay, Ocean Beach, and Roseville, Orcutt[4] has given lists of "Tertiary fossils" without further attempt at correlation.

On the eastern slope of these mountains a very fossiliferous bed has been found, occupying the upper part of a sedimentary deposit which is found along Carrizo Creek. The whole bed is largely made up of the shells[5] of *Ostrea vespertina*, *O. heermani*, *Anomia subcostata*, and *Pecten deserti*, all of which were described by Conrad, and assigned to the Miocene,[6] though Gabb[7] regards these fossil oysters as Pliocene species. Orcutt is inclined[8] to regard them as Cretaceous. This completes the available data on the geology of the Coast Range; but, before taking up the Sierra Nevada we may consider the islands off the coast of Santa Barbara.

Santa Barbara Islands.—There are several small islands near San Pedro which have afforded a good many well preserved fossils. These have been referred en masse by some authors to the Pleistocene or Miocene, but recent observations by M. B. Williamson indicate that some confusion has occurred, a view which is supported by the character of the fossils. It appears that on Deadman Island, near Point Fermin, at least three distinguishable strata appear, the uppermost of which is certainly Pleistocene, while the others are Neocene, and the middle layer probably Pliocene.

The western portion of Anacapa is supposed[9] by Yates to consist in part of sandstone similar to the late Tertiary beds on Santa Rosa.

[1] Pac. R. R. Rept., 1856, vol. 5, pt. 2, art. 2, app. p. 317.
[2] Vol. 7, pt. 2, p. 188.
[3] Vol. 5, pp. 296-299.
[4] The West American Scientist, July, 1889, vol. 6, pp. 70, 71.
[5] Pac. R. R. Rept., 1856, vol. 5, pt. 2, p. 122.
[6] Ibid., p. 235.
[7] Geol. Survey of Cal., Pal., 1869, vol. 2, p. 107.
[8] Tenth Ann. Rep. State Mineralogist Cal., 5, 1890 p. 91.
[9] Lorenzo G. Yates: 9th Ann. Rept. Cal. State Mining Bureau, 1890, pp. 172, 173.

On Santa Cruz, bits of slate and asphalt have been noted by Goodyear[1] in several places; at one locality, near Smugglers Cove, "unmistakable bituminous shale" has been observed.

On Santa Rosa various deposits have been observed by Yates, which are referred by him to the Tertiary.

In the Smithsonian Report for 1877[2] will be found a few notes on the geology of this island, from the observations of Yates. Among the stratified deposits he finds (1) a barren sandstone; (2) impure limestone containing *Ostrea titan;* (3) a fossil-bearing deposit beneath the Pleistocene on the northern part of the island, and (4) Pleistocene fossiliferous beds.

Mr. W. G. Blunt found an elephant's tooth and tusk on this island, the former of which was presented to the California Academy of Sciences,[3] and, more recently, Voy has collected other remains[4] of *Elephas* here. Dr. Yates reports having found the following species in the sandstones of this island: *Hinnites giganteus*, *Turritella ineziana*, *Neverita callosa*, *Pecten pabloensis*, *Liropecten estrellanus*, *Venus kennerlyi* and *Turbinella cœstus*.[5]

Catalina Island is largely composed of metamorphic schists, with serpentine and steatite. It is believed that Cenozoic sandstones also exist, though largely removed by erosion. Pleistocene gravels are found sparsely around the borders of the island.

The island of San Miguel is also partly schistose, with beds of gravel masking the underlying rock, and the presence of sandstone is inferred from fragments found on the beach.

This island, within historic times, was inhabited by Indians, and was covered with a coating of turf and vegetable soil. The introduction of sheep, after the expulsion of the natives, has had the effect of gradually killing the vegetation, which prevented the inroads of the beach sands. The latter are spreading over the island of San Miguel, as well as the other off-shore islands, and already cover to a considerable depth on the lower part of it the dead remains of the former turf, while on the hills the sheep are gradually destroying the remainder. With the destruction of the protective coating the erosive forces will begin to operate in a somewhat different and more energetic manner, and the whole series of operations offers an instructive instance of the modifications due to human interference, which may affect geologic action.

THE SIERRA NEVADA.

In this area will be included that portion of the State lying to the east of the Cascade Range, the Sacramento and San Joaquin rivers, and the Cordilleras.

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[1] W. A. Goodyear: 9th Ann. Rept. Cal. State Mining Bureau, 1890, p. 159.
[2] See also Am. Geol., 1890, vol. 5, p. 49.
[3] Proceedings, vol. 5, p. 152.
[4] Now in the cabinet of the State University at Berkeley.
[5] Ninth Ann. Rept. Cal. State Min. Bur., 1890, p. 173.

Colorado desert.—Blake suspects that some of this area, especially about its periphery, is underlain by Tertiary deposits.[1] The map accompanying his report on this region is so colored as to give his idea of the distribution of these beds.

Death Valley.—Gabb cites at least one species, *Natica recluziana*[2] from this region, and refers it to the Miocene.[3]

Foothills of the Sierras.—It will be recalled that in discussing the Coast Range, attention was called to the extensive Miocene beds in the vicinity of San Emidio Canyon, which extend eastward nearly to the mouth of the Cañada de las Uvas. From this point eastward, if they exist at all, they must pass beneath the Quaternary deposits of the plain until the vicinity of Kern River is reached. Here extensive deposits of soft, friable sandstones may be seen, forming rounded hills from 200 to 600 feet high which rest upon upturned edges of the granitic and metamorphic beds of the Sierra. This sandstone extends continuously as far to the north as White Creek, but is best developed and has been most thoroughly studied in the vicinity of Posé or Ocoya Creek. Blake has devoted several pages in his report[4] to this district. The fossil mollusca, which exist only in the form of casts, were submitted to T. A. Conrad, while the shark's teeth were sent to Agassiz. Both these authorities concluded the horizon represented was doubtless Miocene, a view confirmed by the researches of the California Geological Survey.[5]

The general features of this formation will be found in the following section, compiled by Blake,[6] near "Dupont camp," on the south side of the creek:

		Feet.
n.	Gray sand, with layers of pebbles	20
m.	Gravel and pebbles, with sand	1
l.	Sand, with clay nodules	20
k.	White clay and fine sand	2
j.	Pumice sand or volcanic ashes, very fine and white in thin strata	15
i.	Fine white sand, derived from pumice stone, with intercalated layers of pumice in nodules and in powder	25
	Fine sand, with small spherical and ellipsoidal masses of white pumice stone. Thin layers of charcoal, in fragments	0·6
h.	Fine sand, with curved layers of oxide of iron	4
g.	Argillaceous sand, filled with small nodular masses of clay, from one-fourth of an inch to three inches in diameter	1
f.	Fine gray sand, with an occasional layer of pebbles (this stratum is partly hid)	41
e.	Fine gray sand, cross stratification distinct, contains nodules of clay	24
d.	Casts and molds of fossil shells in sesquioxide of iron, gravel, and sand, layers oblique	1·4

[1] Pac. R. R. Rept., 1856, vol. 5, pt. 2, pp. 234–235; map opp. p. 238 and section sheet 6.

[2] Geol. Survey Cal., Pal., 1869, vol. 2, p. 77.

[3] King regards the immense series of upturned fresh-water deposits in the vicinity of Cajon Pass as Miocene: Explor. 40th Parallel, System. Geol., vol. 1, 1878, p. 413.

[4] Pac. R. R. Rept., 1856, vol. 5, pt. 2, pp. 164–173.

[5] Geol. Survey Cal., Geol., 1865, vol. 1, p. 203.

[6] Pac. R. R. Rept., vol. 5, pt. 3, p. 167.

	Feet.
c. Sand, stained with iron, includes a thin layer of pebbles	2
Gravel and sand, inclosing casts of fossils, obliquely stratified, and all strongly cemented with sesquioxide of iron	0·7
b. Sand, in thin layers, stained with oxide of iron	0·6
a. Fine, friable, gray sand, stained with lines of oxide of iron, and inclosing nodules of various sizes encased in oxide of iron.........	2
Level of Posé Creek.	

North of White Creek this or a similar formation extends along the base of the Sierra, forming low detached foothills as far north perhaps as San Joaquin County, though this portion of their extension has been little studied.

THE AURIFEROUS GRAVELS.

Beds of incoherent Pliocene sands and gravels have already been referred to in connection with our description of the Coast ranges. They have as a rule been found to lie nearly horizontally upon the upturned strata of the Miocene or earlier date, and are usually unfossiliferous.

On the western flank of the Sierra Nevada, extending from Mariposa to Plumas County, a distance of 175 miles, is a district containing numerous patches of sands, clays, and gravels, which, on account of the gold they contain and their generally coarse materials, have usually been termed "Auriferous gravels." Their mode of occurrence, their fossil contents, their probable geological age, etc., were noted with some care in the first volume published by Whitney on the geology of California, but have since been elaborately discussed by the same author,[1] and the able paleobotanist, Leo Lesquereux,[2] in volume VI of the Memoirs of the Museum of Comparative Zoology at Harvard College, 1878–'80. It accordingly seems unnecessary to go into details here regarding the geology of the gravels. The State Mining Bureau of California has been collecting material regarding these gravels for the last ten years, and this has been published in the annual reports of the State mineralogist. It relates almost entirely to economic matters, so that for general geological and paleontological features of these deposits reference must be had to the works of Whitney and Lesquereux.

Neocene lake beds.—Farther north, however, in Plumas, Lassen, Shasta, and Tehama counties, the researches of J. S. Diller have brought to light the existence of various beds of volcanic detrital and ordinary fresh-water sedimentation, which in some instances are auriferous, and doubtless are synchronous with the "Auriferous gravels" to the south. In discussing these deposits Mr. Diller[3] subdivides them into "Miocene" and "Pliocene," though on a local map, including the Lassens Peak district, he colors them all as "Neocene" without distinction. This author says:

[1] J. D. Whitney: The Auriferous Gravels of the Sierra Nevada of California. Memoir, etc., vol. 6 No. 1, pt. 1, 1879. Same, part 2, 1880.

[2] Leo Lesquereux, Rept. on the Foss. Plants, Aurif. Grav. Deposits, etc. Memoir, vol. 6, No. 2, 1878.

[3] 8th Ann. Rept. U. S. Geol. Surv., 1889, pt. 1, pp. 413, 422.

During the Miocene the northern portion of the Sacramento Valley was occupied by an extensive fresh-water lake, which stretched far to the northeastward through Lassen Strait, that marks the limit between the northern terminus of the Sierras and the Coast Range and is now occupied by the volcanic uplift of Lassen Peak. A similar body of water existed northeast of Indian Valley, in the country now occupied by the very crest of the Sierras, northwest of Honey Lake, at an elevation of nearly 7,000 feet. From the fact that the lacustrine deposits on both sides of Lassens Peak pass beneath its lavas, it is believed that they are continuous and were all laid down in the same lake, which at that time covered a large portion of what is now the northern end of the Sierras and extended from the Sacramento valley far into Oregon. Clarence King[1] has called attention to the wide distribution of Miocene lacustrine deposits in that region, extending from beyond the Columbia River south, through Oregon into Nevada and California, and it may now be added that they passed, through the gap separating the north end of the Sierras from the Coast range, into the northern portion of the Sacramento Valley. To the large body of fresh water in which these sediments were found King gave the name of Pah Ute or Piute Lake. The Piute Lake deposits reach much higher up on the Sierras than the littoral deposits of the Chico epoch, indicating clearly that between the close of the Chico epoch and the beginning of the Miocene there was a change in the relative elevation of the Sacramento valley and the Sierra region. This change was effected by the elevation of at least part of the region of the Coast Range, and apparently also of the Cascade Range, so that the oceanic waters were excluded and the formation of Piute Lake was rendered possible. That this elevation occurred at the close of the Cretaceous is rendered altogether probable by the fact that the Tejon group has not yet been recognized within the Piute Lake region. Perhaps we may yet find in the earlier deposits of that lake the fresh-water equivalents of the Tejon group of western Oregon and southern California.[2]

In this Miocene lake there were deposited, at least within the Lassen Peak district, first, shales and sandstones, and afterwards conglomerates. A typical exposure of these beds is found on Little Cow Creek, in Shasta County, at an elevation of about 2,900 feet. At one place a fine shaly bed is intercalated between the sandstone, and contains fossil leaves, some of which have been identified by Lesquereux and by him referred to the Miocene. With these was found *Anodonta nuttalliana*, according to the identification of Dr. R. E. C. Stearns.

The whole thickness of the Miocene here exposed is not less than 500 feet. Its contact with the Chico beds has not been seen, but the relative positions of two at adjacent exposures indicate that they are slightly unconformable.

The prominent ridge between Bear Creek and the south fork of Cow Creek affords an unusually interesting exposure of the upper portion of the Miocene. At the very base of the hill, in the beds of both streams, Chico fossils have been found, so that the hill undoubtedly rests on the Cretaceous. Above the fossiliferous beds is a considerable thickness of sandstone capped by a heavy layer of conglomerate, and overlying this is usually found a remarkable flow of tufaceous rhyolitic lava. The conglomerate at this point shows apparently a greater development than anywhere else within the district. It has been mined for gold, but without marked success. * * *

South of Bear Creek the Miocene is not so extensively developed nor so well exposed.[3]

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[1] U. S. Geol. Explor. of the 40th Parallel, vol. 1, 1878, pp. 451-454.
[2] Ann. Rept. U. S. Geol. Surv., 1889, pp. 420-421.
[3] Ibid., pp. 414, 415.

Similar deposits have been seen in the vicinity of Mountain Meadows and Light Canyon. Near the former, a few fossil leaves have been found, and likewise auriferous gravels.

A short distance north of the road, where it crosses the summit between Light Canyon and Susanville, at the head of a stream which flows into Susan Creek, the gravel is cemented into a firm conglomerate. It is about 350 feet thick and dips slightly to the eastward.[1]

Some fossil leaves were found here in lenticular masses of shale imbedded in the consolidated gravels. Others were found in a clayey stratum in the Monte Christo mine, accompanied by a species of fresh-water fish. All these plants have been identified by Leo Lesquereux, who states that "by the presence of a large number of *Laurineæ* the flora becomes related in its general characters to that of a region analogous in atmospheric circumstances to Florida. With this view Prof. Lester F. Ward also fully agrees."

Within the Lassens Peak districts deposit of Pliocene age have not been definitely distinguished from those of the Miocene, but their presence is rendered altogether probable by several considerations. The auriferous gravels were regarded by Prof. Whitney as accumulating upon the western slope of the Sierras throughout the whole of the Tertiary, reaching their culmination in the Pliocene. This view is very probable, indeed, for although the mass of the gravels of the gold belt are Pliocene, it appears to be evident that other portions, especially that at Cherokee as well as about Mountain Meadows and near the head of Light Canyon, belong to the Miocene.[2]

The tufa of which the Pliocene is composed is often distinctly stratified, clearly indicating that its deposition took place in water.

In the canyon of Mill Creek and also in that of Deer Creek, near the mountains, where the tufa has a thickness of nearly 1,000 feet, it is roughly divisible into three parts, as indicated in Fig. 17. The upper and lower portions are agglomerate, and between them the stratified arrangement of the tufa is clearly discernible. In all parts the sediments are essentially the same, being composed largely and perhaps chiefly of fragmental material ejected from volcanoes.

It is apparent that the water body about the northern terminus of the Sierras during the Pliocene was shallower and more extensive than the Miocene lake, and differed also in the character of its deposits.[3]

The small Pliocene area represented on the map some distance southwest of Honey Lake has recently been described by Mr. Turner before the Washington Philosophical Society.

The Neocene area represented on Klamath River is supposed by Diller to be continuous with that on Pit River, the intermediate development being wholly concealed by lava outflows.

HUMAN REMAINS IN THE AURIFEROUS GRAVELS.

It seems inadvisable to close this sketch of what is known of the Californian Neocene without some reference to the presence of the remains of man associated in the gravels with the bones of Pliocene mammals, fossil leaves, etc., of which a full account to date of publication has been given by Whitney in his work, already cited.

[1] 8th Ann. Rept. U. S. Geol. Surv., 1889, p. 417.
[2] Ibid., p. 422.
[3] Ibid., p. 423.

Since the publication of that work other testimony has come to hand[1] which leaves no valid reason to doubt the occurrence in the gravels of human bones and articles of stone and shell of human handiwork, which are of course as strong an evidence of man's presence as a skeleton would be. These remains are found under a basaltic layer covering the gravels and of which large masses remain forming "table mountains" protected from erosion by their basaltic capping. The remainder of the basalt and much other material has been carried away by erosion leaving these mountains like islands, 1,000 to 2,000 feet above the intervening valleys. As we have seen in the case of the Clear Lake basalt, the eruptive rock is without doubt Pleistocene, and comparatively late Pleistocene, if the term Pliocene be held to have the same meaning in California that it has hitherto had elsewhere.

Cope has pointed out that among the vertebrates from these gravels one (*elotherium*) is not Pliocene nor even Upper Miocene, but belongs to the Eocene or lowest Miocene (White River group), while *Mastodon obscurus* is Upper Miocene.[2] So it is obvious that the gravels, even if man be left out of the question entirely, contain vertebrate remains belonging to more than one epoch. It has been suggested by Becker that in California the Pliocene animals survived after glaciation in the northeastern part of the continent had resulted in extermination or migration and, as in the case of Florida, there is nothing inherently improbable in this view. But that man was contemporaneous with them is a proposition as yet unsupported by direct evidence and a priori improbable.

The really marvelous thing in the discovery of man in these gravels is the unimpeachable evidence of the enormous lapse of time since he wandered in the river valleys of Pleistocene California, which is afforded by the known facts. This offers us no new idea, for geologists have long discussed periods of Pleistocene time which mount up into the tens or hundreds of thousands of years. But the vividness of the testimony offered by these discoveries lends a reality to the assumption which is startling in its emphasis and brings it home to us in a manner which no merely mathematical calculations can approach.

It should not be forgotten that a somewhat similar association of flint implements with Pliocene vertebrate remains was discovered in Oregon,[3] though in this case the formation was not sealed from disturbance by an impermeable covering of lava such as fixes the authenticity of the assembly in the Californian gravels.

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[1] See George F. Becker, Am. Geologist, April, 1891, vol. 7, p. 258; also Bull. Geol. Soc. Am., Feb. 1891, vol. 2, pp. 189–200, and Geo. F. Wright, Atlantic Monthly, April, 1891, p. 501.

[2] Am. Naturalist, January, 1880, vol. 14, p. 62.

[3] Cf. Cope, Am. Naturalist for 1878, p. 125, and for 1880, p. 62. See also, U. S. Geol. Surv. Terr., Bull. No. 4, p. 389, and No. 5, p. 48.

OREGON.

PACIFIC BORDER.

The fresh-water Tertiaries of eastern Oregon will be considered in chapter VI, where they naturally belong.

Along the ocean border of this state three detached areas of Neocene deposits have thus far been recognized.

The first, going northward from the California line, appears just north of Port Orford,[1] and is more or less continuous to Cape Blanco.[2] It is an arenaceous deposit forming a narrow strip, and is said by Newberry to resemble closely the shales and sandstones of Astoria referred by Conrad to the Miocene.

The second appears in the vicinity of Coos Bay,[3] eastward, inland 4 or 5 miles from the ocean.[4] Immediately upon the shore fossiliferous beds are exposed which, as Dr. White[5] has shown, belong without doubt to the Eocene. These dip eastward, presenting their upturned edges to the sea, the eastward slope being formed by the superincumbent Miocene.

The third area of Neocene is exposed on the shore, a little south of Yaquina Bay, whence it is more or less continuous northward as far as the Columbia River, except where broken by recent lavas. In this section of the coast Prof. Condon states that no Eocene rocks appear to crop out.

At Tillamook Head Dana[6] has noted the occurrence of an argillaceous cliff 900 feet in height. Its lower two-thirds appears dark and shaly, while above it is light and chalky. These beds doubtless belong to the same geological horizons as the series displayed at Astoria, to be described hereafter. It seems that Prof. Condon has obtained an *Aturia ziczac* from Tillamook, indicating the presence there of Eocene rocks.

COLUMBIA RIVER.

Three distinct formations along the Columbia have been referred by Dana to the Tertiary period.

Astoria shales.—The first consists of clayey or sandy shales of various colors and various degrees of consolidation. On weathering they become soft and clayey, and so appear along the banks at Astoria. At the time of Dana's visit and until a few years ago numerous Eocene fossil remains were obtained at the water's edge by collectors in the town of Astoria. These came from a single very thin stratum below the Miocene shales. Owing, however, to the fact that the specimens

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[1] Pac. R. R. Rep., 1857, vol. 6, pt. ii, p. 59, and Trans. Acad. Sci., St. Louis, 1860, vol. 1, p. 120.

[2] According to Prof. Thos. Condon, 1890.

[3] Pac. R. R. Rep., 1857, vol. 6, pt. ii, p. 63, and Trans. Acad. Sci., St. Louis, 1860, vol. 1, p. 122.

[4] As verbally described by Prof. Condon, 1890.

[5] U. S. Geol. Survey, Bull, 1889, No. 51, p. 30.

[6] Wilkes's Expl. Exped., Geology, by Dana, p. 653.

were contained in calcareous concretions, which, on account of the scarcity of limestone in this region, have been carefully collected and burned for lime, while the beach has been built over and entirely covered, this bed is no longer accessible, and the supply from this source has virtually been cut off. The same expedition also collected Miocene fossils from the beds above. Specimens inferior in preservation from the superincumbent Miocene beds may still be seen in the banks near Tongue Point at the Bluffs behind the schoolhouse, and at other localities about Astoria; yet the gradings, wharfage, buildings, etc., have concealed to a considerable extent many of these exposures. Collections of molluscan remains were made in this region over forty years ago by both Mr. J. K. Townsend[1] and the United States Exploring Expedition, under Captain Wilkes,[2] and were turned over to Mr. T. A. Conrad. This authority did not hesitate to pronounce them all Miocene; not because he actually found known species of this age among them, but because their nearest analogues were from the Miocene of Virginia and England.

Aturia bed.—Of late Dr. C. A. White has pointed out[3] the great similarity between certain Chico-Tejon forms and those figured by Conrad from the Townsend collection; the Miocene character of the fossils collected by the Wilkes expedition, except the *Aturia*, is not called in question. At a later date collections were made by Prof. Condon from both the Eocene and the Miocene horizons at Astoria and are still preserved in his collection at the State University and properly discriminated. The presence of *Aturia ziczac* and other apparently Eocene forms among those obtained at Astoria and referred by Conrad to the Miocene has led to the suspicion that the whole series of beds might really be of Eocene age,[4] but this evidence, for which we are indebted to Prof. Condon, explains the discrepancy which has been so long a mystery.

Astoria sandstones.—The second formation along the Columbia consists of a series of sandstones which occurs on both sides of the river above Astoria, though best developed on the north or right bank, while the Astoria shales[5] above described are most prominent on the left or south bank. The sandstones are granular, brittle, or friable, sometimes very compact and hard, usually of a brownish color. Dana[6] regards the sandstones as more recent than the shales, a view which is strengthened by the fact that fissures in the shales are still filled with sand resembling that of which the sandstones are composed.

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[1] Am. Jour. Sci., 2d ser., 1848, vol. 5, pp. 432–433.

[2] Wilkes Expl. Exped., Geology by Dana, 1849, p. 659. These were collected at Astoria proper, as at present understood, but the locality of Townsend's fossils is given as "near Astoria." They were very probably from the north bank of the Columbia, opposite Astoria.

[3] U. S. Geol. Survey, Bull. No. 51, 1889, p. 31.

[4] Conrad himself at a later date inclined to this opinion and referred the Astoria beds to the Eocene. Proc. Acad. Nat. Sci., Phila., for 1865, pp. 70–71.

[5] Named by Prof. Condon, Am. Naturalist, 1880, vol. 14, p. 457.

[6] Geol., Expl. Wilkes Exped., 1849, pp. 553–556.

Astoria group.—The impression produced on the mind by an inspection of these rocks,[1] though without the opportunity to examine any large district with care, was that the shales and sandstones form a part of a single series varying in the character of its beds or layers according to fluctuations in the sedimentation, the shales being more argillaceous, the sandstones more arenaceous, neither possessing an exclusive character, the fossils appearing to be the same Miocene species in both, with a tendency to form concretions around them in the shale and to be represented by casts in the sandstones. The name of Astoria group is proposed to include them both, but not the subjacent Eocene Aturia bed.

As Astoria is a classical locality for the geology of this coast, it may be well to give a few descriptive notes taken by W. H. Dall on a recent visit for the purpose of examining these beds.

The Aturia bed, as before explained, is no longer accessible, its outcrop having been close to the water's edge under the most elevated part of the (anticlinal?) high bluffs behind the town, which is strung along on a narrow talus or built out on piles over the river, there being hardly any level land between the bluffs and the water.

At Smiths Point, west of the town, the shales are very low, the vertical face not exceeding 15 feet. They dip about 16° in a southeasterly direction, and are composed of thin layers of chiefly bluish gray shale with numerous fractures lined with peroxide of iron which develop more numerously as the surface dries, while the iron causes the face to weather of a brownish color. The layers mostly contain a little sand; some do not show any. The fluctuations appear to succeed each other with a certain regularity. Here and there a little gravel is mixed in one of the layers, and in these gravelly layers are also small fragments of bivalve shells, the most perfect and numerous being those of a small concentrically undulated *Pecten* of the section *Pseudamusium; Acila* and *Waldheimia* were also observed.

In the upper layers of the shale the clayey parts occasionally form lines of concretions along a bedding plane, partly fossiliferous. The most common fossil here is a species of *Macoma*.

Above the shales at this point is a bed of 8 to 20 feet in thickness of a yellowish clayey sand with irregular, mostly rounded fragments of a harder sandstone, maculated with peroxide of iron with a few traces of marine fossils, and more or less gravel not regularly bedded, and penetrating into fissures in the shaly rock below in the form of dikes. The beach in this vicinity is composed of the pebbles, nodules, and small bowlders of the hard sandstone washed out of this layer, and a few volcanic fragments. Near Tongue Point, at the other end of the town, 2 miles away, the same beds were recognized, but the gravelly layer seemed thicker and the shale much broken up. The same beds seem to compose the bluffs between Tongue and Smiths points, though from

[1] Wm. H. Dall, in August, 1890.

the way the town is built they are difficult of access. The bluffs at their highest point near the high-school building rise perhaps 150 feet. Here a fine section shows 30 to 40 feet of the shales exposed at an angle of 45° to 60°, dipping about 26° south southeast, though the dip is not invariable. The yellowish sandstone gravel overlies the shales to an equal thickness and descends into them in dikes here and there. The upper margin of the shales is sometimes indistinguishable, the clayey and sandy layers merging into one another and being similar in color. It is notable that in the upper part of the shales some of the shells seem to have been fossilized in a sandstone, washed out and reimbedded in the clays. Between the valves, or on one side of a single valve of a bivalve shell, there will be a soft coarse sandstone, while the fossil is otherwise entirely imbedded in a dark waxy clay shale.

Tongue Point itself is a basaltic mass, and on the ridge behind the town, according to Prof. Condon, there is an extensive layer of Pleistocene basalt, fragments of which appear on the beaches. On the south side of the street from the Union Pacific dock and one block west, a fire had destroyed some buildings and a part of the planking of the roadway, revealing a fine solid basaltic rock 10 or 12 feet square and 15 feet high. The original beach at its base was abundantly strewn with fragments of the same material.

These shales and sandstones have much general similarity to those of California and Alaska of Miocene age. A similar rock exists on the west coast of Vancouver Island, British Columbia, containing some of the same species which appear at Astoria, specimens of which have recently been received by the geological survey of the Dominion of Canada.

From a point a few miles south of Oregon City, Clackamas County, Shumard[1] has described a Miocene *Leda* under the name of *L. oregona*.

The Aturia bed and the superincumbent Miocene of the Astoria group appear on the north bank of the Columbia in a good many places, apparently more elevated than on the Oregon side.

The third deposit regarded by Dana as Tertiary consists of a basaltic conglomerate, which is found on this river high up at the Cascades and even beyond. It will be referred to later.

WILLAMETTE RIVER.

Both Dana[2] and Newberry[3] inform us that a sandstone formation extends up the Willamette valley with but slight interruptions at least as far as the Calapooya Mountains. Both note its intrusions of trap, its more or less disturbed condition, its apparent want of fossil remains, its eroded condition, and its lithological resemblance to the various Tertiary sandstones so well developed in California and Oregon.

In 1885 Dr. C. A. White[4] published from information received from

[1] Trans. St. Louis Acad. Sci., vol. 1, 1860, p. 121.
[2] Wilkes Exploring Exped., Geol. by Dana, pp. 651 et seq.
[3] Pacific R. R. Rep., vol. 6, pt. 2., 1857, pp. 58, 59.
[4] Bull. U. S. Geol. Survey, No. 18.

Prof. Thomas Condon an account of the occurrence of *Cardita planicosta* at Albany, Oregon, and remarks incidentally that "strata which bear characteristic Miocene fossils are found in the valley of the Willamette only a few miles away."

During the summer of 1890 Wm. H. Dall collected at several of these Miocene localities, and by the assistance of Prof. Condon has been able to note a wider distribution of the Eocene than has heretofore been recognized in this State.

Miocene rocks are well exposed at Smith's quarry, 1 mile east of Eugene City, and at Springfield bridge, 2 miles farther east. At the former locality the rocks consist of grayish hard sandstone weathering to a yellowish color, irregularly bedded above, but massive below, dipping about 6° southeast, with a total exposure of about 37 feet. The fossils—*Mytilus*, *Modiola*, *Mactra*, *Solen*[1], *Natica*, *Neverita*, *Purpura*, and *Lirofusus*—are crowded or crushed together along certain lines or layers, and are usually in form of molds recrystallized into spar.

The second locality, or that near Springfield, affords an excellent exposure of nearly a mile in length, extending southward from the abutment of the new bridge. The rocks have an easterly dip of from 5° to 8° and form a total perpendicular exposure of about 160 feet; they are overlain unconformably by 5 or 10 feet of alluvial matter which lies on their eroded edges. In the hilly regions, according to the observations of Prof. Condon, they are capped with basalt.

A basaltic conglomerate has already been referred to as occurring in the Cascade Range along the Columbia. In southern Oregon, in the "Boundary Range," according to Dana,[2] this conglomerate graduates into Tertiary sandstone containing fossil remains. The latter Dr. White has recently referred to the Chico division of his Chico-Tejon series.[3]

It is stated in the American Naturalist[4], from Prof. Condon's manuscript notes, that the backbone of the Coast Range consists of argillaceous Miocene shale, which contains fish remains and invertebrate fossils. These Prof. Condon identifies with the outcrops at Astoria, and names the Astoria shales. Above these lie extensive Miocene beds, rich in fossils, which Prof. Condon calls "Solen beds." On the flanks of the highlands there are also Pliocene deposits containing some of the fossils of the Equus beds.

WASHINGTON.

The little that is known regarding the Neocene geology of this State can be most conveniently considered under two heads, viz, (1) geology

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[1] It was probably on account of the presence of this genus in rather unusual abundance that Prof. Condon has applied to the chief Miocene fossiliferous bed of the Willamette Valley the name of "Solen bed." It is not improbable that it may be found to constitute one of the series of beds which are above designated as the Astoria sandstones. Their upper surface is always eroded.

[2] Wilkes Expl. Exped., Geol. by Dana, 1849, pp. 646, 653.

[3] Bull. U. S. Geol. Survey, No. 51, 1889, p. 29.

[4] Vol. 14, 1880, p. 457.

of the Pacific border and (2) geology of the central basin. Although inferences may be drawn from King's works regarding the existence and probable Neocene age of certain volcanic materials in the mountain ranges of this State, yet it is not deemed advisable to indulge in such speculations, and this brief notice will be restricted to what is actually known respecting the sedimentary Neocene deposits.

PACIFIC BORDER.

Siliceous casts of molluscan fossils have been collected at various points on Shoalwater Bay,[1] which show a synchronism of the deposits in which they are found with both the Eocene and the Miocene clay shales of Astoria. The Aturia bed crops out at Bruceport and elsewhere. A Pliocene deposit has been observed by Dr. Condon in this vicinity, which, from its most characteristic fossil, may be called the Mytilus bed. It furnished specimens of *Buccinum cyaneum*, *Mytilus condoni*,[2] *Crepidula*, *Pecten*, and *Panopœa;* this is immediately overlain by a Pleistocene formation, the level of which is from 30 to 40 feet above the sea.

CENTRAL BASIN.[3]

Lignite beds.—In Dana's geology of the Wilkes Exploring Expedition[4] reference is made to the similarity of structure of the Cowlitz valley and the Willamette. A coal deposit is also noted and an analysis of the coal is given.[5] Newberry also speaks of the parallelism of various west coast river basins, and adds that the "lignite" is found near the mouth of the Cowlitz, implying also that the accompanying strata are sandstone and shale.[6]

Farther to the north, along the Nisqually and Chehalis rivers, "bluffs of soft sandstone and crumbling clay" were reported by a Mr. Eld to Dana while on the Wilkes Exploring Expedition.[7]

The extensive coal and lignitic deposits about Puget Sound have been referred by Newberry[8] and White[9] to a group transitional from Cretaceous to Eocene, or to the Laramie or Puget group (Chico?). Still farther to the north, on the Dwamish River, the deposits belong without doubt to a higher horizon, for none but proper Tejon fossils are represented. Mr. Willis,[10] by purely stratigraphic study, arrived at the same conclusion.

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[1] Dr. Leidy figures in the U. S. Geol. Surv. Terr., "Fossil Vert.," vol. 1, pl. 33, fig. 19, an upper molar tooth from the "lignite beds of Shoalwater," which is "undistinguishable from the corresponding part of the domestic horse," op. cit., p. 246.

[2] Nautilus, Dec., 1890, vol. 4, pp. 88, 89; notes by Wm. H. Dall.

[3] In addition to the geological facts given under this head, Cope describes *Taxidea sulcata* from the Pliocene of Washington Ter., but gives no definite locality. Proc. Am. Phil. Soc., vol. 17, 1877, p. 227.

[4] Op. cit., 1849, pp. 616-621, 626.

[5] Ibid., p. 658.

[6] Pac. R. R. Rep., 1857, vol. 6, pt. 2, p. 57.

[7] Op. cit., p. 628.

[8] Bull. U. S. Geol. Surv., No. 51, 1889, p. 51.

[9] Ibid., pp. 49 et seq.

[10] Ibid., p. 56.

Certain deposits in the vicinity of Bellingham Bay were long ago referred by Leo Lesquereux[1] upon paleontological evidence to the Miocene. In this interpretation both Heer[2] and Newberry[3] concur. They may, however, be referable to the Kenai group.

From a manuscript report of Lieut. W. P. Trowbridge, Blake[4] gives the following description of the coal beds.

The coal strata exposed to view on Bellingham Bay are situated in latitude 48° 43′, and occur in a series of stratified rocks, which dip at an angle of 70° from the horizon, and strike E. 15° N., the thickness of the series being about 2,000 feet. The coal beds enter the bank at right angles to the shore line, and rise with a gradual slope to the height of about 350 feet, at the distance of half a mile from the shore, where they are broken in a direction oblique to that of the beds, and fall off in abrupt ledges to their original level.

The total thickness of the coal strata was estimated by Trowbridge as being 116 feet. Blake, however, was inclined to suspect that some of the beds may have been duplicated by dislocation.

But few invertebrate fossils have been observed at this locality. Blake mentions having seen "two well preserved shells of the genus Pecten[5]" in a sandstone block shown him by Lieut. Trowbridge. Dall was informed that an *Aturia ziczac* had been collected here, though the specimen was not accessible. Both the Aturia bed of the Eocene and the Miocene shales will probably be found represented at Bellingham Bay as at Astoria.

Puget group.—During the progress of the Northwest boundary surveys (1858–1862) various naturalists and geologists visited the Puget Sound region. Among them was Dr. Hector, who reported to Col. Palliser on the geology.[6] Mr. Richardson, Dr. Dawson, and others have visited this region for geological researches, and from the sum total of available information, published or otherwise, the latter has prepared a geological map including, in addition to the geology of the British Columbian region just north of the State, a considerable part of Washington. On this map, issued by the Dominion Geological Survey in 1884, the marine Miocene is represented as forming a border along the ocean coast, the shore of Fuca Strait, and the western half of Puget Sound, inclosing the mass of the Olympic Mountains and the coast ranges north of the Columbia. The shores of Puget Sound eastward as far as the bight on which Tacoma is situated, and at the North Whidbey Island and the shore east and southeast from it, and hence northward to Bellingham Bay, Birch Bay, and the international boundary, are indicated as marine Miocene on this map. This may, perhaps, be regarded as covering all post-Cretaceous strata in an approximate way, for it is certain that within the area thus broadly indicated a

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[1] Am. Jour. Sci., vol. 27, 1859, pp. 359 et seq.
[2] Ibid., vol. 28, 1859, pp. 85 et seq.
[3] Boston Jour. Nat. Hist., 1860, vol. 7, pt. 2, p. 509.
[4] Pac. R. R. Rep. 1856, vol. 5, pt. 2, p. 285.
[5] Ibid., p. 287.
[6] Proc. Geol. Society, in Quart. Jour. Geol. Soc., vol. 17, pp. 388-445, and plate xiii. See page 435.

considerable part must be referred to post-glacial deposits, while the presence of Eocene rocks has already been indicated.

It may be added that on the map referred to nearly the whole of eastern Washington, including the Cascade Mountains and the entire region east of them and south from the Wenatchee, Columbia and Spokane rivers, is represented as occupied by volcanic rocks of Miocene age. The determination of the age of these beds can not be said, however, to be conclusive, in view of what is known of the very recent origin of analagous eruptives in California, but at present we are not in a position to discuss the question on account of the paucity of our information.

BRITISH COLUMBIA.

NEOCENE OF THE COAST.

But little relating to the Neocene on the coast of British Columbia has been put on record. As previously stated, a clayey sandstone with fossils of the Astoria group has been collected on the west coast of Vancouver Island. Doubtless the same rocks occur at various points along the coast of British Columbia and the adjacent islands, though the glaciation and violent changes of level to which this region has been subjected in Pleistocene time have probably resulted in the erosion and disappearance of most of the softer Neozoic beds which were deposited along its shores.

One locality of marine Miocene beds is that near Sooke, on the west coast of Vancouver Island, in about west longitude 124° from Greenwich. The area is small. A larger area appears in the northern part of the Queen Charlotte Islands, forming that part of Graham Island east of Masset Inlet and north of Skidegate Inlet. West of this Graham Island is largely composed of volcanic rocks, which on the geological map of the Geological Survey of the Dominion of Canada[1] are colored as belonging to the Miocene, and which overlie sandstones or shales and hard clays with lignites. At a single locality near the north end of Graham Island beds with numerous marine fossils occur.

These, in so far as they admit of specific determination, represent shells found in the later Tertiary deposits of California, some of which are still living on the northwest coast; and the assemblage is not such as to indicate any marked difference of climate from that now obtaining. * * * The Tertiary rocks of the coast are not anywhere much disturbed or altered. The relative level of sea and land must have been nearly as at present when they were formed, and it is probable that they were originally spread much more widely, the preservation of such an area as that of Graham Island being due to the protective capping of volcanic rocks. The beds belong evidently to the more recent Tertiary, and though the paleontological evidence is scanty, it appears probable from this and by comparison with the other parts of the west coast that they should be called Miocene.[2]

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[1] Descriptive sketch of the Physical Geography and Geology of the Dominion of Canada, by A. R. C. Selwyn, director, and G. M. Dawson, Dr. Sci., associate. Montreal, Dawson Bros., 1884. 55 pp., 8°, and large map in two sheets geologically colored. See Part II, by Dr. G. M. Dawson, pp. 52–55.

[2] Dawson, op. cit., 1884, p. 53.

Tertiary rocks also occupy a considerable area about the mouth of the Fraser River, extending northward from the 49th parallel, forming the boundary to Burrard Inlet, where thin layers of lignite occur, but in seams too thin to have much value. Fossil plants from Burrard Inlet are described[1] by Newberry and Lesquereux in connection with those from Bellingham Bay, Washington, and are supposed to indicate a Miocene age for the beds.

NEOCENE OF THE REGION EAST FROM THE COAST RANGES.

East from the Coast ranges Tertiary rocks, according to Dawson,[2] are very extensively developed. They have not, however, yielded any marine fossils and

They appear to have been formed in an extensive lake or series of lakes which may at one time have submerged nearly the entire area of the region known as the interior plateau. The Tertiary lake or lakes may not improbably have been produced by the interruption of the drainage of the region by a renewed elevation of the coast mountains proceeding in advance of the power of the rivers of the period to lower their beds; the movement culminating in a profound disturbance leading to a very extensive volcanic action. The lower beds are sandstones, clays, and shales generally pale grayish or yellowish in color, except when darkened by carbonaceous matter. They frequently hold lignite, coal, and in some even true bituminous coal occurs. These sedimentary beds rest generally on a very irregular surface, and consequently vary much in thickness and character in different parts of the extensive area over which they occur. The lignites appear in some places to rest on true "underclays," representing the soil on which the vegetation producing them has grown, while in others, as at Quesnel, they seem to be composed of driftwood, and show much clay and sand interlaminuated with the coaly matter.

In the northern portion of the interior the upper volcanic part of the Tertiary covers great areas, and is usually in beds nearly horizontal, or at least not extensively or sharply folded. Basalts, dolerites, and allied rocks of modern aspect occur in sheets, broken only here and there by valleys of denudation; and acidic rocks are seldom met with except in the immediate vicinity of the ancient volcanic vents. On the lower Nechacco, and on the Parsnip River, the lower sedimemtary rocks appear to be somewhat extensively developed without the overlying volcanic materials. The southern part of the interior plateau is more irregular and mountainous. The Tertiary rocks here cover less extensive areas, and are much more disturbed, and sometimes over wide districts, as on the Nicola, are found dipping at an average angle of about 30 degrees. The volcanic materials are occasionally of great thickness, and the little disturbed basalts of the north are, for the most part, replaced by agglomerates and tufas, with trachytes, porphyrites, and other feldspathic rocks. It may, indeed, be questioned whether the character of these rocks does not indicate that they are of

[1] Geol. Survey Dom. Canada, Rep. of Progress, 1876–'77, p. 190.

[2] These beds are obviously to be referred to the Kenai group, since they contain essentially the same flora. *Limnæa*, *Physa*, and *Sphærium* have also been noticed at Vermilion Cliff. Localities for the occurrence of plant beds and lignites of the Kenai group in the southern part of British Columbia may be mentioned as follows: The vicinity of Okanagan Lake; the Coal Brook Indian reserve on the north Thompson River (p. 113); Kamloops Lake (p. 114); Vermilion Cliff 3 miles up the north fork of the Similkameen River (p. 130), and also the south fork (p. 132); on Ninemile Creek and Hat Creek (p. 121); 20 miles north of Osoyoos Lake, where 3,000 feet of sandstones and shales have been observed (p. 129); on Tenmile Creek coal is noted (p. 126), and also near the junction of Nicola and Coldwater rivers (p. 122); on the Fraser near Lillooet, and on the upper part of Kettle River (p. 160). Dawson also notes the complete absence of marine Eocene beds (p. 167).

See Dominion Geological Survey, Report of Progress for 1877–1878, Montreal, Canada, 1879; pp. 1–188B, by Geo. M. Dawson (to which above page references refer), including a list of Tertiary plants from various British Columbian localities, by J. W. Dawson, LL. D., op cit. pp. 186–188B.

earlier date than those to the north, but, as no direct paleontological evidence of this has been obtained, it is presumed that their different composition and appearance is due to unlike conditions of deposition and greater subsequent disturbance.

No volcanic rocks or lava flows of post-Glacial age have (1884) been met with, though I believe that still farther to the northwest the rocks are of yet more recent origin than any of these here described, and I have even heard a tradition of the Indians of the Nasse River which relates that at some time very remote in their history an eruption covering a wide tract of country with lavas was witnessed.

The organic remains so far obtained from these Tertiary rocks of the interior consist of plants, insects, and a few fresh-water mollusks and fish-scales, the last being the only indication of the vertebrate fauna of the period. The plants have been collected at a number of localities. They have been subjected to a preliminary examination by Principal Dawson and several lists of species published. While they are certainly Tertiary and represent a temperate flora like that elsewhere attributed to the Miocene, they do not afford a very definite criterion of age, being derived from places which must have differed much in their physical surroundings at the time of the deposition of the beds.

Insect remains have been obtained in four localities. They have been examined by Mr. S. H. Scudder, who has contributed three papers on them in the Geological Reports, in which he describes forty species, all of which are considered new. None of the insects have been found to occur in more than a single locality, which causes Mr. Scudder to observe that the deposits from which they came may either differ considerably in age, or, with the fact that duplicates have seldom been found even in the same locality, evidence the existence of different surroundings and an exceedingly rich insect fauna.

Though the interior plateau may at one time have been pretty uniformly covered with Tertiary rocks, it is evident that some regions have never been overspread by them, while, owing to denudation, they have since been almost altogether removed from other districts, and the modern river valleys often cut completely through them to the older rocks. The outlines of the Tertiary areas are, therefore, now irregular and complicated.[1]

ALASKA.

As might be expected, the geology of this territory is most imperfectly known,[2] but the little which has been recorded leads to the inference that to a great extent the operations of mountain-building forces and the deposition of sediments along the coast of Alaska, south of and including the peninsula, were carried on in a similar and probably generally synchronous manner from Mexico to Bering Sea.

So far we have not been able to find any record of the discovery of marine fossils belonging to the Eocene in Alaska, though of the Miocene marine and leaf-bearing beds with lignitic coal, etc., there are abundant instances.

GENERAL NOTES ON THE ROCKS.

In general, along the southeastern coast of Alaska, the sequence of the rocks where undisturbed appears to be about as follows in descending order:

1. Soil and Pleistocene beds.

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[1] For additional information on the Tertiary rocks of the interior see Reports of Progress, Dominion Geol. Survey for 1871–'72, p. 56; for 1875–'76, pp. 70 and 225; for 1876–'77, pp. 75 and 112B; Dawson, op. cit., pp. 53–55.

[2] Geological notes in this section, except where otherwise stated, are from the unpublished observations of W. H. Dall.

2. Brown Miocene sandstones with marine shells, cetacean bones and water-worn Teredo-bored fossil wood (Astoria group, Nulato sandstones, Crepidula bed).

3. Beds of conglomerate, brown and iron-stained, alternating with gravelly and sandy layers, the finer beds containing fossil leaves of *Sequoia* and other vegetable remains (Kenai group, Unga beds).

4. Bluish sandy slates and shales with a rich Miocene plant flora, interstratified with beds of indurated gravel, fossil wood, and lignitic coal (Kenai group).

5. Metamorphic quartzites and slaty rocks, illustrating the geological series probably from the Jurassic to the upper Cretaceous, with perhaps part of the lower Eocene (Chico-Tejon).

6. Granite and syenite in massive beds, usually without mica and apparently in most instances forming the "backbone" of the mountain ridges or islands, but occasionally occurring as intrusive masses, which have thrust up the metamorphic rocks above them into arches, cracking them and filling the fissures with the syenitic material (Shumagin granite).

Intrusive granites.—Through all the Tertiary beds in various parts of the territory are found penetrating volcanic dikes and larger outflows, sometimes injected between sedimentary strata and sometimes overflowing them, much as in California, Oregon, and elsewhere in western America. The later eruptions, mostly Pliocene and Pleistocene, are generally of a basaltic character.[1]

The occurrence of intrusive syenite later than the metamorphic rocks and penetrating fissures in them is well exhibited at an arch of metamorphic rock near the beach at Granite Point, on the south side of the entrance to Sanborn harbor, Nagai Island, in the Shumagin group, where it was noted by the writer while surveying the harbor in 1872. Instances of the occurrence of the syenite as a massive body forming the fundamental rock are offered in many places, as the Diomedes Islands, Bering Strait, and most of the mountain masses of the Siberian side of the same strait; the central ridge of the island of Unalaska; the islands and hills of the eastern Shumagins, as Little Koniushi Island, and of Port Althorp, Cross Sound, in the Alexander Archipelago.

The age of the intrusive granites is yet undetermined, but in the case of the mass forming the celebrated Treadwell mine of Douglas Island, near Juneau, Alaska, which is of this character, Dr. Dawson refers the slaty rocks through which it has broken to the Vancouver series of Triassic rocks,[2] and the Shumagin quartzites may belong to the same group. At all events it is hardly likely to be Tertiary, and in this connection need not be considered further.

Early observations on Alaskan geology.—The Neozoic strata of southern Alaska were first noticed by Portlock and Dixon who, on their

[1] See Dall, Note on Alaska Tertiary Deposits, Am. Jour. Sci., 3d ser., July, 1882, vol. 24, pp. 67, 68.
[2] Notes on the ore deposit of the Treadwell mine, Alaska, Am. Geologist, August, 1889, pp. 84–93.

voyage to the northwest coast of America in 1785, entered English Bay or Port Graham, Cooks Inlet, and named it Coal Bay, from the lignitic beds exposed in its shores. In the following year the marine Miocene was observed by the naturalists of La Perouse's party, who collected in Lituya Bay at the height of 200 toises above the sea specimens of one of the large Miocene pectens.[1] The first general summary of existing knowledge of geology and geognosy of this region is comprised in the work of Grewingk,[2] who enumerates the localities for the Tertiary rocks among others and illustrates and enumerates many of the fossils. The paleobotany of the region was subsequently treated of by Göppert[3] and Heer.[4] Later, Eichwald[5] reviewed the subject and introduced a certain amount of confusion into the paleontological side of the question by referring to the Cretaceous (Turonian) all the marine Tertiary fossils described by Grewingk, many of which belonged to Miocene beds, but which Eichwald appears to have regarded as of the same age as the Tejon beds of California, which, following Gabb, in the Paleontology of California, he referred with the Chico to the Mesozoic epoch.

MIOCENE OF THE KENAI GROUP.

The coal-bearing Miocene beds best exhibited on the shores of Kachekmak Bay, Kenai Peninsula, Cooks Inlet, but widely spread in British Columbia and over the coast of Alaska and its adjacent islands, are regarded by Heer as the equivalent of the Atane leaf beds of Greenland, the Spitzbergen Miocene plant beds, the Braunkohl of east Prussia and the lower Rhine provinces, and the lower Molasse of Switzerland.

The Unga conglomerate.—On the island of Unga, Shumagin group, Alaska, they are conformably overlain by the brown conglomerates with *Sequoia* which are obviously younger and the result of a somewhat different series of conditions; though the sedimentation appears to have been measurably continuous. To these last I would give the name of the *Unga conglomerate;* but since in the present imperfect state of our knowledge we are unable to specify the exact horizon of most of the leaf beds reported by various observers, the whole series will be treated here under one head. The coal beds of southern Alaska and of the Yukon Valley, so far as identified, all belong to the interbedded lignites of the Kenai series, yet it is quite probable that some older beds are included in the list. In the case of the coal of Kake Strait, Admi-

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[1] Cf. voy. La Perouse, vol. 1, p. 395.

[2] Beitrag zur Kenntniss der orographischen und geognostischen Beschaffenheit der nordwest Küste Amerikas; Verh. Min. Ges. zu St. Petersburg für 1848–'49, 351 pp., 8°. Separately issued by Karl Kray, St. Petersburg, 1850.

[3] Abh. Schles. Ges. für Vaterl. Kultur., 1861, 2, p. 201, and 1867, p. 50.

[4] Flora fossilis Alaskana, Kongl. Svenska Vetensk. Akad. Handl. Bd. 8, No. 4, Stockholm, 1869, 4, pp. 41, 10 pl.

[5] Geogn. Pal. Bemerkungen über die Halbinsel Mangischlak und die Aleutischen Inseln, St. Petersburg, Kais. Akad. Wiss., 1871, 8°, pp. 200, pl. xx; cf. pp. 88–137.

ralty island, there appear, according to Newberry[1] to be several species identical with those of Kenai.

The most southern points which have been noted by us for the occurrences of these sandstones depend for their location on the reports of prospectors and on specimens observed in the mineralogical collection of the Russian-American Company at Sitka in 1865, a duplicate of which is included in the Imperial Zoological Museum of St. Petersburg. The Sitka collection was scattered in 1868.

Localities noted are as follows: The eastern arm of Whale Bay, Baranoff Island, the west shore of Kuiu Island in about the same latitude, the northern shore of the Lindenberg Peninsula, Kupreanoff Island, the mainland opposite the last mentioned locality, St. Johns Bay, on Baranoff Island north of Sitka, the southeastern extreme of Chichagoff Island on Chatham Strait, Kake Strait, Admiralty Island, and the shores of the northern part of Seymour Canal, Admiralty Island. These comprise the localities in the Alexander Archipelago. The Russian governor, Furuhjelm, upon whose collection in the main Heer's descriptions are based, visited a locality near Sitka, perhaps the one above mentioned at St. Johns Bay,[2] one on Kake Strait, and a third on Kuin Island. Of the latter a description and section are given from Furuhjelm's notes by Heer.

Beds of Kuiu Island.—The outcrop is between tide marks and consists of a sandstone with remains of a Hazel (*Corylus McQuarrii*), dipping inland about 25° or 30°, which contain thin layers of blackish gray shale in pairs, inclosing in each pair a layer, varying from 6 inches to 7½ feet in thickness, of brown coal or lignite. The shale contains plants, especially conifers. Above these and rising above high-water mark is a coarse grained sandstone overlain by a coarse conglomerate covered by about 15 feet of humus and turf. The whole section includes a belt of somewhat more than 200 feet wide, on the eroded surface of which are strewn numerous erratic blocks of granite. The section has a good deal of resemblance to that exposed at Coal Bay, Unga Island, at least in the succession of the plant beds, coal and conglomerate.

The shales from this locality afforded *Sequoia langsdorfii*, and species of *Glyptostrobus*, *Pteris*, and *Castanea*. The coal contained 16 per cent of water, about 3 per cent of ash, about 35 per cent of volatile, and 45 per cent of fixed carbonaceous matter, according to Genth.[3] The occurrence of lignite near Sitka is also noted by Erman[4] without precise identification of locality.

Beds of Lituya Bay.—North of the Alexander Archipelago, Cenozoic

[1] Brief descriptions of fossil plants, chiefly Tertiary, from western North America, by Dr. J. S. Newberry, Proc. U. S. Nat. Mus. vol. 5, pp. 502–514; February, 1883. The author describes five species from Cooks Inlet, two from Admiralty Island, Seymour Canal and one from Kake Strait, near Kootznahoo, Alaska.

[2] See report on the Geology of Alaska, House Ex. Doc. 177, Fortieth Congress, second session, February, 1868, pp. 314–325, by Theodore A. Blake.

[3] K. K. Geol. Reichsanstalt, Wien, 1868, p. 397; Heer, op. cit., p. 4.

[4] Reise um die Erde, 3, p. 213.

strata are first reported from Lituya Bay, where they were observed and a fossil *Pecten* collected at a height of 200 toises by the naturalists of La Perouse's party. In May, 1874, while making a reconnaissance of the bay, W. H. Dall landed on Cenotaph Island, which appeared to be chiefly composed of the ordinary marine Miocene sandstones, rather soft, but not at this point fossiliferous. This island lies directly in the trough of this extraordinary bay, and is remarkable in that it shows no evidences either by erosion or in the presence of erratics, of having been glaciated, which, if the bay had ever been filled with ice, must have happened. It would seem as if only a very small amount of erosion would have been sufficient to remove the whole of the relatively soft material of which this small and rather high islet is composed. The mass of the material on the beaches and brought down by the ice from the numerous enormous glaciers which discharge into the bay, appears to be schistose, or syenitic, the comparatively narrow strip of relatively lowland and foot hills, in front of the main range parallel with the coast, probably containing all the Cenozoic beds remaining there. On the main shores of Lituya Bay the basal rocks appeared to be massive syenite or granite overlain by stratified mica slates above which was clay slate with very obscure traces of fossils, and lastly coarse sandstone and conglomerate probably of Miocene age, but from which no fossils were collected. The stratified rocks seem conformable with one another and dip to the northwest at angles of from 15° to 75°. Their surfaces showed no traces of glaciation, though these, if ever present, might have been weathered away.

Port Graham lignite beds.—Passing over temporarily the newer formations observed in the vicinity of Yakutat Bay by Israel C. Russell (1890) and at Middleton Island by Dall (1874), the next locality in geographical order where the Miocene plant beds have been explored, is on the eastern shore of Cook's Inlet, forming the western border of the Kenai Peninsula. Here at Port Graham or English Bay, first visited by Portlock and Dixon in 1785, lignitic beds have long been known to exist, and for a time the coal was mined by the Russian American Company for use in their steamers. The beds at this locality are on the north side of the harbor, just within the entrance. Here Furuhjelm collected a large number of plant remains which formed the chief basis of Heer's report.[1] These beds lie unconformably in depressions in felsitic rock and greenstone, nearly horizontally as follows:

1. Humus and turf.
2. Sandstone with pebbles.
3. Bluish sandy clay with pebbles.
4. Plastic clay.
5. Gray, fine grained sandstone, 5 to 7 inches thick.
6. Lignite, 9 to 11 feet thick.
7. Laminated clay shale, partly bituminous.
8. Light gray, rather soft limestone, with few plants.

[1] Flora fossilis Alaskana, cf. ante.

9. Laminated clay.
10. Hard limestone, with many plant impressions.
11. Brecciated porphyry and greenstone in limy matrix.
12. Felsite and greenstone base.

The coal is black and brilliant, with conchoidal fracture, resembling that of Disco in Greenland. It contains occasional grains of honey-yellow amber rarely more than a centimeter in diameter.

The plants are all terrestrial or fresh-water species. One of the most common is a species of *Trapa* represented by many of its fruit. With them were found *Unio* (*Margaritana*) *onariotis* Mayer, a species probably related to *Margaritana margaritifera* L.; *Ammicola abavia* Mayer; and *Melania* (*Goniobasis?*) *furuhjelmi* Mayer, together with elytra of a beetle described by Heer under the name of *Chrysomelites alaskanus*. Among the plants are both coniferæ and broad-leaved trees, the total number of species amounting to forty-four. The deposit appears to have been formed at the bottom of a lake. The leaf-bearing strata crop out below the level of the sea and are accessible only at extreme low water. They dip slightly to the northward.

Kachekmak Bay lignites.—Northward from Port Graham is the entrance to a large inlet, Kachekmak Bay, on the southern side of which four glaciers extend nearly to the sea level. The rocks on this side of the inlet, as observed by Dall in 1880, are schistose or crystalline, but the northern shore is of a different character. It is formed by the bold edge of a plateau which, in latitude 59° 42′, rises to about 1,800 feet at a distance of 2 miles from the shore. At the shore near Coal Point (a low, sandy spit behind which an anchorage may be had), the bluffs rise abruptly about 200 feet. The line of bluffs extends north and east for some 30 miles and the Miocene plant beds crop out at many points. In some places the bluffs come down to the beach; in others there is a small talus between them and the water which is extremely shallow for some distance out. The lignite beds dip slightly to the northward and are intercalated between sandstones and shales with fossil plants remains, and conglomerates or coarser sandstones above. The largest seam of coal which was observed near Coal Point was about 7 feet thick, with a few thin streaks of shale in it. It is bright, clean to handle, light, and tends to break up in cubical fragments when dried. It resembles anthracite in appearance, but not in weight. Farther up the bay better outcrops were reported, and the coal was pronounced good by the engineers of Sir Thomas Hesketh's yacht, *Lancashire Witch*, who used it for steaming purposes in 1880, and also found it to burn well in an open grate in the cabin.

From this locality most of the plants described from Port Graham by Heer were identified from Dall's collection by Lesquereux[1] and also nine others, making fifty-three species.

[1] Contributions to the Miocene Flora of Alaska, by Leo Lesquereux. Proc. U. S. Nat. Mus., 1882, vol. 5, pp. 443–449, pl. vi–x.

Other Kenai beds.—If the indications of Wossnessenski (in Grewingk) are correct there would seem to be a succession of about four gentle folds from Port Graham to Cape Kassiloff, a distance in a northerly direction of some 35 miles. The plateau previously referred to, representing the western flank of the Kenai Peninsula, is thus composed chiefly of the marine sandstones, shales, and conglomerates, which make up the Kenai group. The lignite beds crop out at many places along the western shore of this area. At Anchor Cape (Kasnatchin) the northern head of Kachekmak (or, as it is sometimes called, Chugachik) Bay the coal is under water, but rises northward with the flexure of the strata. At Anchor Cape Furuhjelm obtained fossil teredo-bored bituminous wood. At Cape Nenilchik, near a small native settlement, the lignite beds are about 35 feet above the sea, and at one place burned for many years. From this locality also many fossil plants have been obtained. The leaves occur in a soft, pale gray clay slate, which can be cut with the knife, but which, where burned, becomes hard and red. Still farther north on the same shore, at Fort Kenai, Capt. Howard, of the revenue marine, obtained several fossil plants which have been described by Newberry.[1] Five of these were new, which raises the number of species actually obtained on the Kenai Peninsula to fifty-eight.

At Cape Staritchkoff two parallel beds of coal are visible for a long distance. The lower one is about 112 feet above the beach and is separated by 9 to 12 feet of sand and clay from the upper coal bed, above which the bluff rises 40 to 70 feet higher. At Cape Nenilchik the upper bed covers about 18 feet of fine yellow sand and is separated from the lower bed by about 20 feet of sand and clay. At this locality an *Anodon* (*A. athlios* Mayer) was found in making Furuhjelm's collection.

Deferring for the present any discussion in regard to their geological age, the other localities for the occurrence of this flora may be referred to. The Kenai beds, from the number of their contained species and their excellent illustration by Heer, will always be regarded as typical for the group.

Beds of Alaska Peninsula and Kadiak Island.—Along the shores of Alaska Peninsula, west and south from Cook's Inlet, lignite beds, doubtless associated with plant impressions, are not uncommon, but the exploration of this shore has been very imperfect. On the main shore behind Takli Island (north latitude 58° 05′) is a good anchorage according to the Russians, and here they report "good coal and plenty of it," which would indicate the existence of the lignitic beds at this place.

On the island of Kadiak marine Miocene strata are found, and among the specimens brought back by Wossnessenski were clay ironstones containing plant remains referable to the Kenai group. These stones were used by the native women for reddening the inner surface of dressed skins, and the only indication of locality for them is that they came from the northern part of the island. About the middle of the island,

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[1] Proc. U. S. Nat. Mus. vol. 5, pp. 502–514, 1882.

surrounding Ugak Bay, at the old settlement of Orlovsk, and on the northern shore of Miliuda Bay next southward, and on the opposite side of the island, part of the shores of Uganuk Bay and of Uganuk Island in the bay, sandstones with lignite in thin seams, overlain in places by marine sandstones like those of Unga, are reported on the authority of Kharitonoff and other Russians familiar with the island.

On the south shore of the peninsula, in west longitude 157° 10′, is a small bay called Yantarnie, near which, in the lignite-bearing beds, amber was found and traded by the natives of the peninsula with the Kadiak Eskimo. It may not be inappropriate to state here that in times preceding the Russian conquest amber was regarded of great value by the natives of this region, a very small bead of this substance being worth in native estimation forty or fifty sea-otter skins, equivalent at present values to some $10,000 of our money. Consequently the localities where it might be found were places of great interest to the aborigines, and the traditions still current are often useful in identifying the presence of beds of this age. A few of these beads are still extant. The largest known is in the possession of W. H. Dall. It was obtained from a grave on the island of Kadiak, traditionally regarded as that of a celebrated prehistoric chief of the tribe. It is about 2 inches long, ovate, roughly three-sided, and an inch in diameter. It has been bored for the passage of a suspensory thread, but otherwise is apparently in its original state. It is clear and of a rich wine color, resembling Levantine amber. The surface, though slightly irregular, is polished. Small grains of the same color, but too small for use as ornaments, are not rare in the lignite beds of this region.

On the south side of Chignik Bay, a little to the westward of the southwestern headland, is a small anchorage surveyed by Dall in 1874, situated in about latitude 56° 20′ and west longitude 158° 24′. Here an outcrop of sandstone belonging to the Kenai group was observed, from which a number of fossil plants were collected. The bluffs here are about 500 feet high, consisting of a series of sandstone, slates, and conglomerates, with thin leaves of lignite, the whole nearly horizontal and extending several miles to Tuliumnit Point. From the specimens obtained six species of plants were identified by Lesquereux.[1]

A short distance southwestward (west longitude 159°) the leaf and lignite beds crop out again on the south shore of the peninsula at Coal Cape. Southwest of this cape lies the small group of Chiachi Islands, *surveyed by Dall in 1874. Here the bedrock is syenite unconformably* overlain in places by sandstones and conglomerates, the latter sometimes of water-worn material and sometimes of sharp gravel, with vegetable remains. The sandstones are often altered by outbreaks of reddish lava in large masses, and all the rocks at this locality appear much contorted and metamorphosed.

[1] Proc. U. S. Nat. Mus., 1882, vol. 5, pp. 443-449.

Still farther west (west longitude 160° 35′) the south coast of the peninsula is indented by Portage Bay, at the head of which a large stream comes in and a low divide affords a portage to Herendeen Bay, a branch of Port Möller, which indents the shore of the peninsula from Bering Sea on the north. West of Portage Bay other inlets enter from the south in the following order, namely, Beaver and Otter bays, Coal Bay, and Pavloff Bay, the latter connected by a very low divide with the head of Herendeen Bay, and thus indirectly with Port Möller. The vicinity in which these bays are found is of extreme geologic interest. From Port Möller several active volcanoes are in view, among the rugged flanks of which may be seen a number of glaciers. Hot springs flow into the bay from a small peninsula, on which are extensive shell heaps indicating prehistoric occupation of the locality by a population of some magnitude. Near the head of the bay Mesozoic fossiliferous strata come down to the beach. On the east are Tertiary sandstones belonging probably to the Kenai group. Fragments of lignite and bituminous shale are not rare on the beach. At the head of Portage Bay, a few miles away, lignite beds are reported by Veniaminoff, and, as the name indicates, they also exist at Coal Bay.[1] On the portage between Pavloff Bay and Herendeen Bay extensive beds of coal (one report says 4 feet of clean coal) are reported, and offer such advantages that a corporation in San Francisco is actually building the first railway in Alaska to transport the product of the mine they have opened to the nearest point where vessels can receive it. These beds are said to be cut by volcanic dikes in such a way as to form out of the lignite a natural coke, which promises to have commercial importance. The Pavloff volcano is a high peak emitting smoke and occasional flames, and is situated on the west side of the bay. From the vicinity of the mountain Wossnessenski obtained "good stone coal" according to Grewingk (op. cit., p. 57), and this is also one of the localities reported to afford amber. When visited in 1874 by the Coast Survey parties, the shores of Port Möller were inhabited by large numbers of brown bear and reindeer, the rivers were alive with salmon, and hundreds of walrus sunned themselves on the sand bars near the sea. It will be seen that for the naturalist and geologist it would be hard to find a place combining more interesting features.

Unga and Popoff Island beds.—South of Portage Bay, across Unga Strait, lies the island of Unga, the principal island of the large Shumagin group, which extends some 50 miles to the south and east, and is noted for its cod and sea-otter fisheries. The eastern islands are granitic; those in the middle of the group largely composed of metamorphic quartzites and schistose rocks. On the island of Unga and the adjacent Popoff Island, Tertiary beds are well exposed.

The principal exposure of the plant beds on the island of Unga is on the western shore of Zacharoff, Zakhareffskaia, or Coal Bay, which indents the northern end of the island for about 3 miles. This locality

[1] See U. S. Coast Survey Chart, No. 806, by W. H. Dall, 1882.

was visited by Dall in 1865 and also in 1871, 1872, and 1873. The earlier observations of Wossnessenski and others are enumerated by Grewingk (op. cit., p. 97), but his details are very incomplete.

The following section was obtained by Dall in 1872. The total height of the cliff is between 500 and 600 feet; two-thirds of it is precipitous, the rest more sloping; the crest is perhaps a third of a mile westward from the water's edge. The strata are somewhat waved in a north and south direction, and dip to the westward from 5° to 20°:

	Feet.
1. Turf and soil	} 200 (Nos. 1–7)
2. Conglomerate of fine pebbles	
3. Conglomerate of larger bowlders	
4. Sandstone with marine fossils (1 foot)	
5. Thin friable sandy shales (6 inches)	
6. Conglomerate like No. 2	
7. Very coarse conglomerate (2 feet)	
8. Sandy shale with indistinct plant remains	$\frac{1}{8}$
9. Thin leaves of lignite aggregated into three series of 3 feet each, interstratified with beds of sand and gravel of variable thickness, with some pyrites and peroxide of iron, total about	40
10. Soft sandstone and gravel without large pebbles and little indurated	150
11. Another series similar to No. 9, but with none of the coal more than 8 inches in thickness, very pyritiferous	200
12. Clay ironstones with leaf impressions to the beach	4

Below ordinary low water another seam of coal is said to exist. The best veins of coal in the cliff are about a foot thick, hard, clear, and black except where weathered. It slacks up on exposure into small cubical fragments. There are three of these foot veins, separated by about 10 feet of sand and gravel. Over the middle vein is very friable blue shale, about 4 feet thick. Over the upper vein is a 4-inch layer of sandy shale containing many plant impressions, from which the collection submitted to Lesquereux was chiefly derived.

The coarser conglomerate (Nos. 3 and 7) contains some iron and weathers black on the face of the cliff. In a section published in a prospectus of a coal-mining company these black bands, which can be seen miles away on the face of the cliff, were indicated as coal veins; as in fact a distant observer would take them to be until otherwise informed.

The species of plants collected at this locality were examined by Lesquereux, and proved to be identical with those from Cooks Inlet; eight species were identified.

In the conglomerate (Nos. 6 and 7) many pieces of rolled silicified wood were found, some of which were bored by *Teredo*. These beds are evidently a beach formation, presaging the depression which followed in which the marine bed above them was laid down. I have called them the Unga conglomerates, and the marine stratum, which will be referred to later, from the great abundance of *Crepidula prærupta* Conrad, I have called the Crepidula bed. It conformably overlies the others and there can be no doubt of the continuity of the sedimentation through the whole series of lignitic and marine strata in this locality.

Fossil wood, referred to *Pinus pannonicus*, has been obtained at Delaroff harbor, in the southern part of Unga, and some large pieces collected on the beaches and forwarded to Dr. Newberry in 1873, were stated to be apparently Cycadaceous. These may have been derived from adjacent Mesozoic strata. According to John Dix, a miner at the coal vein referred to, the mountains inland from the bay consist largely of similar sandstones.

The northeastern extremity of Unga Island and the northwestern part of Popoff Island are composed of sandstones and conglomerates similar to the upper part of the bluff in Zacharoff Bay, but they rise to only about 50 to 75 feet above the sea, and are broken and cut by dikes and larger intrusions of basaltic lava and diorite, and near the contacts much altered and intersected by veins of chalcedonic quartz.

On the western edge of Nagai similar rocks exist above the metamorphic schists and quartzites, but they are greatly altered and contorted and cover but a small area in comparison with underlying beds. It is probable that part of the island of Sannakh is composed of similar strata.

LIGNITIC BEDS OF THE ALEUTIAN ISLANDS.

In the chain of islands extending westward from the peninsula there are many which are more or less volcanic, but the chain is older than the volcanoes and volcanic islands it contains, and many of the islands are composed of sedimentary or metamorphic rocks. The chain doubtless marks a very ancient line of weakness or faulting in the earth's crust; and most of the volcanoes are relatively very modern developments, due to geological changes which have been in progressive operation since early Mesozoic time.

Akun.—Proceeding westward, the first island upon which lignitic beds are reported is Akun, where Postels[1] states he was told that coal exists.

Unalaska.—The northern part of the island of Unalaska is better known than the rest. The principal harbor, Captains Bay, is surrounded with massive beds of clay porphyry and some basaltic lava. But several localities in the interior of the island, according to tradition, afforded amber and consequently should possess lignitic deposits. In the autumn of 1871 Dall endeavored, with a small party and an Aleut guide, to discover one of these so-called amber beds. The expedition reached the main ridge of the island some miles south from Captains Bay, and found the rocks to consist almost exclusively of syenite in mountain masses, overlain in some places by thin beds of clay and sand, apparently the result of decomposition of the syenite itself. The amber lake of Aleut tradition is a small body of water connected with two others. Above the lake rose a precipitous crag of conglomerate, 2,000

[1] Voy. Séniavine, 1836, vol. 3, p. 21.

feet in height by estimation, the horizontal layers very distinctly bedded, graduating toward the top into hard altered sandstone, very black and flinty. No fossils could be found in it, but the weather became so inclement as to render it necessary to return without making an exhaustive search, and these beds may eventually prove to belong to the leaf-bearing series. The Aleuts declare that the disintegrated sandstone in former times afforded occasional bits of amber, which were obtained from the gravel around the edge of the lake.

Another locality for amber, and inferentially for lignitic strata, is reported by Veniaminoff, from statements by the Aleuts, to exist in the western part of the island in the mountains near the head of Makrofski Bay. Here there is said to be a lake containing an island of friable sandstone and unconsolidated gravel, out of which the Aleuts formerly obtained small pieces of amber.

Marine Miocene beds exist on Makushin Bay, near the north-northwest base of the volcano of the same name, but no leaf beds are reported at this place. On the eastern shore of Port Levasheff Wossnessenski obtained small fragments of lignite, which he supposed to have been brought down by streams from lignite beds in the interior of the island, the adjacent rocks being clay porphyry.

Slate Point, 2½ miles eastward from the entrance to Chernoffski Harbor, is composed of a black stratified material, perhaps belonging to this series, but which has not been closely scrutinized.

Umnak.—On the northwestern end of the island of Umnak, the next westward in the chain, near Tulikskoi Volcano, is a lake overhung by a cliff of unconsolidated beds. The Aleuts were in the habit of stretching a seal hide between two kayaks and dislodging this earthy material, which would fall upon the hide, and was carefully washed for amber. Near Cape Yegorkoffski, Eschscholtz and Chamisso collected fossil dicotyledonous wood from the bed of a lake which had been drained by changes due to an earthquake.

Atka.—Westward from Umnak many of the smaller islands are volcanic, and but little is known of any of them until the island of Atka is reached (174° west longitude). On the western side of the north part of this island it is indented by Korovinski Bay, from which several small arms extend southward and northward. The north shores are composed chiefly of nearly horizontal layers of volcanic breccia dipping slightly to the northeast and rising to 1,000 feet, interstratified with beds of ashes, cinders, and solfataric clays, in some of which marine Miocene fossil shells occur. On the south shore, especially on the east shore of Sandy Bay, are found pieces of fossil wood of a gray color, which burn slowly, and other pieces which are silicified. They appear to lie under the soil, between the latter and a conglomerate resembling that of Unga, chiefly composed of rounded porphyritic pebbles, capped on the eastern portion with partly columnar basalt.

Nazan Bay, on the east side of the island, opposite Korovinski Bay, and separated from it by a low isthmus, exhibits highly altered beds of conglomerate and volcanic breccia, nearly horizontal and dipping slightly to the northwest. A more compact, flinty, greenish metamorphic rock, with a similar dip but more contorted and much intersected by dikes of basalt, is the material of which the south shore and the islets protecting the anchorage are composed.

Adakh.—On the west side of the island of Adakh is a harbor called the Bay of Islands, the northern shores of which are composed of coarse sandstones like those of the Kenai group, dipping in general to the northeast. They are greatly altered by basaltic and frothy lavas, which have burned the sandstones overlaid by them to a red color. No fossils were found in them when examined by Dall in 1873.

Amchitka.—The island of Amchitka is notably low and level compared with most of the Aleutians. At Constantine Harbor, on the northeastern shore, the rocks forming its eastern coast are crystalline and probably volcanic. The west side of the harbor appears to be composed of low bluffs, not exceeding 60 feet high, of a much-altered conglomerate. Westward about a mile is Kiriloff Bay, a small, rocky indentation, formerly the site of a village (1849), but now deserted. Here the conglomerate and sandstones are less altered, and specimens of lignite and fossil wood were collected by Wossnessenski. Still farther west small veins of lignitic coal with plant remains are reported by Shayeshnikoff.

Kiska.—The island of Kiska has a fine harbor (west longitude 182° 30′), which is protected on the east by the island of Little Kiska. The shore belonging to the main island borders on the water in many places as steep bluffs to 200 feet high, composed of a coarse conglomerate, of which the upper layers merge into a breccia of volcanic material but obviously arranged in water. These are broken through by eruptive clay porphyries of a greenish color, rising to 150 feet, and capped over all by a basaltic or coarsely crystalline syenitic rock, in some places 300 feet thick. On the bluff of Little Kiska, facing the harbor, the porphyrite appears toward the southwest unconformably over them, and dipping northward are sandstones resembling those of the Kenai series, but in which, in 1873, Dall found no fossils. Covering those, and extending to the northwest point of Little Kiska, is a magnificent cliff of the crystalline eruptive rock before referred to, which here forms enormous prisms, five-sided, from a foot to 20 inches in diameter, standing vertically in the cliff-like organ pipes, and sometimes continuous as a single prism to the length of more than 50 feet.

Attu.—The westernmost of the Aleutian chain is the island of Attu, which is destitute of modern volcanic rocks. The harbor of Chicagoff, at the northeastern end of the island, is surrounded chiefly by metamorphic slates and quartzites, diorite, serpentine, and clay porphyry, probably Mesozoic, and much contorted. It was reported by the natives that fossil wood was occasionally found on the beaches toward the western part of the island, but no Tertiary rocks or sandstones were observed by Dall's party.

Nunivak Island.—Northward from the Alaskan Peninsula little is known of the geology until the island of Nunivak is reached. At the northeastern extreme of this island is an anchorage surveyed by Dall in 1874. Here the shores, though abrupt, are low, and composed of much-altered sandstones, nearly horizontal and more or less overlain by recent basaltic lavas. In the interior small volcanic cones, or hills resembling volcanic cones, were observed and supposed to be the source of these lavas. From their appearance and relation to the lavas it is probable that these sandstones belong to the Kenai group.

In the Yukon valley, and thence to the shores of Norton Sound, a large area is occupied by lignite and leaf-bearing sandstones of the Kenai group, a smaller portion of which are overlaid by the Nulato marine sandstones analogous to the Crepidula bed of Unga in age, but containing a different series of fossil shells.

On the seacoast between Unalaklik and Tolstoi Point these strata are exposed, much contorted, and dipping generally at high angles. At Tolstoi Point they are met by the later basalts which southward form the shores of the sound, St. Michael and Stephens islands, and adjacent islets. In October, 1867, these exposures were examined by Dall, from whose notes and sections made at the time the following description is condensed.

Southward from the mouth of the Unalaklik River, along the seashore for 6 miles, stretches a low, level plain of sand, soil, and turf, horizontal and from 5 to 20 feet thick. Then the alluvial layer rises, and below it is visible bluish or yellowish clay, soft, but distinctly bedded and dipping north by east 28° to 45°. It is 30 to 40 feet thick, covered by about 3 feet of soil. The lower layers of the clay contain fragments of silicified wood and lignite, sometimes preserving the original form of the trunk, but commonly broken. This continues a quarter of a mile to a small creek (No. 1), on the farther side of which appear beds of indurated sandstone, overlain by the clay and soil and underlain by a blackish shale, the succession being as follows:

	Feet.
1. Soil and clay, the latter sometimes absent	3
2. Greenish sandstone, dipping north 35°–40°	25
3. Blackish sandstone, dipping north 35°–40°	20
4. Shale, dipping 30° easterly	10

This series continues about 3 miles to Creek No. 2, along the shore, but the shale only comes up so as to be exposed for about 200 yards.

From Creek No. 2, along the shore, we find for half a mile blackish sandstone, with seams of shale 20 feet thick dipping southeast 80°, covered with clay and soil. This is succeeded by a gray sandstone 30 to 40 feet thick, with a northeast dip of 45° for nearly a mile, followed by

200 yards of the black sandstone, 40 feet thick, dipping southeast 65°. Then a turreted bluff of gray sandstone, vertical, 50 feet high, with seams of quartz and layers of shale and fragments of carbonized vegetable matter. Under this the black sandstone shows again on a level with the beach, both dipping northwest 85° for half a mile. The clay and two kinds of sandstone continue to crop out, with occasional layers of dark colored shale and slaty rock dipping from north by east round to southeast 30° to 85°, to Tolstoi Point, the last 2 miles being formed of clear gray sandstone in bluffs 30 to 70 feet high, dipping northwest 70° to 80°, until the lava is reached at the point.

Topanica beds of Norton Sound.—Creek No. 2 is locally known as Topanica, and at its mouth is a camping place where the natives go to catch fish.

Following Topanica Creek easterly into the hills the greenish and blackish sands dip more and more steeply to the east, interleaved with shaly layers containing leaves and vegetable remains, among which leaves of *Platanus nobilis* Newberry, a foot across, were collected in a fine state of preservation.

Farther inland the same rocks become vertical and then dip toward the west, the beds resembling the radiating ribs of a fan. About 2,000 feet of these beds are continuously exposed without faulting, with the same fossils at intervals all the way. These beds extend inland between the sea and the Yukon River, where they appear again.

Ulukak River beds.—Starting from Unalaklik up the river of the same name, a branch called the Ulukak, about 2 miles above the Indian village of Iktigalik, affords a fine exposure of these rocks, as follows, the whole series dipping conformably north-northwest 25° to 55°, the section beginning at the base:

	Feet.
1. Argillaceous unfossiliferous slaty rock, the layers of which become progressively harder downward	220
2. Shale, with some lignite, showing black	2
3. Argillaceous shale, with leaves of *Platanus*	15
4. The same, without fossils	15
5. White sandstone (probably marine)	20
6. Sand and soil to surface	10

This is the only locality on the river between Unalaklik and the village of Ulukak (some 30 miles in a direct line, but 60 by the river) where fossils were observed. The rocks, as on the coast, were more or less folded, and the dip is irregular.

Lower Yukon valley outcrops.—The Yukon valley affords numerous exposures of the same group of sandstone along the right bank of the river. The first locality noted in ascending the river is just below Andreiffski fort, an old Russian trading post. High bluffs of black sandstone come down to the river just above the fort and continue for 10 miles, and just below the fort is the last small exposure, where a seam of bituminous shale about 6 inches thick was observed by Dall in 1868.

This had been worked a little for fuel by the Russians, but abandoned, as the material was too impure to burn well. It dips in a westerly direction. Ascending the river, the sandstones are next observed along a stretch of about a mile near the native village called by the Russians "Starry Kwikhpak." Two miles and a half below Ikogmiut mission the sandstones along a strip of 3 or 4 miles alternate with older metamorphic and later trachytic rocks. Some layers of the sandstones here weather of a whitish color, dipping in a northwest direction with more or less folding and alteration by the action of the eruptives. Similar exposures appear near Koserski village, and at Lofkas which is nearly in the same latitude as Tolstoi Point, Norton Sound (previously described) the sandstones begin to form the main mass of the strata exposed along the river, though the quartzites appear here and there. The sandstones in general dip toward the northwest, at angles varying from 20° to 45°. A short distance below Kaltag a small seam of lignite occurs.

Exposures on the Upper Yukon and at Nulato.—Above Kaltag the bluish sandstones of the Kenai group are overlain by brownish marine sandstones which are best exposed just above Nulato and hence have been named in Dall's notes the Nulato sandstones. They occur in successive waves or folds extending in a northwest and southeast direction, and cut nearly at right angles by the river. At some points eruptive rocks have forced their way through, tilting the sedimentary rocks nearly vertical and altering them near the contact with the eruptives. The blue sandstones occasionally appear above the level of the water.

About 7 miles below Nulato, on the south side of a level space or flat, a small bluff appears, at the extreme end of which the sandstones are nearly vertical. Here, between two contorted layers of shaly rock, a small coal seam was examined in December, 1866. It has been squeezed out above and below, forming a mere pocket about 2 feet thick and not over 20 feet long on the exposed face. The shales contained obscure vegetable remains, but were much altered, probably by the heat evolved at the time they were folded. The average dip is north 45°. The coal is good, but there are apparently only a few tons of it. The shales are conformable with the brown sandstone, which, however, is a marine formation in which this deposit of lignite is a very exceptional incident.

Nulato marine sandstones.—Above Nulato appears to be exposed the highest of these sandstones, which there form bluffs 60 to 100 feet high, and farther up the river reach to 200 feet. In May, 1866, Dall obtained from the upper part of these beds *Modiola*, *Tellina*, *Mytilus*, *Gastrochæna*, and *Mya*, with worm tracks and obscure vegetable remains. The general appearance indicated a littoral formation.[1] These sandstones extend along the river from Kaltag to the Koyukuk Mountain and westward to the Kuthlatno and Ulukak rivers and the eastern base of the Shaktolik Hills, forming a sort of patch, approximately 90 miles northeast and

[1] Cf. Dall in Am. Jour. Sci., 2d ser., 1868, vol. 45, pp. 97-98.

southwest and not more than 30 miles wide, lying on a much larger area of Kenai sandstones. The latter form the mass of the hills between the Kutelno and Kuthlatno rivers and of the Shaktolik Hills. They extend on the Yukon above the Koyukuk Mountain, which is apparently of intrusive crystalline rock, eastward on the north bank to the Melozikakat River. Above Nulato they first appear about 5 miles above the bluff above mentioned as affording marine fossils, and there conformably underlie the marine sandstones and are themselves underlain by a hard black slate.

Near Melozikakat the bluffs appear also on the left bank, which is rarely the case on the Yukon below the Ramparts. Russell[1] has also noted the leaf beds 15 or 20 miles below the mouth of the Melozikakat on the right bank of the Yukon, in connection with an interesting series of faults which they exhibit.

Colville brown lignite.—In connection with this lignite-bearing series a note on another lignite deposit may be in place. The party commanded by Lieut. Stoney, U. S. Navy, while exploring in the vicinity of the headwaters of the Colvile, the Noatak, and Kowak rivers, north of the Yukon, were obliged to traverse large areas of barren, treeless tundra, and here they found on the surface rather abundantly scattered masses of a brown lignitic material resembling powerfully compressed peat, recalling pitch in hardness and weight, but not brilliant nor disposed to melt with heat, but making a clean cut, like "plug" tobacco when whittled with a knife. This material was sufficiently inflammable to ignite and burn with a steady flame on applying a match to a corner of it, so that in their cold and weary journey it formed a most welcome substitute for wood or other fuel for the campfire. The geological relations of this substance are unknown; it presented no traces of organic structure under an ordinary magnifier, but its nature and geographic location suggest that it may be connected with the lignite-bearing beds to the south of it, which we have just described.

Kowak River lignites.—About 75 miles above the mouth of the Kowak River, which empties into Kotzebue Sound through Hotham Inlet, extensive deposits of lignite, associated with sandstone, shale, and conglomerate, were discovered by Lieut. J. C. Cantwell, U. S. Revenue Marine, and party, while exploring under direction of the Treasury Department in 1884. The coal belt on this river is about 30 miles wide, and passes through a series of high and partly timbered hills. It is often exposed along the river bank, and is frequently associated, as at Kenai, with beds of clay. It is soft, friable, and jet black in color. These beds lie directly in the trend, northwesterly from the main body of beds of the Kenai group north of the Yukon, and there can be little if any doubt that they belong to the same series. The opinions which would connect them with the beds of Paleozoic coal on the Arctic coast, near Cape Lisburne, are, of course, erroneous. It has been determined by

[1] Bull. Geol. Soc. Am., 1890, vol. 1, p. 108.

the observations of *Corwin* party,[1] in 1885, that the coal beds of the Kowak do not extend to the valley of the Noatak, and can not, therefore, be continuous with those at Cape Lisburne.

CAPE BEAUFORT COAL MEASURES.

In regard to these last it may be noted in passing that Silurian fossils, brachiopods, corals, and crinoids have been collected by Buckland, Fischer, Kupreanoff, and Dall at Cape Lisburne and the adjacent Cape Thompson. A few miles farther up the coast coal is found about a quarter of a mile away from the beach at Cape Beaufort. This coal is of a very different quality from the lignites of the southern part of Alaska, and from the presence of corals, apparently referable to the epoch of the Carboniferous period, which were collected from the débris of the rocks adjacent, it has been assumed to be of that age. Similar coal crops out below low-water mark in many places northward to Point Belcher, and is pushed up on the beaches by the grounded icefloes so that in some places nearly the whole of the beach gravel is made up of small fragments of coal. From this region Lesquereux[2] has described *Iritis alaskana*, collected at Cape Lisburne by Henry D. Woolfe, and Newberry[3] enumerates from the same locality and collector ten species which he regards as Neocomian, and which Prof. Ward,[4] enumerating publications on Alaskan Paleobotany, considers to indicate a Lower Cretaceous or possibly Upper Jurassic age. It seems tolerably certain that strata covering a considerable range on the geologic column, beginning with the Silurian, are represented in the vicinity of Cape Lisburne, and that the coal-bearing strata may be Mesozoic rather than Paleozoic.

While referring to the subject of Alaskan paleobotany, it may noted that a few species of fossil plants are enumerated[5] by Prof. Lesquereux as collected at Sitka by E. W. Nelson, but some doubt exists as to the correctness of this locality, though the specimens are doubtless Alaskan. J. Felix[6] has described a fossil wood (*Pityoxylon inæquale*) from the "basalt mountain south of Danaáku," Alaska, a locality which I have not been able to identify.

CORRELATION OF THE KENAI SERIES.

Having indicated the extent and position of beds in Alaska belonging to the Kenai group, as far as our imperfect knowledge of them will permit, it is now in order to discuss their geological age upon the basis of the facts presented. This will of necessity be largely dependent

[1] Cruise of the *Corwin* in 1885, House Ex. Doc. No. 153, 49th Cong., 1st sess. Washington, 1884; see p. 76.
[2] Proc. U. S. Nat. Mus., 1887, vol. 10, p. 36.
[3] Proc. U. S. Nat. Mus., 1888, vol. 11, pp. 31–33.
[4] Eighth Annual Report, U. S. Geol. Survey, 1889, pt. 2, pp. 924–926.
[5] Proc. U. S. Nat. Mus., 1887, vol. 10, pp. 35–37.
[6] Zeitschr. Deutsch. Geol. Gesell., 1886, Bd. 38, pp. 483–484. Leipzig.

upon data other than the similarity of flora, which has been conclusively shown to have little value as a test of synchrony between widely separated geological deposits. Of the 54 species enumerated from the Kenai peninsula by Heer, 30 were previously known from Miocene strata in other parts of the world. Of those from Kuiu and Unga, 65 species, 31 were previously known as Miocene. According to Heer, no doubt can exist as to their Miocene age, in which conclusion Lesquereux agrees, remarking:

The plants described by Heer, representing 56 species, are of marked interest by their intimate relation with those of Atane in Greenland on one side and with those of Carbon in Wyoming and of the Bad Lands of Dakota on the other. They comprise a small group which supplies an intermediate point of comparison for considering the march of the vegetation during the Miocene period, from the Polar circle to the middle of the North American continent, or from the thirty-fifth or fortieth to the eightieth degree of latitude. The remarkable affinity of the Miocene types in their distribution from Spitzbergen and Greenland to the middle of Europe had already been manifested by the celebrated works of Heer. But the Alaska flora has for this continent the great advantage of exposing in the Miocene period the predominance of vegetable types, which have continued to our time and are still present in the vegetation of this continent. (Op. cit., p. 443.)

In his later publication on the same subject Lesquereux[1] remarks:

Alaska has 73 species, of which 13 are found in the Bad Lands, 4 at Carbon (Wyoming), and 2 in and the Chalk Bluffs (California). * * * Of the 13 species common to Alaska and the Bad Lands, 9 are Arctic, of these 6 are European also; and besides *Populus latior*, *P. glandulifera*, and *Juglans nigella* are European, but not yet found in the Arctic flora. The Bad Lands group, therefore, is truly Miocene and shows scarcely any deviation from that of Alaska. The 3 species mentioned as not Arctic may be indicative of a somewhat warmer climate. * * * As the fossil floras of Carbon and the Bad Lands are related by 10 identical species, and those of the Bad Lands and Alaska by 13, these three groups apparently represent the same stage of the North American Miocene. The flora of Carbon has only 4 species identified in that of Alaska; but this lesser degree of affinity may be ascribed to difference in latitude.[2]

Of the 73 species enumerated by Lesquereux from Alaska 21 are tabulated by him as common to Greenland and Spitzbergen also, and 31 as common to the Miocene of Europe and Alaska.

The term Miocene, as used by Heer, seems to have been based primarily on the stratigraphic nomenclature of Switzerland. His method of inferring the age of a given plant bed from the fact of its showing a number of equivalent species with those of any Swiss bed would invariably lead to the conclusion that the possession of a flora in common is sufficient evidence of a general synchrony between the two formations. But I am informed by Prof. L. F. Ward that the vertical range of many fossil plants is very great, and that such conclusions can not safely be reached except by the aid of corroborative evidence in addition to a partial similarity of flora.

[1] Contributions to the fossil flora of the western Territories, part 3 the Cretaceous and Tertiary Floras, Rep. U. S. Geol. Survey of the Terr. by F. V. Hayden, 1883, vol. 8, Washington, 4°, cf Miocene Flora, pp. 219–277.

[2] Op. cit., p. 275.

The beds of Carbon, Wyoming, with which Lesquereux compared the Kenai group, are by Dr. C. A. White, as he informs me, referred on stratigraphic grounds to the Laramie. Prof. Ward[1] agrees with this conclusion, and in his tables places the Carbon beds between the typical Laramie and the Fort Union beds, all of which are included under the general term Laramie.

The newer leaf beds in Greenland have lately been regarded as Eocene by Mr. J. Starkie Gardner, and as equivalent in the main to the flora of the Basaltic (Eocene) beds of Britain.[2] The Spitzbergen beds would naturally follow those of Greenland. But the inferential reference of the plant remains of the Pliocene gravels of California to the Eocene by Mr. Gardner somewhat weakens the force of his opinion on other fossil floras, since it is impossible that the Californian plant remains can be Eocene.

I have already pointed out the probability that, if Miocene at all, the leaf beds of Greenland referred to would be synchronous with that geological epoch during which the old Miocene warm-water invertebrate fauna of the Atlantic coast penetrated as far north as New Jersey.

Since that time it is highly improbable that any temperate conditions, such as the flora would indicate for the Atane period, have obtained in the latitude of Greenland. In other words, the Greenland beds are not later than the Old Miocene, though this does not preclude a reference of them to an older horizon than the Miocene, for during the Eocene also the conditions in the extreme north might have been favorable to such a flora.

In Alaska, at Cook's Inlet, at Unga Island, at Atka, and at Nulato in the Yukon valley, we find the leaf beds of the Kenai group immediately and conformably overlain by marine beds containing fossil shells which are common to the Miocene of Astoria, Oregon, and to middle and southern California.

It is then certain that the Kenai leaf beds immediately preceded and their deposition terminated with the depression (probably moderate in vertical range) which enabled the marine Miocene fauna to spread over part of the antecedently dry land. Further researches along the Alaskan coast will doubtless enable us to determine whether the leaf beds themselves are underlain by marine Eocene beds or not. We know that the Aucella beds underlie the Kenai series, but whether there are any beds representing the marine phase of the Eocene between them is yet uncertain, though very probable. Eichwald's references to the age of the Alaskan Neozoic marine fossils are more or less confused and should not be taken into account in any discussion of the subject, as he has referred most of them indiscriminately to the Cretaceous, by which he means Gabb's Chico-Tejon series.

What may be considered as reasonably certain is that the period dur-

[1] U. S. Geol. Survey, 6th Ann. Rep. for 1884-'85, p. 539.

[2] Proc. Royal Society, 1884, pp. 22, 23. See also Nature, 1879, vol. 20, pp. 10-13.

ing which in the Arctic regions the last temperate flora flourished was in a general way the same for all parts of the Arctic. It would seem highly improbable that a temperate climate should exist in Spitzbergen and not at the same time in Greenland and Alaska, or vice versa. If Alaska was covered by the sea at this time we should find a temperate marine fauna, if it was dry land a temperate flora, and so with the other Arctic localities, and these indications should, it would seem, represent an identical and synchronic phase of geological history in the Arctic regions.

The distribution and character of this group have been somewhat fully discussed because, up to very recently, authorities were practically unanimous in referring it to the Miocene, a view which can not yet be said to be definitely refuted. But when we consider how the Eocene Aturia bed is immediately and conformably overlain at Astoria by shales and sandstones, undoubtedly equivalent to the Alaskan marine Miocene, and that the latter conformably and immediately in like manner overlies the Kenai group, it must be conceded that the view that the latter is probably of Eocene age does not appear unreasonable.

MIOCENE OF THE ASTORIA GROUP.

The marine Neozoic beds overlying the leaf beds and conglomerates of the Kenai group appear indubitably referable to the Miocene series represented in the sandstones and shales of Astoria, though probably to the upper or newer portion of these beds. Eichwald[1] has confounded the unquestionably Neocene species figured by Grewingk with Cretaceous forms collected by Dr. Blaschke in Alaska, and referred the whole to the Turonian or Upper Chalk. The fact that nearly half of Grewingk's species are still found living is quite sufficient to establish the correctness of his original reference of them to the Tertiary, while they are derived, as previously shown, from beds overlying the leaf beds referred by Eichwald himself to the Miocene.

This does not conflict with the possibility that the Blaschke collection, other than those described by Grewingk, may be referable to the Chico or other part of the Cretaceous, which is well known to occur in various parts of Alaska. It is possible that two of Grewingk's species, *Nucula ermani* and *Tellina dilatata* of Girard from Atka, may not belong to the same horizon as the others, though of this there is no proof, and the fossils themselves are not distinctive.

The following table will indicate the known species and their relations:

[1] Geogn. Palaeont. Bemerk., St. Petersburg, 1871, pp. 117-137.

Table showing distribution of the fauna of the Astoria group.[1]

Names of species identified.	Localities of Alaskan Miocene.												Miocene.			Plio-cene.	Pleis-tocene.	Recent.	
	Nulato.	St. Paul Island.	Nushagak.	Port Möller.	Atka Island.	Unalashka.	Morzhowi.	Pavloff Bay.	Unga Island.	Katmai.	Kadiak Island.	Lituya Bay.	B. C.	Oreg.	Cal.	Cal.	Cal.	N.	S.
Ostrea tayloriana Gabb					×			×	×		×				×				
Ostrea veatchii Gabb					×				×						×	×			
Pecten pabloensis Conrad								×	×		×	×			×				
Mytilus middendorfii Grewingk									×		×								
Mytilus mathewsonii Gabb	×							×							×				
Modiola multiradiata Gabb	×		×						×					×	×				
Modiolaria nigra Gray									×										
Pectunculus kashevaroffi Grewingk		×							×		×								
Pectunculus patulus Conrad		×	×					×						×	×	×			×
Nucula teunis Lamarck		×	×															×	
Nucula (acila) ermani Girard		×			×														
Cardita aleutica Girard ?					×														
Astarte borealis Gray		×																×	
Crassatella collina Conrad							×	×			×				×				
Cardium decoratum Grewingk		×			×			×	×		×		×						
Serripes gronlandicus Beck		×	×						×		×		×					×	
Liocyma fluctuosa Beck		×																×	
Tapes staminea Conrad		×						×	×						×	×	×	×	
Lioconcha sp		×				×	×												×
Tagelus sp		×																	
Soletellina sp		×																	
Tellina carlottensis Whiteaves	×	×	×			×							×					×	
Tellina alternidentata Brod. and Sby		×			×	×	×		×									×	
Macoma middendorfii Dall		×	×	×			×		×									×	
Macoma inconspicua Brod. and Sby		×											×			×	×	×	

Names of species identified.	Localities of Alaskan Miocene.												Miocene.			Plio-cene.	Pleis-tocene.	Recent.	
	Nulato.	St. Paul I'd.	Nushagak.	Port Möller.	Atka I'd.	Unalashka.	Morzhowi.	Pavloff Bay.	Unga I'd.	Katmai.	Kadiak I'd.	Lituya Bay.	B. C.	Oreg.	Cal.	Cal.	Cal.	N.	S.
Macoma nasuta Conrad			×										×	×	×	×	×	×	
Mactra albaria Conrad			×											×					
Lyonsia arenosa Möller		×																×	
Kennerlyia grandis Dall		×																×	
Mya præcisa Gould	×				×	×	×	×	×		×							×	
Mya truncata L. (var.)							×	×	×		×							×	
Saxicava arctica L		×	×		×		×	×	×		×							×	
Teredo sp		×	×						×										
Gastrochæna sp	×																		
Cylichna (alba Brown?)		×																	
Buccinum plectrum Stimpson		×				×				×								×	
Chrysodomus (altispira Gabb?)									×										
Odostomia sp		×																	
Litorina (sitkensis Phil. var.?)						×													
Galerus sp									×										
Crepidula prærupta Conrad									×				×	×	×	×			
Lunatia (pallida B. and S.?)		×																×	
Neverita saxea Conrad		×	×										×	×	×				
Natica clausa Brod. and Sby		×	×													×		×	
Margarita striata Brod. and Sby		×				×												×	
Margarita sp		×																	

[1] The synonymy of the species enumerated has been modernized, though the details of the process are reserved for a more appropriate occasion. All Grewingk's species are included, though some of them appear under names different from those he used. Of the forty-six species recognized in Alaskan beds, sixteen occur in the Miocene of British Columbia, Oregon, and California; of these a few are known from the Californian Pliocene, though when the latter fauna is better known this number will doubtless be much enlarged. The table has been enriched by an examination of specimens collected at St. Paul Island by Messrs. Palmer, Townsend, and Elliott; at Nushagak by the late C. W. Mackay; and at Nulato, at Zakharoff harbor, Unga, and the adjacent shores of Popoff Island, by W. H. Dall.

It will be noted that of the forty-six species known twelve belong to genera not now represented in such cold waters as those of Bering Sea, and of these, two species may possibly survive in Californian waters, the remainder being presumably extinct. The nineteen species known to survive in the recent fauna are all forms which belong to northern waters, and are capable of surviving low temperatures, though sometimes ranging farther south. We may then conclude that in Miocene times the waters of this region were warmer than at present, and that the still colder epoch, near the end of the Pliocene or the beginning of the Pleistocene, weeded out the more delicate forms.

ENUMERATION OF SPECIAL LOCALITIES.

The localities where this fauna has been noticed and the marine beds more or less certainly identified, will now be enumerated, beginning at the south.

On the south side of Dixon's entrance at Skookum Point, near Massett, Queen Charlotte Islands, Hon. J. G. Swan collected specimens, now in the National Museum, showing the presence of these beds.

The occurrence of beds of this age at Lituya Bay has already been alluded to (p. 236). Cenotaph Island, in the bay, is chiefly composed of them, and Lamanon collected a species of *Pecten* with other marine fossils from a height of 200 toises above the sea level.

Kadiak.—On the island of Kadiak, north of Tonki Cape, on the south coast from the shores of Igatskoi Bay, Wossnessenski collected a number of species of this fauna, which were imbedded in a volcanic tufa about 10 feet above the sea. On the opposite side of the island near the settlement of Uganak similar beds were found containing analogous fossils.

On the portage from Katmai Bay, across the ridge of Aliaska Peninsula, on the trail to Naknek Lake, the same beds occur, from which the same collector collected *Buccinum plectrum.*

Crepidula bed of Unga and Popoff islands.—One of the most prolific and best known localities is situated at Zakharoff (sometimes called Coal) Bay on the northern end of the island of Unga, one of the Shumagin group. A section on the west shore of this bay has already been described indetail (p. 241) where the marine Miocene is represented in the upper part of the bluff by a layer of sandstone about a foot thick, densely crowded with specimens of *Crepidula prærupta* Conrad, sometimes referred to as *C. princeps* Conrad, which has been erroneously identified with the recent *C. grandis* Middendorf. From the vast number of these shells of which the layer is made up the name of the Crepidula bed is suggested for it.

This layer appears at a much lower level on the northern shore of the northeastern part of Unga, east from Zakharoff Bay. The sandstones lie horizontally or nearly so, except where disturbed by intrusions of later basaltic lavas, which sometimes overflow the sedimentary beds or invade them vertically or laterally, altering the rock at contact and for some distance beyond the lavas.

On the shore of Popoff Island next eastward from Unga and separated from the latter by a narrow strait, the same bed is continued, with a thickness varying from 6 inches to 2 feet, carrying oysters, *Crepidula*, *Chrysodomus*, etc.; it is here separated from the conglomerates above and below by a layer 10 to 25 feet thick, of hardly consolidated sand. The upper conglomerate is of variable thickness and much altered by heat from a bed of lava and volcanic breccia 300 feet thick which overlies it. The special character of the igneous material varies rapidly from point to point horizontally and vertically. The lower part seems more like a cooked conglomerate of pieces of clay-porphyry in a basaltic matrix while the upper portion is composed in part of sharp fragments of porphyrite and dolerite cemented by a thin, glossy, vitreous lava. The strata are roughly conformable and dip 10° to 15° to the eastward. The lowest bed visible in the section exposed appeared to correspond to layer No. 6 of the section p. 241.

The fossiliferous layer here contained *Ostrea veatchii*, *O. tayloria*, *Crepidula prærupta*, *Galerus*, *Pecten*, *Modiola*, *Modiolaria*, *Drillia?*, and *Chrysodomus*, all rather scarce except the oysters. The latter were frequently bored by *Cliona*. The fossils were generally fairly well preserved, and mixed with fragments of silicified or carbonaceous vegetable matter in the matrix of more or less argillaceous sandstone. A cetacean vertebra was also found.

Peninsula of Aliaska.—It can hardly be doubted that these strata reappear on the peninsula north of Shumagin Islands as the Kenai beds do. Grewingk speaks (Geogn. Palaeont. Bemerk. p. 58, foot note) of their existence on the shores of Portage Bay and at Port Möller, while at other points on the north shore of the peninsula in that vicinity, Postels[1] speaks of horizontal fossiliferous strata carrying many bivalve shells, reaching a thickness above the sea level of 300 feet. These are doubtless of the same age as the Crepidula bed of the Shumagin Islands. At Pavloff Bay, both on the flanks of the Pavloff volcano and near the settlement, Wossnessenski obtained a large number of fossil bivalves belonging to this fauna.

Walrus Bay.—On Morzhowi or Walrus Bay, in the first bluff eastward from Sannakh Strait (or Isanotski Strait, as it is also called), at 50 toises above the level of the sea, lies a horizontal bed containing the same species of fossil bivalves previously noted at Pavloff Bay. This layer is covered by about 50 toises more of sand and clay. The same layer is noted by Lütké (Partie nautique, p. 272) on the west shore of Cold Bay.[2]

Unalaska.—On the island of Unalaska at the NNW. foot of the volcano of Makushin the same beds occur again, and from them the char-

[1] Lütké, Voy. Séniavine, vol. 3, p. 27.
[2] Cf. Veniaminoff, t. i., pp. 222 and 236.

acteristic fossils have been collected by Wossnessenski, Kastalski and Dr. Stein.[1] They are also reported to exist in one of the bays near Chernoffski, in the western part of the island.

Atka.—The most western point where they have been recognized in the Aleutian chain is on the western side of the island of Atka, on a small inlet known as Sand Bay, which extends from the northern part of Korovinski Bay. Here the beds are near the sea level, but near by, on the western slope of Koniushi volcano, they appear at an elevation of about 30 feet and consist of hard argillaceous and indurated sandy layers with the usual fossil bivalve shells.

Nushagak.—Proceeding northward along the main land at the head of Bristol Bay, the Nushagak River enters an inlet some miles in extent. At the head of ship navigation is the location of the Russian trading post of other days called Fort Alexander. On the shore of the river in this vicinity, but of which we have no more precise information, a small collection of fossils in an indurated clayey matrix was obtained by the late C. W. McKay. They agree in every respect with those from the Pribiloff Islands, and add some species to our list. The presence of these beds at this place is therefore definitely established, but nothing is known of their extent.

Saint Paul Island.—Nearly due west from Bristol Bay, in the midst of Bering Sea, rises the Pribiloff group of islands, celebrated for their fur-seal fisheries. The settlement on Saint Paul Island is situated on the neck of a small peninsula, on either side of which is a stretch of sand beach bounded by crags of basaltic rock and lava. On the east side of this peninsula, which forms the southeastern extreme of the island, is a bluff or crag known as Black Bluff, which, according to the observations of Wossnessenski in 1847–'48, is composed of horizontal layers of a hard claystone, with others in which lime preponderates, forming a pale gray, fine grained, clayey limestone, or in which a conglomerate of pebbles of volcanic origin is bound together in a limy matrix.[2] Over these are layers of black or brown volcanic breccia and vesicular lava. These bluffs rise abruptly to a height of 60 to 80 feet above the sea at their base. From the limestone and argillite marine fossils have been obtained by Wossnessenski, Elliott, Dall, W. Palmer, and C. H. Townsend, of which a collection exists in the National Museum, enumerated in table on p. 253. About twenty-eight species are known from this locality, which is stated to be the only spot in the whole group where any fossiliferous rocks occur,[3] the remainder of the islands being composed of volcanic rocks and alluvium of very recent origin.

Recent observations by Mr. J. Stanley Brown, special agent of the Treasury Department, in 1891, convinced him that at present no distinct trace of any limy stratum is perceptible in the Black Bluff. The fossils obtained by him were contained in rounded, apparently water-

[1] Grewingk, op. cit. p. 123; Trudi, Mineral. obst. St. Petersburg, 1830, pp. 382–383.
[2] Grewingk, Beitrag, p. 190.
[3] Cf. H. W. Elliott, Condition of Affairs in Alaska, 1875, p. 70.

worn pebbles, which were indiscriminately included in a general mass of volcanic ashes and other eruptive matter of which the bluff is formed. No extinct species appeared in the collection brought back by Mr. Stanley Brown, while several are noted from the material of the earlier collections. It would seem possible that pebbles of more than one geological epoch may be included in the mass, or that the wear of the waves for half a century has cut away enough of the bluff to hide or destroy the limy stratum referred to by Grewingk, and which may have been of limited extent. It is certain that, from an examination solely of the material collected in 1891, the fossils might be referred to an age as late as the post-Pliocene, which would not agree very well with the fauna réported by Grewingk and others. The fossils collected by Mr. Stanley Brown and not included in the earlier collections are as follows: *Buccinum tenue* Gray?, *B. polare* Gray?, *Admete couthoui* Jay?, *Leda* sp., *Yoldia limatula* Say, *Lepton grande* Dall, *Cardium islandicum* (very abundant), *Macoma sabulosa* Spengler, and a fragment possibly of a *Panopea.* All these occur living at moderate depths in the Bering Sea, immediately adjacent to the island, at present. Owing to the doubt as to their age they have not been included in the table of fossils of the Astoria group (p. 253).

Commander Islands.—On the Commander Islands, west of the Aleutians, rocks of the same age probably occur, since on Bering Island Stejneger collected some specimens of a conglomerated hard gravel of highly polished pebbles united by a limy cement, containing fragments of bivalves (*Saxicava?*) and a single piece of claystone with the imprint of a bivalve not yet identified.

Other localities.—The islands northward from the Pribilof group do not appear to contain fossiliferous strata. St. Matthew and its adjacent islets are composed of porphyritic, granitic, and volcanic rocks. Pinnacle Island is a volcanic chimney, still smoking. St. Lawrence is chiefly granitic, though slate is reported to exist at its southeastern extreme. The island as a whole is composed of reddish granitic domes united by stretches of débris, due to weathering alluvium and sea sand. The Diomedes are massive domes of a white or grayish syenite. The statement of Muir[1] that they have been glaciated is without foundation in fact, and the same may be said of other islands to the south.

Returning to the mainland, the last area in which rocks of the Astoria group are known to occur is that of the Nulato sandstones on the Yukon River between Kaltag and the Koyukuk Mountain. These have already been described in connection with the Kenai beds of the same region, and it seems unnecessary to recapitulate the data here.[2]

It may be added here that there is every reason to believe, notwithstanding the imperfect data which are on record, that the Kenai group

[1] Cruise of the Corwin in 1881, Washington, Treasury Dept., 1884, 4°, 147 pp. Treasury Dept. Doc. No. 601; see pp. 140-142.

[2] See page 247.

and the Astoria group are both represented by analogous beds on the southern part of the peninsula of Kamchatka and on the northern shores of the Japanese island of Yesso, though the discussion of those exotic localities is outside of the limits of this essay.

PLIOCENE.

BEDS OF MARINE ORIGIN.

Identifiable Pliocene appears to be remarkably rare north of California. The small patch noted by Dr. Condon at Shoalwater Bay, Washington, lying conformably between beds of marine Miocene and Pleistocene, appears to be the only locality for many miles. In common with the more extended beds in California, its fauna indicates a colder water temperature than at present, and contains a large proportion of species which have since receded northward some hundreds of miles at least and now find a congenial habitat in the Aleutian chain and Sitkan archipelago.

St. Elias Alps.—In his geological researches on the St. Elias Alps and the region westward from the Yakutat Bay, Mr. I. C. Russell has discovered fossiliferous rocks elevated to 5,000 feet above the sea, containing fossils which all belong to recent species, yet which, since they belong to a more northern fauna than at present is known to inhabit that locality, are probably referable to the Pliocene rather than the Pleistocene, a view which is to some extent supported by the enormous elevation to which they have been subjected. Our ideas of what shall constitute Pliocene on the Pacific coast are still rather vague and may be said to involve the idea of a marine fauna containing a certain proportion of extinct species. Hereafter we may be better able to define the period in terms of dynamic geology, but at present both the recent and fossil faunas are but approximately known, and all determinations of the age must be taken as provisional. It can not be safely assumed that either the supposed Pliocene or the glacial and postglacial epochs on the Pacific coast where wholly synchronous with those periods on the Atlantic coast, to which the same appellations have been assigned. We may, however, be not far wrong in assuming that the Pliocene epoch was intimately associated with those great movements of elevation which have been more or less definitely recognized along the whole Pacific coast from California northward.

Middleton Island.—This small island lies broad off Prince William Sound on the continental shelf, at a distance of some 65 miles from the main shore. It was visited by a Coast Survey party directed by W. H. Dall in 1874. It is low and nearly flat, except that the table land formed by the southern half slopes northward to the northern extreme, which is hardly raised above the sea. The southern end of the island is about 2 miles wide and 100 feet high, very flat above, falling to the sea in a perpendicular cliff, at the foot of which in some places is a narrow, steep beach of shingle or bowlders. The middle portion of the island is three-quarters of a mile wide, rather low near the beach, grassy bluffs rising a few rods inland. On the table land are a few small knolls seemingly dunes, now grassy. There are no trees, but the herbage is extremely luxuriant. A single leaf of *Symplocarpus* measured 48 inches long and 24 broad, with a stalk 4 inches in diameter; the same plant on the mainland has leaves usually not exceeding 14 inches in length. The island is composed of nearly horizontal layers of soft clayey rock, containing many pebbles and even bowlders of syenite and quartzite some rounded and others of angular shape. Above the claystone is a layer of gray sand covered with several feet of mold and turf. Below the sea level some of the rock appeared to be quartzite in place and very hard. Whatever its nature, it extends in reefs and shoals to a distance of several miles from the island in different directions. No fossils were found in the claystone, but from its character it was suspected to be post-Miocene and possibly Pliocene.

THE GROUND ICE FORMATION.

A remarkable formation has been recognized in many places in the northern part of Alaska, in which solid beds of ice of considerable thickness perform the functions of rock strata and are covered by beds of blue clay containing numerous remains of Pleistocene mammals, or by beds of alluvium which sustain a layer of turf, with ordinary profuse herbage of the region, or even small thickets of birch, alder and other small Arctic trees.

Eschscholtz Bay ice cliffs.—This formation was first noticed by Kotzebue, during his exploration of the sound which bears his name, in the year 1816.[1] The remains of animals which were associated with the clays above the ice were described in his appendix on the natural history by Eschscholtz.[2] The locality at which the original discovery was made is known as Elephant Point, Eschscholtz Bay, the bay being an arm of Kotzebue Sound.

This locality was visited by H. M. S. *Blossom*, Capt. F. W. Beechey, in 1826,[3] and observations on the ice formation were made by Surgeon Collie of the expedition, which, with the vertebrate remains collected were discussed by Dean Buckland in the appendix to the narrative of the voyage. Kotzebue and Eschscholtz correctly described the formation as interbedded ice. Beechey's party, deceived by the mantle of clay which at the time of their visit had fallen so as to mask the main body of the ice face, concluded that the ice was a superficial deposit. They noted similar deposits of clay more or less associated with ice at numerous other points on the Arctic coast.

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[1] Kotzebue, Voy. of Discovery into the South Sea and Beering's Straits, London, Longmans, 1821. 3 v., 8°. vol. 1, p. 220.

[2] Op. cit., vol. 3.

[3] Narrative of a voyage to the Pacific and Beering's strait, by F. W. Beechey, R. N., London, Colburn & Bentley, 1831, 742 pp., 4°. Cf. Part 1, pp. 257–259, and for Buckland's discussion, see Appendix to the same, pp. 593–612; also Zoology of Capt. Beechey's Voyage, London, H. G. Bohn, 1839, 180 pp., 4°, 46 pl. For Collie's geological notes on the ice cliffs, see Geology, pp. 169–173, and Pl. I.

In 1848 Capt. Kellett, in H. M. S. *Herald*, accompanied by Berthold Seemann and Dr. Goodridge, visited Kotzebue Sound and Elephant Point with the narratives of Kotzebue and Beechey in their hands, and fully confirmed the views expressed by Kotzebue and Eschscholtz as to the interstratified position of the ice and the relation to it of the bone-bearing clay. Their results were subsequently discussed at length by Edward Forbes and Sir John Richardson.[1] The fossil mammals were fully described and illustrated in their publication.

In 1880 W. H. Dall, commanding the U. S. Coast Survey cutter *Yukon*, visited Kotzebue Sound, and carefully examined this classic locality. His report was subsequently printed by direction of the superintendent of the survey.[2] As these notes give the fullest account of this formation at its typical locality they will be cited verbatim:

We landed at a small low point [on the south shore of Eschscholtz Bay, west from Elephant Point][3] near some old huts and proceeded along the beach for about a mile, the banks being chiefly composed of volcanic breccia or a slaty gneissoid rock. They rose 15 to 50 feet above the sea, rising inland to hilly slopes without peaks, and probably not attaining more than 300 or 400 feet anywhere in the vicinity.

As we passed eastward along the beach a change took place in the character of the banks. They became lower and the rise inland was less. From reddish volcanic rock they changed to a grayish clay, containing much vegetable matter, which in some places was in strata in the clay and in others indiscriminately mixed with it. Near the beginning of these clay banks, where they were quite low, not rising over 20 feet above the shore, we noticed one layer of sphagnum (bog moss) containing fresh-water shells belonging to the genera *Pisidium*, *Valvata*, etc. This layer was about 6 inches thick. The clay was of a very tough consistency, and though wet did not stick to or yield much under our feet. The sea breaks against the foot of these banks and undermines them, causing them to fall down, and the rough irregular talus that results is mingled with turf and bushes from the surface above. A little farther on a perpendicular surface of ice was noticed in the face of the bank. It appeared to be solid and free from mixture of soil, except on the outside. The banks continue to increase slowly, but regularly, in height as we passed eastward. A little farther on another ice face presented itself on a larger scale. This continues about 2½ miles to Elephant Point, where the high land turns abruptly to the south and west, and we followed it no farther. The point itself is boggy and low, and is continued from the foot of the high land, perhaps half a mile to the eastward, forming the northwest headland to a shallow bay of considerable extent.

To return to the "cliffs": These, for a considerable distance, were double; that is, there was an ice face exposed near the beach with a small talus in front of it, and covered with a coating of soil 2 or 3 feet thick, on which luxuriant vegetation was growing. All this might be 30 feet high. On climbing to the brow of the bank, the rise from that brow proved to be broken, hummocky, and full of crevices and holes; in fact, a second talus on a larger scale ascending to a second ice face, above which was a layer of soil 1 to 3 feet thick covered with herbage.

The brow of this second bluff we estimated at 80 feet or more above the sea. Thence the land rose slowly and gradually to a rounded ridge, reaching the height of 300 or 400 feet only, at a distance of several miles from the sea, with its axis in a north and south direction, a low valley west from it, the shallow bay at Elephant

[1] Zoology of the voyage of the *Herald*, edited by Edward Forbes, Vertebrals by Sir John Richardson, London, Lovell Reeve, 1854, 171 pp., 4°, 33 pl.

[2] Notes on the vicinity of Bering Strait, Am. Jour. Sci., 1881, vol. 21, pp. 104-111.

[3] Phrases inclosed in brackets are now added for clearness.

Point east from it, and its northern end abutting in the cliffs above described on the southern shore of Eschscholtz Bay. There were no mountains or other high land about this ridge in any direction; all the surface around was lower than the ridge itself.

About half a mile from the sea, on the highest part of the ridge, perhaps 250 feet above high-water mark, at a depth of a foot, we came to a solidly frozen stratum consisting chiefly of bog moss and vegetable mold, but containing good-sized lumps of clear ice. There seemed no reason to doubt that an extension of the digging would have brought us to solid, clear ice, such as was visible at the face of the bluff below; that is to say, it appeared that the ridge itself, 2 miles wide and 250 feet high, was chiefly composed of solid ice overlaid with clay and vegetable mold. It was noticeable that there was much less clay over the top of the upper face than was visible over the lower one, or over the single face when there was but one, and the land and the bluff were low near the beach. There also seemed to be less vegetable matter. Near the beach six or eight feet of clay were observed in some places, without counting what might be considered as talus matter from further up the hillside. In one place only did we notice a little fine, reddish gravel, and nowhere in the talus or strata any stones.

The ice face near the beach was not uniform. In many places it was covered with clay to the water's edge. In others, where the bank was less than 10 feet high, the turf has been bent without breaking after being undermined, and presented a mossy and herbaceous front, curving over quite to high-water mark.

The ice in general had a semistratified appearance, as if it still retained the horizontal plane in which it originally congealed. The surface was always soiled by dirty water from the earth above. This dirt was, however, merely superficial. The outer inch or two of the ice seemed granular, like compacted hail, and was sometimes whitish. The inside was solid and transparent, or slightly yellow tinged, like peat water, but never greenish or bluish like glacier ice. But in many places the ice presented the aspect of immense cakes or fragments, irregularly disposed, over which it appeared as if the clay, etc., had been deposited. Small pinnacles of ice ran up into the clay in some places, and, above, holes were seen in the face of the clay bank, where it looked as if a detached fragment of ice had been and had been melted out, leaving its mold in the clay quite perfect.

In other places the ice was penetrated with deep holes, into which the clay and vegetable matter had been deposited in layers, and which (the ice melting away from around them) appeared as clay and muck cylinders on the ice face. Large rounded holes or excavations of irregular form had evidently existed on the top of the ice before the clay, etc., had been deposited. These were usually filled with a finer grained deposit of clay, with less vegetable matter, and the layers were waved, as if the deposit had been affected by current action while going on.

In these places were noticed, especially, the most unexpected fact connected with the whole formation, namely, a strong, peculiar smell, as of rotting animal matter, burnt leather, and stable manure combined. The odor was not confined to the spots above mentioned, and was not quite the same in all places, but had the same general character wherever it was noticed.[1] A large part of the clay had no particular smell. At the places where the odor was strongest it was observed to emanate particularly from darker, pasty spots in the clay (though permeating elsewhere), leading to the

[1] This phenomenon was observed by Kotzebue, Beechey, and the Herald party, and lends further probability to the view that the animals were mired in the clay and thus met their death. Since, if the clay contained merely the accummulated bones of animals which had died and decayed on the surface of the ground, it is unlikely that so much animal matter would have been hermetically sealed in the clay and kept on ice to offend the nostrils of later visitors. On the other hand, if the ice had not been present and the temperature not kept so low it is unlikely, even in the clay, if animal matter could have been preserved for such an enormous period of time in a condition to give out so ammoniacal a stench. All the circumstances point toward the view that the ice preceded and subsequently coexisted with animals whose remains are now found in its vicinity.

supposition that these might be remains of the soft parts of the mammoth and other animals, whose bones are daily washed out by the sea from the clay talus.

At or near these spots, where the odor was strongest, a rusty, red lichen, or lichen-like fungus, grew on the wet clay of the talus in extensive patches. Some of these, of the bad-smelling deposit, and as many bones of the mammoth, fossil buffalo, etc., as we could carry, were secured. These included a mammoth tusk, with both ends gone, but still 5½ feet long and 6 inches in diameter. Dwarf birches, alders, 7 or 8 feet high, with stems 3 inches in diameter, and a luxuriant growth of herbage, including numerous very toothsome berries, grew with the roots less than a foot from perpetual solid ice.

The formation of the surrounding country shows no high land or rocky hills, from which a glacier might have been derived and then covered with débris from their sides. The continuity of the mossy surface shows that the ice must be quite destitute of motion, and the circumstances appear to point to one conclusion, that there is here a ridge of solid ice, rising several hundred feet above the sea, and higher than any of the land about it, and older than the mammoth and fossil horse, this ice taking upon itself the functions of a regular stratified rock. * * * Though many facts may remain to be investigated, and whatever be the conclusions as to its origin and mode of preservation, this formation certainly remains one of the most wonderful and puzzling geological phenomena in existence.

From the character of some of the bad-smelling deposit which was brought home and appeared to be exclusively composed of vegetable fiber finely comminuted, no doubt is felt that it represents dung of the mammoth or some other herbivorous animal which had been preserved in pockets on the surface of the ice where it was probably dropped, and and by its dark color attracting the rays of the sun had sunk in, as is usual with dark objects dropped on an exposed ice surface. It may be reiterated that the bones, as noted by previous observers, are contained in the clay above the ice; never in the ice itself. They are exposed by the melting away of the ice face and the consequent fall of the superincumbent clay, which is afterward disintegrated by the action of the waves, leaving the bones exposed on the broad, flat, muddy beach. The remarkably fresh appearance of the bones is amply accounted for by the low temperature and dense character of the clay in which they are imbedded, in which the animals may have become mired and so perished.

The report of Dr. Goodridge, which appears to have been prepared with great detail, was unfortunately not printed. In some extracts from it given by Richardson it is stated that at one of the ice cliffs a section was exposed showing 50 feet of pure, clear ice above, and behind it layers of drifted material, peat, covered with a thick bed of broken sticks and vegetable matter, over which lay a stratum of red river gravel, over which lay a bed of argillaceous earth capped by dry, friable mold and surface peat, with the usual turf and herbage. The sticks were larger than any growing in the vicinity, but they may have been drifted from the wooded region of the interior. At another place the ice wall was 80 feet high. E. W. Nelson, who visited this locality in 1881 with the U. S. S. *Corwin*, also observed such an accumulation of sticks, and noted that some of them had been gnawed by beavers. The following list of species is mainly extracted from Richardson's report, those marked with an asterisk having been obtained by Dall in 1880. The nomenclature has been somewhat modernized.

**Elephas primigenius* Blumenbach.
Elephas columbi Falconer.
Equus major De Kay.
Alces americanus Jardine = *machlis* Ogilby.
**Rangifer caribou* Baird.
**Ovibos moschatus* Blainville.
**Ovibos maximus* Richardson = *O. cavifrons* Leidy.
**Bison crassicornis* Rich. = *B. antiquus* Leidy.

Other localities.—Analogous beds of clay, sometimes with vertebrate remains, were observed by Beechey's party at the following localities:[1]

On the north shore of Eschscholtz Bay, and also on the west from it, on the south shore of Spafarieff Inlet and Good Hope Bay; at Shishmaref Inlet, west-southwest from Cape Spanberg; Cape Blossom; northward from Kotzebue Sound, at Point Hope; at various points between Cape Beaufort and a point 20 miles east from Icy Cape; and near Point Belcher, in north latitude 71°.

From information gathered from several masters of vessels in the whaling fleet and derived from experience gained in the effort to dig graves for seamen who have died aboard vessels on this shore from time to time during the last twenty years, it would appear that somewhat north of Cape Beaufort the land between the low hills and the sea is low and the soil chiefly a sort of gravel. "At a depth of 2 feet is a stratum of pure ice (not frozen soil), of unknown depth. This formation extends with occasional gaps, north to Point Barrow, and thence east to Return Reef, where the ice layer is about 6 feet above the level of the sea. It goes south at least as far as Icy Cape without any decided break, and is found in different localities as far south as Kotzebue Sound." At Point Barrow, near the international station, under the direction of Lieut. P. H. Ray, U. S. Army,[2] a shaft was sunk to a depth of 37 feet 6 inches, which passed through successive layers of mud, sand, and fine gravel, with fragments of drift-wood and marine shells, showing here and there large fragments of pure fresh-water ice, but no continuous stratum of ice. The formation here was clearly a beach alluvium, and relatively modern, a pair of Eskimo wooden snow goggles with a sinew string still attached to them being found at a depth of 27½ feet. The temperature of the earth varied from − 5° to + 17.5° F.; below the influence of the external air the temperature of the earth was quite steady at 12° F. for nine months. The earth was frozen and was extremely hard and tough. Blasts put into the side of the shaft blew out without shattering the frozen earth around the drill hole. It is probable that excavations farther inland might have revealed the ice layer, which at the locality of the station did not exist.

Kowak River ice cliffs.—After that at Elephant Point, the most re-

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[1] Op. cit., p. 603.

[2] Report of the International Polar Expedition to Point Barrow, Alaska. Washington. House Ex. Doc. No. 44, 48th Congr., 2nd Sess., 1885, 4°; cf. pp. 24, 338, 339.

markable exhibition of the ground-ice formation which has yet been recognized is situated on the lower part of the Kowak River, which empties into Hotham Inlet. The cliffs are situated along the bends of the river, which is extremely tortuous, almost exactly due north from Elephant Point near where a line drawn from Elephant Point to Deviation Peak cuts the Kowak River. They have been illustrated and briefly referred to by Lieut. John C. Cantwell,[1] U. S. Revenue Marine, who discovered them in 1884 and revisited them during the following year. They are composed of solid ice, covered by a layer of dark colored earth, uniformly about 6 feet thick, the whole rising to the height of 15 to 150 feet, with trees 4 to 8 inches in diameter growing on the surface. Up to this point, and for some distance farther, not a stone or pebble was to be seen, the bluffs along the river appearing to be composed of clay or soft earth, which fell in large masses where undermined by the river.

THE KOWAK CLAYS.

At a point on the river in about west longitude 158°, a remarkable clay bluff, three-quarters of a mile long and 150 feet high, was reached on the left bank of the river. Quantities of mammoth tusks were observed in this clay and its débris, where undermined by the stream. These clays were doubtless of the same age as those in which the mammoth remains are found at Elephant Point over the ice cliffs. Their position is significant, being near the lower end of a tract of open tundra, below the low divides leading northward to the Noatak River and southward to the Selawik Basin, and near where the Kowak River enters a defile which later becomes a sort of canyon obstructed by rapids.

Returning to the ice cliffs, during the explorations of 1885 it was observed that "for miles along the river in this portion of its course these icy cliffs appear and disappear at regular intervals, so that they recur in bends that are parallel with each other." An east-northeast and west-southwest magnetic line drawn through one of the cliffs if prolonged will cut all the others as well as the analogous formation at Elephant Point far to the southward. "Climbing to the top of one if these ice cliffs" Messrs. Cantwell and Townsend pushed their way "through the dense thickets of willow and luxuriant growth of grass into the interior for about 1 mile where we found a shallow lake about a mile in diameter." If the travelers stood still on the peaty soil for any length of time "the spongy moss became saturated and soon a pool of dark-colored water made our position untenable" (op. cit., pp. 48–49). The formation does not extend to the Noatak River, which was explored by McLenegan in 1885.

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[1] Report on the cruise of the Corwin in the year 1885, by Capt. M. A. Healy, U. S. Revenue Marine. Washington. House Ex. Doc. 153, 49th Cong., 1st Sess., 1887; cf. Lieut. Cantwell's Report, pp. 48, 49. Also Science, Dec. 19, 1884. vol. 4, No. 98, pp. 539, 551–554; Jan. 30, 1885, vol. 5, No. 104, pp. 92–93; and Oct. 30, 1885, vol. 6, No. 143, p. 380.

See also Russell (I. C.) Ice Cliffs on Kowak River, Alaska, American Geologist, July, 1890, vol. 6, No. 1, pp. 49–50, and letter of Lieut. Cantwell, following, pp. 51–52.

For these clays, whether independently deposited or found superpos on the ground ice formation, the name of the *Kowak clays* is suggeste

DISTRIBUTION OF FOSSIL VERTEBRATES.

Other Alaskan localities for the animals associated with the clay are the Kotlo River, a stream entering the Yukon from the south abov old Fort Yukon and close to the Arctic circle; the valley of the Ingl talik River, which empties into Norton Bay, and of the Ulukak River, which enters Norton Sound at Unalaklik. A lake near Nushagak is stated on Russian authority to afford abundance of similar bones. The are reported from the upper part of the Knik or Fire River, which debouches into Cooks Inlet; and on the Arctic coast, in latitude 71°, at a point called Skull Cliff, Beechey's party obtained remains of an elephant in a clay overlying a low stratum of ice. Wossnessenski collected tusks, teeth, and bones of *Elephas primigenius* and *E. columb* near Topanica Creek, Norton Sound. Other remains of the same sort have been picked up on the coast between Bristol and Norton Sound. Teeth of the elephant, bones of *Bison antiquus*, and especially of the musk ox, are not rare on the tundra of the Yukon valley, whence specimens were brought by Dall in 1868. But the Kotlo and Inglutal rivers have the reputation of affording these bones in extraordina numbers. Along the Arctic coast, east from Point Barrow, where the bones and ivory occur frozen into the clays, they are so common as to serve the Eskimo carvers for economic purposes. Dall obtained in 1880 a deep ladle, as large as a child's head, carved, handle and all, out of a solid tusk of mammoth ivory by these people. It was said to have come from the mouth of the Colvile River.

Last, but by no means least important, come the discoveries of a mammoth tooth on the island of St. George of the Pribiloff group in 1836, vouched for by Veniaminoff (Unal. I, p. 106) and of tusks and teeth on the island of Unalaska in 1801 according to the report of Dr. Stein.[1] The Ground Ice formation and the Kowak clays have been considered here for several reasons. Though the former may be correlated with the glacial epoch of cold and the latter with the post-glacial era, yet there are certain reasons why this, even if probable, is not inevitable.

ORIGIN OF THE ICE AND CLAY FORMATIONS.

In our ignorance of the chronology of the Alaskan geology it is well to consider alternatives. The fact that the Californian marine Pliocene indicates a colder sea than do the invertebrates of the Pleistocene and that this is confirmed by the evidence of the Oregon and Yakutat fossils which we have called Pliocene in this essay, has been already alluded to. It is quite certain that an elevation of the shores of Bering Sea and the continental shelf lying off them if carried to 200 feet would unite Asia and America; if to 300 feet, would connect the eastern Aleu-

[1] Trudi, mineral. Obst., St. Petersburg, 1830, pp. 382, 383.

tians as far as Umnak and the Pribiloff Islands with America; and would lay bare an enormous level plain covering the northern half and most of the eastern third of the present area of Bering Sea. The diminished body of water which would be left in such a case, in connection with the prevalence of the northwest trade winds over this area, would give to this region such a dry climate as characterizes much of Siberia and the Yukon valley in Alaska. If the elevation took place at the end of the Miocene, as it did in California and Oregon, and as the location and condition of the Nulato sandstones suggests, and if the greatest elevation were toward the west and gradually diminished eastward, we should have conditions favorable for the following results: First, a small precipitation with little snow which with extreme cold and an almost level surface would be unfavorable to the formation of glaciers. Second, the formation by the drainage of the Yukon and other streams coming down from the east of vast shallow lakes of muddy water, the remnants of which in winter, after the escape of the surplus water, might, as now occurs in the same region, freeze solidly to the bottom Third, the ice thus formed might to a certain extent persist, especially if protected from the sun of the short Arctic summer by a deposit of clay from the spring freshets. Fourth, with a return of a milder climate, though the great mass of this ice might melt and escape with the drainage, that in the more northern and colder region, especially where protected by the clays, might be to some extent conserved and over the clay bogs above it a carpet of Arctic vegetation gradually extend.

The wandering vertebrates, attracted by the luxuriant herbage which we know to flourish in such places, might be trapped in the quagmires which the grasses treacherously conceal. Further elevation by affording better drainage would tend to preserve rather than to waste the hidden stores of ice, while the rivers gradually cutting down their channels would expose the formation when it lay along their path.

That the moderate elevations which exist in the region were insufficient to start the ice thus formed into motion, and thus inaugurate glaciers, may be accounted for on several grounds. First, under the assumed circumstances the ice would always be formed on the lowest places of the level lowlands, coming there as water, and not as snow pressing from slopes. Second, the ice under conditions of very low temperature is without doubt much more rigid than at higher temperatures and by the hypothesis would more or less thoroughly be incorporated at its base with the tough and rigid frozen mud upon which it formed; in fact the ice and soil would practically form one body, while ice formed from snow would always behave more like a body extraneous to the soil. Lastly, the very level character of the region would be unfavorable to motion in the ice, as at present on the Arctic coast where we know the land ice is stationary; while in particular localities, where some motion might take place, the character of the Miocene sandstones upon which most of it must have rested in the absence of alluvium is not well suited to retain any evidence of it.

These suggestions are offered as a basis for discussion, in considering the anomalous geological conditions of northwestern Alaska until a greater knowledge of the facts may afford a foundation for some more applicable hypothesis.

VOLCANIC PHENOMENA.

It is impracticable to attempt any extended discussion of the volcanic phenomena which have played so important a part in the geological history of Alaska. Much information has been brought together by Grewingk, while later observers have added much more to the total. Volcanic activity still continues, as evidenced by the recent formation of a new peak[1] the Grewingk volcano, in the immediate vicinity of Bogosloff, itself less than a century old, and to which Grewingk subsequently became joined. It is extremely probable that volcanic action has been long continued in this region, from the time of the Triassic granites to the porphyritic andesites, and modern basalts. But from the facts which are already known, it seems highly probable that the most profuse and extensive outpourings of basaltic and vesicular lava in Alaska, as in Oregon, Idaho, and California, were of Pleistocene age, and in less intensity have continued subsequently to recent historic times.

NOTE ON THE MAP.

Owing to the small scale of the map upon which the notes could be laid down, but little more has been attempted than to indicate approximately the localities where the specified rocks occur. Only in the Yukon valley and on the peninsula of Kenai has any attempt been made to indicate the boundaries of the areas represented.

PLEISTOCENE.

The epoch of the Pleistocene is practically outside the scope of this paper. It might be said, briefly, that it included in Alaska great changes of level and marked volcanic activity, much as in the case of California. Recent papers by G. M. Dawson,[2] W. P. Blake,[3] I. C. Russell,[4] and G. F. Wright,[5] bear on this topic and may be consulted with advantage.

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[1] See A new volcano island in Alaska, by W. H. Dall, in Science, Jan. 25. 1884, vol. 3, No. 51, pp. 89–93; and also Geo. Davidson, in Science, Mar. 7, 1884, vol. 3, No. 57, pp. 282–286, also Aug. 15, 1884, vol. 4, No. 80, pp. 138–139. Also the report on the voyage of the *Corwin* in 1885, previously cited, in which the new and old islands are illustrated.

For observations on the ash and lava of this eruption see:

On Hornblende andesites from the new volcano on Bogosloff Island in Bering Sea, by George P. Merril, Proc. U. S. Nat. Mus. for 1885, pp. 31–33.

The volcanic sand which fell at Unalaska Oct. 20, 1883, by J. S. Diller, Science, Mar. 30, 1884, vol. 3, p. 651; and lava from the new volcano on Bogosloff Island, by J. S. Diller, Science, Jan. 23, 1885, vol. 5, p. 66.

[2] Transactions Royal Society of Canada, 1890, vol. 8, sec. 4, pp. 3–74.

[3] Glaciers of Alaska, in Am. Jour. Sci., July, 1867, 2d ser., vol. 44, No. 130, pp. 96–101, and Notes on the geography and geology of Russian America and the Stickeen River, H. Ex. Doc. 177, 1868, part 2, Washington, 19 pp., 8°. Also, T. A. Blake, "General topographical and geological features of the northwestern coast of America," etc., in Coast Survey Report for 1867, App. 18, E., 1869, pp. 281–290, Washington; and W. Libbey, jr., Bull. Amer. Geog. Soc., New York, 1886, 1887, No. 4, pp. 279–300.

[4] Notes on the surface geology of Alaska, Bull. Geol. Soc. of Amer., March, 1890, vol. 1, pp. 99–162, Washington, 8°.

[5] The Muir glacier, Am. Jour. Sci., Jan., 1887, 3d ser., vol. 33, pp. 1–18; also, Bull. Soc. Alaskan Ethn., 1888, No. 2, 8°, 22 pp.

CHAPTER V.

GENERAL CONSIDERATIONS ON THE CENOZOIC EPOCH ON THE PACIFIC COAST OF NORTH AMERICA.

CALIFORNIA, OREGON, AND WASHINGTON.

The conditions prevailing on the Pacific coast during later geologic time, have been considered by Whitney,[1] Becker,[2] G. M. Dawson,[3] and J. L. Le Conte,[4] from whose publications on the subject the following notes have been extracted or condensed.

Except in certain portions of California, the stratigraphical geology is so imperfectly known that all general considerations must be regarded as of a merely approximate character. Much still remains to be learned in regard to the Neozoic faunas before us before we shall be in a position to express positive opinions upon their sequence, faunal peculiarities, and especially their relations to synchronous Atlantic faunas.

Beginning at the south, in California, according to Becker [5]—

Both the Sierra Nevada and the coast ranges were above water and underwent erosion [in the Cretaceous] during the interval between the Knoxville and the Chico epochs. Both ranges also sank just before the beginning of the Chico, admitting the ocean over a great part of the Coast ranges and over considerable areas at the base of the Sierra. Both appear to have risen partially and gently before the Tejon [Eocene] particularly toward the north; at least the rocks of this epoch as far as is known, are confined to the southern extremity of the Sierra and to the Coast ranges south of the Martinez.

A slow subsidence would seem to have taken place before the Miocene, rocks of this age extending along the Sierra far to the north of the Tejon localities, while in the Coast ranges they lie directly upon the metamorphic at a great number of points, clearly indicating for the Miocene a lower general level than during the preceding epoch. During the Pliocene very little of either range was below water.[6]

Dr. Becker concludes that the information of record necessitates the reference of the Sierra and Coast ranges to a single orogenic system.

The Coast ranges are, and probably always have been, of less altitude than the great Sierra, and they have consequently been more extensively immersed, just as

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[1] Geological Survey of California; Geology by J. D. Whitney, 1865, vol. 1; also, the Auriferous Gravels of the Sierra Nevada of California, by J. D. Whitney; Mem. Mus. Comp. Zool., 1879; vol. 6, No. 1; and the Climatic Changes of later Geological times, Mem. Mus. Comp. Zool., 1880–'82; vol. 7, No. 2, 4°.

[2] Monographs of the U. S. Geol. Survey, vol. 13, Geology of the Quicksilver deposits of the Pacific slope, Washington, the Survey, 1888. 4°.

[3] On the later physiographical geology of the Rocky Mountain region in Canada, etc,; Trans. Royal Soc. of Canada, 1890, vol. 8, sect. 4. 4°.

[4] Tertiary and post-Tertiary changes of the Atlantic and Pacific coasts: Bull. Geol. Soc. America, 1891, vol. 2, pp. 323-330, Rochester, the society. 8°.

[5] Op. cit. pp. 211–212.

[6] Ibid., pp. 211–212.

would be the case if both were now to sink any given number of thousand feet. Between the Miocene and Pliocene periods the Coast ranges also suffered disturbance in which at least the western base of the Sierra has not shared perceptibly. The Sierra, too, has undergone some faulting in which neither the Coast ranges nor the Basin ranges are known to have shared, but these differences do not appear to me sufficient to counterbalance the important coincidences in the history of the ranges.[1]

A great nonconformity certainly exists between the Mesozoic Knoxville beds and the Miocene, but none such is found between Chico-Tejon and Miocene. The Miocene, as at New Almaden, contains abundant pebbles manifestly derived from the surrounding metamorphic rocks. The post-Miocene uplift traced by Prof. Whitney has folded, faulted and broken the Tertiary and newer Mesozoic rocks, as well as the older strata upon which these were unconformably deposited, so that it is usually far from easy to make out the effects due respectively to the earlier and to the later disturbances. The earlier was much the more violent, but the comparatively gentle post-Pliocene upheaval certainly extended throughout the Coast ranges of California and Oregon.

Whitney states that the Miocene and Tejon Eocene seem everywhere mutually conformable. Marcou considers that there is an unconformity between them in the vicinity of Fort Tejon. There would not be any necessary reason for supposing that occasional local unconformities may not exist coincidently with a general conformity to which so many observers have borne witness.

Becker observes:[2]

No sensible nonconformity is known to exist between the Tejon and the Miocene, yet the distribution of these two formations appears to indicate a change of level at or near the period which separates them, for the Miocene frequently rests upon the metamorphic rocks without intervention of other beds. During the Tejon these areas of metamorphic rock must have been land, and the subsidence must have been a gradual one. It may have been more rapid in some localities than in others, however, and it thus appears not unlikely that an appreciable lack of conformity may yet be detected[3] at some point or points between the Tejon and the Miocene.

The Miocene occurs on both sides of the Coast ranges and on the lower western flank of the Sierra. It is but sparsely represented in the northern part of California on the coast, and has not been recognized in the northern part of the valley of California, which appears to have been occupied, if at all, by fresh water at this period. The marine beds are composed in large part of sandstones more or less irregular in texture and color, and usually distinctly differentiated from the older rocks. A great area, however, is mostly occupied by extremely fine-grained schists. These are associated with bitumen in the southern part of the State and extend up the coast to Santa Cruz and beyond. These are unusually barren of fossils, while the sandstones often contain almost incredible quantities of shells. The San Benito valley is very remarkable in this respect.

[1] Op. cit., p. 212.
[2] Op. cit., p. 218.
[3] As in the case observed by Prof. Marcou, above cited.

The Pliocene of the Coast ranges is rather limited in extent, and lies, as shown by Whitney, unconformably upon the Miocene, which is itself greatly disturbed. The combination of these facts shows that a great uplift took place between the two. As before stated, it is often difficult to distinguish in detail the effects of this upheaval from those of the disturbances which preceded the Chico, and Becker adds:

> Still later uplifts further confuse the structure of the Coast ranges. In certain localities * * * these effects can be somewhat satisfactorily compared, and it then appears that the Tertiary upheaval, important as it was, was far less violent than that which took place near the beginning of the Cretaceous. * * * Along the western base of the Sierra the effect of the post-Miocene upheaval of the stratified rocks is scarcely perceptible. It does not follow that it produced no effect in this region; on the contrary the absence of known Pliocene beds from the Sierra foothills seems to show that the range was raised considerably at this epoch, though the energy of this movement was insufficient to produce considerable flexure in the beds. At the eastern side of the range, on the other hand, the fresh-water Truckee beds were thrown into bold folds, their dip reaching 30°. The same upheaval was felt throughout western Oregon, where it has the same comparatively gentle character as in the Coast ranges.[1]

In Oregon, as in the south, the Miocene bays and inlets seem at this time to have been definitely shut out from the sea, no marine Pliocene being noted in this region except from the western slopes of the extreme coast.

In California, from the southern border of the state both north and south, marine Pliocene beds have been shown to exist at various points in the Coast ranges and along the shore. The elevation of these beds above the present sea level or below it shows extraordinary variations, the Pliocene of San Diego well extended through at least 20 feet 140 to 160 feet below the surface. At Deadman Island, Santa Barbara County, Pliocene fossils occur near the sea level. On the Monte Diablo range, as elsewhere noted, they have been reported at altitudes of 2,400 to 2,500 feet above the sea in indurated material.

At Shoalwater Bay, Washington, marine Pliocene occurs at about 35 feet above the sea, the fossils exhibiting a boreal facies. If the fossils collected by Mr. I. C. Russell, of the U. S. Geological Survey, near Mount St. Elias, at Pinnacle Pass, be correctly referred to the Pliocene, as seems probable, they are there elevated some 5,000 feet above the sea. The modifications of the shores which have produced such results are such as the mind finds it difficult to grasp when it is considered that the fossils to a very great extent belong to still surviving species of the marine fauna of the coast.

Of the eruptive disturbances in California incident to this series of changes on the eastern side of the Coast ranges the earliest, according to Becker, is a pyroxene andesite, which may have accompanied the post-Miocene upheaval or may have followed it after an interval, probably early in the Pliocene or just before it. It probably was contem-

[1] Becker, op. cit., p. 219.

poraneous with an orographic change which dammed back the large body of fresh water which has been termed Cache Lake, in which, according to Becker, at least a thousand feet of lake sediments with fresh-water fossils were laid down. A few vertebrate fossils, according to Prof. O. C. Marsh, indicate that the beds represent the close of the Pliocene. At the close of this period another eruption took place, accompanied by an orographic change which shifted the waters, which are represented now by Clear Lake, while the lava rests in places upon the older fresh-water strata, which have been shown to correspond to the end of the Pliocene.

From the relation of the eruptive rocks to the sedimentary strata Becker concludes that they are comparatively recent. The andesitic rocks appear at Mount Diablo; at Steamboat Springs, Nevada; they form the mass of Mount Shasta and Mount St. Helens, as well as of the eruptives about Clear Lake. The basaltic eruptions are later and much inferior in volume, though more widely distributed through the region between Clear Lake, San Francisco Bay, and the Panoche Valley. Their emission continued well into the recent epoch.

At the close of the Miocene great masses of soft sandstones were elevated and subjected to erosion, which, from the nature of the material, might be rapid. Becker intimates that the conditions in the Coast ranges do not exclude the hypothesis that the relief of pressure due to the rapid erosion of these soft rocks brought about by fusion of the lavas.

Joseph Le Conte has also touched on this subject.[1] His views in essentials do not appear to differ greatly from those of Whitney and Becker. In brief, he believes that the Sierra was formed at the end of the Jurassic, but during the Cretaceous and Tertiary this range was cut down to a very moderate height, with gentle eastward and westward slopes. The coast ranges were formed at the end of the Miocene and the Pliocene was a period of fluvial erosion. Orogenic changes took place about the end of the Pliocene in both ranges, latterly accompanied by enormous outpouring of the lava and displacement of the river courses. These changes did not greatly affect the river courses of the Sierra region until the lava streams interfered, and the faulting of the Sierra steepened the western slope. Subsequent continental subsidence submerged the deserted channels of the Pliocene rivers at the coast and preserved their traces in the sea bottom. Elevation since then has been insufficient to restore the old levels, and these channels still remain below the sea.[2]

The relative heights of the various marine beds and character of the deposits, both on the coast and in the interior, as described by Becker and Diller, show that the northern and southern parts of California did not participate equally in the changes of level, and that the changes were probably not altogether synchronous.

[1] Tertiary and post-Tertiary changes of the Atlantic and Pacific coasts, Bull. Geol. Soc. of Am., Mar., 1891, vol. 2, pp. 323–330, Rochester, the society.

[2] Op. cit., pp. 325–327.

In Oregon the variations in a vertical sense seem to have been less marked than was the case in southern California or in the southern part of Alaska, while the changes on the coast of British Columbia seem to have been somewhat intermediate between those exhibited in Oregon and those of Alaska.

BRITISH COLUMBIA.

For information in regard to the British Columbian region, we are chiefly indebted to Dr. George M. Dawson, of the Dominion geological survey. Dawson's views have appeared in his important paper on the Rocky Mountain region of Canada.[1] According to him, in the region of the fortieth parallel surveyed by King, during the Eocene period many thousand feet of beds holding characteristic fossils were laid down in a series of lakes between the Rocky Mountains and the Sierra Nevada, but no such deposits have been met with in any part of the northern Cordillera. The whole sweep of country from the Laurentian region possibly quite to the now submerged edge of the Continental Plateau on the Pacific side thus became and continued to be throughout the earliest Tertiary an area of denudation, within which, if any small area of deposition occurred, the beds formed in these have either been subsequently removed or have become concealed by later deposits. The main result referable to this period of denudation is the first interior plateau or peneplain, as Davis has called the proximately level denudation surface thus formed. Extensive though more or less disconnected fragments of this still exist. The limits of the Interior Plateau of to-day near coincide with the limits of the drainage system, which probably discharged in a northerly direction. A good deal of erosion is supposed to have occurred before the initiation of Miocene sedimentation.

By an interruption of the drainage produced in some way, perhaps by the post-Eocene disturbances, of which the effects have been noted in California, great Miocene lakes were formed in that portion of British Columbia lying between the Coast and the Gold ranges. The character of the Miocene flora seems to indicate that the land did not stand at any great height and that the climate was temperate. The Interior Plateau became the seat of a series of lakes of greater or less dimensions, some of which were formed later than others. As far northwest as the Francis River and quite beyond the limit of the Interior Plateau deposits which are referred to the Miocene have been found, and beds which are believed to belong to the same stage again occur on the Porcupine branch of the Yukon. Lakes which are with some probability referred to the same period also existed in some parts of the Columbia-Kootanie valley and in that of the Flathead River, though no definite paleontological evidence of their age has been obtained.

[1] In the notes here given the data bearing on the British Columbian Neocene have been briefly summarized from Dawson's discussion, op. cit., pp. 3-74.

Had the conditions remained permanent the lacustrine phase of the Interior Plateau would have terminated by the filling up of some lake basins and the drainage through erosion of the effluent river beds of others. Before this had taken place volcanic action recommenced on a grand scale and in a varied manner, while large areas were covered with sheets of lava, which flowed out in great volume. The principal centers of action appear to have been aligned along the eastern base of the Coast ranges, where some of the old volcanic vents may still be recognized.

According to evidence produced by Becker the great andesite lava flow of California took place near the end of the Pliocene and may be regarded as terminating that epoch. He shows that the basaltic eruptions of that region at least are considerably later. Prof. Le Conte believes that the ejection of basalts in Oregon took place earlier, at the close of the Miocene or early in the Pliocene.[1] The last-named region closely corresponds with the interior plateau of British Columbia, but here, according to Dawson, the evidence of the blending of the Miocene lake beds, with the eruptives is in some places so distinct as to justify us in assigning the earliest eruptives to the Miocene period itself. In intervals of the periods of eruptive activity lakes or ponds were formed and have left their traces. Some of these may yet afford organic remains of later date than the Miocene. The recurrence of volcanic phenomena during a considerable length of geological time is shown by the cutting out of valleys in the basalts and the refilling of these by later basalts as in the Stikine region. That volcanic action may have continued into the Pliocene period can not be denied, and we may add to Dawson's observation that in view of the almost continuous action of this sort to the present epoch in the regions both north and south of British Columbia on the Pacific coast, it would be most extraordinary if it did not. Still no proof of Pliocene eruptions in British Columbia has yet been obtained, though owing to the uncertainty which attaches to the definition of Miocene and Pliocene on the northwest coast and the absence of distinctive physical changes by which a strict subdivision of the Cenozoic strata could be established, such negative evidence is not of great weight.

Taken as a whole, in regard to the interior plateau of British Columbia, the Miocene was a period of lacustrine sedimentation followed by an outpouring of eruptive matter so complete as entirely to obliterate the old Eocene and earlier Miocene valleys of which it is doubtful if any one has since been eroded in exactly its old course for any considerable distance.

Toward the end of the Miocene, local folding of the strata, volcanic or otherwise, took place in various directions, after which without any considerable change of the general level, the drainage began to outline an entirely new series of river and stream valleys. The general erosive

[1] Am. Jour. Sci., 3d ser., vol. 19, p. 189, and vol. 32, p. 177.

action thus inaugurated was probably long continued and brought the interior plateau again nearly to the base level of erosion.

The early Miocene valleys, where they may yet be studied, according to Dawson, present all the characters of a drainage system which has been long maintained under stable conditions of the surface.

At a later time in the Pliocene it is evident, that a very considerable and general elevation of the Cordilleran region occurred, bringing it considerably higher than it is at the present day. The gradients of all the rivers being thus increased, the streams, armed with new power of erosion, began to cut channels, which, as they were cut rapidly, were made both deep and narrow. To this time Dawson assigns the cutting out of the deep valleys which now exist as fiords of the coast. Admitting that these fiords may have been to some extent locally enlarged by ice during the later period of glaciation, their depth is such as to convince him that during all the main period of their formation in the Pliocene, the land stood relatively to the Pacific about 900 feet higher than it does now.

Important changes in the drainage system of northwest America were produced by this Pliocene elevation, and to the subsequent erosion, the genesis of the deep preglacial auriferous gravels is assigned with much probability.

The results of Pliocene erosion are geographically very important, as the whole effect of subsequent events can be shown to have been relatively insignificant and the main features of much of the country still remain much as they were at the close of this epoch.

On the seacoast it appears probable that as a result of the Pliocene uplift referred to, a belt of low land wide enough to include Vancouver Island and the Queen Charlotte Islands was formed. Across this the rivers issuing from the Coast ranges cut their way to the sea.

Meanwhile over the interior, in place of lacustrine sedimentation such as King described[1] south of the boundary, Dawson regards the known data as indicating for most of the Pliocene a process of reduction by waste. Certain deposits of gravel, sand and silt found in a number of places in the districts of Alberta and Assiniboin have been named by McConnell the South Saskatchewan gravels. They rest indifferently on various formations and lie beneath the lowest Glacial bowlder clays. These deposits have been assigned to the Pliocene on the ground that any preglacial beds should be so referred. Their material is derived from the antecedent Miocene beds and has been rearranged in the beds of streams or lakes.

It would appear, according to Dawson, that the Pliocene uplift of the Cordilleran region of British Columbia did not materially affect the interior plateau. This uplift in itself he does not regard as sufficient to bring about a glaciation, but considers it possible that at the end of the Pliocene a second uplift may have taken place, though this has

[1] Expl. 40th parallel, vol. 1, pp. 542, 756.

probability rather than ascertained facts in its favor. If as suggested the Pliocene was terminated by such an uplift with the inauguration of glaciation as one of its results (the presence of other factors coinciding to promote glaciation being assumed), the interior plateau seems not to have participated, but rather to have suffered a possibly compensatory subsidence.

ALASKA.

In Alaska we are chiefly dependent on the information summarized in the earlier part of this essay for our knowledge of any changes which have taken place.

Since no marine Eocene beds are known from any part of Alaska, it must be assumed that the coasts of the territory which had been elevated at the end of Mesozoic time stood at an elevation not less than they do at present, and probably considerably higher, since the material accumulated in the 2,000 to 3,000 feet of strata of the Kenai group which were laid down in the lakes or marshes must have been derived from higher ground. At the end of the Kenai period the shores at least would seem to have stood at only a moderate elevation above the sea, since the marine sandstones of the Astoria group appear conformably above them, and all the circumstances indicate for the early Miocene only a very gentle and vertically small depression, as the beds are everywhere thin, and toward the south disappear altogether. This would point toward a stationary condition in southern Alaska, a moderate depression near the peninsula and to the north in the Yukon valley a greater subsidence, since there the marine strata are the thickest.

At the end of the marine Miocene the elevation which followed appears to have been somewhat proportional to the previous subsidence, i. e., it was greater in the north where no part of the present land surface is known to bear any later beds of marine origin, moderate to the south, and perhaps on the coast of southernmost Alaska and British Columbia no very great changes took place, or if there did, most of the traces have been since removed by glacial action.

After the inauguration of the Pliocene, some part of the southern coast subsided slightly, and marine beds indicating a moderate depth of water were laid down. Later on there was a moderate elevation of the same region. At the end of the Pliocene southern Alaska participated in the throes which agitated the rest of the Pacific border and an enormous uplift of the recently formed strata followed, attended or rapidly followed by great volcanic activity. Elevation to the north was apparently much less marked.

There does not appear to be any positive evidence of marked vertical motion in southern Alaska since this time, and to the north also the early Pleistocene appears to have been a time of comparative rest.

Later, both north and south eruptive movement became very active, though not necessarily associated with any great changes of level. In comparatively recent times a moderate subsidence seems to be probable in northern Alaska, though at present there are indications that the coast is rising. But local volcanic action has brought about minor changes of level in many places, while toward the south denuding agencies seem to have had the field almost wholly to themselves.

In glancing over the appended table it will be observed that the entire coast seems to have felt certain vertical motions, while at other times action in that sense seems to have alternated more or less along the coast. In the present imperfect state of our knowledge, however, it would be inadvisable to insist too urgently on the significance of apparent changes, of which the details are yet unknown.

Table indicating conditions existing during Cenozoic time in regard to changes of level and the prevalence of volcanic emissions on the Northwest coast.

Epoch.	Southern California.	Northern California.	Oregon.	British Columbia.		Southern Alaska.	Northern Alaska.
				Coast.	Interior.		
Upper Cretaceous	Depressed	Depressed	Depressed	Depressed	Depressed	Depressed	(?)
Tejon Eocene	Stationary	Elevated	....do	Stationary (?)	Elevated	Elevated	Elevated.
Leaf beds of Kenai	Depressed (?)	Stationary (?)	Stationary	Mod. elevation	Stationary	Mod. elev	Mod. elev.
Astoria Marine Miocene	Depressed	Mod. depression	Depressed	Mod. depression	Stationary (?)	....do	Depressed.
End of the Miocene	Mod. uplift, V	Gt. uplift, V	Uplift, V	Uplift, V	Gt. eruptions	Stationary	Uplift.
Marine Pliocene	Mod. depression	Mod. depr	Mod. depr	Stationary (?)	Stationary, V	Mod. depr	Stationary.
Later Pliocene	Mod. uplift	Mod. uplift	Mod. uplift	Mod. uplift	Mod. uplift (?)	Mod. uplift	Stationary, V.
End of the Pliocene	....do	Gt. uplift, V	....do	Gt. uplift	Stationary (?)	Gt. uplift, V	Mod. uplift.
Early Pleistocene	Gt. depr., V	Mod. uplift	Mod. depr	Elevated	Depressed (?)	Stationary	Stationary.
Later Pleistocene	Gt. uplift	Stationary (?), V	Mod. uplift	Stationary	Stationary	Stationary, V	Mod. depr., V.

In this table "depressed" means stationary at a low level; "Mod. depression" that a moderate subsidence occurred; "elevated" means stationary at a high level; "Gt.," "Mod." or simply "uplift" that a great, moderate, or other movement of elevation took place; "V," indicates that the period was one of volcanic or eruptive activity. It will be borne in mind that in making the table attention has been concentrated rather on the coastal region and the changes indicated by sediments with fossils, than on the more interior country and the changes in the crests of mountain ranges.

Table showing the vertical range of the Neocene formations of the Pacific coast.

	Miocene.			Pliocene.				Formations.
	—	—	—					Astoria group.
	—	—	—					Astoria sandstones.
	—	—						Astoria shales.
—								Aturia bed.
?—	—?	—?	—	—	—	—	?	Auriferous gravels.
						—	—	Cache Lake beds.
?								Calamite beds.
			—					Crepidula bed
						?—	—?	Dalles group.
						—	—	Ground Ice formation.
—	—?							Kenai group.
						—	—	Kowak clays.
						—		Mytilus bed.
	—							Nulato sandstones.
—?								Puget group.
			—					Solen beds.
—	—?							Unga conglomerate.

CHAPTER VI.

SUMMARY OF OUR KNOWLEDGE OF THE SUPPOSED NEOCENE OF THE INTERIOR REGION OF THE UNITED STATES, CONSIDERED BY STATES.

Many difficulties are encountered in attempting to correlate the various formations which have been recognized and named in the Great Interior region. Not only are many of the formations imperfectly known and described in the literature, and some of them unmapped, but many of them are characterized by their local lithologic or stratigraphic peculiarities, and the fossils they contain are not of a sort to be depended upon as indices of stratigraphic position.

Furthermore, some of the localities have been indicated only in the most general manner, so that it has been impracticable to record them on the map; and in regard to the age of formations exposed at these localities the most eminent authorities are uncertain or differ widely in their conclusions. Hence the present attempt to present a summary of what is known is offered with a full appreciation of its imperfections which the compilers have been unable to remedy.

The States and Territories have been taken up in geographic sequence, beginning with the region of eastern Oregon and passing eastward by Idaho, Montana, the Dakotas, south through Nebraska, Kansas and Indian Territory, north again through New Mexico, Colorado and Wyoming, concluding with Utah and Nevada.

OREGON.

FRESH-WATER TERTIARIES.

We have already referred to the fact that in northern California old lake deposits of Miocene or Pliocene age have been to a considerable extent overspread and concealed by vast sheets of lava. In Oregon the sequence of deposition and concealment was practically the same; yet, owing to the fact that these lake deposits contain numerous well-preserved and characteristic vertebrate remains, we can speak with much more confidence regarding the age of their subdivisions than we could of their probable representatives in northern California.

John Day valley.—Perhaps the most important and interesting locality where these lake-beds are exposed is in the valley of the John Day River, a southern tributary of the Columbia. It is clear that the Blue Mountains formed the eastern and perhaps southern shores of the lakes whose deposits are now referred to, but their other limits are rendered indeterminable by the successive outflows of volcanic rocks. The Rev. Thomas Condon discovered[1] and first explored these beds, but they have subsequently been visited by Marsh, Wortman, Sternberg, and Bendire, all of whom have made extensive collections.

Amyzon group?—The oldest Tertiary deposit of this basin is a series of fine grained shales, varying in color from white to reddish brown, and containing plant and fish remains. The plant remains have been reported upon by Lesquereux in the proceedings of the U. S. National Museum for 1888, under the head of "Specimens from Van Horn's ranch, John Day Valley, Oregon, collected by Capt. Chas. Bendire, U. S. Army" (pp. 13–19). The age of the bed whence these specimens are derived is said to be "Miocene; probably latest Miocene." Some of the fish remains were found to be in a condition sufficiently good for identification. "They include," says Cope,[2] "four individuals which belong to a single species of the genus *Plioplarchus*," *P. septemspinosus*. This author continues:

As the shales are, according to Condon, below the John Day beds of the Middle Miocene, they can not be the Upper Miocene of the vertebrate scale. *Plioplarchus* has not been found in the Amyzon beds, and the plants of that horizon are, according to Lesquereux, different from those from Van Horn's ranch. The shale may then represent a horizon later than the Amyzon beds, but earlier than those of the John Day. In spite of the evidence of the plants, they may be even older than the Amyzon beds, since the bed of the Dakota *Plioplarchus whitei* is not distinguishable stratigraphically from the Laramie at its summit, according to Dr. White, a statement which I can confirm by personal observation.

John Day group (?=Truckee group).—This group, according to Marsh,[3] attains an enormous development in the valley under consideration. Prof. Cope characterizes its mammalian fauna as follows: "Presence of *Nimravidæ*, *Poebrotheriidæ*, *Tragulidæ*, *Elotheriidæ*, *Suidæ*, *Muridæ*, and *Saccomyidæ*. Absence of *Lemaroidea* and *Creodonta*, of *Hystricidæ*, *Felidæ*, *Ursidæ*, *Camelidæ*, *Equidæ*, and *Proboscidia*." Its vertebrate remains are numerous and have received much attention from Marsh,[4] Leidy,[5] and Cope,[6] all of whom agree that the fauna was in part contemporaneous with that of the White River group of South Dakota. Cope and King,[7] moreover, have no hesitation in correlating it as a whole with the Truckee beds of Nevada.

In a recent publication[8] Drs. White and Stearns have determined a few species of land and fresh water mollusks which were found by

[1] Marsh, Am. Jour. Sci., 3d ser., 1875, vol. 9, p. 52.
[2] Am. Nat., 1889, vol. 23, p. 625.
[3] Am. Jour. Sci., 1875, 3d ser., vol. 9, p. 52.
[4] Am. Jour. Sci., 1873, 3d ser., vol. 5, 409–410; also, Am. Jour. Sci., 1874, 3d ser., vol. 7, p. 249–250; also, Am. Jour. Sci., 1875, 3d ser., vol. 9, p. 242, 248, 249; and Am. Jour. Sci., 1877, 3d ser., vol. 14, p. 248.
[5] U. S. Geol. Survey Terr., 1873, vol. 1, p. 210.
[6] Proc. Am. Philos. Soc., Dec. 1, 1878 (Paleont. Bull. No. 30); see also Am. Nat., Dec. 1, 1878, p. 833; and Bull. U. S. Geol. Survey Terr., 1879, vol. 5, pt. 1, pp. 55–67; U. S. Geol. Survey Terr., 1884, vol. 3, bk. 1.
[7] U. S. Geol. Explor. 40th Parallel, 1878, vol. 1, p. 413, 458.
[8] U. S. Geol. Surv. Bull. No. 18.

Messrs. Wortman and Condon associated with vertebrate remains *Unio condoni* and *Helix* (*Mesodon?*) *dalli* are described as new to science, while *Helix fidelis*, *Helix perspectiva*, and *Gonostoma yatesii* are well known living forms. The modern aspect of this fauna is indeed remarkable when we take into consideration not only its supposed synchronism with the unique faunas of Fossil Hill, Nevada, and Snake River, Idaho and Oregon, but also when we consider what remarkable physical changes have taken place in this region since these mollusks existed.

Truckee group.—Deposits classified under this head are typically exposed in northern Nevada and are supposed by King [1] and others to be synchronous with the John Day group of Oregon. The arguments for or against this view seem far from convincing. Nevertheless, if it is admitted that the fresh-water beds of southwest Idaho, to be described hereafter, which have furnished specimens [2] of *Latia dalli*, *Melania taylori*, and *Lithasia antiqua*, belong to the Truckee group, then it is reasonable to suppose that the beds along Powder River, Old Emigrant road, and those on the eastern slope of Blue Mountains, Union County, all investigated by Condon [3] and found to contain *Lithasia antiqua* and a large *Vivipara*, may be true representatives of this group.

Ticholeptus beds.—These beds are known to exist in the John Day basin from the notes and collections of J. L. Wortman. They are said[4] to rest upon John Day beds along Cottonwood Creek and contain the following species: *Protohippus* sp., *Hippotherium seversum*, *H. sinclairi*, *H. occidentale*, *Anchitherium ultimum*, *Dicotyles condoni*, *Protolabis transmontanus*, *Merycochœrus obliquidens*, and *Blastomeryx borealis*.

"Considerable interest attaches to the discovery of an *Anchitherium* and of a *Merycochœrus* at this locality, as these genera ally the epoch to the John Day period, while *Hippotherium*, *Dicotyles*, and *Protolabis* are Loup Fork genera." [5] *Blastomeryx borealis* is the only species in common with this and the Deep River, Mont., Ticholeptus bed.[6]

PLIOCENE LAKE BEDS.

The so-called "Idaho group" of Cope probably extends into eastern Oregon somewhat as represented on the accompanying map. The statements of King regarding the outlines of his Shoshone Lake in this district are exceedingly vague; but Cope states[7] definitely that, of the four species of *Cottus* that have been found in the Idaho beds, one at least (*C. divaricatus*) and probably two others (*C. hypoceras* and *pontifex*) were from Willow Creek, Oregon. These beds, as will be seen

[1] U. S. Geol. Explor. 40th Parallel, 1878, vol. 1, p. 423.
[2] Proc. U. S. Nat. Mus., 1882, vol. 5, pp. 99–102, pl. V.
[3] Information furnished Mr. Dall by Prof Condon. See discussion of this group under Idaho.
[4] Am. Nat., 1886, vol. 20, p. 367.
[5] Am. Nat., 1886, vol. 20, p. 368.
[6] Ibid., p. 369.
[7] Proc. Phila. Acad. Nat. Sci., 1883, pp. 162–164.

under "Idaho," are considered by Cope to be of lower or medial Pliocene age.

There is, however, another lake deposit of Oregon which this author regards as "very probably the contemporary of that of the Pliocene lake of Idaho."[1] Its locality is not given, but it is said to contain the following remains: *Canis* sp., *Elephas* or *Mastodon, Holomeniscus* or *Auchenia, Aphelops* sp., *Hippotherium relictum*, and *Equus* sp.[2] "The interest of the list consists in the fact that it represents for the first time a fauna which 'includes the large true horses and llamas and the three-toed horses and *Aphelops* rhinoceros. The latter forms belong to the Loup Fork horizon and the former to the Pliocene, and they have not been found hitherto in association in the Rocky Mountain region."[3]

Another lake bed, of more recent date, is that known as the "Fossil lake" or "Lone yard" situated about 40 miles east of Silver Lake. It forms a slight depression embracing perhaps 20 acres.[4] "The depth of the formation is unknown, but it is probably not great. It consists, first, of loose sand above, which is moved and piled into dunes by the wind; second, of a soft clay bed a few inches in thickness; third, of a bed of sand of one or two feet in depth; then a bed of clay mixed with sand of unknown depth. The middle bed of sand is fossiliferous."[5] Whitened shells of *Carinifex newberryi* Lea, as well as obsidian implements of various degrees of workmanship, are strewn abundantly over the surface. Similar implements are represented by Cope as "mingled in the same deposit in undistinguishable relation" with the fossil remains of this place. They are in some instances covered by a deposit of volcanic sand and ashes to a depth of from 15 to 20 feet.[6]

General discussion of the Equus beds.—The numerous vertebrate remains in the lake basin just described are regarded by Cope as constituting a typical *Equus* fauna. Therefore a general review of the history and fluctuation of opinion regarding these beds may properly be given in this place.

The term Equus beds was first used to denote a subdivision of the geologic scale by Prof. Marsh in an address read before the American Association for the Advancement of Science in 1877. No attempt was then made to give the geographical distribution of these beds; nor, in fact, was much more information imparted than that "our Pliocene forms essentially a continuous series, although the upper beds may be distinguished from the lower by the presence of a true *Equus* and some other existing genera." On the plate accompanying the author's edition of this address the Pliocene is subdivided into *Pliohippus* and

[1] Am. Nat., 1889, vol. 23, p. 254.

[2] Ibid., p. 253.

[3] Ibid., p. 254. They are, however, associated in the Peace Creek beds of Florida. Cope described several Pliocene species from Oregon, collected by Sternberg, in Proc. Am. Philos. Soc., 1877, vol. 17, pp. 230, 231. No definite localities are given.

[4] Am. Nat., 1889, vol. 23, p. 979.

[5] U. S. Geol. Surv. Terr., 1884, vol. 3, book 1, p. 19.

[6] Am. Nat., 1878, vol. 12, p. 126.

Equus beds, the latter being characterized by the genera *Equus*, *Tapir* and *Elephas*. Since that time these beds have been recognized in Washington, Oregon, Idaho, California, Nebraska, Kansas, and Texas at such localities and under such conditions as will be found given under these several states.[1]

According to Cope the fauna of these beds is characterized by the presence of *Glyptodontidæ* (Mexico), *Megatheriidæ*, *Eschatiidæ;* extinct genera, *Holomeniscus*, *Mastodon* (Mexico), *Smilodon* (Texas); extinct species, *Elephas primigenius; Equus*, four species; *Lutra*, *Cervus*, etc.; recent species of *Thomomys*, *Arvicola*, *Castor*, *Canis*,? *Homo*. Absence of *Cosoryx*, *Oreodontidæ*, *Protolabiidæ*, *Raiidæ*, *Cobitidæ*, *Mylocypri* and the fishes of the Idaho beds in general, *Castoroides* and *Amblyrhi*

Much difference of opinion has already arisen regarding their age. Marsh, we have seen, first referred them to the upper Pliocene; in this he has been followed by Cope, King, and others, the first of whom remarks:

> As a conclusion of the comparison of the American *Equus* beds in general with those of Europe, it may be stated that the number of identical genera is so large that we may not hesitate to parallelize them as stratigraphically the same. On the other hand the agreement with the South American Pampean formations is so marked in some respects as to induce us to believe that the distinction is geographic rather than stratigraphic. Believing that the Pampean formation contains too large a per cent of extinct genera to be properly regarded, as it has been, as post-Pliocene or Quaternary, its characters, both essentially and as a result of the comparison which I have been able to make, refer it properly to the Pliocene. It appears, then, that the term Pliocene or Subappenine is applicable to the horizon of this fauna in Europe and North and South America.[2]

G. K. Gilbert,[3] however, in Monograph No. 1, U. S. Geological Survey, on Lake Bonneville, devotes one chapter to a discussion of the "Age of the Equus Fauna" and endeavors to show that it is late Pleistocene. The essential points of the arguments he employs to reach this result may be thus briefly summarized:

(1) The three genera mentioned by Marsh, viz, *Equus*, *Tapirus*, and *Elephas*, are all credited to the post-Tertiaries, while none are credited to the lower Pliocene. "The characterization thus fails to separate the Equus fauna from the Pleistocene."

(2) The post-Tertiary age of the Lahontan beds being well established it necessarily follows that Christmas Lake Equus beds are of this age, since (*a*) the physical history of each has been the same and (*b*) they contain several vertebrate and invertebrate species in common.

(3) "The abandoned lake shores of Christmas valley and of the Lahontan basin, the lacustrine plains below them, and the correlated glacial moraines are all of youthful habit, as youthful as the parallel roads of Glen Roy and other surface features marking the wane of glaciation in Scotland."

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[1] See, also, Cope: Rept. U. S. Geol. Surv. Terr., 1884, vol. 3, book 1, p. 19.
[2] Bull. U. S. Geol. Surv. Terr., 1879, vol. 5, p. 48.
[3] Op. cit., pp. 393–402.

(4) By comparing the Christmas Lake fauna with European standards, it is found that its age falls between the upper Pliocene of the Arno valley and the middle of the Pleistocene of Great Britain. Hence this evidence alone might indicate an *early* Pleistocene age for this fauna; it is, however, outweighed by the foregoing considerations.

Dalles group.—Above the Loup Fork beds of the John Day basin, there is a lava outflow which has furnished the materials for a late lacustrine formation, which contains many vegetable remains.[1] The material is coarse and sometimes gravelly, and is found on the Columbia River and probably also in the interior basin. Prof. Condon calls this the Dalles group.[2] It is in turn overlain by the beds of the second great volcanic outflow. The exact horizon of this group has not been determined. It may be synchronous with the "Equus beds."

IDAHO.

TRUCKEE GROUP.

In Vol. II, Paleontology of California, Gabb figures and describes[3] two species of fresh water Tertiary mollusks from "deposits on Snake River, Idaho territory, on the road from Fort Boise to the Owyhee mining country." These species, *Melania taylori* Gabb, and *Lithasia antiqua* Gabb, were said to be associated with a small bivalve, perhaps a species of *Sphærium*, too poorly preserved to admit of description.

Meek described a *Sphærium? idahoensis* from "Castle Creek" in the Proceedings of the Philadelphia Academy of Sciences in 1870 (vol. 22, p. 57) repeating the same and adding two figures in 1877.[4] This is given as a Tertiary species of the Fossil Hill, Nevada, horizon. To these species of southwestern Idaho, Dr. White[5] added one more in 1882, viz, *Latia dallii*, which is said to have come from "50 miles below Salmon Falls, Snake River," and was associated with *Melania taylori* and *Lithasia antiqua*.

Much confusion has already arisen concerning the horizon of these molluscan forms. This may be stated briefly as follows: In 1870 Meek[6] correlated certain deposits on Castle Creek, Idaho, with others at Fossil Hill, Nevada, by identifying "*Sphærium? idahoense*" from both localities. King having applied the name Truckee group to the beds containing this species at Fossil Hill,[7] would presumably include the Castle Creek beds in the same group; at least he has been quoted[8] as doing so. Dr. White goes still further and states that Gabb's two species evidently come from this same geological horizon, hence they all belong to the Truckee Miocene.

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[1] Am. Jour. Sci., 1879, 3d ser., vol. 18, p. 408.

[2] Am. Nat., 1880, vol. 14, p. 458.

[3] Op. cit., p. 13, pl. 2, figs. 21, 22.

[4] U. S. Geol. Explor. Exped. 40th Parallel, vol. 4, pt. 1, p. 183, pl. 16, figs. 1, 1*a*.

[5] Proc. U. S. Nat. Mus., 1882., vol. 5, p. 100, pl. v, figs. 17-20.

[6] Proc. Phila. Ac. Nat. Sci., 1870, p. 57. Notice that Meek here gives other fossils from "Idaho territory." This should read Nevada. See vol. 4, U. S. Geol. Surv. Terr., "Ornithology and Paleontology."

[7] U. S. Geol. Surv. Terr., 1878, vol. 1, p. 420.

[8] Dr. C. A. White: Proc. U. S. Nat. Mus., 1882, vol. 5, p. 99.

From Castle Creek and other localities in southwestern Idaho, Cope[1] has described numerous fish remains, referring them all to his "Idaho group, or "beds," which he regards as of lower or middle Pliocene age.[2] To this same group he refers Meek's molluscan species from this creek and from Fossil Hill, as well as Leidy's *Mastodon mirificus* and *Equus excelsus*[3] from Sinker Creek, Idaho. Accordingly Truckee group (King) and Idaho group (Cope) become synonyms. If so, in judging by Cope's determination of the age of the latter, the Truckee group must be of Pliocene age. Something of the kind has been suggested by Cope,[4] though for this he gives Dr. White as authority.

The fossiliferous deposits here referred to are of limited geographic extent, as may be seen by consulting the accompanying map. Igneous rocks are met with on all sides. King calls special attention to the fact that in southwestern Idaho "there are two sets of Pliocene strata, separated by basaltic eruptions.[5] He states, moreover, that—

> Sections obtained along the plains between the Owyhee Mountains and Snake River show that a considerable portion of the beds of the valley, which consist chiefly of white sands and marls carrying numerous well defined Pliocene forms, were overlaid by large accumulations of basaltic flow, and that subsequently a second period of lacustrine deposition took place, likewise characterized by Pliocene forms, the latter representing a more advanced stage of development and more recent type than those beneath the basalt.

SALT LAKE GROUP.

By looking at maps 2, 4, and 5 accompanying Hayden's Twelfth Report[6] it will be seen that certain deposits exposed along the borders of Malade, Cache, Port Neuf, Upper Port Neuf, and Bear Lake valleys have been assigned an upper Tertiary age and have been termed the "Salt Lake group."[7]

It seems indeed possible, if not probable, that these various beds, which are made up of clays, sands, marls, limestone, and shales,[8] may have been deposited in outliers of the great Shoshone Lake of King,[9] and, if so, they are synchronous with the Humboldt group of that author.

This so-called Salt Lake group has yielded few fossils in this part of the state. In Utah, however, near "The Gates," Peale has recorded numerous genera of fresh-water mollusca, *Limnæa*, *Valvata*, *Planorbis*, *Sphærium*, *Bythinella*, *Physa*, *Vivipara*,[10] etc.; but these furnish no definite clue as to the age of the group.

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[1] Proc. Phila. Acad. Nat. Sci., 1883, pp. 153-166.

[2] Amer. Nat., 1889, p. 254.

[3] Proc. Phila. Acad. Nat. Sci., 1870, p. 67, and 1883, p. 166.

[4] Am. Nat., 1877, 456, et in litt.

[5] U. S. Geol. Surv. 40th Parallel, 1878, vol. 1, p. 440.

[6] Maps and Panoramas: Twelfth Annual Report of U. S. Geol. and Geog. Survey of the Territories, 1878.

[7] Fourth An. Rept. U. S. Geol. and Geog. Survey Terr., 1870, p. 169.

[8] Eleventh Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1877, pp. 604-605.

[9] U. S. Geol. Explor., 40th Par., 1878, vol. 1, p. 456.

[10] Eleventh Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1877, pp. 604-605.

The *Vivipara*, however, if correctly named, is of much interest, owing to the fact that it is not known west of the Rockies alive. Its occurrence in various places in central and eastern Oregon is referred to in the discussion of that state.

This group is sometimes overlain by Quaternary sedimentary deposits, as by the Cache group in the valley of that name,[1] but not unfrequently it is capped by a bed of basalt as along the low range of hills that border the east side of the great Snake River basin, especially from Port Neuf Canyon northward.[2]

The beds of this group are generally somewhat inclined, though generally at a low angle, rarely exceeding 10°, and always in the same direction as the inclination of the underlying formations.[3]

MONTANA.

NEOCENE LAKE BEDS.

Passing from Idaho, over the "divide" into Montana, beds of Neocene lacustrine materials are found well developed in the valley of Red Rock Creek, one of the head branches of the Jefferson fork of Missouri River. These beds are often several hundred feet in thickness, and consist for the most part of a

light gray marl, with concretionary masses, and a sort of pudding stone.[4] In these concretions are often inclosed masses of basalt, which occur here and there all over the country. While we have the evidence of a period of effusion subsequent to the deposition of these lake beds, from the fact that the basalt lies over them, we see by these isolated masses frequently that there were other periods either before or during the Pliocene. At one locality I found in these lake deposits the fossil remains of a species of *Anchitherium*[5] and a land snail (*Helix*). The inclination of these modern beds is west 5°.

Fort Ellis beds.—In the vicinity of Fort Ellis Peale describes[6] bluffs composed of "Pliocene" sandstones, marls, and conglomerates.

The strata are for the most part horizontal, although inclined sometimes at a very small angle, which is never more than 5°. The height of these bluffs above the level of the creek is 175 feet. They are remnants of Pliocene formations that once spread over the entire valley of the Gallatin and formed the bottom of the vast lake that spread over what are now the valleys of the Jefferson, Madison, and Gallatin rivers, reaching to the junction of the three streams. * * * Each of the rivers has cut deeply into these Pliocene rocks, and their valleys are the results of the erosion that has taken place since the draining of the ancient lake.

The "Pliocene" sandstone and marls of the Yellowstone valley are capped by basaltic plateaus.

Deep Creek beds.—Still farther to the east, along Deep Creek, exist

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[1] Eleventh Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1877, p. 603.

[2] Fifth Ann. Rept. U. S. Geol. and Geog. Survey, Terr., 1871, p. 25.

[3] For a description of certain volcanic ash deposits in this part of the State, termed "Pliocene sandstone," see Am. Jour. Sci., 3d ser., 1886, vol. 32, pp. 199–204.

[4] Hayden, 5th Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1871, p. 33.

[5] *Anchitherium agreste* Leidy. Found in indurated, gray, arenaceous marl, compared with Miocene forms from Dakota and Oregon. Leidy, U. S. Geol. Surv. Terr., 1873, vol. 1, pp. 251–252. Ibid., p. 323, "Miocene?"

[6] Sixth Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1873, pp. 112–113.

remarkable deposits of both "Miocene" and "Pliocene" ages. These were brought to light by the explorations of Grinnell[1] and Dana, who describe them as follows:

The Tertiary beds found here consist for the most part of homogeneous cream-colored clays, so hard as to be with difficulty cut with a knife. The beds are horizontal and rest uncomformably upon the upturned yellow and red slates below. The clays of which they are formed resemble closely those found in the Miocene beds at Scotts Bluffs, near the North Platte River in Wyoming. The deposits at Camp Baker have been extensively denuded and nowhere reach any very great thickness. At a point about 3 miles southeast of the post, some bluffs were noticed where the Miocene beds attained a thickness of 200 feet, and these were capped by 50 feet of Pliocene clays, both beds containing characteristic fossils. * * *

It seems probable that in Pliocene time at least the Baker Lake may have extended north to the Missouri River, and perhaps up that stream to the Three Forks, thus connecting it with the lake which existed near Fort Ellis.

In 1877 Prof. Cope[2] sent his assistant, Mr. Isaac, to collect fossil remains from this basin. The results were satisfactory. A considerable number of species was obtained. Of these *Pithecistes brevifacies*, *Brachymeryx feliceps*, *Cyclopidius simus*, *C. heterodon*, and *Blastomeryx borealis* were described by Cope in 1877[3], while a complete faunal list was given nine years later[4], which includes the following species:

Mastodon proavus Cope.
Protohippus sejunctus Cope.
Merycochœrus montanus Cope.
Merychyus zygomaticus Cope.
pariogonus Cope.
Cyclopidius simus Cope.
Cyclopidius emydinus Cope.
Pithecistes brevifacies Cope.
decedens Cope.
heterodon Cope.
Procamelus vel *Protolabis* sp.
Blastomeryx borealis Cope.

The horizon represented by this old lake formation is that of the Ticholeptus beds of Cope, and is by this author correlated with a somewhat similar deposit on "Cottonwood Creek," Oregon, though but one species, *Blastomeryx borealis*, is found at both localities, "a fact which indicates some important difference in the horizon, either topographically or epochal."[5]

NORTH DAKOTA.

WHITE RIVER BEDS.

Our present knowledge of the existence, characteristics, and distribution of Neocene deposits in this State is limited to the following letter from Prof. E. D. Cope, read before the American Philosophical Society, September 21, 1883,[6] dated Sully Springs, Dakota, September 7, 1883:

I have the pleasure to announce to you that I have within the last week discovered the locality of a new lake of the White River epoch, at a point in this Territory nearly 200 miles northwest of the nearest boundary of the deposit of this age hitherto known. The beds, which are unmistakably of the White River formation, consist of greenish

[1] Am. Jour. Sci., 3d ser., vol. 11, pp. 126–128.
[2] U. S. Geol. Surv. Terr., 1884, vol. 3, book 1, p. XXVI.
[3] Proc. Am. Philos. Soc., 1877–'78, vol. 17, pp. 219–223.
[4] Cope. Proc. Am. Philos. Soc., 1885–'86, vol. 23, p. 359.
[5] Cope, Am. Nat., 1886, vol. 20, p. 369.
[6] Proc. Am. Philo. Soc., 1883, vol. 21, pp. 216–217.

sandstone and sand beds of a combined thickness of about 100 feet. These rest upon white calcareous clay, rocks, and marls of a total thickness of 100 feet. These probably also belong to the White River epoch, but contain no fossils. Below this deposit is a third bed of drab clay, which swells and cracks on exposure to weather, which rests on a thick bed of white and gray sand, more or less mixed with gravel. This bed, with the overlying clay, probably belongs to the Laramie period, as the beds lower in the series certainly do.

The deposit as observed does not extend over 10 miles in north and south diameter. The east and west extent was not determined.

The fossils, which indicate clearly the age of the formation, are the following:

Pisces:	
Rhineastes, sp. nov; *Aminurus*, sp. nov	2
Lacertilia:	
sp. indet	1
Testudinata:	
Trionyx sp; *Trionyx* sp; *Stylemys* sp	3
Rodentia:	
Castor sp	1
Carnivora:	
Galecynus gregarius; *Hoplophoneus* sp; ? *Hoplophoneus* sp	3
Perissodactyla:	
Aceratherium sp; *Aceratherium* sp; *Anchitherium* sp	3
Artiodactyla:	
Elotherium ramosum; *Hyopotamus* sp; *Oreodon* sp; *Oreodon* sp; *Oreodon* sp; *Leptomeryx* sp; *Hypertragulus* sp	7
Total species	20

Interesting features of the above catalogue are: The absence of *Hyracodon* and *Poebrotherium*, so abundant in the beds of this age elsewhere; the presence of fishes, not hitherto detected in them; and the presence of the genus of tortoises, *Trionyx*. The latter genus has not hitherto been found in our western lacustrine beds of later than Eocene age, while they are abundant in our modern rivers. This discovery partially bridges the interval. The same is true of the fishes mentioned, which represent the order *Nematognathi*.

SOUTH DAKOTA.

WHITE RIVER GROUP.

During early Miocene or Oligocene times the triangular area formed by the Cheyenne and Missouri rivers and the Nebraska State line was occupied by the northern limb of a vast fresh water lake that extended southward and westward into Nebraska, Colorado, and Wyoming. To this sheet of water King has applied the name of Sioux Lake,[1] and has

[1] U. S. Geol. Ex. 40th Parallel, 1878, vol. 1, p. 451.

endeavored to demonstrate its contemporaneity with the "Pah-Ute" lake west of the Rockies. Its sedimentary formations now form the well known White River group, so strikingly displayed in the "Mauvaises Terres,"[1] and from which such vast quantities of vertebrate remains have been obtained.

The subdivision of this group into "beds," and the determination of the geographical distribution of each, has been done almost exclusively by Dr. F. V. Hayden. His generalized section,[2] constructed in 1857, must still be considered our most reliable source of information regarding the general stratigraphy of this region. Accordingly, that portion of it which relates to the Tertiary series is here given in full.

Vertical section, showing the order of superposition of the different beds of the Bad Lands of White River, so far as determined.

		Subdivisions.	Localities.	
MIOCENE TERTIARY.	Bed H.	Gray and greenish gray sandstone, varying from a very compact structure to a conglomerate.	Bijou Hills, Medicine Hills, Eagle Nest hills.	20 feet.
	Bed G.	Yellowish gray grit, passing down into a yellow and light yellow argillo-calcareous marl, with numerous calcareous concretions and much crystalline material, like sulphate of baryta. Fossils: *Hipparion*, *Merychippus*, *Steneofiber*, etc.	Bijou Hills, Medicine Hills, Eagle Nest Hills, and numerous localities on south side of White River; also at the head of Teton River.	50 feet.
	Bed F.	Grayish and light gray rather coarse sandstone, with much sulphate of alumina (?) disseminated through it.	Along White River valley on the south side.	20 feet.
	Bed E.	Yellowish and flesh-colored indurated argillo-calcareous bed, with tough argillo-calcareous concretions containing *Testudo*, *Hipparion*, *Steneofiber*, *Oreodon*, *Rhinoceros*, etc.	Seen along the White River valley on the south side.	30 feet.
	Bed D.	Yellow and light yellow calcareous marl, with argillo-calcareous concretions and slabs of siliceous limestone, containing well preserved fresh-water shells.	On the south side of White River. Seen in its greatest thickness at Pianos Spring.	40 feet.
	Bed C.	Light gray siliceous grit, sometimes forming a compact fine-grained sandstone.	Seen on both sides of White River; also at Ash Grove Spring.	20 feet.
	Bed B.	A reddish, flesh-colored, argillo-calcareous, indurated material, passing down into a gray clay, containing concretionary sandstone, sometimes an aggregate of angular grains of quartz, underlaid by a flesh-colored argillo-calcareous indurated stratum containing a profusion of mammalian and chelonian remains. Turtle and Oreodon bed.	Revealed on both sides of White river and throughout the main body of the Bad Lands.	80 feet.
	Bed A.	Light gray calcareous grit, passing down into a stratum composed of an aggregate of rather coarse granular quartz, underlain by an ash-colored argillaceous indurated bed with a greenish tinge. Titanotherium bed.	Best developed at the entrance of the basin from Bear Creek. Seen also in the channel of White River.	50 feet.
Cretaceous system.				

[1] For a vivid description of this region see Owen's Geol. Surv. Minn., Wis., etc., 1852, pp. 196–197.
[2] Proc. Acad. Nat. Sci. Phila., 1857, p. 153.

The White River group includes but the first four "beds" of this section,[1] while bed E, and those above it, belong to the Loup Fork group, to be noticed hereafter.

The manner in which these beds are exposed along Sage and Bear creeks, tributaries of the Cheyenne, as well as along White River in the vicinity of Wounded Knee Creek, is clearly stated in the itinerary of Hayden's journey[2] from Bear Peak to Fort Randall, on the Missouri.

Much detailed information is given regarding the two lower beds of his group, which, it will be observed, must necessitate slight modifications in the thickness given to these beds in the general section.

Exposures about 15 miles above the mouth of Bear Creek, on the left side of the Cheyenne, present the following strata:[3]

		Ft.	*In.*
Titanotherium bed.	1. Light gray indurated clay	6	
	2. Seams of gray sandstone	1	6
	3. Ash-colored plastic clay with a greenish tinge, and a pinkish band of fine grit at the base	30	

Between the Cheyenne and White rivers both Titanotherium and Oreodon beds are exposed. The following section[4] shows their main characteristics:

		Ft.	*In.*
Bed	1. Flesh-colored marl	10	
	2. Bluish laminated clay with a yellowish tinge	2	
	3. Flesh-colored indurated marl	25	
Bed	4. Light gray indurated argillaceous grit, forming conglomerate of nodules of clay	4–6	
Oreodon bed	5. Flesh-colored indurated grit	20	
	6. Bluish argillaceous grit		10
	7. Flesh-colored marl	4	
	8. Argillaceous grit		6–12
	9. Flesh-colored marl	30	
Titanotherium bed.	10. A light gray calcareous grit passing down into an ash-colored clay, with micaceous and siliceous sandstone at base tinged with a purplish hue	80–100	
	11. Cretaceous beds Nos. 5 and 4.		

Still farther southward the White River beds gradually disappear beneath the overlying Loup Fork deposits, showing in many instances that the upper surface of the former must have been extensively eroded before the deposition of the latter.[5]

No attempt will be made in this place to discuss or even to mention by species, genus, or family the vast assemblage of animals which have left the record of their existence in the mud of this bygone lake. For information on this subject the reader should refer to the following works of Dr. Leidy: "Description of the Remains of Extinct Mam-

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[1] U. S. Geol. Surv. Terr., 1884, vol. 3, Tertiary Vertebrata, p. 14.

[2] Trans. Am. Phil. Soc., new series, 1863, vol. 12, pp. 29–33.

[3] Ibid., p. 29.

[4] Ibid., p. 31.

[5] Trans. Am. Phil. Soc., 1863, new series, vol. 12, p, 33, and Jour. Acad. Nat. Sci. Phila., 1869, 2nd series, vol. 7, p. 12.

malia and Chelonia, from Nebraska Territory,"[1] "The Ancient Fauna of Nebraska, or a Description of Remains of Extinct Mammalia and Chelonia from the Mauvaises Terres of Nebraska," and "The Extinct Mammalian Fauna of Dakota and Nebraska."[2]

Though these beds are so well developed and so well characterized by numerous fossil remains, geologists and paleontologists alike have assigned them to different horizons in the Tertiary series. In the earlier publications of Leidy & Owen,[3] they were known as Eocene beds or deposits; later the unanimous verdict was that these same beds are more properly classed as Miocene;[4] still later Cope reversed this upward tendency, showing that several forms were closely allied to the so-called Oligocene[5] forms of Europe; and lastly Scott maintains that some "newly discovered forms strongly confirm the view that the White River beds correspond to the Lower Oligocene of Europe. They largely increase the number of known correspondences between the White River formation on the one hand and the Uinta and Bridger on the other."[6]

LOUP FORK GROUP.

The geographical distribution and lithological characters of the various beds of this group are briefly stated in Hayden's generalized section given on p. 291. It will receive little attention here, since its greatest development and most interesting features are displayed farther south in Nebraska. Yet there are a few outliers of this group some distance east from the typical Mauvaises Terres that must be noticed in this place, viz, Bijou Hills. Concerning them Hayden[7] remarks:

In the summer of 1853 I ascended one of these hills nearest the river in company with my friend Mr. Meek, and from a denuded portion near the summit we obtained several fragments of jaws and teeth belonging to two new species of mammals, which have been described by Dr. Leidy as *Hipparion speciosum* and *Merycadus necatus*. In the autumn of 1856 I discovered on the denuded summits of the same hills *Hipparion occidentalis* and two new genera, *Leptarcus primus*, an animal allied to the racoon, and *Merychippus insignis*, a remarkable new genus of ruminant horse. These remains have all been described by Dr. Leidy in the proceedings of the Philadelphia Academy.

The summits of these hills are capped with a bed of bluish gray, compact rock, quite variable in its character. Sometimes it is very fine, not unlike a metamorphic rock; again it is composed of an aggregation of particles of granular quartz, inter-

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[1] Owen's Geological Survey of Minn., etc., 1852, pp, 535-572.

[2] Smithsonian Contr. to Knowl., 1854, vol. 6, Art. 7. Jour. Acad. Nat. Sci., Phila., 1869, 2d ser. vol. 7. Marsh has also described several new species from the Mauvaise Terres. See Am. Jour. Sci., 1874, 3d ser., vol, 7, p. 534; 1875, vol, 9, p. 240; 1887, vol. 34, pp, 328, 330, 331, 1890, vol. 39, pp. 523, 524; 1890, vol. 40, p. 179; 1891, vol. 12, p. 81. Scott and Osborn give no definite localities to the forms they describe or discuss from the White River group. Bull. Mus. Com, Zool., Harv. Coll., 1890, vol. 20, No. 3.

[3] Owen's Geol. Surv. Minn., etc., 1852, pp. 199, 539, and Smithsonian Contr. to Knowl., vol. 6, art. 7.

[4] F. V. Hayden: Proc. Phila. Acad. Nat. Sci., 1857, p. 153, and Trans. Amer. Phil. Soc., new series, 1863, vol. 12, p. 105.

[5] Amer. Nat., 1887, vol. 21, p. 456.

[6] Princeton Col. Bull., Nov., 1890, vol. 2, pt. 4, p. 75.

[7] Proc. Acad. Nat. Sci. Phil., 1857, p. 157.

spersed with a few small water worn pebbles; then a coarse gray somewhat friable sandstone. Farther into the interior, capping the summit of the long hill, this rock may be seen in places 20 to 30 feet in thickness. The calcareous grits and marls underneath may be subdivided in descending thus:

First. Yellowish gray grit, with compact fine calcareous concretions.

Second. Yellowish white calcareous marl, containing great quantities of the comminuted fragments of bones.

Third. Compact whitish calcareous clay, with a few vertebrate remains and concreting limestone. The aggregate thickness of these beds I could not determine, as the sides of the hill were for the most part covered with a surface deposit of considerable thickness, sustaining a good growth of vegetation.

NEBRASKA.

TERTIARIES OF WHITE AND NIOBRARA RIVERS.

Stratigraphy.—Under South Dakota we have given Dr. Hayden's section of the Loup Fork and White River groups as they are exposed along White River and in that state generally. For convenience in reference we here insert the same author's "vertical section showing the order of superposition of the different beds of the Tertiary basin of White and Niobrara rivers."[1]

		Subdivisions.	Localities.	Estimated thickness.
POST-PLIOCENE.		Yellow siliceous marl, similar in its character to the loess of the Rhine, passing down into variagated indurated clays and brown-yellow fine grits; contains remains of extinct quadrupeds, mingled with those identical with recent ones; also a few mollusca, mostly identical with recent species so far as determined.	Most fully developed along the Missouri River, from the mouth of the Niobrara to St. Joseph; also in the Platte Valley and on the Loup Fork.	300 to 500 feet.
PLIOCENE.	Bed F.	First, dark gray or brown sand, loose, incoherent, with remains of mastodon elephant, etc.; second, sand and gravel incoherent; third, yellowish white grit, with many calcareous, arenaceous concretions; fourth, gray sand, with a greenish tinge; contains the greater part of the organic remains; fifth, deep yellowish red arenaceous marl; sixth, yellowish gray grit, sometimes quite calcareous, with numerous layers of concretionary limestone from 2 to 6 inches in thickness, containing fresh water and land shells, *Succinea, Limnea, Paludina, Helix*, etc., closely allied and perhaps identical with living species; also much wood of coniferous character.	Covers a very large area on Loup Fork from the mouth of North Branch to the source of Loup Fork; also in the Platte Valley. Most fully developed on the Niobrara River, extending from the mouth of Turtle River 300 miles up the Niobrara. Also on Bijou Hills and Medicine Hills. Thinly represented in the valley of White River.	300 to 400 feet.
MIOCENE.	Bed E.	Usually a coarse grained sandstone, sometimes heavy bedded and compact; sometimes loose and incoherent; varies much in different localities. Forms immense masses of conglomerate; also contains layers of tabular limestone with indistinct organic remains; very few mammalian remains detected, and those in a fragmentary condition. Passes gradually into the bed below.	Most fully developed along the upper portion of Niobrara River and in the region around Fort Laramie. Seen also on the White River and on Grindstone Hills.	180 to 200 feet.
	Bed D.	A dull, reddish brown, indurated grit, with many layers of silico-calcareous concretions, sometimes forming a heavy-bedded, fine-grained sandstone; contains comparatively few organic remains.	Niobrara and Platte rivers; well developed in the region of Fort Laramie; also in the valley of White River. Conspicuous and composing the main part of the dividing ridge between White and Niobrara rivers.	350 to 400 feet.

[1] Proc. Phila. Acad. Nat. Sci., 1858, p. 148.

		Subdivisions.	Localities.	Estimated thickness.
MIOCENE.	Bed C.	Very fine yellow calcareous sand, not differing very materially from bed D, with numerous layers of concretions and rarely organic remains passing down into a variegated bed consisting of alternate layers of dark brown clay and light gray calcareous grit forming bands, of which I counted twenty-seven at one locality, varying from 1 inch to 2 feet in thickness.	White River, Bear Creek, Ash Grove Spring, head of Cheyenne River. Most conspicuous near White River.	50 to 80 feet.
	Turtle and Oreodon bed B.	A deep flesh-colored argillo-calcareous indurated grit; the outside, when weathered, has the appearance of a plastic clay. Passes down into a gray clay with layers of sandstone, overlaid by a flesh-colored argillo-calcareous stratum, containing a profusion of mammalian and chelonian remains. Turtle and Oreodon bed.	Old Womans Creek, a fork of Cheyenne River; also on the head of the South Fork of the Cheyenne; most conspicuous on Sage and Bear creeks and at Ash Grove Spring. Well developed in numerous localities in the valley of White River.	80 to 100 feet.
	Titanotherium bed A.	Light gray fine sand, with more or less calcareous matter, passing down into an ash-colored plastic clay, with large quantities of quartz grains disseminated through it, sometimes forming aggregated masses like quartzose sandstone cemented with plaster; then an ash-colored clay with a greenish tinge, underlaid at base by a light gray and ferruginous siliceous sand and gravel with pinkish bands. Immense quantities of silex in theform of seams all through the beds. Titanotherium bed.	Old Woman's Creek; also in many localities along the valley of the South Fork of Cheyenne. Best development on Sage and Bear creeks. Seen at several localities in the valley of the White River.	80 to 100 feet.
CRETACEOUS.	Nos. 4 and 5.	Cretaceous beds 5 and 4, with their usual lithological characters and fossils.	Exposed underneath the Tertiary beds on the South Fork of Cheyenne and its southern branches, also in the White River Valley near its source.	

Concerning the characteristics and distribution of the beds mentioned in the above table Hayden[1] gives the following itinerary notes:

Ascending the Loup Fork, the first indication we observed of this formation was near the old Pawnee village, about 8 miles above the mouth of Beaver Creek. Here we found, near the bed of the river, large masses of pebbly conglomerate, cemented with a calcareous grit, which undoubtedly belongs to bed C of the vertical section. The distant hills on either side of the river are covered with a considerable thickness of Pliocene and post-Pliocene beds.

Near the mouth of North Branch the following section of the strata in descending order was observed:

	Feet.
(*d*) Yellowish brown laminated argillaceous grit; effervesces briskly with muriatic acid.	
(*c*) Similar to the bed above, but of deeper color, more compact, containing a greater per cent of clay, with numerous calcareous concretions disseminated through it	70–100
(*b*) Light brown clay filled with whitish particles like magnesia	70
(*a*) Gray coarse sand forming a heavy bedded sandstone reaches to the water's edge	30

In the upper beds of the above local section fragments of mammalian and chelonian remains were found, and all but the lower bed, which is bed E of the vertical

[1] Proc. Phila. Acad. Nat. Sci., 1858, pp. 150–152.

section, are Pliocene. Lieut. Warren explored the North Branch 30 miles above its mouth, and met with a similar series of beds, containing the same organic remains. Above the mouth of North Branch, bed "a" of the local section appears in the form of large ledges, of light gray arenaceous limestone, filled with silicified tubes like the stems of plants and seeds resembling cherry-stones. On the distant hills, when exposed by erosion, I found numerous fragments of bones and teeth of *Hipparion*, *Cervus*, etc.

About longitude 99° we enter the desolate region of the sand hills. I measured the height of these hills at one locality and found them to be 230 feet above the bed of Loup Fork, and composed of Pliocene beds as a base, then a thin bed of post-Pliocene marl overlaid by a great thickness of loose incoherent sand and gravel derived from the erosion of the different Tertiary beds. The whole country from the head of Loup Fork presents a similar charactêr, consisting of movable sand hills, the true Tertiary beds being being very seldom exposed. On the South Branch the streams cut through the following Pliocene strata:

	Feet.
(*c*) Yellowish brown grit containing *Mastodon mirificus* (Leidy).	
(*b*) White chalky stratum, charged with fresh-water and land shells of the genera *Helix, Planorbis, Limnea*, etc., probably identical with recent species	3
(*a*) Heavy bedded gray sandstone	8–10

From the head of Loup Fork to the Niobrara River the whole country is covered with this superficial deposit of sand, which is blown by the wind into ridges and high conical hills, rendering traveling quite difficult. On reaching the Niobrara, we find bed E quite well developed; also a full series of Pliocene beds filled with Mammalian remains. Passing up the Niobrara about 50 miles the Pliocene strata gradually disappear, and the whole country is occupied by the upper Miocene beds E and D. A butte near this point affords a fine detailed section of the gray sandstone bed E, which measured from the base with a pocket level I found to be 166 feet in height. It is composed mostly of gray, coarse grit, sometimes quite incoherent, containing many layers of concretionary sandstone. On the summit is a thin bed of shelving limestone, similar to that containing organic remains at Pinau's spring, though probably not holding the same geological position. Indistinct traces of fresh-water shells and numerous remains of fish scales, vertebrates, etc., were visible in the tabular masses. It seems to form the upper portion of bed E, and to vary much in its character in different localities. It presents every variety, from a translucent chalcedony to a fine grained sandstone or compact limestone. and furnishes those chalcedonic masses which meet the eye of the traveler so often and have the appearance of erratic blocks. Farther from the river, and holding a higher position than the summit of the Butte, are thin beds of yellow and yellowish gray calcareous grit, undoubtedly of Pliocene age, containing numerous fragments of teeth and finely preserved bones of the mastodon and elephant. As we pass up the river the gray sandstone, bed E, presents a great variety of lithological characters. Sometimes it forms a coarse conglomerate; then an aggregate of grains of quartz cemented by calcareous matter.

About 60 miles above the point where we struck the Niobrara, bed D, of the vertical section, is revealed to the water's edge. The dip of the strata toward the east gradually brings this bed to view quite conspicuously. It is composed of flesh-colored calcareous grit, and the eroded material of this bed gives to the country a dull reddish yellow tint. It also contains many layers of silico-calcareous concretions forming large ledges which break into irregular masses on exposure. The more incoherent material has much the color and appearance of that composing the Turtle bed at Bear Creek, but contains much less clay. It does not differ materially from its equivalent in the White River valley, of which Eagle Nest Butte forms a part.

These notes embody the greater part of all that is known concerning the stratigraphic geology of the Tertiary in Nebraska. The limited area along Lodge Pole Creek in extreme western Nebraska has been reported upon by Cope,[1] as stated under Colorado, while bed D, referred to above, has been studied by Mr. R. S. Hill.[2] Numerous articles have, to be sure, appeared in various reports and periodicals, giving in some instances fairly definite information regarding localities where vertebrate remains have been found, but this is still insufficient to form a basis for stratigraphic generalizations.

The geological maps of Hayden, Hitchcock, and McGee represent all the Tertiaries of Nebraska by one tint, since the areal distribution of the various subdivisions has not been determined. The same method must be followed in the map accompanying this report.

White River group.—The White River group as first defined[3] included beds A–E of the above section, while the Loup Fork group included only a bed F; the former was estimated to have a thickness of "1,000 feet or more," while the latter was given as "300 to 400 feet."

LOUP FORK GROUP.

The taxonomy and general features of the White River group have already been given under South Dakota, where its typical development is attained. Like features of the Loup Fork group will for a similar reason be now presented. Bed F (Hayden, 1858, or "Loup River beds," Meek and Hayden, 1861) was formerly regarded as "Pliocene Tertiary," not only on account of the unconformity between its strata and those of the supposed Miocene below, but also because its fauna was found to be "specifically distinct from, yet intermediate between that of the Miocene and our present period."[4]

This view was unchallenged until 1873, when Cope[5] wrote:

The Loup Fork beds, from the greater proportion of the existing genera which they contain, display a resemblance to the European Pliocene, but they differ strikingly in the greater number of horses and camels which they contain. The smaller percentage of existing genera in the Loup Fork beds, with the presence of an oreodont (*Merychyus*), indicates that these also should be placed anterior to the Pliocene of France.

Later, in 1875[6] he found "that the facies of the fauna of this horizon throughout the West, including as it does *Amphicyon*, *Dicrocerus*, *Hippotherium*, *Aceratherium*, *Mastodon* allied to *M. angustidens*, etc., more nearly resembles the upper Miocene of Europe than the Pliocene of that continent." Marsh,[7] however, that same year, concluded "that

[1] Bull. U. S. Geol. and Geog. Surv. Terr., No. 1, 1874, pp. 10 et seq.
[2] Am. Nat., 1880, vol. 14, p. 141.
[3] Proc. Acad. Nat. Sci., Phila., 1861, vol. 13, p. 433.
[4] Proc. Phila. Acad. Nat. Sci., 1858, p. 157. See also Proc. Phila. Acad. Nat. Sci., 1861, p. 435.
[5] U. S. Geol. and Geog. Surv., Colo., 1873, p. 462.
[6] Proc. Phila. Acad. Nat. Sci., 1875, p. 257.
[7] Am. Jour. Sci., 3d ser., 1875, vol. 9, p. 51.

most of the upper beds (D and E), 500 feet at least in thickness, which were called Miocene by Prof. Hayden," should, from their fossil contents, be regarded as Pliocene. Cope,[1] in 1876, gave a list of Loup Fork genera, showing their stratigraphic position in Europe. This confirmed his views already expressed. In 1879 he instituted a comparison of Loup Fork genera on the one hand and Falunian and Oeningian on the other. The conclusion reached by so doing was "the facies of the Loup Fork horizon is then a compound of that of the Falunian and Oeningian or Middle and Upper Miocene."[2] In the same article he subdivides the Loup Fork group formation into two divisions on paleontological grounds, under the names of Ticholeptus and Procamelus beds. The former name was first applied to certain deposits already described on Deep River, Montana, which were recognized as having more affinity to the White River group than does the "True Loup Fork."

The same subdivisions obtain in vol. 3 (1884) of the Final Reports of Hayden's Survey. It is there observed that bed D of Hayden's section is the Nebraskan representative of the Ticholeptus bed.[3] In a brief article in the American Naturalist (1886) entitled "The vertebrate fauna of the Ticholeptus Beds," Prof. Cope states that the horizon represented "is intermediate in all respects between the Middle and Upper Miocene formations of the West, as represented by the John Day and Loup Fork beds."[4] The same idea is carried out in his paper[5] entitled "The Mesozoic and Cænozoic Realms of the Interior of North America," where the Ticholeptus division of the Miocene is given equal taxonomic importance with the White River or Loup Fork, though its greater affinities to the latter are clearly pointed out.

Prof. Marsh, as we have seen, in 1875 included the greater part of beds D and E of Hayden's section in the Pliocene, i. e., in the Loup Fork or Niobrara formation. By referring to the various papers of this author, cited below, it will be seen that he, although making no special attempt to maintain his position, cites all Loup Fork or Niobrara species as from a Pliocene horizon. Indeed, in a letter dated March 11, 1891, he writes: "The Loup Fork or Niobrara group should be classified as Pliocene and not Miocene."

Profs. Scott and Osborne, in Bull. Mus. Comp. Zool., 1890, vol. 20, No. 3, p. 65, refer the "Loup Fork mammals" to the "Upper Miocene."

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[1] U. S. Geograph. Surv. W. 100th Mer., 1877, vol. 4, pt. 2, p. 364.
[2] U. S. Geol. and Geog. Surv. Terr., Bull. 5, No. 1, 1879, pp. 46-47.
[3] Op. cit., p. 18.
[4] Vol. 20, p. 367.
[5] Am. Nat., 1887, vol. 21, p. 455.

The conclusions of the foregoing discussion may be represented diagrammatically as follows:

Miocene.					Pliocene.	Hayden's section of 1858.
Bed A.	Bed B.	Bed C.	Bed D.	Bed E.	Bed F.	
White River Miocene					Loup River Pliocene.	Meek and Hayden, 1861.
White River Miocene			Niobrara or Loup Fork Pliocene			Marsh, 1875.
White River Miocene					Loup Fork Miocene?	Cope, 1873.
White River Miocene (Oligocene)			Loup Fork Miocene			Cope, 1884.
White River Miocene (Oligocene)			Ticholeptus Miocene.	Loup Fork Miocene		Cope, 1887.
White River Lower Oligocene)			Loup Fork Miocene			Scott and Osborn, 1890.

It seems unnecessary in this place to go into details regarding the genesis of this group. It, like the White River, John Day, Green River, or most of the Tertiary formations of the "interior," resulted from successive sedimentation in an extensive sheet of fresh water. To this, King has given the name "Cheyenne Lake."[1] Its great area has been commented upon by Hayden, King,[2] and Marsh.[3] though most of their personal observations were made to the north of Indian Territory or even Kansas. The labors of R. T. Hill[4] in Texas and Indian Territory have demonstrated what before was but hypothetical, viz, that "Cheyenne Lake" (or whatever name one may choose to call it) extended southward from South Dakota well into the State of Texas. Authors of geological maps embracing this part of the country have as yet been too conservative with their "Neocene" tints. In fact, the area of this particular basin ought nearly to be doubled.[4]

PLIOCENE—EQUUS BEDS.

The Pliocene formation (Equus beds), as understood by Cope, has not yet been properly discriminated from the underlying Loup Fork Miocene within the boundaries of the State. The faunas of the two "have probably been confounded." This is the conclusion arrived at by Cope from a process of reasoning entirely analogous to that used in this essay in determining that both Miocene and Pliocene marine forms are present in the Upper Tertiaries of South Carolina, because the two have since their original deposition been intermingled, and not because the two were contemporary or represent a transition from one epoch to another. In Oregon and extreme southwest Texas he finds the Equus beds, or Pliocene fauna, pure and simple, while in Colorado and New Mexico the Loup Fork fauna presents no Equus-bed features.

[1] U. S. Geol. Explor. 40th parallel, 1878, vol. 1, p. 455.

[2] The Equus beds (Pliocene of Cope) are apparently classified by King as deposits of his "Cheyenne Lake."

[3] Am. Jour. Sci., 1875, 3d ser., vol. 9, p. 52.

[4] Am. Nat., 1891, vol. 25, p. 49.

PALEONTOLOGY.

The first important paper on the paleontology of this State was that of Dr. Leidy in the proceedings of the Philadelphia Academy of Natural Sciences for 1858, entitled "Notice of Remains of Extinct Vertebrata, from the valley of the Niobrara River, collected during the exploring expedition of 1857, in Nebraska, under the command of Lieut. G. W. Warren, Top. Eng., by Dr. F. V. Hayden, geologist of the expedition."

In this paper he described twenty-three new mammalian forms, and determined the identity of four more, with species already described from the Bijou Hills horizon of South Dakota. The same author's memoir on the extinct mammalian fauna of Dakota and Nebraska, published in volume 7 of the Journal of the Philadelphia Academy of Natural Sciences, 1869, sets forth clearly all that was known regarding the paleontology of this class of animals from this State up to that date.[1]

Since then Marsh[2], Cope,[3] Scott and Osborn,[4] and Leidy[5] have occasionally described new forms from this State, most of which are from near Loup Fork and Niobrara rivers, though the avoidance of mention of definite localities is extremely noticeable.

KANSAS.

In the year 1861, Prof. Newberry[6] described the "Tertiary basin of the Arkansas" as it appears along a section from "Pawnee Fork to crossing of Cimarron" and suggested its probable stratigraphic continuity with similar beds in Nebraska.

In 1876 Mudge[7] described the lithological features of this formation in the western part of the State, and determined its thickness on Prairie Dog Creek, Norton County, to be 400 feet. Two years later he mapped[8] the same and estimated its total thickness to be not less than 1,500 feet.

Cope, Marsh, Scott, and Osborn have from time to time described or identified Loup Fork vertebrate remains from various localities within this State, especially from Norton and Phillips counties.

Robert Hay has recently published two important reports which include discussions of the Tertiary geology of Kansas. The first may be found in the Sixth Biennial Report of the Kansas State Board of Agriculture, 1889, entitled "Northwest Kansas; Its Topography, Geology, Climate, and Resources."

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[1] For a general idea of the vegetation of the Loup Fork and White River groups, see "Sketches of the Physical Geography and Geology of Nebraska," 1880, pp. 225, 241, 242. Samuel Aughey.

[2] Am. Jour. Sci., 3d ser., 1871, vol. 2, pp. 41, 121, 124. Ibid., 3d ser., 1874, vol. 7, pp. 251, 252, 253. Ibid., 3d ser., 1875, vol. 9, pp. 246. Ibid., 3d ser., 1877, vol. 14, pp. 251, 252, 254. Ibid., 3d ser., 1887, vol. 34, p. 326.

[3] See "Paleontological Bulletins" Nos. 14, 15, and 16; no definite localities given. Also, Bull. U. S. Geol. Surv. Terr., 1881, vol. 5, No. 1, p. 176. Ibid., 1881, vol. 5, No. 2, pp. 370–389. American Naturalist, 1890, vol. 24, pp. 950, 951, 1067. Ibid., 1891, vol. 25, p. 48.

[4] Bull. Mus. Comp. Zool. Harvard Coll., 1890, vol. 20, No. 3.

[5] U. S. Geol. Surv. Terr., 1873, vol. 1, pp. 227, 252, 260.

[6] Ives' Colorado Expl. Exped., pt. 3, Geol. Rep., p. 109.

[7] Bull. U. S. Geol. and Geog. Surv. Terr., vol. 2, pp. 212–213.

[8] First Bienn. Rep. Kansas Board of Agric., 1878, p. 47.

The Tertiary group is here divided into "Miocene grit" which "is considered to be the Loup Fork of Nebraska," and the "Pliocene marl" which is "probably identifiable" with the Equus beds.

Contrary to the observations of Mudge, Hay finds that the Tertiary beds have a decidedly eastern dip. Moreover, the total thickness of these beds along a section from Glasco to the Colorado line he represents as being not over 500 feet.

The second report by Hay constitutes Bulletin 57 of the U. S. Geological Survey, 1890—"A Geological Reconnaissance in Southwestern Kansas." In this report he says:

Two apparently distinct formations of Tertiary age have been found in all parts of the region explored. Occurring in isolated patches in the eastern part of the area, they are more largely developed as we proceed westward, where they are of such thickness and so related to the previous erosion as to completely hide all other formations from view. Feeling sure of the identity of these formations with similar deposits in northwestern Kansas, I am inclined to use the nomenclature of Prof. Cope, and call these respectively Loup Fork (Miocene) and the Equus beds (Pliocene). But having regard to the extensive area over which the beds are developed and the comparative infrequency of fossils in the latter formation, I deem it best to designate them by purely provisional names and leave others to fix them more specifically when they have been examined over the whole region of the Great Plains and their subdivisions made out. These Tertiary formations then we name in ascending order: (*a*) The Tertiary grit; (*b*) The Tertiary marl.

The Tertiary grit.—The first named division is made up of a mortar-like substance, composed of lime and sand which frequently incloses pebbles of quartz, feldspar, diorite, greenstone, etc., and sometimes contains fine siliceous volcanic matter. Again, the limy matter almost disappears and a coarse, pebbly conglomerate is found. This is stratigraphically above the limy beds. The under surface of the Tertiary grit is very irregular owing to the unevenness of the Permian, Jura-Trias, and Cretaceous surfaces upon which it has been laid down. For its geographical distribution, see map accompanying Hay's report.

The Tertiary marl is arenaceous, argillaceous, and calcareous in texture, and is in most cases readily distinguishable from the mortar grit and the loess. Its color is very uniform. It is a buff marl everywhere.

This formation rests upon the eroded surfaces of the Permian, Jura-Trias, Cretaceous, and Tertiary grit.

It forms the dead level of the high prairie between the great rivers, thinning off toward their valleys, but following the slope of the tributary dales. This thickening on the high prairie is manifest in almost every county—Barber, Pratt, Edwards, Meade, Ford, Hamilton, Seward, Scott, Graham, Norton—from Indian Territory to the Nebraska line. Wells pierce it in most of these counties over 100 feet, and in Meade County and in Graham from 140 to 180 feet, before the grit is reached.

For its areal distribution see map accompanying Hay's report.

Mudge[1] and Hay[2] mention the occurrence of mastodon, rhinoceros, turtle, and other bones in beds of the Loup Fork horizon. The former, however, mentions having found a three-toed horse in a deposit but 10

[1] Bull. U. S. Geol. Surv. Terr., vol. 2, p. 213.
[2] Bull. U. S. Geol. Surv., No. 57, 1890, p. 34.

feet above the Cretaceous, in Ellis County, which may, in his opinion, denote a lower horizon for that locality. The occurrence of *Limnophysa caperata* is noted by Hay from near Kiowa Creek. The new vertebrate species from this horizon have been described mainly by Profs. Cope,[1] Marsh,[2] Scott, and Osborn.[3]

INDIAN TERRITORY.

That Neocene beds exist in the northwestern prolongation of this Territory might readily be inferred from their distribution in adjacent parts of Kansas, New Mexico, and Texas. This inference is placed beyond cavil by the observations of Prof. J. S. Newberry, made in 1859.[4] He says:[5]

The geology of the region lying between the Enchanted Spring and Cottonwood Spring is similar throughout. The rocky basis of the country is formed by the lower Cretaceous sandstone, covered here and there with patches of white tufaceous Tertiary limestone.

A section at Cedar Spring shows the following strata:

		Feet.
(*a*) *Tertiary:*	1. White, chalky, tufaceous limestone, with hard, gray, compact bands	15
	2. Cream-colored, spongy, tufaceous limestone (similar to that on the Arkansas and Cimarron)	40
(*b*) *Cretaceous:*	1. Yellow fine-grained sandstone, etc.	

From Cedar Spring to McNees Creek the road passes over a high prairie underlain by Tertiary limestones. At McNee's Creek the Tertiary rocks are cut through and the Cretaceous series freely opened. No fossils were found here, but the rock is generally similar to that at Cedar Spring.

NEW MEXICO.

Galisteo group.—In New Mexico, the sedimentary Neocene formations may be classed in two groups, viz, the Galisteo group and the Santa Fe marls. The former term was, in a slightly modified form, applied by Dr. Hayden in 1869 to a series of sandstones outcropping along a creek by that name in the central part of the Territory. They were then regarded by him as of "Middle Tertiary"[6] age; later he correlated them with the Wasatch Eocene,[7] while Prof. Cope found them to be Cretaceous.[8] The observations of J. J. Stevenson show that two very different deposits may be referred to in Hayden's original description of this group. The one found on the south side of the creek he regards as Laramie,[9] while

[1] Bull. U. S. Geol. Surv. Terr., 1878, vol. 4, pp. 382–385, 392. Proc. Am. Philos. Soc., 1877–'78, vol. 17, pp. 224–225. (Am. Nat., 1880, vol. 14, p. 141). Am. Nat., 1886, vol. 20, p. 1045. Am. Nat., 1887, vol. 21, p. 1020.

[2] Am. Jour. Sci., 3d ser., 1887, vol. 34, p. 325.

[3] Bull. Mus. Comp. Zool., 1890, vol. 20, No. 3, p. 70.

[4] Exploring Expedition from Santa Fe to the Junction of Green and Grand Rivers, 1859. Macomb. (Published 1876.) Geology by Prof. Newberry.

[5] Op. cit., pp. 30, 31.

[6] Prelim. Field Rep. U. S. Geol. Surv., Colo. and N. Mex., 1869, p. 90.

[7] Am. Nat., 1878; vol. 12, p. 831.

[8] Proc. Phila. Acad. Nat. Sci., 1875, p. 360.

[9] U. S. Geog. Surv. W. 100th Mer.; Suppl. 1881, vol. 3, p. 159.

the other, lying to the north is of much later origin.[1] This author, accordingly, restricts the use of the term Galisteo group to the latter or newer deposits. A typical development of the same may be seen on Galisteo Creek, as follows:[2]

	Feet.
Trachyte breccia	150
Soft light gray sandstone	40

For some distance along the northern banks of this creek both these subdivisions are well exposed. Their areal distribution is represented on sheet 3, accompanying U. S. Geog. Surv. W. 100th Mer., Suppl., 1881, vol. III.

According to Stevenson, this group "can not be older than early Miocene or newer than early Pliocene."[3] It is seen to rest unconformably on the Dakota group; it was undisturbed by the trachytic outbursts which "caused frightful contortions of the Laramie beds."[1] Upon it lie the Santa Fe beds unconformably. It "certainly antedates the great flow of basalt."[3]

The Santa Fe marls were named and described at some length by Hayden in 1869.[4] He characterizes them as "mostly of a light cream color, sometimes rusty yellow, and sometimes yellowish white, with layers of sandstones varying in texture from a very fine aggregate of quartz to a moderately coarse pudding stone." They reach a great thickness north of Santa Fe in the Rio Grande Valley, from 1,200 to 1,500 feet,[5] and have a tendency to weather into the monumental and castellate forms of a Mauvaise Terre. Their areal distribution in this valley may be seen on sheet 3 of the work already referred to.

To the east of Rio Grande Valley, similar beds were long since observed by Dr. Newberry, "lying along the eastern bases of the mountains," and "filling depressions or excavations in the surfaces on which they were deposited."[6] Stevenson says: "This tufaceous limestone," which he refers to the Santa Fe group, occurs in many small patches at many localities south and east from the mountainous area. Evidently it is very thick in the Pecos Basin near the village of Pecos, and it was observed also on Vaca Creek at Las Colonias. Small patches were seen near Las Vegas, and an extended area lies between the Canadian hills and the Mora Canyon, reaching westward to beyond Fort Union. Fragmentary exhibitions were seen much farther north."[7]

The great development of these marls to the south and west of Santa Fe was first pointed out by Cope in 1883. He writes[8] as follows:

In descending the Rio Grande, beds appear on the west side of the river which strongly resemble those of Santa Fe. They extend along the eastern base of the

[1] U. S. Geog. Surv. W. 100th Mer.; Suppl. 1881, vol. 3, p. 161.
[2] Ibid., p. 159.
[3] Ibid., p. 162.
[4] Prelim. Rep. U. S. Geol. Surv., W. 100th Mer., 1869, p. 66.
[5] Prelim. Rep. U. S. Geol. Surv., Colo. and N. Mex., 1869, p. 69.
[6] Expl. Exped., Santa Fe, Junc. Green and Grand Rivers, 1859, p. 52.
[7] U. S. Geog. Surv. W. 100th Mer.; Suppl. vol. 3, 1881, p. 163.
[8] Proc. Am. Philos. Soc., vol. 21, pp. 308–309.

Magdalene Mountains, and as far south as Socorro, in considerable extent and thickness. South of Socorro they appear, but less extensively. The eastern part of the plain which lies between the Rio Grande and Mimbres Mountains is composed of beds of this age where cut by the grade of the Atchison, Topeka and Santa Fe Railroad, west of Hatch Station. West of the Mimbres Mountains the valley of the river of the same name is filled with débris of the bed of eruptive outflow which covered the country as far as traversed by the railroad from Deming to Silver City. Its age I could not ascertain.

A great display of Loup Fork formation is seen in the drainage basins of the heads of the Gila River. In traveling westward from Silver City, its beds first appear in the Valley of Mangus Creek, which enters the Gila from the east. Crossing the Gila, the mail route to the west passes through the valley of Duck Creek, which flows eastward into the river. Though bounded by eruptive hills and mountains and their outflows, the valley was once filled with Loup Fork beds, which have been extensively eroded, the principal exposures being on the north side of the valley, forming the foothills of the Mogollon Range. On the divide between the waters of the Gila and San Francisco rivers, the formation rises in bluffs of 300 feet elevation. The descent into the valley of the San Francisco brings to light a still greater depth of this deposit. The valley which extends from the canyon which incloses the river south from the mouth of Dry Creek to the Tulerosa Mountains on the north, and between the Mogollons on the east and the San Francisco Range on the west, was once filled with the deposits of a Loup Fork lake. This mass has been reduced by the erosive action of the San Francisco and its drainage to a greater or less extent, as it has been protected by basaltic outflows or not. When so protected the river flows through comparatively narrow canyons. Where the outflow is wanting, the valley of the river is wider, and the Loup Fork formations remain as wide grassy mesas, which extend to the feet of the mountain ranges.

As early as 1861 Newberry[1] expressed himself as being "inclined" to refer "the white tufaceous limestones of the Rio Grande Valley" to the same horizon as those of the Arkansas River basin. Hayden in 1869 says,[2] referring to his Santa Fe marls:

They are doubtless of the age of Upper Tertiary and synchronous with the upper beds of the White River group as seen along the North and South Forks of the Platte and near Cheyenne.

In 1874 the horizon of this formation was definitely established by Cope,[3] who found them to contain well known and characteristic Loup Fork vertebrate remains.

For information upon the paleontology of this group the reader should consult:

Leidy, Proc. Phila. Acad. Nat. Sci., 1872, p. 142.
Cope, Proc. Phila. Acad. Nat. Sci., 1874, pp. 147–152, 221–223.
Ann. Rep. Chief of Engineers, 1874, pt. 2, pp. 603–607.
Ann. Rep. Chief of Engineers, 1875, pt. 2, pp. 988–996.
Proc. Phila. Acad. Nat. Sci., 1875, pp. 256–258, 261, 262, 271.
Proc. Phila. Acad. Nat. Sci., 1876, p. 144.
U. S. Geog. Surv. W. 100th Mer., 1877, vol. 4, Paleont., pp. 20, 365.
Proc. Am. Philos. Soc., 1883, vol. 21, p. 309.
Proc. Phila. Acad. Nat. Sci., 1883, p. 301.

[1] Ives's Rep. on Col. Riv. of West, 1861, pt. 3, Geology, p. 109.
[2] Prelim. Rep. U. S. Geol. Surv. Col. and N. Mex., 1869, p. 90.
[3] Ann. Rep. Chief of Engineers for 1874, Appendix FF, p. 127.

COLORADO.

Formations of post-Eocene Tertiary age, so extensively developed on the Great Plains east of the Rockies, as well as in the Great Basin to the west, are found only in patches of limited dimensions within the boundaries of this State. Of these, some have been referred to this section of the geological scale from the evidence afforded by their fossil contents, while others are only provisionally so referred from supposed stratigraphic relations or lithological resemblance to deposits of known horizon. The former class is mainly confined to such areas as were occupied by Sioux and Cheyenne lakes as defined by King, while the latter includes the Monument Creek group in part, and the comparatively recent sedimentary deposits of the "parks" in the central and north central part of the State.

LOUP FORK AND WHITE RIVER GROUPS.

The watershed between Lodge Pole Creek and South Platte River presents not only surface accumulations and Laramie beds, but also deposits known from their fossil contents to belong to the Loup Fork and White River groups. These were traversed by Hayden in 1869 while en route from Cheyenne to Denver; but his notes[1] on the same are very meager. Their fossil contents and true stratigraphic relations were first brought to light by Prof. Marsh,[2] who in 1870 traced them from Little Crow Creek, past Chalk Bluffs, northward into Wyoming, collecting in the meantime characteristic Mauvaises Terres or White River fossils. In 1873 Prof. Cope visited this region, worked out the stratigraphy with considerable detail, and made extensive collections of vertebrate remains. His generalized section extending from Chalk Bluffs southward along Horse Tail Creek is given as follows:[3]

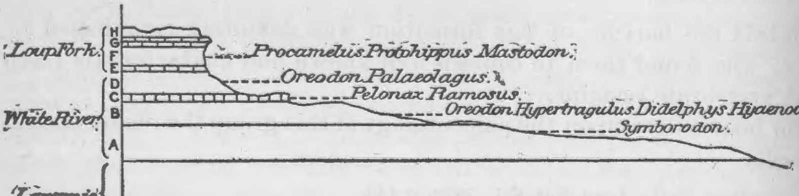

FIG. 43.—Section in eastern Colorado. (After Cope.)

Bed A is a white, calcareous, soft clay rock, breaking into angular fragments. Bed B has a similar mineral character, frequently with a red color of different obscure shades. Bed C is a sandstone of varying persistence. Bed D is a white, argillaceous rock like that of bed A. These four beds constitute the White River group as here represented, which, according to Cope, has at this place a thickness of several hun-

[1] 3d Ann. Rep. U. S. Geol. Surv. Terr., 1869, pp. 11-16.
[2] Am. Jour. Sci., 3d ser., 1870, vol. 1, p. 292.
[3] Rep. U. S. Geol. Surv. Terr., 1884, vol. 3, "Tertiary Vertebrata," p. 16.

dred feet. Above, and including beds E, F, G, H, is the Loup Fork group, which consists of alternating hard and soft layers of sandstone. Its thickness is given by Cope as not over 75 feet, of which the softer beds are the lower and vary in depth from 1 foot to 20. The superior strata are either sandstone conglomerate or a coarse sand of varying thickness, the former of which contains white pebbles and rolled mammalian remains.

Between the White River and Laramie groups there is but little angular unconformity,[1] while the line of demarkation between the White River and Loup Fork groups[2] is mainly determined upon paleontological evidence.

The sum total of the Tertiary strata here represented is, according to King,[3] about 700 feet, of which the "Miocene" includes the lower 300 feet,[4] while the "Pliocene" includes [5] the remaining 300 or 400 feet.

For information regarding the vertebrate paleontology of this region the following articles and reports by Prof. Cope should be consulted:

Third Notice of Extinct Vertebrata from the Tertiary of the Plains. Paleont. Bull. No. 16, August, 1873.

Synopsis of New Vertebrata from the Tertiary of Colorado, October, 1873. Printed as an advance extract from the 7th Ann. Rep. U. S. Geol. Surv., in which, however, it failed to appear.

Report on the Stratigraphy and Pliocene Vertebrate Paleontology of Northern Colorado. U. S. Geol. Surv. Terr., Bull. No. 1, 1874.

Report on the Vertebrate Paleontology of Colorado. 7th Ann. Rep. U. S. Geol. Surv. Terr., 1873, chapter 4, pp. 461–533.[6]

Tertiary marl.—Passing now in a southeasterly direction to the headwaters and tributaries of Republican River, Loup Fork beds, and those of more recent deposition are found well displayed as represented on the map. South of these in turn, the so-called "Tertiary marl," whose distribution in southern and southwestern Kansas Mr. Hay[7] has recently determined, doubtless passes across the state line and extends some distance up the Arkansas Valley[8] and over the broad plains on both sides; as yet, however, its distribution is wholly unknown.

PLIOCENE BEDS.

The Pliocene deposits of limited geographical extent southwest of Pueblo, according to Hills[9]—

Have their greatest development on the southern slope of the divide separating the drainage of the Muddy Branch of the Huerfano from Grape Creek and Wet

[1] King, Ex. 40th, Par., 1877, vol. 1, p. 409.

[2] Ibid., p. 426.

[3] Explor. 40th Par., 1877, vol 1, p. 410.

[4] Ibid., p. 411.

[5] Ibid., p. 426.

[6] The Princeton expedition of 1882 made a collection at Chalk Bluffs. Among the material so collected Scott discovered a new species of *Didelphys* (*D. pygmæa*). See Am. Jour. Sci., 3d ser., 1884, vol. 27, pp. 442–443.

[7] This is in accordance with Newberry's observations made in 1859 (Geol. Rep. Explor. Exped. from Santa Fe to Junction of Grand and Green rivers, 1859; pub. 1876, p. 25.)

[8] Robert Hay: Bull. No. 57, U. S. Geol. Surv., 1890.

[9] Proc. Colo. Sci. Soc., 1888, vol. 3, pt. 1, p. 161.

Mountain Valley. The maximum thickness of the beds was estimated to be between 700 and 800 feet. Loosely aggregated coarse conglomerates and sandstones predominate in the lower half of the series, and fawn or buff colored compact marls, sometimes sandy, in the upper half. The basal conglomerates are distinguished from the conglomerates of the Eocene in being composed of much coarser material and in containing a greater number of eruptive pebbles and small bowlders representing varieties common to the more recent eruptive outflows. One prominent bed of conglomerate situated some distance above the base of the series contains cleavable calcite as a cementing material. This bed is exposed on the south side of the divide near the Gradner and Silver Cliff Road.

The Pliocene exposures have but a limited geographical extent in the section of the country examined, being mostly confined to the vicinity of the Grape Creek divide and to small isolated areas of the basal conglomerate occurring in the neighborhood of Greaser Creek and Poison Canyon. A remnant was also observed resting on the eroded surface of the Colorado shales as far east as the southern of the two black buttes near Silver Mountain.

The deposits were traced northeasterly to the head of Cottonwood Canyon, and branches of Williams Creek north of Promontory Bluffs, and for a short distance southwest of Muddy Creek, but toward the northwest, or in the direction of Wet Mountain Valley, they soon disappear under accumulations of heavy glacial drift. This takes place near the top of the divide referred to, where the greatest thickness of Pliocene strata is developed, indicating that the beds underlie the valley for a considerable distance in the direction of Grape Creek and Silver Cliff. The inclination is observed nowhere more than a few feet in the hundred, less generally than the slope of the land surface in the Huerfano Valley. A nonconformity of about 33° exists between the basal conglomerate and the upturned Eocene on Poison Canyon and Greaser Creek, but elsewhere the points of contact with the Eocene are not exposed. Great nonconformity with the Colorado was observed on the southwest side of Muddy Creek.

Between Muddy and Turkey creeks there exists[1] detached deposits of volcanic ash consisting of flat, angular particles of glass, which rest directly on the marls of the Huerfano beds, and from the vertebrate remains found in them are evidently of Pliocene age. They are usually overlaid by beds of coarse sand clay, and in a few places by ancient deposits of travertine partly consolidated into limestone. The ash beds probably belong at the base of the series of marls and conglomerates exposed near the Grape Creek-Muddy Divide.

The search for mammalian remains in the deposits referred to the Pliocene age has met with the best success in the ash beds, from which have been taken a number of bones, including teeth and portions of the jaws of horses and camels, probably belonging to the Upper Pliocene.

Arkansas Park.—Between the Sawatch and Park ranges there is a broad valley along the upper Arkansas, to which the name Arkansas Park is sometimes applied. It was visited in 1869 by Dr. Hayden, who described its more recent geological formations as follows:

On the west side of the Arkansas Valley the recent Tertiary beds run up to and overlap the margins of the mountains. They are composed mostly of fine sands, arenaceous clays, and pudding stones, cream-colored arenaceous clays, and rusty-yellow marls, fine sand predominating. These beds weather into peculiar architectural forms somewhat like the "Bad Lands" of Dakota. Indeed, they are very nearly the same as the Santa Fe marls, and were doubtless cotemporaneous and dip at the same angle, 3° to 5°, a little west of north. The tops of the hills have all been planed down as if smoothed with a roller. I have called this group the Arkansas marls.

[1] Proc. Colo. Sci. Soc. 1889, pp. 220, 221.

They occupy the entire valley of the Arkansas. This valley is about 40 miles in length, and on an average about 5 to 10 miles in width. It might properly be called a park, for it is completely surrounded by mountains.[1]

In a later report[2] we learn that the upper end of this valley or park is about 5 miles below the mining town of Granite, and that terraces have been formed on both sides, showing the former existence of a lake in which were deposited from 800 to 1,200 feet of fine sediments during the Pliocene age.

Peale says:[3]

Above this valley the river is in a canyon or rather a canyon-like valley, until we get above Twin Lakes, when we have another valley reaching almost to the head of the stream. It is about 16 to 20 miles in length, and about 10 miles in width at the lower end. The whole valley, as far as could be determined, is underlaid by granite. At the lower end, back of Weston's ranch, in the terraces, there are modern Tertiary deposits, soft conglomerate sandstones.

Middle Park lake beds.—The lake deposits of Middle Park have thus been described by Marvin[4]:

After the Lignite there is a geological break, the beds next following being of far more recent age. These occur nowhere at the higher elevations, but occupy all the lower basins. In these and following the streams they usually form broad, low terraces, often much cut by the lateral streams into isolated pieces or long, even-topped tongues running out from the valley sides. Near the borders of these areas these beds often plainly show that their material was derived from the adjacent rock, often being of coarse granitic or schistose débris, or débris of the lignitic sandstone worked over; more frequently they are of finer sands and of characteristic marls of exceedingly white color. They are usually found resting on the Archean rocks, as along the Lower Grand, or on the softer shales of the Cretaceous, which, in former times, as now, afforded the weakest lines for erosion to work at most successfully, and which, therefore, occupy nearly all the lower areas. Along such lines, then, the streams cutting through these terraced beds constantly expose beneath them the more or less upturned edges of the Middle Cretaceous beds. They show a thickness of probably not over 300 feet at any point, though their vertical range seems to reach to or above 1,000 feet. A few dips of 10°, possibly 15°, were observed in them in the eastern portion of the park. Unfortunately no fossils were found in these beds, leaving a satisfactory determination of their age impossible, though they are undoubtedly very late, or, perhaps, post-Tertiary.

Concerning these deposits, Hayden remarks[5] that they are undoubtedly contemporaneous with the Arkansas and Santa Fé marls.

North Park lake beds.—In North Park Hague found extensive lake deposits lying in general nearly horizontally and rarely inclined at a higher angle than 4°.

They lie unconformably upon the lower rocks, resting in places against every formation from the Archean to the top of the Colorado group, and are seen in an undisturbed condition, resting against the basalts. They extend over the entire Park basin, giving it the level, prairie-like aspect which it presents from all the

[1] 3d Ann. Rept. U. S. Geol. Surv. Terr., 1869, p. 77.
[2] 7th Ann. Rept. U. S. Geol. Surv. Terr., 1873, pp. 48, 49, 50.
[3] Ibid., p. 240.
[4] Ibid., p. 157.
[5] 3d Ann. Rep. U. S. Geol. Surv. Terr., 1869, p. 186.

higher elevations. Through these beds the many streams of the Platte drainage have worn their present channels, leaving everywhere long, bench-like ridges with steep sides, which, though offering numerous good exposures, appear in no case to have cut deeply into underlying strata, thus making any determination of their thickness uncertain.

Within the park they probably do not exceed a few hundred feet. Lithologically, these deposits possess a somewhat local character, the material of which the uppermost beds are formed being derived exclusively from the relatively narrow limits hemmed in by the park walls, rendering any comparison with other basins almost impossible, although they present certain features like the Niobrara Pliocene beds east of the Laramie hills.

So far as known to us, neither vertebrate nor invertebrate forms have as yet been obtained from these deposits, so that paleontological evidence, so desirable in determining the age of Tertiary basins, is still wanting for the North Park deposits. It is quite probable that there may be found included within the Park two distinct Tertiary series. Some observations were made at the time of our explorations, which would tend in this direction, showing a lower set of unconformable beds, which, however, reach the surface in only a few localities, the greater part of the area being covered with more recent deposits. From the difficulty of sharply defining the two horizons of these beds, they have been given a local name, the North Park Tertiary, and a distinct designation upon the geological map. Partly from the general appearance of the strata, and in part from their relation to the basaltic rocks, they have been regarded provisionally as of late Pliocene age.[1]

MONUMENT CREEK GROUP.

There is still another series of deposits that must be considered before leaving this state. We refer to the Monument Creek group of Hayden. Its geographical distribution is shown on map 11 of "Maps and Panoramas" accompanying the 12th Annual Report of the U. S. Geological Survey of the Territories, as well as on the map accompanying this report. Hayden encountered this group in 1869 while on his way from Denver southward, and described it substantially as follows[2]:

About 5 miles south of Platte Cañon one meets with a series of variegated beds of sand and arenaceous clays, nearly horizontal, resting on the upturned edges of the older rocks. These beds form the northern edge of an extensive Tertiary basin of comparatively modern date, either late Miocene or Pliocene. From the point of their first appearance to about 5 miles north of Colorado City, these beds jut up against the foot-hills of the mountains, inclining at a small angle, never more than 8 degrees, and entirely concealing all the older sedimentary rocks. Far to the eastward stretches this Tertiary divide, giving rise to a large number of streams, as Cherry Creek, Running Water, Kiowa, Bijou, and other creeks. Through this basin flows Monument Creek, which has become so celebrated for its unique scenery.

The beds of this formation are of various colors—red, yellow, and white—and of various degrees of texture, from coarse pudding-stones to very fine-grained sands and sandstones. There is very little lime in the entire series of beds. There is much ferruginous matter in all the beds, to some of which it gives a rusty brown color. Along the mountain slopes the rocks are mostly coarse pudding-stones, the water-worn pebbles varying in size from a grain of quartz to a mass several inches in diameter. But eastward from the mountains the sediments become finer and finer until the coarse pudding-stones disappear. Lignite is sometimes found in the fine argillaceous beds.

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[1] U. S. Geol. Expl. 40th Par., 2, 1877, pp. 127–128.

[2] See 3d. Ann. Rept. U. S. Geol. Surv. Terr., pp. 139–142.

In Monument Park, there are a great number of columns standing thickly over the surface, each surmounted with a cap of harder material. The shaft of the column is usually thick at the base, rising up 10 or 20 feet, tapering to the cap, composed of a coarse aggregate of quartz grains, small pebbles all water worn, very loosely held together with rather coarse sand cement. The cap is a deep rust color, composed of sand cemented with oxide of iron, and by its greater hardness has resisted more effectually the eroding agencies.

At a late period of geological history, dikes or protrusions of igneous material flowed over the Monument Creek sandstones in broad sheets or beds; and broad table-topped buttes or mesas, 100 to 150 feet high, now indicate the extent of later erosion.

In his report for 1869, Hayden referred this group to the Miocene Tertiary, on account of its modern appearance and its position with reference to the granites, but in 1873 he was inclined to regard it as possibly belonging to the upper division of the Lignitic series, since it contains seams of "impure coal, with deciduous leaves, some of which are identical with species occurring in the Lignitic strata from New Mexico to the Upper Missouri. Indeed, the general aspect of the rocks in this region is much like the Lignitic group on the Yellowstone and Missouri rivers near their junction and in the vicinity."[1]

On this question Cope remarks:[2]

The age of the Monument Creek formation in relation to the other Tertiaries not having been definitely determined, I sought for vertebrate fossils. The most characteristic one which I procured was a hind leg and foot of an Artiodactyle of the *Oreodon* type, which indicated conclusively that the formation is newer than the Eocene. From the same neighborhood and stratum, as I have every reason for believing, the fragment of the *Megaceratops coloradoensis* was obtained. This fossil is equally conclusive against the Pliocene age of the formation, so that it may be referred to the Miocene until further discoveries enable us to be more exact.

WYOMING.

The various beds or formations of this State that have usually been assigned a post-Eocene Tertiary age may be enumerated as follows: Neozoic eruptives (partim) of the Yellowstone Park region; Sweetwater Pliocene; Wyoming conglomerate; and the White River and Niobrara Tertiary of the extreme southeastern part of the State.

CENOZOIC ERUPTIVES.

These have been described under the name of "volcanic Tertiary" with considerable detail by W. H. Holmes.[3] Its geographical distribution is shown on map 6 of "Maps and Panoramas" accompanying the last mentioned annual report.

The materials that enter into its composition are for the most part fragmentary volcanic products, which have been apparently redistributed by water, and now form breccias, conglomerates, and sandstones.[4]

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[1] 7th Ann. Rep. U. S. Geol. Surv. Terr., 1873, p. 33.

[2] Ibid., p. 430.

[3] In vol. 5, Bull. U. S. Geol. and Geog. Surv., and in part 2, of the Twelfth Annual Report of the same survey.

[4] Bull. U. S. Geol. and Geog. Surv., 1879, No. 1, vol. 5, p. 125.

These reach their maximum development in the valley of the "East Fork," where they rest upon the unevenly eroded surfaces of the paleozoic and granitic rocks and present a total thickness of 5,500 feet. They are preeminently characterized throughout by the enormous quantities of silicified wood they contain. Leaves and small twigs are by no means so abundant as stumps and logs, but at least two localities have yielded determinable leaves, and by these Lesquereux has determined their horizon as Eocene and Lower Pliocene or Upper Miocene respectively.[1] By inspecting the map just referred to, it will be seen that the Eocene beds are limited to narrow strips along the Yellowstone River in the vicinity of Elk Creek, while the post-Eocene deposits are much more widely distributed. The conglomerate material of the latter is frequently interstratified with sheets of basalt, while the rhyolitic outflows are, stratigraphically speaking, above the whole.

SWEETWATER PLIOCENE.

In Central Wyoming, the beds of the Sweetwater group have been extensively scooped out or eroded, and upon them have been deposited marls and sands of Pliocene age.[2] "Near the base * * * we find a very loosely aggregated sandstone, almost partaking of the character of a conglomerate. It is light gray and yellowish, easily decomposing." Above this follows a succession of light marls and indurated clays. Usually these are either very light yellow or white, but pink and greenish beds are not wanting. Toward the eastern terminus of the group, the strata become highly siliceous. These beds are nearly horizontal; along their northern border they participate in the southward dip of the Sweetwater group,[3] amounting from 1° to 4°.

The geographical distribution of these "Pliocene" deposits may be seen by consulting maps 3 and 11 of "Maps and Panoramas" accompanying the Twelfth Report of the U. S. Geological and Geographical Survey of the Territories. Endlich estimates their maximum thickness as from 700 to 900 feet.[4] They are probably of Loup Fork horizon, as shown by their lithological characters, their horizontality, and their vertebrate remains.

A small collection of fossils was obtained by Hayden's expedition of 1870, on Sweetwater River, 18 miles west of Devils Gate, Wyoming. Upon these Dr. Leidy reports[5] and finds them "Nearly related with those from the Pliocene Tertiary sands of the Niobrara River," and, "without doubt, of a much more recent date than those of the Bridger beds."

Farther to the west, and "within the narrow depression between the subsidiary Prozoic Range and the western base of the Wind River

[1] Bull. U. S. Geol. and Geog. Surv., 1879, No. 1, vol. 5, pp. 126, 128.
[2] Fourth Ann. Rep. U. S. Geol. and Geog. Surv. Terr., 1870, p. 29.
[3] 11th Ann. Rep. U. S. Geol. and Geog. Surv. Terr., 1877, p. 112.
[4] Ibid., p. 113.
[5] U. S. Geol. Surv. Terr., vol. 1, pp. 198–209.

Mountains," there is a local depression filled with loose white and yellowish clays and marls. Their thickness has been estimated at about 300 feet, and they have been regarded as synchronous with the Pliocene of Sweetwater River, although no fossils except a *Pupa* have been found in them.[1]

WYOMING CONGLOMERATE.

Concerning this formation Endlich remarks:

This term has been used by Emmons and Hague to designate the widespread conglomeritic accumulations of drift which may be assigned to the Pliocene period. It is entirely structureless and composed of most varying material. Essentially it may be regarded as the product of all the formations existing within a given area. During the last era of extensive inundations it was deposited at the most convenient localities. Along the entire northern slope of the Sweetwater and Seminole hills we find enormous deposits of this material. No structure whatever can be observed there, and the whole forms merely a huge cover of erratic bowlders. Their size varies somewhat, but does not reach any considerable dimensions. We find the narrow gullies running down from the hillsides cut into this conglomerate, and the tops of the ridges are covered by it for some distance. Its presence is so marked a feature in this region that it can not be overlooked. With regard to its age, I consider the period of deposition as synchronous with that of the younger portions of the Pliocene marls and shales. It is found near the edges of the ancient lake, and was probably carried there by the waters draining into the former. It must not be mistaken for the glacial drift which occurs in the same region. The relative positions alone of these two deposits will easily determine their character.[2]

This same conglomerate occurs in the limited Pliocene valley west of South Pass. In fact "it is scattered to a greater or less extent all over the country, which has been subjected to extensive erosion."[3]

WHITE RIVER GROUP.

Cenozoic beds in the extreme southeastern part of the State.—Referring to this area, Dr. Hayden remarks:

That portion of Wyoming east of the Laramie range and south of the line of the Union Pacific Railroad is entirely covered with the upper beds of the White River Tertiary basin. The valley of the Lodge Pole, Crow Creek, and Chugwater show the formations of this basin very distinctly from mouth to source. The Union Pacific Railroad ascends the eastern slope of the Laramie range on a sort of bench of this formation, which seems to be unusually developed, and to extend without much interruption up to the very margin of the mountains, sometimes concealing all the rocks of intermediate age and resting on the syenites.

About 20 miles south of Cheyenne these beds disappear entirely along the western flank of the mountains, and the lignite Tertiary beds are exposed to view.[4]

Again:

The geological formations immediately underlying Cheyenne are of Tertiary age, probably Pliocene or very late Miocene. The beds have been slightly disturbed by the upheaval of the mountain range, but their position in relation to the older Ter-

[1] 11th Ann. Rep. U. S. Geol. and Geog. Surv. Terr., 1877, pp. 132–133.
[2] Ibid., pp. 113–114.
[3] Ibid., p. 133.
[4] U. S. Geol. and Geog. Surv. Terr., 1869, vol. 3, p. 11.

tiary beds shows their deposition to have been of late date. They are found deposited in the valleys and sometimes high on the mountain sides, and it is very seldom that they dip at an angle of more than 5°. These beds can be traced far northward to the Black Hills of Dakota, a distance of 350 miles, and they are thus shown probably to be the upper beds or most recent formation of the White River Tertiary.[1]

UTAH.

There are two series of deposits within this territory which for reasons elsewhere given have been referred to the Neocene division of the Tertiary. They are (1) the Humboldt group of King, which includes the Salt Lake group of Hayden, and (2) the Wyoming conglomerate.

THE HUMBOLDT GROUP.

This is well displayed in Weber, Ogden, and Cache valleys east of Great Salt Lake, and in the Terrace and Raft River mountains to the west. In Weber Valley it was that Hayden[2] first studied this formation and found it to consist of light colored sands, sandstones, and marls, reaching in thickness from 800 to 1,200 feet.

The corresponding deposits of Ogden Valley "have been referred to the Humboldt Pliocene, although it should be stated that they are too far removed from well defined Humboldt formations to trace any direct connection, and paleontological evidence is yet too meager to throw any important light on the question."[3]

Beds in Cache Valley, supposed to be of this age, have been described by Hayden,[4] Bradley,[5] Hague,[6] Peale,[7] and others. The central portion of the valley is occupied by Quaternary deposits, termed by Peale the Cache Valley group, while the older beds crop out around the borders. The latter are accredited by Bradley with a dip of 25° in some instances. Hague says: "They are found to have been considerably uplifted, showing angles of dip of 10° and 15°." These figures, it will be observed, indicate a considerably greater amount of dip than is usually shown in the sedimentary "Pliocene" deposits of the West.

The maximum thickness of these beds is not less than 350 feet.[8]

At one locality, Mendon, some of the sandy layers contain vast numbers of *Limnæa*, *Physa*, *Vivipara*, and *Helix;* at the "Gates" the limestones and shales contain *Limnæa*, *Valvata*, *Planorbis*, *Sphærium*.[9] These fossils, however, are of little value for determining the age of the strata in which they are entombed. The determination rests wholly upon lithologic and stratigraphic criteria.

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[1] U. S. Geol. and Geog. Surv. Terr., 1869, vol. 3, p. 11.
[2] Prelim. Rep. U. S. Geol. Surv. Col. and N. Mex., 1869, p. 92.
[3] U. S. Geol. Explor. 40th Par., vol. 2, Descriptive Geology, 1877, p. 418.
[4] U. S. Geol. Surv. Terr., 5th Ann. Rep., 1871, pp. 19–22.
[5] U. S. Geol. Surv. Terr., 6th Ann. Rep., 1872, p. 199.
[6] U. S. Geol. Explor. 40th Par., vol. 2, Descriptive Geology, 1877, pp. 406, 417.
[7] U. S. Geol. Surv. Terr., 11th Ann. Rep., 1877, p. 603.
[8] U. S. Geol. Explor. 40th Par., vol. 2, Desc. Geol., 1877, p. 417.
[9] U. S. Geol. Surv. Terr., 11th Ann. Rep., 1877, pp. 604–605.

On both eastern and western slopes of Terrace Mountain there is a broad canyon, filled to some extent with beds that "resemble the fine sands, reddish gravels, and marls which form the Humboldt Pliocene beds of eastern Nevada, and have been referred to the same horizon."[1]

The western slopes of Raft River Mountains "are covered high up on the flanks by heavy white beds, sloping gently toward the center of the valley, composed of fine white pumiceous sands, loose sandstones, fine conglomerates, which have been referred to the horizon of the Humboldt Pliocene, from their general resemblance to these beds as developed in the valley of the Upper Humboldt."[2]

THE WYOMING CONGLOMERATE.

The Wyoming conglomerate may be seen along both flanks of the Uinta range, forming the cap-rock of minor elevations, such as Ti Ra-Kava and Concrete plateaus and Black Tail Mountain.[3] It is often 100,[4] 200, or even 300[5] feet in thickness, is composed wholly of local materials, and is devoid of organic remains.[6]

(See this formation under Wyoming.)

NEVADA.

The post-Eocene Tertiary geology of this State is known chiefly from the reports of the U. S. Geological Exploration of the fortieth parallel. The various deposits here referred to which are found scattered about in widely different localities are treated in these reports as having been laid down in two great sheets of fresh water, one of Miocene, the other of Pliocene age, to which King has applied the names Pah-Ute and Shoshone lakes. To the deposits of the former this author gives the name "Truckee group;" to those of the latter, "Humboldt group."

TRUCKEE GROUP.

Numerous references have already been made in our discussions of adjacent States to deposits supposed to form a part of the group. King says:[7]

> The rocks of the group are limited on the east, within the boundaries of our exploration, by the one hundred and seventeenth meridian, and on the west by the abrupt wall of the Sierra Nevada. Northward they extend through Oregon and pass into Washington Territory, having their greatest development on Crooked River, the John Day, and the Malheur. South of our work they are all well known in the valley of the Walker River, but beyond that southward I am not aware of their having been observed.

[1] U. S. Geol. Explor. 40th Par., vol. 2, 1877, p. 427.
[2] Ibid, p. 429.
[3] See Maps II and III of Atlas accompanying King's Reports.
[4] U. S. Geol. Explor. 40th Par., vol. 2, Descr. Geol., 1877, p. 247.
[5] Ibid., p. 290.
[6] Ibid., p. 248.
[7] U. S. Geol. Explor. 40th Par., vol. 1, Syst. Geol., 1878, p. 413.

For details regarding their distribution in Nevada, reference should be made to the reports of King, Hague, and Emmons, also to the accompanying atlas.

In King's report on the Systematic Geology (p. 415), he says:

The most important and characteristic development of this series within our limits is at the Kawsoh Mountains and along the southern extremity of Montezuma Range. The northern and eastern portion of the Kawsoh Mountains and the valley which lies north of them, separating the broken detached group of hills from the end of Montezuma Range, together offer a section of about 2,300 feet of Miocene beds, noting from the top as follows:

1. The upper 1,200 feet consists entirely of drab mauve gray, pale buff, and white stratified trachyte tuff, intermixed with more or less detrital material. The beds are characterized by rapid changes of color and texture, are of very variable coarseness, and have a prevailing amount of glassy fragments, as if an enormous amount of the material were the glassy scoria and rapilli of violent and long continued trachytic eruption. At intervals are beds of pure gray sand, with a few seams of slightly marly clay. The microscope shows that this entire series is made up of angular and subangular fragments, many of them excessively small. There are some singular chalcedonic strata, one to two feet thick, of which the lower stratum plane is exceedingly rough, resting upon the trachytic tuff and including a great many minute fragments of the volcanic material, the upper surfaces being rudely botryoidal, the protuberances reaching the size of an egg. Toward the lower edge of this great series of trachytic tuffs, the upper limits of which are nowhere seen, the proportion of their detrital material—quartz and feldspar sand—becomes rapidly greater until the tuff is underlaid by:

	Feet.
2. Coarse, sandy grits, gray and yellow fragments, partially rounded, partially angular, with a slight proportion of calcitic material	250
3. Saccharoidal limestone, rich in fresh-water mollusks[1]	60
4. Marly grits, yellow and drab, rather coarse	40
5. Fine-grained friable buff and gray sandstone, having a peculiarly sharp gritty feel	70
6. Variable gray sandstones	100
7. A marly grit	50 or 60
8. White and yellow infusorial silica	200 to 250
9. Palagonite tuff, base never seen ....(maximum exposure)	250

Intermediate between the times of deposition of the two fresh-water groups already referred to, or perhaps synchronous in part with the earlier portion of the latter, there were enormous outpourings of the rhyolitic materials in the area under consideration. The older, or Truckee group, was accordingly often much disturbed by volcanic and orographic phenomena, and its layers are often inclined 10°, 20°, or even 30° from the horizontal.

Concerning the age of this group, King[2] says:

No vertebrate remains have been found upon the area of Map V, except a single rhinoceros tooth[3] from the grits of the Kawsoh Mountains, a species which has been pronounced to be probably Miocene. The fresh-water mollusca of the saccharoidal

[1] *Sphærium rugosum* Meek, *Sphærium? idahoense* Meek, *Anyclus undulatus* Meek, *Carinifex* (*Vorticifex*) *binneyi* Meek, *C.* (*V.*) *tryoni* Meek, *Melania? subsculptilis?* Meek, *M. sculptilis* Meek (=*M. taylori* Gabb). U. S. Geol. Surv. 40th, vol. 4, pt. 1, pp. 182–196. First published in Proc. Phila. Acad. Nat. Sci., 1870, pp. 56–60.

[2] Systematic Geology, 1878, p. 423-424.

[3] *R. pacificus* probably, King, p. 455.

limestone of Fossil Hill would not alone afford sufficient data for referring this series to the Miocene, although Prof. Meek, independently of any other reason, made this assignment. The main reason for classing the whole group as Miocene is, that farther north in Oregon upon John Day, Des Chutes, and Crooked rivers, Prof. Meek's researches have brought to light an immense formation computed by him to be 3,000 or 4,000 feet thick, containing numerous vertebrate remains of clearly Miocene type. These Oregon beds are all in inclined positions, earlier than basaltic eruptions, and the main material of this whole series, as I have determined by microscopic studies, is of stratified trachytic pumices, tuffs, and hyaline sands. The Oregon Miocene is apparently the direct northern continuation of the Nevada formation. Besides the parallelism between the two series, is the fact of an overlying unconformable Pliocene in each case. The mollusks from Fossil Hill and the rhinoceros tooth distinctly refer the Nevada strata to the Miocene. The overlying Pliocenes and basalts are similar and of identical position in each case; and this, together with the identity of material and similarity of disturbed position, has led us finally to refer our Truckee group to the Miocene.[1]

Paleontology.—If we confine ourselves to the development of this group within the boundaries of Nevada, its paleontologic features can be given in few words. Besides the above-mentioned rhinoceros tooth and fresh-water mollusks, infusorial and vegetable remains have been noted in several localities. Just above the town of Reno, in Truckee valley, Hague finds in beds doubtfully referred to this group, "stems, leaves, and partially carbonized vegetable matter," which "are abundant in certain layers of shale." Coal seams have been observed north of the town of Verdi, and on Dog Creek, a short distance north of Crystal Peak.

Regarding the infusoria referred to in King's section, quoted above, Hague[2] says:

Under the microscope, even with a moderate power, these siliceous beds are seen to be made up of innumerable fragments of Diatomacea. Dr. C. G. Ehrenberg,[3] of Berlin, Prussia, to whom were sent a large number of specimens from this locality has described no less than thirty-three distinct organic forms, one of which may belong to the vegetable world. Of these forms, twelve have been classed as *Polygastrica* and twenty as *Phytolitharia*, the most abundant species being:

Gallionella granulata.
Gallionella sculpta.
Spongolithus acicularis.

Accompanying Dr. Ehrenberg's work is a plate giving the microscopic sections of the infusorial earth from this locality, together with others from the Truckee Valley, and Salt Lake Desert.

A similar deposit is noted about 2 miles south of Winnemucca Lake (p. 820).

HUMBOLDT GROUP.

This group, according to the geologists of the fortieth parallel, was deposited in "Shoshone Lake," whose existence was in part contemporaneous with, but mainly subsequent to, the period of rhyolite outflows,

[1] On p. 450 he correlates it with the White River group.
[2] Descriptive Geol., vol. 2, p. 768.
[3] Ueber die wachsende Kenntniss des unsichtbaren Lebens als felsbildende Bacillarien in California, p. 19, Berlin, 1870.

though often hidden under vast sheets of basalt. References will be found under Oregon, Washington, Idaho, and Utah of outlying portions of this formation, but it is in Humboldt Valley, Nevada, that it is typically developed and accordingly receives its name. King describes this region, as follows:

West of Humboldt and Tucubits ranges there is a long valley drained by Humboldt River and Huntington Creek. Throughout the length of this depression, over 100 miles, there is a nearly continuous exposure of horizontal Pliocene beds. It is difficult to decide what thickness of beds is exposed, since they are often buried by Quaternary, but there can not be less than 600 or 800 feet. In the middle of this valley the beds are horizontal, but on either side there is a dip of from 2° to 3°, which is probably the inclination of deposition. The foot-hills of the ranges on both sides are skirted by continuous belts of Tertiary, which are beveled off to the central valley. Streams have excavated broad depressions down these plains and the intervening spurs have been graded off, so that the whole valley country presents few abrupt exposures and those only along certain exceptionally sharp stream cuts. The most important of these are seen in the valley of the South Fork of the Humboldt, where 100 to 150 feet of sandstone cliffs flank the valley on either side. Here are found sands that are at times quite marly, associated with more or less coarse beds of grit, which nearer the mountains are entitled to be named conglomerate. There are a few calcareous clays, and some limited beds of true marly limestone. It is not surprising that this whole Pliocene exposure should have more or less calcareous material within its mass, since so large a portion of the surrounding mountain sides from which the material has been derived is of Paleozoic limestones.

The descriptions of this formation as it occurs at numerous other localities within the limits of the fortieth parallel survey will be found in volumes 1 and 2 of its reports.

Concerning the age of this group, King remarks:

At Bone Valley, which is drained by the waters of the North Fork of the Humboldt, a few vertebrate remains were found, including a jaw of *Protohippus perditus*, also a jaw of *Merychippus mirabilis*, and fragments of *Cosoryx*. These forms are of importance as proving the identity of the beds in which they were found with those of the Niobrara Pliocene east of the Rocky Mountains.

Cope evidently refers[1] these fossils to the Procamelus division of the Loup Fork (Niobrara) Miocene. Fossil remains are exceedingly rare in the formation within the boundaries of Nevada. They appear to be limited to the forms mentioned above, together with a few undetermined fresh-water mollusks.

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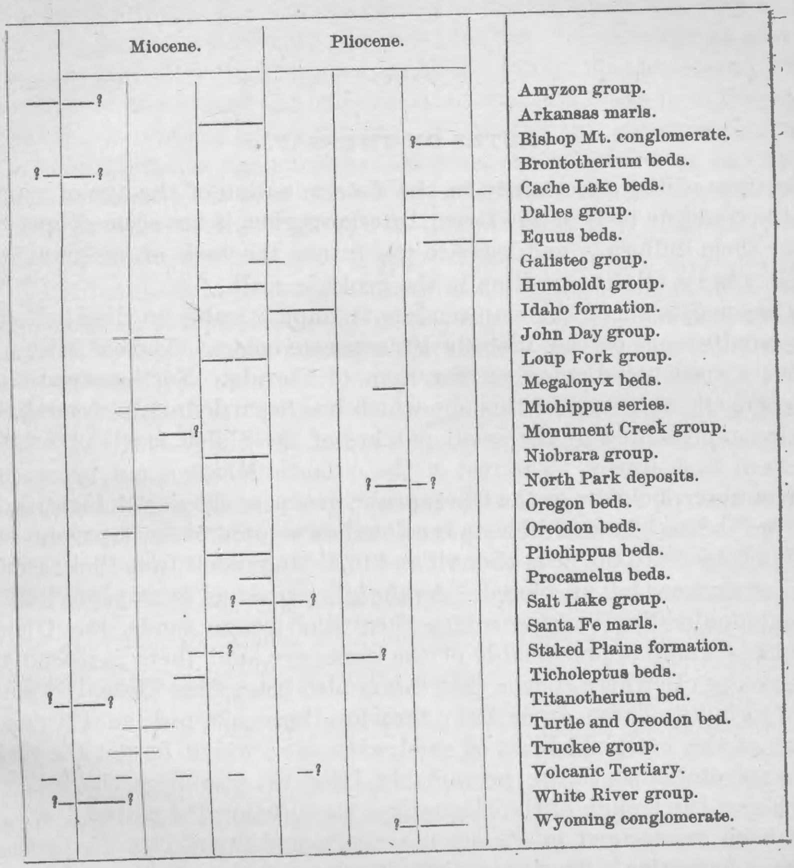
[1] U. S. Geol. Surv. Terr., 1884, vol. 3, p. 19.

Table showing the vertical range of the Neocene formations of the interior region.



NOTES ON THE MAP.

In view of the uncertainty in the determination of the age of many of the Neocene beds of the Great Interior region, it has seemed best to color them uniformly and leave to the future the task of assigning to each area its relative position in the geologic scale.

The small scale of the map renders it impracticable to discriminate the subdivisions of the Miocene by separate colors. The old Miocene area is mostly indicated on the map of Florida. Northeastward of Georgia the only area of this age which has been definitely recognized is that represented by the small patches of the Shiloh marls in southwestern New Jersey. The rest of the Atlantic Miocene, not perezonal in character, belongs to the Chesapeake group as far as yet identified.

The Eocene island of Florida is colored on account of the important relation it bears to the beds about it and to distinguish it from Pleistocene and other areas left uncolored. As the lake areas and swamps of Florida are undoubtedly Pliocene under their Pleistocene sands, the Okeefinokee Swamp is presumably of the same age, and there is reason to believe, as elsewhere shown, that this is also true of the Dismal Swamp of Virginia. These areas have therefore been mapped as Pliocene. Part of the marginal beds of sand, clay, etc., which border the Gulf Miocene on the south, are presumably Pliocene, as well as the central portion of the trough of the Mississippi Basin below the material which has been rearranged in Pleistocene times, and apart from the Appomattox formation. These are distinctively colored to distinguish them from the marine beds denoted by their fauna to be Pliocene. The peneplains of the valley of California and of the Willamette River, Oregon, are similarly treated.

On the Atlantic coast there are gaps in the vicinity of the great Carolinian ridge where the Neocene has been denuded, leaving only smaller or larger patches in the more depressed basins of the Eocene surface. These patches, often too small to be separately platted on a map of this scale, have been generalized for present purposes.

Submarine areas off Hatteras, Nantucket, and on Georges Banks, have been indicated by a circular spot in each case.

The Neocene of the Pacific coast has been indicated from the sources of information mentioned in the text. That of the State of Washington is mapped from the geological map of the Dominion of Canada, no published information other than that being available, especially for the portion west from Puget Sound. No attempt has been made to map the volcanic rocks possibly of Neocene age.

The Appomattox formation is mapped in two shades of color. One of these represents that portion of this formation which has been recognized by McGee as forming the top rock or surface material, and as such has been definitely mapped by him. In the northwestern part of the Gulf of Mississippi the beds of this formation have been denuded, making a gap in the perezonal line. Following the general relation of the known beds to the subjacent Eocene, the remainder of the Appomattox perezone has been carried hypothetically across Arkansas and Texas, in order to enable the eye to take in more fully the relations of the formation as a whole as at present understood.

A lighter shade indicates the extension under the sands of the Columbia formation of beds assigned by McGee to the Appomattox, though in southern Georgia and northern Florida this extension is represented as somewhat less than he would give it, since, theoretically, it would seem improbable that these beds should cover the Okeefinokee Basin, while the oxidized gravels and red clays of northern Florida may well have had another origin.

In the interior, Neocene beds, according to Cope, exist on the line separating the two Dakotas, where beds assigned by him to the White River horizon form a Neocene island separated by a gap of 200 miles from those of the same character to the south. As there are no data for the definite location of these beds geographically, they have been omitted on the map.

In the lower part of the Colorado Valley near the Gulf of California it is probable that Pliocene beds exist, but in the absence of definite information no attempt has been made to place them on the map. Throughout the map the presence of post-glacial or Pleistocene beds above the Neocene rocks has been ignored; the object being to show as fully as existing information would warrant the general distribution of the Neocene formations. If the presence of the superficial Pleistocene materials had been taken into account the underlying beds would have been practically hidden from view, except as almost invisible lines along the water courses or the shores.

CHAPTER VII.

LIST OF NAMES APPLIED TO CENOZOIC BEDS AND FORMATIONS OF THE UNITED STATES, EXCLUDING THE LARAMIE.[1]

ÆOLIAN SANDROCK.

Wind-blown character of contents. W. H. Dall, 1892;[2] this essay, pp. 153-155. Pleistocene of Florida.

ALACHUA CLAYS.

Alachua County, Florida. W. H. Dall, 1892; this essay, p. 127. Pliocene.

ALTAMAHA GRIT.

Altamaha River, southeast Georgia. W. H. Dall, 1892; this essay, p. 81. Older Miocene.

ALUM BLUFF BEDS.

Typically displayed in the upper part of the bluff at Alum Bluff, eastern bank of Appalachicola River, northwest Florida. W. H. Dall, 1892; this essay, p. 112. Miocene.

AMYZON BEDS.

Amyzon, generic name of a characteristic fish. E. D. Cope, May, 1879; Am. Nat., vol. 13, p. 332. Later Eocene or early Miocene.

Amyzon group. Cope; Am. Nat., June, 1880.

These beds were first described, though not named, by Cope in 1872; Proc. Am. Phil. Soc., 1872, p. 478.

APPOMATTOX FORMATION.

Appomattox, a river of Virginia, along which the formation is typically displayed. W. J. McGee, Feb., 1888; Am. Jour. Sci., 3rd ser., vol. 35, p. 125; "Later Tertiary age;" "Much nearer the age of the Columbia formation than that of the fossiliferous Miocene" (Ibid., p. 330); its age corresponds "at least roughly with the Pliocene." (Ibid., vol. 40, p. 33.) "Post-Pliocene?" Langdon (Ibid., vol. 40, p. 238).

See under Lafayette formation.

ARAPAHOE BEDS.

Arapahoe County, Colorado. George H. Eldridge, 1889; Am. Jour. Sci., 3rd ser., vol. 37, p. 282.[3]

Lowest Tertiary.

ARCADIA MARL.

Arcadia, De Soto County, Florida. W. H. Dall, 1892; this essay, p. 131. Older Pliocene.

ARKADELPHIA SHALE.

Arkadelphia, a town, Clarke County, Arkansas. Robert T. Hill, 1888; Rept. Ark. Geol. Surv., vol. 2, p. 53. Eocene.

ARKANSAS MARLS.

Arkansas River, Colorado. F. V. Hayden, 1869; Preliminary Field Report of the U. S. Geol. Surv. of Colorado and New Mexico, p. 77.

"Contemporaneous with the Santa Fe marls."

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[1] The names applied to Pleistocene beds in this essay are included.

[2] Date of publication. This and other names by W. H. Dall were proposed in 1891.

[3] See also Proc, Col. Sci. Soc.; 1888, vol. 3, part 1, p. 97. This publication, though apparently antedating the preceding, did not actually appear until some time after the former.—Whitman Cross.

ASHLEY BEDS.

Ashley River, South Carolina. M. Tuomey, 1848; Report on the Geology of South Carolina, p. 164. Eocene.

ASHLEY AND COOPER BEDS.

Ashley and Cooper rivers, South Carolina. M. Tuomey, 1848; Geology of South Carolina, pp. 162, 211. "Newest Eocene of the State."

ASTORIA GROUP.

Astoria, a town in Clatsop County, Oregon. W. H. Dall, 1892; this essay, p. 225. Miocene.

Includes the Astoria shales and sandstones, the Solen bed of Condon, the Crepidula bed of Dall, and the Nulato sandstone.

ASTORIA SANDSTONES.

Astoria, a town in Clatsop County, Oregon. W. H. Dall, 1892; this essay; p. 224. Miocene.

ASTORIA SHALES.

Astoria, a town in Clatsop County, Oregon. Thomas Condon; published by E. D. Cope from MS. notes of Prof. Condon, June, 1880; American Naturalist, vol. 14, p. 457. Miocene.

ASTRINGENT CLAY.

Astringent property of the clay. H. D. Rogers, 1836; Report of the Geol. Surv. of New Jersey, p. 26. Eocene.

ATLANTIC GROUP.

Lying along the Atlantic border. Otto Meyer, 1888; American Geologist, p. 93. Includes all the Tertiaries of the Atlantic slope.

ATURIA BED.

Aturia, a characteristic fossil. W. H. Dall, 1892; this essay, p. 224. Upper Eocene of Astoria, Oregon.

AURIFEROUS GRAVELS.

Gold-bearing gravels of the Sierra Nevada, California. J. D. Whitney, 1879; Mem. Mus. Com. Zool. at Harvard College, vol. 6, 1. Neozoic, culminating in the later Pliocene.

BASAL OR WILLS POINT CLAYS.

Basal, because "its position is the lowermost of the Eocene," and Wills Point, Texas, where the beds are well exposed. R. A. F. Penrose, jr., 1889; First Ann. Rep. Geol. Surv. Tex., 1890, p. 19. Lower Eocene.

BASHI SERIES.

Bashi Creek, Clarke County, Alabama, on which the series is typhically displayed. Smith and Johnson, 1887; U. S. Geol. Surv. Bull. No. 43, p. 43.

=Wood's Bluff series.

BELL'S LANDING SERIES.

Bell's Landing on Alabama River, Monroe County, Alabama. E. A. Smith and Lawrence Johnson, 1887. U. S. Geol. Surv. Bull. No. 43, p. 46. Lignitic Eocene.

=Tuscahoma series.

BINGEN SANDS.

Bingen, a village, Hempstead County, Arkansas. R. T. Hill, 1888; Ann. Rep. Ark. Geol. Surv., vol. 2, p. 56. Eocene.

BISHOP MOUNTAIN CONGLOMERATE.

Bishop Mountain, Sweetwater County, Wyoming. J. W. Powell, 1876; Geol. Uinta Mts., pp. 40–44. "Pliocene."

=Wyoming conglomerate.

BISON BEDS.

Bison, generic name of a characteristic fossil. O. C. Marsh, 1887; Am. Jour. Sci., 3d ser., vol. 34, p. 324. "Probably later Pliocene."

=Denver group, partim.—Cross.

The name has been canceled by Marsh (in lit.)

BITTER CREEK GROUP.

Bitter Creek, Wyoming. J. W. Powell, 1876; Geol. Uinta Mts., pp. 40, 45, 46. Eocene.

=Wasatch group; see p. 65.

Its upper part includes the Washiki group, p. 65.

BLACK BLUFF SERIES.

Black Bluff on Tombigbee River, Sumter County, Alabama. Smith and Johnson, 1887; U. S. Geol. Surv., Bull. No. 43, p. 61. Eocene.

To be known as the Sucarnochee series in a forthcoming report by Smith and Langdon.

=Buff sand, partim.

BLUFF LIGNITIC.

Bluffs along the Mississippi containing lignite. J. M. Safford, 1864; Am. Jour. Sci., 2d ser., vol. 37, p. 370. Provisional Tertiary?

Identified with Safford's Porter's Creek group by R. H. Loughridge; Jackson Purchase Region, Geol. Surv. Ky., 1888, p. 41.

BRANDON PERIOD.

Brandon, a town of Rutland County, Vermont. H. C. Lewis, 1880; Proc. Acad. Nat. Sci. Phila., vol. 32, p. 289. Oligocene?

BRIDGER GROUP.

Fort Bridger, Uinta County, Wyoming. F. V. Hayden, 1869; Preliminary Field Report of the U. S. Geol. Surv. of Colorado and New Mexico, p. 91. "Upper Tertiary." Eocene.

=Dinoceras beds.

BRONTOTHERIUM BEDS.

Brontotherium, generic name of a characteristic fossil. O. C. Marsh, 1877; Am. Jour. Sci., 3d ser., vol. 14, p. 354. "Lowest Miocene."

A subdivision of the White River group.

BROWN'S PARK GROUP.

Brown's park, northeastern Utah. J. W. Powell, 1876; Geol. of Uinta Mts., pp. 40, 44. Eocene.

=Uinta Group.—White.

BUFF SAND.

Buff color of the component sands. A. Winchell, 1856; Proc. Am. Assoc. Adv. Sci., vol. 10, p. 89. Lower Eocene.

See Black Bluff series.

BULLA STRIATA MARLS.

Bulla striata, characteristic fossil. W. H. Dall, 1892; this essay, p. 147, footnote. Pleistocene.

=Venus cancellata bed, partim, Heilprin.

BURRSTONE FORMATION.

Burrstone (Buhrstone), a rough siliceous rock characteristic of the formation. Charles Lyell, 1845; Quart. Jour. Geol. Soc., Lond., vol. 1, p. 435. Eocene.

Regarded by Lyell as newer than the White Limestone.

John Finch referred to the "Buhr-stone of Georgia" as early as 1823 (Am. Jour. Sci., vol. 7, p. 38), and Vanuxem used the term in 1827 (Jour. Acad. Nat. Sci., Phila., vol. 6, pt. 1, pp. 60, 66), but in each case the usage seems that of a common rather than a proper noun.

CACHE LAKE BEDS.

Cache Lake, Lake County, California. G. F. Becker, 1888; U. S. Geol. Surv., Monograph vol. 13, p. 219. Late Pliocene.

CALAMITE BEDS.

Calamites, characteristic fossil. Thos. Condon, by E. D. Cope, Am. Nat., June, 1880; vol. 14, p. 458. Eocene? of central Oregon.

CALCAIRE OSTRÉE.

Abundance of *Ostrea*. John Finch, 1823; Am. Jour. Sci., 1824, vol. 7, p. 39.

A name applied to portions of the Eocene of South Carolina and Georgia, but which may have included some of the lower Miocene of Florida. Conrad, as early as 1832, pointed out the fact that this formation has no real existence.

CALCAREOUS CLAIBORNE.

Calcareousness of the component strata; its fossils show its equivalency to the beds at Claiborne, Alabama. Eug. W. Hilgard, 1860; Agric. and Geol. Miss., p. 126. Middle Eocene.

CALOOSAHATCHIE BEDS.

Typically exposed on that river in Florida. W. H. Dall, 1887; Am. Jour. Sci., 3d ser., vol. 34, pp. 167, 169.

Includes the upper marine and fresh-water Pliocene of south Florida and South Carolina.

CAMDEN SERIES.

Camden, a town, Ouachita County, Arkansas. Robert T. Hill, 1888; Ann. Rep. Ark. Geol. Surv., vol. 2, p. 49. Eocene.

CAROLINIAN (Upper Atlantic Miocene).

Typically developed in North and South Carolina. Angelo Heilprin, 1882; Proc. Phila. Acad. Nat. Sci., 1882, p. 183. Upper Miocene.

CERITHIUM ROCK.

Abundance of the genus *Cerithium*. Angelo Heilprin, 1887. Trans. Wagner Free Inst. Sci., vol. 1, pp. 11, 123. Older Miocene of Florida.

CHATTAHOOCHE GROUP.

Chattahoochee, river and town, northwestern Florida. D. W. Langdon, 1889; Am. Jour. Sci., 3d ser., vol. 38, p. 324. Basal Miocene, as shown in this essay.

CHATTAHOOCHEE LIMESTONE.

Typical exposure on the Chattahooche River, northwestern Florida. W. H. Dall, 1892; this essay, pp. 106, 107. Older Miocene.

CHESAPEAKE FORMATION.

Typical exposures on the bay of that name. N. H. Darton, 1891; Bull. Geol. Soc. Am., vol. 2, p. 443. Includes the Miocene of Maryland and Virginia, and is the term stratigraphically equivalent to the expression "Yorktown Epoch" of Dana.

CHESAPEAKE GROUP.

Typically developed in the hydrographic basin of Chesapeake Bay. W. H. Dall, 1891; Geological Magazine for June, 1891, p. 287; this essay, p. 123.

Includes the Chesapeake formation of Darton and all other beds containing the same general fauna of the Atlantic and Gulf coasts of the United States.

CHICO-TEJON GROUP.

Chico, a town and creek in Butte County, California, and Tejon, a fort in Kern County, California. C. A. White, 1885; U. S. Geol. Surv., Bull. No. 15, p. 11. Cretaceo-Eocene.

CHIPOLA BEDS.

Typically exposed at Chipola River, Florida. W. H. Dall, 1892; this essay, p. 112. Older Miocene of Florida.

CHIPOLA MARL.

Typically displayed on Chipola River, northwestern Florida. W. H. Dall, 1892; this essay, p. 122. Older Miocene.

=Chipola formation of Frank Burns (MS. notes), 1890.

CLAIBORNE GROUP.

Claiborne, a town, Monroe County, Alabama. T. A. Conrad, January, 1855; Proc. Phila. Acad. Nat. Sci., vol. 7, p. 257. Eocene. "Claibornian," Heilprin; Proc. Acad. Nat. Sci. Phila., 1882, p. 184.

CLAYTON GROUP.

Clayton, Barbour County, Alabama. D. W. Langdon, July, 1891; Bull. Geol. Soc. Am., vol. 2, p. 594. Name applied to a phase of the Midway Eocene in eastern Alabama.

CLEVELAND COUNTY RED LANDS.

Red color of the soil in Cleveland County, Arkansas. Robert T. Hill, 1888; Ann. Rep. Ark. Geol. Surv., vol. 2, p. 58. Eocene.

CORAL LIMESTONE.

Characterized by fossil corals. Smith and Johnson, 1887; U. S. Geol. Surv., Bull. No. 43, p. 18. Uppermost Eocene of Salt Hill, Clarke County, Alabama.

CORYPHODON BEDS.

Coryphodon, name of a characteristic genus. O. C. Marsh, 1877; Am. Jour. Sci., 3d ser., vol. 14, p. 354. Lowest Eocene.

See Wasatch group.

CREPIDULA BED.

Crepidula, characteristic fossil. W. H. Dall, 1892; this essay, p. 255. Marine Miocene of Alaska.

CUCHARA BEDS.

Cuchara River, central Colorado. R. C. Hills, 1891; "Remarks on the classification of the Huerfano Eocene." Abstract from vol. 4, pt. 2, Proc. Colo. Scientific Soc., February, 1891. Lower Eocene.

DALLES GROUP.

"The Dalles," a town, Wasco County, Oregon. Thomas Condon; first published by E. D. Cope, from Condon's MS. notes, June, 1880; Proc. Am. Philos. Soc., vol. 19, p. 61. Pliocene.?

= ? Equus beds.

DENVER GROUP.

Denver, Colorado. O. C. Marsh, 1887. Am. Jour. Sci., 3d ser., vol. 34, p. 324. Eocene? ("Probably late Pliocene."—O. C. M.) "D. Formation," Whitman Cross, Mining Industry, August 3, 1888, and Am. Jour. Sci., 3d ser., vol. 37, p. 261. "Eocene."

DE SOTO BEDS.

De Soto, a supposed Pliocene lake in Florida named for the Spanish explorer. W. H. Dall, 1892; this essay, p. 133. Pliocene.

Includes the lower marine Pliocene beds of Peace Creek and the Alachua clays.

DINOCERAS BEDS.

Dinoceras, generic name of a characteristic fossil. O. C. Marsh, 1877. Am. Jour. Sci., 3d ser., vol. 14, p. 354. Middle Eocene.

= Green River group and Bridger group.—Marsh, 1877.

= Bridger group.—Marsh, 1886.

DIPLACODON BEDS.

Diplacodon, generic name of a characteristic genus. O. C. Marsh, 1877. Am. Jour. Sci., 3d ser., vol. 14, p. 354. Uppermost Eocene.

= Uinta group.—Marsh.

ECPHORA BED.

Ecphora, a characteristic genus. W. H. Dall, 1892; this essay, p. 124. Newer Miocene of Alum Bluff, Chattahoochee River, Florida.

EOCENE.

ἠώς, Ionic form for Att. ἕως = Lat. *Aurora;* dawn, and καινός, ή, όν, Lat. *recens;* new, fresh, recent. Charles Lyell, 1833 (1832, lectures delivered at King's College, London). Principles of Geology, 1st ed., about p. 53 of vol. 3.

NOTE.—We have not had access to the volume itself; the above data are mainly derived from statements made in Lyell's Principles of Geology, ed. of 1834, vol. 1, pp. xiv, xv. and vol. 3, pp. 305, 306, and in Lea's Contributions to Geology, introd. p. 14. It should be noted that the conclusions and researches, which finally resulted in the classification for which the terms Eocene, Miocene, Pliocene, and post-Pliocene were framed, were the joint work of Lyell and G. P. Deshayes. See Bull. Soc. géol. de France, 1830, vol. 1, pp. 185–188.

EO-LIGNITIC.

ἠώς, dawn, and lignitic. Angelo Heilprin, 1881. Proc. Acad. Nat. Sci., Phila., 1881, p. 159, foot-note. Lower Eocene.

EQUUS BEDS.

Equus, a characteristic genus. O. C. Marsh, 1877. Am. Jour. Sci., 3d ser., vol. 14, p. 355. See also plate accompanying "Introduction and Succession of Vertebrate Life in America." Author's edition, 1877. Upper Pliocene. Pleistocene.—G. K. Gilbert, U. S. Geol. Surv., Mon. vol. 1, 1890, p. 393.

EVERGLADES LIMESTONE.

Rock forming about the margin and underlying the basin of the Everglades of Florida. W. H. Dall., 1891; this essay, p. 154. Pleistocene and recent.

FAYETTE BEDS.

Fayette, a county of Texas. R. A. F. Penrose, jr., 1889. First. Ann. Rep. Geol. Surv. Tex., 1890, p. 47, of Penrose's Rep. Equivalent at least in part to the Grand Gulf (Miocene).

FERRUGINOUS GRAVEL.

Character of the beds. W. H. Dall, 1892; this essay, p. 109. Older Miocene of Hawthorne beds of Florida and Georgia.

FLATWOODS CLAY.

Characteristic gray clay formation of the Flatwoods region; a level tract of land bordering the Cretaceous on the west, from Tippah to Kemper County, Mississippi. Eug. W. Hilgard, 1860. Agric. and Geol. Miss., pp. 110, 112, 113. Lowest Eocene.

FLORIDIAN SERIES.

Typically developed in the State of Florida. Angelo Heilprin, 1887. Trans. Wag. Free. Inst. Sci., vol. 1, p. 32. "The Pliocene series of the Caloosahatchie." Loc cit.

= Floridian group, partim, this essay, which includes in this group all the Pliocene beds of Florida.

FLORIDITE PHOSPHATIC ROCK.

Phosphate bearing; locality, Florida. E. T. Cox, 1890; Am. Nat., vol. 24, p. 1185. Eocene.

FORT UNION (OR GREAT LIGNITIC) GROUP.

Fort Union, western North Dakota. F. B. Meek and F. V. Hayden, 1861; Proc. Phila. Ac. Nat. Sci., 1861, vol. 13, p. 433. Eocene or Laramie.

GALISTEO GROUP.

Gallisteo (Galisteo) Creek, New Mexico. J. J. Stevenson, 1881; U. S. Geol. Surv. W. 100th Mer., vol. 3, Suppl., p. 159. "Miocene or early Pliocene."

GALLISTEO (SAND) GROUP.

Gallisteo Creek, New Mexico. F. V. Hayden, 1869; Prelim. Field Rep. U. S. Geol. Surv. Colo. and N. Mex. Third Ann. of Hayden's Surv., 1869, p. 40. "Middle Tertiary," p. 90. "Cretaceous," Cope, 1875; Proc. Phila. Ac. Nat. Sci., p. 360. "Wasatch Eocene," Hayden, 1878; Am. Nat., p. 83. "Laramie," (?) Stevenson, 1881; U. S. Geol. Surv. W. 100th Mer., p. 160 (Suppl. to vol. 3).

There seems to be some doubt as to what beds Hayden intended to apply this name. This may in part account for the various ages assigned to the group. See Galisteo group, Stevenson.

GAY HEAD SERIES.

Gay Head, a promotory on the extreme western end of the island of Marthas Vineyard, off Massachusetts. N. S. Shaler, 1888; U. S. Geol. Surv., 7th Ann. Rep., pp. 339, 340. Publ., 1888.

This, according to Shaler (in litt.), includes that portion of the Vineyard series shown at Gay Head; consequently we must regard it as in part Cretaceous and in part Upper Miocene, or Pliocene.

See Vineyard series.

GNATHODON BED.

Gnathodon, a characteristic genus. W. H. Dall, 1892; this essay, p. 164. Fossiliferous bed in Grand Gulf group, Mississippi.

GRAND GULF GROUP.

Grand Gulf, a village in Claiborne County, Mississippi. Eug. W. Hilgard, 1860; Rep. Agric. and Geol. of Miss., pp. 108, 147. Miocene.

Sometimes called the Southern Lignitic group.

GRAND GULF SANDSTONE.

Grand Gulf, a village, Claiborne County, Mississippi, where the sandstone is is typically exposed. L. C. Wailes, 1854; Agric. of Miss., p. 216. Miocene.

This sandstone forms the most characteristic phase in the Grand Gulf group of Hilgard (q. v.).

GREAT CAROLINIAN BED [of marl].

Typically developed in South Carolina. Edmund Ruffin, 1843. Report on the Commencement and Progress of the Agric. Surv. of S. C., p. 7. Eocene.

GREEN RIVER GROUP.

Green River, southwest Wyoming. F. V. Hayden, 1869. Prelim. Field Rep. U. S. Geol. Surv. of Colo. and N. Mex., p. 90. Eocene.

Subdivided into Upper and Lower Green River groups by Powell. (Geol. Uinta Mts., 1876, pp. 40, 45, 46.)

See Dinoceras beds and Haliobatis beds.

GREEN SAND.

An expression used by A. Winchell to denote a supposed stratigraphic unit in the Alabama Eocene series. He would have it include beds that are now known to belong to the Claiborne group, as well as others that belong to the Lignitic series, maintaining in the meantime that they are all above the Buhrstone. The impossibilities of these conditions will be at once apparent by consulting the generalized sections in Bull. No. 43, U. S. Geol. Surv.; Proc. Am. A. A. Sci., 1856, vol. 10, p. 86.

GROUND ICE FORMATION.

Interstratified ice of Kotzebue Sound and northern Alaska. W. H. Dall, 1892; this essay, p. 260. Pliocene or early Pleistocene.

GULF GROUP.

Proximity to the Gulf of Mexico. Otto Myer, 1888. Am. Geologist, vol. 2, p. 89.

Includes all the Tertiaries of the Gulf States.

HATCHETIGBEE SERIES.

Hatchetigbee, a bluff on Tombigbee River, Washington County, Alabama. Smith and Johnson, 1887. U. S. Geol. Surv., Bull. No. 43, p. 39. Eocene.

HAWTHORNE BEDS.

Hawthorne, a village of Alachua County, Florida. W. H. Dall, 1892; this essay, p. 107. Basal Miocene.

HELIOBATIS BEDS.

Heliobatis, characteristic genus. O. C. Marsh, 1886. Mon. on Dinocerata, pp. 6–7. Middle Eocene.

=Green River beds.—Marsh.

HICKMAN GROUP. (Provisional.)

Hickman, a town, Fulton County, Kentucky. R. H. Loughridge, 1888. Geol. Surv. Ky. Jackson Purchase region (F), p. 37. Lowest Eocene.

HUERFANO BEDS.

Huerfano River, south central Colorado. R. C. Hills, 1888. Proc. Colo. Sci. Soc., vol. 3, pt. 1, 148. Eocene.

Huerfano series, Hills. "Remarks on the Classification of the Huerfano Eocene." Abstract from vol. 4., pt. 2, Colo. Sci. Soc., Feb. 1891.

HUMBOLDT GROUP.

Humboldt Valley, Nevada. Clarence King, 1876; Atlas accompanying U. S. Geol. Explor., 40th Par., 1876, map iii, western half. Vol. 1 of the report of the above expedition, p. 434; "Pliocene."

Probably Loup Fork Miocene.

Includes the Salt Lake group of Hayden.

IDAHO FORMATION.

Idaho, a State. E. D. Cope, 1883; Proc. Phila. Ac. Nat. Sci., 1883, p. 135; "earlier Pliocene."

=Idaho beds, Cope, Am. Nat., 1889, vol. 23, p. 354.

INFUSORIAL EARTH.

Stratum containing *Infusoria*. J. W. Bailey, 1850; Smithsonian Contr. to Knowledge, vol. 2, No. 8, p. 19; older Miocene of Tampa, Florida.

Recent observations make the infusorial character of this bed somewhat questionable.

INFUSORIAL STRATUM.

Stratum containing *Infusoria*. W. B. Rogers. 1840; Rep. of Prog. of the Geol. Surv. of Virginia for 1840; or, A Reprint of the Annual Reports and Other Papers on the Geology of the Virginias, 1884, p. 449; Miocene.

INTERMEDIATE YELLOW CLAYS AND SANDS.

Intermediate between the "northern" and "southern" Tertiary of Delaware. J. C. Booth, 1837-'38; Mem. Geol. Surv. Del., Senate ed., p. 49; Miocene?

JACKSON GROUP.

Jackson, a village, Hinds County, Mississippi. T. A. Conrad, 1855; Proc. Phila. Acad. Nat. Sci., vol. 7, p. 257; Upper Eocene.

"Jackson Tertiary;" see Wailes's Geol. Mississippi, 1854, pp. 274, 289.

"Jacksonian;" Heilprin, Proc. Phila. Acad. Nat. Sci., 1882, p. 184.

JACKSONVILLE LIMESTONE.

Jacksonville, a town, northeast Florida. W. H. Dall, 1892; this essay, p. 124; newer Miocene.

JOHN DAY GROUP.

John Day River, northern Oregon. O. C. Marsh, 1875; Am. Jour. Sci., 3d ser., vol. 9, p. 52; equivalent to the upper part of the White River (Miocene?) group.

It will be noticed that at the place referred to Marsh does not use the expression "John Day group," but "John Day basin."

?=Northern extension of the Truckee group.

KENAI GROUP.

Kenai peninsula, Alaska. W. H. Dall, 1892; this essay, p. 234; Miocene of paleobotanists, possibly Eocene.

KOWAK CLAYS.

Kowak River, northern Alaska. W. H. Dall, 1892; this essay, p. 265; Pliocene or Pleistocene.

LAFAYETTE FORMATION.

Lafayette County, Mississippi. Hilgard, Safford, and McGee, 1891; Am. Geologist, August, 1891, pp. 129–131; Pliocene.

The circumstances under which this name has come to be adopted instead of prior designations are set forth by the geologists concerned as follows: (Op. cit. pp. 129–131.)

"Orange sand, Lagrange, and Appomattox. The study lately bestowed upon the formations of the Southwestern States in connection with those of the North, and especially those of the Atlantic slope by McGee, seems to render a revision and redefinition of the above names desirable. The first two, Orange sand and Lagrange, were first applied in 1856, by Safford, to a series of beds in west Tennessee that bear a very close resemblance in general aspect; and in the mere reconnoissance then made by Safford of the region were by him presumed to be of identical age. In a subsequent report (1869) Safford recognized the fact that a portion of the beds included by him in the above designation belonged to the Cretaceous; and he accordingly defines the 'Orange sand or Lagrange group' as being of Tertiary (probably Eocene) age.

"Meanwhile I had, in 1856, examined the portion of Mississippi adjacent to the Tennessee line, and in subsequent years up to 1860 the remainder of the State. I had found what I presumed to be Safford's Orange sand more widely developed in Mississippi than even in Tennessee, and found it overlying the latest recognized Tertiary beds—the Grand Gulf rocks. Accordingly I adopted Safford's name in my Mississippi report of 1860, in which the features of the formation are described in considerable detail; and for reasons there given the 'Orange sand' is assigned to the early Quaternary.

"The intervention of the war prevented any early conference between Safford and myself on the subject; and it was only in 1869 that I learned that Safford assigned his 'Orange sand' and 'Lagrange,' as a unit, to the Eocene age.

"During our subsequent correspondence it was developed that lignitiferous beds of unquestionably Eocene, exposed not far from Lagrange, Tenn., were included by Safford within his group. I therefore suggested to him that the latter name should be retained for the yellow and gray lignitiferous sands of the Eocene that immediately overlie the 'Flatwood' or 'Porter's Creek' beds, which themselves overlie directly, and almost conformably, the uppermost Cretaceous. The name of 'Orange sand,' on the other hand, it was agreed, should designate the higher series to which it is peculiarly appropriate. To this agreement we have since adhered, and have therein been followed by other western geologists.

"As stated in my Mississippi report of 1860, I had concluded from the description of Tuomey and others that the Orange sand extended with more or less similarity of character at least to South Carolina, and probably along the Atlantic coast plain as far north as Washington.

"The excellent work carried out for some years past by McGee along the coastal plain of the Atlantic slope, while restricting somewhat the supposed northward extension of the formation, has shed much new light upon its general relations and regional modifications; and while the identity of the whole is unquestionable, and hence the prior designation (Orange sand) should stand in place of the name Appomattox applied by McGee to the Atlantic portion of the formation, yet the deviation of the former name from the accepted rule of forming such names from type localities, as well as a certain degree of confusion that has occurred in its actual use, seems to render a change advisable.

"At a late conference on the whole subject, participated in by Messrs. McGee, Joseph Le Conte, Loughridge, and myself, it was suggested that in view of the various objections to all the later names, that of 'Lafayette,' which the

LAFAYETTE FORMATION—continued.

formation had borne for several years in my early field notes (from the type localities in Lafayette County, Miss., where I first discriminated it from the Eocene sands), might appropriately be adopted, with the assent of Safford, as one of the parties to the former agreement. This having been secured, it would seem advisable that all unite upon the use hereafter of 'Lafayette' as the equivalent of the Orange sand (as understood by Safford and myself) of the Southwest and of the Appomattox as defined by McGee for the Atlantic and Southeastern States. Whatever differences of opinion may exist in regard to the genesis of the formation, or the assignment of particular local phases, will be more readily discussed and reconciled when a single name only is employed by all.

"E. W. HILGARD.

"BERKLEY, CAL., *June 15, 1891.*"

"The above paper was sent to me previous to publication for examination, and, if acceptable, for my approval. Prof. Hilgard has given the correct history of the names 'Orange sand' and 'Lagrange,' and, in the prospect of harmonizing views all around, thereby facilitating the study of the beds concerned, I heartily concur in the conclusion reached by him in conference with the gentlemen mentioned above. It is pleasant to know that in important points a satisfactory understanding now exists.

"JAS. M. SAFFORD.

"NASHVILLE, TENN., *June 22, 1891.*"

LAGRANGE GROUP, or ORANGE SAND.

Lagrange, a village, Fayette County, Tennessee. J. M. Safford, 1864; Am. Jour. Sci., 2d ser., vol. 37, p. 369.

Regarded then as Eocene; now considered by McGee as belonging to the Appomattox (Pliocene) formation.

See under Lafayette formation.

LIGNITIC, or LIGNITE GROUP.

Terms used loosely in American geology to denote—

(1) Portions or the whole of the so-called Laramie group.

(2) That portion of the Eocene of the Gulf states which lies beneath the Buhrstone formation; the Eo-lignitic of Heilprin, Northern Lignite of Hilgard, Bluff Lignitic of Safford.

LOUP FORK BEDS.

Loup Fork of Platte River, central Nebraska. F. V. Hayden and F. B. Meek, 1861; Proc. Phila. Acad. Nat. Sci., vol. 13, pp. 433, 435. "Pliocene." Miocene according to Cope.

= Loup Fork group. F. V. Hayden, 1863; Am. Jour. Sci., 2d ser., vol. 33, p. 312.

MANSFIELD GROUP.

Mansfield, a town, De Soto Parish, Louisiana. Eug. W. Hilgard, 1869; "Prelim. Rept. Geol. Reconn. La.," De Bow's Review, Sept., 1869, p. 9; also Am. Jour. Sci., Nov., 1869.

Regarded at first as intermediate in age between the Jackson and Vicksburg Eocene; more recently (Hopkin's 2d Ann. Rept. Geol. La., p. 8, and Hilgard's "Suppl. and Final Rept. Geol. Reconn. La.," pp. 40, 41) shown to be a subdivision of the Jackson.

MANTI BEDS.

Manti, name of a valley and town in eastern Utah. E. D. Cope, 1880; Am. Nat., vol. 14, p. 304. Middle Eocene, probably equivalent to the Green River shales.

MALARYNDIAN (or Lower Atlantic Miocene).

Typically developed in Maryland. Angelo Heilprin, 1882; Proc. Phila. Acad. Nat. Sci., 1882, p. 183. "Lower Miocene."

MEGALONYX BEDS.

Megalonyx, name of a characteristic genus. E. D. Cope, 1879; Bull. U. S. Geol. Surv. Terr., vol. 5, pt. 1, p. 48. Later Pliocene or Pleistocene.

MIDWAY SERIES.

Midway, a plantation and landing on Alabama River, Wilcox County, Alabama. Smith and Johnson, 1887; U. S. Geol. Surv. Bull. No. 43, p. 62. Lowest Eocene.

MILIOLITE LIMESTONE.

From the various Miliolite foraminifera it contains. Angelo Heilprin, 1887; Trans. Wagner Free Inst. Sci., vol. 1, p. 4. Upper Eocene, or "Oligocene" of Florida.

MIOCENE.

μείων (irreg. comp. of *μικρός*), less, and *καινός*, recens, new. Charles Lyell, 1833 (lectures at King's College, May or June, 1832); Principles of Geology, 1st ed., vol. 3, (about) p. 53.

See Eocene.

MIOHIPPUS SERIES.

Miohippus, a characteristic genus. O. C. Marsh, 1877; Am. Jour. Sci., 3d ser., vol. 14, p. 355. Miocene.

This term has priority over all others in designation of a certain series of deposits in Oregon now known commonly by the term John Day beds or group. The expression "John Day basin" was coined by Marsh in 1875, but this basin includes Loup Fork beds as well. The name Truckee group was in print as early as 1875, but the correlation of the Oregon deposits with those of the typical locality of this group is, in a measure, open to criticism. Cope's name, "Oregon beds," was applied in 1879.

MISSISSIPPI CLAYS.

Developed in the basin of Mississippi River. W. H. Dall, 1892; this essay, p. 157. Miocene of Grand Gulf perezone.

MONUMENT CREEK GROUP.

Monument Creek, Central Colorado. F. V. Hayden, 1869; Prelim. Field Rept. U. S. Geol. Surv. Colo. and N. Mex., pp. 39, 40. Miocene, probably. (See Rept. U. S. Geol. Surv. Terr., 1873, p. 430.)

MYTILUS BED.

Mytilus condoni, characteristic fossil. W. H. Dall, 1892; this essay, p. 228. Pliocene of Shoalwater Bay, Washington.

NAHEOLA AND MATTHEWS LANDING SERIES.

Naheola, a post-office and landing on Tombigbee River, Marengo County, Alabama; and Matthews Landing on Alabama River, Wilcox County, Alabama. Smith and Johnson, 1887; U. S. Geol. Surv. Bull. No. 43, p. 57. Eocene.

NANAFALIA SERIES.

Nanafalia, name of a village in Marengo County; also a landing and bluff on Tombigbee River, Alabama. Smith and Johnson, 1887. U. S. Geol. Surv. Bull., No. 43, p. 51. Eocene.

NASHAQUITSA SERIES.

Nashaquitsa Cliffs, southwest part of Martha's Vineyard, Massachusetts. N. S. Shaler, 1888; U. S. Geol. Surv., 7th Ann. Rept., p. 343. "Pliocene, probably."

= Weyquosque series—Shaler.

NAUSHON SERIES.

Naushon, name of an island between Martha's Vineyard and the mainland. N. S. Shaler, 1888; U. S. Geol. Surv., 7th Ann. Rept., p. 342, Pl. xx. Late Pliocene or Quaternary.

NIOBRARA GROUP.

Niobrara River, northern Nebraska. F. V. Hayden, 1870; U. S. Geol. Surv. Terr., 4th Ann. Rept., p. 170. Formerly regarded as Pliocene; according to Cope, Miocene. "Niobrara basin," Marsh, Am. Jour. Sci., 1875, 3d ser., vol. 9, p. 52.

= Loup Fork group.

NORTHERN LIGNITIC.

Containing lignite, and lying north of the marine Tertiary in Mississippi. Eug. W. Hilgard, 1860. Agric. and Geol. Miss., p. 110. Lower Eocene. Eo-lignitic of Heilprin.

NORTHERN TERTIARY.

Northern portion of the Tertiary in Delaware. James C. Booth, 1837–'38; Memoir Geol. Surv. Del. Senate edition, p. 48.

NORTH PARK DEPOSITS.

North Park, northern Colorado. A. Hague, 1877; U. S. Geol. Exp. 40th Par., vol. 2, "Descriptive Geology," p. 128; also Map 1 of Atlas accompanying the report of this exploration. 1876.

Dr. C. A. White informs us that this sheet was printed in advance of the Atlas and was distributed as early as November, 1875.

Pliocene?

NULATO SANDSTONE.

Nulato, village on the Yukon River, Alaska. W. H. Dall, 1892; this essay, p. 247 Miocene.

NUMMULITIC BEDS.

Prevalence of Nummulites. W. H. Dall, 1892; this essay, p. 103.

Include the foraminiferal phases of the uppermost part of the Vicksburg group in Florida as well as the deposits of floridite, which have resulted from their modification in the presence of phosphoric acid.

NUMMULITIC LIMESTONE.

Abundance of a supposed Nummulite (*Orbitoides mantelli*). Samuel G. Morton, 1834. Synop. Organ. Rem. Cret. Group, p. 22.

Then supposed to be Upper Cretaceous. Shown by Lyell in 1846 to be Upper Eocene. In 1847, when Lyell, through the aid of his friend, Mr. Forbes, found that the so-called *Nummulites mantelli* should be referred to the genus. *Orbitoides*, he immediately adopted the term "Orbitolite limestone" for this deposit. See Am. Jour. Sci., 1847, 2d ser., vol. 4, p. 189.

The term "Nummulitic limestone" has been applied by Heilprin to an Upper Eocene bed of Florida, characterized by *Nummulites willcoxii*. See Trans. Wagner Free Inst. Sci., 1887, vol. 1, p. 4.

OCALA GROUP.

Typical locality at Ocala, Florida. W. H. Dall, 1892; this essay, p. 331.

Includes the various foraminiferal limestones in which the Floridian and Georgian Eocene culminates, above the typical Orbitoides limestone.

OCALA LIMESTONE.

Typically developed at Ocala, Florida. W. H. Dall, 1892; this essay, p. 103. Eocene or "Oligocene."

"Ocala nummulitic bed," Dall, Trans. Wagner Free Inst. Sci., 1890, vol. 3, p. 9.

Nummulitic limestone of Heilprin, *non* Morton.

OCHEESEE BEDS.

Typically developed at Ocheesee, Jackson County, Florida. W. H. Dall, 1892; this essay, p. 105. Older Miocene.

ORANGE SAND GROUP.

Orange color of its component sands. James M. Safford, 1856. Geol. Reconn. Tenn., 1st Bienn. Rep., p. 161.

This name Safford here applies to the "Cretaceous system" of Tennessee. In an article in the Am. Jour. Sci., 2d ser., vol. 37, and in his "Geology of Tennessee," 1869, the same term is used to designate the medial portion of the Tertiary series of this State. Finally in 1876 (See Elem. Geol., by Safford and Killebrew) the term is applied to the lowest member of the post-Tertiary.

For Hilgard's application of the same. See Agric. and Geol. Miss., 1860. He considers it Quaternary.

McGee includes the greater part of Hilgard's "Orange sand" in his "Appomatox formation;" Am. Jour. Sci., July, 1890, 3d ser. vol. 40. See Lafayette formation.

As used in this essay the Orange sand refers solely to the red Pliocene sands of the Appomattox formation.

ORBITOIDES LIMESTONE.

Abundance of *Orbitoides mantelli*. M. Tuomey, 1850. 1st Bienn. Rep. Geol. Ala., pp. 154–157. Eocene.

See Nummulitic limestone.

ORBITOLITE LIMESTONE.

Abundance of *Orbitoides mantelli*. Charles Lyell, 1847. Am. Jour. Sci., 1847, 2d ser., vol. 4, p. 189. Upper Eocene. Vicksburg group, partim.

See Nummulitic limestone. This bed has also been called Orbitoides rock, Heilprin; Proc. Phila. Ac. Nat. Sci., 1881, p. 155; Orbitoitic, Heilprin, Proc. Phila. Ac. Nat. Sci., 1882, p. 184. Orbitoides limestone, Tuomey, 1st Bienn. Rep. Geol. Ala.

ORBITOLITE LIMESTONE.

Abundance of *Orbitolites floridanus* (Con.) Heilprin. Angelo Heilprin, 1887. Trans. Wag. Free Inst. Sci., vol. 1, pp. 4, 12. Lower Miocene.

This name is used by Heilprin, loc. cit., to distinguish "a type of foraminiferal rock" and not as the name of a formation or a stratigraphic unit.

= Tampa limestone, q. v.

OREGON BEDS.

Oregon, a State. E. D. Cope, 1879. U. S. Geol. Surv. Terr. Bull., vol. 5, No. 1, p. 50. Miocene.

This name was withdrawn by its author in 1884 (Bull. 3, U. S. Geol. Surv. Terr., p. 16) because King's name "Truckee group" was supposed to include the same deposits.

= John Day group.

See Miohippus series.

OREODON BEDS.

Oreodon, name of a characteristic genus. F. V. Hayden, 1862. Trans. Am. Phil. Soc., 2d ser., vol. 12, pt. 1, p. 31. Miocene, or perhaps Oligocene.

A subdivision of the White River group.

ORTHAULAX BED.

Prevalence of the genus *Orthaulax*. W. H. Dall, 1892; this essay, p. 113. Older Miocene of Florida.

The bed has also been known colloquially as the Tampa silex bed; see Dall, Trans. Wag. Free Inst. Sci., 1890, vol. 3, p. 47.

OYSTER MARL.

Abundance of the genus *Ostrea* in the marl along Peace Creek, Florida. W. H. Dall, 1892; this essay, p. 132 Lower Pliocene.

PAMUNKEY FORMATION.

Typically exposed on the river of that name in Virginia. N. H. Darton, 1891. Bull. Geol. Soc. Am., vol. 2, p. 439.

Includes the Eocene beds of Virginia and Maryland, and is the equivalent of the Eocene of Rogers and Conrad.

PATUXENT BEDS.

Typically exposed on the Patuxent River, Maryland. W. H. Dall, 1892; this essay p. 157.

Provisional term, to include the lower Chesapeake Miocene if the latter prove divisible.

PEACE CREEK BONE BED.

Vertebrate remains near Peace Creek, Florida. W. H. Dall, 1892; this essay, p. 130. Older Pliocene.

PERNA BEDS.

Prevalence of the genus *Perna*. Angelo Heilprin (colloquial ?) 1884. Jour. Acad. Nat. Sci., 2d ser., vol. 9, p. 13. Older Chesapeake Miocene of Patuxent River, near Benedict, Maryland.

PLANORBIS ROCK.

Planorbis, an abundant and characteristic genus contained in it. W. H. Dall, 1892; this essay, p. 143. Uppermost Pliocene bed of Florida.

PLIOCENE.

πλείων (comp. of *πολύς*, many) more; and *καινός*, recens, new. Charles Lyell, 1833. Principles of geology, 1st ed., vol. 3 (about), p. 53.

In a course of lectures delivered at King's College, London, during May and June, 1832, Lyell communicated to the public his views on the Tertiary formations, and accordingly the names Eocene, Miocene, and Pliocene may have been published in some scientific periodicals during the same year.

See Eocene.

PLIOHIPPUS BEDS.

Pliohippus, a characteristic genus. O. C. Marsh, 1877. "Introduction and Succession of Vertebrate Life." Plate. Author's edition, 1877. "Lower Pliocene."—Marsh. Upper Miocene.—Cope.

POISON CANYON SERIES.

Poison Canyon, along Poison Creek. South central Colorado. R. C. Hills, 1888. Proc. Colo. Sci. Soc., vol. 3, pt. 1, p. 152. Eocene. (Applied to the lithological sequence of the Huerfano Eocene in Poison Canyon.")

Poison Canyon beds, Hills, 1891; "Remarks on the classification of the Huerfano Eocene." Abstract from Proc. Colo. Sci. Soc., vol. 4, pt. 2.

PORTERS CREEK GROUP.

Porters Creek, Hardeman County, Tennessee. Jas. M. Safford, 1864. Am. Jour. Sci., 2d ser., vol. 37, p. 368. Lower Eocene.

In their Elementary Geology of Tennessee, 1876, Safford and Killebrew substitute for this name that of Hilgard, i. e., Flatwoods sands or group.

Shown by Loughridge to be stratigraphically continuous with Safford's "Bluff lignite." See Geol. Surv. Ky., Jackson Purchase Region (F), 1888, p. 41.

PROCAMELUS BEDS.

Procamelus, characteristic genus. E. D. Cope, 1879. U. S. Geol. Surv. Terr. Bull., vol. 5, pt. 1, pp. 50-52. Upper portion of the Loup Fork "Miocene."

PUGET GROUP.

Puget Sound, Washington. C. A. White, 1888. Am. Jour. Sci., 3d ser., vol. 37, p. 443. Eocene or Laramie.

RED BLUFF GROUP.

Red Bluff, a railway station, Wayne County, Mississippi. Eug. W. Hilgard, 1860. Agric. and Geol. Miss., 1860, pp. 135–6. Eocene. Probably includes Conrad's "Shell Bluff group."

RED HILLS.

Color of the formation in South Carolina. Colloquial expression locally in use for the area covered by the red Buhrstone formation, and in the geologic works of Tuomey and subsequent writers; but, perhaps, never explicitly assigned a definition in systematic stratigraphy. Upper Claiborne Eocene of South Carolina.

SALT LAKE GROUP.

Salt Lake, Utah. F. V. Hayden, 1869. Prelim. Field. Rep. U. S. Geol. Surv. Colo. and N. Mex., p. 92. "Pliocene." Miocene of Cope.?

= Humboldt group of King (partim), see Hayden's 7th Ann. Rep., 1877, p. 640.

SAND HILLS.

Composition of the formation in South Carolina.

A local expression occasionally used by geologists treating of the region, indicating the area where the country rock is composed of white siliceous Buhrstone in contradistinction to the red Buhrstone.

Lower Claibornian Eocene.

SAN FRANCISCO GROUP.

San Francisco, city and county of California. J. S. Newberry, 1857; Pac. R. R. Rept., vol. 6, pt. 2, p. 11. Miocene, for the most part.

SANTA FÉ MARLS.

Santa Fé, a town in New Mexico. F. V. Hayden, 1869. Prelim. Field. Rep. U. S. Geol. Surv. Col. and N. Mex., p. 66. "Modern Tertiary," p. 72.

Shown in Cope's report to Wheeler, 1874, to be a member of the Loup Fork division of the Miocene.

SANTEE BEDS.

Santee River, South Carolina. M. Tuomey, 1848. Rep. on Geol. of S. C., p. 156. Eocene.

SHELL BLUFF GROUP.

Shell Bluff, bluff on Savannah River, Georgia. T. A. Conrad, 1866. Am. Jour. Sci., 2d ser. vol. 41, p. 96. Upper Eocene.

The meager grounds upon which this so-called group was founded are clearly pointed out by Eug. W. Hilgard in an article in the Am. Jour. Sci., 2d ser., vol. 42, pp. 68–70. Its characteristic phase, as exhibited in the State of Mississippi, doubtless falls into Hilgard's Red bluff group, q. vid.

SHILOH MARLS.

Shiloh, a hamlet of Cumberland County, New Jersey. W. H. Dall, 1892; this essay, p. 40. Older Miocene of New Jersey.

SILICEOUS CLAIBORNE.

Siliceous character of the rocks in contrast with the calcareous Claiborne beds above. Eug. W. Hilgard, 1860. Agric. and Geol. Miss., p. 123. Eocene.

On page 226 of vol. 20, Am. Assoc. Adv. Sci., 1871, Hilgard accepts the term "Buhrstone" of Lyell and Tuomey for his "Siliceous Claiborne." See also explanation of the accompanying map opposite page 222 of that article.

SOLEN BEDS.

Prevalence of the genus *Solen*. Thomas Condon; first published by Cope from MS notes of Dr. Condon. Am. Nat., 1880, vol. 14, p. 457. Upper Miocene of Oregon, Condon.

SOPCHOPPY LIMESTONE.

Sopchoppy, a village, Wakulla County, Florida. W. H. Dall, 1892; this essay, p. 119. Older Miocene.

STAKED PLAINS FORMATION.

Staked Plains, Llano Estacado, northwestern Texas. R. T. Hill, 1889. Proc. Am. Assoc. Adv. Sci., vol. 38, p. 243. "Later Tertiary or early Quaternary." Tertiary, Hill; Amer. Geol., Feb., 1890.

ST. MARY'S BEDS.

Typically exposed on St. Mary's River, Maryland. W. H. Dall, 1892; this essay, p. 157.

Provisional term for the upper Chesapeake Miocene if the latter prove divisible.

ST. STEPHEN'S GROUP.

St. Stephen's Bluff, Washington County, Alabama. T. A. Conrad, 1855; Proc. Phila. Acad. Nat. Sci., vol. 7, p. 257. Upper Eocene.

SOUTHERN LIGNITIC GROUP—Grand Gulf group.

Hilgard writes (in litt.): "I have always used Grand Gulf group as the final equivalent of the designation first adopted in my field notes, viz, Southern Lignitic. The latter designation has hardly been used enough to entitle it to more than mere mention, and it is misleading because of the lignitic facies of the Port Hudson beds of the Gulf border."

SOUTHERN TERTIARY.

Southern portion of the Tertiary in Delaware. J. C. Booth, 1837-'38; Memoir Geol. Surv. Del., Senate edition, p. 49.

SUMTER BEDS.

Sumter, name of a town and county of South Carolina. M. Tuomey, 1848; Geol. Surv. S. C., p. 178. "Pliocene;" probably a mixture of both Miocene and Pliocene.

Sumter epoch, Dana; Manual of Geology, 1862, pp. 506-511. This term as used by Dana seems to have been intended as an equivalent in the nomenclature of American stratigraphy for the term Pliocene Period.

SWEETWATER GROUP.

Sweetwater River, south central Wyoming. F. V. Hayden, 1870. 4th Ann. Rep. U. S. Geol. Surv. Terr., 1871, p. 29. Eocene, probably.

TAMPA BEDS.

Typically exposed about Tampa, Florida. W. H. Dall, 1892; this essay, p. 112. Miocene.

Include the cherty beds of Hillsboro River and Tampa limestone.

TAMPA FORMATION.

Typically exposed at Tampa, Florida. L. C. Johnson, 1888; Am. Jour. Sci., 3d ser., vol. 36, p. 235. Miocene (at least in part. There is serious doubt as to whether the "formation" as defined is a stratigraphic unit.)

=Tampa limestone, Dall (partim).

TAMPA GROUP.

Typically exposed at Tampa, Florida. W. H. Dall, 1892; this essay, p. 112. Older Miocene, between the Chattahoochee and Chesapeake groups.

TAMPA LIMESTONE.

Typically exposed at Tampa, Florida. Heilprin (colloquially), 1887; Trans. Wagner Free Inst. Sci., vol. 1, p. 52. Dall (specifically), 1891; this essay, p. 117. Older Miocene.

Tampa Silex beds. Dall, Trans. Wag. Free Inst. Sci., 1890, vol. 3, p. 47.

See Orthaulax bed.

TEJON GROUP.

Fort Tejon, Kern County, California. W. M. Gabb, 1869; Geol. Surv. Cal., Pal., vol. 2, pp. xii-xiii. Eocene.

On the pages above referred to it is stated that Gabb read a paper before the National Academy of Sciences at Northampton, Massachusetts, in August [1868], wherein the above-mentioned group was defined.

TICHOLEPTUS BEDS.

Ticholeptus, name of a characteristic genus. E. D. Cope, 1879; Bull. U. S. Geol. Surv. Terr., vol. 5, pt. 1, pp. 50–52.

"Intermediate in all respects between the Middle and Upper Miocene formations of the West, as represented by the John Day and Loup Fork beds."—Cope, Am. Nat., 1886, vol. 20, p. 367.

TIMBER BELT OR SABINE RIVER BEDS.

Timber belt, a term applied to a certain wooded belt in Texas, and Sabine River, Texas. R. A. F. Penrose, jr., 1889; 1st Ann. Rep. Geol. Surv. Tex., 1890; p. 22 of Penrose's Report. Eocene.

TITANOTHERIUM BED.

Titanotherium, name of characteristic genus. F. V. Hayden, 1857. Proc. Phila. Acad. Nat. Sci., 1857, p. 120. Oligocene.

The lowest bed of the White River group.

TRUCKEE GROUP.

Truckee Mountains and River, Nevada. Clarence King, 1875; western half, map 1 of atlas accompanying the Repts. U. S. Geol. Explor., 40th Par. See also vol. 1 of these reports, pp. 412, 424.

Supposed by King and others to be of the same age as the John Day or Oregon beds in Oregon, and also the same as a part or the whole of the White River group east of the Rocky Mountains.

TURRITELLA MARL.

Turritella, a characteristic genus. W. H. Dall, 1892; this essay, p. 147. Pliocene of the Caloosahatchie, Florida.

TURTLE AND OREODON BEDS.

Abundance of turtle and *Oreodon* remains. F. V. Hayden, 1858; Proc. Phila. Acad. Nat. Sci., 1858, p. 150. Subdivision of the White River Miocene (Oligocene?.)

TUSCAHOMA SERIES.

Tuscahoma Landing, Choctaw County, Alabama. D. W. Langdon, July, 1891; Bull. Geol. Soc. Am., vol. 2, p. 596.

Lignitic Eocene.

UINTA GROUP.

Unita Mountains, Utah. Clarence King, 1876; atlas accompanying the 40th Par. Rept., 1876. Upper Eocene.

In 1871 Marsh (Am. Jour. Sci., 3d ser., vol. 1, p. 196) uses the term "Uintah basin" for the depression in which this group was deposited.

Brown's Park group, Powell.—White.

Diplacodon beds, Marsh.—Marsh.

UNGA CONGLOMERATE.

Unga Island, Shumagin Islands, Alaska. W. H. Dall, 1892; this essay, p. 234. Upper beds of the Kenai group, early Miocene or latest Eocene.

VENUS CANCELLATA BED.

Prevalence of this species in the bed. Angelo Heilprin, 1887; Trans. Wag. Free Inst. Sci., vol. 1, pp. 31, 32. "Post-Pliocene" of south Florida.

The bed to which this name was first applied has been proved to be late Pliocene; and to Pliocene beds of this character Dall has restricted the name, reserving for the similar Pleistocene beds the name of Bulla striata marls (q. vid.).

VENUS CANCELLATA BED.

Venus cancellata, a predominant species. W. H. Dall, 1892; this essay, p. 147, footnote. Upper Pliocene.

Venus Cancellata bed of Heilprin (partim).

VERMETUS ROCK.

Formed by the agency of that mollusk on the coast of Florida. W. H. Dall, 1892; this essay, pp. 153, 157. Pleistocene and recent "Worm rock" of the residents of Florida.

VERMILION CREEK GROUP.

Vermilion Creek, northwestern Colorado. Clarence King, 1875; Map 1, western half, of atlas accompanying the 40th Par. Reports. Eocene.

This particular sheet, Dr. White informs us, was printed in advance of the atlas above mentioned, and a copy was sent him in November, 1875. See Wasatch group of Hayden.

VICKSBURG GROUP.

Vicksburg, a city of Warren County, Mississippi. T. A. Conrad, 1846; Am. Jour. Sci., 2d ser., vol. 2, p. 124. Upper Eocene.

Otto Meyer divides this group into "Higher Vicksburgian, Middle Vicksburgian, and Lower Vicksburgian." Am. Jour. Sci., 1885, 3d ser., vol. 30, p. 71.

As used in this essay the term comprehends both the "Jackson" and "Vicksburg" groups of Conrad, and is the equivalent of the "White Limestone" as used by Smith and Johnson.

VINEYARD SERIES (or Marthas Vineyard series).

Martha's Vineyard, an island off the southern coast of Massachusetts. N. S. Shaler, 1888; U. S. Geol. Surv., 7th Ann. Rept., p. 303. "Later Miocene or Pliocene," p. 332. Now known to include both Tertiary and Cretaceous beds.

VIRGINIAN (Middle Atlantic Miocene).

State of Virginia, in which the representative beds are well developed. Angelo Heilprin, 1882; Proc. Phila. Acad. Nat. Sci., 1882, p. 183; "Middle Miocene."

VOLCANIC TERTIARY.

Volcanic origin of the material. F. H. Bradley, 1872; map of the source of Snake River; accompanying Hayden's Ann. Rep. for 1872, publ. 1873.

WALDO FORMATION.

Waldo, a village, Alachua County, Florida. L. C. Johnson, 1888; Am. Jour. Sci., 3d ser., vol. 36, p. 234. Miocene.

As defined by Johnson this includes old Miocene phosphatic rock, forming one phase of the Hawthorne beds, with newer or Chesapeake Miocene limestone analogous to the Jacksonville limestone of Florida. The typical locality near Waldo belongs in the latter category.

WASATCH GROUP.

Wasatch Mountains, Utah. F. V. Hayden, 1869; Prelim. Field Rep. U. S. Geol. Surv. Colo. and N. Mex., p. 91. Eocene. (See Cope; Proc. Am. Philos. Soc., Feb., 1872.)

=Vermilion Creek group, King,
=Bitter Creek group, Powell, } according to Dr. C. A. White.
=Washakee group, Hayden,
=Coryphodon beds, Marsh.

WASHAKEE GROUP.

Washakee (Washakie) station, Sweetwater County, Wyoming. F. V. Hayden, 1869; Prelim. Field Rept. U. S. Geol. Surv. Col. and N. Mex., p. 90. Eocene.

See Wasatch group.

WEYQUOSQUE SERIES.

Weyquosque Cliffs, in southwestern part of Martha's Vineyard. N. S. Shaler, 1888; U. S. Geol. Surv., 7th Ann. Rep., p. 320, and plate opposite p. 308. "Probably Pliocene."—Shaler.

WHITE BEACH SANDROCK.

White Beach, locality on Little Sarasota Bay, in western Manatee County, Florida. W. H. Dall, 1892; this essay, p. 114. Older Miocene.

WHITE LIMESTONE.

Character and color of its component material. Charles Lyell, 1845; Quart. Jour. Geol. Soc. Lond., vol. 1, p. 429. Eocene of South Carolina.

White limestone, Tuomey; 1st Biennl. Rept. Geol. Ala., 1850, p. 154.

Also in frequent use colloquially as an equivalent for the "Jackson group" limestone.

White limestone, Smith and Johnson; U. S. Geol. Surv. Bull. No. 43, 1887, p. 19, equals the Upper Eocene of Alabama, or the "Vicksburg group" of this essay.

WHITE RIVER GROUP.

White River, southern South Dakota. F. B. Meek and F. V. Hayden, 1861. Proc. Phila. Acad. Nat. Sci., vol. 18, pp. 443, 434.

Regarded by Leidy as Eocene in 1852 (see Leidy's Memoir in Owen's Geol. Surv. Minn., Iowa, Wisconsin, pp. 539–572), but upon paleontologic as well as stratigraphic evidence Leidy, Meek, and Hayden conclude that this group should be referred to the Miocene (Proc. Phila. Acad. Nat. Sci., 1857, p. 120). Later Cope (Am. Nat., vol. 18, p. 686) refers the same to the Oligocene; likewise Scott (Princeton Coll. Bull., 1890, vol. 2, No. 4, p. 75).

WHITE SAND.

Prevalent color of the beds in Florida. W. H. Dall, 1891. This essay, p. 156. Upper Pleistocene or recent.

WILLOW CREEK BEDS.

Willow Creek, central Colorado. Geo. H. Eldridge, 1888. "Mining Industry" of Denver, July 13, 1888. (See Am. Jour. Sci., 1889, 3d. ser., vol. 37, p. 263.)

Mr. Eldridge finding this name preoccupied, substitutes for it "Arapahoe Beds," q. vid.

WIND RIVER GROUP.

Wind River, northwest Wyoming. Meek and Hayden, 1861; Proc. Phila. Acad. Nat. Sci., vol. 13, p. 447. Eocene.

In the American Naturalist, 1878, vol 12, p. 831, Hayden states that he named and described this group in detail in 1859. Thus far we have failed to find this early description.

=Wasatch group. Hayden, Am. Nat., 1878, vol. 12, p. 831.

WOODS BLUFF OR BASHI SERIES.

Woods Bluff, a river bluff, Clarke County, Alabama; Bashi Creek, Clarke County, Alabama, Smith and Johnson, 1887; U. S. Geol. Surv. Bull. No. 43, p. 43. Eocene.

WYOMING CONGLOMERATE.

Typically developed in the State of Wyoming. Clarence King, 1875. Atlas sheet No. 1, western half, U. S. Geol. Explor. 40th Par. "Pliocene."

YELLOW CLAYS OF THE APPOQUINIMINK HUNDRED.

Appoquinimink Hundred, name given to a certain district in the State of Delaware. Jas. C. Booth, 1837–8. Memoir Geol. Surv. Del., Senate ed., p. 49, "Tertiary."

YELLOW SAND.

Color of the formation. W. H. Dall, 1891. This essay, p. 154. Late Pliocene or early Pleistocene of Florida.

YORKTOWN EPOCH.

Yorktown, York County, Virginia. J. D. Dana, 1862. Dana's Manual of Geology, 1st ed., pp. 506–511.

This term appears to have been used by Dana to indicate in American geological nomenclature the period of time occupied in the deposition of the Miocene and not as a stratigraphic term. Similarly the American Pliocene was deposited during the epoch called by Dana the Sumter epoch.

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WASHINGTON, D. C., *September*, 1892.

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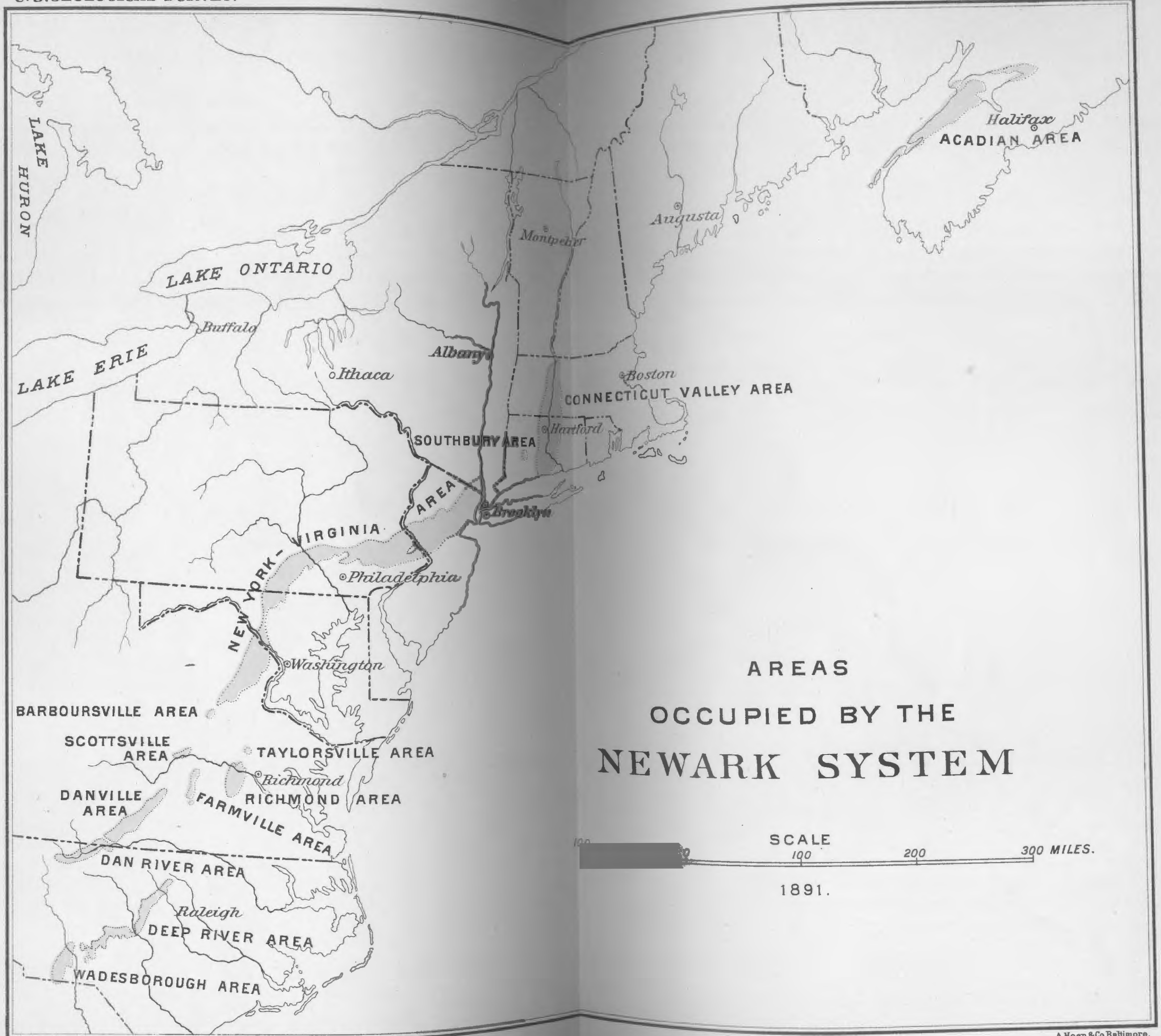

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UNITED STATES GEOLOGICAL SURVEY

J. W. POWELL, DIRECTOR

CORRELATION PAPERS

THE NEWARK SYSTEM

BY

ISRAEL COOK RUSSELL

WASHINGTON
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1892

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ILLUSTRATIONS

LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
U. S. GEOLOGICAL SURVEY,
DIVISION OF GEOLOGIC CORRELATION,
Washington, D. C., February 12, 1892.

SIR: I have the honor to transmit herewith a memoir by Mr. I. C. Russell on the Newark system, prepared for publication as a bulletin.

The Division of Geologic Correlation was created for the purpose of summarizing existing knowledge with reference to the geologic formations of North America and especially of the United States, of discussing the correlation of formations found in different parts of the country with one another and with formations in other countries, and of discussing the principles of geologic correlation in the light of American phenomena. The formations of each geologic period were assigned to some student already well acquainted with them and it was arranged that he should expand his knowledge by study of the literature and by field examination of classic localities and embody the results in an essay. The general plan of the work has been set forth on page 16 of the Ninth Annual Report of the Survey and on pages 108 to 113 of the Tenth Annual Report, as well as in the letter of transmittal of Bulletin No. 80.

The present essay is the sixth of the series, having been preceded by essays on the Carboniferous and Devonian, the Cambrian, the Cretaceous, the Eocene, and the Neocene, prepared severally by Messrs. Williams, Walcott, White, Clark, and Dall and Harris, and constituting Bulletins Nos. 80, 81, 82, 83, and 84.

The subject originally proposed for Mr. Russell covered the entire Jura-Trias of North America, and he was invited to discuss not only the correlation of American formations one with another and with European formations but also the question whether it was advisable in American geology to recognize the Jurassic and the Triassic separately as periods coordinate with the Devonian and the Carboniferous, or only to recognize the Jura-Trias as a single period. Circumstances subsequently led to important modifications of this arrangement. In the formulation of a plan for the preparation of the geologic atlas of the United States it was found necessary to adopt and define a scheme of geologic periods without awaiting the discussions contemplated in this series of essays, and, after due consideration, it was determined to recognize the Jura-Trias as a single period. One of the principal questions proposed for Mr. Russell's consideration was thus decided in advance so far as the most important work of the Survey was concerned. The acceptance by the Survey of an opportunity for Alaskan exploration by Mr. Russell left to this division the option of diminishing the scope of the present essay or of postponing its completion, and the former alternative was preferred. It was consequently arranged that Mr. Russell restrict attention to the Newark system and the principles of correlation involved in the discussion of its relations.

The rocks of the Newark system occur in a number of separate areas. In this essay these are correlated one with another primarily on physical, secondarily on paleontologic evidence. Through paleontologic evidence the system is compared with formations west of the Mississippi river and with formations in Europe, and it is concluded that homotaxial relations are approximately determined. The feasibility of determining relations of close synchronism is questioned.

Very respectfully, your obedient servant,

G. K. GILBERT,
Geologist in Charge.

Hon. J. W. POWELL,
Director U. S. Geological Survey.

OUTLINE OF THIS PAPER.

The aim of this paper is to review the progress of our knowledge concerning a well defined system of rocks on the Atlantic border, named the Newark system; to summarize the present state of information concerning it, and to discuss the bearing that its study has on principles of correlation.

Chapter I contains a historical summary of the numerous names by which the system has been designated from time to time, and also a statement of the author's reasons for adopting the term *Newark system* now used.

Chapter II contains a brief account of the geographical distribution of the various areas occupied by the system, and is accompanied by a series of maps on which the areas are shown, together with the relative age of the adjacent terranes.

Chapter III. The evidence as to the presence of Newark rocks on Prince Edward island is discussed and the conclusion reached that the system is not there represented.

Chapter IV. The lithological character of the sedimentary rocks of the system is described, and the evidence as to their thickness is presented. Coal is treated as a "rock," and some account given of its distribution and thickness.

Chapter V contains a discussion of the physical and climatic conditions under which the sedimentary rocks of the system were deposited. From an examination of the evidence bearing on the possible existence of glacial conditions in Newark times, the conclusion is reached that glaciers were not immediately concerned in the accumulation of any of the rocks of the system.

Chapter VI is a résumé of our knowledge of the life of the Newark period, as shown by the animal and plant remains that have been discovered.

Chapter VII deals with the igneous rocks which traverse the system in a great series of dikes and sheets. Following a description of the mineralogical and chemical composition of these rocks is a general account of the principal characteristics of dikes and sheets.

Chapter VIII is devoted to a description of the structure of the various Newark areas, and a discussion of its origin. The present inclination of the strata over broad areas is shown to be due principally to the tilting of faulted blocks. The effect of erosion on the upturned blocks is also considered. Original data are introduced concerning especially the structure of the more southern areas.

Chapter IX. The question of the original geographical extent of the system has been considered by several geologists, and diverse conclusions have been reached. In this chapter the opinions bearing on this question are summarized and classified under two heads: First, the "local-basin hypothesis," which includes those opinions based on the assumption that the stratified rocks of the system were deposited in several detached basins, the approximate boundaries of which are still traceable. Second, the "broad-terrane hypothesis," which embraces the conclusions of those who consider the detached areas of the system as remnants of possibly one broad terrane, which has been broken up by orographic movements and greatly eroded. The evidence is thought by the author to favor the second of these hypotheses.

Chapter X is devoted to a brief discussion of the general principles of correlation and of the relations of the Newark system to several other terranes.

Under general principles of correlation, the evidences from physical phenomena, such as superposition of strata, contained fragments, relation to folds and dikes, and to great unconformities, are considered. Under biological phenomena as a basis for correlation, the imperfections of the geological records and our incomplete knowledge of the records, such as they are, receive brief attention; as does also the bearing of evolution on the interpretation of the life history of the earth.

The difficulties in the way of correlating the rocks of America with those of other countries are indicated, and the conclusion is reached that the first aim in the study of the geology of a new country should be the definite determination of the sequence of rocks there represented, by physical phenomena, as a basis for the determination of the relative age of the faunas and floras they may contain. Subsequently, the fossils may be compared with those of distant terranes for the purpose of wider generalizations. It is pointed out that the life records in any restricted regions can not be accepted as a standard whereby to determine the age of fossil-bearing beds in other and especially in entirely disconnected terranes.

The chapter closes with a brief discussion of the relations of the Newark system to certain formations in the western part of the United States and in other countries.

THE NEWARK SYSTEM.

By Israel C. Russell.

CHAPTER I.

NOMENCLATURE.

The name "Newark system" has many synonyms. The body of rocks to which it is applied is naturally differentiated with peculiar clearness. It is separated from older rocks and from newer rocks by profound unconformities, and its boundaries are marked by strong lithological contrasts. For various reasons it is not easy to determine its precise position in the chronologic classification founded on the geologic systems of Europe. The synonymy has arisen not from doubt as to what should be included under one name, but from the fact that opinions as to correlation have been embodied in names, and these opinions have varied from time to time and from author to author. The name Newark is here preferred, because it is the oldest specific title not implying opinion as to geologic age. It was proposed by W. C. Redfield in 1856, in the following language:

> I prefer the latter designation [Newark Group] as a convenient name for these rocks [the red sandstone extending from New Jersey to Virginia], and to those of the Connecticut valley, with which they are thoroughly identified by footprints and other fossils, and I would include also the contemporaneous sandstones of Virginia and North Carolina.[1]

The term "group" used by Redfield and the term "system" here used do not imply any difference of conception, and the selection of one or the other is a matter of comparatively small importance. I have chosen system because it conforms approximately to the rule adopted by the International Congress of Geologists.

Something of the history of the study of the Newark system may be gathered from the following table, in which the various names by which it has been designated are arranged chronologically.

[1] Am. Jour. Sci., 2d ser., vol. XXII, 1856, p. 357; also in Am. Assoc. Adv. Sci., Proc., vol. X, Albany meeting, 1856, p. 181.

Names and correlations applied to the whole or to portions of the Newark system.

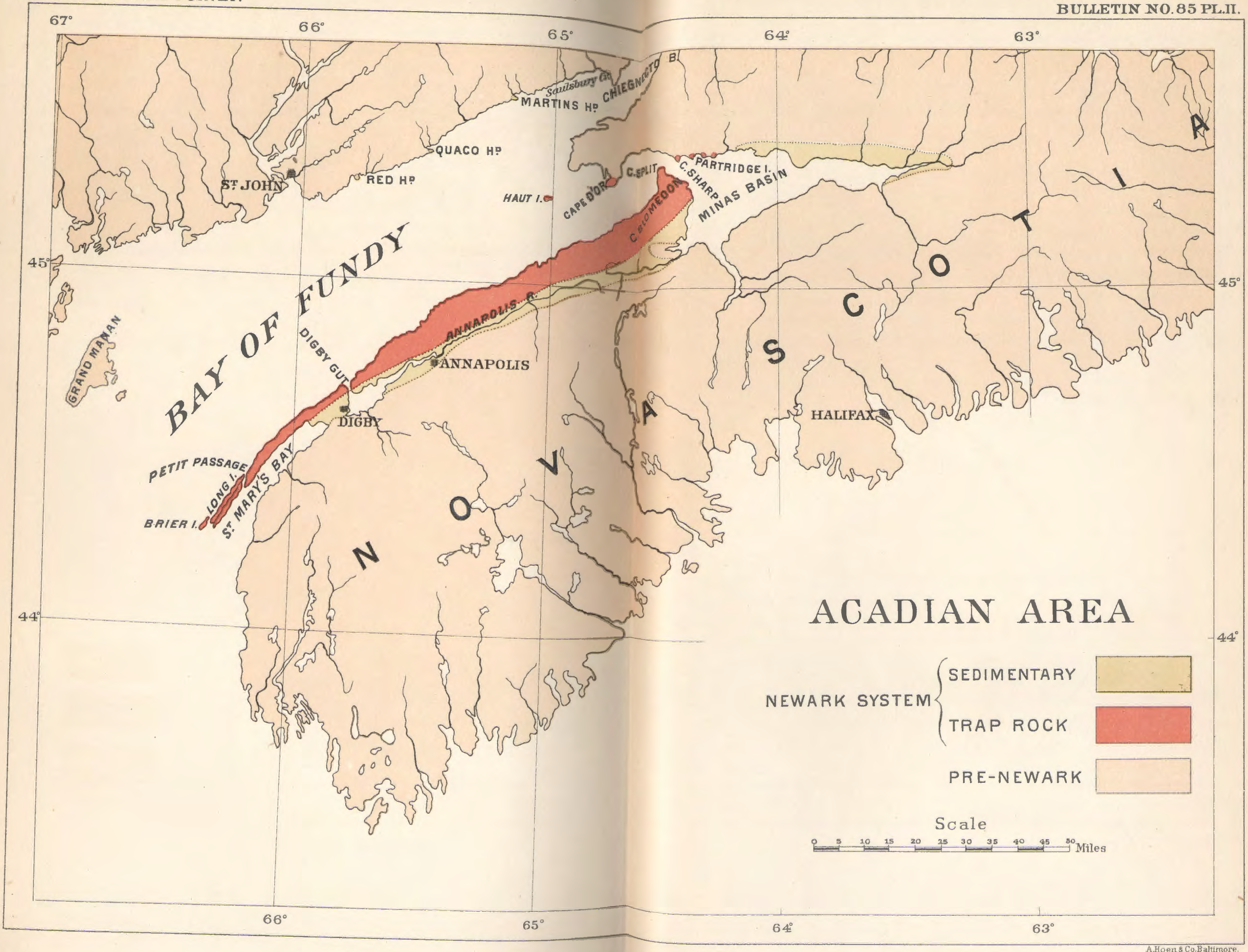
Date.	Name used.	Author.	Place of publication.
1817	Old red sandstone	Maclure, W	Am. Philo. Soc. Phila., Trans., vol. I, n. s., p. 20 and map.
1820	......do	Silliman, B	Am. Jour. Sci., 1st ser., vol. II, p. 147.
1820	......do	Nuttall, F	Acad. Nat. Sci. Phila., Jour., vol. II, p. 37.
1826	New, or variegated sandstone	Finch, J	Am. Jour. Sci., 1st ser., vol. X, p. 209.
1832	Old red sandstone and coal formation.	Hitchcock, E	Am. Jour. Sci., 1st ser., vol. VI, pl. op. p. 86.
1824	Freestone and coal formation of Orange and Chatham [N. C.].	Olmsted, D	Rep. Geol. N. C., p. 12.
1833	New red sandstone	Hitchcock, E	Rep. Geol. Mass., p. 206.
1835	Carboniferous	Taylor, R. C	Geol. Soc. Pa., Trans., vol. I, p. 294.
1836	Lias [?]	Redfield, J. H	Lyc. Nat. Hist. N. Y., Ann., vol. IV, p. 40.
1837	New red sandstone	Barratt, J	Am. Jour. Sci., 1st ser., vol. XXXI, p. 165.
1839	Silurian	Conrad, T. H	Am. Jour. Sci., 1st ser., vol. XXXV, p. 249.
1839	Middle secondary strata	Rogers, H. D	Third Ann. Rep. Geol. Pa., p. 12.
1842	Secondary formation	Percival, J. G	Rep. Geol. Conn.
1841	New red sandstone system	Hitchcock, E	Am. Jour. Sci., 1st ser., vol. XLI, p. 244.
1842	Keuper	Rogers, W. B	Am. Jour. Sci., 1st ser., vol. XLIII, p. 175.
1842	New red system; new red sandstone.	Emmons, E	Geol. of N. Y., part IV, p. 429.
1843	New red sandstone	Mather, W. W	Rep. Geol. of N. Y., part IV, p. 293.
1843	Old red sandstone and Coal Measures.	Cozzens, I	Geol. Hist. of Manhattan, p. 43.
1843	Permian	Murchison, R. I	Ann. Address Geol. Soc. London, p. 108.
1843	Oölite	Rogers, W. B	Assoc. Am. Geol. Nat., Trans., p. 298.
1844	New red sandstone	Silliman, B	Assoc. Am. Geol. Nat., Proc., pp. 14, 15.
1847	Triassic or Jurassic	Bunbury, C. J. F	Quar. Jour. Geol. Soc., Lond., vol. III, p. 288.
1847	Permian or Triassic	Lyell, C	Quar. Jour. Geol. Soc., Lond., vol. III, p. 275.
1847	Inferior Oölite?	......do	Quar. Jour. Geol. Soc., Lond., vol. III, p. 278, 280.
1849	Keuper or Lias	Marcou, J	Géol. Soc. France, Bull., vol. VI, p. 575.
1849	Lower Carboniferous	Gesner, H	Industrial Resources of Nova Scotia, p. 244.
1850	Silurian	Jackson, C. T	Am. Jour. Sci., 1st ser., vol. III, p. 335.
1851	New red sandstone	Agassiz, L	Am. Assoc. Adv. Sci., Proc., vol. V, p. 46.
1851	Triassic	Lyell, C	Roy. Institution [of Gr. Br.], vol, I, p. 50.
1851	Post Permian	Redfield, W. C	Am. Assoc. Adv. Sci., Proc., vol. V, p. 45.
1853	New red sandstone or Keuper.	Marcou, J	Geol. Map of North America.
1853	Upper Permian	Lea, I	Phil. Acad. Nat. Sci., Jour., n. s., vol. II, p. 189.
1854	Jurassic	Rogers, W. B	Boston Soc. Nat. Hist., Proc., vol. V, p. 14.
1855	Oölitic	Taylor, R. C	Statistics of coal, 2d ed., p. 289.
1855	Near the Lias of Europe	Jackson, C. T	Am. Jour. Sci., 1st ser., vol. V, p. 186.
1856	Trias or new red sandstone	Hitchcock, E	Outlines of the Geol. of the Globe, p. 96.
1856	Oölitic	......do	Outlines of the Geol. of the Globe. Map.
1856	Newark Group	Redfield, W. C	Am. Jour. Sci., 1st ser., vol. XXII, p. 357.
1856	Triassic and Jurassic	Dana, J. D	Do.
1856	Trias and Permian	Emmons, E	Geol. Rep. N. C., p. 273.
1856	Jurassic	Rogers, H. D	Geol. Map of U. S. in Johnson's Phys. Atlas.
1857	Keuper	Heer, O	Geol. of N. Am. by J. Marcou, p. 16.
1857	Permian and Triassic	Emmons, E	American Geol., part VI, p. 1.
1857	Chatham series	......do	Amer. Geol., part VI, p. 19.

Names and correlations applied to the whole or to portions of the Newark system—Cont'd.

Date.	Name used.	Author.	Place of publication.
1857	Keuper	Lyell, C	Cited by J. Marcou in Geol. of N. Am., p. 16.
1857	......do	Heer, O	In Geol. of N. Am., by J. Marcou, p. 16.
1858	Lias	Agassiz, L	In Geol. of N. Am., by J. Marcou, p. 15.
1858	Mesozoic red sandstone	Rogers, H. D	Geol. of Pa., 4to., vol. II, p. 667.
1858	Refers various portions of the system to the Keuper Trias and Jurassic.	Marcou, J	Geol. of N. Am., pp. 10–13 and map.
1859	Between the new red sandstone and the Oölitic.	Agassiz, L	Am. Assoc. Adv. Sci., Proc., vol. IV, p. 276.
1860	Mesozoic or new red sandstone.	Tyson, P. T	First Rep on Agr. Chem., Maryland, map.
1861	Carboniferous	Stevens, R. P	New York Lyc. Nat. Hist. Ann., vol. VII, p. 414.
1864	Trias	Hall, J., and W. E. Logan.	Geol. map of Canada.
1864	New red	Lesley, J. P	Am. Philo. Soc., Proc., vol. IX, pp. 478–480.
1865	Permian	Credner, H	Neues Jahrbuch, 1865, pp. 803.
1865	New red sandstone or Trias.	Matthew, G. F	Rep. on New Brunswick.
1866	Richmond coal field	Daddow, S. H., and Bannon, B.	Coal, Iron, and Oil, p. 395.
1866	Jurassic	Lyell, C	Elem. of Geol., 6 ed., p. 451.
1868	Triassic or red sandstone age.	Cook, G. H	Geol. of New Jersey, p. 173.
1869	Triassic period	Dana, J. D	Manual of Geol., p. 414.
1871	Trias	Lyell, C	Student's Elem. of Geol., p. 361.
1871	Triassic or Liassic	Shaler, N. S	Boston Soc. Nat. Hist., Proc., vol. XIV. p. 117.
1875	Triassic	Kerr, W. C	Rep. Geol. of North Carolina, p. 116.
1876	Permian	Owen, R	Quart. Jour. Geol. Soc. London, vol. XXXII, p. 359.
1876	Triasso-Jurassic	Lesquereux, L	Ann. Rep. U. S. Geol. and Geog. Surv., Hayden, for 1874, p. 283.
1878	Mesozoic formation	Heinrich, O. J	Am. Inst. Min. Eng., Trans., vol. VI, p. 227.
1878	Trias or new red sandstone.	Dawson, J. W	Acadian Geology, 3d ed., p. 86.
1878	Triassic	Russell, I. C	N. Y. Acad. Sci., Ann., vol. I, p. 220.
1878	Jura-Trias	Le Conte, J	Elem. of Geol., p. 439.
1879	Triassic-Jurassic	Dana, J. D	Am. Jour. Sci., 3d ed., vol. XVII, p. 330.
1879	Jurasso-Triassic	Rogers, W. B	Macfarlane's Railway Guide, p. 180.
1879	American new red sandstone.	Frazer, P	Am. Nat., vol. XIII, p. 284.
1879	Rhetic or Younger	Fontaine, W. M	Am. Jour. Sci., 3d ser., vol. XVII, p, 39.
1882	Triassic	Geikie, A	Text Book of Geol., p. 770.
1883	Older Mesozoic	Fontaine, W. M	Monograph No. VI., U. S. Geol. Surv.
1883	Rhetic	......do	Do.
1883	Triassic	Davis, W. M	Mus. Comp. Zool., Bull., vol. VII, No. 9.
1884	Jurasso-Triassic	McGee, W J	5th Ann. Rep. U. S. Geol. Surv., vol. II.
1884	Lower Jurassic, passing downward into Triassic.	Hotchkiss, Jed	[Reprint of Rogers's Ann. Rep., etc., of Va.], Map.
1885	Triassic	Cope, E. D	Philo. Soc. Proc., vol. XXIII, p. 403.
1885	Triassic or Mesozoic	Lesley, J. P	Geol. Atlas of Pa., vol. X, p. vii.
1886	Tria-Jurassic	Chapin, J. H	Meriden Sci. Assoc., Proc., vol. II, p. 23.
1886	Triassic	Hitchcock, C. H	Am. Inst. Min. Eng., Trans., vol. XV, pl. op. 486.

Names and correlations applied to the whole or to portions of the Newark system—Con

Date.	Name used.	Author.	Place of publication.
1887	Tria-Jurassic or Jura-Triassic.	Chapin, J. H	Meriden Sci. Assoc., Proc. and Trans., vol. II, p. 23.
1887	Trias	Emerson, B. K	Gazetteer of Hampshire Co., Mass., p. 18.
1888	Upper Trias	Zeiller, R.	Géol. Soc. France, Bull, 3d ser., vol. XVI, p. 699.
1888	Triassic	Newberry, J. S.	Monograph vol. XIV, U. S. Geol. Surv.
1889	Newark system	Russell, I. C.	Am. Geol., vol. III, pp. 178–182, vol. VII, 1891, pp. 238–291.
1890	Triassic	Marcou, J	Am. Geol., vol. V, p. 160.
1890	Connecticut, or Connecticut River sandstone.	Hitchcock, C. H.	Am. Geol., vol. V, pp. 200–202.
1890	Newark system	Darton, N. H.	U. S. Geol. Surv., Bull. No. 67.
1891	Jura-Trias	Dana, J. D	Am. Jour. Sci., 3d ser., vol. XLII, p. 79.


67°
66°
65°
64°
63°
45°
44°
BAY OF FUNDY
NOVA SCOTIA
ST. JOHN
QUACO HD.
RED HD.
MARTINS HD.
Saulsbury Co.
CHIEGNECTO B.
HAUT I.
CAPE D'OR
C. SPLIT
C. SHARP
PARTRIDGE I.
MINAS BASIN
C. BLOMEDON
ANNAPOLIS R.
ANNAPOLIS
DIGBY GUT
DIGBY
GRAND MANAN
PETIT PASSAGE
LONG I.
BRIER I.
ST. MARY'S BAY
HALIFAX
ACADIAN AREA
NEWARK SYSTEM
SEDIMENTARY
TRAP ROCK
PRE-NEWARK
Scale
0 5 10 15 20 25 30 35 40 45 50 Miles
A. Hoen & Co. Baltimore.

CHAPTER II.

AREA OCCUPIED BY THE NEWARK SYSTEM.

In studying the Newark system it has been found convenient to give specific names to the several detached portions into which it is divided. The distribution of the principal areas, together with the names by which they are designated, are shown on the general map forming Pl. I (frontispiece). Each area is also shown on a larger scale on a separate map. These form Pls. II–VI, and in several instances indicate the positions of subordinate or secondary areas. Special names have previously been applied to some of these areas by Dana,[1] Fontaine,[2] Heinrich,[3] and others, and these will be retained so far as is practicable in the general scheme of classification now adopted.

The following descriptions of the various areas have been made brief, for the reason that the accompanying maps will enable the reader to determine their positions and boundaries more conveniently than could be done from detailed descriptions. The references given will serve to indicate where special information may be found.

ACADIAN AREA.

Acadian Area, Dana.

Under this name are included all the outcrops of Newark rocks in New Brunswick and Nova Scotia (Pl. II). In New Brunswick these rocks occur in small, detached areas at Red head, Quaco head, Martin head and Salisbury cove, on the west side of the bay of Fundy, each of which occupies probably less than 1 square mile.

In Nova Scotia it forms the east shore of the bay of Fundy from Blomidon to Brier island, a distance of about 120 miles. The width of this belt varies from 5 to 10 miles, excepting at the north, where it widens and forms a large part of the shores of the basin of Minas and Cobequid bay. A portion of Grand Manan island should perhaps also be included in this enumeration. The total extent of the Acadian area is approximately 1,050 square miles.

The distribution given above is shown in part by Dawson[4] on the map accompanying his "Acadian Geology," and in part on the geological atlas sheets published by the Geological Survey of Canada.[5]

[1] Manual of Geology, 2d ed., New York, 1875, pp. 404–406.

[2] Notes on the Mesozoic of Virginia; in Am. Jour. Sci. 3d ser., vol. XVII, 1879, pp. 26–29, 31–37.

[3] The Mesozoic of Virginia; in Am. Inst. Min. Eng., Trans., vol. VI, 1879, pp. 228–238.

[4] Province of New Brunswick, Atlas sheets No. 1, N. E., and No. 1, S. E.

[5] The region occupied by the Acadian area is shown in part, on the Geological Map of Canada and Adjacent Regions, by James Hall and W. E. Logan, 1866; also on the map of the Dominion of Canada, geologically colored, from surveys made by the Canadian Geological Survey, 1842–1882.

The reason for not including Prince Edward island in this area, as has been done by many writers, is stated a few pages later.

CONNECTICUT VALLEY AREA.

Connecticut River Area, Dana.
Connecticut Valley Area, Dana.

This area occupies the Connecticut valley from a few miles south of the Massachusetts-Vermont boundary southward to Long Island sound, a distance of 110 miles. Near its eastern margin in Massachusetts there are two subordinate areas, one at Amherst and the other east of Turner Falls. Total extent about 2,000 square miles.

For the determination of the distribution of the Newark rocks in Massachusetts and Connecticut, we are indebted principally to the state surveys under the direction of Hitchcock and Percival. The map given on the accompanying plate has been compiled from Percival's geological map of Connecticut, and from a manuscript map of the geology of a portion of Massachusetts, kindly loaned by B. K. Emerson.[1]

SOUTHBURY AREA.

Southbury Area, Dana.

This outlier of the Connecticut valley area is situated 16 miles west of its western border, in the towns of Woodbury and Southbury, Connecticut. It is about 10 miles long, from north to south, and from 3 to 4 miles wide. Its outlines as shown on the accompanying plate (Pl. III) are from Percival's geological map of Connecticut, with some details added by W. M. Davis.

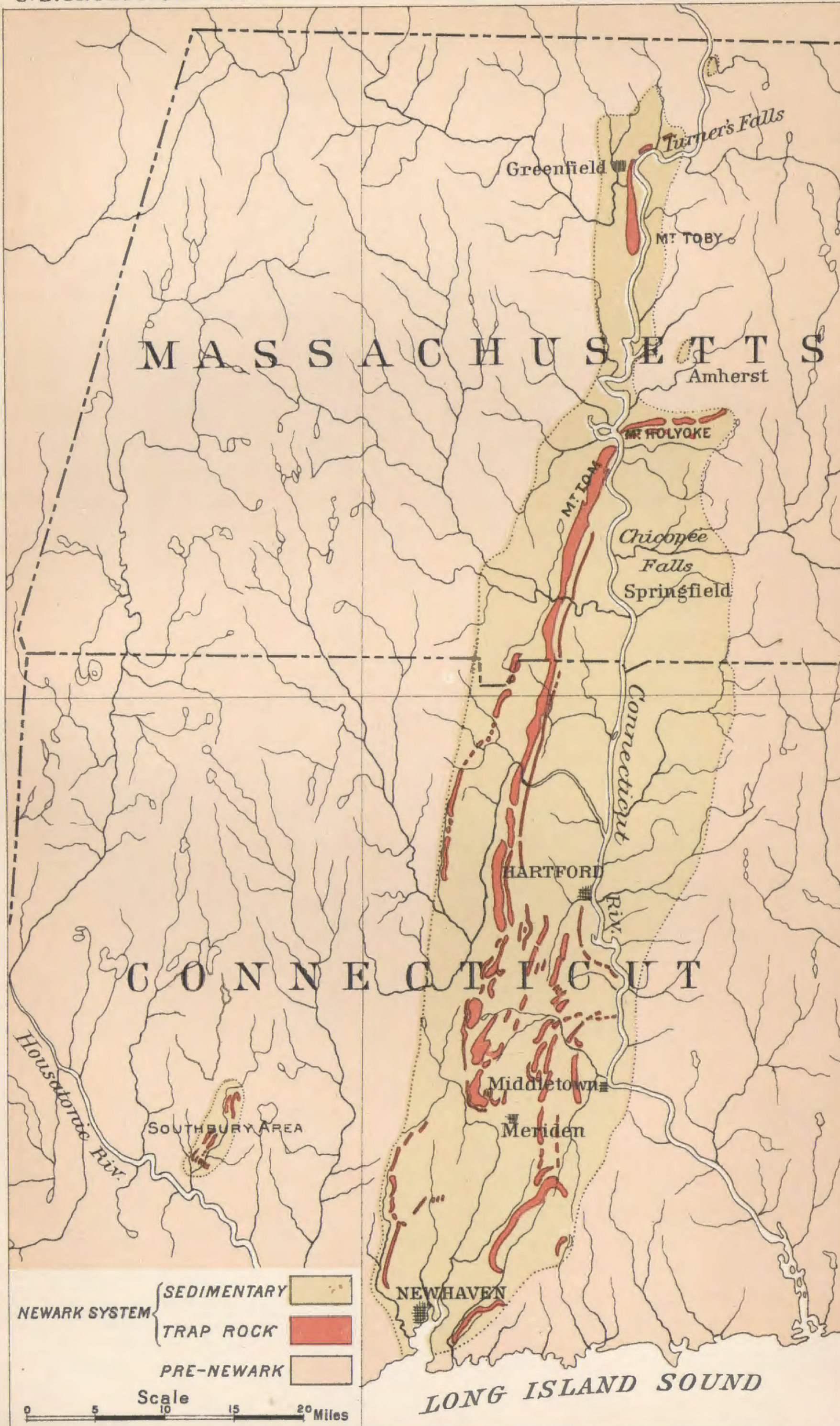
NEW YORK–VIRGINIA AREA.

Palisade Area, Dana.
New York Belt, Fontaine.
Potomac Deposit, Heinrich.

This area extends with unbroken continuity from the Hudson river, near Stony Point, New York, southward, through New Jersey, Pennsylvania, Maryland, and into Virginia as far as the Rapidan river, about 10 miles south of Culpeper (see Pl. IV). The distance in a straight line between its northern and southern extremities is about 300 miles. Its greatest width, where it is crossed by the Delaware, is 32 miles. Its area is about 5,000 square miles.

In Pennsylvania its width is greatly decreased, and the entire area bends westward and then southward. Its eastern margin is irregular, owing to deep erosion which has laid bare the Paleozoic rocks beneath. In Maryland it becomes again nearly north and south in trend, and west of Frederick, Maryland, is less than 3 miles broad. At the

[1] This map has since been published in Bull. Geol. Soc. Am., vol. II, pl. XVII.



MAP OF CONNECTICUT VALLEY AND SOUTHBURY AREAS.


NEW YORK-VIRGINIA
and other Newark areas
Scale.
0 5 10 15 20 25 30 35 40 Miles.
LEGEND
POST-NEWARK
NEWARK
SEDIMENTARY
TRAP ROCK
PRE-NEWARK
PENNSYLVANIA
NEW JERSEY
NEW YORK
HUDSON RIV.
PHILADELPHIA
DELAWARE RIVER
SUSQUEHANNA RIVER
MARYLAND
DELAWARE
DELAWARE BAY
CAPE MAY
Frederick
BALTIMORE
Leesburg
POTOMAC RIV.
WASHINGTON
Manassas
Culpeper
Charlottesville
Rappahannock Riv.
CHESAPEAKE BAY
VIRGINIA
Carbon Hill
Midlothian
RICHMOND
Clover Hill
Farmville
James Riv.
C. CHARLES
OLD PT. COMFORT
C. HENRY
79°
78°
77°
76°
75°
74°
41°
40°
39°
38°
37°
A. HOEN & CO. BALTIMORE.

Potomac it increases suddenly in width to 17 miles, and terminates abruptly south of Culpeper.

The outline of this area, as shown on P. IV has been compiled from the geological maps published by the state surveys of New York, New Jersey, Pennsylvania, and Virginia. The boundaries in Maryland are from a manuscript map prepared by G. H. Williams, of the U. S. Geological Survey. The portion in Virginia has been corrected in part by N. H. Darton and Arthur Keith, of the U. S. Geological Survey, from recent observations.

The southern part of the New York-Virginia area, and all of the areas farther south in Virginia, described below, were mapped and studied by W. B. Rogers, during his survey of Virginia, and have since been described in detail by W. M. Fontaine and O. J. Heinrich, who availed themselves of previous observations in the same field. A map showing distribution of the various Newark areas in Virginia and the northern part of North Carolina, based largely on the work of Rogers, but containing some new data, was published by Heinrich in connection with his paper on the Mesozoic of Virginia.[1] The boundaries of the Newark rocks in Virginia are minutely described by Heinrich, and it is from his essay that most of the measurements of the Virginia areas given in this paper are obtained.

BARBOURSVILLE AREA.

Barboursville Deposit, Heinrich.

This area is really an outlier of the great New York-Virginia area, from the southern end of which it is separated by about 8 miles of crystalline rocks (Pl. VII). It is situated in Orange county, Virginia, to the west of Orange, and is named from the village of Barboursville, on its west border. It is elliptical in shape and measures about 9 miles from north to south and 2 miles from east to west. Its area is about 14 square miles.

SCOTTSVILLE AREA.

Buckingham Belt, Fontaine.
James River Deposit, Heinrich.

This area is situated immediately west of Scottsville, Virginia, and is probably composed of two or more detached belts, the boundaries of which are not definiteiy known (Pl. IV). The total area of the Newark outcrops in this vicinity, as computed by Heinrich, is from 40 to 45 square miles. They form a long, narrow belt, trending northeast and southwest, intermediate between the New York-Virginia area, already referred to, and the Danville area described below.

[1] Am. Inst. Min. Eng., Trans., vol, VI, 1873, pp. 227-274.

DANVILLE AREA.

Part of Pittsylvania Belt, Fontaine.
Danville Deposit, Heinrich.

This area begins at the north near Falling river, in Campbell county, and extends southward across Staunton river to the north side of Dan river, just above Danville, Virginia (Pl. VI). Its extreme length from north to south is 54 miles, its greatest width 8 miles, and its area between 260 and 270 square miles.

DAN RIVER AREA.

Part of Pittsylvania Belt, Fontaine.
Dan River Deposit, Heinrich.
Dan River Coal Field, of various authors.

The northern end of this area is in Virginia, near Cascade creek some 10 miles west of Danville. From there it extends southward to Germantown, North Carolina, a distance of about 40 miles. Its greatest width is 8 miles, and its area approximately 200 square miles. Lakeville, North Carolina, is situated near its northern end (see Pl. VI).

TAYLORSVILLE AREA.

Taylorsville Deposit, Heinrich.

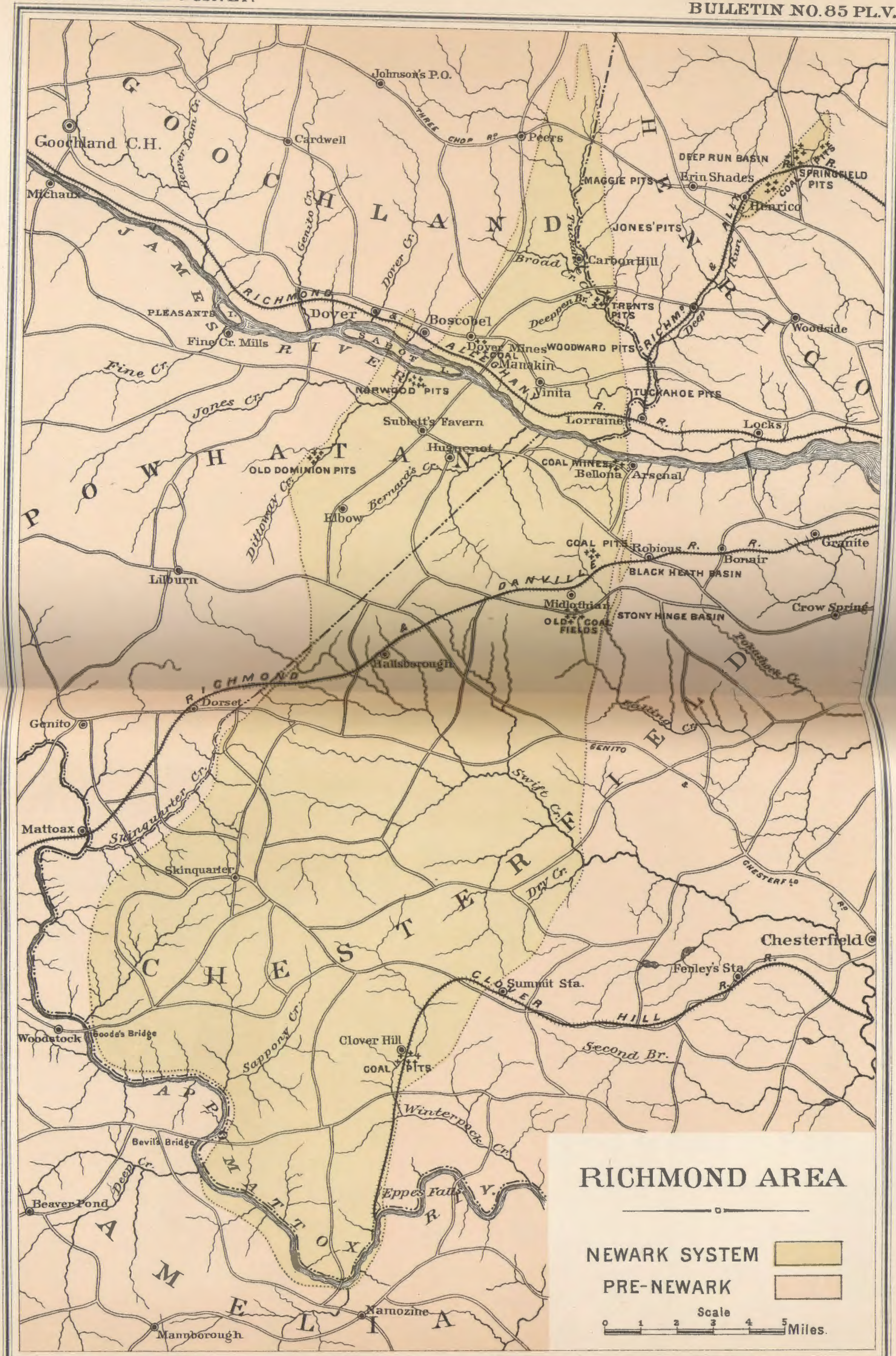
Taylorsville, Virginia, about 17 miles a little west of north of Richmond, is situated in the center of this area. Its width from east to west is about 8 miles, and its length from northwest to southeast approximately 10 miles. Its area is about 60 square miles (see Pl. V).

RICHMOND AREA.

Richmond Area, Dana.
Richmond Deposit, Heinrich.
Richmond Coal Field, of various authors.

The east border of this area is 11 miles west of Richmond, Virginia (see Pl. V). It is crossed from east to west by the James river, and thus divided into two unequal parts, the larger of which is to the south. Its extreme length from north to south, including a narrow spur which projects into the crystalline rocks at the north end, is 31½ miles. The main field, as determined by Heinrich, is 24 miles long from north to south, and 7½ to 10 miles broad. Its area is about 189 square miles.

Included under the name here used are several small detached basins along the eastern border of the main area. The most distant of these is the one in which the Deep Run mines are located, about 6 miles east of the northern end of the main area. The deposit at Deep run is designated as the Springfield deposit by Heinrich, and is stated to have an area of about 1·6 square miles.



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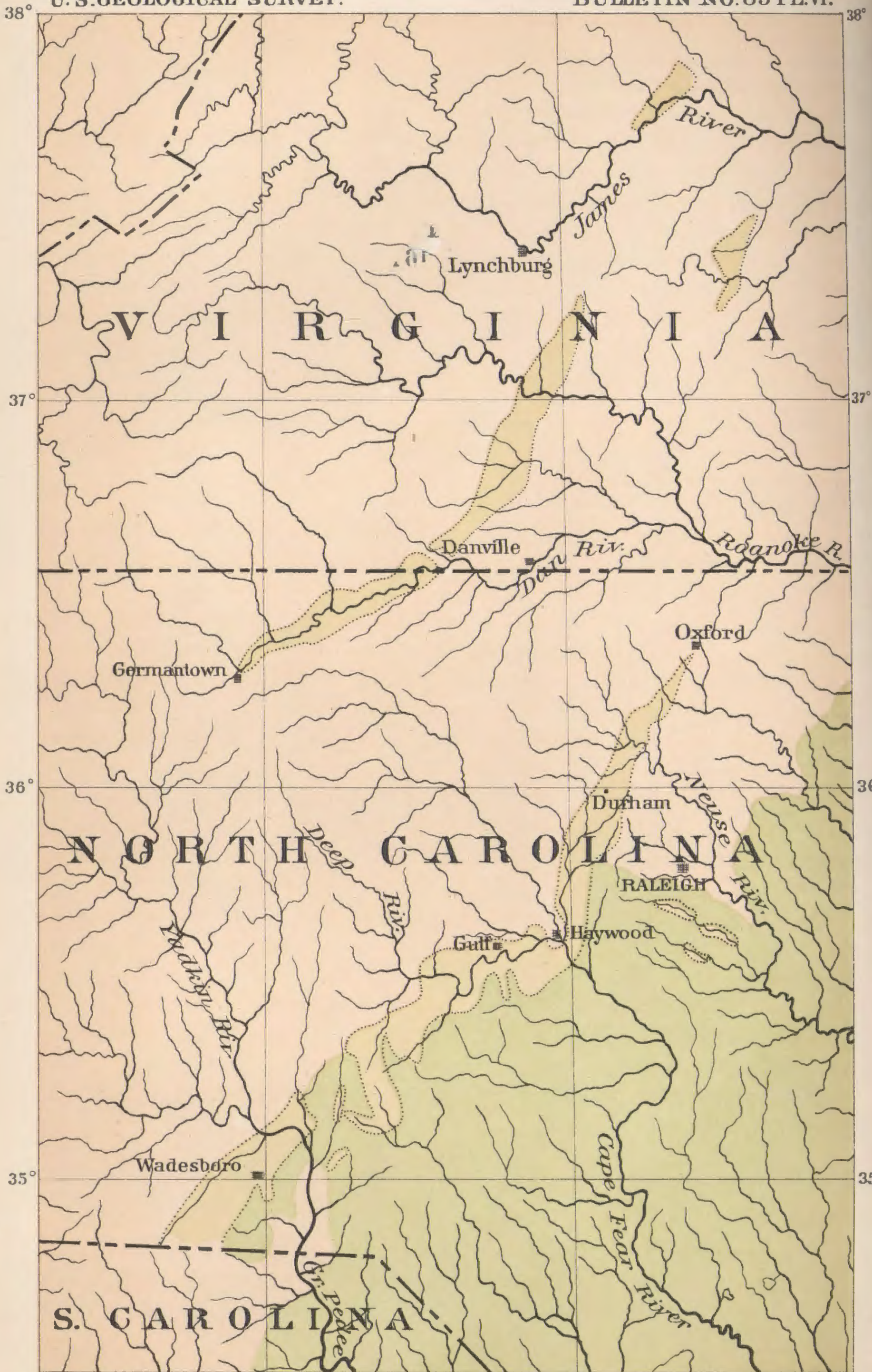

NEWARK AREAS IN SOUTHWESTERN VIRGINIA AND NORTH CAROLINA.

POST-NEWARK NEWARK SYSTEM PRE-NEWARK

Scale 0 5 10 15 20 25 30 35 40 Miles.

FARMVILLE AREA.

Farmville Deposit, Heinrich.
Prince Edward Belt Fontaine.
Farmville Coal Belt of various authors.

Under this head are included two detached areas of Newark rocks, one on the south and the other principally on the north of the Appomattox river near Farmville, Virginia (see Pl. IV). The larger area lies to the northwest of Farmville and is crossed near its southern end by the Appomattox river; it is about 10 miles long from north to south, and 2 miles wide, and has an area of about 22 square miles. The smaller area is south of the river and is less than 2 miles long from north to south, and about a mile broad. The entire surface occupied by Newark rocks near Farmville measures about 24 square miles.

DEEP RIVER AREA.

Deep River Coal Fields, Emmons.
Part of "North Carolina Area," Dana.

This area is situated wholly in North Carolina, its northern terminus being near Oxford (See Pl. VI). It extends southward in an irregular belt for about 100 miles, and has an average breadth of approximately 8 miles, but its boundaries have never been accurately determined. Its area may be stated roughly at 800 square miles. Its outline, as shown on the accompanying map, is from Kerr's geological map of North Carolina, and as determined from a reconnaissance by the present writer is only approximately correct. Owing to the lack of topographic maps in this region, it has not been practicable up to the present time to determine its boundaries more accurately than was done by Kerr. I may state in passing, however, that its east border, near Raleigh, is distant about 8 miles from that city, instead of 16 miles as shown by Kerr.

The coal mines of Egypt, Gulf, etc., are situated in this area, and next to those of the Richmond area, are the most important in the Newark system.

On both the east and west borders of the main area there are detached basins occupied by Newark rocks, some of which are indicated on Kerr's geological map.

A description of the extent of this area was given by Emmons,[1] and portions of its outline were mapped by Wilkes.[2]

WADESBORO AREA.

Part of "North Carolina Area," Dana.

The northern end of this area is near Pekin, North Carolina. From that place it extends southward to the state line, a distance of about

[1] Geological Report on the Midland Counties of North Carolina, 1856, pp. 227-254.
[2] Report on the Deep River Country, in North Carolina; in Report of the Secretary of the Navy to the Thirty-fifth Congress, second session, Senate Ex. Doc. No. 26, 1858.

30 miles. Its width near Wadesboro, where it is crossed by the Carolina railroad, is about 16 miles (see Pl. VI).

It has been stated by several writers that its southern end is in South Carolina, and it is so indicated on Kerr's map, but my own reconnaissance in that region indicates that it ends in North Carolina, close to the state boundary. Associated with it are several secondary areas, some of which were mapped by Kerr. The boundaries of the Wadesboro area, like those of the others in North Carolina, are only approximately known. Its area is in the vicinity of 275 square miles.

The Newark areas in North Carolina were studied by Emmons and Kerr during their respective surveys of the state and were mapped by Kerr.[1]

SUMMARY—AREAS AND DISTRIBUTION.

The Newark system is confined to the Atlantic border, and occurs in narrow belts, the longer, larger axes of which trend in general northeast and southwest, their general course being parallel to the folds of the Appalachians.

The distance in a straight line from the most northerly to the most southerly exposure is about 600 miles. The bearing of a line joining their two extremities is about northeast. The entire area occupied by the system is, in round numbers, 10,000 square miles.

Some of the areas were indicated in an indefinite manner on the geological maps of the United States by McClure and Marcou. They also appear on the recent geological maps of the United States, compiled by Bradley, Hitchcock, and McGee.

[1] Report on the Geology of North Carolina, vol. I, 1875, map.

CHAPTER III.

PRESENCE OR ABSENCE OF NEWARK ROCKS ON PRINCE EDWARD ISLAND.

HISTORICAL.

In the account of Prince Edward island given by Dawson in "Acadian Geology"[1] nearly all of the surface rocks, consisting mainly of sandstones and shales, are referred to the "Trias or New Red Sandstone;" but the occurrence of older rocks, considered as belonging to the Permian or to the upper portion of the Carboniferous, was noted at Gallas (Gallows) point, on the south side of the island. On the geological maps accompanying the various editions of the "Acadian Geology" the whole of the island, excepting the sand dunes along the northern shore and the trap rock of Hog island, is colored as "Trias or New Red Sandstone."

The island was reexamined by Dawson and Harrington[2] in 1871, and the classification previously established retained, but the area occupied by Carboniferous rocks was somewhat extended. On the map accompanying this report all of the island is colored as Triassic, excepting small areas at Gallas point and a narrow strip extending from West Point to Cape North, on the west shore. This distribution is retained by Dawson in the supplement to the "Acadian Geology" published in 1878. In this paper a typical section, 500 feet thick, at Oswald bay, adjacent to the Carboniferous area of Gallas point, is presented, in which the lower portion, it is stated, "may be referred to the lower division of the 'Bunter,' and the remaining to the upper division of the formation, or 'Keuper.'" That this classification was provisional is implied by the author, who remarks:[3] "The dips are so low, and the beds so much affected by oblique stratification, that those of the Trias can not be said to be unconformable to the underlying Carboniferous rocks; and for this reason, as well as on account of the similarity in mineral character between the two groups, some uncertainty may rest on the position of the line of separation. That above stated depends on fossils, on a somewhat abrupt change of mineral character, and on a slight change in the direction of the dip." The fossils on which this classification was based are referred to on a later page.

[1] Third edition, London, 1878, pp. 116–124.

[2] Report on the Geological Structure and Mineral Resources of Prince Edward island. Montreal, 1871, pp. 7, 8, 13–22, 45, 46, Pl. III.

[3] Supplement to the third edition of Acadian Geology. London, 1878, pp. 29, 30.

In 1881 some fossil plants were obtained by Bain[1] from localities on the south side of the island, in rocks previously regarded as Triassic by Dawson. These plants were identified by Bain and referred to the Permo-Carboniferous. These fossils led their discoverer to the inference that the Permo-Carboniferous formation is more extensively distributed on the south side of the island than had previously been supposed.

A few years later the geology of Prince Edward island was studied by Ellis.[2] In his report the extension of the lower series of rocks was greatly enlarged, and the conclusion reached that the area occupied by Triassic rocks was very limited. The evidence presented by this author suggests that all of the sandstones and shales of the island belong to one system. Ells states that he visited the greater part of the coast between Cape North and Oswald bay, on the south and west; various portions of the north side of the island were also carefully examined. The great similarity of the rocks at these localities to the Permo-Carboniferous rocks of New Brunswick is pointed out. It is also stated that the rocks differ in a marked manner from the Newark beds of the Minas basin, Nova Scotia. In a note on the margin of atlas sheet No. 5, S. W., accompanying this report, the author states:

> The examination made last fall showed that strata identical in character and in their contained plants, which were abundant at many points, extended around the entire south and west coast and a portion of the north of Richmond bay. The drawing of any line separating the Trias from the Upper Permo-Carboniferous in this area is not deemed practicable. The finding of the fossil reptile *"Bathygnathus"* in the rocks near New London, as well as several plants in the vicinity of Richmond bay, which have been recorded by Dr. Dawson as typical of a true Trias horizon, renders it possible that small areas of that age may occur, but their delineation will be very difficult. The great similarity of the strata of the eastern and northeastern portions of the island shows that the Triassic, if existing at all, occurs in isolated patches. It has been deemed best, therefore, to color the island uniformly Permo-Carboniferous, as most in accordance with the age of the greater portion of its strata. The great similarity of much of the formation to that seen in the northern portion of Cumberland and Colchester counties, in Nova Scotia, and which is undoubtedly the Upper Carboniferous, is very apparent.

The discussion of the geology of Prince Edward island was renewed by Bain and Dawson[3] in 1885. In the paper by these authors, Dawson refers to the conclusion cited above as follows: "Mr. Ells * * * not only extends the limits of the lower series, but regards the Trias as very limited and not clearly distinguishable from the Permo-Carboniferous; but in this last respect I can not but think he exaggerates the difficulty occasioned by the low dip of all the beds, and the strong mineral resemblance of the Trias to the underlying Permo-Carboniferous, from whose disintegration it has undoubtedly been derived." Dawson then presents the evidence furnished by fossils, and as I shall have occasion

[1] Note on fossils from the Red Sandstone System of Prince Edward island. In Canadian Naturalist, n. s., vol. IX, 1881, pp. 463–464.

[2] Report of Explorations and Surveys in the Interior of the Gaspé Peninsula, 1883. In Geol. and Nat. Hist. Surv. of Canada, Report of Progress, 1882–'83–'84. Montreal, 1885, pp. 11 E–13 E. (Accompanied by 9 atlas sheets.

[3] Notes on the geology and fossil flora of Prince Edward island. In Canadian Record of Science, vol. I, pp. 154–161.

to refer to the meagerness of these records, I quote his statement nearly entire, as it appears in the "Notes on the fossil flora of Prince Edward island," referred to above. The same evidence is presented also more or less fully in the writings of Dawson previously cited, and especially in the report of 1871. In describing the fossil plants Dawson says:

The beds at Miminigash, Gallas point, St. Peter island, Governor island, Rice point, and other places on the south coast contain plants which elsewhere characterize the Upper Carboniferous and Lower Permian. At certain points in the interior of the island and in the bays of the north coast, which represent troughs between the Permo-Carboniferous anticlinals, there are found plants indicating a higher horizon. Here the characteristic Carboniferous species are absent, and their place is taken by others, either Permian or Triassic. For example, the abundant coniferous wood of the Carboniferous species, *Dadoxylon materiarium*, is replaced by an entirely different type more characteristic elsewhere of the Trias, *Dadoxylon edvardianum*. Some of the fossils found in this by Mr. Bain are undoubtedly of Permiam aspect, as, for instance, the Walchias and *Calamites gigas*. Others, like the Dadoxylon above referred to and the curious *Cycadoidea abequidensis*, are undoubtedly more Triassic in aspect.[1]

The description of these plants is continued as follows:

The few plants collected by Mr. Bain in the Upper Trias, or Trias proper, are especially interesting in consequence of the paucity of well preserved fossils in this formation. He finds in these beds a Calamites with very fine ribs of the type *C. arenaceous*, and which may be an internal cast of that Triassic species which, when perfect, is really an Equisetum rather than a Calamite, also certain Knorri-like branches different from Tylodendron, but probably branches of coniferous trees, and a species of Walchia apparently distinct from that of the lower beds. It has very stout and straight branches marked with interrupted furrows. Its branchlets are long, slender, and crowded, and at right angles to the branch. The leaves are closely appressed, triangular, and scale like. Detached branchlets have thus the aspect of the Mesozoic genus *Pachyphyllum*, but the habit of growth is that of Walchia. The species is near to *W. imbricata* of the European Permian, but sufficiently distinct to deserve a name, and I have therefore called it *W. imbricatula*. [Figure given.]

It is to be observed that in the red sandstones of Prince Edward island all the more delicate plants and even twigs of coniferous trees have completely lost their organic matter and are represented by mere impressions, stains, or casts in clay or sand, so that it is very difficult to ascertain their minute characters.

The general result, in so far as the subdivision of beds is concerned, would seem to be that the lower series is distinctly Permo-Carboniferous, that its extent is considerably greater than was supposed in 1871, that there is a well characterized overlying Trias, and that the intermediate series, whether Permian or Lower Triassic, is of somewhat difficult local definition, but that its fossils, so far as they go, lean to the Permian side. [Pp. 160, 161.]

DISCUSSION OF THE EVIDENCE.

The evidence advanced in favor of the presence of both the Permo-Carboniferous and Triassic systems on Prince Edward island is entirely paleontological. The absence of an unconformity between the lower and upper rocks and the similarity in their lithological characters are admitted by all. The evidence of the Newark age of the upper portion of the rock series is based on a small number of fossil plants and

[1] Op. cit., p. 158.

on a single reptilian fossil, which have been considered as indicating a parallelism with the Triassic Europe.

PLANTS.

The first of the fossil plants referred to by Dawson in the quotation given above is ***Dadoxylon edvardianum***, determined from a microscopic study of fossil wood. It is related generically to other fossil woods found in the Carboniferous, and even as low down as the Devonian, and is represented by the Araücarias at the present day.

There is no reason why fossil wood should not be used as a means of determining geological horizons, if sufficient observations were recorded to determine the range of various genera and species. At present, however, only a few species of Dadoxylon are known, and these range from the Devonian upward to beyond the Mesozoic. The fact that the wood described by Dawson belongs to a hitherto unknown species of a genus of wide geological range does not indicate any definite horizon. As stated by Dawson, it has its nearest specific ally in the Trias of Europe, but also resembles a species from the Permian. If we knew the geological age of various species of this ancient pine more thoroughly, its evidence might have some weight; but at present it is a fact of interest, which it is proper to record, but can not be considered as having taxonomic importance.

The *Cycadoidea (Mantellia) abequidensis*, described by Dawson in the report for 1870, as evidence of the Triassic age of the sandstones of Prince Edward island, is based on a fragment of the trunk of a supposed Cycadeian plant, in which the structure has disappeared. It was found near Gallas point, in the immediate neighborhood of rocks that are admitted by all to be Permo-Carboniferous, and in rocks which Ells has since shown to belong to that system. Dawson refers this fossil, with doubt, to the Cycadoidea, for the reason that the limits of that genus are stated to be "less restricted than the genera *Mantellia* or *Carruthers*."

Besides the fossils just mentioned, the rocks under consideration have yielded certain obscure stems, for which Dawson creates the provisional genus "Knorria." These are stated to resemble closely certain Permian stems, described as *Schizodendron* of Eichwald, from the Permian of Europe. Whether related most nearly to the conifers or the cycads is uncertain.

In addition, there are certain flattened branches, referred to Sternbergia, and closing the list are obscure impressions referred to the fucoids.

The obscure condition in which these fossils are found is referred to by Dawson in the quotation given above. It is evident that their value as a means of determining geological age is small, on account of their imperfect preservation. There is not a single species in the list that has been found in other localities, and even the generic relations of all but the Dadoxylon are uncertain. In the rocks determined by Dawson as Permo-Carboniferous he finds Knorria-like stems and a species of *Sternbergia* which, from his description, can not be distinguished from those in the upper series. The genera *Walchia* and *Dadoxylon* also occur in the lower series. The specific identity of these plants is stated by Dawson to be different from those above; but to one reading his report the relation of the flora in the so-called Triassic rocks to the flora in the supposed lower series seems certainly more intimate than to any other flora cited by Dawson. Such relations as are pointed out seem more strongly Permian than Triassic.

To a geologist whose knowledge of paleobotany is but slight the evidence of geological age furnished by the plants in the upper portion of the sandstone of Prince Edward island seems to be very meager and unsatisfactory, but appears to tend toward Paleozoic rather than Mesozoic affinities.

While venturing to point out the small taxonomic value of the plants referred to above I do not wish to be understood as undervaluing the work of paleobotanists. By accumulating such evidence as has been recorded by Dawson and Bain we may ultimately have a reliable means of determining the identity of widely separated formations.[1]

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[1] Since writing the above I have had occasion to consult F. H. Knowlton of the U. S. Geological Survey in reference to certain specimens of fossil wood from the Newark system, and found that he had also examined the evidence as to the age of the rocks of Prince Edward island; his letter on this subject is here inserted:

I have examined the slides of the six pieces of fossil wood obtained by you from the Triassic of North Carolina, and, with the possible exception of one piece, have been able to identify them to my entire satisfaction with *Araucarioxylon arizonicum* Knowlton. This species was described (Proc. U. S. Nat. Mus., vol. XI, 1888, pp. 1-4, pl. I) from specimens collected in New Mexico and Arizona from the Shinarump group of Powell; I have also recently detected the same species, or at most only a slightly divergent variety of it, from the vicinity of the copper mines near Abiquiu, New Mexico.

This species is entirely unlike *Dadoxylon Edvardianum* described by Dawson from the so-called Triassic of Prince Edward island.

In regard to Prince Edward island, a portion of which has been referred to the Triassic by Dawson, largely upon paleobotanical evidence, I may say that I have been over the evidence with some care, and in the absence of the actual specimens for study and comparison, I think I am safe in saying that the data upon which he bases his conclusions are by no means sufficient or satisfactory. The only two forms to which he gives specific names are new to science and, *as species*, can of course have no weight in determinining stratigraphic position, but *as genera* they may have.

The first species, *Dadoxylon edvardianum*, is regarded by Dawson as being closely allied to two species from the Permian and one obscure species from the Keuper. Now, as at present understood the genus Dadoxylon does not come up into the Mesozoic, but is a Devonian or Carboniferous genus. Moreover, judging from the somewhat crude figures, it belongs decidedly to the more ancient forms showing the Araucaria-like structure characteristic of the Paleozoic, rather than the more highly differentiated forms which are now referred to Araucarioxylon.

Sternbergia is a Paleozoic genus and represents the pith of Cordaites, a genus which never goes above the Permian and had its maximum development in the Devonian and early Carboniferous.

Knorria is of no value in the present instance in determining age, since Dawson says they "very closely resemble the *Permian* stems to which Eichwald has given the name "Schizodendron," and further show internal structure similar to that of stems from undoubted Carboniferous strata (Gallas point) already referred to Dadoxylon.

Fucoids.—These are also of no value in the present case as they are very obscure and are doubtfully regarded as being fucoidal.

Cycadoidea.—This is the other form to which Dawson has given a specific name, and if it is really a cycad undoubtedly argues a Mesozoic age even later than the Triassic. But without the specimen in hand, and only judging from the figure of it, it seems not improbable that it may be a cone of some conifer, particularly when we remember the other things with which it is associated, and further than this the specimen is doubtfully from what he calls Triassiac. It is the only thing which is characteristically Mesozoic.

As for the value of the Dinosaurian remains (*Bathygnathus borealis*) I am of course unable to judge.

Very truly, yours,

F. H. KNOWLTON.

ANIMALS.

Vertebrate fossils.—In discussing the age of the sandstones of Prince Edward island the fossil reptile known as *Bathygnathus borealis* is frequently referred to. This is the only fossil besides plant remains now known from these rocks. The fossil bone with teeth, on which the genus and species mentioned were founded, was obtained by Dawson near New London, on the north side of the island, and described and figured by Leidy[1] in 1854. The remains were referred to the New Red Sandstone by Dawson and Leidy on geological determinations simply, and not on account of the zoological relations of the fossil. Even the family to which *Bathygnathus* belonged was not established until long afterwards, if it is now definitely fixed. In a later discussion of the age of the rocks in which this fossil was found, it is advanced as evidence that they are Triassic. This reasoning is not such a complete circle as it appears, however, as our knowledge of fossil reptiles has been greatly increased since *Bathygnathus* was described, and it has been determined by Cope that its nearest relation is to the Dinosaurs, which had their greatest development in Mesozoic time.

The fossil referred to was described by Leidy "as the right dental bone" of the lower jaw, with seven teeth attached. Its position was reversed, however, by Owen,[2] who claims that the bones are portions of the "skull, including the left maxillary, premaxillary, and nasal bone." It is considered by Owen as a Theirodont reptile, probably of Permian age.

Able paleontologists thus differ as to the zoological affinities of *Bathygnathus*, and as it is the sole representative of a genus, its value to the geologist as a means of identifying the horizons of the strata in which it occurs is not conspicuous. If a *Dinosaur*, as considered by several paleontologists, it would seem to indicate that the rocks in which it occurs are Mesozoic. If a *Theirodont*, as claimed by Owen, it would indicate a Permian age. To the geologist who must look to the paleontologist for the determination of the fossils he finds, the evidence of age furnished by *Bathygnathus* seems nearly equally divided between the Paleozoic and Mesozoic, but bending perhaps more strongly toward the latter.

OTHER INDICATIONS OF GEOLOGICAL POSITION.

Trap rock, undistinguishable from the similar rocks so abundant throughout the Newark system, occurs at a single locality on Prince Edward island. This has been considered by some as evidence of the Triassic age of the sedimentary beds with which it is associated. Elsewhere in this paper it is shown that the trap rocks of the Newark system belong to a vast series stretching for nearly 1,000 miles along the Atlantic coast. This series appears in the sedimentary beds of the

[1] On *Bathygnathus borealis*, an Extinct Saurian of the new red sandstone of Prince Edward island. In Philadelphia Acad. Nat. Sci. Jour., 2d ser., vol. II, 1850–1854, pp. 327–330, pl. XXXIII.

[2] Evidence of the Theirodonts in Permian deposits elsewhere than in South Africa. In Geol. Soc. of London, Quart. Jour., vol. XXXII, 1876, pp. 352–366.

Newark system as dikes and sheets, and occurs also in dikes in the rocks surrounding the various Newark areas, and cutting formations of all ages from the Archean upward to the base of the Potomac, but does not occur in rocks younger than the Newark. The only evidence of age, therefore, that can be claimed for the trap on Prince Edward island is that the rocks which it penetrates are presumptively not younger than the Newark system; they may belong to the Carboniferous or to any older series.

Throughout the various areas of the Newark system from North Carolina to Nova Scotia there is a great unconformity between the rocks of that system and those on which it rests. On Prince Edward island an unconformity between the rocks referred to the Permo-Carboniferous and those supposed to be of Newark age is wanting. While the absence of such an unconformity does not prove that there is but one system of rocks on Prince Edward island, it is strongly suggestive that such is the case.

In discussing the age of the rocks in question, nearly all comparisons have been made with the Triassic and other formations of Europe. What is of special interest, however, is their relation to the Newark system. This, it is to be presumed, can be better attained by a direct comparison than by comparisons through a more distant formation. Evidence of the relation of rocks of Prince Edward island to those of the Newark system may be looked for (1) in the fossils they contain; (2) in the lithological resemblances of the beds to those of the Newark system; and (3) their structural relations to other systems, the relations of which to the Newark are known:—

1. No fossils are known to be common to the rocks of Prince Edward island and to the Newark system.

2. Lithologically the rocks in question on Prince Edward island, as stated by Ells and others, differ widely from the rocks of the Newark system in the Acadian area, with which they are geographically nearest related; and besides, they bear a marked resemblance to the Permo-Carboniferous rocks on which they rest, and to those of New Brunswick.

3. Throughout all of the various Newark areas, as will be described later in this paper, there is a great unconformity between the rocks of the Newark system and the formations, some of which are Carboniferous, on which they rest.

CONCLUSIONS.

The absence of Newark fossils in the rocks of Prince Edward island; the close lithological similarity of the beds in the upper and lower portions of the sections there exposed, the lower rocks being Permo-Carboniferous; and the lithological difference of the rocks from the sandstone and shales of the Newark system, seem to me sufficient ground for not considering any portion of the stratified rocks of Prince Edward island as belonging to the Newark system.

CHAPTER IV.

LITHOLOGY AND STRATIGRAPHY.

The main portion of the Newark system is composed of conglomerate, breccia, arkose, sandstone, shale, and slate.[1] Of these sandstone and shale are by far the most abundant. There are besides a few thin limestone layers and deposits of coal. The igneous rocks are described in a separate section.

CONGLOMERATES AND BRECCIAS.

Coarse deposits, composed of both rounded and angular stones, occur especially at the base of the system, and along the borders of some of the areas.

Conglomerates have been reported by Emmons[2] in some of the southern areas in the medial portion of the system, or, at least, far above its base, but in some instances, as shown by my own observations, these exposures are portions of the basal conglomerate, brought to light by faulting. The prevailing structure of the system was not recognized at the time Emmons made his survey of North Carolina, and the hypothesis that the presence of conglomerates at the surface in the central portions of the Newark areas might be due to faulting was not considered. No unconformities by erosion have been recorded at the horizons where the conglomerates referred to are supposed to

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[1] Descriptions of the character and distribution of the clastic rocks of the Newark system may be found in the following works:

Acadian area: J. D. Dawson, Acadian Geology, 2d and 3d ed., pp. 86–124.

Connecticut valley area: J. G. Percival, Rep. Geol. Connecticut, 1842, pp. 426–452. Edward Hitchcock, Final Rep. Geol. Massachusetts, 1841, vol. II, pp. 441–446.

New York-Virginia area: W. W. Mather, Geol. of New York, 1843, pp. 285–289. H. D. Rogers, Description of the geology of New Jersey, Final Report, 1840, pp. 117–141. G. H. Cook, Geology of New Jersey, 1868, pp. 206–226. G. H. Cook, Geol. of New Jersey, Ann. Rep. for 1882, pp. 17–43. N. H. Darton, U. S. Geol. Survey, Bull. No. 67, 1890. H. D. Rogers, Geol. of Pennsylvania, 1858, vol. II, pp. 667–680.

New York-Virginia and other areas to the south: W. B. Rogers, A reprint of annual reports and other papers on the geology of the Virginias, 1884, pp. 323–328, 475–480. O. J. Heinrich, Mesozoic formation of Virginia; in Am. Inst. Min. Eng., Trans., vol. VI, 1878, pp. 227–274, W. M. Fontaine, Notes on the Mesozoic of Virginia; in Am. Jour. Sci., 3d ser., vol. XVII, 1879, pp. 25–39, 151–157. Ebenezer Emmons; Geological report of the midland counties of North Carolina, 1856, pp. 227–268.

The building stones of the Newark system have been described by S. W. Hawes, Report on the building stones of the U. S.; in Tenth Census of the U. S., vol. x, 1884, pp. 25–27, pl. 13. N. S. Shaler, Report on the building stones of the U. S.; in Tenth Census of the U. S., vol. x, 1884, pp. 126, 127, 141–144, 155–157, 177, 178, 179, 180, 181, 182, pls. 45, 46. S. P. Merrill, Collection of building and ornamental stones in U. S. National Museum; in Smithsonian Inst. Ann. Rep. for 1885–'86, pp. 277–648.

[2] Emmons, Ebenezer: Geol. Rep. of the midland counties of North Carolina, 1856, pp. 227–239; also, American Geology, part VI. Albany, N. Y., 1857, pp. 9–11.

occur, and additional study is necessary before such marked physical changes in the history of the system as would be implied by the presence of a widespread stratum of coarse material far above its base, can be accepted as proved.

The important and characteristic conglomerate of the system occurs at its base, and is quite generally exposed along the borders of the various areas toward which the rocks dip.

In the Acadian area the lower rocks are coarse, and form characteristic conglomerates, as is shown by exposures on the borders of the basin of Minas, and in isolated patches on the west side of the bay of Fundy.

In the Connecticut valley a coarse conglomerate, sometimes containing rounded bowlders 2 or 3 feet in diameter, occurs along the eastern margin of the area and about its northern end, but is seldom seen on its west border.

Coarse deposits also form the basal portions of the Southbury area.

In the New York-Virginia area a coarse brecciated conglomerate occurs at intervals all along the western margin. The same is true of the detached areas farther south, which fall in line with the New York-Virginia area. These are the Barboursville, Scottsville, Danville, and Dan river areas. On the east side of the New York-Virginia area coarse deposits are mostly wanting, but have been observed at a few localities in New Jersey and Pennsylvania. Beneath the Palisades along the west bank of the Hudson the basal conglomerate is represented by a coarse arkose, apparently derived from the waste of an area of feldspathic gneiss. Coarse brecciated conglomerates occur also in the more easterly areas in Virginia and North Carolina, but, contrary to what might perhaps be expected, are frequently exposed on their west borders and but seldom seen along their eastern margin. It is also frequently well exposed in small linear, outlying patches of Newark rocks, near the borders of the Richmond, Farmville, Deep river, and Wadesboro areas. These detached or secondary areas adjacent to the larger ones owe their preservation to the downward faulting of the Newark beds, which has carried portions of the basal member of the series below the plane of present denudation. The conglomerates exposed in these situations are clearly portions of the basal conglomerate.

The general absence of coarse conglomerates along the eastern border of the southeastern areas just mentioned is due, in part, to the presence of marginal faults, which bring fine offshore deposits of the Newark system in direct contact with the encircling crystalline rocks. In other places the junction of the Newark system with the crystallines is obscured by quite recent sedimentary beds and by the products of subaerial decay, so that it is difficult to determine the nature of the rocks near the line of contact.

A study of the voluminous reports and essays of various geologists, a portion of which are indicated in the foot note on page 32, aided by a personal reconnaissance, seems to warrant the conclusion that the basal portion of the system is generally a coarse brecciated conglomerate, having a thickness ranging from a few feet to perhaps 150 feet. Over considerable areas, especially along the west border of the Connecticut valley area and the east border of the New York-Virginia area, the lower beds are fine and must have been deposited at a distance from shore. The shore line against which the Newark rocks were deposited at various stages may frequently be distinguished by a marked thickening and an increase in the size of the fragments composing the basal conglomerate.

The marginal conglomerate is not a separate and independent formation capping the Newark system, as has been at times supposed, but is an extension and a local thickening of the basal conglomerate. Coarse deposits extended out from the ancient shore line in certain localities, as has been stated, and on their outer margins became interstratified with finer offshore sediments. The coarse shore deposits and the finer offshore deposits overlap and form a heterogeneous terrane.

In speaking of the former shore of the Newark estuary, it is not intended to convey the idea that the shore line at the last stage of deposition is still preserved. The whole region occupied by the Newark system has been upheaved since the last of its strata were laid down, and reduced to a base level by erosion. This process has possibly been repeated more than once. The result is that the marginal conglomerates now exposed belong in large part to the earlier stages in the deposition of the system. Neither do all of the shore deposits now exposed belong to a single horizon. As will be mentioned when the structure of the system is described, the plane of base-level erosion which determined the present surface of the Atlantic slope cuts deeper into the Newark rocks in North Carolina and Virginia than it does in New Jersey and the Connecticut valley. The marginal conglomerates are composed of both rounded and angular débris derived from adjacent portions of the encircling crystalline and Paleozoic terranes. In places it is highly calcareous, and is used for ornamental building stone and for the manufacture of lime. At other places it is largely composed of quartz pebbles and is sufficiently compact to be used for millstones. Again, it is made up of schists and slates, and can scarcely be distinguished, especially when somewhat decomposed, from the rocks of the adjacent gneissic areas from which its material was derived. The conglomerate, when calcareous and when largely composed of quartz pebbles, is usually light colored, commonly gray. It frequently carries the remains of tree trunks and branches, now changed to lignite, and obscure impressions of leaves. At other localities it is highly ferruginous, barren of fossils, and passes by insensible gradations into the ordinary brown sandstone, which is the most widely known rock of the system. In all cases, so far as can now be judged, the coarse deposits are of local origin and were derived from neighboring shores.

Associated with the coarse shore deposits, especially in the Connecticut valley and in New Jersey, there are fine, dark carbonaceous slates which contain fossil fishes and the impressions of plants.

SANDSTONES, SHALES, AND SLATES.

The greater part of the clastic rocks of the Newark system are reddish brown sandstones and ferruginous shales. These grade into each other so as to form a great variety of lithologic variations, ranging from a compact and almost vitreous sandstone to friable shales and clays so soft that they crumble between one's fingers.

Interstratified with these deeply colored rocks are occasional layers of gray sandstone and mottled shales. Although light colored strata are present in considerable thickness in certain localities, they are not sufficiently abundant to justify a modification of the statement that the characteristic color of the system is brown or brownish red.

The more compact sandstone is quarried at a large number of localities throughout the system, and is extensively used for architectural purposes in nearly all of the cities of the Atlantic coast. The reports on building stone mentioned in the footnote on page 32, give detailed information in this connection.

When the sandstones are examined under the microscope they reveal the fact that they are composed of a great variety of mineral and rock fragments, but in the main are formed of grains of quartz, feldspar, and mica. In the rocks having the characteristic ferruginous color, the individual grains are coated with a ferriginous, clayey incrustation, which also cements the particles one with another and imparts its color to the rocks.

It seems probable that the origin of the coloring matter is to be found in the subaerial decay of the crystalline and Paleozoic rocks from which the débris forming the strata were derived.[1]

Some of the strata of the Newark system are fine grained, black, highly bituminous slates. These occur to a limited extent in the Connecticut valley and New Jersey, but are present in great abundance in the Richmond, Deep river, and Dan river areas. In the southern areas these rocks are associated with coal seams, and in some instances pass into black-band iron ore of limited economic value.

LIMESTONES.[2]

The limestones are seldom more than a few feet thick and are mostly confined to a few localities in the Connecticut valley and the northern

[1] Russell, I. C.: Subaerial decay of rocks and the origin of the red color of certain formations. Bull. U. S. Geol. Surv., No. 52, 1889, pp. 45–56.

[2] Hitchcock, Edward: Geol. Massachusetts, Final Rep., 1841, vol. II, p. 444. Percival, J. G.: Geol. Connecticut, 1842, pp. 442–444. Mather, W. W.: Geol. of New York, 1843, p. 288. Rogers, H. D.: Description of the Geol. of New Jersey, Final Report, 1840, p. 134. Cook, G. H.: Geol. of New Jersey, 1868, pp. 214, 215.

part of the New York-Virginia area. Very impure limestone, scarcely distinguishable from carbonaceous slates, does occur, however, in connection with some of the coal-bearing strata at the south. These strata are distinct from the marginal calcareous conglomerates, and frequently occur at a distance of several miles from the borders of the system, and are interstratified with shales and fine-grained sandstones.

They are usually compact, light colored, fine-grained rocks, and are without fossils or other evidence of being of organic origin. Neither do they have the characteristics of chemically formed deposits. In some instances they seem to have originated from the deposition of calcareous mud derived from the erosion of adjacent limestone areas.

COAL.

In the New York-Virginia and more northern areas no coal seams have been found, although the presence of carbonized tree trunks, or other very limited quantities of carbonaceous material, have been reported from time to time as true coal seams. The usual high dip of the strata in the northern areas renders it evident that coal seams would be likely to reveal themselves did they exist. The presence of strata of highly carbonaceous shales in these areas is the only suggestion of the possible presence of coal that the geologist has to offer.

Workable beds of coal have been discovered in the Richmond, Farmville, and Deep river areas. The coal is bituminous except where alteration has occurred, owing to the heat of intruded igneous rocks.

QUALITY OF COAL.

In the Richmond field it is described by Heinrich[1] as being highly laminated, bright black, highly resinous, and composed of thick laminæ in thin layers alternating with dull black laminæ of less dimensions. On the fresh fracture, which is more or less conchoidal, it is jet black, luster resinous and splendent. It splits most readily parallel to the stratification, which is strongly marked by the alternate dark and bright layers.

This description would apply equally well to much of the coal of the Farmville and Deep river areas. As it is seen at the mines, the better grade is bright and compact, and indicates at once that it is a valuable fuel. This general impression is sustained by many tests that have been made, and by the favor with which the coal of the Richmond field, especially, has been received by those interested in gas and other industries in the city of Richmond.[2]

The average composition of eleven samples of coal from as many mines

[1] The Mesozoic formation in Virginia: Am. Inst. Min. Eng. Trans., vol. VI, 1879, p. 248.

[2] Johnson, W. R.: A report to the Navy Department of the United States on American Coal, Washington, 1844, p. 448. Other analyses may be found in O. J. Heinrich's essay on the Mesozoic of Virginia; Am. Inst. Mining. Eng., Trans., vol. VI, 1879, p. 269.

in the Richmond coal field, is given in column I below, and the analysis of an average sample of coal from Farmville, in the Deep river area, in column II.[1]

Average composition of the coals of the Newark system.

	I.	II.
Specific gravity	1.436	....
Water, at 115° C	....	2.15
Sulphur	1.232	3.72
Volatile matter	29.432	28.88
Fixed carbon	58.113	52.56
Ash	10.903	12.69
	....	100.00

NATURAL COKE.

Besides the bituminous coal which is the characteristic fuel deposits of the areas here treated, there are beds of "carbonite," "natural coke," and "semianthracite," which are modifications of the normal coal due to the heat of intruded igneous rocks.[2] Of these the most interesting and important is the natural coke. This occurs both in the Richmond and Deep river coal fields, and is of considerable economic importance. It is iron black in color, porous, has a metallic luster, and resembles artificial coke. It has been mined especially at Carbon hill and Midlothian, on the east side of the Richmond area.

The average of five analyses by various chemists, gives the composition of this substance as follows:

Average composition of natural coke.

Volatile matter	12·50
Fixed carbon	79·93
Sulphur	0·26
Ash	6·55
	99·24

[1] This and other analysis of the coal of the Deep river area may be found in H. M. Chance's report on an exploration of the coal fields of North Carolina, Raleigh, 1885, pp. 33, 34.

[2] The history of our knowledge of this substance may be traced in the following works: W. B. Rogers: On the porous anthracite, or natural coke of eastern Virginia. In Am. Jour. Sci., vol. XLIII, pp. 175–176. Also in Am. Ass. Geol. and Nat. Proc., 1840, p. 60. Report of the progress of the Geol. Surv. of Virginia for 1840, p. 124.

Johnson, W. R.: [Remarks on the Natural Coke of Virginia.] In Acad. Nat. Sci., Philadelphia Proc., vol. I, 1842, pp. 223–224. Reprinted in The Coal Trade of British America, Washington and Philadelphia, 1850, pp. 155–156. "Natural Coke" from Tuckahoe, Virginia. In a report to the Navy Department of the United States, on American coals; Washington, 1844, pp. 138–151.

Lyell, C.: On the structure and probable age of the coal field of the James river, near Richmond, Virginia. In Quart. Jour. Geol. Soc. of London, vol. III, 1847.

Rogers, W. B.: [Observations on the natural coke of the Richmond coal field, Virginia.] In Boston Soc. Nat. Hist., Proc., vol. V, 1855, pp. 53–56.

Wurtz, Henry: Preliminary note upon the carbonite or so-called "natural coke" of Virginia. In Am. Inst. Min. Eng., Trans., vol. III, 1874–'75, pp. 456–458.

Heinrich, O. J.: The Mesozoic formation in Virginia. In Am. Inst. Min. Eng. Proc., vol. VI. 1877–'78, pp. 244–269.

Chance, H. M.: Report on the North Carolina coal field, Raleigh, 1885, p. 34.

RICHMOND AREA.

The coal seams of the Richmond field are irregular in thickness, and have been greatly disturbed by faulting, as will be explained in the section of this paper devoted to structure. The seams are not continuous throughout the field, although they occur at approximately the same horizon. There is no assurance that the seams worked on one side of the basin are individually the same as those explored on the opposite side, or even in adjacent mines. Seemingly the coal occurs in lenticular beds, the outlines of which have not been determined. The edges of these beds overlap, so that while the series as a whole may be continuous over comparatively large areas, individual beds die out and are replaced by others. What is a thin seam in one mine may thicken and become the most important bed in an adjacent mine. This hypothesis, it is true, has not been fully demonstrated, but it explains many peculiarities in the field.

In the Norwood mine on the west side of the area the coal is worked by means of "inclines," in which the following section was exposed in 1885:

	Feet.
Sandstone and shale, dipping W. 20 to 25	10 to 200
Coal, with medial partings of shale	5 to 7
Shales	10 to 12
Coal, with medial parting of shale	6

In the neighboring Powhatan mine there are five coal seams, the most important having a thickness at least locally of 7 feet.

The Old Dominion mines, a mile or two south of the Norwood mines, were worked several years ago by means of a shaft, but are now abandoned. At this locality the strata were penetrated to the depth of 125 feet and found to contain three coal seams. The upper one, where it outcropped at the surface, was about 4 feet 6 inches thick, but increased to 12 feet when followed down the dip. The second was from 18 to 24 inches thick near the surface, and increased to 4 feet in the lower part of the mine. The third was struck 4 feet below the second, and contained 3 feet of coal of inferior quality.

The mines of Manakin (Dover), on the west side of the Richmond area, north of the James, were worked for more than 50 years, and a large quantity of coal obtained. They are now abandoned and the shafts are in ruins. The "Sinking shaft" at this locality penetrated over 900 feet of strata, but failed to reach a workable coal seam. F. W. Stone, the former superintendent of this mine, informed me that there were two coal seams in the Dover region. No detailed account of these deposits is available.

Coal has been mined all along the east border of the area and in adjacent local fault basins, and a large amount of data concerning the thickness and association of the local seams is available.

The section at Carbon hill, north of the James, is as follows:[1]

Section at Carbon hill, Virginia.

	Feet.
Recent formation, soil	20
Alternating shales and sandstones	450
Cinders, so-called fire clay	195
Nodula pyrites	15
Shales and sandstones	60
Coke seam { coke, 2′ 4″ ; coal, 3′ 8″ }	6
Shale and sandstone	50
Coal seam	3
Shale, third seam	17
Coal	4·5
Shale and shale and sandstone, containing 6-inch coal seam, second seam	40
Coal seam, slope seam 8 to 10 feet, first seam	9
Sandstone and slate to supposed granite base	160
	1,032·5

An extremely detailed record of the strata passed through in exploring for coal with a diamond drill at Midlothian, in the central portion of the east border of the field, has been published by Heinrich, in the paper just cited. These explorations passed through 1,518 feet of Newark rocks, and reached the underlying granite. Four coal seams were penetrated, the lowest of which is 570 feet above the granite. The record of the coal-bearing portion of this section is here copied, with some slight verbal changes:

Section at Midlothian, Virginia.

Stratum.	Thickness.		Distance above granite.	
	Feet.	In.	Feet.	In.
Sandstone, arkose, light gray, hard, partially coarse	34	9	566	4
First coal seam, 3′ 6″ coal, 1′ 6″ slate	5	0	571	4
Slate and schistose sandstone, dark gray	6	2	577	6
Sandstone, arkose, light gray, partially schistose	4	3	581	9
Slate, dark gray	8	0	589	0
Sandstone, arkose, gray	9	10	599	7
Second coal seam	1	0	600	7
Slate, gray	9	0	609	7
Sandstone, arkose, gray, hard	9	0	618	7
Third coal seam, divided by slaty bands from 2 to 24 inches	12	0	....	
Sandstone, gray, silicious, and gray slate	10	3	655	4
Fourth coal seam, divided by slaty bands	14	6	....	
Slate, block and argillacious sandstone	4	0	659	4

At Clover Hill, in the southern part of the eastern border of the Richmond area, the character of the coal-bearing strata has been

[1] Heinrich, O. J.: The Mesozoic formation of Virginia. Am. Inst. Min. Eng. Trans., vol. VI, 1879, pp. 260, 261.

recorded by Fontaine.[1] There are three main coal seams, and four others of less thickness, designated in the section as local. The strata intervening between the lowest coal seam and the granitic floor on which the system rests has not been penetrated. The dip is here to the westward at an angle of about 25 degrees, and the coal beds outcrop at the surface.

Section at Clover Hill, Virginia.

	Feet.	Inches.
Coal seam, local (?) 18 inches to	4	0
Sandstone and shale	14	0
Coal seam, local	0	12
Sandstone and shale	12	0
Coal seam, local	0	14
Sandstone and shale	25	0
Coal seam, local	0	18
Sandstone and shale	40	0
Upper bed of main coal	5	0
Shale, of varying thickness	5	0
Main coal, lower bed	13–26	0
Sandstone and shale	40	0
Lower persistent coal bed	4	9
Sandstone and shale, about	250	0
Gneissic floor		

The section here given indicates the character of the coal seams about the border of the Richmond field. In the detached secondary areas along its eastern border the rocks have been so greatly disturbed that it is difficult to obtain reliable record of the strata. It has been stated that the coal seams in these basins were from 40 to 60 feet thick. The high inclination of the beds, however, and such descriptions of the mines as can be found in books or obtained from men who worked in the mines, render it evident that the thickness of the seams has been exaggerated, as will be shown in discussing the structure of the area.

The presence of workable coal beds in the central portion of the Richmond area seems probable, although that region has not been explored. The nearly horizontal position of the rocks over the central area is a promise that the coal, when reached, will be found in a much less disturbed and broken condition than on the borders of the field. The depth at which coal will have to be looked for in the central area is in the neighborhood of 2,500 feet. At present this depth would probably render economic mining impracticable, owing to the low price of coal in neighboring markets.

FARMVILLE AREA.

Coal was formerly worked in this area in a systematic way for several years, but the seams are thin, ranging from 6 to 30 inches, and are greatly disturbed. No definite records of the strata penetrated in the various mining operations are to be had.

[1] Older Mesozoic Flora of Virginia. U. S. Geol. Surv., Monograph vol. 6, 1883, p. 6.

DEEP RIVER AREA.

There are reasons for considering the Richmond and Farmville areas in Virginia as having been formerly directly connected with the Deep river and Dan river areas of North Carolina. The coal-bearing rocks in the Deep river area have a striking analogy to the medial portion of the section obtained in the Midlothian mines. While it is presumable that the formations are continuous, there is no reason for surmising that the coal seams of one area represent individually the coal seams of the other.

At Egypt, North Carolina, in the central portion of the Deep river area, the section penetrated by what is known as the "Egypt shaft" was carefully recorded by Wilkes.[1] This shaft was 460 feet deep, and ended in black slate just below the lowest coal seam.

Section at Egypt, North Carolina.

	Feet.	Inches.
Sandstone (410 feet below surface)	3	0
Black slate	9	0
Coal	4	0
Black band, upper bed	1	4
Coal	1	1
Slate	0	6
Coal	0	7
Black bituminous slate	8	0
Gray sandstone and fire clay	16	0
Black band	1	5
Coal	1	0
Black band	3	0
Black slate	1	0

At Farmville, North Carolina, 2 or 3 miles west of the Egypt shaft, the coal-bearing strata come to the surface but are disturbed by faults and by dikes of igneous rock. The section at this locality, after Chance,[2] is as follows:

Section at Farmville, North Carolina.

	Feet.	Inches.
Upper coal (coal 3 feet, shale 2 feet, coal and slate 3 feet)	8	0
Slate and sandy fire clay	17	0
Coal	0	4
Slate and fire clay	6	0
Coal	1	0
Slate and fire clay	4	0
Coal	1	2
Slate and fire clay	4	0
Lower coal	2	0

[1] [Report on the Deep river country in North Carolina.] 35th Congress, 2d session. Senate Ex. Doc. No. 26.

[2] Report on the North Carolina coal fields, to the Department of Agriculture (of North Carolina), Raleigh, 1885, p. 22.

DAN RIVER AREA.

The rocks in this area are similar in nearly every respect to those of the Deep river area, but the shaly slates in the central portion of the series are thicker and perhaps of greater extent. They contain many bands of black bituminous and carbonaceous layers, which have been frequently mistaken for coal.

This area has been critically examined by Chance,[1] who reports that the coal occurs merely as sporadic deposits of limited extent and too thin, irregular, and uncertain to be of commercial value.

COMMERCIAL DEVELOPMENT.

Mr. Heinrich[2] states that coal was discovered in the Richmond area as early as 1700 and was then mined for local use. Systematic mining was begun about 1790. This was the first coal mined for shipment in the United States. The total production of the area from 1822 to 1878 is estimated at 5,647,621 tons. Since 1878 mining has been carried on at Clover Hill and at the Norwood and Powhatan mines, the annual output being about 700,000 tons.

Coal is reported to have been mined in a small way in the Farmville area[3] between 1855 and 1870, but no definite record of the operation is available. I have been informed that mining was resumed in 1890 with a promise of good results.

The coal seams of the Deep river and Dan river areas, like those near Richmond, outcrop at the surface. Coal was dug from open pits, for local use, early in this century, but no systematic mining was carried on until about 1850, when improvements in the navigation of Deep river rendered its shipment practicable. The most active period in the history of this field was just preceding and during the civil war.

When I visited the area in 1885 no mining was being done, although a systematic examination of the value of the coal seams near the Gulf was being made. At Egypt all work had been suspended for fully twenty years, and the deep shaft was in ruins.

In the Dan river area a little coal was mined during the war, for use in Danville.[4]

The reason for the unsatisfactory history of the Newark coal fields lies primarily in the great disturbances that the various areas have suffered on account of tilting, faulting, and igneous intrusions. The presence of "fire damp" in many of the mines and a tendency to spontaneous combustion have also added to the danger and expense of

[1] Report on the North Carolina coal fields to the Department of Agriculture (of North Carolina), Raleigh, 1885, pp. 62–66.

[2] The history of this coal field and a detailed record of the amount of coal produced in various years is given by Heinrich. Am. Inst. Min. Eng., Trans., vol. VI, pp. 266–274.

[3] The history and character of this field and of related coal-bearing areas, is given by S. H. Daddow and B. Bannan, in "Coal, Iron, and Oil, etc," Pottsville, Pa., 1866, pp. 393–406.

[4] The history of these various fields has been summarized by H. M. Chance in report on the coal fields of North Carolina, made for the State Board of Agriculture, Raleigh, 1885, pp. 22–24.

working. In all the fields mining was begun at the surface. Water was thus admitted and the most valuable portions of the beds permanently injured. The lack of foresight in the early development of the mines has practically ruined large areas.

At present the cheapness with which coal can be furnished along the Atlantic border, from the extensive mines on the west slope of the Appalachians, practically closes competition in the mines of the Newark area, where mining is more expensive than in the great fields farther west, owing to the natural difficulties suggested above. Those best qualified to judge of the value of the Richmond field are of the opinion that it contains an important reserve supply of coal which will be utilized in the future.

The value of some of the highly carbonaceous slates associated with the coal, for gas manufacture, indicates that they too will ultimately be used.

The disturbed and broken condition of the rocks here considered precludes the hope that they will ever yield even limited supplies of oil or gas.

THICKNESS OF THE NEWARK ROCKS.

Many estimates have been made of the thickness of the Newark rocks, but owing to the faulted structure that characterizes the system no generally accepted results have been reached. It is possible to measure the thickness in the Danville, Dan river, and Wadesboro areas with a reasonable approximation to accuracy, but this has not been done. The only reliable evidence of the thickness of the system available is the records of various deep borings that have been made.

An artesian well at Northampton, Massachusetts, sunk in the lower sandstone of the system, reached a depth of over 3,000 feet without reaching the underlying crystalline rocks.[1] A well bored near New Haven, Connecticut, by the Winchester Arms Company, approximately 2 miles from the west border of the Newark rocks, reaches a depth of 2,400 feet without passing through the system.[2]

Many wells have been sunk in the Newark area of New Jersey in search of artesian water. The deepest of these is at Paterson and reached a depth of 2,100 feet, all but the upper 6 feet being in the sandstones, shales, etc.[3]

Explorations for coal with the diamond drill at Midlothian, Virginia, near the eastern margin of the Richmond area, reached the underlying granite at a depth of 1,518 feet.[4]

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[1] Emerson, B. K.: (Topography and Geology of Hampshire county, Massachusetts.) In Gazetteer of Hampshire county for 1854–1887. Compiled and edited by W. B. Gray, Syracuse, N. Y. (1888), p. 19.

[2] Hubbard, O. P.: New York Acad. Sci., Trans., vol. IX, 1889–1890, p. 3. It is stated by J. D. Dana that this well shows a depth of Newark rock of at least 3,100 feet. Am. Jour. Sci., 3d ser., vol. XLII, p. 442.

[3] Cook, G. H.: Geol. Surv. of New Jersey. Ann. Rep. for 1885, Trenton, N. J., 1885, p. 115.

[4] Heinrich, O. J.: The Mesozoic Formation in Virginia. In Am. Inst. Min. Eng., Trans., vol. VI, 1879, pp. 256–260.

At Durham, North Carolina, near the west margin of the Deep river area, a well was bored a few years ago to the depth of 1,600 feet, all in rocks of the Newark system.

The data in hand are not sufficient to determine the thickness of rock in the various Newark areas, but it is evident from the records of the Northampton well that an estimate of 4,000 feet could not be considered excessive. When it is remembered that great erosion has taken place, it is evident that the original thickness of the system must have far exceeded the amount just stated.

CHAPTER V.

CONDITIONS OF DEPOSITION.

In the present section, the manner in which the various beds of the Newark were deposited as well as the evidence they contain as to the character of the climate during the time of their accumulation, will be considered.

PHYSICAL CONDITIONS.

PREVIOUS INTERPRETATIONS.

A hypothesis proposed by Rogers,[1] which refers the deposition of the rocks of a large part of the Newark system south of New York to the action of a river rising in the Southern States and emptying into the ocean in the neighborhood of the present site of New York, has met with so little favor and is so inconsistent with later observations that it seems unnecessary to consider it at this time.

The rocks of the Acadian area are considered by Dawson[2] as having been deposited in a bay resembling the present Bay of Fundy, which was swept by strong tides and currents that carried away the argillaceous matter and prevented the deposition of muddy sediments.

In reference to the conditions of deposition of the Newark system in general, Dana[3] observes that the absence of radiates, the paucity of mollusks, and the presence of few species that are properly marine, prove that the ocean had imperfect access, where any, to the regions in which the rocks were deposited. The beds are not seashore formations like the Cretaceous and Tertiary, which goes far to confirm the idea that they are partially estuary and partly of lacustrine origin.

A little later in the same volume Dana states:[4]

The position of the [Newark] beds on the Atlantic border shows that this part of the continent stood nearly at its present level. The strange absence of marine deposits along the Atlantic border may be accounted for by supposing that the dry land stretched farther out to the eastward, and that seashore deposits were formed which are submerged. A change of level of 500 feet would take a breadth of 80 miles from the ocean and add it to the continent.

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[1] Description of the geology of the state of New Jersey. A final report. Philadelphia, 1840, pp. 115, 166-171. The hypothesis proposed by Rogers is quoted by W. W. Mather in Geol. of New York, part 1, 1843, pp. 289-293, who agrees with Rogers in the main, but ascribes the deposition of the rocks of the Newark system in an inclined position to the meeting of equatorial and polar oceanic currents. The hypothesis proposed by Rogers is dissented from by E. Mitchell in "Elements of Geology, with an outline of the geology of North Carolina," 1842, p. 133.

[2] Acadian Geology, 2d and 3d editions, 1868, 1878, p. 111.

[3] Manual of Geology, 2d ed., 1875, p. 420.

[4] Ibid, pp. 422-423.

In this connection LeConte[1] writes:

During the Jura-Trias [Newark] the shore line to the north was still beyond what it is now, for no Atlantic border deposit is visible; and along the Middle and Southern States it was certainly beyond the bounding line of Tertiary and Cretaceous, for all the Atlantic deposits of this age have been covered by subsequent strata; and yet, probably not much beyond, for some of these Jura-Trias patches seem to have been in tidal connection with the Atlantic Ocean. It is probable, therefore, that the shore line was a little beyond the present New England shore line, and a little beyond the old Tertiary shore line of the Middle and Southern Atlantic States.

A little back from this shore line, and at the foot of the Appalachian chain, there was a series of old erosion or plication hollows stretching parallel to the chain. The northern ones had been brought down to the sea level, and the tides regularly ebbed and flowed there then as in the Bay of San Francisco or Puget Sound at the present time. In the waters of these bays lived swimming reptiles, Crocodilian and Lacertian, and on their flat, muddy shores walked great bird-like reptiles, and possibly reptilian birds. The more southern hollows seemed to have been been above the sea level, and were alternately coal marshes and fresh-water lakes, emptying by streams into the Atlantic; or, according to Russell, there may have been but one great sound stretching from Nova Scotia to North Carolina, in which the tides flowed and ebbed, the southern end being swampy or marshy. Since that time the coast has risen 200 or 300 feet, and these patches are therefore elevated so much above the sea level.

The physical conditions under which the rocks of the Newark system in New Jersey and the Connecticut valley were deposited, as described by Newberry,[2] are here cited:

Many of the beds show ripple marks, sun cracks, and rain drop impressions, which prove that they were once beaches or mud flats, sometimes exposed to the air. They are also frequently impressed by the tracks of large and small animals. Everything indicates that these tracks were made by animals that frequented the shores of bays and estuaries where the retreating tide left broad surfaces which were their feeding grounds. Inasmuch as many successive beds show ripple marks, sun cracks, and tracks, the conclusion seems inevitable that the areas where these strata were deposited were slowly sinking and that the land-wash spread by the tide constantly formed new sheets, upon which fresh records were inscribed.

CONCLUSIONS.

The generally accepted conclusions of geologists in reference to the mode of deposition of the rocks under discussion seem to be, that the beds were water laid and must have accumulated in land-locked estuaries and swamps. The suggestion many times advanced that these rocks are lacustral in origin has never been sustained by direct evidence.

The facts on which these conclusions are based may be summarized as follows:

(1.) Absence of characteristic marine or fresh water fossils, thus suggesting brackish water and unstable condition.

(2.) Fossil fishes closely allied to existing ganoids of rivers and lakes, which were, perhaps, migratory in their habits and, like salmon at the present time, were destroyed in large numbers at the mouths of the small streams which they frequented during the breeding season.

[1] Elements of Geology, 1882, pp. 469–470. [2] U. S. Geol. Survey, Monograph vol. 14, 1888, p. 5.

(3.) Rapid alternations of sediments which are frequently cross-bedded, and the presence of footprints, raindrop impressions, etc., indicating the prevalence of high tides.

(4.) The presence of land plants in the more carbonaceous portions of the deposit, and of fossil wood in many localities in the sandstone, indicating the proximity of land.

These facts favor the conclusion already stated, that the rocks, especially of the northern portion of the Newark system, were deposited in broad, shallow, tide-swept estuaries, in which broad expanses of mud were left exposed at low water. The southern part of the area of deposition was low and swampy, and received accumulation of carbonaceous matter. A slow subsidence during the period of deposition is shown, particularly in the northern areas, by the occurrence of footprints and raindrop impressions at many horizons.

CLIMATIC CONDITIONS.

Several expressions of opinion have been published respecting the prevailing climatic conditions during the Newark period. I will state the conclusions that have been reached, and then review briefly the evidence on which they rest.

In describing certain coarse deposits on the east border of the Deep river area in North Carolina, Kerr[1] suggested that they indicated a sub-Newark glaciation. But these deposits have been shown by Fontaine,[2] to belong at the end rather than at the beginning of the Newark period. A similar remark was made by Shaler, Davis[3] and Hitchcock,[4] in reference to the origin of the coarse conglomerates of the Newark system in the Connecticut valley.

It has been suggested by Dana[5] that the Connecticut valley had its violent floods during the Newark period, which may have been enlarged by the waters and ice of a semiglacial era.

GLACIAL HYPOTHESIS.

The most extended discussion of the glacial origin of the coarse conglomerates of the Newark system that has been made, is by Fontaine.[6] In order to give an impartial hearing to the hypothesis of Mesozoic glaciation, his conclusion is cited in full:

> I think that many of the features described in the preceding pages can best be explained by supposing that in Triassic and Jurassic times, the Appalachian mountain region was receiving supplies of snow too great to be removed by melting. Consequently the excess must have been discharged by glaciers. These must have advanced and receded more than once in the earlier periods, but did not penetrate to the sea. Toward the close of the Jurassic they advanced in such force that they

[1] Rep. of the Geol. Survey of North Carolina, vol. I, 1875, p. 146.
[2] Am. Jour. Sci., 3d ser., vol. XVII, 1879, p. 34.
[3] Illustrations of the earth's surface, Glacier, Boston, 1881, pp. 95–96.
[4] Geology of New Hampshire, Concord, 1878, vol. III, Part 3, p. 283.
[5] Am. Jour. Sci., 3d ser., vol. XVII, 1879, p. 330.
[6] Ibid., pp. 236–237.

reached the sea. In the intervening time, while the ice was gathering force, ice rafts, charged with stones and earth, floated down the streams which issued from the foot of the ice. To the frequent pushing forward, and the consequent abrasion of the matter accumulated at the foot of the ice, and in the upper course of the rivers, we must attribute much of the rounded and polished condition of the Potsdam stones now found so far to the east of their original position. This ice may have made its final advance over the whole of the portion of the Atlantic slope in which the features above described are found, or it may have issued from the Blue Ridge, mainly along the line of the Potomac and James, and then in its farther advance to the east have spread laterally, so near the border of the Azoic, as to have coalesced into one sheet. The facts observed rather favor the latter method of advance. From this supposition it would follow that the Mesozoic areas were fed by the cold waters issuing from the ice and snow on the mountains. This may account for the paucity of animal life, especially molluscan life, that they show. The only marine waters with which they could communicate contained forms that could not live in the cold inland waters.

It is probable that the courses of the present principal streams were marked out by this ice action, and hence comes their direct course and independence of the character of the rocks over which they flow. There is no difficulty in explaining the growth of the plants, now found fossil, at a time when the Appalachian mountain belt was covered with snow. All that was needed was a raising of the present winter temperature in the lowlands, for we shall show that for the formation of glaciers on the heights the climate need not have been colder than at present. Owing to the nonexistence of the Rocky mountains, the cold western and northwestern winds of the present time would not by reflection from that chain then reach the eastern slopes. At the same time the greater extension of the Gulf waters northward would cause southerly winds to sweep over these slopes. These winds passing over the cold waters of the lakes and great rivers would form abundant fogs. Thus a mild, equable, and moist climate would be produced in the lowlands, even if the earth had its present amount of cold, causing the growth of ferns, cycads, etc., and covering the hills with the immense growth of coniferous trees which we know must have existed. This condition of things would also be eminently favorable for the production of coal. This was only brought to a close in the final advance of the ice at the end of the Jurassic period, when all the abundant forms of plants of that period were extinguished to appear no more. No other cause seems adequate to explain the total extinction of the Jurassic flora, and the complete change which we find in the succeeding Cretaceous flora.

But while the plants were growing in the lowlands and around the lakes, a very different condition of things prevailed in the high Appalachians. The stratigraphy of the formations composing this belt, and the amount of erosion which, as we know, took place, make it clear that in the early Mesozoic times much of this region must have stood above the snow line, and a still larger portion near it. If we recall the physical features of the North American continent which existed at that time, we shall see that even with our present climate then prevailing, the conditions would have been eminently favorable for the formation of glaciers. Along with a sufficient degree of cold we must have abundance of moisture to produce glaciers. This would be supplied by the western and southwestern winds. The latter would sweep unchecked from the Pacific over vast bodies of warm waters in the interior, and meeting the lofty mountain belt of the Appalachians, would give unlimited supplies of snow. The configuration of this elevated district with its broad slopes, and long valleys inclining in one direction, would be eminently favorable for the collection of snow and its discharge in the form of glaciers. Indeed this region must at that time have formed a perpetual storm center. We are not without evidence, however, that a period of cold greater than that now existing, prevailed toward the close of the Jurassic, and in this we find the explanation of the advance of the ice so far to the east at that time.

The statement has recently been made by J. D. Dana[1] that the Newark period "ended in a semiglacial era, as is admitted by all who have studied the beds." The evidence which is advanced to support this view "consists of thick deposits of stones and bowlders in which occur masses 2 to 4 feet in diameter, and therefore such as only ice could have handled and transported. They are situated along the west side of the area in Virginia, Maryland, and New Jersey (where the dip of the Jura-Trias [Newark] beds is westward),[2] and on the eastern, in Connecticut and Massachusetts (where the dip is eastward). Fontaine has found in Virginia and Maryland that they are the *later beds* of the formation." Beds north of Amherst, Massachusetts, containing bowlders 3 to 4 feet in diameter are referred to, and Edward Hitchcock's conclusion, that they are the upper beds of the series, is cited. Coarse deposits near East Haven, Connecticut, are also mentioned.

The considerations which are thought to maintain the hypothesis of glaciation during the Newark period may be briefly stated as follows:

(1) Presence of coarse conglomerates and breccias at many localities.

(2) Absence of fossil mollusks, radiates, etc.

(3) Unexplained phenomena in the drainage and relief of the Appalachians.

(4) Extinction of the fauna and great changes in the flora of the Atlantic border in the interval between the Newark and Cretaceous period.

Before discussing the value of this evidence let us see what records might reasonably be looked for in case glaciers did assist in the deposition of the Newark sediments.

PRESERVATION OF GLACIAL RECORDS.

All records of glaciation when not buried beneath subsequent deposits would certainly be destroyed by atmospheric decay and erosion during such a vast lapse of time as has intervened between the Newark period and the present day. An exception to this statement may possibly exist in the effects which glaciation might impress upon the drainage and topography of a region. It is possible that some of the seemingly abnormal features in the drainage of the Appalachians may be accounted for on the hypothesis that they are an inheritance from an ancient period of ice invasion.

Among the direct evidences of glaciation which might be preserved for indefinite ages are:

(1) Smooth and striated rock surfaces, characteristic of ice action. Such surfaces if buried beneath fine sediments might be preserved in their original condition; or casts of them might be made, in the same manner that impressions of foot-prints showing the most delicate markings, have been preserved.

(2) Bowlders, smooth and striated and faceted by glaciers, might

[1] Am. Jour. Sci., 3d ser., vol. XL, 1890, p. 436.

[2] Ibid., vol. XLI, 1891, note of errata.

retain their peculiar markings for an indefinite period, especially when cemented with fine sediment or united by calcareous or other infiltrations.

(3) When a glacier enters a lake or estuary, morainal material is deposited in irregular, unassorted heaps about its foot. The distance seaward to which terminal moraines may be deposited, depends on the size of the glaciers and on the depth of the water bodies they enter. A shallow estuary or lake would offer but feeble resistance to the advance of a glacier, and might have moraines widely distributed over its bottom. On the other hand, a deep water body with precipitous shores, would retard the progress of a glacier or check its advance altogether. The result would be the formation of moraines near the water margin.

(4) When glaciers enter water sufficiently deep the ice breaks off and forms bergs which may transport stone and bowlders to great distances, and finally drop them in the fine sediments that accumulate in deep water.

(5) The effects of a glacial period on animal and plant life has received much attention, but it is difficult to indicate what permanent records of this nature might be expected. A long period of glaciation might revolutionize the fauna and flora of a region, while many alternations of warm and cold climates would produce even greater changes. Luxuriant forests, however, are known to grow close to existing glaciers. not only in tropical and subtropical regions, but in high latitudes, The Malaspina glacier, Alaska, is not only bordered by exceedingly dense forests, but the moraines resting upon its margin are covered over an area of many square miles with dense vegetation, and support forests of spruce trees, many of which are fully 3 feet in diameter. Plants indicating temperate and tropical conditions might easily be preserved in connection with glacial deposits, but such paradoxical records must, for the most part, occur in connection with the deposit of glaciers originating in lofty mountains, and not along the borders of continental glaciers like those that covered the northeastern part of North America during the Pleistocene.

The water into which large glaciers discharge either directly or after melting are cold and could not be inhabited by animals characteristic of tropical conditions. It is in the animal remains found in the fine deposits, intimately associated with glacial accumulations, that we should expect to find the best records of the climatic conditions under which the strata were deposited.

WEIGHT OF THE EVIDENCE OF GLACIATION.

Having in mind what records might reasonably be expected to occur in the rocks of the Newark system if glaciers had assisted in their deposition, let us see what the facts are:

(1) No smooth and striated rock surfaces have been discovered beneath the system.

(2) No glaciated bowlders have been observed in the coarse conglomerate.

(3) The bowlders in the conglomerates are usually rounded and are such as streams, especially if assisted by river ice, could transport. Large angular erratics are conspicuous by their absence.[1]

(4) The coarse material characteristic of portions of the system is confined principally to its bottom and sides. As the fine sediments closely associated with the coarse deposits are frequently ripple-marked and contain footprints and raindrop impressions, it is evident that the water bodies in which these beds were deposited were shallow. The water being shallow, there is no reason why glaciers should invariably stop at the shores and deposit their loads, instead of spreading widely over the basin. Besides, the coarse deposits do not have the heterogeneous character of moraines, but are frequently stratified and show current bedding, as if deposited by strong currents.

(5) Along the outer or seaward margins of the coarse layers they are interstratified with fine sediments which are not crumpled or contorted as would be expected had glaciers invaded the basins in which they were laid down.

(6) No scattered bowlders or large rock fragments, indicating iceberg drift, have been found in the fine sandstones and shales which make up the great bulk of the system.

(7) No fossils that are indicative of a cold climate have been found. As stated in a previous paper,[2] it is not probable that the great numbers of reptiles, some of them of gigantic size, which lived during the Newark period, could have existed in estuaries that were partially occupied by ice and in which icebergs were floating. Coldblooded animals at the present day are confined to warm regions, and there is no reason to suppose that this law was reversed during the Newark period. The swarms of reptiles that formerly inhabited the Connecticut valley and New Jersey regions must have required a large amount of plant or animal food. This would imply also that the shores of the Newark basin were more like those of Florida than those of Greenland at the present time.

To make more specific objections to the hypothesis of glaciation, it may be remarked that paucity of molluscan life does not necessarily indicate a cold climate, as implied by Fontaine,[3] since, as is well known, many species of shells are found in the mud at the foot of existing glaciers which terminate in the sea. The same and allied species of mollusks occur in the Pleistocene glacial clays of both Europe and America, thus showing that the existence of glaciers is not necessarily attended

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[1] Even angular rock masses 20 or 30 feet in diameter are not alone sufficient evidence of glacial action, since such masses occur in alluvial cones in the arid regions 2 or 3 miles from the outcrop from which they were derived.

[2] On the former extent of the Triassic formation of the Atlantic States. Am. Nat., vol. XIV, 1880, p. 710.

[3] Am. Jour. Sci., 3d ser., vol. XVII, 1879, p. 52.

with the extermination of the lower grades of marine life. Besides, the glacial hypothesis for accounting for the general absence of molluscan life in the Newark system is not the only one in the field; other more or less satisfactory explanations of the same phenomena have been offered, which do not imply an arctic climate.

From what has been stated in the last few pages it seems obvious that the only basis that can possibly be claimed for the glacial hypothesis under discussion, is the presence of coarse conglomerate along portions of the borders of the Newark areas. That the character and distribution of this conglomerate are such as would result from the action of waves and currents along a shore from which débris was being derived is seemingly sufficiently upheld by observations to exclude other hypotheses.

As shown elsewhere in this paper the coarse deposits are not confined to the present surface, but occur at the base of the system and interstratified with fine sediments along certain portions of the margins of the existing areas. Furthermore, the fine sediments associated with the coarse deposits are not crumpled or contorted, as would be expected had glaciers ridden over them. The rock masses forming the conglomerate are usually either rounded or subangular, and are such as high grade streams might sweep down into an estuary. Large angular masses like those occurring on many glaciers are notably absent.

In reference to the break in the succession of animal life and the great changes in the flora of the Atlantic coast between the deposition of the Newark beds and the next succeding formation, it is to be remembered that a great unconformity occurs at this horizon which makes a gap in the life records. How long this time was we have no means of judging, unless it is that during the interval the animals characteristic of the Newark become extinct and the flora greatly modified. As is well known, such breaks in stratigraphy are accompanied by equal marked modifications in the life records at many horizons in geological history. To assume that the changes in the flora and fauna between the close of the Newark and the beginning of the next period of which there is any record in the Atlantic coast region are due to a glacial epoch is doing violence to a general rule. Great breaks in stratigraphy are always accompanied by breaks in the life records.

INDICATIONS OF A MILD CLIMATE.

In an essay on the subaerial decay of rocks and the origin of the red color of certain deposits,[1] I have shown that there are reasons for considering the characteristic red color of the rocks of the Newark system as due to the subaerial decay of the débris of which they are composed previous to its deposition. It is also shown in the paper referred to that such decay occurs especially in warm humid regions. The suggestion was also made, as has been done in substance previously by Von Richthofen, that the decay indicated by the character of the ma-

[1] Bull. U. S. Geol. Survey, No. 52.

terial forming the Newark rocks may have occurred in a great measure during the Carboniferous. This hypothesis is not necessarily inconsistent with the hypothesis of glaciation, however, as the accumulated débris resulting from a long period of decay might have been removed and deposited during a subsequent period of glaciation.

The plants that have been found in the Newark system are represented at the present time mainly by Araucarian pines, ferns, equiseta, and cycads, thus suggesting a temperate or subtropical climate. Although this flora is not inconsistent with the contemporaneous existence of local glaciers, yet it may be taken as evidence that a decidedly glacial period like that of the Pleistocene did not occur during the time it flourished.

CONCLUSIONS.

The absence of glacial records seems to warrant the conclusion that glaciers did not enter the basins in which the Newark rocks were deposited. It does not follow, however, that the Appalachians were not occupied by local glaciers. The suggestion that those mountains were higher in the Newark period than now, and were covered with perennial snow, while the adjacent low lands enjoyed a mild climate, seems an attractive and very possible hypothesis, but definite evidence as to its verity has not been obtained. The proof that the climate of the Atlantic slope during the Newark period resembled that of Italy at the present day, with glaciers on the neighboring mountains, must be looked for in the drainage and sculpturing of the mountains, and the character and distribution of the débris washed from them. A period of long decay preceding the birth of the Appalachian glaciers would have prepared land to furnish abundant débris when the facilities for transportation were augmented.

RÉSUMÉ.

In this chapter an attempt has been made to show that the Newark sedimentary rocks including conglomerate, sandstones, and shales were probably deposited in tide-swept estuaries, while the carbonaceous shales and associated coal seams originated in basins more thoroughly shut off from the sea. The carbonaceous deposits are confined to the southern areas, and indicate that subsidence was there less rapid than farther north.

The eastern borders of the Newark estuary can only be determined in part; portions of an eastern shore are preserved in the Connecticut valley, and course conglomerates on the east side of the Deep river area seem to show that there was land to the eastward in that region, as has been suggested by Kerr. Further than this, the facts in hand do not warrant definite conclusions.

The climate of the period does not seem to have been marked by extremes. Certainly the evidence indicating glaciation is weak, while the suggestion of a mild climate has many considerations in its favor.

CHAPTER VI.

LIFE RECORDS.

The fossils now known from the system under review comprise two genera of Marsupialoid mammals; a large number of batrachians and reptiles, represented in part by bones and teeth, but principally by footprints; several genera of fishes; a few imperfectly preserved molluscan shells; a small number of insects, known from larvæ and tracks; crustaceans of the genera Estheria and Cladonia, and what are supposed to be the trails of higher forms, and a rich flora containing conifers, cycads, equiseta, and ferns.

The most abundant fossils are footprints and trails impressed upon the strata while in the condition of mud and sand and retained with wonderful fidelity. Records are thus preserved of many animals, some of them of gigantic size, no other relics of which have been found.

MAMMALS.

The mammalian remains thus far discovered consist of the jaws of insectivors, obtained by Emmons[1] at Egypt, in the Deep river area, North Carolina, some fifty years ago. These were described by Emmons under the name *Dronotherium sylvestre*, but have recently been revised by Osborn[2], and shown to belong to two genera, for one of which the name *Microconodon* is proposed. The mammalian remains now known are *Dronotherium sylvestre* Emm., and *Microconodon tenuirostris* Osb.

BATRACHIANS AND REPTILES.

The earliest discovery of fossil bones in the Newark system was at Phœnixville, Pennsylvania. The fossils there obtained were determined to be reptilian remains by Isaac Lea,[3] and described by him under the name *Clepsysaurus pennsylvanicus*. Clepsysaurus has since been referred to the *Dinosauria* by E. D. Cope.

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[1] American Geology, part VI. Albany, 1857, pp. 93–96.

[2] Observations upon the Upper Triassic mammals Dronotherium and Microconodon. In Philadelphia Acad. Nat. Sci., Proc., vol. XXXVIII, 1887, pp. 259–363. A new mammal from the American Trias. In Science, vol. VIII, 1886, p. 540. The Triassic mammals Dronotherium and Microconodon. In Am. Phil. Soc., Proc., vol. XXIV, 1887, pp. 109–111, pl. op. p. 111.

[3] Mentioned in Philadelphia Acad. Nat. Sci., Proc., vol. V, 1850–'51, p. 205. Described in Philadelphia Acad. Nat. Sci., Jour., 2d ser., vol. II, 1850–'54, pp. 185–202, pl. 17–19.

The next important discoveries were numerous reptilian teeth and fragments of bones obtained in North Carolina. These were studied by Leidy and Emmons, and descriptions and figures of them published.[1]

The Newark rocks near Phœnixville and Upper Milford, Pennsylvania, also yielded a number of vertebrate fossils, consisting of teeth and fragments of bone, which were studied and classified by Leidy and Lea.[2]

Reptilian bones were also found in the Connecticut valley and described by E. Hitchcock,[3] but these were too imperfect to admit of accurate determination.

Recently, the vertebrate fossils from the Newark rocks of North Carolina and Pennsylvania have been systematically investigated by E. D. Cope,[4] who has revised their classification and added several new names to the list.

One of the most important finds in recent years of Reptilian remains in the Newark rocks was near Manchester, Connecticut. This consisted of the skeleton of an animal 6 or 8 feet long, embedded in the ordinary brown sandstone of the region, which is supposed to have been nearly perfect when discovered, but owing to ignorance of its value, only portions were preserved. These have been described by Marsh[5] under the name *Anchisaurus major*. This was probably one of the reptiles that left their footprints in such abundance on the sandstones of the Connecticut valley, and encourages the hope that these rocks,

[1] Geological Survey of the Midland Counties of North Carolina. New York, 1856, pp. 293–322, pl. 5–8. American Geology, part VI. Albany, 1857, pp. 54–93, pls. 5a, 6a, 8, 10.

[2] Lea, Isaac: [On the finding of fossil reptile bones in a calcareous conglomerate near Upper Milford, Lehigh county, Pa.] In Philadelphia Acad. Nat. Sci., Proc., vol. V, 1852, pp. 171–172. Description of a Fossil Saurian of the New Red Sandstone formation of Pennsylvania, with some account of that formation. In Philadelphia Acad. Nat. Sci., Jour., 2d ser., vol. II, 1850–'54, pp. 185–202, pls. 17–19. Remarks on the teeth of a Sauroid Reptile from near Phœnixville [Pa.]. In Philadelphia Acad. Nat. Sci., Proc., vol. VIII, 1856, pp. 77–78. Abstract in Am. Jour. Sci., 2d ser., vol. XXII, 1856, pp. 122–123. [Remarks on fossils from near Phœnixville, Pa.] In Philadelphia Acad. Nat. Sci., Proc., vol. IX, 1858, p. 149. Leidy, Jos.: [Remarks on fossils found near Phœnixville, Pa.] In Philadelphia Acad. Nat. Sci., Proc., vol. XI, 1859, p. 110.

[3] Ichnology of New England: Boston, 1858, pp. 186–187. Supplement to the Ichnology of New England: Boston, 1865, pp. 39–40, pl. 9.

[4] The writings in which these fossils have been treated are noted below:

[Remarks on extinct vertebrates from the Mesozoic Red Sandstone of Pennsylvania.] Philadelphia Acad. Nat. Sci., Proc., vol. XVIII, 1866, pp. 249–250, 290.

Synopsis of the Extinct Batrachia, Reptilia, and Aves of North Carolina. Am. Phil. Soc., Trans., vol. XIV, 1871, pp. 1–252, pls. 1–14.

Observations on the Reptilia of the Triassic formations of the Atlantic region of the United States. Am. Phil. Soc., Proc., vol. XI, 1871, pp. 444–446.

Observations on the distribution of certain extinct Vertebrata in North Carolina. Am. Phil. Soc., Proc., vol. XII, 1871–'72, pp. 210–216, pls. 1–4.

Synopsis of the Vertebrata whose remains have been preserved in the formations of North Carolina. Report of the Geol. Surv. of North Carolina, vol. I. By W. C. Kerr, Raleigh, 1875. Appendix B, pp. 29–52, pl. 5–8.

Descriptions of extinct Vertebrata from the Permian and Triassic formations of the United States. Am. Phil. Soc., Proc., vol. XVII, 1878, pp. 182–196.

On some Saurians found in the Triassic of Pennsylvania by C. M. Wheatley. Am. Phil. Soc., Proc., vol. XVII, 1858, pp. 231–232.

[Vertebrate fossils of the Triassic beds of Pennsylvania.] In Sketch of the Geology of York County, Pennsylvania. By P. Frazer. In Am. Phil. Soc., Proc., vol. XXIII, 1886, pp. 403–404.

A contribution to the history of the Vertebrata of the Trias of North America. In Am. Phil. Soc., Proc., vol. XXIV, 1887, pp. 228–229, pl. 1, 2.

[5] Notice of New American Dinosauria. In Am. Jour. Sci., 3d ser., vol. XXXVII, 1889, pp. 331, 332.

usually so barren in organic remains, may yield other vertebrate remains in the future. Marsh has published a figure of the hind foot of this fossil, and states that it is nearly related to the animal whose remains were found at Springfield, Massachusetts, and described by Hitchcock[1] under the name of *Megadactylus polyzelus*. Both fossils are referred to the same genus by Marsh.

In studying the records that have been made from time to time of the vertebrate fossils of the Newark rocks, one is impressed by the large number of the genera and species that have been established on very fragmentary remains. It seems, at least to one who is not a paleontologist, that many changes in their classification must be expected when more complete material is in hand. The detached teeth and fragments of bone that have been found, however, are important in showing that the Newark period had an abundant and varied batrachian and reptilian fauna. This fact is also manifest from the numerous footprints discovered.

No bones or other remains of birds have been obtained. This, although negative evidence, supports in a measure the conclusion reached by various students of the subject, to the effect that the abundant footprints discovered in the Connecticut valley, New Jersey, and Pennsylvania were made by reptiles.

The batrachians and reptiles from the Newark system now known from fragments of their skeletons are as follows:

Name.	Localities.
BATRACHIA.	
Eupelor durur Cope	Phœnixville, Pa.
Pariostegus myops Cope	North Carolina.
Dictyocephalus elegans Leidy	Do.
REPTILIA.	
Anchisaurus major Marsh	Manchester, Conn.
Belodon pirscus Leidy	Emylsville and Phœnixville, Pa.
B. caroliniensis Emm	Egypt, N. C., Emylsville, and Phœnixville, Pa.
B. leaii Emm	Do.
B. lepturus Cope	Egypt, N. C., and Phoenixville, Pa.
Paleosaurus frazerianus Cope	Emylsville, Pa.
Suchoprion cyphodon Cope	Do.
S. aulacodus Cope	Do.
Clepsysaurus pennsylvanicus Lea	Phœnixville, Pa.
C. beatleianus Cope	Emylsville, Pa.
Palaeoctonus appalachianus Cope	Do.
Thecodontosaurus gibbidens Cope	Do.

FISHES.

A monograph by Newberry, on the fossil fishes of the Newark system, has recently been published, which contains all the information

[1] Supplement to the Ichnology of New England. Boston, 1865, pp. 39-40, pl. 9.

obtainable on the subject and renders it unnecessary at this time to refer to the works of previous writers in this connection. In the work referred to twenty-eight species of fossil fishes are described and referred to seven genera. The works of previous authors, including those of Emmons, W. C. Redfield, J. H. Redfield, and others, have been revised and a large amount of new material added. This important monograph places our knowledge of the fossil fishes of the Newark system on an equality with, if not in advance of, that of any other rock series in this country.

The fossils described and illustrated by Newberry were obtained from Boonton, New Jersey, Durham, Connecticut, and Turner Falls, Massachusetts. They occur for the most part in fine grained black shales, and are to be looked for anywhere in the Newark system, where rocks of this description occur. The localities now known from which fossil fishes have been obtained in greater or less abundance in the system under review are as follows: Clover Hill and Maniken, Virginia; Phoenixville, and Yerkes, Pennsylvania; Boonton, Pompton Furnace, Weehawken, Shady Side, Field's copper mine (near Dunellen; this locality is in Washington valley, 2 miles northwest of Dunellen, and is probably referred to as "Plainfield" by Newberry), and Washington Crossing (8 miles above Trenton), New Jersey; Durham, Westfield, Middlefield, Glastonbury, Middletown, Berlin, and Southbury, Connecticut; Amherst, Chicopee Falls, Hadley Falls, Middletown, Sunderland, Turner Falls, Deerfield, and West Springfield, Massachusetts.

All of the fossil fishes thus far discovered at these localities are Ganoids, and, with one exception, have small rhomboidal scales and belong to the order Lepidosteidæ. The exception is Diplurus, described by Newberry, which is referred to the order Crossopterygidæ.

The genera and species now known from these rocks are as follows:

Fossil fishes of the Newark system.

Name.	Locality.
Acentrophorus chicopensis Newb	Massachusetts.
Catopterus redfieldi Egt	New Jersey (?), Connecticut, Massachusetts (?).
C. anguilliformis W. C. R.	New Jersey, Connecticut, Massachusetts (?).
C. gracilis W. C. R.	New Jersey, Connecticut.
C. minor Newb	Connecticut.
C. ornatus Newb	Do.
C. parvulus W. C. R	New Jersey, Connecticut, Massachusetts.
Dictyopyge macrura Egt	Virginia.
Dipturus longicaudatus Newb	New Jersey, Connecticut.
Ischypterus agassizii W. C. R	New Jersey, Connecticut, Massachusetts.
I. alatus Newb	New Jersey.
I. braunii Newb	Do.
I. elegans Newb	Do.
I. fultus Ag	New Jersey, Connecticut, Massachusetts.
I. gigas Newb	New Jersey.
I. latus J. H. R	New Jersey, Connecticut.

Fossil fishes of the Newark system—Continued.

Name.	Locality.
I. lenticularis Newb	New Jersey.
I. lineatus Newb	Do.
I. macropterus W. C. R	Connecticut.
I. marshii W. C. R	Massachusetts.
I. micropterus Newb	New Jersey, Connecticut, Massachusetts.
I. minutus Newb	Do.
I. modestus Newb	New Jersey.
I. ovatus W. C. R	New Jersey, Connecticut, Massachusetts.
I. parvus W. C. R	New Jersey, Connecticut (?), Massachusetts.
I. robustus Newb	New Jersey.
I. tenuiceps Ag	New Jersey, Connecticut, Massachusetts.
Ptycholepis marshii Newb	Connecticut.

INSECTS.

The presence of insect life in the Newark period is recorded by the larva of a certain insect in considerable numbers in the rocks of the Connecticut valley, and by numerous trails and minute footprints on the glossy surfaces of certain strata in the same region. The larva referred to has been found at Turner Falls, Massachusetts, and was figured by Hitchcock[1] under the name *Mormolucoides articulatus.* It has been more recently described and figured by Scudder,[2] who concludes that it is probably the larva of a *Sialidan neuropteron,* and remarks that it has special interest from the fact that it is the oldest insect larva known.

In "The Ichnology of New England" the footprints of insects are included under one head with those supposed to have been made by crustaceans and myriapods, but in the "Supplement to the Ichnology of New England" they stand by themselves and include twenty-four species referred to eight genera. Some of these are illustrated by photographs by Hitchcock, and others are shown in a similar manner by Deane[3] in his beautifully illustrated work on the footprints of the Connecticut valley.

The classification proposed by Hitchcock for these delicate impressions is based wholly on the footprints themselves, and would no doubt be greatly modified if additional data were obtained. The markings are of great value, however, and record faithfully that there was an abundance of invertebrate life on the shores where the gigantic reptiles of the Newark period made their home.

[1] "The Ichnology of New England," pp. 7–8, pl. 7.

[2] The oldest known insect larva, *Mormolucoides articulatus*, from the Connecticut river rocks. In Boston Soc. Nat. Hist., Mem., vol. III, 1886, pp. 431–438, pl. 45. Republished in the Fossil insects of North America. New York, 1890. 4to, vol. I, pp. 323–330, pl. 19.

[3] Ichnographs from the sandstone of the Connecticut river. Boston, 1861. Pls. 40–41.

CRUSTACEANS.

In the fine black shales and slates, and sometimes in the reddish brown shales accompanying the coal seams of the Deep river, Dan river, and Richmond areas, are great numbers of small crustaceans, belonging to the genera Estheriæ and Candonia (cypridæ). The same fossils occur in abundance in the black shale at Phœnixville, Pennsylvania, and in the similar rocks beneath the Palisades in New Jersey. They have recently been found also by Nason[1] at many other localities in New Jersey, and are thought by him to belong to certain definite horizons, and therefore to be of value in deciphering the structure of the system. The occurrence of these fossils throughout a wide range in the fine grained strata at the south, has led the present writer to doubt their value in determining special horizons, and indicates that they may be expected almost anywhere in the system where fine grained rocks occur.

These fossils attracted the attention of the pioneer geologists of the Eastern states, and were described in part by Rogers, Lyell, Lea, Emmons, and others; but the most systematic and exhaustive study of them that has been made is by Jones.[2] In the important monograph by this author the descriptions and discussions of previous writers are reviewed, and the fossils themselves described and illustrated. The several genera and species proposed by previous writers are shown to belong to a single species of Estheriæ and two species of Cadonia (?). The classification of these fossils as it now stands is as follows: *Estheria ovata* Lea (including the *Posidonomya minuta*, of Rogers and Lyell; *Posidonia* Lea; *P. parva* Lea; *P. ovalis* Emm.; *P. multicostata* Emm.; *P. triangularis* Emm.); *Candona* (?) *rogersi*, Jones (including the *Cypris*, of Rogers, Leidy and Wheatley, and *Bairidia* and *Cypris*, of Emmons); *Candona* (?) *emmonsii* Jones (including the granulated species of *Cypris*, mentioned by Rogers and Wheatley). Full references to the writings of previous authors on these fossils will be found in the monograph just cited.

Besides the cases of minute crustaceans referred to above, fragments of a shell of *Limulus* and of other crustaceans have been reported by Wheatley[3] from the black shales near Phœnixville, Pennsylvania, but these remains seem to have been too imperfect to admit of more than a provisional classification.

Among the numerous tracks discovered on the sandstone of the Connecticut valley, there are a number which seem to have been made by crustaceans, some of them of large size, as was determined by Hitchcock. Several illustrations of these footprints are given by

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[1] Geol. Surv. of New Jersey, Ann. Rep. for 1888, pp. 28–30.

[2] A Monograph of the Fossil Estheriæ. Paleontographical Society, London, 1862. 4to. Pp. 84–89, 124–126, pl. 2.

[3] Remarks on the Mesozoic red sandstone of the Atlantic slope, and notice of the discovery of a bone-bed therein at Phœnixville, Pa., in Am. Jour. Sci., 2d ser., vol. XXXII, p. 43.

Hitchcock in his work on Ichnology. From the meager records left by these animals, it is manifest that we must wait for further evidence before their place in the zoological series can be assigned.

MOLLUSKS.

Molluscan remains are exceedingly rare in the rocks of the Newark system. The earliest record of the supposed occurrence of a shell is by E. Hitchcock, jr. The fossil referred to was found in the coarse sandstone of Mount Tom, Hampshire county, Massachusetts, and was thought by its discoverer to be allied to the *Rudistæ* of Lamarck, but the fossil was so imperfect that even its family relations could not be assigned with confidence. From the description and the rude figure published by Hitchcock,[1] it seems doubtful if the object referred to can even be classed among mollusks. Even if it is a shell, as supposed, its imperfect condition and the fact that no other specimens have been found, deprive it of nearly all taxonomic value. It was used by Hitchcock,[2] however, as evidence of the post-Triassic age of the rocks in which it was found.

Two species of *Astarte*, from near Washington, Middlesex county, New Jersey, were described as being from the rocks now under discussion, by T. A. Conrad,[3] but the rocks in which they were found have been shown by Whitfield[4] to belong to the Raritan clays, which are classed by McGee[5] in the Potomac formation. Conrad has also described a fossil shell, *Solemya triasina*,[6] from near Perkiomen creek, which empties into the Schyulkill near Valley Forge, Pennsylvania, and still another, the *Myacites pennsylvanicus*,[7] from Phœnixville, Pennsylvania.

Lewis[8] announced in 1884, the discovery of five distinct species of lamellibranchs at Phœnixville, Pennsylvania. Two of these are Unios somewhat resembling *U. calceolus* and *U. lanceolatus*, of Lea; the others were marine forms. In order to complete the record certain doubtful references of fossil shells to the Newark rocks may be mentioned. Isaac Lea[9] found small gasteropod shells in calcareous conglomerate, but those were probably in fragments of Silurian limestone contained in the conglomerate. Another discovery referred with doubt to this system, was

[1] A new fossil shell in the Connecticut river sandstone, in Am. Jour. Sci., vol. XXII, 1856, pp. 239–240.

[2] Ichnology of New England, pp. 6–7, pl. 5.

[3] Descriptions of and references to Miocene shells of the Atlantic slope, and descriptions of two supposed Cretaceous species, in Am. Jour. Conch., vol. IV, 1868, p. 279.

[4] Brachiopoda and Lamellibranchiata of the Raritan clays and greensand marls of New Jersey; U. S. Geol. Surv., Monograph vol. IX, 1886, pp. 22–27.

[5] Three formations of the Middle Atlantic slope, in Am. Jour. Sci., 3d ser., vol. XXV, 1888, pp. 136–137.

[6] Descriptions of new fossil Mollusca, principally Cretaceous, in Am. Jour. Conch., vol. V, 1870, p. 102.

NOTE.—From the arrangement of this article it would appear that three other fossils, one of them from Haddenfield, N. J., were also referred to the Newark system, but it does not seem as if this could have been Conrad's intentions. I. C. R.

[7] Description of new species of Myacites, in Philadelphia Acad. Nat. Sci., Proc., vol. IX, 1857, p. 166, vol. XII, plate.

[8] Science, vol. III, p. 295.

[9] Phil. Acad. Nat. Sci., Jour. n. s., vol. II, 1853, p. 194.

made by W. M. Gabb,[1] at Warm Springs, Virginia; we now know that the beds at that locality are much older than the Newark.

The nearly complete absence of molluscan fossils and the total absence of sponges, corals, and other life records characteristic of oceanic conditions, as well as the discovery of Unios by Lewis is evidence that the waters in which the Newark beds were deposited were not in open communication with the ocean.

FOOTPRINTS.

Footprints in sandstone and shale have been found at a large number of localities in the Connecticut valley, New Jersey, and Pennsylvania. In the areas south of Pennsylvania no records of this character have yet been discovered. The numerous localities in the Connecticut valley in which footprints have been obtained are indicated in part on the map accompanying Hitchcock's work on Ichnology. In New Jersey these fossils have been found at New Vernon, Whitehall, Pompton Furnace, and Boonton, Morris county; underneath the Palisades at Weehawken, in Washington valley near Plainfield, near Princeton; and at Milford and Tumble station on the Delaware. The localities that have yielded the most abundantly are Whitehall and Milford.

In Pennsylvania fossil footprints were found many years ago and described by Lea.[2] More recently they have been found by Wanner[3] in considerable numbers, at Goldsboro, York county. Many of the footprints from New Jersey and Pennsylvania have been examined by C. H. Hitchcock, and found to belong to the species which occur in the Connecticut valley.

The history of the discovery of footprints in the Connecticut valley is well known and does not require more than brief mention at this time. The chief works on the subject are indicated below,[4] and in these references will be found to earlier publications.

In Hitchcock's great work on the Ichnology of New England, and in the supplement that followed, the footprints of more than one hundred distinct species of animals, some of them of gigantic size, were described and named. In this investigation the footprints alone were available for study, and on them a detailed classification was based. In this classification the footprints are referred to animals ranging from marsupialoid mammals, through birds, batrachians, lizards, turtles, crustaceans, myriapods and insects to annelids. There are besides certain peculiar markings which are supposed to have been made by fishes. In addition to the records of animal life, the surfaces bearing the footprints are frequently pitted with raindrop impressions, beautifully cor-

[1] Phil. Acad. Nat. Sci., Jour., vol. IV, 1860, p. 307.

[2] Philadelphia Acad. Nat. Sci., Proc., vol. VIII, 1856, p. 8.

[3] Annual Report of the 2d Geol. Surv. of Pennsylvania, for 1887, Harrisburg, 1889, pp. 31–35.

[4] Hitchcock, E.: Ichnology of New England, Boston, 1858, 4to, pp. I–XII, 1–220, pls. 1–60. Supplement to the Ichnology of New England, Boston, 1865, pp. I–X, 1–96, pls. 1–20. Deane, J. Ichnographs from the sandstone of the Connecticut river. Boston 1861, 4to, pp. 1–61, pls. 1–46.

rugated with ripple marks, and covered with a network of intersecting shrinkage cracks.

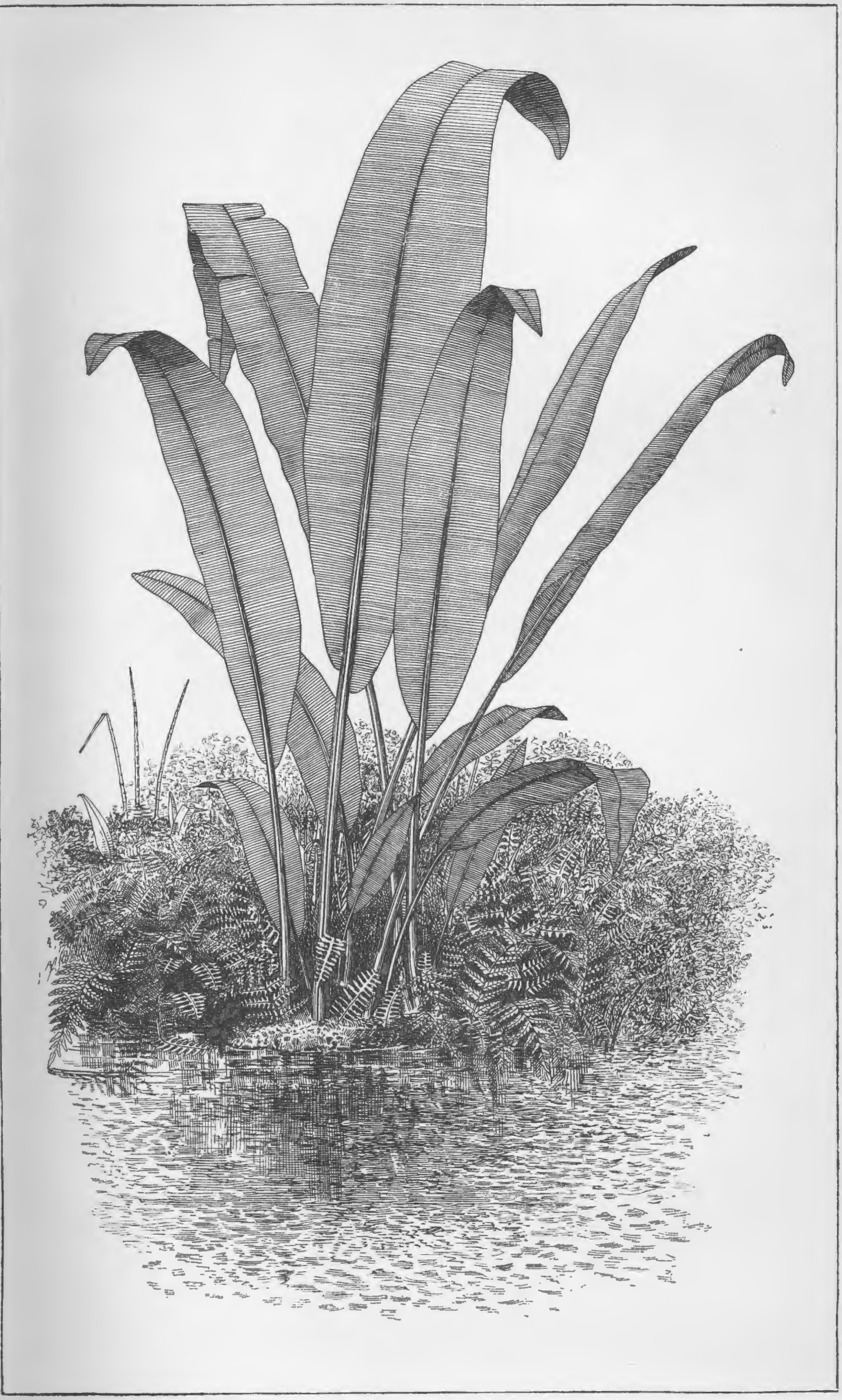
The majority of the tracks discovered by Hitchcock have three toes, and were supposed by him to have been made by birds. This conclusion has subsequently been greatly modified owing to the fact that four and five toed tracks have been discovered in such relation to the three-toed ones, as to show that the animals that made them were four footed. The true ornithic character of any of the tracks can not be considered as proved, and the opinion now prevails among those best qualified to judge in such matters, that the greater part of the tracks were made by reptiles and amphibians.

PLANTS.

Fossil plants have been found in several of Newark areas, from the Connecticut valley southward, but they occur in greatest abundance in connection with the coal seams of the Richmond and Deep river areas. In the Connecticut valley they have been found sparingly at Turner Falls and Sunderland, Massachusetts, and at Durham, Middletown and Portland, Connecticut. In New Jersey they occur in small numbers at Newark, Milford, Boonton, and a few other less important localities. In Pennsylvania a few have been found at Phœnixville, Guynedd, and Goldsboro. In the Richmond area they occur in great abundance at Clover Hill, and have been found at Midlothian and Manikin, Deep run, etc., where fine dark slates occur. They have been found also in the Farmville area, but no considerable collections have been made there. In the Deep river area they are abundant in the fine slates associated with the coal deposits near Egypt, and were found also by Emmons in considerable numbers near Locksville, in a dark slate intimately associated with coarse conglomerate.

In the northern areas the plant remains are largely in sandstone, and consist usually of the more durable portions of plants which could withstand long transportation. At several places in the Connecticut valley and New Jersey they consist of stems deprived of their leaves and bark and scattered through the sandstone. In such cases it is evident that they have been subjected to long transportation, and swept into the areas of deposition from neighboring highlands. In the south, however, the conditions in the majority of instances were different, the plants were preserved where they grew, and even the most delicate fronds were faithfully preserved. In some of the sandstone areas the silicified trunks of trees are preserved in considerable numbers. One of the most important localities is at Germantown, at the southern end of the Dan river area. Similar silicified trunks have also been found at Manassas, Virginia, and in Massachusetts.

Obscure vegetable remains from the Connecticut valley were described principally by Hitchcock, but were too imperfect to be of much value. The plants of the Richmond coal field attracted the attention of Rogers



MACROTÆNIOPTERIS MAGNIFOLIA.

and of Lyell, while those of North Carolina were described and illustrated by Emmons.

A few plants from the Richmond coal field found their way to Europe and were described in the classic works of Schimper and Brongniart. Recent studies of these fossils, however, have carried our knowledge of them far beyond the early attempts, and in the monographs of Fontaine[1] and Newberry[2] is contained our present knowledge of this flora.

In Fontaine's monograph descriptions and figures are given of forty-two species of fossil plants from the Richmond coal field, and it is supplemented by descriptions of about the same number from North Carolina by Emmons. The contributions to this flora from the localities mentioned in New Jersey and the Connecticut valley are few in number and consist principally of the leaves of cycads. The plants thus far found include conifers, cycads, equiseta, and ferns, besides a few species the relations of which have not been definitely determined. The most characteristic and at the same time the most abundant is a magnificent broad-leafed fern, referred to the genus *Macrotæniopterus*. The appearance of this beautiful plant as it grew beside the still waters of the ancient swamps of Virginia, is shown in Plate VIII. This restoration has the approval of Fontaine, and may help to render more real the usual fragmentary records from which our knowledge of this ancient flora is derived. The luxuriant subtropical vegetation of the lowlands of Virginia during the Newark period has its nearest analogue to-day in the silent fern forests of New Zealand. In Virginia the ground must have been thickly covered with lowly ferns, above which rose the graceful bending equiseta and those ferns which had broad, palm-like fronds. On the drier ground grew the stiff-leafed cycads with their immense cones. The uplands must have been clothed with a dark forest of pine resembling the beautiful Auracaia now growing in certain of the South Sea islands. This beautiful flora, which to us seems so strange, probably covered all the region adjacent to the basin in which the Newark rocks were being deposited. In the swamps of the South where the conditions were most favorable for its preservation abundant records were preserved, but in the North only occasional fronds and water-worn trunks were deposited in the accumulating sands.

The plants now known from the Newark system are indicated in the following list. In making this catalogue the works of Fontaine and Newberry have been followed, but Fontaine's monograph has recently been reviewed by Stur,[3] and many of the plants described in it identified with those of the Lettenkohlen of Germany. Should these identifications prove correct many of the names given in the list will have to be changed.

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[1] U. S. Geol. Surv., Monograph vol. 6, 1883.

[2] U. S. Geol. Surv., Monograph vol. 14, 1888.

[3] Die Lunzer-(Lettenkohlen-) Flora in den "older Mesozoic beds of the Coal Fields of Eastern Virginia." In Verhandlungen der K. K. geologischen Reichsanstalt, No. 10, 1888, pp. 203–217.

Plants from the Newark System.

Name.	Locality.
CONIFERÆ.	
Araucarites carolinensis	North Carolina.
Baiera multifida	Connecticut valley, North Carolina, Virginia.
B. münsteriana	Connecticut valley, North Carolina.
Pachyphyllum brevifolium.	Connecticut valley, New Jersey.
P. münsteri	Connecticut valley, New Jersey, Virginia.
P. peregrinum	North Carolina.
P. simile	Connecticut valley, New Jersey.
Palissya ——	New Jersey.
Palissya ——	North Carolina.
P. carolinensis	Do.
P. diffusa	Do.
ZAMIEÆ AND CYCADEÆ.	
Ctenophyllum braunianum, var. a.	North Carolina, Virginia.
C. braunianum, var. B	North Carolina.
C. emmonsi	Do.
C. giganteum	Virginia.
C. grandifolium	Do.
C. lineare	North Carolina.
C. robustum	Do.
C. taxinum	Do.
C. truncatum	Virginia.
Cycadites acutus	North Carolina.
C. longifolius	Do.
C. tenuinervis	Virginia.
Cycadinocarpus chapini	Connecticut valley.
Dioönites longifolius	North Carolina, New Jersey.
Otozamites brevifolius	Connecticut valley.
O. carolinensis	North Carolina.
O. latior	Connecticut valley.
Podozamites emmonsi	North Carolina, Virginia.
P. tenuistriatus	Virginia.
Pterophyllum, affine	
P. decussatum	North Carolina, Virginia.
P. inæquale	Virginia.
P. pectinatum	North Carolina.
P. spatulatum	Do.
Sphenozamites rogersianus.	North Carolina, Virginia.
Zamiostrobus virginiensis.	Virginia.
Z. emmonsi	North Carolina.
EQUISETEÆ.	
Calamites arenaceus	Virginia.
Equisetum arundiniforme.	Do.
E. meriani	Connecticut valley.
E. rogersi	North Carolina, New Jersey, Virginia.
Schizoneura planicostata.	Connecticut valley, New Jersey, Virginia.
Schizoneura, sp.?	Virginia.
S. virginiensis	Do.
FILICES.	
Acrostichides densifolius.	Virginia.
A. ægyptiacus	North Carolina.
A. linnææfolius	North Carolina, Virginia.
A. microphyllus	Virginia.
A. rhombifolius	North Carolina, Virginia.
A. rhombifolius, var. rarinervis.	Virginia.
Actinopteris quadrifoliata.	North Carolina.
Asterocarpus penticarpas.	Virginia.
A. platyrachis	North Carolina, Virginia.
A. virginiensis	Virginia.
A. virginiensis, var. obtusiloba.	Do.
Asplenites rösserti	North Carolina,
Cladophlebis auriculata	North Carolina, Virginia.
C. microphylla	Virginia.
C. obtusiloba	North Carolina.
C. ovata	Virginia.
C. pseudo-whitbiensis	Do.
C. rotundiloba	Do.
C. subfalcata	Do.
C. platyphylla	Connecticut valley, New Jersey, Virginia.
C. platyphylla, var. expansa.	Virginia.
Dicranopteris, sp?	Do.
Lacopteris emmonsi	North Carolina.
L. carolinensis	Do.
L. elegans	Do.
Lonchopteris oblongus	Do.
L. virginiensis	Virginia.
Macrotæniopteris crassinervis.	Do.

Plants from the Newark System—Continued.

Name.	Locality.	Name.	Locality.
FILICES—continued.		FILICES—continued.	
M. magnifolia	North Carolina, Virginia.	P. reticulata	North Carolina, Virginia.
Mertensides bullatus	North Carolina, Virginia.	Sagenopteris rhoifolia	North Carolina, Virginia.
M. distans	Virginia.	PLANTS OF UNDETERMINED RELATIONS.	
Pecopteris rarinervis	North Carolina, Virginia.	Dendrophycus triassicus	Connecticut valley.
Psuedodanæopteris nervosa.	North Carolina, Virginia.	L. simplex	Connecticut valley, Virginia.

Besides the plants catalogued above, a few minor discoveries may be noted: Isaac Lea[1] has recorded the discovery of a single plant resembling *Noeggerathia cuneifolia* Brog., near Phœnixville, Pennsylvania. A fucoid named *Palæophycus limaciformis* Lew., was found by Lewis,[2] at Milford, New Jersey. A stem with markings similar to those of Lepidodendron was found at Belleville, New Jersey.[3]

[1] Phil. Acad. Nat. Sci., Proc., vol. VIII, 1856, p. 78.
[2] Phil. Acad. Nat. Sci., Proc., vol. XXXII, 1880, p. 293.
[3] Geol. of N. J., Ann. Rep. for 1879, pp. 26–27.

CHAPTER VII.

ASSOCIATED IGNEOUS ROCKS.

Intimately associated with the sedimentary strata of the Newark system in nearly all its various areas, are dikes and sheets of igneous rock. The outcrops of these rocks are everywhere remarkably uniform in general appearance, and have but little variety in their mineralogical and chemical composition. They are classed as basalt and dolerite by petrographers, but have all been known as "trap rocks," a term sufficiently accurate for general use and which will be retained in this paper.

In the various Newark areas trap rock appears in two ways, either as dikes breaking across the sedimentary strata, or as sheets more or less uniformly interbedded with them. The sheets are either extrusive, and were spread out as overflows of lava before the accumulation of the sedimentary strata was completed, and subsequently buried beneath the shales and sandstones of later date; or intrusive, and forced in between the strata after their consolidation.

The trap rocks are not confined to the Newark areas, but, in the form of dikes, occur throughout nearly the entire Atlantic coast plain and in the adjacent Appalachians. The evidence showing that the trap dikes in the crystalline and Paleozoic rocks surrounding the Newark areas are a part of the same great system of dikes and sheets occurring within those areas, will be stated in describing their geographical distribution. The age of the trap rocks and their importance in a general study of the Atlantic coast region, will be considered in the summary at the end of this chapter.

MINERALOGICAL COMPOSITION.

As one sees the traps in the field, they are dense, heavy rocks, having a dull, nearly black color when somewhat weathered, but frequently appear bluish or greenish on fresh surfaces. They appear under two general aspects, compact and vesicular. The former occurs in dikes and sheets, and is frequently columnar, while the latter occurs almost entirely in sheets. The vesicular trap has frequently been changed to an amygdaloid by the filling of its cavities with a secondary mineral.

Determinations of specific gravity and mineralogical analyses of trap rock from various localities, from Nova Scotia to the Carolinas, have shown that they are remarkably similar throughout their entire extent.[1] Their essential elements in an unweathered condition, as shown by E. S. Dana, are pyroxene, labradorite, and magnetite, with occasionally some chrysolite and apatite; chlorite is often present as a result of local change.

It has been shown by Hawes that the feldspar element is not a single feldspar, but labradorite and another mineral having the ratio of andesine.

The iron, in places at least, is uncombined, as has been shown by Van Dyck, and elsewhere appears as magnetite and titanic iron. Among the minerals resulting from secondary alteration are a great variety of zeolites, calcites, etc.

As determined by Iddings,[2] the trap rocks are generally holocrystalline, and formed of lath-shaped basic feldspar, irregular grains and crystals of augite, grains of iron oxide, together with considerable green serpentine or chlorite, which is disseminated through the mass and is evidently the alteration product of a fourth primary constituent. Specimens collected at Orange, New Jersey, where the trap occurs in large, well defined columns, when examined in thin sections, however, were found not to be holocrystalline, but to contain a variable amount of glass base. The large serpentine blotches contain olivine in their centers, the primary mineral from which the serpentine is formed. This rock is in every way identical with many medium grained basalts which have been poured out at the surface in recent times, and should be called basalt. The coarser grained varieties are dolerite, as determined by E. S. Dana. The presence of hornblende as an essential constituent in the trap near Gettysburg, Pennsylvania, has been reported by Frazer.[3]

It has been shown by several petrographers that when the rock is somewhat altered, either during its extrusion, through the action of heated solutions, or by weathering after exposure at the surface, that hydration has taken place and various secondary minerals formed. When the trap rocks are more thoroughly decomposed, they form a tenaceous residual clay, usually yellowish or mottled in color, and showing no resemblance to the rock from which it was derived. In the unglaciated portions of the Newark belt the trap rocks are frequently completely decomposed to a depth of from twenty to fifty feet. Owing to their greater solubility than the adjacent sandstone and shales,

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[1] Dana, J. D. [Density and composition of Newark Dolerites]: Am. Jour. Sci., 3d ser., vol. VI, 1873, pp. 106–107. Dana, E. S.: Trap rocks of the Connecticut valley. Am. Ass. Adv. Sci., Proc., vol. XXIII, 1874, pp. 45–47. Van Dyck [Native iron in the trap rocks of New Jersey]: Geol. Surv. of New Jersey, Ann. Rept. for 1874, p. 57. Frazer, P.: On the traps of the Mesozoic sandstone in York and Adams counties, Pennsylvania. Am. Phil. Soc., Proc., vol. XIV, 1875, pp. 402–414, 431; Pls. 1–4. Also, Second Geol. Surv. of Pennsylvania, vol. C, 1876, pp. 124–129; pls. 2, 3. Frazer, P.: A Study of the Igneous Rocks. Am. Inst. Mining Eng., Trans., vol. V, 1877, p. 146. On the physical and chemical characteristics of the trap occurring at Williams Point (Lancaster County, Pennsylvania). Am. Phil. Soc., Proc., vol. XVIII, 1880, pp. 96–103, and plate. Hawes, G. W.: On the mineralogical composition of the normal Mesozoic diabase upon the Atlantic border. U. S. Natl. Mus., Proc., vol. IV, 1881, pp. 129–134. Marsters, V. F.: Triassic traps of Nova Scotia. In American Geologist, vol. V, 1890, pp. 144–145.

[2] The Columnar structure in the Igneous Rocks of Orange Mountain, N. J.; Am. Jour. Sci., 3d ser., vol. XXXI, pp. 321–331, Pl. 9.

[3] Am. Phil. Soc., Proc., vol. XIV, 1875. p. 43.

they frequently give origin to depressions in the topography of the region they traverse.[1] In the glaciated region the outcropping edges of trap sheets usually stand in bold relief. The difference in their appearance in glaciated and unglaciated regions is due to the fact that while more resistant than the associated strata to mechanical erosion, they are usually much more susceptible to chemical changes.

CHEMICAL COMPOSITION.

Numerous analyses of the trap rocks have been made, principally from Connecticut valley, New Jersey, and Pennsylvania. It is not necessary to assemble these analyses here, as they may be found from the following references; but, in order to show the general composition of the rock, the average composition of eight samples of unaltered dolerite from New Jersey and the Connecticut valley, analyzed by G. W. Hawes, is inserted.

Average composition of unaltered dolerite.[2]

	Per cent.
Silica (SiO_2)	52·50
Alumina (Al_2O_3)	14·15
Ferrous oxide (FeO)	9·24
Ferric oxide (Fe_2O_3)	1·96
Manganous oxide (MnO)	0·45
Lime (CaO)	10·03
Magnesia (MgO)	7·48
Chromic oxide (Cr_2O_3)	
Soda (Na_2O)	2·30
Potash (K_2O)	0·69
Phosphoric acid (P_2O_5)	0·14
Titanic acid (TiO_2)	
Water (by ignition, (H_2O)	0·92
Total	99·86

[1] Bull. U. S. Geol. Surv., No. 52, pp. 15–18.

[2] Analyses of Newark trap rocks may be found as follows:

Cook, G. H.: [Name of analyst not given]. Analyses of trap from many localities in New Jersey; Geol. of N. J., 1868, pp. 215–218.

Tyson, S. T.: Analysis of West Rock, Conn. Am. Jour. Sci., 3d ser., vol. VI, 1873, p. 107.

Allen, O. D.: Partial analysis of trap from near lake Saltonstall, Conn. Am. Jour. Sci., 3d ser., vol. VI, 1873, p. 107.

Mixter, W. G.: Analysis of traps from the Palisades, N. J. Am. Jour. Sci., 3d ser., vol. VI, 1873, p. 106.

Hawes, G. W.: Analyses of trap from West Rock, Wintergreen lake, lake Saltonstall, South Durham mountain, Conn.; Mt. Holyoke, Mass., and Jersey City, N. J. Am. Jour. Sci., 3d ser., vol. IX. 1875, pp. 185-192, 454–457.

Frazer, P.: Discussion of the analyses of trap rock from West Rock, Conn., and from near York, Pa. Second Geol. Surv. of Pa., vol. C, pp. 118–124.

Genth, jr., F. A.: Analyses of trap rocks from Pennsylvania. In Second Geol. Surv. of Pa., vol. C 6, 1881, pp. 94–99, 134. Analyses of trap from Gulf Mills, Pa. Am. Phil. Soc., Proc., vol. XXII, 1885, p. 454. Analysis of trap from Cornwall iron mines, Pa. Ann. Rep. 2d. Geol. Surv. Pa., for 1885, pp. 498–499. Analyses of trap from Williams Point, Lancaster county, Pa. Am. Phil. Soc., Proc., vol. XVIII, 1880, p. 96.

Genth, F. A.: Analysis of trap from near York, Pa. Second Geol. Surv. of Pa., vol. C, 1876, pp. 122–124. Analyses of minerals and rocks from Bucks, Montgomery, and Philadelphia counties, Pa. Second Geol. Surv. of Pa., vol. C 6, 1881, pp. 94–99, 134.

Chatard, T. M.: Analyses of decomposed trap from North Carolina. Bull. U. S. Geol. Surv., No. 52, 1889, p. 18.

CHARACTERISTICS OF TRAP DIKES.

The general trend of the dikes throughout the Newark system and in the surrounding areas is northeast and southwest. Those in the crystalline rocks, as a rule, are narrower than those penetrating sedimentary strata. Where dikes occur in the Newark system a hardening and alteration in color of the adjacent sedimentary beds is noticeable. This change seems to be due directly to a baking of the strata; but in some sandstones, especially at the south, it appears to have resulted from the deposition of mineral matter by heated solution. Observations on the change in color and texture in the strata adjacent to trap dikes and sheets have been summarized by W. M. Davis,[1] who has shown that such alterations are confined to the immediate vicinity of the intrusion. The alterations in color consist frequently in the darkening of the rocks. A reddening is not common, and the fallacy of supposing that the general reddish color of the Newark rocks is due to an alteration in the iron they contain, by the heat of the intruded rocks, is clearly proved.

The observations of the present writer have shown that one of the most common changes in the color of the sandstones and shales adjacent to the trap dikes in Virginia and the Carolinas is an alteration to a deep purple color, which fades out into the normal brownish red tint of the Newark rocks at a distance, usually, of two or three feet. Many times the presence of a dike which is deeply decomposed and does not appear at the surface is indicated by two parallel bands of dark purple shale which define its boundaries. The hardened walls adjacent to the dikes resist weathering more effectually than the dikes themselves, and frequently stand in relief when the dike itself is depressed several feet below the general surface.

In some cases the dikes have a columnar structure at right angles to their walls, indicating the manner in which they were cooled and crystallized. In many instances the borders of the dikes show a fine, cryptocrystalline structure, while the central portion, owing to their cooling more slowly, is coarsely crystalline.

In the deeply decomposed dikes at the south a concentric structure is frequently developed by the decomposition. Rounded bowlders, resulting from disintegration, frequently occur scattered through yellowish clay in dikes that are partially decomposed; but when the alteration is more complete, the characteristics of the original rock entirely disappears and yellowish clay alone remains.

CHARACTERISTICS OF TRAP SHEETS.

The trap sheets interstratified with the sedimentary beds of the Newark system are of two classes, as has been shown especially by W. M.

[1] On the relation of the Triassic traps and sandstones of the eastern United States. In Mus. Comp. Zool., Harv. Coll. Bull., vol. VII, 1883, pp. 300-302.

Davis: First, contemporaneous sheets, or those formed by the surface eruption of igneous rocks and subsequently buried beneath sedimentary beds; second, intruded sheets or those forced in between the sedimentary strata subsequent to their consolidation.

The contemporaneous sheets are conformable with the stratified beds both above and below, while the intruded sheets, although conformable over large areas, in many instances break across the strata, forming dikes which connect the sheets at various horizons. The contemporaneous sheets have altered the sedimentary beds on which they rest, and are scoriaceous at their upper surfaces. The strata resting upon them are unaltered, and may contain fragments of the underlying trap or extruded scoria, volcanic tuff, and the finer products of eruption known as volcanic ash.

The intruded sheets have metamorphosed strata both above and below, and, cooling under pressure, are more compact throughout than the extruded sheets. They cooled most rapidly at their surface, and hence are compact and cryptocrystalline above and below, while their central portions are usually coarsely crystalline.

These characteristics have been discussed by Davis, in connection with the study of the trap sheets of the Connecticut valley, and have been applied by Darton[1] in the investigation of the trap sheets of New Jersey.

GEOGRAPHICAL DISTRIBUTION.

TRAP DIKES OUTSIDE THE NEWARK AREAS.

The great extent of the series of dikes intersecting the Newark areas and their extension into the surrounding areas of crystalline and paleozoic rocks have already been referred to; but it is only within the Newark areas themselves that the distribution of the traps has been approximately determined. Numerous dikes have been described and mapped in Newfoundland, Nova Scotia, New Brunswick, Maine, Vermont, New Hampshire, and eastern Massachusetts, some of which, it seems probable from the descriptions given, belong to the series which traverse the Newark system, but much study is required before this connection can be determined with certainty.

It has been stated by Hobbs[2] that certain diorite dikes near Boston have generally been considered as post-Newark in age, on account of their lithological resemblance to the diabases of the Connecticut valley.

On the geological map of Connecticut published by J. G. Percival in 1842, several narrow trap dikes, somewhat disconnected, are indicated as traversing the crystalline region outside the Newark area.

The work of the Second Geological Survey of Pennsylvania has shown the presence of several such dikes in crystalline and Paleozoic regions

[1] On the relations of the traps of the Newark system in the New Jersey region. U. S. Geol. Survey, Bull. No. 67.

[2] On the petrographical characters of the dike of diabase in the Boston basin. In Mus. Comp. Zool., Harv. Coll. Bull., vol. XVI, 1888, p. 1.

of the eastern part of that State. One of the dikes starting just west of the border of the Newark area, near Holly Springs, Cumberland county, Pennsylvania, runs north with some breaks and irregularities, across Perry county and into Dauphin county, a distance of about 35 miles. Other dikes traversing Paleozoic and crystalline rocks occur in Lancaster county, a little south of the Newark area.

The most remarkable dike in this region, however, begins at the north, in Bucks county, and runs in a general southwesterly direction across Pennsylvania and into Maryland for a distance of 90 miles. This dike has been described and mapped by Lewis.[1] Its northern end is in the Newark system, but throughout the greater part of its course it traverses Silurian and crystalline strata.

Southwest of the southern end of the dike described by Lewis, and possibly a continuation of it, is another dike, more or less broken, the course of which has been traced by S. H. Williams for about 30 miles. This dike, as I have been informed by Williams, is later than any of the associated igneous rocks in the region, and was intruded after the crystalline rocks had their present attitude. Lithologically it is undistinguishable from the characteristic trap rocks of the Newark system. Williams has also traced the course of another dike beginning in the Newark area of Maryland, near the Pennsylvania boundary, and running southward to the Potomac. This dike leaves the Newark rocks about 10 miles north of Frederick, and for the remainder of its course traverses the crystalline area.

In Virginia, west of the southern end of the New York–Virginia area, there are trap dikes of the same character as those mentioned above, which trend a little west of north and cut across the folds of the Appalachians. Again, in the western part of Virginia, on the west side of the great Appalachian valley, several small trap dikes have recently been observed by Darton; specimens from these, examined by Diller, are found in all cases to be closely similar to, and in one instance identical with, those of the Newark system.

Farther north in Virginia and the Carolinas trap dikes outside of the Newark areas are of common occurrence but have not been mapped, and little is definitely known concerning their distribution. In South Carolina the same great system continues southward far beyond the last remnants of the sedimentary beds of the Newark, but still retaining all the geological and lithological characters that distinguish it in the north. The dikes of South Carolina were recognized by Tuomey[2] in his admirable report of 1848, and their relation to the series of similar dikes farther north fully understood. The author cited states that he traced the dikes referred to through Georgia, and as far as the Coosa river in Alabama, and also that the direction of the dikes in South Carolina is exceedingly uniform, varying between 15 and 35 degrees east of north,

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[1] A great trap dike across southeastern Pennsylvania. In Am. Phil. Soc. Proc., vol. XXII, 1885, pp. 438–456 and map.

[2] Report Geology of South Carolina, Columbia, S. C., 1848, 4to., pp. 65–68.

and that they are but slightly inclined from the vertical. My opportunities for observation in South Carolina, although limited, are sufficient to indicate that Tuomey's conclusions seem in every way correct. The reports of the State geologists of Georgia and Alabama contain brief accounts of trap dikes which are supposed to belong to the series under review. Such observations as have been made in this region show that the dikes are abundant, and probably much more numerous than in the northern part of the Atlantic coast plain. Their southern limit is unknown for the reason that, in common with the crystalline rocks they traverse, they disappear beneath the Cretaceous and Tertiary strata, wrapping around the southern end of the Appalachian mountains.

This hasty sketch of the extent of the trap dikes outside of the Newark system will serve to show their importance in the geology of the Atlantic slope and suggest future lines of investigation. The length of the series of dikes as now known is about 1,000 miles, and its width, although its eastern border is concealed by more recent geological deposits, and by the ocean, is not less than 200 miles.

TRAP ROCKS OF THE ACADIAN AREA.

The trap rocks belonging to the Newark system in Nova Scotia form a bold mountain ridge extending along the eastern shore of the bay of Fundy from Blomidon southward to Brier island, and also many bold headlands and picturesque islands in and about the basin of Minas and the waters connecting with it. These rocks have been studied by J. W. Dawson, especially, and it is to his well known work on Acadian geology that we owe the greater part of our information concerning them. The trappean mass bordering the bay of Fundy on the east is vesicular below and compact and basaltic above. It is considered by Dawson and Marsters[1] to have been poured out as a subaqueous lava flow. In a general way, at least, it is conformable with the sandstones and shales on which it rests, and dips westward beneath the waters of the bay of Fundy at an angle of about 15 degrees. Its relation to higher stratified beds is not known, as no upper contacts have been seen. The vesicular character of the lower part of the sheet and its marked contrast with the compact basalt forming the upper portion suggests the possibility that they are in reality two separate sheets, the lower one being a contemporaneous overflow, and the upper and intruded sheet of later date.

Many of the isolated trap masses in the Minas basin and elsewhere rest on sedimentary Newark beds, and are probably remnants of an extensive lava sheet. The structure in this region is imperfectly understood, and the possible presence of faults not fully investigated.

On the west side of the bay of Fundy, at the island of Grand Manan, trap rock again appears, which has been referred with more or less doubt to the Newark system.[2]

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[1] Triassic traps of Nova Scotia, Am. Geol., 1890, pp. 140-145.
[2] Geol. Surv. of Canada, atlas sheet, No. 1, S. W., note 7.

TRAP ROCKS OF THE CONNECTICUT VALLEY.

The trap rocks of this area have received greater attention than those of any other similar area, but diversity of opinion still exists as to the method of their occurrence. The history of the geological study of this area has been summarized by Davis[1] and need not be repeated here.

On the accompanying map (Pl. III) the outlines of the trap outcrops are shown as accurately as the scale of the illustration will allow. Those in Connecticut are from Percival's map, with some revisions by Davis, and those in Massachusetts are from a manuscript map kindly furnished by B. K. Emerson. All of the outcrops indicated are edges of trap sheets more or less conformable with the associated stratified rocks. Trap dikes are seldom seen and are too small to appear on the maps.

Davis's studies have shown that by far the larger part of the trap sheets were formed by overflows of volcanic rock during the deposition of the Newark strata. The trap sheet in the extreme northern part of the Newark area, near Turner's Falls, Massachusetts, is of this nature, and so also is the great trap sheet following Mount Holyoke and Mount Tom and extending southward as far as Meriden, Connecticut. The conclusion that this trap sheet was extruded at the surface and subsequently buried was advanced by Hitchcock during his survey of Massachusetts, and has since been sustained by Davis and Emerson.

Numerous trap ridges in the eastern part of the Newark area in Connecticut have also been shown by Davis to be extruded sheets, while the intruded sheets are confined to the western border of the area south of Massachusetts. This series begins at the south, at East Rock; a conspicuous bluff North of New Haven appears also in West Rock and forms the long broken ridge running northward. The same series of intruded sheets appears to outcrop again in the Barndoor hills of Granby, on the northern border of the state.

All of the trap sheets of Connecticut were considered as of intrusive origin by Percival, and his conclusion seems to have been accepted by all subsequent writers until Davis's study showed that there were strong reasons for believing that some of the sheets were extrusive and not intrusive. This opinion, although sustained by a large mass of the evidence, is not accepted by all students of the subject, and more detailed work evidently remains to be done before a final and generally accepted conclusion will have been reached. The trap sheet at Tariffville, Connecticut, has been shown by Rice[2] to be of extrusive origin.

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[1] On the relation of the Triassic traps and sandstones of the eastern United States. In Mus. Comp. Zool., Harv. Col., Bull. vol. VII, 1883, pp. 279–281.

The structure of the Triassic formation of the Connecticut valley, in Seventh Ann. Rep. U. S. Geol. Surv., 1885–86, pp. 455–490, Pl. 52.

The lost volcanoes of Connecticut. Pop. Sci. Mo., vol. XL, 1891, pp. 221–235.

[2] On the trap and sandstone in the gorge of the Farmington river, at Tariffville, Conn. In Am. Jour. Sci., 3d ser., vol. XXXII, 1886, pp. 430–433.

In a review of Davis's conclusions, Dana[1] refers to the uniformity in the character of the Connecticut valley as indicating a common mode of formation. The vesicular texture of the upper surfaces of some of the trap sheets is referred to an escape of vapor, but is not considered as necessarily showing that the lavas were extruded at the surface.

In a recent paper on some of the trap ridges of southeastern Connecticut, by Hovey,[2] the conclusion is reached that all of the trap rocks in that portion of the state—considered by Davis as extrusive—are intrusive.

TRAP ROCKS OF THE NEW YORK-VIRGINIA AREA.

In the central and northern part of this area, as in the Connecticut valley, trap rocks are abundant, and appear principally as sheets, conformable more or less thoroughly with the bedding of the associated stratified rocks. In the southern part of the area, in Maryland and Virginia, trap sheets are much less abundant than farther north, but dikes increase in number. This change accompanies a decrease toward the south in the thickness of the system as it now remains, and favors the conclusion, that when the Newark rocks are deeply eroded, trap sheets disappear and trap dikes take their place.

In New Jersey the outcropping edges of the trap sheets form bold ridges, trending in a general way, north and south and facing eastward. Their westerly slopes conform to the dip of the associated shales and sandstones, and are inclined westward at angles of about 15 degrees.

The studies of Davis, and later of Darton,[3] have shown that the trap sheets of New Jersey are of two classes, intrusive and extrusive. The intrusive sheets comprise the Palisade, and what is probably its southern extension, known as Ten Mile run, Rocky hill, Pennington mountain, etc., a few miles north of Trenton, and other associated ridges in the same region.[4] The sheets forming the Watchung mountains are extrusive and are high up in the stratified beds unless a fault along the base of the most easterly of these ridges, believed to exist by Darton, can be proved. If such a fault does exist, and the basal conglomerate

[1] Am. Jour. Sci., 3d ser., vol. XXV, pp. 474–475. The origin of the trap rocks near New Haven, Conn., has been critically discussed by J. D. Dana, since this paper was written on some of the features of nonvolcanic igneous ejections, or illustrated in the four "rocks" of the New Haven region, West Rock, Pine Rock, Mill Rock, and East Rock in Am. Jour. Sci., 3d ser., vol. XLII, 1891, pp. 79–110, pl. 2–7, and "on Percival's map of the Jura-Trias trap belts of central Connecticut, with observations on the upturning, or mountain-making disturbance of the formation," in Am. Jour. Sci., 3d ser., vol. XLII, 1891, pp. 439–447, Pl. 16. Proofs that the Holyoke and Deerfield trap sheets which are contemporaneous flows has been given Ben. K. Emerson in Am. Jour. Sci., 3d ser., vol. XLIII, 1892, pp. 146–148.

[2] Am. Jour. Sci., 3d ser., vol. XXXVIII pp. 361–383, and map.

[3] U. S. Geol. Sur. Bull. 67.

[4] As stated by Darton, Am. Jour. Sci., 3d ser., vol. XXXVIII, 1889, p. 136, the intrusive sheets of New Jersey comprise those forming the Palisades, Sour Land mountain, Cushetunk mountain, Round mountain, and the series including Lawrence brook and Ten Mile Run mountain, Rocky hill, Pennington mountain, Bald Pate, and Jericho hill, and the outcrops at Point Pleasant, Snake hill, Arlington, Martin's Dock, Neshanic, Bell mountain, Granton, and Brookville.

The extrusive sheets include all the outcrops constituting First, Second, and Third Watchung mountain and the ridges to the westward and the outlying outcrop near New Germantown.

appears at the surface east of Paterson, it is probable that the extrusion of these rocks took place early in the history of the system.

The intruded sheets, although mostly near the eastern border of the area and near the base of the sedimentary series, are not all so situated. The trap of Cushetunk mountain is at the extreme western border and, in part, in contact with the bordering Paleozoic rocks. The generalization suggested by Davis, to the effect that the intruded sheets of the Newark system are all low down in the series, while the extruded sheets occur at higher levels, apparently can not now be applied in New Jersey; but when the structure of the New York-Virginia area is more thoroughly known, the hypothesis referred to may find support there as well as in the Connecticut valley.

Of the intruded sheets the most interesting is the one forming the Palisades. It is about 400 feet thick in Jersey City, and, as shown by Darton, rises northward by breaking across the bedding of the stratified rocks until, at the Hook mountains, in New York, its base is nearly a thousand feet higher than in Jersey City, and its thickness 850 feet. When followed westward to the extreme western end of the Hook mountain, it appears that the intruded rock reached the surface and overflowed.

Detailed observation regarding the nature and distribution of the trap rocks of New Jersey is given in the reports of the Geological Survey of New Jersey by Darton, in his article on the great lava flows and intruded trap sheets of the Newark system, and in Bulletin 67 of the U. S. Geological Survey, already referred to, and by Davis, in his paper on the relation of the Triassic traps and sandstones of the eastern United States.

The conclusion reached by Davis and Darton as to the extrusive origin of the traps of the Watchung mountains has not been accepted by the geologists of the New Jersey Survey, who urge that all of the trap sheets of New Jersey are intrusive.[1]

In that portion of the New York-Virginia area which crosses Pennsylvania, trap rocks are abundant and appear both as sheets and dikes, but little information is at hand to determine the nature of the sheets, though they are spoken of by the geologists of the Pennsylvania Survey as extrusive. The dikes are known to be numerous, and, as already stated, branch far out into the surrounding crystalline and Paleozoic rocks. In Maryland trap sheets are absent, but dikes occur which have been traced for many miles, principally in crystalline rocks. South of the Potomac several dikes have been observed, and intruded trap sheets are also present, as has recently been observed by Arthur Keith, but sufficient observation in this region has not been made to enable one to determine the distribution of their outcrop.

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[1] N. J. Geol. Surv., Ann. Rep. for 1888, pp. 16-44; ibid., 1889, pp. 66-72. Frank L. Nason, On the Intrusive Origin of the Watchung traps of New Jersey, in Geol. Soc. Am. Bull., vol. I, pp. 562-563.

TRAP ROCKS OF THE NEWARK AREAS SOUTH OF THE NEW YORK-VIRGINIA AREA.

Throughout the numerous areas of Virginia and North Carolina, south of the New York-Virginia area, trap dikes are abundant, but no trap sheets have been observed. Some of the trap rocks in the Richmond area appear to be interstratified with the coal-bearing beds, but sufficient observation has not been made to prove whether these are truly interbedded sheets or simply dikes breaking obliquely across the strata. Dikes in the southern areas are most abundant in the easterly, but are not entirely wanting in the westerly belt of Newark areas. The dikes observed are in general parallel with the strike of the rocks, and are approximately vertical. In width they vary from a few inches to 50 or 75 feet, and have produced alterations in the texture and color of the adjacent rocks for a few feet along the lines of contact. In many instances the dikes may be followed for several miles across the country, their courses being marked usually by black, weather-beaten bowlders, but in no instance have they been mapped, and their number and distribution are unknown. They are indistinguishable in general appearance and in lithological and chemical characteristics from the trap rocks forming the great sheets of New Jersey and the Connecticut valley, or from the dikes traversing the adjacent crystalline areas.

SUMMARY RESPECTING THE DISTRIBUTION AND AGE OF THE TRAP ROCKS.

That the trap rocks traversing the Newark system in dikes and sheets belong to the great series of dikes intersecting the Atlantic coast plain from Nova Scotia to central Georgia seems sufficiently well established. The trap series at the south, in common with the sedimentary rocks they traverse, pass beneath Cretaceous and Tertiary beds, and therefore their full extent in that direction is unknown. The eastern border of the belt they occupy is also concealed in part beneath the ocean and, in part, by Cretaceous and more recent deposits. On the west the series reaches out in long dikes across the folds of the Appalachian.

In the crystalline and Paleozoic areas deep erosion has occurred, and only dikes now remain. The overflows of lava which probably once existed have been entirely eroded away. In some portions of the Newark areas, however, where the trap rocks, in common with the sedimentary beds, have been depressed below the base-level of erosion, trap sheets of great thickness still remain, and in other portions, where erosion has spared but little of the Newark series, trap sheets are absent, but trap dikes are common.

There is a direct association of trap dikes with the faults of the Newark system, as is illustrated by the contacts in the great fault crossing Bucks county, Pennsylvania, and in the Wadesboro area, where the strata adjacent to the narrow dikes show diverse dips. From this coincidence and the fact that both dikes and faults are a result of fracturing of the earth's crust and are hence due to the action of similar forces, it seems safe to conclude that both the dikes and faults are closely related and were probably, in part at least, contemporaneous. There are good reasons for believing that faulting was common at the time the Newark beds were being deposited, as is indicated by the great thickness of the conglomerates along the borders of the areas toward which the strata dip, but the widely extended faulting which imparts the characteristic structure of the Newark system took place after the beds were deposited and before or during the period of erosion which preceded the deposition of the next succeeding series of stratified beds. It was in this interval, also, that the intruded trap sheets and dikes were injected into the stratified series. This is shown by the fact that the next succeeding Potomac formation rests on the upturned and eroded edges of the Newark strata and on the truncated edges of the trap dikes which traverse them. The trap dikes in the crystalline and Paleozoic areas surrounding the Newark system do not assist in determining the age of the intruded rocks, for the reason that these terranes are all older than the Newark.

CHAPTER VIII.

DEFORMATION.

INTRODUCTION.

Throughout the Newark system the structure is monoclinal over broad areas. In general the strata are inclined at angles varying from ten to twenty degrees, but higher dips are of frequent occurrence. There is an absence of folds such as characterize the adjacent Appalachian system, and the strata have not been crumpled, except locally along fault lines. Displacements trending in general in a north and south direction have been shown to exist in very many instances, and are the controlling structural elements of the system. There are also a few great faults which trend at right angles to the prevailing strike of the rocks.

The prevailing monoclinal structure was one of the first features to be observed when the study of the system began, and many explanations of its origin have been suggested. It has been explained by H. D. Rogers[1] as being the position in which the strata were originally deposited. A similar suggestion was made by J. D. Whitney, after studying the structure of portions of the Connecticut valley area. The explanation advanced by H. D. Rogers was accepted by W. B. Rogers,[2] W. W. Mather,[3] and others, in the early days of American geology. More recent investigations have shown that none of the various Newark areas have a uniform structure throughout, and besides, the varied composition of the rocks and their great thickness, as shown by direct vertical measurements, so completely exclude all hypotheses of oblique deposition that their discussion is unnecessary.

Neither is it desirable, in the present state of geologic knowledge, to discuss the various suggestions that have been made with reference to the existing Newark areas being basal remains of great anticlinal ridges, or that they owe their monoclinal structure to the tilting of segments of the earth's crust many miles in width, without the formation of secondary faults.

These and other provisional hypotheses have been reviewed by Davis,[4]

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[1] Description of the geology of New Jersey. Philadelphia, 1840, pp. 166–171.

[2] Report of Progress, Geological Survey of Virginia, for 1839.

[3] Geology of New York, Albany, 1841, pp. 289–293.

[4] On the relations of the Triassic traps and sandstones of the Eastern United States; in Mus. Comp. Zoology, Harvard College, Bull., vol. VII, 1883, pp. 302–304.

and their failure to explain the facts observed fully demonstrated. As the study of the Newark system has advanced and become more detailed, a large number of observations have been recorded, which show that the various fragments of the system now remaining owe their preservation to the fact that they are below the horizon of present base-level erosion, and occupy that position in large part by reason of depression, or the elevation of contiguous area through faulting.

Each area is characterized by the presence of faults of all degrees of displacement up to many hundreds of feet, which have repeated the outcrops of individual strata. In many instances the fault blocks have been tilted in the same direction, so as to be easily mistaken for a continuous monoclinal dip. Closer study in certain instances, however, has shown that each of these supposed monoclinal areas is broken into many independent blocks.

The study of the structure of the system consists in determining what deformations have resulted from the faulting and tilting of horizontally stratified beds resting unconformably on much older rocks, which are generally metamorphosed and highly inclined. This being the direction in which recent investigation leads, let us see what evidence should be required to demonstrate that it is in reality the structure of the system under review.

It has been clearly shown by Davis, in discussing the structure of the Connecticut area, that the larger faults found in that region must affect the underlying crystalline rocks. My own studies have shown that the same conclusion may be extended to other areas of the system. Should the plane of erosion be depressed sufficiently, it is evident that at horizons near the base of the Newark system, the upheaved edges of fault blocks composed of crystalline rocks should appear at the surface as narrow belts intersecting the sedimentary beds. Owing to the greater resistance usually offered by the crystalline rocks to erosion, such protrusions would appear as ridges, standing in relief and dividing the superimposed beds. Bordering such ridges and resting on the crystalline rocks, one should find outcrops of the basal conglomerate of the Newark system, succeeded by sandstones and shales. On margins of the Newark areas where the line of junction with the surrounding crystalline rocks crosses the strike of the sedimentary beds, there should be long, narrow, finger-like extensions of crystalline rock, entering and dividing the sedimentary beds.

Another result of the deep erosion of faulted sedimentary beds resting on crystalline rocks would be the occurrence of narrow strips of sedimentary beds occupying the depressed borders of fault blocks and separated from larger areas by a ridge of the lower formation.

In the study of the various Newark areas peculiarities in outline and in topographic form which should be expected to result from the faulting and erosion of horizontally stratified beds resting on more resistant crystalline rocks as stated above have been found abundantly developed.

In the present chapter the available evidence in reference to the structure of the various Newark areas will be briefly summarized and the conclusion to which it points indicated. After ascertaining what the structure of the system is, the attempts that have been made to explain its origin will be considered.

STRUCTURE OF THE ACADIAN AREA.

For our knowledge of the structure of the Newark rocks of Nova Scotia we are indebted almost entirely to the writings of Dawson.[1] The general dip of the rocks along the eastern border of the bay of Fundy is northwest at an angle of about 15 degrees. On the New Brunswick shore there are several isolated areas belonging to the same system which dip northeastward at angles varying from 25 to 35 degrees. These inclinations have led to the conclusion that the Acadian area has a synclinal structure. That such is the case, however, can not be accepted as a final conclusion, for the reason that a faulting and tilting of the strata would account equally well for the observed dips. In the eastern part of the Acadian area, about the Minas Basin and Cobequid bay, the strata are much disturbed and dip toward all points of the compass, and at all angles from near horizontality up to 50 degrees or more. Some faults have been recognized in this region, but a characteristic fault structure, although indicated, has not been demonstrated. The structure is, however, certainly distinct from the great synclinal suggested by the opposite dips on the east and west shores of the bay of Fundy, and so far as recorded observations indicate falls in line with the prevailing fault structure characteristic of the more southern areas of the same system.

The presence of two ridges of trap at Digby neck, in the southern portion of the Newark area bordering the bay of Fundy on the east, can apparently be explained by a fault, as can also the presence of parallel submerged ridges in the adjacent portion of the bay of Fundy. Further field study is necessary, however, before the structure of this area can be considered as definitely determined; but the recorded evidence, supplemented by observations made during a brief reconnaissance by the present writer, certainly favors the hypothesis that the attitude of the Newark system in Nova Scotia has resulted from the tilting of faulted blocks.

STRUCTURE OF THE CONNECTICUT VALLEY AREA.

This area has been more thoroughly studied than any other in the series, and its general structure is known, although much detail work undoubtedly remains to be done. Our knowledge of its structure and of the nature of the trap sheets that traverse it has been greatly ad-

[1] Acadian Geology, 3d ed., London, 1878; pp. 86–127 and map. Supplement, pp. 28–30.

vanced during the last few years by the investigations of Davis.[1] In the southern portion of the area concerning which the most recent reports have been made the strata are broken by numerous faults, trending in general north and south with the strike of the rocks. The fault blocks, with some exceptions, are tilted eastward at varying angles up to 15 degrees. Other faults trend obliquely to the strike of the rocks in such a way at to throw the outcrops of hard beds out of line. There is good evidence for believing that in many portions of the eastern border of the area there are marginal faults which cause the eastward-dipping strata to abut against the adjacent crystalline rocks. The marginal faults belong to the same system as the strike faults in the central portion of the area, but deserve separate mention on account of their great importance in indicating the former extent of the stratified beds now claiming our attention.

The structure along the east margin of the Connecticut valley area, as illustrated by Davis, is shown in Fig. 1, in which a portion of the marginal fault mentioned above is indicated. The throw of this fault must be several thousand feet.

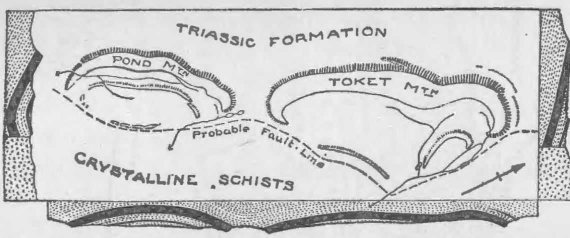

FIG. 1.—Fault on east side of Connecticut valley area, after W. M. Davis.

The determination of the structure of the Connecticut valley area has been rendered possible by the discovery of Davis that some of the trap sheets traversing it were extruded at the surface during the deposition of the Newark sediments and were buried by later deposits. In the deformation and erosion of the area they play the rôle of hard, sedimentary beds, and enable one to determine the structure in a manner more satisfactory than seems possible in other portions of the same system where sandstones and shales alone occur. Since these pages were written the structure of the Connecticut valley area has been still further discussed by Dana.[2]

STRUCTURE OF THE SOUTHBURY AREA.

This area may be considered as an outlier of the Connecticut valley area from which it is separated by about 16 miles of crystalline rocks.

[1] On the relations of the Triassic traps and sandstones of the Eastern United States; in Mus. Comp. Zoology, Harv. Coll. Bull., vol. VII, 1883, pp. 249-309, Pl. 9-11. Also "Triassic formation of the Connecticut Valley," U. S. Geol. Survey, Seventh Ann. Rep., 1885-'86, Washington, 1888, pp. 455-490, Pl. 52, and the lost volcanoes of Connecticut, Pop. Sci. Mo., vol. XL, 1891, pp. 221-235.

[2] "On Percival's map of the Jura-Trias trap belts of Central Connecticut, with observations on the upturning or mountain-making disturbance of the formation," in Am. Jour. Sci., 3d ser., vol. XLII, 1891, pp. 439-447, Pl. 16.

It is so far removed from the Connecticut valley area that its former connection is not usually admitted; but the fact that similar areas in detached fault basins are common in connection with the main areas in Virginia and North Carolina suggests that the Southbury area also occupies a local fault basin, and that its preservation is due to the depression by faulting of a small portion of the original Newark terrane below the present horizon of base-level erosion.

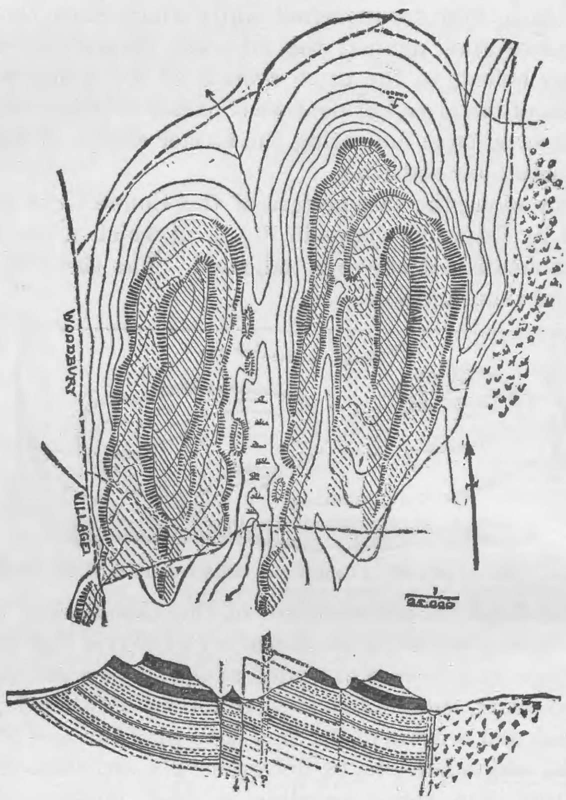

FIG. 2.—Map and section of Southbury area, after W. M. Davis.

This area has been studied by Davis,[1] and its structure illustrated by the accompanying map and section (Fig. 2). The rocks comprise several hundred feet of sandstone and conglomerates at the base; next, a thin, amygdaloidal trap; then 200 feet or more of shale and calcareous beds; then a heavy sheet of trap. Other superior members exist, but are mostly concealed by drift. The attitude of these beds is so well shown in the accompanying figure that further description may be dispensed with.

[1] U. S. Geol. Survey, Seventh Ann. Rept. for 1885–'86. Washington, 1888, p. 468.

STRUCTURE OF THE NEW YORK-VIRGINIA AREA.

Although a large amount of time has been devoted to the study of this area, its structure has not been satisfactorily determined.

In New York and New Jersey the general dip of the strata is toward the northwest, but many exceptions have been recorded. As shown by Darton and Nason, the observations of dip indicate that the strata are broken into blocks which have a monoclinal structure. Only a few faults have been distinctly traced, however, and these are usually small. A great fault, having a throw of perhaps 2,000 feet, is supposed by Darton[1] to exist on the east side of the Watchung mountains, in the neighborhood of Paterson, which brings to the surface the characteristic basal conglomerate of the system.

There are several reasons for believing that the western border of the area, from near Morristown, New Jersey, northward to the Hudson, is determined by a displacement. Along this junction the Newark rocks dip uniformly westward to within a short distance of the line of contact, but the actual junction has not been seen, owing to the thickness of the superficial drift. The conditions are here apparently the same as along portions of the eastern margin of the Connecticut valley area, and at the junction of some of the Newark areas in Virginia and North Carolina with bordering crystalline rocks where marginal faults are known to exist.

The line of bluffs of crystalline rock overlooking the Newark area from Morristown to the Hudson continues eastward and forms a bold line of hills, when seen from the south, through Westchester county, New York, and into Connecticut. The presence of a fault along the base of these hills, I have been informed by Darton, is indicated by an abrupt change in the character of the rocks. This region has been studied by Smock,[2] who describes an abrupt change in the lithology, but does not explain its origin.

Perhaps I go too far in making the above suggestion, but there are several indications which lead to it as a working hypothesis which future students of the region would do well to bear in mind. The line of bluffs referred to northward of Morristown marks the shore line during certain stages of the deposition of the Newark rocks, which was possibly determined by a line of faulting that was in process, and increased its displacement from time to time during the deposition of the Newark beds.

The most important fault observed in the New York-Virginia area occurs in Bucks county, Pennsylvania, and in adjacent portions of New Jersey. The course of this fault is known for about 40 miles and probably has a greater length. Its general direction is north and south, but it is strongly curved, being concave toward the northwest. From

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[1] Bull. U. S. Geological Survey, No. 67, p. 18.

[2] A Geological Reconnaissance in the Crystalline Rock Region of Dutchess, Putnam, and Westchester counties, New York. 39th Ann. Rept. of the Trustees of the New York State Museum of Natural History, Albany, 1886, pp. 165–185.

near Lambertville, where it crosses the Delaware, for about 6 miles northwestward, it has brought to the surface a narrow outcrop of Silurian rocks on which rest the basal conglomerate of the Newark system. On the east side of the Delaware, in New Jersey, an outcrop of trap occurs in the midst of the fault rock which marks the course of the displacement, suggesting that the fracture was sufficiently deep to reach molten material. In general, on the north side of the fault the strata are inclined toward the northwest, while on the south they dip northeast. The rocks immediately adjacent to the displacement have been greatly fractured and slickensided, and in places where the exposures are obscure this fault rock enables one to trace the line of fracture with tolerable certainty. The strip of Silurian rocks brought up by this fault is represented on the large maps accompanying the reports of the First Geological Survey of Pennsylvania; but the structure of the region does not seem to have attracted special attention during the progress of the survey. Its position is shown on the accompanying map, forming Pl. IV. The facts here stated are principally from an account published by Lewis.[1] Secondary faults, at right angles to the prevailing strike of the Newark rocks of Pennsylvania are reported by Lewis, but these are of small importance in a study of the general structure.

In a section across the eastern rocks of southeastern Pennsylvania, from near Dillsburg, S. 47° 31′ E., to Beelers Cross Road, by Frazer,[2] a uniform southwesterly dip is given, ranging from 16 to over 40 degrees, excepting near the west end of the section, where a broad, gentle syncline is introduced. The dips and rock structure recorded in describing this section might apparently be equally well explained by the introduction of faults. Unless the exposures are as complete as represented by Frazer, it does not seem safe to assume such a great thickness as his section indicates, or to introduce a synclinal structure, which is exceptional for these rocks. A portion of the western border at Cornwall iron mine, near Dillsburg, has been shown by J. P. Lesley and E. V. d'Invilliers[3] to be determined by a great displacement, which brings the westward dipping strata of the Newark system in abrupt contact with Paleozoic strata.

The most recent studies of the Newark system in Pennsylvania have, in general, not indicated the presence of a faulted monoclinal structure. The absence of easily recognizable strata, as in many other parts of the system, unfortunately renders it difficult to determine the structure of the region. Many observations of dip and other phenomena have been recorded by the Second Geological Survey, but no digest or systematic study of these observations has been made. Until this is done by one

[1] A great trap dike across southeastern Pennsylvania. In Am. Phil. Soc. Proc., vol. XXII, 1885, pp. 438–456. Map op. p. 40.

[2] Second Geol. Surv. of Pennsylvania, Report of Progress in the counties of York, Adams, Cumberland, and Franklin. Vol. C 2, 1875. Harrisburg, 1887, pp. 265–270. Pl. op. p., 264.

[3] Second Geol. Surv. of Pennsylvania. Ann. Rep. for 1885, pp. 496, 498, 506.

familiar with the region it is impracticable to draw any general conclusion from the many observations recorded.

The eastern border of the Newark system in Pennsylvania, Maryland, and Virginia is irregular, owing apparently to inequalities in the floor on which the stratified beds were deposited, or possibly to subsequent disturbances. These inequalities have been exposed at the surface by erosion, and indicate that along this border the Newark beds have but little thickness. In some places they have been cut through by stream erosion so as to expose the crystalline rocks beneath.

The structure of the southern portion of the New York-Virginia area has not been determined. The inclination of the beds south of the Potomac is in general northwestward, and to a casual observer the strata appear to have a continuous monoclinal dip from side to side. The rocks, however, are mainly shales and shaly sandstones, and the presence of faults would be difficult to determine.

At Brooklyn, a few miles west of Centerville, Virginia, there is a series of parallel ridges trending nearly north and south, which present sharp escarpments to the eastward. These ridges owe their prominence to the outcropping edge of a trap sheet which has been broken by faults. The trap sheets in each fault block have a dip of about 25° to the northwest, corresponding with the inclination of the associated shales and sandstones. The presence of trap sheets in this region, it is to be hoped, will assist in the future study of its structure in the same manner that similar sheets in the Connecticut valley have led to the determination of the deformations that there occurred.

STRUCTURE OF THE BARBOURSVILLE, STOCKVILLE, DANVILLE, AND DAN RIVER AREAS.

These areas fall in line with the southern extension of the New York-Virginia area, and have the same general structure. The strata of which they are composed dip westward, and in many places abut against the bordering crystalline rocks. The presence of marginal faults has not been determined by direct observation, but the persistent westward dip of the Newark strata, close to the line of junction, can not be explained unless such faults are postulated. In the Dan river area especially, the high dip of the Newark system, amounting in many instances to fully 50 degrees within a few rods of the line of junction with the crystalline rocks, is a very strong indication of marginal faulting. The western border of each of the areas here considered is composed of coarse conglomerate, derived from the crystalline rocks toward which the strata are inclined. In general the conditions are the same as along the northwestern border of the New York-Virginia area and the eastern border of the Connecticut valley area.

In the Barboursville area the structure is obscure and greatly disturbed. The presence of coarse conglomerates along both its western and eastern margins indicates that the strata have not great thickness.

The dips observed at several places are uniformly westward, at angles of about 20 degrees. No faults or folds have been discovered, but may exist, as the exposures are not good. The area is bordered on all sides by old hills, and forms a topographic basin which owes its origin to the greater ease with which the stratified rocks yield to erosion.

In the Scottsville area the dip is westward throughout, at angles varying from 15 to 20°. No structural features excepting the dip of the strata have been observed.

The Danville and Dan river areas are remarkable for the high inclination of the strata composing them. In many places, throughout continuous sections over a mile in length, the beds have a persistent westward dip at angles varying from 35 to over 50°. The White Oak mountains forming the most conspicuous portion of the Danville area are composed of sandstones and shales, and stand in relief and form an exception to the statement made on a preceding page to the effect that the Newark areas at the south are usually lower than the crystalline areas bordering them. The trend of the range is a little east of north, but does not coincide with the strike of the strata composing it, which is nearly northeast and southwest.

The Danville area terminates abruptly at the south, and appears to have been separated from the Dan river area by a profound displacement trending northwest and southeast, or at right angles to the prevailing strike of the rocks. The abrupt manner in which the strata at the northeast extremity of the Danville area abut against the crystalline rocks, when followed northwestward along the strike, is well shown near the little hamlet of Cascade. The junction of the two formations is a straight line at right angles to the strike of the Newark beds. Along the line of junction the Newark strata dip northwest at angles varying from 30 to 35°.

This locality has not been thoroughly studied, but from the reconnaissance made it seems as if the Newark strata had been depressed into the crystalline rocks along the junction of two faults which meet each other at nearly right angles. In a newly constructed mill race, situated between Cascade and the neighboring railroad station, the following detailed section was measured: The section is 1,370 feet long as measured at the surface, and runs at right angles to the strike of the rocks. The dip throughout is northwest 30 to 33°. The rocks were well exposed, and show no indications of faults or folds, excepting that the hard sandstone strata are very similar in composition, and are repeated with surprising regularity in certain portions. Only a few rods northeast of this section, i. e., in the direction of strike, the stratified beds end abruptly, and are replaced by crystalline rocks. The measurements given below show vertical thickness; the first or highest member in the series is at the west, where the dam from which the race starts is situated.

Vertical section, near Cascade, North Carolina.

	Feet.
Compact black slate, becoming sandy in weathered outcrops	33·0
Compact gray sandstone	2·5
Black shale, poorly exposed	122·0
Hard, gray sandstone	2·0
Thin-bedded sandy shale, passing into sandstone below	19·0
Compact gray sandstone	2·5
Sandy shale	3·0
Compact gray sandstone	2·0
Shale, light-colored, even-bedded	19·0
Hard sandstone, with partings of shale	3·5
Shale, yellowish, sandy	19·0
Sandstone, hard, bluish, resembling gneiss	3·5
Shale, yellowish	12·0
Sandstone, compact, somewhat broken	2·5
Shale	8·0
Sandstone, compact	3·0
Shale	12·0
Sandstone	2·0
Shale	6·0
Sandstone	2·0
Shale, broken, exposures obscure	8·0
Sandstone, hard, bluish, resembling gneiss	6·0
Shale	19·0
Sandstone, hard, bluish, resembling gneiss	6·0
Sandstone, compact	5·0
Sandstone, shaly	5·0
Shale, black	1·0
Sandstone, shaly	2·0
Sandstone, shaly, irregular, disturbed	3·5
Shale, black	1·0
Sandstone, compact, even-bedded	2·0
Sandstone and shale, in thin layers	4·0
Slate, black	2·0
Sandstone, compact	3·0
Shale or slate, black	5·0
Sandstone, in thin layers with shaly partings, even-bedded	15·0
Shale, yellowish, micaceous, black at bottom	3·5
Sandstone, compact, bluish	5·5
Slate, black, shaly	3·5
Sandstone, with shaly partings, passing below into slate	13·0
Shale, black	4·0
Sandstone, compact, bluish	2·0
Shale, black, yellowish on weathering	7·0
Sandstone and shale, in thin layers	9·5
Sandstone, shaly	5·0
Sandstone, compact, bluish	10·0
Shale, yellowish	20·0
Unexposed	100·0
Shale, sandy	22·0
Sandstone, compact, bluish	2·5
Total vertical thickness, about	473·5

Another section exhibiting the characteristics of the strata of the Dan river area occurs at Leekville, and resembles closely that given above excepting that on the west it passes into a heavy granitic conglomerate, which in limited exposures can not be distinguished from the undisturbed granitic terrane bordering the Newark area on the west.

The system throughout the Dan river area is characterized by the presence of heavy beds of black slate and of dark colored shales, resembling closely the medial portions of the Richmond and Deep river areas.

All through the Dan river area the rocks are inclined westward, and no faults of any considerable extent have been observed, although small ones in much disturbed sandstones and shales may be seen in cuts along the Cape Fear and Yadkin Valley railroad. A marginal fault, on the west side of the area near Leeksville, is suggested by the high westward inclination of the conglomerates close to their junction with the granitic rocks on the west. The Dan river area, as shown on Pl. I, is the most southern of the western belt of Newark areas, the northern terminus of which is on the Hudson. Throughout this entire series the general dip is westward, except in Pennsylvania, where the terrane curves to the west and the prevailing dip is northward. Throughout the entire belt, however, the dip is toward the ancient shore from which the debris forming the Newark beds was derived.

In Virginia and North Carolina there is another belt of Newark areas, to the eastward of the one here described, in which the prevailing dips are to the southeast. Between these two belts is the small Farmville area, in which the strata are greatly disturbed and dip sometimes to the westward and sometimes to the eastward.

STRUCTURE OF THE FARMVILLE AREA.

In crossing this area from east to west, one finds that the strata have diverse inclinations and change abruptly from northeast to northwest dips. During my reconnaissance of the area, in 1885, the presence of at least four north and south faults in the central portion of the area was determined. The area as a whole, however, is, topographically, a basin surrounded by hills of crystalline rocks, and exposures are too indefinite to admit of a ready determination of its structure. On its eastern border, about 2 miles north of Farmville, the presence of a heavy marginal fault is clearly shown in recent mining explorations. At this locality the Newark system is composed of fine, light colored sandstones and shales, with several much disturbed coal seams, and abuts against granite. The stratified rocks near the line of contact are much disturbed, broken, and slickensided. They are not shore deposits, no coarse conglomerates being present, but offshore and swamp accumulations. That their abrupt termination against the granite has resulted from displacement and is not due to original deposition is beyond question.

In the small detached area about 6 miles south of Farmville the rocks are principally shales, with some sandstone layers and occasional coal seams. Coarse conglomerates do not appear at the surface. The prevailing dip is northwest, 20 degrees. No folds exist, and the presence or absence of faults has not been determined.

STRUCTURE OF THE RICHMOND AREA.

PREVIOUS OBSERVATIONS.

In Lyell's well known essay on the Richmond coal field,[1] and in other writings by the same author, the rocks of this area are considered to have been deposited in a local basin of about the same extent as the present coal field, and to have a synclinal structure. These conclusions have been repeated by nearly all subsequent writers on the subject with the exception of W. M. Fontaine, whose work will be noticed later, and F. H. Newell,[2] who has shown that the coal seams were not accumulated in the restricted basin, and do not thin out at the outcrops, as previously considered, but are faulted and crushed.

The occurrence of a double line of coal outcrops along the eastern margin of this area was recognized by Rogers,[3] during his survey of Virginia, and considered to be a result of faulting. He believed, however, that the Newark strata in the Richmond area and elsewhere were deposited in an inclined position, as had been explained by H. D. Rogers, and did not determine its structure or advance any definite ideas concerning the deformations that had taken place.

The presence of faults on the eastern border of the area is indicated in a section published by Taylor[4] in 1835, unaccompanied by any discussion.

This area has been studied by Fontaine,[5] in connection with other areas of the same system. His conclusions respecting its structure are stated as follows:

> My examination of some of the finger-like remnants of the Mesozoic, now found at the northern end of this field, thrust out in the Azoic, put me in possession of what I think is the explanation of the peculiarities of the structure of this field, and of the interior belts. The history of these areas, briefly stated, seems to be as follows:
>
> The strata were laid down in depressions, which, originally shallow, were subsequently deepened by a more or less rapid subsidence. The subsidence was due, as previously stated, to the operation of a lateral thrust. It continued until faults and overturned anticlinals were produced. In the interior belts (the New York-Virginia, Barboursville, Scottsville, Danville, and Dan river areas) these operated to produce a constant northwest dip. This resulted from the fact that the western sides of the severed earth prisms dropped, producing, sometimes, by a roll of the prisms, an upthrow of the eastern side. This appears to occur in some of the faults of the Richmond coal field also. When the strain did not result in producing rupture and

[1] Geol. Soc. London, Quart. Jour., vol. III, 1847, pp. 261–280, Pls. 8, 9.
[2] The Richmond Coal Field, Virginia. Geol. Mag., London, Dec. 3, vol. VI, 1889, pp. 138–140.
[3] Reports on the Geology of Virginia for 1835, p. 55, and for 1840
[4] Pennsylvania Geol. Soc., Trans., vol. I, pp. 275–294, Pls. 16, 17.
[5] Notes on the Mesozoic of Virginia. Am. Jour. Sci., 3d series, vol. XVII, 1879, pp. 36–37.

faulting, it caused the development of an anticlinal, affecting but a narrow belt, which was overturned to the eastward, thus producing also a continuous northwest dip. Where the strata have suffered enormously from erosion, and where almost precisely similar beds are formed by the similar conditions of depositi n found repeated at different horizons, as is often the case in the interior belts, it is almost impossible to detect reduplications by faulting and folding. When the period of faulting was reached eruptions of trap took place. It will thus be seen that the continuous dips would by no means give a true indication of the thickness of the series.

In the Richmond coal field the faults and narrow overturned folds are not of sufficient magnitude to produce, as in the interior belts, continuous dips, but suffice only to render very variable and uncertain the dip and position of the strata toward the center of the field. The general result seems to have been to flatten the dip here and to steepen it on the western side. Some of the twists in the strata produced by the overturned anticlinals are of extremely limited extent. I have seen them only a few feet wide.

The direction in which the lateral thrust operated in this field was from east to west, and it seems not yet to be exhausted, for this region is often affected by minor earthquakes, and at intervals of ten or fifteen years by very powerful ones; the last occurring a few years ago. The shocks pass from east to west. It is probable that the gradual depression of the coast is connected with this westward thrust.

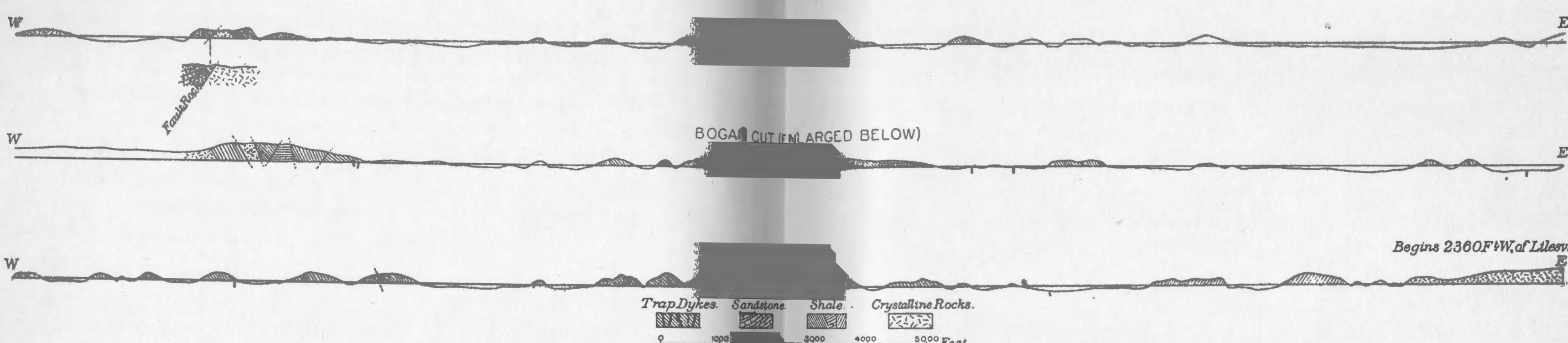
A detailed account of the strata penetrated during mining operations near Midlothian has been given by Heinrich[1] and the structure indicated in the plates which accompany his paper.

PERSONAL OBSERVATIONS.

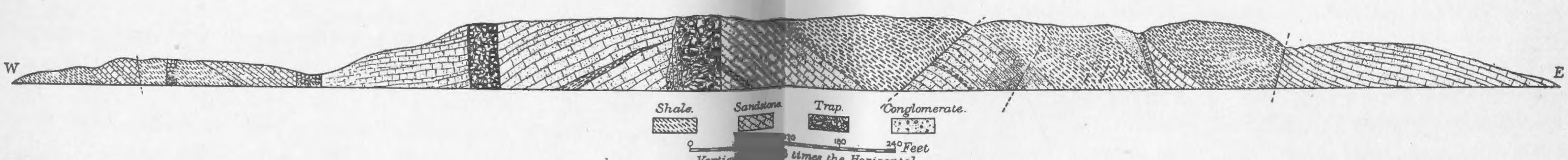
The observations of the present writer made in 1885 seem to warrant the conclusion that the Richmond area has been greatly disturbed by fracturing, especially along its eastern and western margins, and that as a whole it owes its preservation to faulting which carried the strata below the horizon of subsequent base-level erosion, or else elevated the contiguous areas. The faulting that has taken place along the margins of the area indicates that the strata were formerly more extended than now. Erosion has been great, and it is evident that what now remains of the Newark strata is but the remnant of their original extent.

Section along the James river.—The only natural section of any considerable extent in this area is along the left bank of the James from a point on the east nearly opposite the site of Bellona arsenal, westward to Dover, a distance of between 7 and 8 miles. At each end of this section the rocks are much disturbed and broken along north and south displacements. The general dip at each end is toward the center of the area, at angles varying from 15 to 70 degrees. In the central portion of the section, for a distance of about 4 miles, the strata form a broad, gentle synclinal, the central part of which is nearly horizontal, the dips on the eastern and western borders varying from 5 to 8 degrees. Near the west end of the section, at Boscobel, there is a mass of crystalline rocks included between highly inclined Newark strata. This is formed

[1] Mesozoic formation in Virginia. In Am. Inst. Min. Eng., Trans., vol. VI, 1879, pp. 221-224, Pls.1-2.



SECTION OF NEWARK ROCKS ALONG CAROLINA R.R THROUGH WADESBOROUGH N.C.



SECTION ON NORTH SIDE OF BOGAN CUT.

SECTIONS.

by the tongue-like prolongation of crystalline rock which enters the Newark area from the north and extends across the James river as shown on the map forming Pl. v. The presence of this wedge of crystalline rock, disturbing the continuity of the sedimentary strata, is due to a fault which has brought up the floor on which the Newark rocks were deposited, together with the basal conglomerate which rests upon it. On the east side of the wedge near the Dover mines the Newark rocks are disturbed and faulted, and have a general southwest inclination at angles varying from 15 to 20 degrees. On the west side the stratified rocks are also much disturbed and faulted, and in general dip eastward.

West border of the area.—The Dover mines, on the north side of the James, and the Powhatan, Norwood, and Old Dominion mines, on the south side of the river, are ranged in line along the west border of the area, and may be considered as constituting a single district. In this district, as has been demonstrated by mining operations, the inclinations of the rocks change abruptly from northwest at some localities to southeast at others near at hand, the inclinations varying from 15 to 20 degrees. This diversity is explained by the fact that the district has been broken by approximately north and south faults, and that the included beds have been variously tilted. The structure is especially well illustrated in the Norwood mine, in which the coal in certain of the fault basins has been worked out and the forms of the troughs demonstrated. These mines are located on the low bluff bordering the flood plain of the James, and the coal comes to the surface, although the lines of outcrop are concealed by superficial clays and gravels. The coal is worked by means of "slopes" following the dip of the seams. In the workings which were open in 1885 the dip is westward at an angle of from 20 to 25 degrees. The main slope had been excavated, following the inclination of the strata, for about 300 feet, and exposed sections of two coal seams, both of which are irregular in thickness, owing to disturbances along small faults. Three principal faults were exposed at the time of my visit, all remarkably uniform in strike and hade, and in the direction in which the fault blocks had been tilted. The displacement amounted to 5 or 6 feet in each instance, and the fault planes are inclined eastward at angles of from 60 to 70 degrees with a horizontal plane. Each of the fault blocks is tilted at an angle of 20 to 30 degrees toward the northwest. At the bottom of the slope another fault of greater magnitude was encountered, the hade of which is westward at an angle of 20 to 30 degrees. Along each line of faulting the coal had been pinched out to a mere "stringer" of comminuted and slickensided fragments. The fracturing and crushing were so complete near the lines of disturbance that the fragments of coal and associated shale are intimately mingled, much to the detriment of the former. In many cases the slickensided fragments, measuring an inch or two in diameter, can be removed with the hand.

Owing to the drag of the strata on the thrown side of the faults, the dip of the beds seems to be in opposite directions from the lines of displacement, and decreases in inclination a few feet distant. This occurrence has led the miners of this district to apply the term "roll" to these disturbances. In some instances it was apparent that motion had taken place throughout a belt of comminuted and slickensided fragments or "fault rock," several feet broad, thus rendering it impossible to indicate a precise line of fracture.

These displacements are accompanied by a thinning of the coal adjacent to the planes of fracture and a thickening in the central portion of the fault blocks. This phenomenon has been observed in many other mines in the Richmond area and is probably the explanation of the great thickness reported in some of the coal seams along the eastern margin of the area and in detached basins adjacent thereto.

East border of the area.—In the neighborhood of Midlothian there is a double line of coal outcrops separated by a strip of crystalline rocks having a breadth of approximately 2,000 feet. The western line of outcrop marks approximately the boundary of the main coal field, while the eastern line is formed by coal seams in detached basins. Mining in this region has demonstrated that there are at least two separate basins in the outlying strip of coal-bearing rocks. These are the Black Heath and Green Hole areas, widely known during early mining operations in Virginia. Other small areas are indicated on some maps as falling in line with these, but whether they form separate basins or not is uncertain. So far as the dominating structure of the region is concerned, all of these small local areas may be considered as one.

In the eastern border of the main area at Midlothian the strata, although disturbed by many small faults, are inclined westward at an angle of between 15 and 20 degrees. In the outlying local basins the strata are reported to be inclined from each side toward the center, so that each stratum forms two parallel lines of outcrop. It is also reported that the coal seams are thin along their outcrops and thicker in the central part of the basins. The structure of these basins was not accurately recorded during the time that coal was being removed and it is now impracticable satisfactorily to renew their study. From such observations as I was able to make, aided by the writings of Lyell and the verbal reports of miners who helped to win the coal, I judge that the strata dip to the westward, but that the softer layers, including the coal, were dragged along the plane of faulting and thus simulate a sharply folded synclinal. The fault which cut off the basins follows their western border and hades eastward.

The small detached area in which the Deep river mines are situated, north of the James and about 3 miles east of the east border of the main area, is another illustration of the occurrence of a narrow strip of Newark rocks occupying a detached fault basin. The main fault to which this little area owes its depression, and consequent preservation, follows

BOGAN'S CUT, NORTH CAROLINA, LOOKING WEST.

its west border. The bluff of crystalline rocks overlooking it on the west is in reality the heaved side of the fault, the strike of which is about northeast and southwest and the hade eastward. In this area, as in the Green Hole and Black Heath basins, some of the soft strata appear to have parallel lines of outcrop. The line of supposed outcrop along the west side of the basin, however, is due to the drag of the coal and associated shales along the fault plane. As in similar basins south of the James, the coal is thin at the outcrops and thickens in the center of the fault blocks. As in the areas mentioned above, the structure simulates an abruptly folded synclinal, with strata thickening in the center. The coal in this area is much broken and slickensided, and secondary faults were encountered during mining operations. The roof of shale above the coal is in many places a mass of comminuted and slickensided fragments, which in some instances during mining operations flowed out from openings like so much gravel. Here, as elsewhere in the secondary areas and in the bordering outcrops of the Richmond coal field, the difficulties and uncertainties of mining were greatly enhanced by the faulting and crushing that the strata had suffered.

At Clover hill, in the southern part of the eastern border of the Richmond coal field, coal has been mined for a long series of years. In 1885, this was the only point at which active mining operations were being carried on. The "incline" which was being worked followed the slope of the coal seams for about 250 yards. The dip of the strata is northwest 20 to 35 degrees, and the strike S. 10° 30′ W., agreeing very nearly with similar measurements at Midlothian. At the date mentioned, mining operations were limited on the west by a fault, striking about north and south, the throw of which was undetermined but exceeds 50 feet. In the mines there are several minor faults, parallel to the one on the west, some of which have a displacement of 40 to 50 feet. The structure, although seemingly more regular than the Midlothian or Norwood, is essentially of the same character; that is, the rocks are faulted, but the strata in each fault block return with remarkable persistency to about the same dip.

A marginal fault along portions of the east border of the Richmond coal field, which brings the broken edges of the Newark strata in direct contact with the surrounding crystalline rock, has been determined. A cross fracture is indicated by a break and offset in the line of coal outcrops just east of Midlothian. The tongue of crystalline rock penetrating the main Richmond area at the extreme northern end, as shown on Pl. v, seems also to be due to a fault which has brought up the crystalline floor on which the Newark rocks rest. The actual presence of such a fault, however, has not been demonstrated by observation.

Failures in mining due to geological structure.—It is safe to say that a large part of the failures which have attended the working of the coal in the Richmond coal field are due to the faulting and crushing that the rocks have suffered. Mining has been attempted only along the immediate borders of the main area and in the small secondary basins, that is, in localities where the greatest amount of disturbance has occurred. The central and undisturbed portion has never been explored. A few drill holes midway between Midlothian and the Old Dominion mine would demonstrate whether the coal in the central portion of the field is sufficiently thick and of such a quality that it would repay mining at the considerable depth at which it occurs. While the central portion of the field is practically without faults, it is possible that it is traversed by sheets and dikes of trap, the effect of which on the coal, whether to decrease or increase its value, can not be predicted.

Absence of oil and gas.—Although mining in the Richmond coal field has been retarded by the escape of natural gas and by spontaneous combustion, the fact that it has been penetrated by mines and drill holes without developing any reservoirs of oil or gas of economic importance must be considered as sufficient evidence that such deposits do not exist. The broken condition of the strata and the attitude in which they occur are in themselves sufficient indication that reservoirs of oil and gas need not be looked for.

STRUCTURE OF THE DEEP RIVER AREA.

The most usual dip of the strata in this area is southeast at an average angle of perhaps 15 degrees. Faults are exposed in several of the excavations along the railroads crossing the area, and changes of dip occur adjacent to many of the trap dikes which break through the stratified beds, indicating that they were intruded along displacements.

On the east side of the area, near Carey, and again on the west border, a mile or two north of Egypt, there are notches in its outline which probably indicate the presence of faults. The junction of the Newark rocks and the adjacent crystalline rocks of the eastern border, where it is crossed by the Piedmont Air Line Railroad, 1½ miles west of Carey, is well exposed. The Newark strata at the junction consist of a coarse, brecciated conglomerate, dipping westward and resting on the crystalline terrane from which they were derived. These coarse beds belong to the basal conglomerate of the series, and agree in all essential features with the same stratum where exposed along portions of the west margin of the same area and in adjacent secondary areas. The most remarkable evidence of faulting in this region is furnished by a narrow strip of Newark strata adjacent to the west border of the main area, immediately west of Lockville. The trend of the axis of this outlier is parallel with the margin of the main area, and distant less than a mile from it. In the central part of the strip the strata dip a little east of north at an angle of 20 degrees. On the west side of the area, and resting on crystalline rocks, is the coarse basal conglomerate of the Newark.

FAULT IN BOGAN'S CUT, NORTH CAROLINA.

On Kerr's[1] geological map of North Carolina, three small detached areas of the Newark system are represented as occurring about 20 miles east of the eastern border of the main area and 10 miles south of Raleigh, but no observations on the character or structure of these outliers are known.

Without entering into a detailed account of observations made by the writer in the Deep river area, it may be stated that the evidence throughout is decidedly in favor of the prevailing fault structure. There is an absence of anticlinals and synclinals, and also an absence of a continuous monoclinal dip throughout the area, as has been stated.

STRUCTURE OF THE WADESBORO AREA.

In this, as in the Deep river area, the prevailing dip is southeast, but there are many exceptions in which the inclination is reversed along lines of displacements or adjacent to trap dikes. There are also outlying or secondary areas that still further illustrate the fault structure of the region.

The best section obtained in this area, and perhaps the most instructive that can be found anywhere in the Newark system, is exposed along the Carolina Central railroad from Lylesville westward through Wadesboro, to the western margin of the area. The width of the Newark rocks along this line, including two tongues of crystalline rock penetrating the sedimentary series from the north, is about 16 miles. The section referred to above, as measured during my reconnaissance in 1885, is shown on Pl. IX. On the same plate is a more detailed section of a portion of the general section, in which the characteristic structure of the Newark system is well illustrated. West of Lylesville for about 1 mile the rocks are granitic and deeply decomposed. Bordering the granite on the west are the Newark beds. The Newark strata adjacent to the eastern border of the area are composed of the débris of granitic rocks, plainly derived from the crystaline area on the east. At the immediate eastern end of the Newark section there are certain structureless, mottled clays, which were apparently deposited above the Newark strata and may possibly belong to the Potomac formation; but the relations of these deposits have not been satisfactorily determined. The dip of the Newark beds for about a mile westward from the eastern margin, as shown on the accompanying sections, is westward at angles varying from 10 to 20 degrees. The dip then changes abruptly near a trap dike, and the strata are inclined southeastward at an angle varying from 15 to 25 degrees. This general inclination prevails all the way across the remainder of the section until the crystalline rocks interrupting the continuity of the Newark beds just east of Browns creek are reached.

In this section over fifty trap dikes were observed, ranging from a few inches to over 50 feet in width, and at least fourteen displacements

[1] In Rep. Geol. Surv. of North Carolina. Raleigh, 1875.

of considerable but usually undetermined throw were noted. As the rocks were seen for less than half the distance included in the section, there being no exposures where the railroad is constructed by filling, it is probable that less than half the dikes and faults that exist have been seen. The most typical as well as the best exposed portion of this section is in Bogans cut, about 3½ miles west of Wadesboro, which is indicated at the bottom of Pl. IX. In this cut there are four well exposed faults, besides abrupt changes in the inclination of the strata adjacent to the trap dikes. The displacements in each instance have a throw of less than 50 feet, and with one exception are normal faults, hading westward. The exception is a reversed fault, as shown in the section, a photograph of which is reproduced in Pl. XII. Comminuted rock occurs along the immediate plane of the fault, and a triangular block of sandstone is included in it. The structure in Bogans cut is rendered unusually plain by the contrast of reddish brown shales and gray sandstones brought into abrupt contact by the displacement. The fault planes in each instance are smooth and slickensided; the striations on the smooth slopes record vertical movements.

A mile and a half west of Bogans cut the basal conglomerate of the Newark system comes to the surface with an easterly dip of about 25 degrees, and rests on crystalline strata. West of this junction the crystalline rocks are well exposed for nearly a mile to the eastern border of the valley of Browns creek. There is then an unexposed area about a mile broad occupied by flood-plain deposits, but it is probably underlain by Newark strata. On the west border of the flood plain the Newark system again appears, dipping eastward at a high angle, and continues to be again exposed occasionally for 2½ miles along the railroad. In this portion of the section the rocks are shales and sandstones, traversed by many trap dikes and broken by several faults. The basal member of the series again appears, as shown on Pl. IX, with an easterly dip of about 40 degrees, and resting upon metamorphosed rocks. West of this junction the metamorphosed rocks form the surface for about 300 feet, when the basal conglomerate again appears, this time dipping westward at an angle of about 20 degrees. A fault between the Newark strata and the metamorphosed rocks is here plainly indicated by a band of comminuted fragments. The conglomerate on both sides of the upthrust slates is composed of the same rock in rounded and angular masses, and was evidently of local origin. West of the last exposure of the basal conglomerate, the characteristic shales and sandstones of the Newark system continue to be exposed westward along the railroad for several hundred feet. The crystalline rocks then begin and continue indefinitely.

In the section just described the basal conglomerate is exposed four times by faulting. There are also, as we have seen, many faults not of sufficient vertical extent to bring up the basal member of the system. The disturbances that the rocks have undergone are still further illustrated by the great number of trap dikes penetrating them.

FAULT IN BOGAN'S CUT, NORTH CAROLINA.

The Wadesboro area as a whole is depressed below the level of the surrounding plateau of crystalline rocks, thus indicating that the rocks composing it are more easily eroded than the surrounding terranes. When the crystalline rocks penetrate the Newark area, they form bold hills and by their relief enable one to judge of the structure of the rocks beneath. South of Bogans cut, near Whites store, there is a high north and south ridge composed of crystalline rocks traversing the Newark system, which is probably the upheaved side of a fault and may be an extension southward of the ridge which appears on the west side of Browns creek farther north.

The structure of the Wadesboro region is still further illustrated by two small outlying areas belonging to the same system. These are situated to the eastward and are indicated on Kerr's geological map of North Carolina. These were examined by the writer in 1885 and are supposed to occupy fault basins, as in the case of the numerous outlying areas previously noted. The first of these visited is about 3 miles east of the eastern border of the main area in the valley of Mountain creek. It is between 2 and 3 miles long from north to south and perhaps a quarter of a mile broad. The dip of the strata is in general southeastward at an angle of 10 degrees. South of this, and about 4 miles west of Rockingham, is another similar area, separated from the main area by about 8 miles of crystalline rock. In this intervening belt there are trap dikes identical with the numerous dikes of the Newark system, and in the Rockingham area there are other dikes of the same character. The area near Rockingham is nearly 2 miles broad, with possibly a ridge of metamorphosed rocks in the center, and coarse conglomerate is exposed along its western border. The strata above the conglomerate are normal sandstones and shales dipping eastward 15 degrees.

My notes show many other details of structure which are in harmony with the general conclusions presented above, and strengthen the hypothesis that the Wadesboro area, like others in the system to which it belongs, is characterized by diverse monoclinal structure due to the tilting of faulted blocks.

SUMMARY.

The brief account given in this chapter of our present knowledge of the structure of the Newark system, shows that it is monoclinal throughout. The structure is due to a fracturing of the rocks along lines having in general a northeasterly and southwesterly trend, and a tilting and perhaps overthrusting of the included blocks. In many instances the fault blocks are inclined in a uniform direction, and when the similarity in strata renders it difficult to detect repetitions, the system appears to be a continuous mass of vast thickness. Some of the faults observed are of sufficient magnitude to bring to the surface the crystalline or Paleozoic rocks on which the system rests. Others expose the basal conglomerate, but the greater number are small, and owing to the similarity of the strata affected by them are difficult and many times impossible to trace.

While faults are numerous, pronounced folds are absent. Broad, gentle undulations do occur, however, especially in the broader areas, and in the Connecticut valley and New Jersey, explain in part, the curvature of the outcrops of some of the trap sheets.

An examination of the entire system shows that faulting is as important an element in the structure of the Atlantic coast plain as it is in the Great basin. These two regions have this important difference, however: In the Great basin the fault scarps stand in relief and form mountain ranges, while along the Atlantic coast the relief has been subdued by erosion, and for the most part a featureless plain takes the place of the mountain uplifts that would otherwise appear.

It is to be supposed that the faults traversing the Newark rocks are but a portion of a great system which affects a large part, and perhaps the entire region of metamorphic rocks, in the midst of which remnants of the Newark system have been preserved.

ORIGIN OF FAULT STRUCTURE.

The only hypothesis that has been advanced in explanation of the characteristic fault structure of the Newark system was proposed by Davis,[1] in discussing the deformation of the rocks of that system of the

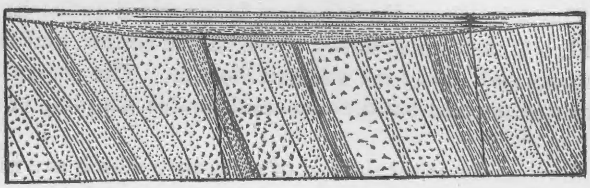


FIG. 3.—Ideal east and west sections of Connecticut valley area previous to deformation.

Connecticut valley. Starting with horizontal Newark strata deposited on the truncated edges of highly inclined crystalline beds, Davis shows that a force of compression, acting at right angles to the bedding of the crystalline rocks, would increase their inclination and cause the beds of which they are composed to slip one on another. The eroded surface forming the floor on which the Newark beds rest would thus become faulted along lines of strike. The faults would be carried upward through the superjacent stratified beds, and produce a series of monoclinal fault blocks, the prevailing dip of which would be in one direction.

This explanation will be readily understood by reference to the accompanying diagram (Fig. 3), copied from Davis's paper already referred to, in which the Newark strata of the Connecticut valley are shown in the attitude they held up to the initiation of their present structure. Two dikes have been introduced, one on the left to show the supposed source

[1] U. S. Geol. Surv., 7th Ann. Rpt., 1885–'86, Washington, 1888, pp. 486–490.

FAULT IN BOGAN'S CUT, NORTH CAROLINA.

of the intruded trap sheets, and one on the right to explain the successive overflows of trap that appeared at times during the depression of the Connecticut valley area and the accumulation of the Newark strata. Deposition is supposed to have continued as long as depression was in progress, but was stopped when the fundamental schists began to be affected by lateral compression. The compression caused the strata in the schist to slip one on another, thus increasing their dips, and in some instances carrying them over beyond the vertical.

The result of the compression and slipping of the schistose layers, as postulated above, on the stratified beds resting on them is shown in Fig. 4. The slabs in the underlying schists are separated by faults, and their beveled edges are canted over at an angle equal to their change of dip. The overlying beds, unable to support themselves on this uneven floor, have been broken into fault blocks and tilted in a uniform direction.

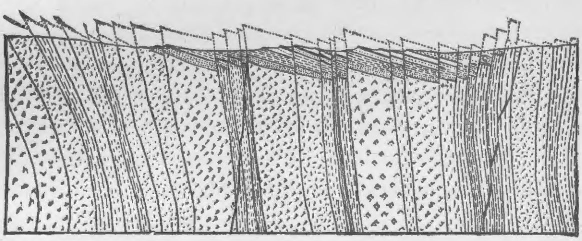


FIG. 4.—Ideal east and west section of Connecticut Valley area after deformation.

The occurrence of reverse faults has also been considered by Davis, and their origin explained by a curvature of the underlying schistose strata in place of the more regular bedding previously indicated, as shown in the following diagram:[1]

This attractive hypothesis finds some support outside of the Connecticut valley area, in the fact that the strike of the numerous faults in the Newark rocks south of Connecticut, is in a general way parallel with the trend of the strata in the associated crystalline rocks. The actual tracing of faults, however, from the Newark area into the adjacent crystalline, has not been done. The most favorable locality for continuing the study is unquestionably the Wadesboro area, where the structure of the crystalline floor beneath the Newark system can be determined with some degree of accuracy, and the conditions for tracing faults from stratified to crystalline rocks are better than in any other area.

As shown in a preceding section of this paper, a general study of the structure of the Newark system should include the consideration of the origin of the trap dikes and sheets which traverse it. Like the faults,

[1] For a more recent discussion of the structure of the Connecticut valley area see an article by J. D. Dana, On Percival's map of the Jura-Trias trap belt of central Connecticut, with observations on the upturning or mountain-making disturbance of the formation. Am. Jour. Sci., 3d ser., vol. XLII, pp. 439–447, Pl. XVI.

these are due to a disturbance and breaking of the strata. While it is highly probable that the faulting and injection of igneous rocks are portions of the same process, yet this has not been proved. It may be presumed, if the subsidence of the region of accumulation in Newark times was due to displacements, as is suggested by marginal faults along the borders of certain of the areas, that the contemporaneous overflows of igneous rock came to the surface through fissures thus formed. Subsequent faulting may have been accompanied by the injection of dikes and intrusive sheets. If such an association of faults and trap rock can be shown it follows, on the hypothesis of the origin of the faulted structure proposed by Davis, that the trap dikes in the crystalline area should follow lines of bedding. Observation in this connection is very incomplete; but so far as is known the dikes referred to do not follow the lines of bedding, but cross them in an irregular manner.

CHAPTER IX.

FORMER EXTENT.

Considerable diversity of opinion has arisen concerning the original extent of the rocks of the Newark system. The conclusions of geologists in this connection fall in two groups: First, those implying that the present detached areas of the system are local deposits which were originally but little, if any, greater than at present; second, those implying that the detached portions of the system as they now exist are remants of terranes much larger than any of the areas now remaining, a very large and perhaps the greater part of the original deposits having been removed by erosion. For convenience the common element of the first group of explanations will be called the *local-basin hypothesis*, and that of the second group the *broad-terrane hypothesis.*

THE LOCAL-BASIN HYPOTHESIS STATED.

This hypothesis has been advanced more or less definitely by a number of writers.

In describing the rocks of the Newark system about the Bay of Fundy, Dawson[1] states that when they were deposited, the form and contour of the country already made some approach to what it still retains, and that the sedimentary strata were deposited in a bay coinciding with the present Bay of Fundy, but a little wider and larger.

The Connecticut valley area and the much larger New York-Virginia area are also considered by a number of geologists as representing about the original boundaries of the estuaries or lakes which became filled with sediment during the Newark period.

This view is expressed by Newberry[2] in an essay on the geological history of New York, island and harbor, in the following language:

> The trough between the New York axis and the Blue Ridge was occupied by water, and in this trough the Triassic [Newark] shales and sandstones were deposited. A similar trough east of New York, where now is the valley of the Connecticut, was also a lagoon or estuary in which similar sediments accumulated.

These conclusions are again stated in a recent monograph of the fossil fishes and fossil plants of the rocks under consideration.[3]

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[1] Acadian Geology, 3d. ed., 1878, pp. 86, 87.

[2] Pop. Sci. Monthly vol, XIII, 1878, p. 644.

[3] U. S. Geological Survey, Mon., vol. XIV, 1888, p. 6.

Somewhat similar conclusions have been reached by Davis,[1] and may be found in his recent contribution to the study of the structure of the Connecticut valley region.

The most definite statement of the local-basin hypothesis that has been published is Emerson's graphic description of the condition of the Connecticut valley at the time it received its filling of sandstone:[2]

If one will picture the broad valley [of the Connecticut] from Pelham across to Westhampton [Massachusetts] as a half mile deeper than the present river, and imagine the rocky surface of the upland as half a mile higher than now, with the canal-like channel filled by the fiord waters to a height above the level of Mount Holyoke while the bordering streams swept sand and gravel into the basin and strong currents spread the material over its bottom, he will have a rude outline of Triassic [Newark] times in the valley.

The picture suggested by this clear description is of a plateau region cut by a profound canyon a mile in depth, where now the Connecticut flows.

Percival[3] remarks that the two Newark areas of Connecticut are of a local, isolated character, each forming a complete system in itself, and apparently independent of any more extensive formation.

Dana[4] has expressed the opinion that the Connecticut valley was an estuary during the Newark period, and had its violent floods, which may have been for a part of the time enlarged by the water and ice of a semiglacial era. J. Le Conte[5] also considers the Connecticut valley to have been a restricted basin during the Newark period.

The small Newark areas in Virginia and North Carolina, which contain coal, have been regarded as owing their origin to the filling of local basins which were swamps during portions of the Newark period.[6]

Similar opinions have been expressed more or less definitely by other writers, but without making further quotations I will attempt a general statement of the local-basin hypothesis:

During the Newark period the Atlantic border of the continent was about in its present position, and the land had about its present relief. Then, as now, there was a Piedmont plain, and in this plain there were long, narrow basins, formed in the region of the Connecticut by erosion, apparently, but in the other cases probably by orographic movements, which held lakes, or being connected with the ocean, formed estuaries, fiords, etc. Into these basins the debris from the adjacent land surface, composed of crystalline rocks, was carried and deposited. Since the filling of the basins the strata accumulated in them have been tilted, but beyond this there has been no pronounced orographic movement and no very considerable amount of erosion.

[1] U. S. Geological Survey, Seventh Ann. Rept., 1888, pp. 461–462.

[2] In Gazetteer of Hampshire county, Massachusetts. [From] 1654–1887. Compiled by W. B. Gray, Syracuse, New York. [1888] p. 18.

[3] Rept. Geol. of Connecticut, 1842, p. 430.

[4] Am. Jour. Sci., 3d ser., 1879, vol. XVII, p. 330.

[5] Elements of Geology, 2d ed., 1882, p. 453.

[6] Richmond Coal Fields, Virginia, by W. Clifford, Manchester [England] Geol. Soc. Trans., vol. XIX. 1888, p. 333.

THE BROAD-TERRANE HYPOTHESIS STATED.

The former connection of various Newark areas south of New York was implied in the explanation of the origin of the prevailing dips exhibited by these rocks in New Jersey and Pennsylvania, advanced by Rogers,[1] in 1840. This author states that the rocks referred to seem to have originated in a long, narrow trough, which had its source as far south at least as the eastern base of the Blue Ridge in Virginia and North Carolina, and probably opened into the ocean somewhere near the present position of the Raritan and New York bays.

The former extension of the rocks of the Newark system beyond the boundaries of the areas now remaining, although suggested by Maclure[2] as early as 1817, seems to have been first clearly indicated by Kerr,[3] who sought to explain the opposite dips of the rocks of the Deep river and Dan river coal fields of North Carolina on the hypothesis that the two areas were formerly united and owe their separation to the upheaval and erosion of the belt of country between them, the portions remaining being in a general way of the nature of bordering or basal remnants of a great anticlinal.

The union of the various areas south of New York, in which sediments were deposited during the Newark period, into one great estuary having its capes at Trenton, New Jersey, and Manhattan Island, New York, has been suggested by Lesley.[4]

The hypothesis proposed by Kerr in reference to the former union of the Deep river and Dan river coal fields, was received with favor by Bradley,[5] who extended it to the Connecticut valley and the New York-Virginia areas. Some arguments tending to show that the rocks of the Newark system in New Jersey and in the Connecticut valley were originally connected were advanced by the present writer several years ago, and need not be restated.[6] The various areas of the Newark system in Virginia, according to Heinrich,[7] were formerly connected, and their continuity was broken by a slow and unequal movement of the floor of crystalline rocks on which they were laid down, accompanied by the erosion of the elevations thus formed.

Briefly stated the broad-terrane hypothesis claims that the various areas of the Newark system now remaining are remnants of much broader terranes, and that many and perhaps all of them were originally united. More than this, the hypothesis implies that marked orographic movements, accompanied by upheaval, faulting, and diking, have affected the beds since they were deposited, and that they have suffered very greatly from erosion.

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[1] Description of the Geol. of New Jersey, final report, Philadelphia, 1840, 12mo., p. 115.

[2] Observations on the Geology of the United States, Philadelphia, 1817, p. 41.

[3] Rep. of the Geol. Surv. of North Carolina, vol. I; Raleigh, 1875, p. 141.

[4] Cited in Coal Regions of America, by J. Macfarlane, 3d ed., New York, 1877, p. 512.

[5] Am. Jour. Sci., 3rd ser., vol. XII, 1876, p, 289.

[6] New York Acad. Sci., Ann., vol. I, 1878, p. 220–244; also in Amer. Nat., vol. XIV, 1880, pp. 703–712.

[7] Am. Inst. Mining Eng., Trans., vol. VI, 1879, pp. 227–274.

With this brief statement of the case let us endeavor to determine on what facts the two hypotheses rest.

EVIDENCE FAVORING THE LOCAL-BASIN HYPOTHESIS.

No definite statement of observations tending to show that the various areas of the Newark system did not extend much beyond their present boundaries has been made and perhaps should not be expected. That the various areas are now isolated, and are formed of débris derived from crystalline rocks of the same character as those now bordering them, seems to be all the direct evidence there is that they were originally deposited in independent basins.

In reference to the Connecticut valley area, W. M. Davis states that "its original area was greater than at present, as there has been demonstrable loss by marginal erosion, but it is generally thought that the loss has not been very great." In continuing the discussion he says:[1]

We are not, however, confined to this conclusion by a very strong line of argument. The rapid change from finer standstones and shales which generally appear in the central part of the formation to the coarse sandstones and conglomerates that characterize the margin is usually cited as implying a narrow limitation of the area of the deposits, but it is not yet demonstrated that the finer central strata are the equivalents of the coarser marginal layers. The latter may mark localities on the advancing shore during submergence that were favorable to the formation of coarse deposits, while the former may correspond to a later date of more general submergence; moreover, in some cases the finer shales approach close to the present margin of the formation. No isolated outliers of the formation have yet been discovered unless the little Southbury-Woodbury area in western Connecticut be so regarded; but the region around the area that is still covered by the Triassic [Newark] rocks has been elevated to an altitude and during a time sufficient to have suffered much loss by post-Triassic erosion. The general freedom of the same surrounding region from the igneous rocks so closely associated with the Triassic formation in its various areas along the Atlantic slope may also suggest its escape from Triassic submergence; but in our present state of knowledge concerning the cause of this peculiar association it can hardly be employed in this argument. It therefore does not seem impossible that the original Triassic area may have been much larger than the present, but the burden of proof lies clearly in those who would contend for what now appears to be so far beyond the necessities of the case.

EVIDENCE FAVORING THE BROAD-TERRANE HYPOTHESIS.

The data on which this hypothesis rests have been presented in the preceding pages, and although it is not necessary to reassemble it, we may designate the classes into which it naturally falls. *First.* The stratigraphic incompleteness of all of the Newark areas now remaining. *Second.* The presence of marginal faults which have determined the limits of some of the areas in certain directions. *Third.* Evidence of great erosion since the Newark rocks were deposited.

It is well known that when water basins become filled by sediment

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[1] Seventh Ann. Rep. U. S. Geol. Survey, 1888, pp. 461-462.

washed in from the shores, the material deposited has an orderly arrangement, the coarser portions being dropped near shore, while the finer portions are carried farther out. The slow subsidence of a basin which is being filled in this way would result in the formation of a basal conglomerate with layers of fine sediments superimposed upon it. A horizontal section of such a deposit taken at any horizon above the basal conglomerate first laid down would show a central area of fine material surrounded by a fringe of coarse detritus.

In no instance in the various Newark areas now remaining does such an arrangement appear. Along portions of the margins of some of the areas referred to coarse deposits are found, but in other parts of their borders the rocks are fine grained and of the nature of off-shore deposits. The necessary conclusion seems to be that the terranes now remaining do not represent the original extent of the deposits at any stage.

The presence of faults along the margins of several of the Newark areas show that their present limits have, in part at least, been determined by displacement and subsequent erosion. The marginal faults referred to frequently bring fine grained Newark rocks in direct contact with bordering areas of crystalline rock, thus proving conclusively that the original extent of the sedimentary beds was beyond the limits indicated by this present outcrop.

Evidence of great erosion since the Newark period is furnished by the topographic relief of the outcropping edges of intruded trap sheets, which were originally forced in among the sedimentary beds and cooled far below the surface. Since their intrusion, the system has been tilted and reduced nearly to a base level by subærial erosion. To bring about the conditions now prevailing very large portions of the original deposits must have been removed.

The occurrence of soft strata of shale and sandstone dipping in one uniform direction over large areas, which are now nearly at base level, demonstrates that much erosion has taken place. The amount of this erosion can not be quantitatively determined, but I think that every geologist who has studied the matter will agree with me that many hundreds and possibly thousands of feet of strata have been removed from the areas in question. This again implies that the areas now occupied by the system are remnants of the original deposits.

The Potomac formation rests unconformably on the Newark, the unconformity being due to the erosion of the lower rocks previous to the deposition of younger beds upon them.[1] There is also evidence that the Newark rocks were again exposed to erosion previous to the deposition of the Cretaceous. Another elevation of the Atlantic sea border, followed by a reduction to base level, followed the deposition of the Cretaceous rocks, and removed them from large areas now occupied by the

[1] Three formations of the Middle Atlantic Slope, by W. J. McGee. Am. Jour. Science, 3d series, vol. xxxv, 1888, p. 135.

Newark system, as has been quite clearly demonstrated by Davis.[1] During these various stages of erosion when the country, occupied in part by the Newark system, was being reduced again and again by sea level after upheavals, all of the Newark rocks above the horizon of base-level erosion were cut away. The port ons now remaining appear to owe their preservation, as previously stated, to their having been depressed along lines of displacement below the horizon at which subærial agencies could act.

The considerations mentioned, and some others which are more difficult to state briefly—as the relations of drainage on the Atlantic slope to the Newark areas, and the absence of overflow of volcanic rock on crystalline and Paleozoic terranes surrounding the islands occupied by the Newark system—all tend in one direction, and furnish cumulative evidence tending to show that the Newark rocks were formerly much more extensive than at present, and that many of them must have been united.

OBJECTIONS TO THE BROAD-TERRANE HYPOTHESIS.

Although the broad-terrane hypothesis has met with but a limited number of adherents, only a few specific objections have been made to it.

Newberry[2] observes that it seems scarcely probable that some thousands of feet of Triassic [Newark] rocks, including thick beds of hard and resistant trap, should have been so completely carried away from the interval of 100 miles now separating the Connecticut valley and the New York-Virginia areas that not a trace of them should anywhere be left. It should be borne in mind, however, in this connection, that an outlier—the Southbury area—does exist in the interval mentioned. This area is shown on Pl. III. It is situated 16 miles west of the west border of the Connecticut valley area, and probably owes its preservation to its having been depressed below the plane of base-level erosion to which the country has been reduced and to the numerous sheets of trap which traverse it. Whether other trap sheets existed in the interval mentioned is not known, and but scanty suggestions that such was the case can be derived from such studiesof this area as have been made.

It is implied in the objection cited above, that trap rock is much more difficult of erosion than the sandstones and shales with which it is associated in the Newark system. Under such climatic conditions as now prevail in Virginia and North Carolina this is not the case. The trap dikes are there deeply decayed, and frequently so soft, even at a depth of 50 feet from the surface, that they can be molded in one's fingers like potter's clay. Instead of forming prominent ridges their presence is not indicated in the relief of the country.

Not only are dikes under certain conditions easy of erosion, but it is

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[1] The Geographical Development of Northern New Jersey, in Boston Soc. Nat. Hist. Proc., vol. XXIV, 1889, pp. 265–427.

[2] The Geol. Hist. of New York Island and Harbor. Pop. Sci. Monthly, vol. XIII, 1878, p. 646. Also U. S. Geol. Survey, Monograph vol. XIV, 1888, p. 3.

an accepted principal in geology that the amount of erosion in any region depends on time and opportunity rather than on lithological conditions. Were the rocks of the Newark system, including thick sheets of trap, elevated sufficiently to secure rapid transportation, their erosion would be certain. The laws of subærial decay and erosion apply to hard as well as to soft rocks; the length of time required for the removal of hard beds is great, but is not infinite.

The Cretaceous rocks of Long Island, it has been observed by Newberry,[1] rest directly on the crystalline schists, with no trace of the Newark system between. It is claimed that "this would indicate that the Trias [Newark] of the New Jersey basin never reached over that portion of the divide."

On a previous page of this paper I have cited evidence which shows that the rocks of the Newark system were upheaved and eroded to a base level before the deposition of the Potomac formation or the Cretaceous. Beneath portions of the Cretaceous of New Jersey, near its western border, as has been shown by Cook,[2] only a few feet of Newark sandstones and shales intervene between the Cretaceous and the crystalline rocks. This remnant is of fine material, not a coarse shore deposit. The absence of the Newark system in a similar position on Long Island seems clearly to indicate that the pre-Cretaceous erosion was there a little more complete than at the locality referred to in New Jersey.

The conclusion that there was a line of elevation through New York, Trenton, etc., after the Newark period and before the deposition of succeeding formations, certainly seems to be warranted from our present knowledge of the region. That this line of elevation has undergone post-Cretaceous movement is indicated by the present attitude of the Cretaceous beds.

CONCLUSION.

My conclusion from a study, not only of the writings of all who have published on this subject, but from personal observation, is that each of the Newark areas was originally much larger than now, and that there is a strong probability that all of the areas between Massachusetts and South Carolina were originally united. It is quite possible, also, that this great area was connected with the Acadian region, but observations to support this hypothesis are wanting.

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[1] U. S. Geol. Survey, Monograph vol. XIV, 1888, p. 6.

[2] U. S. Geol. Survey, Monograph vol. IX, 1885, p. x. See also record of wells at Perth Amboy, N. J. Geol. Survey of New Jersey, Ann. Rep. for 1885, p. 111.

CHAPTER IX.

CORRELATION.

GENERAL PRINCIPLES.

The phenomena by means of which the relative age of terranes may be more or less definitely determined are of two principal classes, physical and biological.

PHYSICAL PHENOMENA AS A BASIS OF CORRELATION.

The physical evidence on which strata may be correlated is of varied character, but in general may be classed in the divisions given below:

Superposition.—The simplest case in which the relative age of strata may be determined is when they are conformably superposed one upon another. The highest in the series is then the youngest. The relative position of beds as is well known may be modified or even reversed by folding, faulting and overthrust, and in the correlation of strata by vertical sequence these modifying conditions have to be eliminated. Overflows of volcanic rocks and ejections of volcanic ash may play the role of sedimentary beds and form a time record by means of which the relative age of terranes not themselves in contact may be determined.

Contained fragments.—One series of rocks may contain recognizable fragments of another series. Manifestly the strata containing such fragments are newer than the strata from which they were derived. This is a common means of determining the relative age of conglomerates and is applicable also in some instances to volcanic rocks.

Relation to systems of folds, faults and dikes.—The relative age of rock series not in direct contact may sometimes be shown by their mutual relation to widely spread geological structure. For example, in the Appalachians a characteristic structure has been impressed upon the strata from the Coal-measures downward; consequently any rocks in this region not affected by the corrugations characteristic of the Appalachian structure, may be assumed to be of later date than the Coal-measures. In a similar way the relation of strata to a well determined series of faults or to a persistent system of dikes may be of service in indicating their relative age.

Relation to unconformities.—A series of rocks resting unconformably on a lower series in one region and conformably on a lower series in another region, the relative age of the two lower series may be inferred.

In such an instance the lower bed conformable with the upper would be expected to be later than the unconformable lower series, for the reason that great unconformities result from slow changes and are wide reaching in their effects. They leave a record which provisionally, at least, may be used as a time record. The conditions here postulated, while serving as a suggestion to the field geologist, would require additional evidence before being accepted as a definite means of correlation.

Relation to glaciation.—Widespread glaciation, by leaving characteristic records, enables the geologist to separate the beds deposited before its occurrence from those of subsequent date.

Lithological similarity.—The identity in age of various strata is sometimes suggested by their lithological similarity, but this is an uncertain indication, and except in regions of limited extent is apt to lead to erroneous conclusions. The lithological character of clastic rocks may depend on the physical conditions under which the debris composing them was formed. For example, the conditions which influence the disintegration of rocks are wide-reaching, and the characteristics of the rocks resulting from the assorting and deposition of such debris may be sufficiently constant over wide areas to be of assistance in determining relative age. To illustrate, the rocks forming the surface may suffer decomposition over a region of broad extent, and the resulting debris acquire certain characteristics, as a uniform red color, for example, due to the incrustation of ferruginous clay on the grains composing it. The removal and deposition of this incrusted material might produce rocks of similar appearance over broad areas and even in separate basins.

Rocks subjected to heat, pressure, crust movement, etc., have frequently acquired a schistose structure, due to rearrangement of the mineral matter composing them—that is, they are metamorphosed. Such alterations have been used as a basis for deciding on the age of strata, nearly all metamorphosed rocks having formerly been considered as Archean; but it is now known that strata of any age may have undergone the changes referred to above. Conditions may be postulated, however, under which metamorphism might be of service in determining the relative age of terranes. For example, a metamorphosed terrane may be considered as the record of a wide-reaching physical and chemical change, thus making a definite time record. Terranes found by contact or by contained fragments to be younger than the metamorphosed terrane may be assumed to be younger than other terranes with which they are not in contact, but which can be proved to be of the same age as or older than the metamorphosed terrane. True, the metamorphism of even the same stratum might not be confined to a single period, but to the field geologist such an association as suggested above would furnish a working hypothesis to be proved or disproved by additional evidence.

Summary concerning physical phenomena.—Besides direct contact of terranes and the evidence furnished by included fragments, which are the most definite means of correlation, the relative age of the elements in a geological series may be determined more or less accurately by their relation to physical events which were wide-reaching in their effects; among these the most common are folding, faulting, diking, volcanic eruptions, metamorphism, and glaciation. The degree of confidence to be placed on correlations depending on relations to these phenomena must be determined by the nature of the evidence in each case. Close correlation of strata, except by contact and unbroken stratigraphical succession, is not possible by means of the relations here indicated, but when these various methods are taken in connection with other records they become important.

Chemical phenomena considered.—The classification of volcanic rocks, spring deposits, precipitates from inclosed lakes, etc., according to their chemical composition, is fruitful of results, but is foreign to the present discussion. The chemical changes involved in disintegration, decomposition, lithification, etc., may be included under lithological characters. In the lithological comparison of clastic rocks their mineralogical and chemical characteristics are considered, but the classification of strata with reference to relative age, on purely chemical grounds, has not been found practicable.

A sequence in chemical changes might accompany the cooling of a molten globe and result in the formation of a stratified crust having a definite chemical arrangement, but that such was the case with the earth has not been determined.

In the correlation of ordinary sedimentary beds chemical may be included with physical phenomena, and need not be separately discussed at this time.

LIFE RECORDS AS A BASIS OF CORRELATION.

The study of fossils has shown that life began on the earth in low, simple forms, and progressed with unbroken continuity throughout all subsequent geological ages, with the production of higher and higher forms and greater and greater specialization as it advanced. During this development many forms became extinct and were succeeded by other forms. The length of time during which individual species were persistent was sometimes short and at other times embraced geological ages: sometimes they even extended throughout nearly the entire life history of the earth. Biology thus furnishes a record extending from the dawn of life to the present day, by means of which the relative dates of various physical changes may be more or less definitely determined. It has been assumed that this record affords a ready and infallible means of determining the age of all rocks in which organic remains occur. This seemingly simple and direct method of correlation, however, has many limitations which it will be well to glance at before attempting to apply it.

Imperfections of the geological record.—Throughout the time that life has existed on the earth there has been land and water, and the land, wherever it appeared, has been subjected to disintegration and erosion. The débris thus formed has been carried into the sea and into lakes and contributed to the formation of sedimentary deposits. In these deposits the remains of plants and animals have been buried and preserved. Large portions of the strata with these records impressed upon them have been raised above the ocean and subjected to denudation, and the material removed from them contributed to the formation of later deposits, in which other life records were preserved. In many cases these later deposits were, in their turn, upheaved and another cycle of erosion and deposition initiated. In this way large portions of the material composing stratified rocks has been worked over and over and large portions of the life records obliterated. Again, large portions of the sedimentary rocks have been metamorphosed and all their fossils destroyed. In other instances the strata have been subjected to pressure and to the passage of solutions through them, and their organic records crushed and obliterated or removed in solution. The lack of dense tissues in many animals and plants renders it evident that the preservation of any records of their existence, even under the most favorable conditions, must be an extremely rare event; for this reason, if for no other, our knowledge of past floras and faunas must always be incomplete.

The life records, as we now find them, are also imperfect, owing to the fact that many animals and plants, especially those inhabiting the land, did not live in situations where their remains were likely to be preserved. The deep sea, also, has its fauna, which, owing to the slowness with which sedimentation takes place in the depth of the ocean, and to the persistence of oceanic basins, is even of rarer occurrence in a fossil condition than the fauna of the land. The animals whose remains are most frequently found in the rocks are those that inhabit the littoral zone, where sedimentation has always been the most active and where slow subsidence is frequently in progress.

In these several ways, and in others that might be mentioned, the records of the succession of plant and animal life found in the rocks are incomplete and fragmentary. It is not necessary at this time to do more than glance at this subject, as it has been ably treated by many writers, especially by Darwin, and the term "incompleteness of the geological record" has acquired a well understood meaning.

Imperfections of our knowledge of the geological record.—Besides the incompleteness of the geological record itself, there is the incompleteness of our knowledge of that record, such as it is, which must be considered in attempting to generalize upon the life history of the earth as now known. No better proof that our knowledge of the geological life record is incomplete can be asked than the volumes on paleobiology filled with descriptions of new forms of life which appear from year to year in increasing instead of diminishing numbers. Explorations in all parts of the earth are constantly bringing to light not only new species but new genera and new families, while our knowledge of the distribution of forms already known is constantly being modified and extended.

The fact that the greater part of the earth's surface is occupied by the sea shows that large portions of the life record lie so completely beyond the limits of search that man can never hope to see them. When it is remembered, also, that large portions of the land surface of the earth are geologically unexplored, and that new fossils are being found from year to year in those portions most thoroughly examined, the imperfections of our knowledge of the imperfect geological record becomes apparent.

Influence of distribution on the life records.—The usefulness of the life history of the earth as a means of correlating geological terranes is still further complicated by a principle inherent in life itself; that is, development has been in progress but has not taken place uniformly over the whole earth, but with local modifications depending upon local environment.

Whether life began at one or many centers there is no definite proof, but assuming as the simplest postulate that it spread from one center and during the lapse of ages expanded over the whole earth, advancing at the same time to higher and higher stages of development, the specific forms in various regions would, according to the principles of natural selection, be influenced and modified by the local conditions under which they live. Under similar conditions in various regions more or less similar forms would appear. The modified forms thus arising would, in their turn, originate new centers of distribution and lead to the establishment of distinct colonies, from which in their turn, again, new forms would be propagated.

The laws of development now accepted by biologists render it evident that life has not been uniform, the world over, at any one period; hence if sedimentation had been continuous over the whole earth, the organic remains entombed at any one time would have been diverse in various regions. We know from the distribution of organic forms at the present day that variations in temperature, changes in the character of the sea bottom, the abundance or scarcety of food, and many other conditions determine the character of the organic remains now being imbedded in sediments. Even in different portions of the same strata within limited areas the organic forms are diverse. These considerations and others that might be enumerated seemingly indicate that the life record has too many modifying conditions to render it available as a basis for geological correlation.

On the other hand, it may be urged that development in many instances has been exceedingly slow and that genera and even species of plants and animals, especially in the earlier stages of the earth's history, became widely spread, and hence afford a means of determining what strata were deposited at more or less definite periods in the life history. Taken in its general meaning, this proposition can not be advantageously disputed. It has been shown, however, that the appearance and disappearance of the same species or the same genera in widely separated regions could not have been the same. Species, and even genera and families, might become extinct in the region where they first appeared long before their migrations had carried them to distant regions. Hence the discovery of identical fossils in the rocks of two widely separated regions is not considered as proof of their identity in age, except within certain broad limits. This subject was long ago discussed by Huxley, who showed that rocks containing the same species of fossils at widely separated localities, while not necessarily of the same age, hold homologous positions in relation to the development of life, and proposed the word "homotaxis" in place of the term "contemporaneity" frequently used.

The life record continuous.—The value of paleontological evidence as a means of geological correlation may be considered in another way. As previously stated, the life current has been unbroken from the time of its first appearance to the present day. Development from a humble beginning has led to the gradual productions of higher and higher forms and an equally gradual extinction of species, genera, etc. It is thus evident that if a complete and unbroken record of the life history of the earth had been preserved, it would be continuous, without sharply defined natural divisions, from end to end. It may be asked, how is it possible in such a record to draw the lines connecting groups, systems, series, etc., as at present understood? Where would the limit between Paleozoic and Mesozoic, or between Mesozoic and Cenozoic, occur?

As a matter of fact, the physical breaks in the life record have been the principal means of establishing divisions in the scale. The greater the imperfections of record, the more important have been the divisions. In various land areas this system has been found not only practicable but highly advantageous. Next to vertical sequence of terranes, it is without question the most valuable means of correlation available. It has been assumed, however, that the breaks in the life records in one region agree in time with similar breaks in distant regions. Here lies the principal objection that can be raised to the manner in which the method has been applied.

This brings us to the consideration of the standard of geological correlation first used.

The European standard.—The fact that the life record of terranes in widely separated regions, although perhaps containing the same species of plants and animals, can not be considered as contemporaneous, except in a very broad sense, has already been referred to. We have also seen that even in regions of limited extent the lithological characters frequently of the same stratum undergo important changes and are accompanied by changes in the fossils found in it. When we add to these the further considerations that the rock series in no two regions can reasonably be expected to have the same sequence or to have been subjected to the same conditions of sedimentation, or affected by the same physical breaks, it is apparent that neither the succession of organic forms nor the succession of strata found in one region can be expected to occur in the same sequence in other regions. Hence the fallacy of assuming that the succession of life, the succession in sedimentation, or the physical breaks in any one region can be adopted as a rigid standard for comparison in other regions becomes apparent.

That geology was first studied in Europe is an accident so far as correlation is concerned, by which the succession of fossils and of strata there found have been assumed by many as a standard for all other regions. The error of this assumption has been pointed out by many writers, but the practice of attempting a detailed correlation of the rocks of distant regions with those of Europe, on the evidence furnished by fossils, sometimes of very indefinite character, is continued. The history of the numerous and persistent attempts that have been made to correlate the strata of America with those of Europe, even down to the smaller divisions of the scale, on the evidence indicated above, is a chapter of confusion, controversy, and failure. No better example of the diverse conclusions arrived at when such correlations are attempted can be asked than the history of the discussions that have occurred over the correlations of the Newark system, some account of which is given in the succeeding pages of this paper.

An essay on the flora of the Richmond area has come to hand, which illustrates the method followed by many paleontologists in attempting to correlate widely separated terranes. The paper referred to is a review of Fontaine's Monograph on the Older Mesozoic Flora of Virginia by Stur,[1] director of the geological survey of Austria-Hungary, but contains also the results of an examination of a box of fossil plants from the Richmond area sent to him for comparative study. As determined by Stur, many of the fossil plants from the Richmond coal mines are specifically identical with those occurring in the Lettenkohlen group of Germany. The confidence placed in this evidence as a basis for detailed correlation between terranes of America and Europe is expressed in the following translation of an extract from the paper referred to:

From the foregoing it becomes evident that even on the first comparison, made with no great care, between a box of American specimens and our specimens in hand, Clover Hill on the one hand and the Lunz sandstone on the other, have a great number of plant species in common, and should, therefore, be regarded as contemporaneous, particularly as most of the species that have thus far been regarded as peculiarly Virginian, are precisely the ones found at Lunz. The species enumerated

[1] Die Lunzer (Lettenkohlen) Flora in den "older Mesozoic beds of the Coal Field of eastern Virginia." In Verhandlungen der k. k. geologischen Reichsanstalt, Nr. 10, 1888, pp. 203–217. The passages quoted were translated by Robert Stein, of the U. S. Geological Survey.

however, show also that Clover Hill comprises, besides the Lunz sandstone, also a part of the flora of the bituminous slate of Raibl (p. 211).

Thus we have recognized in the coal field of Richmond representatives of the Weng slate, the Aon slate, the Reingraben slate, the bituminous slate of Raibl, and the Lunz sandstone, that is, the equivalent of the Lettenkohle group of Germany.

What lies under it should represent the German Muschelkalk, possibly also the the Bunter Sandstone, while the roof of the Richmond Coal-measures should represent the German Keuper.

This remarkable result, furnishing a starting point for continued studies of the deposits that have been compared and identified and declared contemporaneous, could be obtained only through the assistance of our Washington geologists * * * (p. 212).

The result obtained is of a nature to set forth the utility of the procedure employed in this case.

I must not allow this occasion to pass without drawing further conclusions from the results obtained; that the flora of the Lunz strata, that is, of the Lettenkohle, appears in perfect identity at Richmond, Virginia, at a vast distance from the northern margin of the Alps.

This shows * * * that as late as the time of the Lettenkohle, the species of the flora then prevailing possessed an enormously vast distribution on an area of whose dimensions we may form an idea by drawing an air line drawn between Vienna, Germany (Lettenkohle), and Richmond, Virginia (p. 212).

Near the end of the essay, another passage, bearing on the correlation of American terranes, reads as follows:

* * * I am convinced that shipments of plants from the American Culm and Carboniferous, which may possibly be sent to me, will enable me to demonstrate the various divisions and series of strata in that country, just as I was enabled, by the shipment of Lunz plants from Richmond, to define the age of the Older Mesozoic flora on the James river in Virginia (p. 216).

Concerning the actual identity of many of the plants of the Newark system with those of the Lettenkohlen I am not able to offer an opinion; but such an exceptional occurrence, it seems to me, should be fully verified before being used as the basis for detailed correlation. If a large number of the plants of the Newark and of the Lettenkohlen are identical, is it necessary to conclude that they were contemporaneous? As already stated, it has been pointed out by Huxley and others that, even if the fossils in widely separated regions are of the same species, it does not follow that they lived at the same time. Their identity indicates a similar position in the geological scale, and nothing more. To go beyond this, and conclude that because of the occurrence of plants in the Richmond area identical with those of the Lunz sandstone the strata above the plant-bearing beds in the former region should be referred to the Keuper, and those below to the Muschelkalk, is to grant certain assumptions the verity of which is more than questionable. One of these assumptions is that sedimentation progressed in the same order in the Virginia region that it did in Central Europe. This implies that elevation and depression of the earth's crust producing changes in sedimentation occurred synchronously in the areas referred to. Such a coincidence is far from probable, and, even if it did occur, is not a logical basis for correlation. Such considerations, and the fact that the Newark after prolonged study has not been subdivided, so as to correspond with any portion of the European standards, point to the absence of a logical basis in the method of correlation indicated in the above quotation, and render it evident that we must be skeptical as to the accuracy of the very definite conclusions there reached.

That the strata of each separate land area should be studied and correlated so far as possible among themselves before attempting anything more than the most general correlation with the strata of other land areas is, in my opinion, well illustrated by the example just cited.

That even the groups found on this continent can not be definitely correlated with those of Europe, has been pointed out especially by White[1] in an essay on "The North American Mesozoic." It is there shown that the Chico-Tejon series of the Pacific coast, containing a well characterized Cretaceous fauna and an equally well characterized Tertiary fauna, has intermediate beds in which there is no stratigraphic break. The same principle is again illustrated in New Mexico, where an unbroken succession exists between Paleozoic and Mesozoic groups. Other instances of similar transitions between groups shown by their fossils to be closely similar to certain great divisions of European rocks, are known in India and New Zealand. These instances illustrate the fallacy of assuming that the life record or the stratigraphic sequence, in any two regions is the same. They show, too, the impossibility of applying an inflexible standard of classification determined from a study of the rocks and fossils of one region to the rocks and fossils of another region. This matter could be still further discussed and illustrated, did it seem advisable, but enough has probably already been said to indicate the weakness of the system criticised. The question, What is the most practicable method of correlating the terranes of widely separated regions, is still a matter for discussion.

PRINCIPLES ON WHICH WIDELY SEPARATED TERRANES MAY BE CORRELATED.

Of the physical and biological phenomena cited in the last few pages, by means of which terranes may be correlated, it is evident that the only infallible method capable of general application is based on the contact of strata. Sedimentation has gone on ever since life existed on the earth, but no universal sheet of sediment has been spread out. On the contrary, continuous sheets of sediments of like kind are frequently restricted to comparatively small areas. This is well illustrated by the manner in which sediments are now being deposited along the Atlantic border of America. These have recently been mapped by Alexander Agassiz from data obtained from soundings, and classed in thirteen divisions, ranging from the sands and clays of the littoral zone

[1] Am. Assoc. Adv. Sci., Proc., vol. XXXVIII, 1889, pp. 205–226.

to the ooze, and the red clay of the deep ocean, and in each deposit characteristic life forms are being entombed.

Moreover, in no region has sedimentation gone on without many changes and many breaks from the dawn of life to the present time, as is abundantly proved by the generally fragmentary condition of the geological series.

These considerations show in a general way, and without taking account of orogenic disturbances, that the sedimentary strata of which the earth's crust is largely composed may be considered as a series of irregular lenticular sheets, some of which are piled in an orderly sequence; others touch only on their edges; others are completely separated and connected by intermediate layers by which their relative age may be determined; others still have no physical connection, and their relative age must be determined by other means. The correlation of these various strata the world over is one of the problems that geologists have before them. What is the most practicable way of accomplishing the task?

In order to arrive at a general scheme of geological correlation for the whole earth it seems evident that each separate land area should be studied by itself and the sedimentary strata composing it arranged, so far as possible, in the order of their age as determined by physical relations.

When correlation by contact and relation to physical phenomena shall have been determined for the terranes over a large part of the separate land areas of the earth, and their corresponding life records determined, the correlation of these various fragmentary histories, with the object of determining the life history of the earth, may be practicable. Evidently the correlation of the strata forming separate land areas can not be made by contact, and it is doubtful if the relation of the strata to widely reaching physical phenomena will ever be valuable for this purpose. The only resource, therefore, is the comparison of life records. The great advances that have been made in paleontology are such as to indicate that when the life records of all the continents shall have been studied independently, and the strata in each correlated by contact, so far as possible, there will result a sufficient body of facts to enable paleontologists and geologists to formulate a somewhat complete history of the progress of life on the earth, showing the special modifications in various regions. Such a standard, when well advanced toward completion, could be used for the determination of the homotaxial relation of the terranes in various regions, and would serve as an important factor in determining what general scheme of classification is most advantageous for showing the approximate correlation of the more important rock series. But not until the relation of the systems composing the various continental land areas shall have been determined, so far as practicable, by contact and the character of their faunas and floras ascertained, can we hope to have a biological time scale by means of which the position of the rock systems forming various continents can be adjusted. Even when this ideal stage is reached it will probably be found that the correlation, even of systems in widely separated regions, will still be general and not specific.

In studying the geology of any region, the primary aim should be to establish the succession of rocks there found by means of their relation to each other and to wide-reaching physical phenomena. At the same time the varied physical events recorded in the rocks should be interpreted and their organic remains carefully studied. The fossils from various natural subdivisions should be preserved separately and submitted to the zoologist and botanist for the determination of their place in the zoological and botanical series. In all cases the relative age of the various faunas and floras should be determined by the relation of the strata containing them, and not the relation of the strata except in a general way and after many fossils have been collected from the contained organic records.

MANNER IN WHICH AMERICAN TERRANES HAVE BEEN CORRELATED.

From the beginning of geological investigation on this continent to the present time, one of the primary and immediate ends that many geologists have had in view was the close correlation of the terranes found here with those occurring in Europe. This correlation has frequently been attempted on the basis of a large number of fossils either specifically or generically identical with those found in Europe. In other cases but few fossils have been obtained, but great weight has been given to these in deciding on the age of the beds in which they occur. In still other instances mere lithological resemblances have been used as a basis for correlation. Again, in many instances, opinions have been expressed as to the position of our terranes in the European scale, and European names adopted in geological treatises and on geological maps, without any statement whatever of the facts on which the correlations were made, or of the principles of correlation which led to a decision. The result is that European names have been fastened especially on the larger divisions of the geological column, without adequate proof that the groups, systems, series, etc., thus designated correspond, except in the most general way, with those bearing similar names across the Atlantic. As the larger divisions in the geological column are supposed to be determined by great unconformities, or by almost complete breaks in the organic records, it is by no means probable that these lines of demarcation coincide in age with the dividing lines in the European standard. Who can say, for instance, that the upper and lower limits of the American Silurian or of the American Devonian corresponds to the upper and lower limits of the divisions bearing these names in Europe. The life histories of these groups undoubtedly coincide in a general way with the life histories of the similar groups in Europe, and in this sense their position is determined. But when the principles of correlation are carried to the smaller divisions in the column, as many geologists and paleobiologists have attempted to do, failure has resulted.

The firm manner in which the European names have been fastened to the American rock series compels their use at present, but always with a mental reservation that they do not strictly coincide with the terranes for which they have been named. As an example, the red beds of the far West and the strata immediately above and below them may be cited. These terranes have been classified as Permian, Triassic and Jurassic, and will have to be spoken of under these titles, although we know that their natural divisions are not the same, and that they can not be correlated except in the most general way, with European systems. It would have been just as logical to have named the strata referred to after terranes bearing somewhat similar fossils in Asia, Africa, or New Zealand as it was to give them the names by which they are now known. It is in fact only after the biological succession in these and other land areas shall have been worked out and compared that anything like a geological history of the earth can be written.

The correlation of the terranes of one with those of another land area is a matter for special consideration, not in the initiative, but in an advanced stage in the study of its geological history.

The adoption of the name "Newark system," proposed by Redfield for the great deposits of sandstone, shale, etc., along the Atlantic border, which form a sharply defined system, limited above and below by great unconformities, is an attempt to break away from the practice of correlating our strata with those of Europe on indefinite evidence and by illogical methods, and is a move toward the establishment of a definite American standard based on a natural system.

In thus venturing to indicate what I consider errors in the method commonly employed in correlation, I do not wish to be understood as attempting to detract in the least from the great importance of the study of the fossil plants and animals. On the contrary, I have the highest admiration for the grand results that have been reached in this direction, and wish to see the work continued. The value of fossils as a practicable means for correlating strata, after their relative age has been determined by superposition, is well established and thoroughly appreciated by every working geologist. It is, perhaps, possible that the life history of the earth is now sufficiently well known to be used at least tentatively in establishing the homotaxial position of terranes in widely separated areas. By applying and correcting the standard from time to time, more precision in the divisions of the scale will result.

CORRELATION OF THE NEWARK SYSTEM.

In the Acadian area the rocks of the Newark system rest unconformably upon the Carboniferous as has been determined by Dawson.[1] In the Connecticut valley the system is underlain unconformably by metamorphosed and crystalline rocks, believed to be in part of lower Silurian age. In the northern part of the New York-Virginia area the rocks beneath the Newark are also crystallized and their age as yet undetermined. In the southern portion of the western border of the system in New Jersey, however, the Newark rocks rest unconformably upon Silurian limestone, as has been determined by the Geological Survey of New Jersey, and a similar relation exists in Pennsylvania. In Maryland the rocks beneath the Newark system are in part Silurian and in part metamorphosed and of indeterminate age. Through all of the Newark areas south of the Potomac, the system rests unconformably upon more or less metamorphosed rocks, the age of which is as yet undecided.

As pointed out by Rogers, the Newark system in Pennsylvania is unaffected by the crumpling and folding impressed upon a large portion of the Appalachian region, and hence is of later date than what is known as the "Appalachian structure." As this structure was produced after the deposition of the Coal-measures, the relation of the Newark system to this crust movement is proof that the system is younger than the Carboniferous. This conclusion, as we have seen, is sustained by the unconformity between the Newark system and Carboniferous rocks beneath in Nova Scotia.

The nature of the unconformity at the base of the Newark system throughout is not only proof that the system is of younger date than the rocks on which it rests, but is evidence that a long period of erosion intervened between the deformation of the underlying beds and the depositions of the superior system.

The next series of rocks deposited in the Atlantic coast region after the Newark is the Potomac. As described by McGee,[2] this formation in Pennsylvania and New Jersey rests in part on the eroded edges of tilted Newark strata and on truncated trap dikes which traverse it. The unconformity between the Newark system and the Cretaceous rocks resting upon it along its eastern border in New Jersey was determined also by the Geological Survey of New Jersey. In Virginia the Taylorsville and Richmond areas are overlain unconformably by the Lafayette.

On the eastern edge of the Deep river and Wadesboro areas in North Carolina, there are sands of Tertiary or more recent date, which rest upon the eroded surfaces of the rocks of the Newark system. The presence of the Potomac formation in this region, resting unconformably upon the Newark, is also suspected, but has not been definitely determined.

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[1] Acadian Geology, 3d ed., London, 1878, pp. 86-113.

[2] Three formations in the middle of the Atlantic slope. In Am. Jour. Sci., 3d ser., vol. xxxv, 1888, pp. 134-136.

The evidence furnished by the formations resting unconformably upon the Newark system is such as to prove that the rocks of that system were upheaved, faulted, diked, and subjected to decay and deep erosion before the oldest of the overlying formations was deposited.

A long interval of land conditions, during which crust movements on a grand scale as well as decay and erosion took place, intervenes both between the Newark system and the rocks on which it rests, and between that system and the rocks which rest upon it.

So far as stratigraphy can be used in determining the age of the system, it proves that it is younger than the Carboniferous rocks of the Atlantic coast region, from which it is separated by a period of erosion, and older than the Potomac formation, from which it is also separated by a period of erosion.

There are no other terranes in the eastern part of the United States. falling in the interval which is shown by stratigraphy to be occupied in part by the Newark system, and there is, therefore, no necessity at this time for discussing the homotaxial relation of that system to neighboring terranes.

RELATION TO TERRANES IN THE WESTERN PART OF THE UNITED STATES.

There are several rock series in the Rocky Mountain region which have been shown by their stratigraphic relations to be intermediate between the Carboniferous and the Cretaceous. These have been referred to the Permian, Triassic, and Jurassic of Europe, on account of their stratigraphical position and the nature of the fossils which they contain. The accuracy of this correlation or the character of the evidence on which it rests, it is not necessary to discuss at this time. There is no physical connection between the Newark system and the terranes just referred to, by means of which their relative age can be determined. Only a few fossils have been found common to the two systems, and hence there is no adequate basis for close correlation.

A few plants collected by Newberry[1] at Abiquiu, New Mexico, were determined by him to be specifically identical with fossil plants found in the Newark system in Virginia and North Carolina. From this evidence it is believed by Newberry that the plant-bearing beds in the two areas referred to are of about the same age, and correspond with the upper Triassic of Europe. The similarity in age between the Newark system and the terrane at Abiquiu, New Mexico, is indicated also by specific identity of the silicified wood found in the two regions, as has recently been determined by Knowlton.[2]

A few fossil bones obtained by Cope, from the so-called Triassic rocks of New Mexico, have been determined by him to be closely allied to the

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[1] U. S. Geol. Surv., Monograph vol. XIV, pp. 14-15. See also by the same author, Report of the Exploring expedition from Santa Fé, N. Mex., to the junction of the Grand and Green rivers of the great Colorado of the West, in 1859, under the command of J. N. Macomb. Washington, 1876, pp. 141-148, pls. 4-8.

[2] Ante, p. 29.

reptilian remains of the Newark system, and in each case are referred to the upper Trias of Europe.

The rich reptilian and mammalian fossils discovered by Marsh at Como (Aurora), Wyoming, near Canyon City, Colorado, and at other points in the Rocky Mountain region, from so-called Jurassic rocks, are considered by their discoverer to be of younger date than the Newark system.

Other vertebrate fossils collected in the so-called Permian of the far West are considered by Cope to be of older date than the Newark.

So far as indicated by organic remains, therefore, the Newark system may be considered as occupying a place in the geological column similar to that occupied by the Triassic rocks or Red beds of the Rocky mountain region. That this correlation is extremely indefinite is shown by the fact that in the Rocky mountain region the rocks referred to the Permian, Triassic, and Jurassic belong to a natural system, in which there are no great unconformities and no persistent features by means of which they may be divided at various localities. Had they been studied in connection with the geology of the region in which they occur, independent of any preconceived notions of European correlation there is no question that the lines of division would have been drawn differently than at present. The scarcity of fossils in that portion of the western system which coincides most nearly with the Newark system is such that a definite correlation with other similar faunas and floras at a distance must be accepted as provisional even by the most sanguine of those who believe in a detailed correlation of strata by means of fossil remains. The uncertainties arising from this cause are still further increased by the fact that the attempts which have been made to correlate the Newark system with the Triassic of the Rocky mountains, depend in large part upon the relation of the fossils of each of these systems to the Triassic fossils of Europe. It seems wise to conclude, therefore, that only a very general relation between the Newark system and the so-called Triassic rocks of the Rocky mountain region has been established, and to wait for further evidence before deciding that a close correlation is practicable.[1]

RELATION TO EUROPEAN TERRANES.

No other system in America has been the subject of so much discussion respecting its position in the European standard of classification as the one now under review.

I have made abstracts of such determinations and opinions of the age of this system as are based on paleontological evidence, not including

[1] Since this paper was written L. F. Ward, from a comparison of the fossil plants of the Newark and of the Trias of the Rocky mountain region, has reached the following conclusion: 'As regards the western deposits, notwithstanding the poverty of their present known flora, there seems to be some indication that they were not laid down at the same exact epoch as those of the Atlantic coast; but, assuming such an asynchronism, the question as to whether they are earlier or later can not be profitably considered with the present insufficient data."—Bull. Geol. Soc. Am., vol. XXIII, 1891, p. 28.

those in which mere opinions have been expressed without stating the basis on which they are founded. The number of these abstracts is over eighty.

Rejecting certain early correlations which referred the Newark system to Silurian, Carboniferous, and Devonian groups, which need not be discussed at this stage of geological study, the remainder of the determinations referred to, and especially the more recent ones, correlate the rocks in question, either wholly or in part, with the Triassic or the Jurassic systems of Europe. Without attempting to give the chronological history of the discussions and controversies that have arisen on this subject, and which are still being pressed in certain quarters, I shall try to indicate, so far as practicable, the nature of the evidence that has been obtained and the conclusions which have been derived from it.[1] The reader will then, at least to some extent, be in a position to judge for himself as to what is the safest position to maintain in reference to the age of the system we are studying.

Fossils of the Newark system, as has already been stated, consist of obscure molluscan remains, larvæ of insects, cases of minute crustaceans, fragmentary portions of the skeletons of mammals, batrachians, and reptiles, fossil fishes, footprints, and plant remains. Owing to the great rarity and to the obscurity of molluscan and insect fossils, the only organic record at present available as a means of correlation are vertebrates, crustaceans, and plants.

TESTIMONY OF THE VERTEBRATES.

Mammals.—The remains of small mammals were discovered by Emmons in the Newark rocks of North Carolina and referred by him to the Permian, on account, principally, of the reptilian fossils associated with them.[2] These remains were studied also by Leidy, who stated that they find very close representatives in the Purbeck beds of the Oolitic of England.[3] The fossil mammalian jaws described by Emmons have recently been reexamined by Osborn, who concludes that they are widely aberrant forms, and not closely related to any fossils hitherto discovered.[4] The investigations by O. C. Marsh in the Jurassic system of the Rocky mountain region have brought to light a large number of small mammalian fossils having a resemblance to the remains found in the Newark system, but these, as stated by their discoverer, are generally distinct.[5]

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[1] Some account of the various determinations of the age of the Newark that have been made is given by—

Lea, Isaac: Description of a fossil saurian of the New Red Sandstone formation of Pennsylvania, with some account of the formation. In Philadelphia Acad. Nat. Sci. Jour., 2d ser., vol. II, 1850–1854, pp. 185–189.

Newberry, J. S.: Fossil fishes and fossil plants of the Triassic rocks of New Jersey and the Connecticut valley. U. S. Geol. Surv., Mon. vol. XIV, Washington, 1888, pp. 8–15.

Marcou, J.: The Triassic flora of Richmond, Virginia, Am. Geol., vol V, 1890, pp. 160–174.

[2] American Geology, part 6, Albany, 1857, pp. 95-96.

[3] Philadelphia Acad. Nat. Sci., Proc., vol. IX, p. 150.

[4] Philadelphia Acad. Nat. Sci., Proc., vol. XXXIX, 1887, p. 291.

[5] Am. Jour. Sci. 3d ser., vol. XXXIII, p. 344.

The small number of mammalian remains thus far obtained from the Newark system, and the limited knowledge possessed at the present time of the early forms of mammalian life, renders it evident that they can not be used, except in a most general way, in determining the age of the strata in which they occur.

Batrachians and reptiles.—Fragmentary portions of the skeletons of large animals were discovered by E. Emmons in his early exploration of the Newark rocks of North Carolina, and determined by him and by Leidy to be most nearly related to the Permian vertebrates of the Old World. These same fossils were studied also by Isaac Lea in connection with similar remains from Pennsylvania, and considered to agree most nearly with similar remains found in the Triassic rocks of Europe.[1]

The fossils studied by Emmons, Leidy, and Lea have since been reexamined and their classification revised by Cope, who finds that certain of the genera found in the Newark rocks occur also in the Triassic rocks of New Mexico. After describing the vertebrate fossils of the New Mexico deposits, this author states that there is a close parallelism between them and the similar fossils from the upper Keuper of Wurtemberg. To quote the author's words:[2] "In both regions the genera Belodon and Tanystrophaeus are abundant and the Artosaurus of the former [Wurtemberg] is represented by the Tylothoras of the latter [New Mexico]. The association of such very diverse forms is good evidence of general identity of fauna, and is a sufficient basis for asserting taxonomic identity of the forms of the two regions."

Again, after studying the vertebrate fossils of the Newark rocks of Pennsylvania, Cope observes:[3] "Geologists have been inclined to identify these beds with the Upper Trias and the Lower Jurassic. The identification of the Belodon and Mastodonsaurus points most strongly to the age being that of the Keuper or upper divisions of the Trias."

The testimony of the fossil footprints so abundant in certain portions of the Newark system is less definite than that derived from the bones and teeth found in the same rocks and probably belonging in part to the same species. No fossil footprints found in other countries have a sufficiently close relation to those of the Newark system to be indentified with them, and, therefore, no close correlation can be based upon these interesting records of a vanished host. Paleontologists would probably agree if no other fossils than footprints were known from the Newark system, that the only admissable conclusion as to their age would be that they are probably somewhat younger than the Carboniferous.

The evidence from vertebrate remains evidently indicates that the position of the Newark beds in the geologic series coincides in a general way with that of the Upper Trias of Europe and with the horizon of the so-called Triassic beds of the Rocky mountain region.

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[1] Philadelphia Acad. Nat. Sci., Proc-, vol. x, p. 92.
[2] Am. Phil. Soc. Proc., vol. XXIV, 1887, p. 227.
[3] Philadelphia Acad. Nat. Sci., Proc., vol. XVIII, 1866, p. 250.

Fishes.—The fossil fishes of the Newark system have been studied, especially by J. H. Redfield and W. C. Redfield, Agassiz, Edgerton, and Newberry. The conclusion reached by the Redfields,[1] father and son, was that the rocks could not be older than the Trias, but must be placed as low as the Lias and Oolite. Agassiz, on examining the fossil fishes of the Richmond area, suggested from their analogy with European forms, that they were of the age of the Lias.[2] Later, in discussing a paper on the Coal-bearing rocks of Virginia and North Carolina, by Johnson, he observes that the fossil fishes of the Richmond area and from "the so-called New Red Sandstone, indicate an age intermediate between the European New Red and the Oolite."[3] Still later he states that the fossils referred to do not agree either with the fossil fishes of the Trias of Southern Germany or with those of the Lias of England, but seem intermediate between the two, and is inclined to refer the Newark system to a group intermediate between the Trias and the Lias for which there is no equivalent in Europe.[4]

By far the most important contribution to our knowledge of the fossil fishes of the Newark system have been made by Newberry. His opinion with reference to the age of the system, based principally on fossil plants, is that it represents only the uppermost portion of the Triassic, and is the equivalent of the Rhetic beds of Germany. In reference to the bearing of the fossil fishes on the question of age, he says:[5] "The fishes so abundant in our Trias [Newark]—*Ischypterus* and *Catopterus*—have never been found in the Old World, and therefore throw no light on the question. But their affinities are more with the Mesozoic fishes (Jurassic and Cretaceous) than with *Palæoniscus*, etc., of the Permian. Much rarer fishes have recently been obtained by the speaker from the Connecticut Trias—*Dipleurus* and *Ptycholepis*—which, though new, represent groups confined to the Jura of the Old World."

The question of the geological equivalents of the Newark system is discussed at length in Newberry's recent monograph on the fossil fishes and fossil plants of the Newark system, but the value of fossil fishes as a basis of correlation is not specifically considered. The final conclusion in reference to correlation expressed in the volume mentioned is the same as previously stated, and places the Newark system on a parallel with the Rhetic of the Old World.[6]

TESTIMONY OF THE CRUSTACEANS.

The minute fossil crustaceans of the Newark system were studied to some extent by Emmons, Rogers, and others, and certain conclusions

[1] Am. Assoc. Adv. Sci., Proc., vol. IX, 1856, p. 185.
[2] Geol. Soc., London, Quart. Jour., vol. III, 1847, p. 275
[3] Am. Assoc. Adv. Sci., Proc., vol. IV., 1850, p. 276.
[4] Am. Acad. Proc., vol. III, 1852–1857, p. 69.
[5] New York Acad. Sci. Trans., vol. V, 1885–'86, p. 18.
[6] U. S. Geol. Surv., Mon. vol. XIV, Washington, 1888, pp. 8–15.

in reference to geological age based on them. The results reached by these authors were subsequently reviewed by T. Rupert Jones, with the aid of abundant specimens.[1] In summing up the evidence furnished by the crustaceans, this author says: "Whether or not these deposits have a Keuperian character, as Prof. O. Heer's late determinations of the Coal plants from Richmond, Virginia, seem to indicate, there is no doubt of their being the products of lagoons in the Lower Mesozoic period, and contemporary either with the marine formation intermediate to the Trias and Lias, namely, the Rhetic, or with the Upper Trias itself, and exactly equivalent to the Lettenkohle (carbonaceous shales at the base of the Keuper.)"[2]

The evidence furnished by the crustaceans, minute as they are, must evidently be considered as important and as sustaining the more recent conclusions reached from a study of the reptilian remains.

TESTIMONY OF THE PLANTS.

The resemblance of some fossil plants of the Richmond area to those of the Keuper of Central Europe led Marcou[3] to assign them to the same horizon as early as 1849.

The plants, like the reptilian remains, were studied at an early date by Emmons, who concluded from this and other evidence that the upper part of the Newark system in North Carolina represented the Keuper. This conclusion was based largely, however, on the opinion of Heer, who, from a study of a small collection of fossil plants, concluded that "Certain forms found in North Carolina are characteristic of the Keuper and Marnes Irisées of Germany, France, and Switzerland; and certain other forms are closely related to the species found in Europe in the Keuper and Lower Lias, but are all different specifically; but there are none which are really Oolitic either in Virginia or North Carolina."[4]

Rogers, in 1858, after reviewing all the available evidence as to the geological position of the Newark system, reached the following conclusion:[5]

> These strata are placed in parallelism with the Lower Mesozoic formation of Europe—the Upper Triassic and the Lower Jurassic rocks—not merely through the few European species which they possess, but quite as obviously by the general aspect or *facies* of nearly all the organic remains which they have hitherto disclosed. Every year is adding to this list, and, as they multiply, the impression produced leans more and more toward the conviction that they were created in a period which unites the Triassic and Jurassic ages.

Rogers, in an essay on the age of the Newark system, after a comprehensive review of all the evidence furnished by fossil plants at that time available, concludes that these fossil remains as a group bear a

[1] A Monograph on the Fossil Estheria. Paleontological Soc., London, 1862.
[2] Ibid, p. 126.
[3] The Triassic flora of Richmond, Virginia., Am. Geol., vol. v, 1890, pp. 163.
[4] Am. Assoc. Adv. Sci., Proc. vol. XI, 1858, p. 79.
[5] Geol. of Pennsylvania, 4to, Philadelphia, 1858, vol. II, p. 697.

remarkable resemblance to those of the Oolitic rocks of Europe. Some of the species are stated to be specifically identical with European forms, while others are very closely allied to certain species found in the Oolitic of the Old World (p. 299). In conclusion, Rogers states that he has no hesitation in referring the coal of eastern Virginia to a place in the Oolitic system on the same general parallel, and with the carbonaceous beds of Whitby and Brora, that is, in the lower part of the Oolite group [1] (p. 300).

A few vegetable remains found in the Newark rocks of the Connecticut valley were figured and described by Hitchcock, and considered by him to indicate a parallelism with the Jurassic of Europe. These remains were so imperfect, however, and so little was then known concerning the fossil floras of the systems with which they were considered to be most nearly related, that but little weight can be attached to this examination.[2]

Fossil plants collected in the Richmond field by Lyell were studied by Bunbury whose final conclusions in reference to their age, as stated by Lyell,[3] placed them on a parallel with the Keuper.

By far the most important contributions made to our knowledge of the fossil flora of the Newark system, is contained in a monograph by Fontaine.[4] As stated by this author there are 42 species of plants from the Richmond area sufficiently well preserved to be of some value in determining the age of the beds. Of these 21 appear to have no near relation in the European floras, but their general character points strongly to a Rhetic or Jurassic age. Three identical and 5 allied species, or 19 per cent, find their representatives in the Jurassic formation. The Jurassic element is much stronger than the Triassic, even without counting the plants of Jurassic generic type found in the species peculiar to Virginia (p. 95). There are 4 species identical with Rhetic forms, and 8 allied to them, or 28 per cent. The Rhetic can, then, claim the largest percentage of identical and allied species. Among them are some of the most abundant and characteristic forms of the Virginian flora. The great abundance and wide diffusion of the *Macrotaeneoptereis magnifolia*, and *Ctenophyllum braunianum* give these plants great weight.

Fontaine's conclusion from the facts briefly indicated above is that we must consider this flora as not older than the Rhetic, the only question being whether its strong Jurassic evidence ought to cause us to regard it as at least Lower Jurassic in age (p. 96).

In the same monograph there is contained a review of the fossil plants of the Newark rocks of North Carolina, described by Emmons, in which 49 species are identified. Of these, 9 are stated to be pecu-

[1] On the age of the coal rock of eastern Virginia. In Assoc. Am. Geologists and Naturalists, Trans., 1840-1842, pp. 299-300.

[2] Ichnology of New England, Boston, 1858, pp. 5, 6, 7.

[3] Elements of Geology, 6th ed., 1886, p. 452.

[4] U. S. Geol. Surv., Mon. vol. VI, Washington, 1883, pp. 92-96, 121-128.

liar to North Carolina, and have no very near allies in other countries. Fifteen species are found in the Newark rocks of Virginia. Assuming, as stated by the author, that the Rajmaahal group, India, is of Liassic age, there are 2 species identical with, and 6 nearly allied to Jurassic plants. Seven species are identical and 8 closely allied to Rhetic plants. Twenty-three per cent are peculiar to North Carolina, while 41 per cent are found in the Newark rocks of Virginia; 20 per cent are allied to or identical with Jurassic forms. Thirty per cent are identical with or allied to Rhetic species. After studying the fossil plants of both Virginia and North Carolina, Fontaine's final conclusion is that these floras are probably of the age of the Rhetic. In his own words: "We are, then, I think, entitled to consider that the older Mesozoic flora of North Carolina and Virginia is most probably Rhetic in age and certainly not older."

"Some authors hold that the Rhetic beds form the uppermost of the Triassic strata. Others think that they are transition beds having affinity with the Lower Lias. The latter view will, I think, be justified by a study of the flora, and I have, in this memoir, assumed its correctness" (p. 128).

Newberry, in his monograph on the fossil fishes and fossil plants of the Newark system already referred to, concurs with Fontaine in referring the flora of the system to the Rhetic (p. 13). He also says that several species of plants common in the Newark system are found at Abiquiu, New Mexico, and at Sonora, Mexico. The author states that this "indicated a parallelism between the plant-bearing beds of the Atlantic Trias [Newark] and those of New Mexico and Sonora, and go far to prove that all of our Triassic rocks which have yet yielded plants belong to the uppermost division of the system" (pp. 14–15).

Stur,[1] in a review of Fontaine's monograph on the flora of the older Mesozoic of Virginia, has identified a large number of the plants from the Richmond area with those of the Lunz sandstone of Germany, and concludes that the plant-bearing beds of the Newark are the equivalent of the Lettenkohle group of Germany. The great confidence that this author gives to his determinations is indicated in the quotations given in this paper on pp. 114–115.

B. Zeiller[2] has also reviewed Fontaine's monograph, and identified certain of the plants there described with those of the grès bigarré of Europe. This identification of species and also the absence in the Newark system of certain types that had an immense distribution during the Rhetian epoch, and as stated by Zeiller, have been found in nearly all the Rhetian deposits of Europe lead to a final conclusion in reference to correlation, which is stated as follows:

[1] Die Lunzer (Lettenkohlen) Flora in den "older Mesozoic beds of the coal-field of eastern Virginia." In Separatabdruck der Verhandlungen der k. k. geologischen Reichsanstalt No. 10, 1888, pp. 203–217.

[2] Sur la présence, dans le grès bigarré des Vosges, de l'Acrostichides rhombifolius, Fontaine. In Société géologique de France, Bull., 3e série, t. XVI, p. 693–698, séance 18 Juin, 1888.

Thus, without pretending, at so great a distance, to make a formal correlation, I think that one may, with great plausibility, arrange the coal-bearing strata of Virginia and North Carolina, with the Upper Trias, as was done by O. Heer, and to place them parallel with those of Bâle (Neue Welt), Stuttgart and Lunz; that is to say, at a level little different, on the whole, from that assigned to them by Mr. Fontaine, but yet a little higher (p. 698).

The evidence furnished by the fossil plants, while not interpreted in the same way by various paleobotanists, points on the whole to a somewhat higher division in the time scale of Europe than the vertebrate and invertebrate fossils.

Before closing the review it will be well to consider what may be classed as negative evidence. This is furnished by the remarks of Dana, made more than thirty years ago, in connection with a review of Emmons geological report of the Midland counties of North Carolina. He says:[1]

In the determination of the exact age of this sandstone, the only rock in this country east of the Mississippi occurring between the Carboniferous and the Cretaceous, we can not be too cautious in the use of evidence. One or two considerations are, therefore, here suggested. In the first place the fauna and flora of America of this modern epoch is represented in Europe, and quite strikingly, as has been shown by the fauna and flora of the later Tertiary of Europe. The life of corresponding ages in the two continents has thus been older in America than in Europe. This is one point to be well weighed. Again, in determining the age of a rock from its fossils, we should rather look to those which indicate the more recent period than those which bear the other way. This criterion would bring us right with regard to our own epoch, while by avoiding it we might be able to prove that we in America are of the Tertiary age of the world. Now, as Mr. Redfield has shown, the fossil fishes—the most characteristic species of any formation—are but *half* heterocercal and come nearer to the Jurassic type than the Triassic. There is hence reason for the opinion, notwithstanding the important evidence brought forward by Dr. Emmons, that the Lias period may be represented by the formation; and we may be nearest the truth if we regard the whole formation as corresponding to the Lias and the latter half to the Trias. The examinations by Mr. Heer accord with this conclusion. The European subdivisions of the Trias we should not look for on this continent, even if we had the whole of the formation, any more than the European subdivisions of the Devonian in the American Devonian. American geology is deeply interested in the decision of this question, and owes much to Prof. Emmons for all that he has done toward its elucidation.

SUMMARY.

The conclusions reached, as indicated above, by those best qualified to determine the nearest equivalents of the Newark system in the geological series of Europe, present some diversity.

The Batrachians and reptiles as shown by the most recent and most extended studies, that have been made, have their nearest known representatives in the Keuper of Germany.

The fossil fishes are not nearly related to those of any formation in Europe, but represent groups confined, so far as is now known, to the Jurassic.

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[1] Am. Jour. Sci., 2d ser., vol. XXIX, 1857, pp. 429-430.

The crustaceans have their nearest representatives in the upper Trias or in the Rhetic.

The plants have been assigned to various horizons, but the most recent and probably the most reliable determinations, place them in the upper part of the Triassic or in the Rhetic; Heer, Stur, and Zeiller claiming them as belonging to the Keuper, while Fontaine and Newberry consider that they more nearly represent the flora of the Rhetic.[1]

This brief résumé of what must be considered the most trustworthy correlations now possible, shows that there is a closer accord in the various determinations than, perhaps, might have been supposed. The geologist who has to depend on the paleontologist for the correlation of strata in widely separated regions, is thus furnished with all the data available on which to base his conclusions. It is probable that the evidence, as it now stands, when considered by various persons, will be interpreted in two ways.

Those who are inclined to believe that a close correlation is possible between the divisions of the geological column in America and Europe, will probably demand further evidence and will continue the controversy as to the equivalency of particular horizons in the two countries.

Those who take the ground that the large natural division of the rock series in America and in Europe admit of correlation only in a broad, general way, will conclude that the correspondence reached from the comparisons already made are sufficient to show that the fossil-bearing strata of the Newark system may be placed in general parallelism with the upper part of the Triassic and the lower part of the Jurassic of Europe. As a system, however, it can not be considered as the equivalent of any definite portion of the European scale.

When the geological succession in the other portions of the earth shall have been determined, and the existing blanks in our knowledge of the succession of organic forms filled, at least in part, it may be possible to form a more comprehensive scheme of classification than any now known, in which the relative position of the strata in various widely separated localities may be some time definitely determined. Until such a standard of comparison approaches completion, we must conclude that the Newark system is a well defined unit in American geology, having a great unconformity both above and below, and that it belongs in the lower portion of the Mesozoic group of the American geological column. The Mesozoic itself, however, does not agree either as to its upper or lower limits with the Mesozoic of Europe, but repre-

[1] The most recent review of the relation of the fossil plants of the Newark to the Triassic flora of Europe which has come to hand is by L. F. Ward (Bull. Geol. Soc. Am., vol. III, 1891, pp. 23-31). The conclusion reached is that our present knowledge fixes the horizon of the Newark "with almost absolute certainty at the summit of the Triassic system, and narrows the discussion down chiefly to the mere verbal question whether it shall be called Rhetic or Keuper. * * * The beds that seem to be most nearly identical, so far as the plants are concerned, are those of Lunz, in Austria, and of Neue Welt, near Basle, in Switzerland. These have been placed by the best European geologists in the Upper Keuper. Our American Trias [Newark] can scarcely be lower than this, and it probably can not be higher than the Rhetic beds of Bavaria."

sents, as nearly as can be determined from our present knowledge of its organic remains, about the same relative position in the life history of the earth.

RELATION TO TERRANES OF ASIA AND CENTRAL AMERICA.

Direct comparisons have been made by Newberry between the fossil plants of the Newark system and similar fossils from China and from Honduras.

A comparison with fossil plants from China collected by Pumpelly in the Kwei basin on the Yangtse river, province of Hupeh, showed that one species is common to the two regions. Another species found in the Kwei basin agreed closely with a European Jurassic species. Another has a remarkable likeness to a fern which occurs both in the Liassic and Oolitic floras of Europe. The Kwei fossils were also compared with fossil plants from Abiquiu, New Mexico, and Sonora, Mexico, regarded by Newberry as Triassic. The conclusion reached from this study was that the plant-bearing beds of the Kwei basin were of Mesozoic age, but whether they should be considered as Triassic or Jurassic remained undecided. Only a very general conclusion as to the relation of the Newark system to the plant-bearing beds of the Kwei basin, is shown by fossils now known, but it is evident that interesting results might be expected from a continuation of the comparisons of the fossil floras of the two regions.[1]

A collection of fossil plants from San Juancito, Honduras, has recently been described by Newberry and shown to be related to the Rhetic of Europe. This collection contains at least one species that is very close to a plant described by Emmons from the Newark rocks of North Carolina. Others are closely related to the plants of Abiquiu, New Mexico, and Sonora, Mexico. After describing the Honduras fossils, Newberry refers to their relation to other floras in the following language:

"This discovery of a Triassic flora in Honduras is a matter of special interest, as nothing of the kind had before been met with in that section of the globe; but it is only another illustration of the uniformity of the vegetation of the world during the Triassic age. This uniformity was, however, only a development of the systematic progress of plant life. The reign of Acrogens ended with the Permian. The Rhetic epoch was, therefore, about the middle of the reign of Gymnosperms. No Angiosperms were yet in existence, for they began in the Cretaceous. * * *

"Where the Gymnospermous flora originated, or how it was developed from the Acrogens, if it was so developed, and through the exercise of what elements of superiority it superseded them, we are yet in ignorance. It is, however, a matter that may well excite our wonder that,

[1] Appendix No. 1 to geological researches in China, Mongolia, and Japan [etc.] by Raphael Pumpelly. Smithsonian Contributions to Knowledge, vol. VII, Washington, 1867, pp. 119-123.

migrating such immense distances from their place of origin, through every phase of soil and climate—through all the zones of the Eastern Hemisphere, and now, as we learn from this group of Honduras plants, through the New World—they march, holding so firmly to their original group of characters, generic and specific, that wherever we open their tombs we recognize them instantly as old friends. In their long marches some perish by the way, and here and there, their numbers were recruited by new forms, imported or developed; but the leading members of the troop in virtue of some occult protection against outside influences, preserved almost without alteration all the complicated characters of their vegetative and reproductive systems.

"We shall look now with eagerness to South America for the full identification there of this Mesozoic flora, which we have found in full development in Virginia, New Mexico, Sonora and now in Honduras. It had before been recognized in Australia—where it seems to emerge from the Paleozoic flora and perhaps began—New Zealand, India, Tonquin, China, Turkestan and various parts of Europe."[1]

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[1] Rhetic plants from Honduras. In Am. Jour. Sci., 3d ser., vol. XXXVI, 1888, pp. 342–351.

INDEX TO THE LITERATURE OF THE NEWARK SYSTEM.

SOURCES OF INFORMATION.

In compiling this index the principal sources of information have been the national and state geological reports included in Frederick Prime's catalogue of official reports,[1] and all similar reports, published since the appearance of the second supplement of that catalogue, on the subjects referred to in this list. Included with these reports, and mentioned in part in Prime's catalogue, are the publications of the Smithsonian Institution, the U. S. National Museum, the U. S. Coast and Geodetic Survey, the U. S. Department of Agriculture, and handbooks of information published by various states. In addition all books and papers published unofficially, containing information relating to the Newark system, have been examined.

Besides these, the following serial publications have been examined:

CATALOGUE OF SERIAL PUBLICATIONS EXAMINED.

Name.	Published at—	Abbreviation.	Examined.
Albany Institute, Proceedings	Albany, N. Y	Albany Inst., Proc	Vols. 1-12.
Albany Institute, Transactions	Albany, N. Y	Albany Inst., Trans	Vols. 1-10.
American Academy of Arts and Sciences, Memoirs.	Cambridge and Boston, Mass.	Am. Acad., Mem	1st series: Vols. 1-5; 2d series: Vols. 1-15.
American Academy of Arts and Sciences, Proceedings.	Boston and Cambridge, Mass.	Am. Acad., Proc	1st series: Vols. 1-5; 2d series: Vols. 1-15.
American Association for the Advancement of Science, Proceedings.	Salem, Mass	Am. Assoc. Adv. Sci., Proc.	Vols. 1-37.
American Association of Geologists and Naturalists, Proceedings.	Boston, Mass	Am. Assoc. Geol. and Nat., Proc.	Meetings 1-6.
American Association of Geologists and Naturalists, Transactions.	Boston, Mass	Am. Assoc. Geol. and Nat., Trans.	Vol. 1 (1840-1842.)
American Chemical Journal	Baltimore, Md	Am. Chem. Jour	Vols. 1-9.
American Chemist	New York, N. Y	Am. Chem	Vols. 1-7.
American Geologist	Minneapolis, Minn	Am. Geol	Vols. 1-6.
American Institute of Mining Engineers, Transactions.	Easton, Philadelphia, Pa., and New York, N. Y.	Am. Inst. Mining Eng., Trans.	Vols. 1-17.
American Journal of Conchology	Philadelphia, Pa	Am. Jour. Conch	Vols. 1-7.
American (Monthly) Journal of Geology and Mineralogy (Featherstonhaugh).	Philadelphia, Pa	Am. Jour. Geol. and Min.	Vol. 1, Nos. 1-10.
American Journal of Science	New Haven, Conn	Am. Jour. Sci	1st series: Vols. 1-50; 2d series: Vols. 1-50; 3d series: Vols. 1-40.
American Mineralogical Journal (Bruce).	New York, N. Y	Am. Min. Jour. (Bruce).	Vol. 1.
American Museum of Natural History, Bulletin.	New York, N. Y	Am. Mus. Nat. Hist., Bull.	Vol. 1, 2.

[1] Am. Inst. Min. Eng.. Trans., vol. VII, pp. 455-525. First supplement, vol. VIII, pp. 466-478. Second supplement, vol. IX, pp. 621-632.

Catalogue of serial publications examined—Continued.

Name.	Published at—	Abbreviation.	Examined.
American Naturalist	Salem, Mass., and Philadelphia, Pa.	Am. Nat	Vols. 1-24.
American Philosophical Society, Proceedings.	Philadelphia, Pa	Am. Philo. Soc., Proc.	Vols. 1-26.
American Philosophical Society, Transactions.	Philadelphia, Pa	Am.Philo.Soc., Trans.	1st series: Vols 1-6; 2d series: Vols. 1-16.
Annals of Science (Cleveland)	Cleveland, Ohio	Ann. Sci. (Cleveland)	Vols. 1, 2.
Annual of Scientific Discovery	Boston, Mass	Ann. Sci. Discov	1850-1871.
Appalachia	Boston, Mass	Appalachia	Vols. 1-5.
British Association for the Advancement of Science, Report.	London, England	British Assoc. Adv. Sci., Rep.	Vols. 1-59.
Boston Journal of Natural History	Boston, Mass	Boston Jour. Nat. Hist.	Vols. 1-7.
Boston Society of Natural History, Anniversary Memoirs.	Boston, Mass	Boston Soc. Nat. Hist., Ann. Mem.	1880.
Boston Society of Natural History, Bulletin.	Boston, Mass	Boston Soc. Nat. Hist., Bull.	Vols. 1-4.
Boston Society of Natural History, Memoirs.	Boston, Mass	Boston Soc. Nat. Hist., Mem.	Vols. 1-4.
Boston Society of Natural History, Occasional Papers.	Boston, Mass	Boston Soc. Nat. Hist., Occasional Papers.	Vols. 1-3.
Boston Society of Natural History, Proceedings.	Boston, Mass	Boston Soc. Nat. Hist.. Proc.	Vols. 1-24.
Brookville Society of Natural History, Bulletins.	Richmond, Ind	Brookville Soc. Nat. Hist., Bull.	Nos. 1, 2.
Buffalo Society of Natural History, Bulletins.	Buffalo, N. Y	Buffalo Soc. Nat. Hist., Bull.	Vols. 1-5.
California Academy of Sciences, Bulletins.	San Francisco, Cal	California Acad. Sci., Bull.	Vols. 1, 2, Nos. 5-8.
California Academy of Sciences, Memoirs.	San Francisco, Cal	California Acad. Sci., Mem.	Vol. 1, parts 1, 2.
California Academy of Sciences, Proceedings.	San Francisco, Cal	California Acad. Sci., Proc.	Vols. 1-7; second series: Vols. 1, 2.
Canadian Institute, Proceedings	Toronto, Canada	Canadian Inst., Proc.	Vols. 1-5.
Canadian Journal of Industry, Science and Art.	Toronto, Canada	Canadian Jour. Ind., Sci. and Art.	Vols. 1-3; new series: Vols. 1-15.
Canadian Naturalist	Montreal, Canada	Canadian Nat	Vols. 1-8; new series: Vols. 1-10.
Canadian Record of Science	Montreal, Canada	Canadian Rec. Sci	Vols. 1-4.
Canada, Royal Society, Transactions and Proceedings.	Montreal, Canada	Canada, Roy. Soc., Trans. and Proc.	Vols. 1-4.
Central Ohio Scientific Association, Proceedings.	Urbana, Ohio	Central Ohio Sci. Assoc., Proc.	Vol. 1, parts 1, 2.
Chicago Academy of Sciences, Bulletin.	Chicago, Ill	Chicago Acad. Sci., Bull.	Vol. 1, No. 6.
Chicago Academy of Sciences, Proceedings.	Chicago, Ill	Chicago Acad. Sci., Proc.	Vol. 1.
Chicago Academy of Sciences, Transactions.	Chicago, Ill	Chicago Acad. Sci., Trans.	Vol. 1.
Cincinnati Society of Natural History, Journal.	Cincinnati, Ohio	Cincinnati Soc. Nat. Hist., Jour.	Vols. 1-10; Vol. 12, Nos. 1-3.
Cleveland Academy of Sciences, Proceedings.	Cleveland, Ohio	Cleveland Acad. Sci., Proc.	1845-1859.
Colorado Scientific Society, Proceedings.	Denver, Colo	Colorado Sci. Soc., Proc.	Vols. 1, 2.
Colorado State School of Mines, Reports.	Golden, Colo	Colorado State School of Mines, Rep.	1885-1887.
Columbia College (*see* School of Mines).			
Connecticut Academy of Sciences, Memoirs.	New Haven, Conn	Connecticut Acad. Sci., Mem.	Vol. 1, part 1.
Connecticut Academy of Sciences, Transactions.	New Haven, Conn	Connecticut Acad. Sci., Trans.	Vols. 1-7.
Cornell University, Scientific Bulletin	Ithaca, N. Y	Cornell Univ., Bull	Vols. 1, 2.
Cornwall Royal Geological Society, Transactions.	Cornwall, England	Cornwall Roy. Geol. Soc., Trans.	Vols. 7-9.
Dakota School of Mines, Report	Rapid City, Dak	Dakota Sch. Min., Rep.	1888.
Davenport Academy of Natural Sciences, Proceedings.	Davenport, Iowa	Davenport Acad. Nat. Sci., Proc.	Vols. 1-4.
Denison University Scientific Laboratory, Bulletin.	Granville, Ill	Denison Univ., Bull	Vols. 1-3.
Des Moines Academy of Sciences, Bulletin.	Des Moines, Iowa	Des Moines Acad. Sci. Bull.	Vol. 1. No. 1.
Dublin Geological Society, Journal	Dublin, Ireland	Dublin Geol.Soc., Jour.	Vols. 1-10.
Dublin Quarterly Journal of Science.	Dublin, Ireland	Dublin Quart.Jour.Sci.	Vols. 1-6.
Edinburgh Geological Society, Transactions.	Edinburgh, Scotland	Edinburgh Geol. Soc., Trans.	Vols. 1-4.

Catalogue of serial publications examined—Continued.

Name.	Published at—	Abbreviation.	Examined.
Edinburgh (The) New Philosopical Journal.	Edinburgh, Scotland	Edinburgh New Phil. Jour.	New series, 1-4, 6, 8-19.
Elisha Mitchell Scientific Society, Journal.	Raleigh, N. C	Elisha Mitchell Sci. Jour.	1883-1889.
Elliott Society of Natural History, Journal.	Charleston, S. C	Elliott Soc.Nat.Hist., Jour.	Vol. 1.
Elliott Society of Natural History, Proceedings.	Charleston, S. C	Elliott Soc.Nat.Hist., Proc.	Vol. 1.
Essex Institute, Bulletin	Salem, Mass	Essex Inst., Bull	Vols. 1-18.
Essex Institute, Proceedings	Salem, Mass	Essex Inst., Proc	Vols. 1-6.
Essex Natural History Society, Journal.	Salem, Mass	Essex Nat. Hist. Soc., Jour.	Vols. 1-6.
France, Geological Society, Bulletin	Paris, France	France, Geol.Soc.,Bull	1st series: Vols. 1-14; 2d series: Vols. 1-26; 3d series: 1-15.
France, Geological Society, Memoirs.	Paris, France	France Geol. Soc.,Mem	1st series: Vols. 1-5; 2d series: Vols. 1-10; 3d series: Vols. 1-4.
Franklin Institute, Journal	Philadelphia, Pa	Franklin Inst., Jour	3d series: Vols. 77-92.
Geological Association (*see* London Geological Association).			
Geological Magazine	London, England	Geol. Mag	1st series: Vols. 1-10; 2d series: Vols. 1-12; decade 3d: Vols. 1-6.
Geological Society of America, Bulletin.	New York, N. Y., and Washington, D. C.	Am. Geol. Soc	Vols. 1, 2.
Geological Society (of London) (*see* London Geological Society).			
Geologist, The	London, England	Geologist	Vols. 1, 2 (1842-1843).
Geologist, The	London, England	Geologist	Vols. 1-7 (1858-1863).
Great Britain (*see* Royal Institution of Great Britain).			
Hamilton Association, Journal and Proceedings.	Hamilton, Ontario	Hamilton Assoc ,Jour. and Proc.	Vols. 1, 2.
Hartford Natural History Society, Transactions.	Hartford, Conn	Hartford Nat. Hist. Soc., Trans.	No. 1 (1836).
Harvard College, Museum of Comparative Zoology, Bulletin.	Cambridge, Mass	Harvard Coll. Mus. Comp. Zool., Bull.	Vols. 1-18.
Harvard College, Museum of Comparative Zoology, Memoirs.	Cambridge, Mass	Harvard Coll. Mus. Comp. Zool., Mem.	Vols. 1-15.
Illinois Natural History Society, Transactions.	Springfield, Ill	Illinois Nat. His. Soc., Trans.	Vol. 1.
International Congress of Geologists, American Committee, Report.		Internat. Cong., Geol. Am. Com., Rep.	
International Congress of Geologists, American Committee, Reports.	Philadelphia, Pa	Internat. Cong., Geol. Am. Com., Rep.	Report for the London meeting.
Iowa Academy of Sciences, Proceedings.	Des Moines, Iowa	Iowa Acad. Sci., Proc.	1887-1889.
Ireland, Royal Academy, Proceedings.	Dublin, Ireland	Ireland Roy. Acad., Proc.	Second series: Vols. 1-3.
Ireland, Royal Geological Society		Ireland Roy. Geol. Soc.	Vols. 1-14.
Ireland, Royal Geological Society, Journal.		Ireland Roy. Geol. Soc., Jour.	
Johns Hopkins University, Circular.	Baltimore, Md	Johns Hopkins Univ., Circ.	Vols. 1-7.
Kansas Academy of Science, Transactions.	Topeka, Kans	Kansas Acad. Sci	Vols. 1-7, 9-11.
Kirtland Society of Natural Science, Papers.	Cleveland, Ohio	Kirtland Soc. Nat. Sci., Papers.	1874.
Liverpool Geological Society, Proceedings.	Liverpool, England	Liverpool Geol. Soc., Proc.	Vols. 1-5.
London Geological Society, Proceedings.	London, England	London Geol. Soc., Proc.	Vols. 1-4.
London Geological Society, Quarterly Journal.	London, England	London Geol. Soc., Quar. Jour.	Vols. 1-44.
London Geological Society, Transactions.	London, England	London Geol. Soc., Trans.	1st series: Vols. 1-5; 2d series: Vols. 1-7.
London Geologists' Association, Proceedings.	London, England	London Geol's. Assoc., Proc.	1st series: Vol. 1; 2d series: Vols. 1-9.

Catalogue of serial publications examined—Continued.

Name.	Published at—	Abbreviation.	Examined.
London Royal Society, Philosophical Transactions.	London, England	London Roy. Soc., Phil. Trans.	From 1837 to 1884.
London, Edinburgh and Dublin Philosophical Magazine and Journal of Science.	London, England	London Philo. Mag.	5th series: Vols. 1–21.
Maclurean Lyceum, Contribution	Philadelphia, Pa	Maclurean Lyc., Cont.	Vol. 1.
Manchester, Geological Society, Transactions.	Manchester, England	Manchester Geol. Soc., Trans.	Vols. 1–25.
Manitoba Historical and Scientific Society, Transactions.	Winnipeg, Canada	Manitoba Hist. and Sci. Soc., Trans.	Vols. 1–29.
Maryland Academy of Sciences, Transactions.	Baltimore, Md	Maryland Acad. Sci., Trans.	1888, pp. 1–97.
Maryland Academy of Sciences and Literature, Transactions.	Baltimore, Md	Maryland Acad. Sci. Lit., Trans.	Vol 1.
Massachusetts Institute of Technology; Technology Quarterly (*see* Technology Quarterly).			
Meriden Scientific Association, Transactions.	Meriden, Conn	Meriden Sci. Assoc., Trans.	Vols. 1–4.
Minnesota Academy of Science, Bulletin.	Minneapolis, Minn	Minnesota Acad. Sci., Bull.	Vols. 1, 2.
National Academy of Science, Annual.	Washington, D. C., and Cambridge, Mass.	National Acad. Sci., Ann.	Vols. 1–4.
National Academy of Science, Memoirs.	Washington, D. C.	National Acad. Sci., Mem.	Vol. 1.
National Geographic Magazine	Washington, D. C.	Nat. Geog. Mag	Vol. 1, No. 1–4.
National Institution, Bulletin of the Proceedings.	Washington, D. C	National Inst., Proc	1840–1844.
Neues Jahrbuch für Mineralogie, Geologie und Paleontologie.	Stuttgart, Germany	Neues Jahrbuch	Vols. 1836–1887. Beilage Bd. 1–4.
New Brunswick Natural History Society, Bulletin.	Fredericton, N. B	New Brunswick Nat. Hist. Soc., Bull.	Vols. 1–6.
New Orleans Academy of Sciences, Papers.	New Orleans, La	New Orleans Acad. Sci., Papers.	Vol. 1, No. 2.
New Orleans Academy of Sciences, Proceedings.	New Orleans, La	New Orleans Acad. Sci., Proc.	Vol. 1, No. 1.
Newport Natural History Society, Documents.	Newport, R. I	Newport Nat. Hist. Soc., Doc.	Documents 2–5.
New York Academy of Sciences, Annals.	New York, N. Y	New York Acad. Sci., Ann.	Vols. 1–5.
New York Academy of Sciences, Transactions.	New York, N. Y	New York Acad. Sci., Trans.	Vols. 1–10 (No. 1–3).
New York Lyceum of Natural History, Annals.	New York, N. Y	New York Lyc. Nat. Hist., Ann.	Vols. 1–11.
New York Lyceum of Natural History, Proceedings.	New York, N. Y	New York Lyc. Nat. Hist., Proc.	Vol. 1 (1870–'71) 2d series Vol. 1 to p. 156.
Nova Scotian Institute of Natural Science, Transactions.	Halifax, Nova Scotia	Nova Scotian Inst., Trans.	Vols. 1–7.
Orleans County Society of Natural Sciences, Transactions and Archives of Science.	Lunenburg, Vt	Orleans (Vt.) Soc. Nat. Sci., Trans.	Vol. 1, No. 1–6.
Ottawa Field-Naturalists' Club, Transactions.	Ottawa, Canada	Ottawa Field-Nat. Club, Trans.	Vol. 1, No. 1–4. Vol. 2, No. 5–7.
Ottawa Naturalist and Transactions of the Ottawa Field-Naturalists' Club.	Ottawa, Canada	Ottawa Nat. and Field-Nat. Club, Trans.	Vol. 1.
Pennsylvania Geological Society, Transactions.	Philadelphia, Pa	Pennsylvania Geol. Soc., Trans.	Vol. 1.
Petermann's Mittheilungen	Gotha, Germany	Petermann's Mitt	Vols. 1–33; Ergänzungsbände 1–12.
Philadelphia Academy of Natural Sciences, Journal.	Philadelphia, Pa	Philadelphia Acad. Nat. Sci., Jour.	1st series, Vols. 1–8; 2d series, Vols. 1–8.
Philadelphia Academy of Natural Sciences, Proceedings.	Philadelphia, Pa	Philadelphia Acad. Nat. Sci., Proc.	Vols. 1–39, to 1890.
Philosophical Society of Washington, D. C. (*see* Washington Philosophical Society).			
Portland Society of Natural History, Journal.	Portland, Me	Portland Soc. Nat. Hist., Jour.	Vol. 1, No. 1.
Portland Society of Natural History, Proceedings.	Portland, Me	Portland Soc. Nat. Hist., Proc.	Vol. 1.
Pottsville Scientific Association, Bulletin.	Pottsville, Pa	Pottsville Sci. Assoc., Bull.	1855.
Royal Institution of Great Britain, Journal.	London	Roy. Inst. Gr. Br., Jour.	Vols. 1, 2.
Royal Irish Academy (*see* Ireland, Royal Academy).			

Catalogue of serial publications examined—Continued.

Name.	Published at—	Abbreviation.	Examined.
Royal Society, London (*see* London, Royal Society).			
Saint Louis Academy of Sciences, Transactions.	Saint Louis, Mo	Saint Louis Acad. Sci., Trans.	Vols. 1-4; Vol. 5, pp. 1-336.
School of Mines, Quarterly	New York, N. Y	School of Mines, Quart.	Vols. 1-11.
Science	Cambridge, Mass., and New York, N.Y.	Science	Vols. 1-14.
Science	New York, N. Y	Science (ed. by John Michels).	Vols. 1, 2.
Smithsonian Institution, Annual Report.	Washington, D. C	Smith. Inst., Ann. Rep.	1853-1887.
Smithsonian Institution, Contribution to Knowledge.	Washington, D. C	Smith. Inst., Cont. Knowl.	Vols. 1-25.
Smithsonian Institution, Miscellaneous Collections.	Washington, D. C	Smith. Inst., Misc. Coll.	Vols. 1-12.
Societé géologique de France (*see* France, Geological Society).			
Technology Quarterly	Boston, Mass	Tech. Quart	Vols. 1-3.
Texas State Geological and Scientific Association, Bulletin.	Houston, Tex	Texas State Geol. and Sci. Assoc., Bull.	Vol. 1, No. 1-6.
Trenton Natural History Society, Journal.	Trenton, N. J	Trenton Nat. Hist. Soc., Jour.	Vol. 1.
United States Geological Survey, Annual Reports.	Washington, D. C	U. S. Geol. Surv., Ann. Rep.	1st-7th.
United States Geological Survey, Bulletin.	Washington, D. C	U. S. Geol. Surv., Bull.	No. 1-50.
United States Geological Survey, Mineral Resources.	Washington, D. C	U. S. Geol. Surv., Min. Resourc.	1883-1887.
United States Geological Survey, Monographs.	Washington, D. C	U. S. Geol. Surv., Mono.	Vols. 1-14.
United States National Museum, Bulletin.	Washington, D. C	U. S. Nat. Mus., Bull	Vol. 1.
United States National Museum, Proceedings.	Washington, D. C	U. S. Nat. Mus., Proc	Vols. 1-10.
Vassar Brothers' Institute, Transactions.	Poughkeepsie, N. Y	Vassar Brothers' Inst., Trans.	Vols. 1-4.
Virginias, The	Staunton, Va	The Virginias	Vols. 1-6.
Washburn College Laboratory of Natural History, Bulletin.	Topeka, Kans	Washburn Coll., Bull.	Vol. 1.
Washington Biological Society, Proceedings.	Washington, D. C	Washington Biol. Soc., Proc.	Vols. 1-3.
Washington Philosophical Society, Bulletin.	Washington, D. C	Washington Phil. Soc., Bull.	Vols. 1-10.
Wisconsin Academy of Science, Arts, and Letters, Bulletin.	Madison, Wis	Wisconsin Acad. Sci., Bull.	No. 1-5.
Wisconsin Academy of Science, Arts, and Letters, Transactions.	Madison, Wis	Wisconsin Acad. Sci., Trans.	Vols. 1-5.
Wyoming Historical and Geological Society, Proceedings and Collections.	Wilkesbarre, Pa	Wyoming Hist. and Geol. Soc., Proc. and Coll.	Vols. 1-3.
Zeitschrift der deutschen geologischen Gesellschaft.	Berlin	Deutsch., Zeitschr. geolo, Gesell.	Whole set.

PLAN OF THE INDEX.

This index consists of principal and secondary entries arranged in a single alphabetic series.

Principal entries.—These consist of the names of books and papers arranged under authors. The author's name is printed in **BLACK FACED** (capitals) type, with a date to the right in the same type. The date designates the year of publication, or, instead of this, in the case of many serials, the date at which the paper appeared, or was read. When two or more papers bear the same date, the second one is designated as *a*, the third as *b*, and so on. When a paper has been published in more than one edition, the edition given first in the description of the book is the one referred to.

The abstract following the description of a paper indicates briefly its contents so far as it relates to the Newark system. References are given to so-called Newark rocks on Prince Edward island, for the reason that the index was compiled before it was concluded that the Newark system is not there represented.

Secondary entries.—The chief words of the secondary or subject entries are printed in **black faced** (small letters) type and in these the reader is referred by author's name and date to the principal entries in **BLACK FACED** (capitals) type.

These secondary entries include:

(1) Places where observations on the Newark system have been made. In these entries the method of locating observations in use by each author has been followed. For example, a locality may be referred to in reference to its proximity to a town, a mountain, a river, etc., by different writers. This necessarily leads to lack of uniformity in the index, but when practicable, cross-references from one method of entry to others have been made.

(2) Under the names of states, the principal papers relating to the rocks of the Newark system within their borders.

(3) The works of authors cited in publications not their own. These are referred to under the name of the author cited, but the information contained in the reference or quotation is treated as a portion of the paper in which it appears.

(4) Under the head of Plants (fossil), Invertebrates (fossil), and Vertebrates (fossil), references to papers containing descriptions of species or genera.

(5) In structural and general geology, references to the following subjects whenever the information recorded seemed sufficiently definite:

Age (discussion or determination of).	**Dip.**	**Oil.**
Analyses.	**Dike.**	**Raindrop impressions.**
Anticline.	**Fault.**	**Salt.**
Arkose.	**Footprints.**	**Sandstone.**
Coal.	**Gypsum.**	**Shale.**
Coke, natural.	**Limestone.**	**Shrinkage cracks.**
Conformity.	**Map, geological.**	**Strike.**
Conglomerate.	**Metamorphism.**	**Synclinals.**
Copper.	**Metamorphism, contact.**	**Trap.**
	Minerals (principal papers only).	

In making references to the subjects mentioned above, as great consistency has been observed as the diversity of the papers indexed would allow.

Besides the subjects enumerated some irregular entries have been inserted, but not systematically noted for the whole body of literature examined. An effort has been made to complete the list up to 1891, but a few papers published in 1890 were received too late to be fully indexed. A further delay in publication has enabled me to introduce references to a few published in 1891, but for these only a limited number of secondary entries have been inserted.

When not otherwise indicated the papers referred to are octavo.

In preparing this index I have been greatly assisted by Mr. Nelson H. Darton, who has permitted unrestricted use of the manuscript of an unpublished "Author's Catalogue of North American Geology," and has assisted me in many other ways. I am also indebted to Prof. W. O. Crosby, for a short bibliographic list which has been used in verification.

LITERATURE.

Abbeville, S. C. Description of trap dikes near (Tuomey, '44, pp. 11-12).

Trap dikes near (Hammond, 1884, p. 466).

ABBOT, [S. L.] Cited on fossil footprints. (E. Hitchcock, 1843*a*, p. 260).

Abbotstown, Pa. Character of strata near (H. D. Rogers, '58, vol. 2, p. 679).

Conglomerate near (H. D. Rogers, '58, vol. 2, p. 680).

Dip near (Frazer, '76, p. 101).

Acadia. Section of the rocks of (Dawson, '78, Pl. op., p. 20).

ACKERLY, S. Cited on the character of the rocks forming the Palisades, N. J. (Cooper, '22, p. 240).

ADAMS, C. B. 1846.

Second annual report on the geology of the state of Vermont. Burlington Vt., pp. 1-267.

Contains a brief account of the Newark system in general, pp. 101-102. Discusses the amount of erosion indicated by the trap dikes of the Connecticut valley and of Vermont. States that some of the material forming the Newark rocks of the Connecticut valley came from the North, pp. 159-162.

ADAMS, C. B. 1846a.

Notice of a small Ornithichnite.

Am. Jour. Sci., 2d ser., vol. 2, pp. 215, 216.

Describes and gives two outline figures of a small footprint from Westfield, Conn.

ADAMS, C. B. 1860.

Elements of geology.

See Gray and Adams, 1860.

ADAMS [C. B.]. Cited on the mode of formation of the Newark rocks of the Connecticut valley (Lea, '53, pp. 191-192).

Adams County, Pa. Brief report on (Lesley, '85, p. xxi, pl. 1).

Contact metamorphism in (H. D. Rogers, '58, vol. 2, p. 691).

Detailed account of copper ore in (Frazer, '80, pp. 299-304).

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Black slate near (Emmons, '56, p. 243).
Boundary of Newark area near (Emmons, '52, p. 119. Johnson, '51, p. 4. Mitchell, '42, pp. 36–130).
Breadth of the Newark area east of (Emmons, '56, p. 241. Olmstead, '24, p. 12. Wilkes, '58, p. 2).
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Thickness of trap sheet at (Darton, '90, p. 23).

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Description of trap dike near (Frazer, '80, p. 28-29).

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Limestone outlying in the Newark system near (Invilliers, '83, p. 205).

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Minerals near (Willimott, '84, p. 20L, 24L).

CLARKE, F. W. 1887.

[Analyses of trap rock, coke and coal from the Newark system.]

In U. S. Geol. Surv., Bull. No. 42.

Analyses of trap rocks from North Carolina, p. 138. Natural coke from the Richmond coal field, Va., p. 146. Coals from the Newark system in North Carolina, p. 146.

CLARKE, FRANK WIGGLESWORTH. 1889.

[Analyses of Newark sandstone from near Hancock, Md.]

CLARKE, FRANK WIGGLESWORTH—Continued.

In U. S. Geol. Surv., Bull. No. 55, p. 80.

Two analyses given.

Clark and Brother's quarry near Greenburg, N. J. (Cook, '81, pp. 56, 57).

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Clayton, Pa. Conglomerate near (d'Invilliers, '83, p. 202).

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CLEAVELAND, PARKER. 1822.

An elementary treatise on mineralogy and geology [etc.].

Boston, 2d ed., vol. 1, pp. i-xii, 1-818, pls. 1-6.

Contains a brief account of the trap rocks of the Newark system, compiled from the writings of Pierce, Silliman, Hitchcock, and Webster, pp. 746, 747; and of the sandstone of the same system compiled from the writings of Maclure and Olmstead, p. 579. The geological map of the eastern part of the United States, forming the frontispiece, is mainly from Maclure's map of 1817. Localities where native copper occurs are mentioned on p. 555.

Cited on the extent of the Dan river area, N. C. (Olmstead, '27, p. 128).

Clegg's coal mine, N. C. Anthracite near trap in (Genth and Kerr, '81, p. 82).

Clements, N. S. Iron ores at (Alger, '27, pp. 229, 330).

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Analysis of some of the coal from the Richmond mines.

In Pennsylvania Geol. Soc., Trans., vol. 1, p. 295-297.

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In Pennsylvania Geol. Soc., Trans., vol. 1, pp. 298-313, pl. 17.

Contains brief descriptions of volcanic rocks which may prove to be a portion of the Newark system of traps.

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CLIFFORD, WILLIAM. 1887.

Richmond coal field, Virginia.

In Manchester Geol. Soc., Proc., vol. 19, 1887-1888, pp. 326-353, 355-358, pls. 1-5.

Reviewed by F. H. Newell in Geol. Mag., dec. 3, vol. 6, 1889, pp. 138-140.

Discusses briefly the mode of formation and the age of the Richmond coal field. Presents a historical sketch of coal-mining, and indicates what is to be expected from

COOK, GEORGE H. 1864.

Report of Prof. George H. Cook upon the geological survey of New Jersey and its progress during the year 1863.

Trenton, N. J. Pp. 1-13.

Contains a brief notice of extent of Newark rocks in Hunterdon county, together with an account of prevailing dips, and a qualified statement of the age of the Newark system in New Jersey. Pp. 6-7.

COOK, GEORGE H. 1865.

The annual report of Prof. George H. Cook, state geologist, to his excellency Joel Parker, president of the board of managers of the Geological Survey of New Jersey, for the year 1864.

Trenton, N. J. Pp. 1-24, pl. 2.

East border of the Newark system in New Jersey defined, p. 5. Northwest border defined, pp. 6-8. Geological map, p. 21. Geological section, p. 22. Tabular statement to accompany geological map, giving principal rocks and localities where found, p. 24.

COOK, GEORGE H. 1868.

Geology of New Jersey.

Newark [N. J.]. Pp. i-xxiv, 1-900, pl. 6. Accompanied by a portfolio containing 8 maps in 13 sheets.

The following table indicates the contents of this volume so far as it relates to the Newark system:

COOK, GEORGE H.—Continued.

COOK, GEORGE H. 1871.

[Annual report of the state geologist of New Jersey, for the year 1870].

New Brunswick, N. J. Pp. 1-75, pl. 4.

Deposits of copper ore described, pp. 55, 57.

COOK, GEORGE H. 1873.

Geological Survey of New Jersey. Annual report of the state geologist for the year 1873.

Trenton, N. J. Pp. 1-128, pl. 2.

Junction of Newark and Azoic rocks mentioned, pp. 13-14. Color given to Newark rocks on geological map, p. 22. Copper ores briefly mentioned, pp. 98-99. Part of the east boundary of the Newark system briefly described, p. 103.

COOK, GEORGE H. 1874.

Geological Survey of New Jersey. Annual report of the state geologist for the year 1874.

COOK, GEORGE H.—Continued.

Trenton [N. J.]. Pp. 1–115, with map.

Copper ores, p. 32. Junction of Newark and Cretaceous rocks mentioned, p. 43. Native iron in trap rocks, pp. 56–57.

COOK, GEORGE H. 1876.

Catalogue of the Centennial exhibit of the Geological Survey of New Jersey.

[Trenton, N. J.] Pp. 1–84.

Brief account of extent of the Newark system in New Jersey, with catalogue of 30 specimens of sandstones, shale, flagstone, conglomerate, and trap, pp. 24–25. Four other specimens of sandstone mentioned on p. 45.

COOK, GEORGE H. 1878.

Geological survey of New Jersey. Annual report of the state geologist for the year 1878.

Trenton, N. J., pp. 1–131, with map in pocket. Glacial markings in trap rock, p. 10. Soil formed from Newark shales, pp. 24–25, 29. Soil from trap rock ridges, p. 39. Coal in thin seams, p. 110.

COOK, GEORGE H. 1879.

Geological survey of New Jersey. Annual report of the state geologist for the year 1879.

Trenton, N. J., pp. 1–199, pl. 1, and geological map of New Jersey in pocket.

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COOK, GEORGE H. 1880.

Geological survey of New Jersey. Annual report of the state geologist for the year 1880.

Trenton, N. J., pp. 1–220, pl. 1, and folding map.

COOK, GEORGE H.—Continued.

Abstract in Am. Jour. Sci., 3d ser., vol. 22, pp. 77–78.

Contains an account of certain deep wells bored in the Newark rocks, including the record of a well at Paterson with analysis of water obtained, pp. 162–166. Brief statement concerning deep wells in Jersey City.

COOK, GEORGE H. 1881.

Geological survey of New Jersey. Annual report of the state geologist for the year 1881.

Trenton, N. J., pp. 1–87, 1–107, i–xiv, and map.

Brief account of reopening of copper mines, pp. 39–40. Description of the building stones of the Newark system, pp. 42–64.

COOK, GEORGE H. 1882.

Geological survey of New Jersey. Annual report of the state geologist for the year 1882.

Camden, N. J., pp. 1–191, pl. 1–6, and 3 maps.

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Little Falls, N. J., view of (Cook, '82, pl. 2).

COOK, GEORGE H. 1883.

Geological survey of New Jersey. Annual report of the state geologist for the year 1883.

Camden, N. J., pp. 1–188, pls. 1–3.

Abstract in Am. Jour. Sci., 3d ser., vol. 27, pp. 408–409.

Contains a brief review of a paper "On the relations of the Triassic traps and sandstones of the eastern United States," by W. M. Davis. The conclusion reached by Davis in reference to the extrusive origin of the Watchung mountain trap, is controverted, and facts presented with the view of showing that all the trap rocks of New Jersey are intrusive. In this discussion a summary is given of localities in New Jersey, where metamorphism adjacent to trap rock has been observed, pp. 22–26.

Native iron, and copper ores, pp. 162–166.

COOK, GEORGE H. 1884.

Geological survey of New Jersey. Annual report of the state geologist for the year 1884.

Trenton, N. J., pp. 1–168, pls. 1–5.

Abstract in Am. Jour. Sci., 3d ser., vol. 30, pp. 161–162.

Contains description with illustrations of an exposure of columnar trap at Orange, pp. 23–28.

Artesian wells with analyses of water, pp. 135–136.

COOK, GEORGE H. 1885.

Geological survey of the state of New Jersey. Annual report of the state geologist for the year 1885.

Trenton, N. J., pp. 1–228, pls. 1–13.

Abstract in Am. Jour. Sci., 3d ser., vol. 33, p. 79.

An incomplete list of localities in New Jersey, where fossils have been found, together with names of some of the specimens obtained, pp. 95–96.

Artesian and bored wells, with some account of the strata passed through, together with several analyses of the water obtained, pp. 111–123.

A section of Newark rocks between Jersey City and Boonton, on pl. op. p. 109.

COOK, GEORGE H. 1886.

Sketch of the geology of the Cretaceous and Tertiary formations of New Jersey.

In geological survey of New Jersey, brachiopoda and lamellibranchiata of the Raritan clays and greensand marls of New Jersey, by Robert P. Whitfield. Trenton, N. J., 4to., pp. i–xx, 1–338, pls. 1–35, with folding geological map of New Jersey.

Published also as Monograph IX, U. S. Geological Survey.

Junction of Cretaceous and Newark described, and shown in diagrams, p. x. On the map a portion of the Newark system is shown.

COOK, GEORGE H. 1887.

Geological survey of New Jersey. Annual reports of the state geologist for the year 1886.

Trenton, N. J., 1887, pp. 1–254, and two maps.

Reviewed in Science, vol. 9, 1887, pp. 595–596.

Describes briefly the general condition of the Newark rocks in New Jersey, and notices briefly the various explanations of their structure, character of trap sheets, etc., that have been suggested.

COOK, GEORGE H. 1888.

Report of the subcommittee [of the International Geological Congress] on Mesozoic.

In Am. Geol., vol. 2, pp. 257–261. Published also in International Cong. Geol. Am. Comm. Rep., 1888, pp. E1–E15.

Contains a brief review of the Newark system.

COOK, GEORGE H. 1889.

Geological survey of New Jersey. Annual report of the state geologist for the year 1888.

COOK, GEORGE H.—Continued.

Camden, N. J., 1889, pp. 1–87, pl. op. p. 42.

An introduction to F. L. Nason's paper on the Newark system in New Jersey (pp. 11–13). States briefly the boundaries of the system, its area, and the character of its principal rocks, mode of their formation, thickness, structure, etc. Presents two sections showing small faults.

COOK, GEORGE H. 1889 *a*.

On the International Geological Congress, and our part in it as American geologists.

In Am. Assoc. Adv. Sci., Proc., vol. 37, pp. 159–177.

Expresses belief that faults have been identified in the Newark system, which explain its structure and apparent great thickness. Refers also to the position of the system in the geological column.

COOK, G. H. Analysis of trap from New Jersey, by (J. D. Dana, '73, vol. 6, p. 106).

Cited on analysis of sandstone from New Jersey (Wurtz, '71).

Cited on columnar trap near Orange, N. J. (Iddings, '86, p. 329).

Cited on conglomerate near Paterson, N. J. (Darton, '90, p. 17).

Cited on curved form of certain trap ridges (W. M. Davis, '83, p. 307).

Cited on dips, indicating a fault in New Jersey (Lewies, '85, p. 451).

Cited on footprint localities in New Jersey (C. H. Hitchcock, '88, p. 122).

Cited on former extent of the Newark system (J. D. Dana, '83).

Cited on geology near Martin's dock, New Jersey (W. M. Davis, '83, p. 276).

Cited on the cause of the monoclinal structure of the Newark rocks of New Jersey (W. M. Davis, '86, p. 343).

Cited on the inclination of the red sandstone of New Jersey (Walling, '78, p. 196).

Cited on the occurrence of conglomerate along the Delaware in New Jersey (Russell, '78, pp. 235–236).

Cited on the origin and deposition of Newark strata (W. M. Davis, '83, p. 287).

Cited on the origin of the red color of the Newark sandstone (Russell, '89, p. 50).

Cited on the origin of prevailing dip of the Newark rocks of New Jersey (Wurtz, '70, pp. 99–100).

Cited on the tilting of sandstone and trap in New Jersey (W. M. Davis, '83, pp. 302, 303).

Cited on trap dikes in New Jersey (W. M. Davis, '83, p. 292).

Cited on upper contact of palisade trap sheet, New Jersey (Davis and Whittle, '89, p. 106).

Notice of work done by in New Jersey (Miller, '79–'81, vol. 2, pp. 157–158).

COOK, GEORGE H., and SMOCK, JOHN C. 1874.

Geological survey of New Jersey. [A geological map of] northern New Jersey, showing iron ores and limestone districts, scale 2 miles to 1 inch.

COOK, GEO. H., and SMOCK, JOHN C.—Cont'd.
New York. Two sheets in an envelope. [Revision of edition of 1868.]
Includes a portion of the area occupied by Newark sandstone and trap.

COOK, GEORGE H. and JOHN C. SMOCK. 1878.
Geological survey of New Jersey. Report on the clay deposits of Woodbridge, South Amboy and other places in New Jersey.
Trenton, N. J. Pp. 1–381, pls. 2, and map in pocket.
The references to the Newark system in this volume are brief and incidental to the description of the Cretaceous clays, etc. An unconformity between the Plastic clays at the base of the Cretaceous and the Newark rocks beneath is stated, pp. 5, 24, 39, 171, 172. Several localities are also described where the Newark has been reached in excavations begun in clays, pp. 304–305.

Cook's gap, Conn. Description of trap ridges near (Percival, '42, pp. 370–371, 373, 375, 376, 379, 381).
Detailed study of the geological structure near (W. M. Davis, '89).
Sketch map of (W. M. Davis, '89, pl. 5).

Coontown, N. J. Dip at (Cook, '68, p. 196).
Dip in shale near (Cook, '79, p. 30).

COOPER, THOMAS. 1822.
On volcanoes and volcanic substances with a partial reference to the origin of the rocks of the floetz trap formation.
In Am. Jour. Sci., vol. 4, pp. 205–243.
Contains a general account of the trap rocks of the Newark system from Massachusetts to North Carolina. The trap is considered of igneous origin, pp. 239–243.

Coopersburg, Pa. Dip near (Lesley, '83, p. 180).
Dip of shale at (H. D. Rogers, '58, vol. 1, p. 101).
Ripple marks at (H. D. Rogers, '58, vol. 1, p. 101).

Cooperstown, Pa. Boundary of the Newark near (H. D. Rogers, '41, p. 16, 39).
Boundary of the Newark near (H. D. Rogers, '58, vol. 2, p. 668).

COPE, [E. D.] 1866.
[Remarks on extinct vertebrates from the Mesozoic red sandstone of Pennsylvania.]
In Philadelphia Acad. Nat. Sci., Proc., vol. 18, pp. 249–250, 290.
Presents the results of an examination of certain vertebrate fossils from Phoenixville, Pa., and describes a new Mastodonsaurus; states that the fossils in question properly belong to the Keuper or upper division of the Trias.

COPE, EDWARD D. 1868.
Synopsis of the extinct reptilia found in the Mesozoic and Tertiary strata of New Jersey.
In geology of New Jersey; by George H. Cook. Newark [N. J.], 1868, pp. 733–737.
Brief remarks on the general character of *Clepsysaurus pennsylvanicus.*

COPE, EDWARD D. 1869.
Synopsis of the extinct batrachia, reptilia, and aves of North America.
In Am. Phil. Soc., Trans., n. s., vol. 14, 1871, pp. 1–252, pls. 1–14.
Abstract in Am. Jour. Sci., 2d ser., vol. 49, pp. 390–392.
Presents a synopsis of the batrachians and reptiles that have been described from the Newark system.

COPE, [E. D.] 1870.
Observations on the reptilia of the Triassic formations of the Atlantic region of the United States.
In Am. Philo. Soc., Proc., vol. 11, 1871, pp. 444–446.
Abstract of a paper in which several fossil reptiles from the rocks mentioned are reclassified and a new fossil reptile from Phœnixville, Pa., briefly described.

COPE, EDWARD D. 1873.
Observations on the distribution of certain extinct vertebrata in North Carolina.
In Am. Philo. Soc., Proc., vol. 12, 1871–1872, pp. 210–216, pls. 1–4.
Discusses the biological relation of certain fossil reptiles from North Carolina and Pennsylvania.

COPE, EDWARD D. 1875.
Synopsis of the vertebrata whose remains have been preserved in the formations of North Carolina.
In report on the geological survey of North Carolina, vol. 1, by W. C. Kerr. Appendix B, pp. 29–52, pls. 5–8.
Contains references to or descriptions of fossil fishes, batrachians and reptiles, pp. 30, 32, 34–35, pl. 8.

COPE, E. D. 1877.
Descriptions of extinct vertebrata from the Permian and Triassic formations of the United States.
In Am. Philo. Soc., Proc., vol. 17, 1878, pp. 182–196.
Describes a number of vertebrate fossils from Phœnixville, Pa.

COPE, E. D. 1877.
On some saurians found in the Triassic of Pennsylvania, by Mr. C. M. Wheatley.
In Am. Philo. Soc., Proc., vol. 17, 1878, pp. 231–232.
Describes fossil reptilian remains from Phœnixville, (?) Pa.

COPE, E. D. 1885.
[Vertebrate fossils of the Triassic beds of Pennsylvania.]
In sketch of the geology of York county, Pa.
In Am. Philo. Soc., Proc., vol. 23, 1886, pp. 403–404.
Presents a list of twelve species of vertebrate fossils from the rocks mentioned.

COPE, E. D. 1885a.
Marsh on American Jurassic dinosauria.
In Am. Nat., vol. 19, pp. 67–68.
A review of "The principal characters of American Jurassic dinosaurs," by O. C. Marsh.

COPE, E. D. 1887.
A contribution to the history of the vertebrata of the Trias of North America.
In Am. Phil. Soc. Proc., vol. 24, pp. 209–228, pls. 1, 2.
Describes vertebrate fossils from Pennsylvania and North Carolina.

COPE [E. D.]. 1888.
Mesozoic realm.
In report of the subcommittee [of the International Geological Congress] on Mesozoic. By George H. Cook.
In Am. Geol., vol. 2, pp. 261–268.
Published also in International Cong. Geol., Ann. Comm., Rep. 1888, pp. E7–E9.
Contains a brief review of the Triassic and Jurassic systems of North America.

COPE, E. D. 1889.
[Review of H. F. Osborn's paper on the structure and classification of Mesozoic mammalia.]
In Am. Nat., vol. 23, pp. 723–724, pl. 14.
States the contents of the paper received. Reproduces one of the plates.

COPE, E. D. Cited on the age of the Mesozoic sandstone of York county, Pa. (Frazer, '85, p. 403).

COPE, E. D. Notice of the study of fossil reptiles from Pennsylvania by (Miller, '79–'81, vol. 2, pp. 156, 223, 233).

Copeville, Pa. Mention of trap dike near (Frazer, '89, p. 693).

Copper, deposition of, in (Chapman, '56, pp. 43–45).

Copper hill station, N. J. Dip near (Cook, '68, p. 197).
Dip in shale near (Cook, '82, p. 26).

Copper hill, N. J. Indurated shale at (Cook, '82, p. 63).

Copper in Connecticut valley. Associated with trap (Percival, '42, p. 318).
Brief account of (E. Hitchcock, '35, pp. 71–72. E. Hitchcock, '35, pp. 228–229. E. Hitchcock, '41, p. 448. Brongniart and Silliman, '22. Percival, '42, p. 318. Silliman, '21, pp. 221, 222).
Discussion concerning (Gilbert, '22, '22*a*. Hoffman, '22. Silliman and Whitney, '55).
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From Mt. Carmel trap ridge, Connecticut (Percival, '42, pp. 320–321).
From West Rock and in North Hamden, Conn. (Percival, '42, p. 436).

Copper in Nova Scotia (How, '69, pp. 65–66, 72. Gesner, '36, pp. 193, 234. Gesner, '36, pp. 192, 193. Willimott, '84, pp. 20L, 21L).

Copper in Pennsylvania. Brief account of (Frazer, '77*c*. Frazer, '82, pp. 131–134. H. D. Rogers, '58, vol. 2, p. 763).
In Adams county (H. D. Rogers, '58, vol. 2, p. 691).
Detailed account of (Frazer, '80, pp. 299–304).
In York county. Notice of (Frazer, '85, p. 403).

Copper in Pennsylvania—Continued.
Near Gettysburg. Exploration for (Frazer, '77, pp. 263–264).
On the occurrence of, near Gettysburg (Frazer, '77*b*).

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From the bay of Fundy (Gilpin, '77, p. 749).
From Bridgewater mine, New Jersey (Cook, '81, p. 39).
From cape Dory, Nova Scotia (Alger, '27, p. 232).
From Hamden hills, Connecticut (Silliman, '14, p. 149).
From Long island, Nova Scotia (Gesner, '36, p. 174).
From Simsbury mines, Massachusetts (E. Hitchcock, '35, p. 229).
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From Woodbridge, New Jersey. Mention of (Akerly, '20, p. 61).
In connection with trap sheets (Jackson, '50, p. 336).
Localities where found (Cleaveland, '22, p. 555).

Copper ore in New Brunswick. On Grand Manan island (Bailey, '72, pp. 47, 221, 225, 226. Chapman, '72. Chapman, '78, p. 106.)

Copper ore in New Jersey. At Bellville (Cook, '81, p. 46).
At Copper hill (Cook, '68, p. 679).
At Flemington. Report on (E. and C. H. Hitchcock, '59).
At Somerville. Analysis of (Bowen).
Brief account of (Cook, '71, pp. 55–57. Credner, '70).
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Detailed description of (H. D. Rogers, '40, pp. 158–165).
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Near New Brunswick (Beck, '39).
Near Warrenville (Cook, '74, p. 32).
Occurrence of (Cook, '68, pp. 218–224, 675–680).
Reference to early working of (D. S. Martin, '88, p. 8).
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Reopening of mines (Cook, '81, pp. 39–40).
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Copper ores in South Carolina (Lieber, '56, p. 51).
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Relation of, to trap (Lyell, '54, p. 33).

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On the geology, mineralogy, scenery, and curiosities of parts of Virginia, Tennessee and the Alabama and Mississippi Territories [etc.].
In Am. Jour. Sci., vol. 1. pp. 215–226, 317–331.
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CORYELL, MARTIN. 1875.
East Virginia coal field.
In Am. Inst. Mining Eng., Trans., vol. 3, pp. 228–231.
Gives a list of papers that have been published on the Richmond coal field, and also a section of coal seams at Carbon hill.

CORYELL, MARTIN. 1875.
[Remarks on mining and on natural coke in the Richmond coal field, Virginia.]
In the Engineering and Mining Journal, vol. 19, p. 35.
Discussion of a paper by O. J. Heinrich, on deep borings with a diamond drill, read before the American Institute of Mining Engineers, December 26, 1874. States that excellent coal in thick seams, exists in the Richmond coal field, Virginia, and also that the field has not been greatly disturbed. Describes a vein of natural coke or "carbonite" 5 feet thick on the north side of the James. Remarks were also made by O. J. Heinrich and T. S. Hunt.

COZZENS, ISSACHAR. 1843.
A geological history of Manhattan or New York island [etc., etc.]
New York, pp. 1–114, pls. 1–9.
Describes the trap and associated sedimentary rocks on the west side of the Hudson, near New York city.

CREDNER, HERMANN. 1865.
Geognostische Skizze der Umgegend von New York.
In Zeitsch. Deutsch. geol. Gesell., vol. 17, pp. 388–398, pl. 13.
Describes diorite dike west of New York, with an account of its composition, structure, extent, and contact with sandstone on the west.

CREDNER, HERMANN. 1865.
Geognostische Reiseskizzen aus New Brunswick in Nordamerika.
Neues Jahrbuch, 1865, pp. 803–821.
Describes the rocks of Quaco, New Brunswick, referring them to the Permian. States that the Triassic and Jurassic formations are not known in New Brunswick.

CREDNER, HERMANN. 1866.
Geognostische Skizzen aus Virginia, Nordamerika.
In Zeitsch. Deutsch. geol. Gesell., vol. 18, pp. 77–85.
Gives a brief description of Clover hill coal basin, Virginia. Discuses differences of opinion as to the age of the coal and the impossibility of correlating with European formations.

DANA, EDWARD S.—Continued.

A preliminary microscopic examination of trap rock from more than a hundred localities.

DANA, EDWARD S. 1877.

On the occurrence of garnets with the trap of New Haven, Conn.

In Am. Jour. Sci., 3d ser., vol. 14, pp. 215-218.

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DANA, EDWARD S. Cited as to the composition of trap rocks (W. M. Davis, '83, p. 284).

Cited on the optical properties of trap from Connecticut (Frazer, '75*b*).

Cited on the trap rocks of Connecticut (Hovey, '89, pp. 364-368).

Cited on trap (dolerite) in the Connecticut valley (Iddings, '86, p. 331).

Cited on tufaceous conglomerate in Massachusetts (W. M. Davis, '83, p. 263).

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On the analogies between the modern igneous rocks and the so-called Primary formations, and the metamorphic changes produced by heat in associated sedimentary deposits.

In Am. Jour. Sci., vol. 45, pp. 104-122.

Cites H. D. Rogers in reference to contact metamorphism at Rocky Hill, N. J., pp. 113-115.

DANA, JAMES D. 1845.

Origin of the constituent and adventitious minerals of trap and the allied rocks.

In Am. Jour. Sci., vol. 49, pp. 49-64.

Published also in Am. Assoc. Geol. and Nat., Proc., 6th meeting, pp. 26-28.

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DANA, JAMES D. 1845a.

On the minerals of trap and the allied rocks.

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Published also in Am. Jour. Sci., vol. 49, pp. 49-64.

Discusses the origin of adventitious and secondary minerals in trap rocks.

DANA, JAMES D. 1847.

On the origin of continents.

In Am. Jour. Sci., 3d ser., vol. 3, pp. 94-100.

Brief statement of a hypothesis to the effect that the trap dikes of the Newark system may be a result of contraction subsequent to the Carboniferous, pp. 99-100.

DANA, JAMES D. 1847a.

Origin of the grand outline features of the earth.

In Am. Jour. Sci., 2d ser., vol. 3, pp. 381-398.

The trap ridges of the Connecticut valley are referred to as illustrating the view that certain grand features of the earth's surface have resulted from fissures, pp. 391-392.

DANA, JAMES D. 1847b.

[Note on phalangial impressions in fossil footprints.]

See Silliman, Silliman, jr., and Dana, 1847.

DANA, JAMES D. 1847c.

[Note on] Ornithichnites.

See Silliman and Dana, 1847.

DANA, [J. D.] 1855.

[A note relating to a new fossil plant from the Connecticut valley sandstone.]

In Boston Soc. Nat. Hist., Proc., vol. 5, p. 212.

Brief reference to a letter relating to the finding of a specimen of Clathropteris in the sandstone of the Connecticut valley.

DANA, J. D. 1856.

On American geological history: Address before the American Association for the advancement of Science. August, 1855.

In Am. Jour. Sci., 2d ser., vol. 22, pp. 305-334. Published also in Am. Assoc. Adv. Sci., Proc., vol. 9, pp. 1-36.

States briefly the leading facts concerning the distribution, thickness, mode of formation, and geological position of the Newark system, pp. 321-323. A brief abstract is also given of the conclusions of previous writers in reference to the age of the deposits in question, footnote p. 322.

DANA, JAMES D. 1856a.

Plan of development in the geological history of North America.

In Am. Assoc. Adv. Sci., Proc., vol. 10, 1857, pt. 2, pp. 1-18, and a map op. p. 9.

Contains a brief reference to the position of the eastern continental margin during the Newark period, p. 11.

DANA, JAMES D. 1857.

Additional remarks [on E. Emmons' geological report of the midland counties of North Carolina].

In Am. Jour. Sci., 2d ser., vol. 24, pp. 429-430.

Remarks on the determination of the geological position of the Newark system.

DANA, JAMES D. 1858.

[Note on a supposed fossil insect from Turner Falls, Mass.]

In Ichnology of New England, by Edward Hitchcock, pp. 7-8.

Gives a brief description of a supposed fossil insect from the Connecticut valley sandstone, subsequently named *Mormolucoides articulatus* by Hitchcock.

DANA, JAMES D. 1858a.

[Note on supposed crustacean tracks in Connecticut valley sandstone.]

In Ichnology of New England, by Edward Hitchcock, p. 165.

An extract from a letter referring to certain drawings of footprints, supposed to have been made by crustaceans.

DANA, JAMES D. 1859.

Reply to Prof. Agassiz on Marcou's Geology of North America.

In Am. Jour. Sci., 2d ser., vol. 27, pp. 137-140.

Reprinted in "Reply to the criticisms of James D. Dana" by Jules Marcou, Zurich, 1859, pp. 30-35.

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Fossil larvæ in the Connecticut river sandstone.
In Am. Jour. Sci., 2d ser., vol. 33, pp. 451–452.
Quotes the opinion of John Le Conte in reference to the nature of the fossil in question.

DANA, J. D. 1865.
[A letter relating to the footprints from the Connecticut valley described by Edward Hitchcock.]
In supplement to the Ichnology of New England, by Edward Hitchcock, pp. 33–34.
Contains statements in reference to the character of the footprint animals.

DANA, JAMES D. 1870.
Excursion to the Hanging hills of Meriden [Connecticut].
In history of Wallingford, Conn. [etc., etc.], by C. H. S. Davis, Meriden, Conn., pp. 53–56.
A popular account of the leading geological features of the region about Meriden, Conn.

DANA, JAMES D. 1871.
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In Connecticut Acad. Sci., Trans., vol. 2, pp. 45–112, and map.
Describes the topography of the region about New Haven, Conn., and discusses briefly its relation to pre-Tertiary geology, pp. 45–47.

DANA, JAMES D. 1871a.
[Review of "Historical notes on the earthquakes of New England, 1838–1839, by William T. Brigham."]
In Am. Jour. Sci., 3d ser., vol. 1, pp. 304–305.
Percival's determination of the intrusive character of the trap rocks of the Connecticut valley upheld. The eruptions were in all cases through fissures. An outcrop of "scoria" near Durham, Conn., shown to be scoriform sandstone. No eruptions since the Mesozoic, p. 305.

DANA, JAMES D. 1871b.
[On the presence of albite and orthoclase in the Newark sandstone of New Jersey and Connecticut.]
In Am. Jour. Sci., 3d ser., vol. 2, pp. 459–460.
A notice of a paper by P. Schweitzer relating to the mineralogical composition of certain sandstones in New Jersey, in the Am. Chemist, July, 1871; see also Am. Jour. Sci., 3d ser., vol. 3, p. 57.

D[ANA,] JAMES D. 1872.
[Note on the character of the trap of the Palisades, N. J., and of trap near New Haven, Conn.]
In Am. Jour. Sci., 3d ser., vol. 4, p. 237.
Review of a paper by Henry Wurtz, on the rocks of the Palisades, N. J. Compares the trap of the Palisades with similar trap in Connecticut.

DANA, JAMES D. 1873.
On some results of the earth's contraction from cooling, including a discussion of the origin of mountains, and the nature of the earth's interior.
In Am. Jour. Sci., 3d ser., vol. 5, pp. 423–433, vol. 6, pp. 6–14, 104–115, 161–172.
Refers to the Newark system in illustration of various points in the discussion mentioned, vol. 5, pp. 427, 430–431, 432, 437; vol. 6, pp. 8, 9, 106, 108, 114.

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Text-book of Geology [etc.].
New York and Chicago, 12mo., 2d ed., pp. i–vii, 1–358.
The condensed account of the Triassic and Jurassic systems contained in this text-book is essentially the same as is given in the Manual of Geology by the same author, to which references have been given in this index.

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New York, rev. ed., pp. i–xvi, 1–828, plate and map.
1st ed. Philadelphia, 1869, pp. i–xvi, 1–800, plate and map.
Contains a condensed summary of observations concerning the Newark system.

DANA, JAMES D. 1875a.
On southern New England during the melting of the great glacier.
In Am. Jour. Sci., 3d ser., vol. 10, pp. 168–183, 280–283, 353–357, 409–438, 497–508.
Contains a brief statement in reference to the main topographic features of the Newark sandstone and trap in the vicinity of New Haven, Conn., pp. 170–171. Considers that the Connecticut valley was an estuary during the Newark period, p. 497. Describes the general togography of the valley, and origin of the trap ridge, character of drainage, etc., pp. 497–502.

D[ANA], J[AMES] D. 1878.
On "indurated bitumen" in cavities in the trap of the Connecticut valley. From the report on the geology of Connecticut by Dr. J. G. Percival.
In Am. Jour. Sci., 3d ser., vol. 16, pp. 130–132.
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[DANA], J. D. 1879.
[Review of] the physical history of the Triassic formation of New Jersey and the Connecticut valley by I. C. Russell.
In Am. Jour. Sci., 3d ser., vol. 17, pp. 328–330.
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DANA, JAMES D. 1880,1881.
On the geological relations of the limestone belts of Westchester county, New York.

DANA, JAMES D.—Continued.

In Am. Jour. Sci., 3d ser., vol. 20, pp. 21-32, 194-220, 359-375, 450-456; vol. 21, pp. 425-443; vol. 22, pp. 103-119, 313-315, 327-435.

Contains a map of Stony Point, N. Y., showing approximate junction of Newark system and the Cortland series, and also a note in reference to the beds beneath the Newark conglomerate at the same locality, vol. 22, pp. 112, 113.

D[ANA], J[AMES] D. 1881.

[Review of a paper by G. W. Hawes, on Doleryte (trap) of the Newark system.]

In Am. Jour. Sci., 3d ser., vol. 22, pp. 230-233.

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D[ANA], J[AMES] D. 1883.

The origin of the Jura-Trias of eastern North America.

In Am. Jour. Sci., 3d ser., vol. 25, pp. 383-386.

Notices briefly certain conclusions in reference to the former extent of the Newark system, published in the annual report of the state geologist of New Jersey for 1882, and presents a number of observations and theoretical considerations, with the view of showing that the rocks referred to were formed in various detached areas, at the mouths of rivers which were flooded owing to the prevalence of a cold climate similar to that which prevaled over the same region during the Pleistocene glacial epoch.

DANA, J[AMES] D. 1889.

Areas of continental progress in North America, and the influence of the conditions of these areas on the work carried forward within them.

In Geol. Soc. Am., Bull., vol. 1, pp. 36-48.

Refers to thick deposits of Newark strata in the southern half of the Connecticut valley, p. 38.

D[ANA], J[AMES] D. 1890.

[A review of a paper by I. C. Russell on the "Subaerial decay of rocks and origin of the red color of certain formations."]

In Am. Jour. Sci., 3d ser., vol. 39, pp. 317-319.

Discusses the origin of the prevailing red color of the sandstones and shales of the Newark system.

DANA, JAMES D. 1890a.

Long Island sound in the Quaternary era, with observations on the submarine Hudson river channel.

In Am. Jour. Sci., 3d ser., vol. 40, pp. 425-437.

Discusses the question of glaciation during the Newark period. Pp. 436-437.

DANA, JAMES D. 1891.

Some of the features of nonvolcanic igneous ejections, as illustrated in the four "rocks" of the New Haven region, West rock, Pine rock, Mill rock, and East rock.

DANA, JAMES D.—Continued.

In Am. Jour. Sci., 3d ser., vol. 42, pp. 79-110, pls. 2-7.

Consists of a critical study of the character of the igneous injections, by which the trap forming the rocks named was introduced among the inclosing sedimentary beds. The principal conclusions are:

The igneous eruptions took place after the tilting of the sedimentary beds inclosing them had been commenced.

The igneous material was not erupted at the surface, and it did not form overflow sheets.

The igneous rocks were injected from below, and made space for themselves by lifting the sedimentary beds, after the manner of laccolites. This took place at comparatively shallow depths.

The course and dip of supplying fissures was not determined by the foliation or bedding of the schist underneath the sandstone.

DANA, JAMES D. 1891a.

On Percival's map of the Jura-Trias trap belts of central Connecticut, with observations on the upturning, or mountain-making disturbances, of the formation.

In Am. Jour. Sci., 3d ser., vol. 42, pp. 439-447, pl. 16.

Presents facts which are thought to indicate that the trough in which the Newark rocks of the Connecticut valley area were deposited terminated at the south in what is now New Haven bay. Discusses the relative age of the trap ejections and the tilting of the inclosing sandstones, and the character of the mountain uplifts made at or near the close of the Newark period. Discusses the probability of fault planes being concerned in the monoclinal dip of the strata. Reproduces Percival's map of the southern portion of the Newark area of the Connecticut valley.

DANA, J. D. Cited on cause of the tilting of the Newark (W. M. Davis, '83, p. 303).

Cited on character of certain footprints from Turner Falls, Mass. (Deane, '56).

Cited on contact metamorphism in Connecticut (W. M. Davis, '83, pp. 300, 301).

Cited on coprolites from the Connecticut valley (Lyell, '66, p. 455).

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DANA, J. D.—Continued.
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Cited on mode of deposition of the Newark rocks of Pennsylvania (Frazer, '77*c*, p. 653).
Cited on *Mormolucoides articulatus* (Scudder, '84, p. 431).
Cited on origin of Newark estuaries (W. M. Davis, '83, p. 282).
Cited on origin of the red color of the Newark sandstone (Russell, '89, p. 49).
Cited on origin of the trap rock of Connecticut (Hovey, '89, p. 376).
Cited on relation of trap and sandstone in Massachusetts (W. M. Davis, '83, p. 286).
Cited on similarity in the trap rocks from Nova Scotia to South Carolina (How, '75, vol. 1, p. 136).
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Cited on trap rock (S. P. Merrill, '89, pp. 433, 434).
Table of geological formations by (Macfarlane, '79, pp. 8, 50).

DANA, SAMUEL L. [and EDWARD HITCHCOCK]. 1845.
Analysis of coprolites from the New Red sandstone of New England.
In Am. Jour. Sci., vol. 48, pp. 46–60.
Abstract in Neues Jahrbuch, 1848, pp. 368–369.
Gives result of analyses, and also a discussion based on the same.

DANBERRY, CHARLES. 1889.
Sketch of the geology of North America [etc., etc.].
Oxford [England]. Pp. i–xviii, 1–73.
Contains a brief sketch of the Connecticut valley. Pp. 19–23.

Danboro, Pa. Trap dikes near (Lewis, '85, p. 453).

Dan river area. Brief account of (Emmons, '57, p. 4).
Coal of. Brief account of (Patton, '88, p. 23).

Dan river area, N. C. Brief description of (Kerr, '75, p. 141).
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Section of Newark rocks in (Jones, '62, pp. 89–90).
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Dan river area, Va. Boundaries and area of (Heinrich, '78, pp. 237–239).

Dan river coal field, N. C. Account of (McGehee, '83, pp. 75–77).
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Darnley, P. E. I. Remarks on structures near (Bain and Dawson, '85, p. 156).

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Describes certain minerals obtained from the locality referred to.

DARTON, NELSON H. 1882a.
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In Am. Jour. Sci., 3d ser., vol. 23, pp. 458–459.
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On the disintegrated sandstone at New Durham, N[ew] J[ersey].
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DARTON, NELSON H. 1883a.
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In the Scientific American supplement, vol. 16, pp. 6513–6514.
Describes in detail the structure at King Point near Hoboken, N. J.

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On the occurrence of native silver in New Jersey.
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Describes the occurrence of native silver in the Bridgewater copper mine near Somerville, N. J.

DARTON, NELSON H. 1889.
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In Am. Jour. Sci., 3d ser., vol. 37, pp. 134–139.
The observations recorded embrace the whole of the Newark area of New Jersey. Concludes that the trap ridges of New Jersey were formed in part by extrusive and in part by intrusive sheets.
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North American Geology for 1886.
In Smithsonian Inst., Ann. Rep. for year ending June 30, 1887, pp. 189–229.
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The relations of the traps of the Newark system in the New Jersey region.
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Describes dikes of trap near Staunton, Va., which probably belong to system of dikes so largely developed in the Newark.
Petrographic notes by J. S. Diller.

Dauphin County, Pa. Brief report on (Lesley, '85, pp. XLV, XLVI, pl. 22).
Description of the Conewago hills in (Gibson, '20).

Davidson mill, N. J. Altered shale near (Cook, '68, pp. 213–214. Cook, '83, p. 23).
Altered shale near, used for building (Cook, '81, p. 55).
Trap boundary at (Cook, '68, p. 189).

DAVIS, CHARLES HENRY STANLEY. 1870.
[A sketch of the geology in the vicinity of Meriden, Conn.)
In history of Wallingford, Conn. [etc., etc.], by C. H. S. Davis, Meriden, Conn., pp. 36–53.
A popular sketch of the "physical history, geology, mineralogy, and mines" of the region mentioned.

DAVIS, CHAS. H. S. 1887.
The *Catopterus gracilis*.
In Meriden Sci. Assoc., Proc. and Trans., vol. 2, 1885–1886, pp. 19–22.
Contains an account of the occurrence of fossil fishes at Little Falls (Conn.), and a description of *Catopterus gracilis*.

DAVIS, W. M. 1881.
Illustrations of the earth's surface. Glaciers. Boston, folio, pp. 95–96.
See Shaler and Davis.

DAVIS, W. M. 1882.

Brief notice of observations on the Triassic trap rocks of Massachusetts, Connecticut, and New Jersey.

In Am. Jour. Sci., 3d ser., vol. 24, pp. 345–349.

Abstract in Neues Jahrbuch, 1884, pp. 231–232.

An account of a recent examination of the trap ridges in the regions referred to, with references to certain hypothesis proposed by previous writers concerning the origin of trap sheets, and the dip of the associated sedimentary beds. An announcement is made of new generalizations and hypothesis to account for the phenomena observed.

DAVIS, WILLIAM MORRIS. 1882a.

The structural value of the trap ridges of the Connecticut valley.

In Boston Soc. Nat. Hist., Proc., vol. 22, pp. 116–124.

Mentions the geographical extent of the Newark system. Considers the hypotheses that have been advanced to account for the uniform dip observed in certain of the Newark areas, and also the hypotheses concerning the former extent, especially of the Connecticut valley sandstone bed of the similar formation in New Jersey. Reasons are given for believing that many of the trap sheets of the Connecticut valley and of New Jersey are contemporaneous overflows and that they afford evidence of faulting and folding.

DAVIS, WILLIAM MORRIS. 1883.

On the relations of the Triassic traps and sandstones of the eastern United States.

In Museum of Comp. Zoöl., Bull., vol. 7, 1880–1884, pp. 249–309, pl. 9–11.

Reviewed by J. D. Dana in Am. Jour. Sci., 3d ser., vol. 25, pp. 474–475; and by G. H. Cook in Ann. Rep. Geol. of New Jersey, 1883.

Abstract in Science, vol. 1, p. 430; also in Neues Jahrbuch, 1884, pp. 230–232.

CONTENTS.

DAVIS, WILLIAM MORRIS—Continued.

DAVIS, WILLIAM MORRIS. 1886.

The structure of the Triassic formation of the Connecticut valley.

In Am. Jour. Sci., 3d ser., vol. 32, pp. 342–352.

Reviews several hypotheses that have been advanced to account for the uniform easterly dip of the rocks of the Connecticut valley. Presents the results of exact observation in the same region, and advances a new hypothesis to account for the monoclinal structure in question.

DAVIS, WILLIAM MORRIS. 1888.

The structure of the Triassic formation of the Connecticut valley.

In Seventh Ann. Rep., U. S. Geol. Survey, 1885–1886, pp. 455–490, pl. 52.

Notice in Am. Geol., vol. 4, pp. 112–113.

CONTENTS.

DAVIS, WILLIAM MORRIS—Continued.

Some of the conclusions in reference to the origin of certain trap sheets in southern Connecticut, expressed in this paper, are controverted by E. O. Hovey, '89.

DAVIS, W. M. **1888a.**

Remarks on the mechanical origin of the Triassic monoclinal in the Connecticut valley.

In Proc. Boston Soc. Nat. Hist., vol. 23, pp. 339–341.

Abstract in Am. Assoc. Adv. Sci., Proc., vol. 35, pp. 224–227.

Abstract of a paper, the substance of which is contained in "The Structure of the Triassic formation of the Connecticut valley." U. S. Geol. Surv., Seventh Ann. Rep., 1885–1886, pp. 455–490. Describes the prevailing structure of the sandstone of the Connecticut valley, and proposes an explanation of their monoclinal structure.

DAVIS, W. M. **1888b.**

The topographical map of New Jersey.

In Science, vol. 12, pp. 206–207.

In describing the topographic map published by the New Jersey geological survey the topography of the Newark area is briefly referred to, and suggestions made as to its origin.

DAVIS, WILLIAM MORRIS. **1889.**

The faults in the Triassic formation near Meriden, Conn. A week's work in the Harvard summer school of geology.

In Museum Comp. Zool., Harvard College, Bull., vol. 16, pp. 61–87, pls. 1–5.

A detailed study of the geological structure near Meriden. The divisions of the essay are: Cross-section of Lamentation mountain, pp. 61–64; cross-section of Shuttle meadow, pp. 64–69; the great fault west of Lamentation mountain, pp. 69–73; faults north of Lamentation mountain, pp. 73–76; faults in the Hanging hills, pp. 76–82, and north of West peak, pp. 82–85; review, pp. 85–86. Illustrated by sketch maps, views, and sections.

DAVIS, WILLIAM MORRIS. **1889a.**

The rivers and valleys of Pennsylvania.

In Nat. Geol. Mag., vol. 1, pp. 183–253.

Notice in Am. Geol., vol. 5, p. 60.

In discussing the origin of the relief of eastern Pennsylvania the denudation that preceded the deposition of the Newark system is referred to, and also the manner in which the Newark rocks were deposited. The origin of the monoclinal structure of the Newark system in New Jersey and Pennsylvania is briefly considered, as is also the denudation that preceded the deposition of the next succeeding system, pp. 194–198, 229–236. General distribution of high and low land and drainage in early Jurassic time is indicated on p. 233.

DAVIS, WILLIAM MORRIS. **1889b.**

The ash bed at Meriden and its structural relations.

In Meriden Sci. Ass., Proc. and Trans., vol. 3, 1887–1888, pp. 23–30.

Contains an account of an ash bed near Meriden, Conn., and a discussion of the structure of the Newark system of the Connecticut valley.

DAVIS, W. M. **1889c.**

Topographical development of the Triassic formation of the Connecticut valley.

In Am. Jour. Sci., 3d ser., vol. 37, pp. 423–434.

Itinerary of Harvard summer school of geology: Faults in the Meriden region; cross-section of the district; means of detecting the unfaulted sequence of Triassic beds; mechanism of monoclinal faulting; topographical development of the Triassic belt; initial constructional stages represented by the faulted blocks of southern Idaho. [Oregon]. Mountain ranges of the Great Basin, equivalent to a later Jurassic stage; the whole region base-leveled in late Cretaceous time; the present valley worn in the Cretaceous base-level plain after its elevation.

Polygenetic topography: The origin of the Connecticut river outlet via Middletown. The Connecticut river was originally consequent on the monoclinal faulting, and still persists near the course then taken, but has entered a second cycle of life as a result of the elevation of the lowland that was produced in the first cycle.

DAVIS, W. M. **1890.**

[Filling of fissures from above.]

In Geol. Soc. Am., Bull., vol. 1, p. 442.

DAVIS, W. M.—Continued.

In discussing a paper on sandstone dikes, by J. S. Diller, Davis describes certain fissures in trap at Meriden, Conn., which were filled from above.

DAVIS, WILLIAM MORRIS. 1891.

The lost volcanoes of Connecticut.

In Pop. Sci. Mo., vol. 40, pp. 221-235.

Contains a popular account of certain beds of volcanic ash near Meriden, Conn., and shows that the ash was probably extruded from volcanoes that have since been removed by erosion.

DAVIS, W. M. Cited on the absence of contact metamorphism at Feltville, N. J. (Darton, '89, p. 135).

DAVIS, WILLIAM MORRIS. Cited on the faults in the Newark rocks of New Jersey (Cook, '89, p. 14).

Cited on the geology of Connecticut (Hovey, '89).

Cited on metamorphism (Russell, '89, p. 50).

Cited on the origin of the trap hills of Connecticut, etc. (Chapin, '87, p. 26).

Cited on the origin of the trap of Connecticut (Hovey, '89, pp. 375-376).

Cited on the origin of trap sheets near Meriden, Conn. (Nason, '89, p. 66).

Cited on the structure of the Newark system (Newberry, '88, pp. 6-7).

Cited on the structure of the Newark system in the Connecticut valley (Chapin, '89).

Cited on the structure of the Newark system and the origin of its trap sheets (Cook, '87).

Cited on trap at Feltville, N. J. (Darton, '90, p. 26).

Cited on the trap rocks of Connecticut (Marsters, '90).

DAVIS, W. M., and S. WARD LOPER. 1891.

Two belts of fossiliferous black shale in the Triassic formation of Connecticut.

In Geol. Soc. Am., Bull., vol. 2, pp. 415-430.

CONTENTS.

DAVIS, W. M., and S. WARD LOPER—Cont'd.

DAVIS, W. M., and CHARLES LIVY WHITTLE. 1889.

The intrusive and extrusive trap sheets of the Connecticut valley.

In Mus. Comp. Zool., Bull. Harvard College, vol. 16, pp. 99-138, pl. 1-5.

CONTENTS.

DAVIS, W. M., and J. WALTER WOOD. 1889.

The geographic development of northern New Jersey.

In Boston Soc. Nat. Hist., Proc., vol. 24, pp. 365-423.

Describes the effect of erosion on the Newark rocks of New Jersey and endeavors to determine the geological history of the region from a study of its drainage. Given sections illustrating the structure of the Newark terrane.

Davisburg, Pa. Dolerite, etc., from (C. E. Hall, '78, p. 35).

DAWSON, JOHN [WILLIAM]. 1845.

On the newer coal formation of the eastern part of Nova Scotia.

In London Geol. Soc., Quart. Jour., vol. 1, pp. 322-330 and map.

The Newark system about the east end of basin of mines (Cobdequid bay) is shown in a general way on the map accompanying this paper.

DAWSON, JOHN WILLIAM. 1847.

On the New Red sandstone of Nova Scotia.

In London Geol. Soc., Quart. Jour., vol. 4, pp. 50-59, pl. 5.

Describes exposures of the Newark system about the shores of Minas basin and Cobdequid bay, Nova Scotia. Mentions the relation of the sedimentary to the igneous rocks associated with them, and discusses briefly the conditions under which the sandstones and shales were deposited. The trap of Blomidon is considered as extrusive.

DAWSON, J. W. 1848.

On the coloring matter of red sandstones and of grayish and white beds associated with them.

In London Geol. Soc., Quart. Jour., vol. 5, 1849, pp. 25–30.

Describes red and gray sandstones in Nova Scotia, chiefly Carboniferous, and discusses the origin of their colors.

DAWSON, J. W. 1848a.

A handbook of the geology and natural history of Nova Scotia.

Pictou, Nova Scotia, 12mo.

Not seen.

DAWSON, JOHN WILLIAM. 1852.

Additional notes on the red sandstones of Nova Scotia.

In London Geol. Soc., Quart. Jour., vol. 8, pp. 398–400.

Describes sections near the mouth of Petite river, in which a marked unconformity between Carboniferous and Newark rocks is exposed

DAWSON, J. W. 1853.

Fossil saurian bones from Prince Edward island.

In Am. Jour. Sci., 2d ser., vol. 16, p. 283.

An abstract of an article published in the "Eastern Chronicle" of Nova Scotia, describing the discovery of *Bathygnathus borealis*.

DAWSON, J. W. 1854.

On fossil coniferous wood from Prince Edward island.

In Philadelphia Acad. Nat. Sci., Proc., vol. 7, pp. 63–64.

Describes briefly the resemblance of certain rocks on Prince Edward island to the Newark system in Nova Scotia, and records the results of a microscopical examination of fossil wood from Gallas point, Des Sables, and other localities.

DAWSON, J. W. 1854a.

[On the discovery and geological age of Bathygnathus borealis from Prince Edward island.]

In Philadelphia Acad. Nat. Sci. Jour., 2d ser., vol. 2, 1850–1854, pp. 329–330.

Describes the rocks in which the fossil mentioned was found, and discusses their geological position.

DAWSON, J. W. 1856.

On the parallelism of the rock formations of Nova Scotia with those of other parts of America.

In Am. Assoc. Adv. Sci., Proc., vol. 10, 1857, part 2, pp. 18–25.

Indicates briefly some of the leading characteristics of the Newark system in Nova Scotia and Prince Edward island. Pp. 20, 21.

DAWSON, JOHN WILLIAM. 1858.

[A note relating to the age of the Newark system of North Carolina, Connecticut, etc., indicated by fossils obtained by E. Emmons in North Carolina.]

In Canadian Nat., 1st ser., vol. 3, p. 80.

DAWSON, JOHN WILLIAM—Continued.

Discusses briefly the probable age of the Newark system.

DAWSON, J. W. 1863.

[Note on fossil plants from St. John county, New Brunswick.]

In Canadian Nat., vol. 8, pp. 259–260.

Brief note on fossil wood from near Gardner's creek, New Brunswick.

DAWSON, J. W. 1872.

Notes on the geology of Prince Edward island, in the gulf of St. Lawrence.

In Geol. Mag., vol. 9, pp. 203–209.

This paper is essentially an abstract of Dawson and Harrington's report on the geological structure and mineral resources of Prince Edward island. See Dawson and Harrington, 1871.

DAWSON, J. W. 1872a.

[The physical geography of Prince Edward island.]

In Canadian Nat., vol. 6, pp. 342–343.

Mentions the occurrence of sandstone above the upper coal formation, in which fossil plants and reptilian remains occur, considered of Triassic age.

DAWSON, J. W. 1873.

The story of the earth and man.

New York, pp. i–ix, 1–403, and 12 plates.

Contains a popular account of the life of the Mesozoic ages, pp. 188–233.

DAWSON, JOHN WILLIAM. 1874.

On the upper coal formation of eastern Nova Scotia and Prince Edward island in its relation to the Permian.

In London Geol. Soc., Quart. Jour., vol. 30, pp. 209–219.

The conformity of the Upper Carboniferous and so-called Newark beds on Prince Edward island is briefly stated, and also the evidence from fossil plants on which this generalization is mainly based. The views of Geinitz in reference to the Permian age of the newer red sandstone of Price Edward island are dissented from, pp. 209, 210, 217, 218.

DAWSON, J. W. 1874a.

On the upper coal formation of eastern Nova Scotia and Prince Edward island, and its relation to the Permian.

In Geol. Mag., n. s., vol. 1, pp. 281–282.

States that the Carboniferous of Prince Edward island is overlain, apparently conformably, by the Newark system.

DAWSON [J. W.]. 1875.

On the upper coal formation of eastern Nova Scotia and Prince Edward island, in its relation to the Permian.

In Canadian Nat., vol. 7, n. s., pp. 303–304.

From a study of the fossil plants contained in the younger sandstones of Prince Edward island the synchronism of these beds with the Permian of Europe is suggested. The name Permo-Carboniferous is proposed for these beds, which heretofore have been called Triassic.

DAWSON, JOHN WILLIAM. **1878.**

Acadian Geology. The geological structure, organic remains, and mineral resources of Nova Scotia, New Brunswick, and Prince Edward island.

London, 3d ed., pp. i–xxvi, 1–687, pls. 1–9, and map, supplement, pp. 1–102, pl. 1.

Second edition, London, 1868, pp. i–xxvi, 1–694, pls. 1–9 and map. Pages and plates numbered the same as in 3d ed.

The first edition bears the following title: Acadian Geology: An account of the geological structure and mineral resources of Nova Scotia. Edinburgh, 1855, 12 mo., pp. i–xii, 1–388, pls. 1–5 and map.

Abstract in Neues Jahrbuch, 1855, pp. 333–337.

Reviewed in Edinburgh New Philosophical Journal, n. s., vol. 2, 1853, pp. 380–392; also in Canadian Jour., n. s., vol. 1, pp. 39–48.

The following is a table of contents of the third edition so far as it relates to the Newark system:

DAWSON, JOHN WILLIAM—Continued.

DAWSON, JOHN WILLIAM. **1878a.**

Supplement to the second edition of Acadian Geology, containing additional facts as to the geological structure, fossil remains, and mineral resources of Nova Scotia, New Brunswick, and Prince Edward island.

In Acadian Geology, 3d ed., pp. 1–102, pl. 1.

Reviewed in Canadian Nat., vol. 8, pp. 472–475.

This supplement is bound with the third edition of the Acadian Geology, and contains new observations relating to the classification of the rocks of Prince Edward island, and indicates the difficulty of separating the Newark and Carboniferous, pp. 28–31. The fossils of the Newark on Prince Edward island are briefly discussed, p. 30. The occurrence of lignite at Martin's head, N. B., is noticed on p. 99.

DAWSON, WILLIAM. **1885.**

Notes on the geology and fossil flora of Prince Edward island (see Bain and Dawson, 1885).

DAWSON, JOHN WILLIAM. **1887.**

Presidential address: Some points in which American geological science is indebted to Canada.

In Canada Roy. Soc., Proc. and Trans., vol. 4, sec. 4, 1886, pp. 1–8.

Contains a brief historical reference to the study of the Newark system in Canada.

DAWSON, J. WILLIAM. **1888.**

The geological history of plants.

New York (The International Scientific Series), pp. i–viii, 1–290.

Contains a popular account of the early Mesozoic floras, pp. 175–190.

DAWSON, J. WILLIAM. **1888.**

On the Eozoic and Paleozoic rocks of the Atlantic coast of Canada in comparison with those of western Europe and of the interior of America.

In Quart. Jour. Geol. Soc., London, vol. 44, pp. 797–817.

States briefly that the rocks of the Newark system in Canada resemble the Triassic rocks of Europe. They contain no important marine limestones, and their fossils are limited to a single Dinosaurian reptile and a few plants. The flora and land and fresh water faunas seem to have been of southern origin, p. 815.

DAWSON [J. W.]. Cited as to the relations of trap and sandstone in Nova Scotia (W. M. Davis, '83, p. 285).

Cited on the age of the Newark system (Lea, '58).

Cited on the age of the red sandstone of Nova Scotia (Jackson, '50, p. 338).

Cited on the discovery of Bathygnathus on Prince Edward island (Owen, '76, p. 361).

Cited on the geology of cape Blomidon, N. S. (Marsters, '90).

Cited on the geology of Prince Edward island (Bain and Dawson, '85, pp. 156, 157).

Cited on the overflow trap sheets in Nova Scotia (W. M. Davis, '83, p. 297).

Cited on the tilting of sandstone and trap in Prince Edward island (W. M. Davis, '83, p. 302).

Cited on trap dikes in Prince Edward island (W. M. Davis, '83, p. 291).

Notice of work done by, in Nova Scotia, etc. (Miller, '79–'81, vol. 2, pp. 151, 152, 158–161, 223).

DAWSON, JOHN WILLIAM, and B. J. HARRINGTON. **1871.**

Report on the geological structure and mineral resources of Prince Edward island.

Montreal [Can.]: Pp. 1–51, pls. 1–3, together with a geological map (frontispiece) and one plate of sections.

Abstract in Neues Jahrbuch, 1872, pp. 439–441; also in Am. Jour. Sci., 3d ser., vol. 3, p. 222.

Contains a description of the character and extent of the red sandstones, red and mottled clays, calcareous sandstones and conglomerates, arenaceous limestones, dolomite and trap of the Newark system on Prince Edward island, pp. 13–22. Also a number of measured sections (pp. 33–34, and an account of the building stones and water supply. Analyses of limestones are given on page 41, and an account of fossils, comprising descriptions of fossil wood and fucoids; and remarks on a reptile, *Bathygnathus borealis*, pp. 45, 46.

Nearly all of the rocks described in this report as Triassic have been referred to the Carboniferous by later observers. See supplement to the second edition of Acadian Geology, by J. W. Dawson, London, 1878, pp. 32–33; Geol. Surv. Canada, Rep. of Progress for 1882–1883–'84, p. 16E; and a note on the margin of map No. 5 S W, which accompanies this report.

Day's point, N. J. Dip at (Russell, '80, p. 47).

Section at, showing junction of trap with sedimentary rocks beneath (Russell, '80, p. 47).

Dead swamp, Conn. Description of trap ridges near (Percival, '42, p. 374).

DEANE, JAMES. **1842.**

[Notice of the footprints of birds in the New Red sandstone of Connecticut.]

In London Geol. Soc., Proc., vol. 4, p. 22.

Describes very briefly some newly found bird tracks, rain marks, and other impressions in the red sandstone of Connecticut.

DEANE, JAMES. **1843.**

[A letter to G. A. Mantell relating to the fossil footprints of the Connecticut valley.]

In Am. Jour. Sci., vol. 45, pp. 177–188.

Contains a general description of certain footprints, and compares some of the fossil tracks with the tracks of living birds. Published by B. Silliman in a paper entitled Ornithichnites of the Connecticut river sandstones and the Dinornis of New Zealand.

DEANE, JAMES. **1844.**

On the fossil footmarks of Turners Falls, Massachusetts.

In Am. Jour. Sci., vol. 46, pp. 73–77, pls. 1, 2.

Abstract in Neues Jahrbuch, 1844, pp. 635–637.

Gives a general description of certain footprints found at the locality mentioned.

DEANE, JAMES. **1844a.**

On the discovery of fossil footmarks.

In Am. Jour. Sci., vol. 47, pp. 381–390.

Relates to priority in the discovery of fossil footprints in sandstone of the Connecticut valley.

DEANE, JAMES. **1844b.**

Answer to the "Rejoinder" of Prof. Hitchcock.

In Am. Jour. Sci., vol. 47, pp. 399–401.

Relates to the question of priority in the discovery of fossil footprints in the sandstone of the Connecticut valley.

DEANE, JAMES. **1848.**

Fossil footprints of a new species of quadruped.

In Am. Jour. Sci., 2d ser., vol. 5, pp. 40–41.

Abstract in Neues Jahrbuch, 1851, p. 497.

Describes and illustrates the tracks of a quadruped discovered in the sandstone at Turners Falls, Mass.

DEANE, JAMES. **1845.**

Description of fossil footprints in the New Red sandstone of the Connecticut valley.

In Am. Jour. Sci., vol. 48, pp. 158–167, pl. 3.

Describes four and five toed footprints near Turners Falls, Mass.

DEANE, JAMES. **1845a.**

Notice of a new species of Batrachian footprint.

In Am. Jour. Sci., vol. 49, pp. 79–81.

Abstract in Am. Assoc. Geol. and Nat., Proc., 6th meeting, p. 25.

Describes and figures the footprints of a quadruped found in the Connecticut valley sandstone.

DEANE, JAMES. **1845b.**

Fossil footmarks and raindrops.

In Am. Jour. Sci., vol. 49, pp. 213–215.

Describes the tracks of "birds" and "batrachians" found at Turners Falls, Mass., and gives a figure of a slab of sandstone with several series of tracks.

DEANE, JAMES. **1845c.**

Illustrations of fossil footmarks.

In Boston Soc. Nat. Hist., Proc., vol. 2, p. 32.

A notice of the presentation of a paper on the above title to the society.

DEANE, JAMES. 1845d.
Illustrations of fossil footmarks.
In Boston Jour. Nat. Hist., vol. 5, pp. 277–284, pl. 23.
Gives a general description of certain fossil footprints from the Connecticut valley.

DEANE, JAMES. 1847.
Notice of new fossil footprints.
In Am. Jour. Sci., 2d ser., vol. 3, pp. 74–79.
Abstract in Neues Jahrbuch, 1849, pp. 379–381.
Describes three, four, and five toed tracks found at Turners Falls, Mass.

DEANE, JAMES. 1847a.
[Note on fossil footprints from Turners Falls, Mass.]
In Am. Jour. Sci., 2d ser., vol. 4, pp. 448–449.
Refers to the claim of a certain series of tracks to be regarded as belonging to a new species.

DEANE, JAMES. 1849.
Illustrations of fossil footprints of the valley of the Connecticut.
In Am. Acad., vol. 4, pp. 209–220, pls. 1–9.
Presents general description, with figures, of a large number of footprints from the Connecticut valley. The matter contained in this paper is incorporated in Deane's later and larger work "Ichnographs from the sandstones of the Connecticut river," 1861.

DEANE, JAMES. 1850.
Fossil footprints of Connecticut river.
In Philadelphia Acad. Nat. Sci. Jour., 2d ser., vol. 2, 1850–1854, pp. 71–74, pls. 8, 9.
A general description of fossil footprints from Turners Falls, Mass.

DEANE, JAMES. 1856.
On the sandstone fossils of the Connecticut river.
In Philadelphia Acad. Nat. Sci. Jour., 2d ser., vol. 3, 1855–1858, pp. 173–178, pls. 18–20.
Abstract in Neues Jahrbuch, 1857, pp. 877–878.
Gives a general description of several footprints, both vertebrate and invertebrate, from Turners Falls, Mass.

DEANE, JAMES. 1861.
Ichnographs from the sandstone of Connecticut river.
Boston, 4to, pp. 1–61, pls. 1–46.
Notice in Am. Jour. Sci., 2d ser., vol. 36, pp. 126–127.

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Plates 3–15, 18–30, 32–39, 42 were drawn on stone from nature by James Deane. Pls. 16–17, 31, 40–41, 43–46 are photographs.

DEANE, [JAMES]. Cited on Anomœpus major (E. Hitchcock, '65, p. 37, pl. 19).
Cited on fossil footprints (Murchison, '43).
Cited on fossil footprints from the Connecticut valley (Gray and Adams, '60, pp. 247–252. E. Hitchcock, '44*a*, p. 305. Lea, '53, pp. 185, 189. Lyell, '66, p. 454. Lyell, '71, p. 362. Owen, '59, pp. 181, 325. Pictet, '53, vol. 1, p. 407).
Cited on fossil footprints from Turners Falls, Mass. (Mantell, '46. Winchell, '70, p. 133).
Cited on fossil footprints near Turners Falls, Mass. (E. Hitchcock, '43*a*, p. 254).
Cited on fossil plant from Montague, Mass. (E. Hitchcock, '43*b*, p. 296, pl. 12).
Cited on number of joints in the toes of fossil footprints (Silliman and Dana, '47).
Cited on the number of phalanges in the toes of birds (Silliman, Silliman, jr., and Dana, '47).
Cited on priority in description of footprints (E. Hitchcock, '58, pp. 192, 196).
Credited with the early discovery of footprints in the Connecticut valley (H. D. Rogers, '44, pp. 249–250).
Discovery of fossil footprints by (E. Hitchcock, '58, p. 4).

Dean's, N. J. Trap outcrops at (Cook, '82, pp. 59–60).

Dean's Pond, N. J. Boundary of Newark at (Cook, '68, p. 176).
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Trap hills near (Cook, '68, pp. 189–190).

Debert river, N. S. Coal measures at, overlain by New Red sandstone (Gesner, '43).
Description of (Dawson, '78, pp. 99–100).
Dip of the Newark near (Ells, '85, p. 43E).
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Deep river, N. C., and Richmond, Va., coal fields. Compared (Emmons, '56, pp. 338–342).

Deep river coal field, N. C. Age of, as indicated by fossil fishes (Agassiz, '53).

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In this report the outcrops of the Newark system along the north shore of Minas basin are briefly described on pp. 6E, 7E, and in connection with a description of the Lower Carboniferous north of Minas basin several references to this system are included, pp. 43E–51E.

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Fossils of the sandstones and slates of North Carolina.

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Abstract in Ann. Sci. Discov., 1857, pp. 312–314.

Presents a generalized section of the Newark rocks of North Carolina, followed by a summary of results obtained from a study of their fauna and flora, and a discussion of their age as compared with certain formations in Europe.

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In Edinburgh New Philosophical Journal, N. S., vol. 5, p. 370.

Abstract in Neues Jahrbuch, 1857, p. 343.

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In Am. Jour. Sci., 3d ser., vol. 31, p. 72.

Brief description of fossil footprints from near Milford, Hunterdon county, New Jersey.

EYERMAN, JOHN. 1889.

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FOSTER [J. W.]. **1851.**

[Remarks on the geological position of the Newark system and on the structure of the Connecticut valley sandstone.]

In Am. Assoc. Adv. Sci., Proc., vol. 5, p. 46.

Abstract in Ann. Sci. Discov., 1852, p. 260.

Remarks on a paper by W. C. Redfield, in reference to the age of the rocks mentioned, as indicated by stratigraphy. Discusses also the evidence of an unconformity in the sandstones of the Connecticut valley.

FOSTER, J. W. **1869.**

The Mississippi valley, its physical geography, [etc.].

Chicago and London, pp. i-xvi, 1-443.

Contains a brief account of the Newark system, p. 306, and a geological sketch map of the United States, pl. op. p. 273.

Fountainville, Pa. Trap dikes near (Lewis, '85, p. 453).

Franklin, N. J. Bored well at (Cook, '85, pp. 117-118).

Oolite at (Eaton, '30).

Franklin copper mine, N. J. Description of (Cook, '68, p. 679. H. D. Rogers, '36, p. 168. H. D. Rogers, '40, p. 161).

Franklin county, Mass. A study of stratigraphy in (Walling, '78).

Franklin county, Pa. Geological map of (Sanders, '81).

Report on the geology of (Frazer, '77).

Franklin lake, N. J. Boundary of Second mountain, trap near (Cook, '68, pp. 183, 184).

Dip in sandstone at (Cook, '82, p. 30).

Dip near (Cook, '68, p. 199).

Sandstone quarry at (Cook, '79, p. 22).

Trap hill near (Cook, '82, p. 49).

Franklintown, Pa. Catalogue of specimens of sandstone, etc., near (Frazer, '77, pp. 332-381).

Concerning the mines at (Frazer, '77c, pp. 654-655).

Isolated area of schist in Newark rocks near (Frazer, '77c, p. 651).

Mention of various rock specimens from near (C. E. Hall, '78, pp. 33-36).

Section from near, to Wellsville (Frazer, '77, pp. 271-273, pl. op. p. 272).

FRAZER, PERSIFOR, Jr. **1874.**

Weathering of rocks [at Gettysburg, Pa.].

In Philadelphia Acad. Nat. Sci., Proc., vol. 26, p. 228.

Brief description of the weathering of trap rock (syenite) at Gettysburg.

FRAZER, P[ERSIFOR], Jr. **1874a.**

On exfoliation of rocks near Gettysburg.

In Am. Phil. Soc., Proc., vol. 14, 1874-1875, pp. 295-297.

Describes the weathering of trap rock (syenite) near Gettysburg, Pa.

FRAZER, PERSIFOR. **1875.**

On some thin sections of the Lower Paleozoic and Mesozoic rocks of Pennsylvania.

In Am. Inst. Mining Eng., Trans., vol. 3, pp. 327-328.

Brief general statement of the results of an examination of thin sections of sandstone and trap from York and Adams counties, Pa.

FRAZER, PERSIFOR. **1875a.**

On the traps of the Mesozoic sandstone in York and Adams counties, Pa.

In Am. Philo. Soc., Proc., vol. 14, 1876, pp. 402-414, pls. 1-4.

Discusses the chemical composition and optical properties of certain trap rocks from West Rock, Conn., and from near York, Gettysburg, and Dillsburg, Pa. Presents complete analyses of trap from West Rock and from near York.

FRAZER, PERSIFOR. **1875b.**

[Comparison of microscopical section and fragments of trap from near Gettysburg, Pa., with similar samples and sections of the trap rocks of Connecticut.]

In Am. Philo. Soc., Proc., vol. 14, pp. 430-431.

Presents the results of the comparison indicated in the title.

FRAZER, PERSIFOR. **1875c.**

On the Trias of York county, Pa.

In Philadelphia Acad. Nat. Sci., Proc., vol. 27, p. 123.

Brief remarks on the dip of Newark strata and on the unconformity of Newark and Silurian rocks in York county, Pa.

FRAZER, PERSIFOR, Jr. **1875d.**

On the Mesozoic red sandstone of the Atlantic states.

FRAZER, PERSIFOR, Jr.—Continued.

In Philadelphia Acad. Nat. Sci., Proc., vol. 27, pp. 440–442.

General considerations relating to the problems presented by the Newark system.

FRAZER, PERSIFOR, Jr. 1876.

Second geological survey of Pennsylvania, 1874. Report of progress in the district of York and Adams counties [etc., etc.].

Harrisburg, 1876, vol. C. pp. i-viii, 1-198, with 10 plates and maps.

Contains brief reports of observation on boundaries, dip, trap dikes, etc., pp. 71, 88–89, 91, 92–93, 94, 95, 101, 102, 103, 122-129, 152, 153, 159, 160, pls. op. pp. 64, 92, 94, 112, 128, 196.

FRAZER, PERSIFOR. 1876a.

Geological map of Adams county, Pa.

See Lesley and Frazer, 1876.

FRAZER, PERSIFOR, Jr. 1876b.

Notes on two traps; a case of alteration of earthy sediments.

In Philadelphia Acad. Nat. Sci., Proc., vol. 28, p. 60.

Describes the appearance of a sandstone that has been altered by a trap intrusion.

FRAZER, PERSIFOR. 1876c.

Notes on some Paleozoic limestones.

In Philadelphia Acad. Nat. Sci., Proc., vol. 28, pp. 60–63.

Gives an analysis of limestone from the Newark system at Dillsburg, Pa., p. 63.

FRAZER, PERSIFOR. 1876d.

A study of the specular and magnetic iron ores of the New Red sandstone in York county, Pa.

In Am. Inst. Mining Eng., Trans., vol. 5, pp. 132–143, pl. 2.

Describes the character and mode of occurence of certain iron ores and of associated trap dikes near Dillsburg, Pa.

FRAZER, PERSIFOR. 1876e.

A study of the igneous rocks.

In Am. Inst. Mining Eng., Trans., vol. 5, pp. 144–146.

Gives the mineralogical composition of a number of trap rocks from Adams and York counties, Pennsylvania, p. 146.

FRAZER, PERSIFOR, Jr. 1877.

Second geological survey of Pennsylvania, 1875. Report of progress in the counties of York, Adams, Cumberland, and Franklin [etc., etc.].

Harrisburg [vol. CC], pp. 201–401, and 17 plates and maps.

Contains a detailed account of the Newark system in the counties mentioned, with special reference to the deposits of iron ore and to trap rocks. A large number of observations of dip are recorded, pp. 206-230, 239–317, 348–381, pl. op. pp. 232, 264, 272, 274, 298, 304, 328, and map.

FRAZER, PERSIFOR. 1877a.

The position of the American New Red sandstone.

FRAZER, PERSIFOR—Continued.

In Am. Inst. Mining Engi., Trans., vol. 5, pp. 494–501.

Reviewed by P. Frazer in Am. Nat., vol. 13, pp. 284-292.

Compares a section of the Newark rocks in Adams county, Pennsylvania, with general sections of the Permian, Triassic, and Jurassic rocks of England and Germany.

FRAZER, PERSIFOR, Jr. 1877b.

On copper-bearing rocks of the Mesozoic formations.

In Philadelphia Acad. Nat. Sci., Proc., vol. 29, pp. 17-19.

Describes the occurrence of copper ore at Bonnaughton, near Gettysburg, Pa.

FRAZER, PERSIFOR. 877c.

Regarding some Mesozoic ores.

In American Phil. Soc., Proc., vol. 16, pp. 651-655.

Mentions outliers of schist in Newark areas, and also outliers of Newark rocks in the bordering crystalline rocks of Pennsylvania. Considers the mode of formation of the Newark sandstones, and advances a hypothesis to account for the ores they contain.

FRAZER, P. 1877d.

[Remarks on the Newark system in Pennsylvania.]

In Am. Phil. Soc., Proc., vol. 1-16, p. 664.

Brief abstract of remarks concerning the origin of the prevailing dip of the Newark rocks, and the occurrence of iron ores as a definite line in both the Newark and adjacent terranes.

FRAZER, PERSIFOR, Jr. 1878.

On the physical and chemical characteristics of a trap occurring at Williamson's Point [Pennsylvania].

In American Phil. Soc., Proc., vol. 18, 1880, pp. 96-103, and pl. op. p. 96.

Discusses the optical properties and the chemical and mineralogical composition of trap from the locality mentioned, and presents a complete analysis of it. The colored plate accompanying this paper shows the appearance of a thin section of the trap in polarized light.

FRAZER, PERSIFOR, Jr. 1879.

The Mesozoic sandstone of the Atlantic slope.

In Am. Nat., vol. 13, pp. 284-292.

A review of the following paper on the formation mentioned: "The position of the American New Red sandstone," by Persifor Frazer, jr.; "The Mesozoic formation of Virginia," by Oswald J. Heinrich; "Notes on the Mesozoic of Virginia," by Wm. M. Fontaine, and "The physical history of the Triassic formation of New Jersey and the Connecticut valley," by I. C. Russell.

FRAZER, PERSIFOR, Jr. 1880.

Second geological survey of Pennsylvania. Report of progress in 1877. CCC. The geology of Lancaster county.

FRAZER, PERSIFOR, Jr.—Continued.
Harrisburg, pp. i-x, 1-350, with 12 plates and an atlas of 13 sheets of maps and sections.
Contains a detailed description of the boundaries of the Newark system and of local features of the sandstone, conglomerate, trap dikes, etc., composing the system, in the county mentioned.

FRAZER, PERSIFOR. 1882.
Mémoire sur la géologie de la partie sud-est de la Pennsylvanie. In Thèses présentées à la Faculté des Sciences de Lille Université de France pour obtenir le grade de docteur ès-sciences naturelles. Lille [France], 4to, pp. 1-179, and 4 plates.
Contains a description of the Newark system in Pennsylvania. Describes the extent of the system, its geological position, the character and origin of the copper and iron ores it contains, and also the extent and character of the trap rocks that traverse it. Discusses briefly the origin of the red color of the Newark sandstone. Gives analyses of copper and iron ores, and of trap rock. The geological map shows the distribution of stratified and igneous rocks of Adams and Lancaster counties.

FRAZER, PERSIFOR. 1883.
Geological notes in the several townships of Chester county [Pa.].
In second geological survey of Pennsylvania, vol. C[4], pp. 215-245 and maps in pocket.
Preliminary remarks on the varieties of rock in Chester county, including the sandstone, shale, and trap, p. 219. Distribution and general character of the Newark in various towns, pp. 220, 221, 222, 223, 224, 226, 235, 236, 244.

FRAZER, PERSIFOR. 1884.
Trap dikes in Archean rocks of southeastern Pennsylvania.
In Am. Phil. Soc., Proc., vol. 21, pp. 691-694.
A review of a paper by H. C. Lewis, on "A great trap dike across southeastern Pennsylvania." See Lewis, 1885.

FRAZER, PERSIFOR. 1885.
General notes, sketch of the geology of York county, Pa.
In Am. Phil. Soc. Proc., vol. 23, 1886, pp. 391-410, and a map.
Describes the extent and character of the Mesozoic rocks of York county, Pa. Discusses the evidence of their thickness and quotes E. D. Cope, in reference to their age.

FRAZER, P. Cited on amount of iron in trap rocks (Russell, '89, p. 51).
Cited on composition of trap rocks (W. M. Davis, '83, p. 284).
Cited on a great trap dike in southeastern Pennsylvania (Lewis, '85, p. 456).
Cited on intrusive trap sheets in Pennsylvania (W. M. Davis, '83, p. 294).
Cited on iron-ore mines near Dillsburg, Pa. (d'Invilliers, '86, pp. 1502).

FRAZER, P.—Continued.
Cited on trap dike in Pennsylvania (Lewis, '85, p. 444. Macfarlane, '79, p. 43).

Frederick, Md. Account of a search for coal near (Ducatel, '37, p. 36).
Occurrence of conglomerate south of (Lea, '53, p. 190).
Potomac marble from (Shaler, '84, p. 177).

Freedman ford, Va. Boundary of Newark near (Heinrich, '78, p. 235).

Freetown, P. E. I. Limestone near (Dawson and Harrington, '71, p. 34).

French cove, N. S. Minerals of (Gesner, '36, pp. 197, 198).

French cross, N. S. Description of (Gesner, '36, pp. 196-198).

French cross cove, N. S. Description of (Jackson and Alger, '33, pp. 248-251).

Frenchtown, N. J. Detailed description of sandstone and shale near (H. D. Rogers, '36, pp. 151, 152).
Dip near (Cook, 68, p. 198).
Dip of red shale near (Cook, '79, p. 29. Cook, '82, p. 27).

Fresh Kills, N. Y. Trap rock at (Cook, '68, p. 178).

Fritz mill, Pa. Detailed account of dips near (d'Invilliers, '83, p. 212).

Fritz island, Pa. Conglomerate from (d'Invilliers, '83, p. 392).

Fritz island mine, Pa. Detailed account of (d'Invilliers, '83, pp. 333-342).

GABB, WM. M. 1860.
Description of new species of fossils, probably Triassic, from Virginia.
In Philadelphia Acad. Nat. Sci., Jour., n. s., vol. 4, 1858-1860, pp. 307, 308.
Describes several species of mollusks from Bath county, Va. [Do not belong to the Newark system].

GABB, WM. M. 1861.
Illustrations of some fossils described in the proceedings of the [Philadelphia] Academy of Natural Science.
See Conrad and Gabb.

Gabel hill, Pa. Dip near (d'Invilliers, '83).
Trap dike (d'Invilliers, '83, pp. 200, 201).

Gabel mine, Pa. Analysis of ore from (d'Invilliers, '83, pp. 331-333).
Detailed account of (d'Invilliers, '83, pp. 327-333, maps in atlas).

Gale, (——). Cited on fossil fish from New Jersey (W. C. Redfield, '39).
Cited on the discovery of fossil fishes in New Jersey (Silliman, '39).

Gallas point, P. E. I. Analysis of limestone from (Dawson and Harrington, '71, p. 41).
Anticlinal at (Dawson and Harrington, '71, p. 16).
Description of (Dawson, '78, p. 116).
Description of fossil wood from (Dawson, '54).
Dip at (Dawson, '78, p. 116).
Fossil plants from (Bain and Dawson, '85, pp. 156-158. Dawson and Harrington, '71).
Fossil wood on (Dawson, '78, pp. 117, 118).
Reference to geology of (Chapman, '76, p. 92).

Germanton, N. C.—Continued.

Dip of sandstone with coal at (McLenahan, '52, p. 170).

Fossil plants from (Emmons, '57, pp. 27, 28, 145).

Fossil tree trunks at (Emmons, '56, p. 256. Kerr, '75, p. 143).

Fossil wood near (Olmsted, '27, p. 127).

General section of Newark rocks near (Jones, '62, p 89).

Newark rocks near (Macfarlane, '77, pp. 527, 528).

Saurian remains from (Emmons, '57, p. 145).

Section at (Emmons, '56, pp. 259-260).

Section of shale and coal at (Emmons, '52, p. 152).

Southern limit of Newark area near (Olmsted, '27).

Germantown, N. J. Boundaries of Newark system near (Cook, '89, p. 11).

On the occurrence of conglomerate at (Lea, '53, p. 190).

Germantown, Va. Boundary of Newark near (Heinrich, '78, p. 235).

Detailed description of geology near (W. B. Rogers, '40, p. 67).

Gerrish mountain, N. S. Brief account of trap of (Honeyman, '74*a*).

Copper at (Dawson, '78, p. 102).

Height of (Dawson, '78, p. 101).

Iron at (Dawson, '78, p. 102).

Red sandstone and conglomerate beneath amygdaloid at (Dawson, '47, p. 52).

Traces of plants near (Ells, '85, p. 7E).

Trap on sandstone and conglomerate at (Dawson, '78, p. 101).

GESNER, ABRAHAM. **1836.**

Remarks on the geology and mineralogy of Nova Scotia.

Halifax, N. S. 12mo, pp. i-xl, 1-265, pl. 2 and a map.

In this report pages 71-101 are devoted to a description of the "red sandstone district," in which the author includes the Newark areas proper, and also much of the region about the basin of Mines, which is now known to be Carboniferous (see map accompanying Dawson's Acadian Geology). Pages 169-265 are devoted to a description of the "trap district," in which all the trap outcrops of the province receive attention. In this portion of the report considerable space is devoted to the description of the occurrence of minerals in the trap.

GESNER, ABRAHAM. **1839.**

First report on the geological survey of the province of New Brunswick. St. John [N. B.], 12mo, pp. 1-87.

Devoted principally to a description of the geology of the coast of New Brunswick between St. Andrews and St. John. In this and in four subsequent reports by the same author the Newark and other systems have not been separately described, but treated as new red sandstone. For this reason but few references to the report in question will be found in this catalogue. For more recent reports on the region referred to see "Observations on the geology of southern New Brunswick," by L. W. Bailey, 1865, and a report on the new red sandstone or Trias in the same volume; also geological map accompanying J. W. Dawson's Acadian Geology and "Map of the Dominion of Canada, 1842 to 1882," accompanying a "Descriptive sketch of the physical geography and geology of the Dominion of Canada," by A. R. C. Selwyn and G. M. Mason, Montreal, 1884.

GESNER, ABRAHAM. **1840.**

Second report on the geological survey of the Province of New Brunswick.

St. John [N. B.], 12 mo, p. i-xii, 1-72.

Contains a description of the Newark rocks of Quaco Head. Other localities where rock is found supposed by Gesner to belong to the Newark system are also described. (See Gesner, '39).

GESNER, ABRAHAM. **1841.**

Third report on the geological survey of the province of New Brunswick.

St. John [N. B.], 12 mo, pp. i-xiv, 1-83.

Contains brief accounts of the Newark rocks at Quaco and Red Heads and describes several other localities where rocks which Gesner supposes to be of the same age occur, pp. 14, 15, 16, 33.

GESNER, ABRAHAM. **1842.**

Fourth report on the geological survey of the Province of New Brunswick.

St. John [N. B.], 12 mo, pp. 1-101.

Contains brief references to strata that are called New Red sandstone, pp. 64, 88.

GESNER, A. **1843.**

A geological map of Nova Scotia, with accompanying memoir.

In London Geol. Soc., Proc., vol. 4, 1845, pp. 280-281, and map.

Describes briefly the red sandstones and shales south and east of the basin of Minas, and the intrusive igneous rocks southeast of the bay of Fundy. States that the sandstones underlying and bordering the igneous rocks mentioned belong to the Old Red sandstone, p. 190, and map.

GESNER, ABRAHAM. **1843*a*.**

Report on the geological survey of the Province of New Brunswick, with a topographical account of the public lands, and the district explored in 1842.

St. John [N. B.], 12 mo, pp. 1-88.

Contains a table showing the geological position of the red sandstone (Newark) and the character of the strata composing it. Also an account of the rocks referred to the New Red sandstone period, pp. 54, 61-63.

GESNER, ABRAHAM. **1849.**

The industrial resources of Nova Scotia.

GRATACAP, L. P. 1886.

Fish remains and tracks in the Triassic rocks at Weehawken, N[ew] J[ersey].

In Am. Nat., vol. 20, pp. 243-246, pls. 12, 13.

Description of the occurrence of fossil fishes and fossil footprints, together with ripple marks and raindrop impressions in slate beneath the trap of the Palisades at the locality mentioned.

GRATACAP, L. P. Cited on fossils in the Newark system (Newberry, '88, p. 44).

Gravel hill, N. J. Boundary of Newark at (Cook, '68, p. 175).

Conglomerate of (Cook, '79, p. 19).

Dip in conglomerate near (Cook, '82, p. 27).

Supposed to be Newark in part (Cook, '68, p. 75).

GRAY [A.]. Cited on the character of certain footprints from Turners Falls, Mass. (Deane, '56).

GRAY, ALONZO, and C. B. ADAMS. 1860.

Elements of geology.

New York, 12mo, pp. i-xv, 1-354.

Contains a brief compilation in reference to the structure and fossils of the Newark system, pp. 241-252.

Great clove, N. Y. Faults near (Nason, '89, p. 25).

Great falls, N. J. Columnar trap (Cook, '84, p. 27).

Great notch, N. J. Fault at (Darton, '90, p. 23).

Great swamp, N. J. Bored well in (Ward, '79, p. 139).

Boundary of Long hill trap near (Cook, '68, p. 187).

Section from, Plainfield, N. J. (Cook, '68, p. 199, and map in portfolio).

Trap hill near (Cook, '68, p. 188).

Great valley river, N. S. Rocks near (Dawson, '78, pp. 100-101).

Great Village, N. S. Brief account of Newark rocks at (Honeyman, '78).

Great Village river, N. S. Account of (Dawson, '78, pl. op. p. 125).

GREEN, J. Stone quarry of, near Greensburg, N. J. (Cook, '81, p. 56).

Green brook, N. J. Boundary of First mountain trap near (Cook, '68, p. 181).

Referred to as a locality for copper ore (H. D. Rogers, '36, p. 166).

Greenfield, Mass. Conglomerate in (E. Hitchcock, '35, p. 214. E. Hitchcock, '41, p. 442).

Contact metamorphism in (E. Hitchcock, '35, pp. 423-424. E. Hitchcock, '41, p. 658).

Copper ore in (E. Hitchcock, '35, p. 229).

Description of Deerfield dike in (Emerson, '82).

Dip at (E. Hitchcock, '35, pp. 224, 423).

Dip of sandstone at (Emmons, '57, p. 22).

Discovery of a fossil footprint at (Field, '56).

Footprints found at (D. Marsh, '48, p. 272).

Footprints from (C. H. Hitchcock, '66. Warren, '55, pp. 305-306).

Fossil plants at (E. Hitchcock, '35, pp. 235-236. E. Hitchcock, '41, p. 456).

Greenfield, Mass.—Continued.

General description of fossil footprints found near (Deane, '44).

Geology of (W. M. Davis, '83, p. 259. E. Hitchcock, '18, pp. 105, 108).

Junction of Newark system with slate in (E. Hitchcock, '35, p. 214).

Locality for fossil footprints (E. Hitchcock, '48, p. 132).

Origin of the conglomerate in (E. Hitchcock, '35, p. 244).

Sandstone covered with footprints from (Field, '55).

Section near (Emmons, '57, pp. 5-7).

Thickness of strata at (Emmons, '57, pp. 5-6, 22).

Trap near (E. Hitchcock, '23, vol. 26, p. 46).

Trap ridges in (E. Hitchcock, '35, p. 409. Percival, '42, p. 409).

Trap ridges near (E. Hitchcock, '41, p. 648).

Greenhole shaft, Va. Analysis of coal from (Clifford, '87, p. 10. Macfarlane, '77, p. 515. Williams, '83, p. 82).

Depth of (W. B. Rogers, '43*b*, p. 534).

Situated in an isolated basin (Heinrich, '78, p. 232).

Thinning of coal seams in (Clifford, '88).

Greensburg, N. J. Building stone near (Cook, '68, p. 510).

Conglomerate at (Cook, '82, p. 22).

Description of quarries near (Cook, '81, pp. 55-58).

Dip at (Cook, '68, p. 197).

Dip in sandstone at (Cook, '82, p. 26).

Dip of sandstone at (Cook. '79, p. 29).

Folds near (Cook, '82, p. 16).

Quarries at (Cook, '81, pp. 55-58).

Sandstone at (Cook, '82, p. 20).

Sandstone quarries near (Cook, '79, p. 24. Shaler, '84, pp. 143-144).

Greensburg Granite and Freestone Co. Quarries of, near Greensburg, N. J. (Cook, '81, p. 57).

Greenstone. (See Trap.)

Green valley, N. J. Boundary of First mountain trap near (Cook, '68, p. 181).

Green valley copper mine, N. J. (Cook, '68, pp. 676-677).

Green Village, N. J. Dip in shale near (Cook, '79, p. 30).

Trap exposed at (Russell, '80, p. 36).

Trap hill near (Cook, '68, p. 188).

Trap ridges near (Cook, '82, pp. 57, 58).

Reference to geological features (H. D. Rogers, '40, p. 133).

Greenville, Pa. Boundary of the Newark in (Frazer, '80, p. 15).

Boundary of the Newark near (d'Invilliers, '83, p. 198).

Sandstone at (Frazer, '80, p. 46).

GREER, JAMES. 1871.

Oolite coal field of Virginia.

[A "separate;" place of publication not known.]

Contains an extract from C. Lyell's paper on the structure and probable age of the Richmond coal field, Virginia (see Lyell, 1847),

HALE, P. M.—Continued.
Raleigh, 12mo, pp. i-viii, 9-425, and map.
Contains voluminous extracts from the reports of Emmons, Wilkes, Laidley, and Kerr, pp. 11-181, 226-229.

Haledon, N. J. Boundary of First mountain trap near (Cook, 68, p. 181).
Boundary of Second mountain trap near (Cook, '68, pp. 183-184).
Building stone near (Cook, '68, p. 505).
Dip in sandstone at (Cook, '82, p. 30).
Lower contact of trap sheet at (Darton, '90, pp. 31, 32).
Quarries at, described (Cook, '81, p. 52).
Quarries near, described (Cook, '89, p. 52).
Reference to fault near (Cook, '89, p. 14).
Sandstone quarry near (Cook, '79, p. 22).

Haledon quarry, N. J. Contact of trap and sandstone at (Cook, '83, pp. 23-24, and pl.).

Hale's mills, Mass. Localities of fossil footprints near (E. Hitchcock, 41, p. 465).

Hales mine, S. C. Brief account of contact metamorphism in (Tuomey, '48, p. 68).

Halifax county, Va. Boundaries of the Newark in (W. B. Rogers, '39, pp. 74-76).

HALL, CHARLES E. 1878.
Second geological survey of Pennsylvania, 1874-'75-'76-'77. Catalogue of the geological museum.
Harrisburg 1878 [vol. O], part 1, pp. 1-217.
A catalogue of rock specimens.

HALL, CHARLES E. 1880.
The relations of the crystalline rocks of eastern Pennsylvania to the Silurian limestones, and the Hudson river age of the hydromica schists.
In Am. Phil. Soc., Proc., vol. 18, 1878-1880, pp. 435-443.
Accompanied by a small map showing the distribution of Newark rocks in Pennsylvania.

HALL, CHARLES E. 1881.
Second geological survey of Pennsylvania, Report of Progress, C6. The geology of Philadelphia county and of the southern parts of Montgomery and Bucks (counties).
Harrisburg, pp. i-xx, 1-154, map in 3 sheets and 1 sheet of sections in pocket.
Describes the boundaries and notes some of the local features of the Newark system in the southern parts of Montgomery and Bucks counties. Notices also the course of a trap dike in Montgomery county.

HALL, CHARLES E. 1883.
[Itinerary notes on] the South mountain gneiss [Pennsylvania].
In second geological survey of Pennsylvania, D3, vol. 1, pp. 215-258, pls. 2-4.
Contains a few observations of dip, character of rock, etc., in Lehigh county, Pa., pp. 232, 233, 247.

HALL, C. E. Cited on the trap dikes in Pennsylvania (Lewis, '85, pp. 439, 441).

HALL, JAMES. 1843.
Natural History of New York, Part IV, geology. Comprising the survey of the fourth geological district.
Albany, 4to, pp. i-xxvii, 1-686, pls. 1-19, and geological map of the Middle and Western states.
A brief reference to the geological position of the Newark system is given on page 19. On the map the extent of the rocks referred to in New York, New Jersey and southward is shown.

HALL, JAMES. 1852.
Key to a chart of the successive geological formations, with an actual section from the Atlantic to the Pacific ocean [etc.].
Boston, 16mo, pp. 1-72.
Contains a very brief account of the Newark system, p. 49, and a brief list of fossils from the Richmond coal field, Va., p. 66.

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In Am. Jour. Sci., vol. 3, p. 247.
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In Am. Nat., vol. 1, pp. 169–176, 234–243.
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Haverstraw, N. Y. Analysis of sandstone from (Schweitzer, '71).
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Haverstraw, N. Y.—Continued.
Brief description of trap ridge at (Russell, '78, p. 241).
Conglomerate quarries near (Mather, '39, pp. 124–125. Nason, '89, p. 40).
Dip and strike of rocks in (Mather, '43, pp. 616–617).
Dip of sandstone and trap near (Darton, '90, p. 41).
Gap in trap ridge near (Darton, '90, p. 41).
Junction of trap and sandstone near (Darton, '90, p. 48).
Red marl near (Mather, '43, p. 288).
Section of Palisade trap sheet near (Darton, '90, p. 37).
Section of sandstone beneath trap near (Mather, '43, pl. 5).
Small trap sheet in arkose near (Darton, '90, p. 49).
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Upper contact of trap and sandstone near (Darton, '90, p. 51).

HAWES, GEORGE W. **1875.**
The trap rocks of the Connecticut valley.
In Am. Jour. Sci., 3d ser., vol. 9, pp. 185–192.
Compares the chemical composition of trap rocks from localities in the Connecticut valley and in New Jersey, and points out the changes that have taken place in rocks since their ejection.

HAWES, GEORGE W. **1875a.**
On diabantite, a chlorite occurring in the trap of the Connecticut valley.
In Am. Jour. Sci., 3d ser., vol. 9, pp. 454–457.
Describes the occurrence and gives analysis of the mineral mentioned, from amygdaloidal cavities in trap in the Farmington hills, Conn.

HAWES, G. W. **1878.**
[Note on the microscopical characteristics of a thin section of Jura-Trias sandstone from the Connecticut valley.]
In Geology of New Hampshire, by C. H. Hitchcock, vol. 3, pp. 239–240, pl. 12.
Remarks that all of the grains in the sandstone are coated with red oxide of iron, which cements them together and determines the color of the rock. The colored illustration accompanying this note shows the appearance of a thin section of sandstone when viewed through a microscope.

HAWES, GEORGE W. **1882.**
On the mineralogical composition of the normal Mesozoic diabases upon the Atlantic border.
In U. S. Nat. Mus., Proc., vol. 4, 1881, pp. 129–134.
Abstract in Neues Jahrbuch, 1882, p. 44.
Reviewed by J. D. Dana in Am. Jour. Sci., 3d ser., vol. 22, pp. 230–233.
Discusses the mineralogical composition of trap rocks, diabase, from Bergen hill, N. J., and from West rock, Conn., with chemical analysis of constituent minerals.

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Cited on mineral analysis of trap from Bergen hill, N. J. (Shaler, '84, p. 145).
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Cited on trap rocks of Connecticut (Hovey, '89, pp. 366–368).

Haycock hill, Pa. Analysis of trap from (Genth, '81, pp. 98–99).
Description of (H. D. Rogers, '58, vol. 2, p. 686).

Haydens station, Conn. Sandstone quarries near (Shaler, '84, p. 127).

HAYES, JOHN L. 1842.
[Remarks on fossil footprints from the Connecticut valley sandstones.]
In Am. Assoc. Geol. and Nat., Proc., 1840–1842, pp. 55–56.
Brief notice of remarks on the above subject.

HAYES, JOHN L. 1843.
[Remarks on recent and fossil footprints.]
In Am. Jour. Sci., vol. 45, p. 316.
Brief remark on a paper by W. C. Redfield.

HAYES, J. L. 1850.
[Comparison of recent bird tracks from the shore of the bay of Fundy with fossil impressions of a similar origin.]
In Boston Soc. Nat. Hist., Proc., vol. 3, p. 227–228.

Haywood, N. C. Analysis of iron ore from near (Kerr, '75, p. 225).
Breadth of Newark rocks near (Olmstead, '24, p. 12).
Brief account of geology near (McLenahan, '52, p. 169).
Boundary of Newark area near (W. R. Johnson, '51, p. 4. Mitchell, '42, p. 130).
Conglomerate at (Emmons, '56, pp. 237–238).
Dip and strike at (McLenahan, '52, p. 168).
Dip of sandstone near (Kerr, '75, p. 225).
Fossil plants from (Emmons, '57, pp. 105, 118).
Iron ore near (Kerr, '75, p. 225).
Mention of trap dikes near (Burbank, '73, p. 152).
Silicified trees near (Emmons, '56, p. 284).
Thickness of strata at (Fontaine, '83, p. 100).

Heathcote brook, N. J. Sandstone quarry at (Cook, '79, p. 23).

Heath's coal mine, Va. Analysis of coal from (Macfarlane, '77, p. 515).

Heath's coal mine, Va.—Continued.
Brief account of (Macfarlane, '77, p. 507).
Brief reference to (Nuttall, '21, p. 35).
Explosions in (Taylor, '48, p. 49).
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Thickness of coal in (Grammar, '18, p. 126–127. Taylor, '35, p. 282).

Hebron, Conn. Description of trap dikes in primary rocks in (Percival, '42, pp. 423–424).

HEER, OSWALD. 1857.
[A letter concerning the geological position of the rocks of the Richmond coal field, Virginia, as indicated by fossil plants.]
In geology of North America, by Jules Marcou, Zurich, 1856, p. 16.
Published in part in Am. Jour. Sci., 2d ser., vol. 24, 1857, pp. 428–429.
Questions the accuracy of certain determinations of the genera and species of fossil plants from the Richmond coal field, Va., made by E. Emmons and C. T. F. Bunbury, and states an opinion concerning the age of the rocks from which the plants referred to were obtained.

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HEILPRIN, ANGELO. 1884.
On a remarkable exposure of columnar trap near Orange, New Jersey.
In Philadelphia Acad. Nat. Sci., Proc., vol. 36, pp. 318–320, pl. 8.
A popular description of an exposure of columnar trap at the locality mentioned.

HEILPRIN, ANGELO. 1887.
The geographical and geological distribution of animals.
New York (The International Scientific series), 12 mo, pp. i–xii, 1–435, pl. 1.
Contains a general description of the fauna of the Triassic and Jurassic periods, pp. 157–168.

HEINRICH, OSWALD J. 1873.
The Midlothian colliery, Virginia.
In Am. Inst. Mining Eng., Trans., vol. 1, pp. 346–359, supplementary paper, pp. 360–364, pl. 5.
Devoted principally to mining methods, but contains a detailed section of the coal seams at Bailey's hill, Midlothian.

HEINRICH, O. J. 1874.
The diamond drill for deep boring, compared with other systems of boring.

HEINRICH, O. J.—Continued.

In Am. Inst. Mining Eng., Trans., vol. 2, pp. 241-263.

Refers to the method and cost of boring certain deep holes at Midlothian, Va.

HEINRICH, O. J. 1875.

[Remarks on trap dikes and on natural coke in the Richmond coal field, Virginia.]

In The Engineering and Mining Journal, vol. 19, p. 35.

A part of a discussion following the reading of a paper on deep boring with a diamond drill, read by O. J. Heinrich before the American Institute of Mining Engineers, Dec. 26, 1874. Describes the natural coke of the Richmond coal field, and states its connection with trap dikes. Remarks on the same subject were made by M. Coryell and T. S. Hunt.

HEINRICH, O. J. 1875a.

Deep boring with the diamond drill (supplementary paper).

In Am. Inst. Mining Eng., Trans., vol. 3, pp. 183-186.

Explains the method of boring, cost, etc., of certain diamond drill explorations made at Midlothian, Va.

HEINRICH, OSWALD J. 1876.

An account of an explosion of fire-damp at the Midlothian colliery, Chesterfield county, Va.

In. Am. Inst. Mining Eng., Trans., vol. 5, pp. 148-161, pl. 3.

Accompanied by a section and plan of underground work of the colliery referred to.

HEINRICH, OSWALD J. 1876a.

The Midlothian, Va., colliery in 1876.

In Am. Inst. Mining Eng., Trans., vol. 4, pp. 308-316.

Gives a brief history of coal mining in the Richmond coal field, and describes the condition of the Midlothian colliery in 1876.

HEINRICH, OSWALD J. 1878.

The Mesozoic formation in Virginia.

In Am. Inst. Mining Eng., Trans., vol. 6, pp. 227-274, pls. 5-6.

Reviewed by P. Frazer in Am. Nat., vol. 13, pp. 284-292.

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Cited on faults in the Richmond area, Va. (W. M. Davis, '83, p. 304).

Cited on the Newark of Virginia (Russell, '80*a*).

Cited on relation of trap and sandstone in Virginia (W. M. Davis, '83, p. 288).

Cited on section of coal-bearing rocks at Midlothian (Clifford, '87, p. 23).

Cited on thickness of Newark in Virginia (Frazer, '77, p. 270).

Cited on tilting of the sandstone and trap of the Richmond area, Va. (W. M. Davis, '83, p. 302).

Cited on value of the Richmond coal field, Va. (Hotchkiss, '80, p. 92).

Heists' mill, Pa. Dip of conglomerate near (d'Invilliers, '83, p. 214).

Helcura. Description of genus (E. Hitchcock, '58, p. 140).

Hemingway mountain, Conn. Description of (Hovey, '89, p. 366).

Discussion of the origin of (Hovey, '89, p. 381).

Henderson, Pa. Boundary of the Newark near (C. E. Hall, '81, pp. 22, 84).

HENDERSON, J. T. 1885.

The commonwealth of Georgia.

Atlanta, Ga., pp. i-viii, 1-397.

HITCHCOCK, CHARLES H.—Continued.

In official topographical atlas of Massachusetts, by H. F. Walling and O. W. Gray. Boston, folio, pp. 17-23, and map.

Contains a brief sketch of the general geology of the state, accompanied by a colored geological map; also a list of fossil footprints found in the Newark system.

HITCHCOCK, CHARLES H. **1874.**

The Coal Measures of the United States.

In statistical atlas of the United States, by Francis A. Walker, pp. 12-14, pls. 11, 12.

Contains a brief account of the coal fields of eastern Virginia and of North Carolina. Accompanied by two maps, one (pl. XI) showing the distribution of coal fields and the other (pl. XII) a general geological map of the United States, compiled by C. H. Hitchcock and W. P. Blake.

HITCHCOCK, CHARLES H. **1877.**

The relation of the geology of New Hampshire to that of the adjacent territory.

In the geology of New Hampshire, by C. H. Hitchcock, vol. 2, pp. 3-36, pl. op. p. 8.

Contains a brief reference to the Newark rocks of the Connecticut valley, Nova Scotia, New Brunswick, etc. These areas are shown on the map op. p. 8.

HITCHCOCK, CHARLES H. **1877a.**

Geology of the Connecticut valley district [of New Hampshire].

In geology of New Hampshire. Concord, vol. 2, 4to, pp. 271-407, 428-462, and 7 plates.

Refers briefly to the position of the north end of the Connecticut valley area, and the presence of a heavy conglomerate in Northfield, Mass.

HITCHCOCK, CHARLES H. **1881.**

Geological map of the United States, compiled by C. H. Hitchcock.

New York. Published by Julius Bien.

A wall map; scale 20 miles to an inch.

Map, geological, of the United States (C. H. Hitchcock, '81).

HITCHCOCK, CHARLES H. **1886.**

The geological map of the United States.

In Am. Inst. Mining Eng., Trans., vol. 15, pp. 465-488, map op. p. 486.

Contains an account of previously published geological maps of the United States and Canada, and shows the distribution of the Jurassic and Triassic systems of the United States.

HITCHCOCK, CHARLES H. **1888.**

Recent progress in ichnology.

In Boston Soc. Nat. Hist., Proc., vol. 24, pp. 117-127.

Presents a revised list of the footprints of the Newark system, and gives descriptions of several new species. Notices also the localities where footprints have been found in New Jersey and Pennsylvania.

HITCHCOCK, CHARLES H. **1889.**

[Remarks on a paper by Atreus Wanner, concerning the discovery of fossil tracks in the Newark rocks of York county, Pa.]

HITCHCOCK, CHARLES H.—Continued.

In Am. Assoc. Adv. Sci., Proc., vol. 37, p. 186.

States that fossil footprints recently discovered in rocks of the Newark system of New Jersey and Pennsylvania belong to the same genera as the tracks previously discovered in the Connecticut valley.

HITCHCOCK, CHARLES H. **1890.**

The use of the terms Laurentian and Newark in geological treatises.

In Am. Geol., vol. 5, pp. 197-202.

Reviewed by I. C. Russell in Am. Geol., vol. 7, pp. 238-241.

A review of a paper on "The Newark System," by I. C. Russell. Gives reason for objecting to the use of "Newark" as a group name, pp. 200-202.

H[ITCHCOCK], C. H. Description of Grallator gracilis by (E. Hitchcock, '65, p. 8, pl. 9).

Note on Anomœpus gracillimus (E. Hitchcock, '65, p. 6).

Plants collected by. in the Newark system (Newberry, '88, p. 92).

Remarks on Brontozoum giganteum by (E. Hitchcock, '65, p. 23).

Remarks on the origin of the Connecticut valley sandstone (Whitney, '60).

HITCHCOCK, C. H., and W. P. BLAKE. **1874.**

Geological map of the United States.

In Statistical atlas of the United States, based on the Ninth Census, 1870 [etc.], by Francis A. Walker, pls. 13-14.

First published in the reports of the Ninth Census of the United States, by F. A. Walker. Appeared also in the statistics of mines and mining, by R. W. Raymond, 1873; in "Special report on the Smithsonian Institution for the Centennial," Washington, 1876; and in "Atlas of the United States and the World," by Gray, Philadelphia, 1877.

A compiled map showing the distribution of geological formations in the United States.

H[ITCHCOCK], EDWARD. **1815.**

Southampton lead mine and basaltic columns at Mount Holyoke, Mass.

In North American Review, vol. 1, pp. 334-338.

A popular letter on the subjects referred to in the title.

HITCHCOCK, EDWARD. **1818.**

Remarks on the geology and mineralogy of a section of Massachusetts on Connecticut river, with a part of New Hampshire and Vermont.

In Am. Jour. Sci., vol. 1, pp. 105-116, 436-439, and map.

Describes in general terms the geology in the neighborhood of Mounts Holyoke and Tom, Mass., pp. 105, 108, and map.

HITCHCOCK, EDWARD. **1823.**

A sketch of the geology, mineralogy, and scenery of the region contiguous to the river Connecticut; with a geological map and drawings of organic remains; and occasional botanical notices.

HITCHCOCK, EDWARD—Continued.

In Am. Jour. Sci., vol. 6, 1823, pp. 1-86, 201-236, pl. 9, and map op. p. 86; vol. 7, 1824, pp. 1-30, pl. 1.

Describes the Newark rocks of the Connecticut valley, in part under the name of the Old Red sandstone, vol. 6, pp. 39-42. The "greenstone dikes" in the Old Red sandstone are described on pp. 56-59, and their origin discussed on pp. 59-61. Another division of the Newark receives attention under the name of the "Coal formation," pp. 61-80. In vol. 7 the scenery of the Connecticut valley is described, and in this connection the relief of several trap hills receives attention.

H[ITCHCOCK], E[DWARD]. 1824.

Notice of a singular conglomerate, and of an interesting locality of trap tuff, or tufa.

In Am. Jour. Sci., vol. 8, pp. 244-247.

Describes exposures of trap tuff on the east side of Mount Tom, Mass.

HITCHCOCK, EDWARD. 1824a.

A geological and agricultural survey of the district adjoining the Erie canal in the State of New York, part 1, containing a description of the rock formations; together with a geological profile; extending from the Atlantic to Lake Erie.

Albany. 12mo, pp. 1-163, pls. 1-2.

The sections accompanying this report show the positions of the Newark rocks and associated traps of the Connecticut valley.

HITCHCOCK, EDWARD. 1828.

Miscellaneous notices of mineral localities, with geological remarks.

In Am. Jour. Sci., vol. 14, pp. 215-230.

Refers briefly to an exposure of sandstone beneath trap on the east side of Mount Holyoke, Mass., p. 218, and records a few facts concerning the small outlying Newark area in Woodbury and Southbury, Conn., pp. 227-228.

HITCHCOCK, EDWARD. 1832.

Report on the geology of Massachusetts; examined under the direction of the government of that state, during the years 1830 and 1831.

In Am. Jour. Sci., vol. 22, pp. 1-70, and map op. p. 1.

Contains a brief account of the sandstone along the Connecticut river, but refers principally to its value as a building stone. The formation is termed the New Red sandstone.

HITCHCOCK, EDWARD. 1835.

Report on the geology, mineralogy, and botany of Massachusetts, in four parts; Part I, Economic geology; Part II, Topographical geology; Part III, Scientific geology; Part IV, Catalogue of animals and plants. Amherst, 1835. Second edition, corrected and enlarged, pp. i-xii, 13-702, accompanied by 4to atlas of 19 plates.

HITCHCOCK, EDWARD—Continued.

First edition of Part I, Economic geology, Amherst, 1832, pp. 1-70, and geological map of Massachusetts.

First edition of full report, Amherst, 1833, pp. i-xii. 1-692, and 4to atlas of 19 plates.

The contents of the 2d ed., so far as it relates to the Newark system, is as follows:

HITCHCOCK, EDWARD—Continued. Page.

HITCHCOCK, EDWARD. 1836.

Ornithichnology. Description of the footmarks of birds (Ornithichnites) on New Red sandstone in Massachusetts.

In Am. Jour. Sci., vol. 29, pp. 307-340, and 3 plates.

Abstract in Neues Jahrbuch, 1836, pp. 467-472.

Refers to early discussion of fossil footprints in Massachusetts, mentions several localities at which they occur, discusses the nature of the animals that made the tracks, and describes and figures several species.

HITCHCOCK, EDWARD. 1837.

Researches in theoretical geology by H. T. De La Beche, with a preface and notes by Prof. Edward Hitchcock.

New York. 12mo, pp. i-xv, 1-342.

Contains a note on the fossil fishes of the Connecticut valley, p. 267, and also on the fossil footprints of the same region, pp. 271-273.

HITCHCOCK, EDWARD. 1837a.

Fossil footsteps in sandstone and graywacke.

In Am. Jour. Sci., vol. 32, pp. 174-176.

Abstract in Neues Jahrbuch, 1837, pp. 602-603.

Mentions the advance that has been made in the study of the fossil footprints of the Connecticut valley and gives a list of species described.

HITCHCOCK, E. 1837b.

Ornithichnites in Connecticut.

In Am. Jour. Sci., vol. 31, pp. 174-175.

Brief mention of additional localities in Connecticut at which fossil footprints have been found. The footprints are described briefly and their names given in some instances.

HITCHCOCK, EDWARD. 1841.

Final report on the geology of Massachusetts.

Northampton, 4to, vol. 1, pp. i-xii, 1a-11a, 1-299, pls. 1-14 and a map; vol. 2, pp. 300-381, pls. 15-55.

The contents of this report, so far as it relates to the Newark system, is as follows:

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HITCHCOCK [EDWARD]. **1841a.**

[Remark on joints and fractures in the sandstone and trap of the Connecticut valley.]

In Am. Jour. Sci., vol. 41, p. 173, and also in Am. Assoc. Geol. and Nat., Proc., p. 25.

Brief abstracts of remarks on a paper, by Prof. Mather, concerning joints in rocks.

HITCHCOCK, EDWARD. **1841b.**

First anniversary address before the Association of American Geologists, at their second annual meeting at Philadelphia, April 5, 1841.

In Am. Jour. Sci., vol. 41, pp. 232–275.

States briefly the geographical distribution of the Newark system and discusses the question of its age, pp. 244–245. The "New Red sandstone system" is mentioned on p. 267.

HITCHCOCK [EDWARD]. **1842.**

On a new species of Ornithichnite from the valley of the Connecticut river, and on the raindrop impressions from the same locality.

In Am. Jour. Sci., vol. 43, p. 170; also in Am. Assoc. Geol. and Nat., Proc., p. 63.

Title of paper only, followed by remarks by Charles Lyell and H. D. Rogers, W. B. Rogers, Benjamin Silliman, jr. [C. W.] Redfield, and John L. Hayes.

HITCHCOCK, EDWARD. **1843.**

The phenomena of drift, or glacio-aqueous action in North America, between the Tertiary and Alluvial periods.

In Am. Assoc. Geol. and Nat., Trans., pp. 164–221, pls. 7, 8, 9.

Describes briefly the general geology and topographical features of the region about Mount Tom and Mount Holyoke, Mass.

HITCHCOCK, EDWARD. **1843a.**

Description of five new species of fossil footmarks, from the Red sandstone of the valley of Connecticut river.

In Am. Assoc. Geol. and Nat., Trans., pp. 254–264, pl. 11.

Devoted principally to the description of new species of footprints, obtained near Turners Falls, Mass., by James Deane.

HITCHCOCK, EDWARD. **1843b.**

Description of several species of fossil plants, from the New Red sandstone formation of Connecticut and Massachusetts.

In Am. Assoc. Geol. and Nat., Trans., pp. 294–296, pls. 12, 13.

Describes briefly the character of the rocks forming the small Newark area at Southbury, Conn., and gives the results of a microscopical examination of a specimen of fossil wood found there. Fragments of fossil ferns from localities in Massachusetts are also briefly described.

HITCHCOCK [EDWARD]. **1844.**

The trap tufa or volcanic grit of the valley of the Connecticut river, with inferences as to the relative age of the trap and sandstone.

In Am. Jour. Sci., vol. 47, pp. 103–104.

Abstract of remarks describing the character of the tufa, method of its formation, etc.

HITCHCOCK [EDWARD]. **1844a.**

Report on ichnolithology, or fossil footmarks, with a description of several new species, and the coprolites of birds, from the valley of the Connecticut river.

In Am. Jour. Sci., vol. 47, pp. 292–322, pls. 3, 4. Abstract ibid., pp. 113–114; also in, Neues Jahrbuch, 1845, pp. 753–757.

Reviews the discussion of the question of first discovery of fossil footprints in the sandstone of the Connecticut valley, describes several new species of footprints, and discusses the nature of certain coprolites.

HITCHCOCK, EDWARD. **1844b.**

Discovery of more native copper in the town of Whately, in Massachusetts, in the valley of Connecticut river, with remarks on its origin.

In Am. Jour. Sci., vol. 47, pp, 322–323.

Describes the occurrence of a mass of native copper in the drift at the locality mentioned.

HITCHCOCK, EDWARD. **1844c.**

Geological map of Massachusetts: Scale 5 miles to 1 inch, or $\frac{1}{316800}$, 1844.

On wall map of Massachusetts.

HITCHCOCK, EDWARD. **1844d.**

[On priority in the discovery of fossil footmarks in the sandstone of the Connecticut valley.]

In Am. Jour. Sci., vol. 47, pp. 390–399.

Devoted to the question of priority in the discovery of the footprints in question.

HITCHCOCK, EDWARD. **1844e.**

Explanation of the geological map attached to the topographical map of Massachusetts.

Boston, 12mo, pp. 1–22.

Contains a brief description of trap and trap-tuff or tufaceous conglomerate occurring in the Connecticut valley, and also refers to the distribution of the Newark sandstone in the same region.

HITCHCOCK, EDWARD. 1845.

An attempt to name, classify, and describe the animals that made the fossil footmarks of New England.

In Am. Assoc. Geol. and Nat., Proc., sixth meeting, pp. 23-25.

Presents a list of families, genera, and species of the animals that made the footprints in the Newark rocks of the Connecticut valley. A revised classification based on a new set of measurements.

HITCHCOCK, EDWARD. 1845a.

Remarkable facts respecting the magnetic polarity of trap rocks in New England.

In Am. Assoc. Geol. and Nat., Proc., sixth meeting, p. 32.

Brief abstract of a paper recording observations on the magnetic attraction of the trap rocks of the Connecticut valley.

HITCHCOCK, EDWARD. 1845b.

Analysis of coprolites from the New Red sandstone of New England.

See Dana, S., and E. Hitchcock, 1845.

HITCHCOCK, EDWARD. 1845c.

[Miscellaneous remarks upon fossil footmarks.]

In Am. Jour. Sci., vol. 48, pp. 62-64.

Brief remarks on very large footprints found principally in Northampton, Mass.

HITCHCOCK, EDWARD. 1847.

Description of two new species of fossil footmarks found in Massachusetts and Connecticut, or of the animals that made them.

In Am. Jour. Sci., 2d ser., vol. 4, pp. 46-57.

Describes two new genera of footprints, represented by a single species each, from South Hadley, Mass. Discusses also the conditions under which the footprints in the sandstone of the Connecticut valley were made.

HITCHCOCK, EDWARD. 1847a.

On the trap tuff, or volcanic grit of the Connecticut valley, with the bearing of its history upon the age of the trap rock and sandstone generally in that valley.

In Am. Jour. Sci., 2d ser., vol. 4, pp. 199-207.

Describes the lithological characters of the various trappean rocks of the Connecticut valley, explains the structure of mounts Tom and Holyoke, and the topography of the trap ridges; also considers certain organic remains associated with the trap; discusses the mode and the period of the production of the trap.

HITCHCOCK, EDWARD. 1848.

An attempt to discriminate and describe the animals that made the fossil footmarks in the United States, and especially New England.

In Am. Acad., Mem., n. s., vol. 3, pp. 129-256, pls. 1-24, and a table op. p. 256.

Discusses the principles on which animals are classified from their footprints. Describes large number of genera and species. The matter contained in this paper is embodied in Hitchcock's later work on the "Ichnology of New England," 1858.

HITCHCOCK [EDWARD]. 1853.

[Remarks on the fossil footprints of the Connecticut valley.]

Boston Soc. Nat. Hist., Proc., vol. 4, pp. 375-379.

Gives an account of a measured section across the Connecticut valley, showing a great thickness of strata. Thickness of rock above the highest footprint found is also stated. Considers that the dip of the sandstone containing footprints has not been caused by the intrusion of trap. Infers that the entire thickness of sandstone can not all belong to the Newark system.

HITCHCOCK, EDWARD. 1855.

Description of several sections measured across the sandstone and trap of Connecticut river valley in Massachusetts.

In Am. Assoc. Adv. Sci., Proc., vol. 9, 1856, pp. 225-227.

Describes briefly the principal facts resulting from the measurement of three sections across the Connecticut valley, located at Turners Falls, Mount Tom, and Chicopee, Mass. The thickness of the rocks is stated as well as their probable age.

HITCHCOCK, EDWARD. 1855a.

Elementary geology.

New York, 30th ed., 12 mo, pp. i-xviii, 19-424, pl. 1.

Earlier editions not noted.

Gives a brief account of columnar trap at Mount Holyoke, Mass., pp. 87-88.

Describes briefly the footprints and rain drop impressions of the Connecticut valley sandstones, pp. 181-190. Discusses the age of the Newark system, pp. 407-409.

HITCHCOCK, EDWARD. 1855b.

Additional facts respecting the tracks of the Otozoum Moodii on the Liassic sandstone of the Connecticut valley.

In Am. Assoc. Adv. Sci., Proc., vol. 9, 1856, p. 228.

Describes certain features of the tracks mentioned, and states localities at which they have been discovered.

HITCHCOCK, EDWARD. 1856.

Outlines of the geology of the globe.

Boston, 3d ed., pp. 1-136, pls. 1-6, and two maps.

Contains a short account of the Newark system and a brief discussion of its probable age, pp. 66-99.

HITCHCOCK, EDWARD. 1856a.

Description of a new and remarkable species of fossil footmark, from the sandstone of Turners Falls, in the Connecticut Valley. [Part 2 of an article entitled "On a new fossil fish, and new fossil footmarks.]

In Am. Jour. Sci., 2d ser., vol. 21, pp. 97-100.

Abstract in Neues Jahrbuch, 1856, pp. 237-238.

Describes the genus Gigandipus, and the species *G. caudatus*.

HITCHCOCK [EDWARD]. 1857.

[On some regular, polygonal depressions found in the sandstone of the Connecticut valley.]

In Boston Soc. Nat. Hist., Proc., vol. 6, 1856–1859, p. 111.

Brief description of the depressions, with the statement that they might have been made by tadpoles.

HITCHCOCK, EDWARD. 1858.

Ichnology of New England. A report on the sandstone of the Connecticut valley, especially its fossil footmarks, made to the government of the commonwealth of Massachusetts.

Boston, 4to, pp. i–vii, 1–220, pls. I–LX.

Reviewed in Am. Jour. Sci., 2d ser., vol. 27, pp. 270–272.

Abstract in Neues Jahrbuch, 1859, and in Am. Jour. Sci., 2d ser., vol. 27, pp. 270–272.

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HITCHCOCK, E. 1859.

[Catalogue of rocks, minerals, and fossils in the Massachusetts state cabinet.]

In sixth annual report of the secretary of the Massachusetts Board of Agriculture [etc.], Boston, 1859, appendix, pp. i–lxix.

Contains a list of specimens, including samples of rock, fossil plants, fossil fishes, and footprints, from the Newark system in Massachusetts and Connecticut.

HITCHCOCK, EDWARD. 1860.

Additional facts respecting the Clathropteris of East Hampton, Mass.

In Am. Assoc. Adv. Sci., Proc., vol. 14, 1861, pp. 158–159.

HITCHCOCK, EDWARD—Continued.

Records some of the characteristics of the fossil fern mentioned.

HITCHCOCK, E. **1860.**

Remarks upon certain points in ichnology.

In Am. Assoc. Adv. Sci., Proc., vol. 14, 1861, pp. 144–156.

Refers to the characteristics of fossil footprints and their paleontological value.

HITCHCOCK, EDWARD. **1863.**

New facts and conclusions respecting the fossil footmarks of the Connecticut valley.

In Am. Jour. Sci., 2d ser., vol. 33, pp. 46–57.

Records additional observations and conclusions concerning the fossils mentioned.

HITCHCOCK, EDWARD. **1865.**

Supplement to the Ichnology of New England.

Boston, 4to, pp. i–x, 1–96, pls. 1–20.

Notice in Am. Jour. Sci., 2d ser., vol. 40, p. 392.

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HITCHCOCK, E. Cited on the age of the coal fields of North Carolina (Emmons, '56, p. 271).

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Cited on the age of the Newark system (C. H. Hitchcock, '71, p. 21. Mather, '43, pp. 293–294. Newberry, '88, p. 9. H. D. Rogers, '44, p. 248. H. D. Rogers, '58, vol. 2, p. 693).

HITCHCOCK, E.—Continued.

Cited on the cause of the tilting of the Newark (W. M. Davis, '83, p. 303).

Cited on coarse deposits in Massachusetts (J. D. Dana, '90, p. 436).

Cited on contact metamorphism in Massachusetts (W. M. Davis, '83, p. 300).

Cited on the dip of the Newark of the Connecticut valley (W. M. Davis, '83, p. 306).

Cited on the distribution of conglomerate in the Jura-Trias of the Connecticut valley (Russell, '78, pp. 231, 238).

Cited on the early discovery of fossil fishes in the Newark system (Newberry, '88, p. 19).

Cited on the extrusive trap sheets in the Connecticut valley (Davis and Whittle, '89, p. 99).

Cited on the first discovery of the Triassic in America (Marcou, '88, p. 31).

Cited on fossil fern from the Connecticut valley (Fontaine, '83, p. 57. E. Hitchcock, '55*a*, p. 407).

Cited on fossil fishes from the Connecticut valley (Eaton, '20, pp. 215–216. Harlan, '34, pp. 92–94. J. H. Redfield, '36. Silliman, '21, pp. 221–222).

Cited on fossil fishes of the Newark system (Newberry, '88).

Cited on fossil footprints (Murchison, '43).

Cited on fossil footprints from the Connecticut valley (Deane, '45, pp. 159, 160, 161, 166, 167. D'Orbigny, '49, vol. 1, pp. 27–32. Gray and Adams, '60, pp. 247–252. Lea, '53, pp. 185, 186, 187, 188, 189, 193–194. Lyell, '66, pp. 453–456. Lyell, '71, p. 361. Owen, '59, pp. 325–327. Pictet, '53, vol. 1, p. 403. W. C. Redfield, '38. H. D. Rogers, '58, vol. 2, p. 694. Russell, '78, p. 231. Winchell, '70, pp. 182–185).

Cited on fossil plants from the Connecticut valley (Lyell, '47, p. 279).

Cited on the geology of the Connecticut valley (Danberry, '39, pp. 19, 21).

Cited on the mode of formation of the Newark rocks of the Connecticut valley (Lea, '53, pp. 191–192).

Cited on Mormolucoides articulatus (Scudder, '68, p. 218. Scudder, '84, p. 431).

Cited on the names of certain fossil footprints from Turners falls, Mass., figures by James Deane (Silliman and Dana, '47).

Cited on the nature of the trap of the Connecticut valley (Cooper, '22, pp. 242–243).

Cited on the number of joints in the toes of fossil footprints (Silliman and Dana, '47).

Cited on the number of phalanges in the toes of birds (Silliman, Silliman, jr., and Dana, '47).

Cited on the occurrence of fossil fishes at Sunderland, Mass. (Brongniart and Silliman, '22. Silliman, '21*a*).

Cited on the occurrence of fossil footprints at Middletown, Conn. (Anonymous, '38*a*).

Cited on the origin of the Newark rocks of the Connecticut valley (J. D. Dana, '83).

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Holland station, N. J. Boundaries of Newark system near (Cook, '89, p. 11).
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HOLLICK, ARTHUR. 1889.
[Remarks on the pressure of Newark rocks on Staten island.]
In Am. Nat., vol. 23, pp. 1033–1034.
Describes the occurrence of Newark rocks on the north shore of Staten island at Mariner's harbor.

HOLLICK, ARTHUR. 1889a.
[Exposures of Newark rocks on Staten island, N. Y.].
In Staten Island Nat. Hist. Assoc., Proc., Oct. 10, 1889.
Refers briefly to exposure of Newark rocks.

Holts hill (Meriden), Conn. Decomposition of sandstone at (Percival, '42, p. 436).

Holyoke, Mass. Columnar trap of (E. Hitchcock, '55a, pp. 87–88).
Contact of sandstone and trap near (W. M. Davis, '83. p. 262).
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Homestead, N. J. Alteration of rock at (Cook, '82, p. 45).
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Honey Bush, Pa. Trap dikes in (Frazer, '83, p. 246).

HONEYMAN, D. 1867.
Geology of Antigonish county, N[ova] S[cotia].
In Nova Scotia Inst., Proc. and Trans., vol. 1, pt. 4, pp. 106–120.
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HONEYMAN, D. 1874.
Nova Scotian geology. Intercolonial railway.
In Nova Scotia Inst., Proc. and Trans., vol. 3, pp. 345–356.
Brief account of certain Newark rocks near Truro, N. S., pp. 45, 46.

HONEYMAN, D. 1874a.
Nova Scotian geology.
In Nova Scotia Inst., Proc. and Trans., vol. 3, pp. 385–393.
Contains brief references to the trap of Gerrish mountain, Blomidon, Briar island, etc., pp. 386, 387, 388.

HONEYMAN, D. 1878.
Nova Scotia geology, pre-Carboniferous, lower Carboniferous, etc., retrospective to 1859.
In Nova Scotia Inst., Proc. and Trans., vol. 4, pp. 139–487.
Contains brief references to the Newark rocks of Five islands, Great Village, etc., p. 471.

HONEYMAN, D. 1879.
Nova Scotian geology. Kings county.
In Nova Scotian Inst., Proc. and Trans., vol. 5, pp. 21–31.
Includes a short account of the sandstones, trap, amygdaloid, volcanic ash, etc., in the neighborhood of cape Blomidon, N. S., pp. 27–28.

HONEYMAN, D. 1883.
Notes on a polariscopic examination of crystalline rocks of the Yarmouth gold-bearing series.
In Nova Scotia Inst., Proc. and Trans., vol. 6, pt. 1, pp. 7–8.
Contains a brief petrographical comparison of the rocks of cape Blomidon with certain rocks at Jebogue point, N. S., p. 7.

HONEYMAN, D. 1885.
Notes of a polariscopic and microscopic examination of crystalline rocks of Nova Scotia and Cape Breton.
In Nova Scotia Inst., Proc. and Trans., vol. 6, pp. 121–130.
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HONEYMAN, D. 1888.
Geology of Aylesford, Kings county, N[ova S[cotia].
In Nova Scotian Inst., Proc. and Trans., vol. 7, 1886–'87, pp. 7–12.
Contains a brief account of amygdaloid and associated trappean rocks near Morden, on the east shore of the bay of Fundy.

HOOKER [J. D.]. 1847.
[Note of vegetable structure in coal from the Richmond coal field, Virginia.]
In London Geol. Soc., Quart. Jour., vol. 3, pp. 268–269.
Results of a microscopical examination of coal, reported to Charles Lyell.

HOOKER [J. D.]. Cited on organic structure of coal from Richmond coal field, Virginia (Lyell, '47, p. 268).

HOTCHKISS, JED. 1883.
The natural coke of V[irgini]a, reply to Dr. Raymond.
In The Virginias, vol. 4, p. 164.
Refers to the observations of W. B. Rogers and C. Lyell in reference to the origin of the coke referred to.

[HOTCHKISS, JED.] 1883a.
The Richmond, Va., coal field.
In The Virginias, vol. 4, p. 171.
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Virginia minerals for the New Orleans Exposition.
In The Virginias, vol. 5, pp. 139–140, 153.
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HOUGHTON [DOUGLASS]. 1844.
[On the connection of the metallic copper with other trap of Connecticut and Michigan.]
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House's quarry, N. C. Conglomerate at (Emmons, '56, pp. 237–238).
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Fossil plants from (Emmons, '56, pp. 328–329. Emmons, '57, pp. 119–132).

HOVEY, A. H. Opening of copper mine by (Cook, '81, p. 39).

HOVEY, EDMUND OTIS. 1889.
Observations on some of the trap ridges of the East Haven-Bradford region.
Am. Jour. Sci., 3d ser., vol. 38, pp. 361–383, pl. 9.
Abstract in Am. Assoc. Adv. Sci., Proc., vol. 38, pp. 232–233.
Contents: The topography of the region. Its trap belts and sandstone ridges. Position and forms of the trap belts. Particular description of Pond rock, and ridges east of it. Kinds of trap rock in different parts of the region. The amygdaloid, and its relation to that which is nonvesicular. The relation of the sandstone to the trap. Contact phenomena. Main theories which have been advanced to account for the occurrence of the trap. Special discussion of the theory of "contemporaneous overflow." The age of the trap. Concludes that all of the traps in the region described are intrusive.

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HOW, HENRY. 1861.
On gryolite occurring with calcite in apophyllite in the trap of the bay of Fundy.
In Am. Jour. Sci., 2d ser., vol. 32, pp. 13–14.
An analysis of gryolite is given.

HOW, HENRY. 1869.
The mineralogy of Nova Scotia.
Halifax, N. S. Pp. 1–217.
A brief description is given of the occurrence of copper ore on the shores of the bay of Fundy and the Minas basin, pp. 65–66, and at Indian point and Five island, p. 72. A catalogue of mineral localities on pp. 202–208 contains numerous references to Newark localities.

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Contributions to the mineralogy o Nova Scotia.
In Philo. Mag., 4th ser., vol. 41, 1871, pp. —, 274, 5th ser., vol. 1, 1876, pp. 128–138.
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HOWE, A. B. 1876.
On gmelinite from Nova Scotia.
In Am. Jour. Sci., 3d ser., vol. 12, pp. 270–274.
Describes mineral mentioned; gives localities and analysis.
Analysis of minerals composing trap rocks (Hawes, '82, pp. 131–132).
Cited on mineral analysis of trap rock from Bergen hill, N. J. (Shaler, '84, p. 145).

HOWELL, M. A. Trap rock quarried by (Cook, '81, p. 62).

Howellville, Pa. Trap dike near (Lewis, '85, p. 444).

HUBBARD, OLIVER P. 1842.
Chemical examination of a large sample of bituminous coal from the pits of the Midlothian coal mining company, south side of James river, 14 miles from Richmond, Va., in Chesterfield county.
Silliman and Hubbard, 1842.

HUBBARD, OLIVER P. 1850.
The condition of trap dikes in New Hampshire an evidence and measure of erosion.
In Am. Jour. Sci., 2d ser., vol. 9, pp, 158–171.
States the amount of erosion that has taken place in the Connecticut valley and describes certain trap rocks in New Hampshire that are perhaps of the same age as the similar rocks of Massachusetts, etc., p. 170.

HUBBARD, OLIVER P. 1885.
Two varieties of the New Red sandstone used for building in New Haven, Conn.
In New York Acad. Sci., Trans., vol. 5, 1885–1886, pp. 12–13.
Refers briefly to the mineralogical composition and dip of a ridge of sandstone in East Haven, Conn., and to the durability of building stone derived from it.

HUBBARD, O. P. 1889.
[Note concerning a bored well near New Haven, Conn.]
In New York Acad. Sci., Trans., vol. 9, p. 3.
Gives the depth of a well bored by the Winchester Arms Co.

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In Am. Jour. Sci., 3d ser., vol. 31, pp. 321–331, pl. 9.

Abstract in Washington Philo. Soc., Bull., vol. 8, pp. 19–24.

Describes an exposure of columnar trap near Orange N. J., and discusses the origin of the columnar structure in igneous rocks.

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Ingham spring, Pa. Description of a fault near (Lewis, '85, p. 451).

Insects, footprints of. On Connecticut valley sandstone (Warren, '55).

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Trap rocks of (Cook, '82, p. 18).

Invertebrate fossils. Description and discussion of (Jones, '62).

Description of the tracks of (E. Hitchcock, '65, pp. 18–19).

From Pennsylvania, an account of (Lewis, '84).

See also Footprints.

See also Footprints of insects.

INVILLIERS, E. V. d'. **1883.**

Second geological survey of Pennsylvania, report of progress, D3, vol. 11, pt. 1. The geology of the South mountain belt of Berks county.

Harrisburg, pp. i–xxii, 1–441, pl. 4, and 6 maps in atlas.

Contains descriptions, with many observations of dip, of the Newark system in the region referred to, pp. 48–50, 127, 159, 197–226, 239, 317–322, 344–348, 351, 353, 380, 382, 387, 392, and maps in atlas.

INVILLIERS, E. V. d'. **1885.**

Report on the Cornwall iron ore mines, Lebanon county [Pa.].

See Lesley and d'Invilliers. 1885.

INVILLIERS, E. V. d'. **1886.**

Report on the iron ore mines and limestone quarries of the Cumberland-Lebanon valley [Pennsylvania].

In annual report of the geological survey of Pennsylvania for 1886, pt. 4, pp. 1411–1567, with 7 maps.

Contains an account of iron mines near Dillsburg, pp. 1501–1514, and of sandstone quarries in Lebanon valley, pp. 1563–1567.

INVILLIERS, E. V. d'. **1886a.**

The Cornwall iron ore mines, Lebanon county, Pa.

In Am. Inst. Mining Eng., Trans., vol. 14, pp. 873–904, pl. op. p. 874.

Contains an account of dikes of trap rock and their association with iron ore deposits, pp. 876–879; also a description of the stratified rocks of the Newark system exposed at Cornwall, pp. 890–892.

Native, in trap rock of New Jersey (Cook, '74, pp. 56–57).

On the occurrence of, at Berlin, Conn. (E. Hitchcock, '35, p. 232).

Iron in Massachusetts. Brief account of (E. Hitchcock, '41, pp. 448–449).

Iron in North Carolina. Analyses of (Kerr, '75, pp. 225–230. Willis, '86, pp. 305–306).

Brief account of (Anonymous, '66, p. 108. Chance, '85, p. 24).

At Egypt (Emmons, '56, p. 262).

At Gulf (Emmons, '56, p. 262).

Brief account of (Emmons, '57*a*, pp. 9–11. W. R. Johnson, '51, p. 20).

In Dan river coal field (Emmons, '52, p. 154).

In Deep river coal field (Emmons, '52, p. 124. Emmons, '56, pp. 262–265. Olmstead, '24, p. 22. Wilkes, '58, pp. 12–17).

Iron Hill, Pa. Trap dikes near (Lewis, '85, p. 453).

Iron, native, in trap rock of New Jersey (Cook, '74, pp. 56–57).

On the occurrence of, at Berlin, Conn. (E. Hitchcock, '35, p. 232).

Iron ores in Nova Scotia. At Blomidon (Gesner, '36, p. 217).

Brief account of (Harrington, '74, pp. 207, 219. Alger, '27).

In the trap rocks, determination of (How, '75, vol. 1, pp. 136–137).

Near Digby (Jackson and Alger, '33, pp. 235–236).

Iron ore in Pennsylvania. (Frazer, 77*a*, pp. 500–501. Frazer, '82, pp. 129, 135. d'Invilliers, '83, pp. 320–352. H. D. Rogers, '39, p. 22. H. D. Rogers, '58, vol. 1, pp. 86, 87, 88).

Age of, discussed (T. S. Hunt, '76, p. 320. H. D. Rogers, '58, vol. 2, p. 691).

Brief account of (d'Invilliers, '83, p. 239. H. D. Rogers, '58, vol. 2, p. 763.)

Near Cornwall. Detailed description of (Lesley and d'Invilliers, '85).

Near Dillsburg. Discussion concerning (Frazer, '77, pp. 317–331, pl. op. p. 328).

Near Dillsburg. Study of (Frazer, '76*d*).

JACKSON, CHARLES T. **1837.**
First report on the geology of the State of Maine.
Augusta. 12mo, pp. i-viii, 10-190, accompanied by an atlas of 24 plates.
Certain rock in Maine which are traversed by trap dikes are described in this report as being of the age of the "New Red sandstone," but more recent investigations have shown them to be of older date. (The trap dikes of this region may possibly belong to the Newark system of intrusions.) Cross references to this report are not given in the present index.

JACKSON, CHARLES T. **1841.**
First annual report on the geology of the State of New Hampshire.
Concord, N. H. 12mo, pp. i-iv, 5-164.
Describes the occurrence of Newark rocks in Northfield, Mass., and considers the mode of formation of the Connecticut valley sandstone. The Newark rocks of the Connecticut valley, exclusive of the intrusive rocks, do not extend north of the Massachusetts-New Hampshire boundary.

JACKSON, C. T. **1841a.**
[Remarks on joints in the trap dikes of Nova Scotia.]
In Am. Jour. Sci., vol. 41, p. 173; also in Am. Assoc. Geol. and Nat., Proc., p. 26.
Abstract of remarks on a paper by Prof. Mather concerning joints in rocks.
Calls attention to the columnar structure of larger trap masses and the prevalence of a similar structure from side to side in small dikes. Refers these phenomena to manner of cooling.

JACKSON, C. T. **1845.**
Nature of the minerals accompanying trap dikes which intercept various rocks.
In Am. Assoc. Geol. and Nat., Proc., 6th meeting, pp. 28-31.
States that several systems of trap dikes occur in New England. Describes briefly those intersecting the Connecticut valley sandstone and notes the metamorphic effects produced on contiguous stratified beds.

JACKSON, C. T. **1850.**
[On the age of certain sandstones of the United States.]
In Boston Soc. Nat. Hist., Proc., vol. 3, pp. 335-336, 337-338.
Brief statement in reference to the supposed age of the sandstone of lake Superior, and of the sandstone of the Connecticut valley, New Jersey, etc. It is suggested that the latter may belong to the Silurian system. The occurrence of trap in the Connecticut valley is briefly described.

JACKSON, C. T. **1850a.**
Analysis of red marl from Springfield, Mass.
In Am. Assoc. Adv. Sci., Proc., vol. 4, pp. 337-338.
Presents an analysis of a highly ferruginous marl or shale adjacent to trap rock.

JACKSON, C. T. **1853.**
[Age and structure of the Deep river coal field, N. C.]
In Am. Acad., Proc., vol. 3, 1852-1857, pp. 68-69.
A brief abstract of remarks relating to the structure and possible age of the coal field mentioned. Followed by brief remarks by W. B. Rogers and L. Agassiz.

JACKSON, CHARLES T. **1853a.**
Sur les mines de cuivre et de houille de la Caroline du Nord.
In Geol. Soc. Trans. Bull., 2d ser., vol. 10, 1852-1853, pp. 505-506.
Extract from a letter to M. Delesse, giving a brief account of the Deep river coal field, N. C. Refers the rocks containing coal to the New Red sandstone. Cites Rogers and Agassiz in reference to the age of the Richmond coal field.

JACKSON, C. T. **1855.**
[On raindrop impressions in footprints.]
In Boston Soc. Nat. Hist., Proc., vol. 5, p. 189.
Remark on a paper by J. C. Warren.

JACKSON, C. T. **1855a.**
[On the identity in age of the coal-bearing rocks of Virginia and North Carolina.]
In Boston Soc. Nat. Hist., Proc., vol. 5, p. 186.
Remarks on a paper by W. B. Rogers. Suggests that the rocks of the Newark system may be the equivalent of the Lias of Europe.

JACKSON, C. T. **1856.**
[Trap dikes in relation to Zeolite minerals, native copper, etc.]
In Boston Soc. Nat. Hist., Proc., vol. 6, pp. 23-24.
Reference to the agency of trap rocks in producing various minerals.

JACKSON, CHARLES T. **1856a.**

[On the Deep river coal field, N. C.]

In Boston Soc. Nat. Hist., Proc., vol. 6, pp. 30–33.

Brief account of an exploration for coal near Egypt, N. C., with a section of the coal-bearing strata near the bottom of the Egypt shaft. Analyses of coal are given; also the result of some experiments in reference to the value of the coal for gas-making.

JACKSON [C. T.]. **1856b.**

[Remark on unconformable interruption.]

In Boston Soc. Nat. Hist., Proc., vol. 6, p. 184.

Mentions the occurrence of the Newark of the Connecticut valley resting on gneiss, granite, etc., as an illustration of interruption where the whole Paleozoic group is wanting.

JACKSON, C. T. **1859.**

[Note on the copper mines, so called, at Elk run, Fauquier county, Va.]

In Am. Assoc. Adv. Sci., Proc., vol. 6, 1856–1859, p. 183.

Brief statement of the occurrence of copper minerals in trap dike breaking through sandstone.

JACKSON, C. T. **1859a.**

[Amygdaloid minerals of the Nova Scotia and lake Superior traps.]

In Boston Soc. Nat. Hist., Proc., vol. 7, p. 46.

JACKSON, C. T. **1860.**

[On the age of the red sandstone of Perry, Me.; Nova Scotia; Keweenaw point, Mich.; Connecticut valley, etc.]

In Boston Soc. Nat. Hist., Proc., vol. 7, p. 396–398.

The sandstones at the various localities mentioned are briefly compared and certain general conclusions inferred as to their age.

JACKSON [C. T.]. Cited on the age of the Newark system (Lea, '53, pp. 185, 188. W. C. Redfield, '51).

Cited on analysis of coal from North Carolina (Genth, '71).

Cited on the extent of Triassic rocks in America (Archaic, '60, pp. 634–636, 646–655).

JACKSON, CHARLES T., and FRANCIS ALGER. **1828-1829.**

A description of the mineralogy and geology of a part of Nova Scotia.

In Am. Jour. Sci., vol. 14, 1828, pp. 305–330; map op. p. 305, vol. 15, 1829, pp. 132–160, pls. 1–2.

This paper was published with additions as "Remarks on the mineralogy and geology of Nova Scotia," in Am. Acad., Mem., n. s., vol. 1, 1833, and appeared as an independent publication under the title "Remarks on the mineralogy and geology of the peninsula of Nova Scotia; Cambridge, 1832, 4to. See Jackson, Charles T., and Francis Alger, 1833.

JACKSON, CHARLES T., and FRANCIS ALGER. **1833.**

Remarks on the mineralogy and geology of Nova Scotia.

In Am. Acad., Mem., n. s., vol. 1, pp. 217–330, pl. 4, and map.

Issued separately as "Remarks on the mineralogy and geology of the peninsula of Nova Scotia." Cambridge, 1832, 4to, pp. 1–116, pls. 1–4, and map. Published originally as "A description of the mineralogy and geology of a part of Nova Scotia" in Am. Jour. Sci., vol. 14, 1828, pp. 305–330, and map op. p. 305, vol. 15, 1829, pp. 132–160, pls. 1–2.

Reviewed by C. Moxon, in The Geologist [London], vol. 1, 1842, pp. 301–306.

Describes the trap outcrops along the east shore of the bay of Fundy and on the shore of Minas basin, etc. The presence of amygdaloid beneath trap at many localities is noted, and also the metamorphism of sedimentary rocks beneath the amygdaloid. A large portion of the report is devoted to describing the occurrence of minerals in the trap. The Newark sedimentary rocks are not clearly separated from similar Carboniferous rocks.

JACKSON and ALGER. Cited on lignite in Nova Scotia (Dawson, '78, p. 99).

Cited on the relation of trap and sandstone in Nova Scotia (W. M. Davis, '83, p. 285).

Cited on the trap of Nova Scotia (Beaumont, '34, pp. 247–248.

JACKSON, J. B. S. **1854.**

[Remarks on fossil footprints.]

In Boston Soc. Nat. Hist., Proc., vol. 5, 1854–1856, p. 30.

Brief remarks in discussion of a paper by Bouvé.

Jacksonville, N. J. Course of trap ridge near (Cook, '82, p. 55).

Description of conglomerate near (Kitchell, '56, pp. 144, 145).

Jacksonwald, Pa. Dip of strata, and exposure of trap near (d'Invilliers, '83, pp. 217-218, 219, 220).

Prevailing dip near (d'Invilliers, '83, p. 49).

Sandstone and trap at (d'Invilliers, '83, p. 203).

Trap dikes near (d'Invilliers, '83, pp. 200, 201).

JAMES, JOSEPH F. **1889.**

On variations; with special reference to certain Paleozoic genera.

In Am. Nat., vol. 23, pp. 1071–1087.

Refers to *Dendrophycus triassicus*, and states that it is probably an inorganic marking.

JAMES, THOMAS P. **1876.**

Handbook of the State of Georgia.

Atlanta, Ga., pp. i–vii, 1–256, and a geological map of Georgia.

Contains reference to trap dikes, pp. 38, 40, and map.

Jarrettown, Pa. Trap dike near (Lewis, '85, p. 441.

JOHNSON, WALTER R. 1850.
The coal trade of British America together with researches on the character and practical values of American and foreign coals.
Washington and Philadelphia, pp. 1-179.
Gives a synopsis of the character and efficiency of the coal from the Richmond coal field, pp. 133-134, and table op. p. 134. Analysis of the natural coke, pp. 155-156.
Analysis of coals from the coal fields of North Carolina, pp. 161-166. Natural coke from Clover hill, pp. 175-176.

JOHNSON, WALTER R. 1851.
Report on the coal lands of the Deep river mining and transportation company, with analyses of the minerals.
Albany, pp. 1-21, pls. 1-5.
Contains a number of observations on the dip and strike of the strata in the coal field referred to, as well as several analyses of coal from the same field.

JOHNSON, WALTER R. 1851a.
On the coal formation of central North Carolina.
In Am. Assoc. Adv. Sci., Proc., vol. 4, 1850, pp. 274-276.
Refers to the unconformity of Newark system with crystalline rocks beneath. Thickness of coal. Analyses of coal from Deep river coal field.

JOHNSON, W. R. Analysis of coal by (Kerr, '75, pp. 293-294).
Analysis of coal from the Richmond coal field, Va. (Clifford, '87, p. 10).
Cited on analyses of North Carolina coals (Macfarlane, '77, pp. 525-526).
Cited on composition of coal from the Richmond coal field, Va. (Chance, '85, p. 19).

Johnson's ferry, N. J. Boundary of Newark at (Cook, '68, p. 175).
Conglomerate at (Cook, '68, p. 210. Cook, '82, p. 41).
Detailed description of calcareous conglomerate near (H. D. Rogers, '40, pp. 140-141).
Dip in conglomerate near (Cook, '82, p. 27).
Dip in sandstone at (Cook, '82, p. 28).
Dip near (Cook, '68, p. 198).
Dip of conglomerate at (Cook, '79, p. 29).
Sandstone near (Cook, '68, p. 97).

Joints and veins in Richmond county, N. Y. (Mather, '43, p. 625).
In flagstone at Milford, N. J. (Cook, '68, p. 521. Shaler, '84, p. 144).
In sandstone and shale near Chatham, N. J. (H. D. Rogers, '40, p. 133).
In sandstone and trap (Hitchcock, '41*a*).
In sandstone of the Connecticut valley (Silliman, jr., '41).
In sandstone in New Jersey. Table of (Cook, '68, p. 201).
In sandstone in Washington valley, N. J. (Cook, '81, p. 53).
In sandstone on the Delaware, N. J. (H. D. Rogers, '40, p. 121).
In trap (Jackson, '41*a*).

Joints—continued.
In trap in New Jersey (Cook, '68, pp. 204-205).
On Prince Edward island (Dawson and Harrington, '71, p. 21).

Jolly river, N. S. Coal Measures at, overlain by New Red sandstone (Gesner, '43).

JONES, T. RUPERT. 1862.
A monograph of the fossil Estheria.
In Paleontological Soc. [London], Monograph, 4to, pp. i-viii, 1-134, pls. 1-5.
Reviews what has been written on the crustaceans of the Newark system, and also on the determination of the age of the system. Gives sections in the Dan river and Deep river areas, N. C., after Emmons, and at Phœnixville, Pa., after Wheatley, pp. 84-97. Describes two species of Candona, pp. 123-126. Cites J. Marcou on the age of the system, p. 134.

JONES, RUPERT T. 1862a.
Trails, tracts, and surface-markings.
In The Geologist, vol. 5, pp. 128-139, pl. 7.
Refers briefly to the footprints of the Connecticut valley.
Footprints, brief reference to (Jones, '62*a*).

JONES, R. T. Cited on the age of Richmond coal field, Virginia (Hull, '81, p. 460).

Jones's falls, N. C. Age of rock exposed near (Emmons, '56, pp. 276-277).
Breadth of the Newark area near (Emmons, '56, p. 241).
Conglomerate at (Emmons, '56, pp. 237-238. Wilkes, '58, p. 5).
Silicified trees near (Emmons, '56, p. 284).
Thickness of the Newark near (Emmons, '56, pp. 231-232).

Jones's mine, Pa. Description of trap dikes near (H. D. Rogers, '58, vol. 2, p. 687).
Section of (H. D. Rogers, '58, vol. 1, p. 90).
Trap dikes at (Lesley, '83, p. 193).

JOYCE. See Robinson and Joyce.

JULIEN, ALEXIS A. 1880.
On the geological action of the humus acids.
In Am. Assoc. Adv. Sci., Proc., vol. 28, pp. 311-410, map op. p. 320.
Discusses the origin of the prevailing brownish-red color of the Newark rocks, pp. 406, 407.

JULIEN, A. A. Cited on the decay of Newark sandstone (Smock, '90, p. 301).

Junction of Newark system and Primary rocks at "Glen" in Leyden, Mass. (E. Hitchcock, '35, p. 223).
In Leyden, Mass. (E. Hitchcock, '41, p. 448).

Junction of Newark and Silurian rocks (Cook, '79, pp. 33, 39).
Of trap and associated sandstones, shales, etc., in Newark system. Detailed description and discussion of (W. M. Davis, '83).
Of trap and sandstone in the Connecticut valley (E. Hitchcock, '41, pp. 657-659).

Kedidica hook, N. Y. Account of (Pierce, '20, pp. 185-187).

KEELER, C., and SON. Stone quarry of, near Greensburg, N. J. (Cook, '81, p. 56).

LEA, ISAAC A.—Continued.

In Philadelphia Acad. Nat. Sci., Proc., vol. 5, 1852, pp. 171-172, 205.

Describes the position and character of the beds in which the fossil bones were found, and discusses the relation of the strata to outcrop of calcareous conglomerate found elsewhere in the Newark system, pp. 171-172. Remarks continued on p. 205, where the name *Clepsysaurus pennsylvanicus* for certain fossil bones is proposed.

LEA, ISAAC. 1853.

Description of a fossil saurian of the New Red sandstone formation of Pennsylvania; with some account of that formation.

In Philadelphia Acad. Nat. Sci., Jour., 2d ser., vol. 2, 1850-1854, pp. 185-202, pl, 17-19.

Abstract in Am. Jour. Sci., 2d ser., vol. 14, p. 451.

Presents a critical review of the works of previous writers on the paleontology and the geological position of the Newark system, followed by a description of a genus of fossil saurians, based on certain fossil bones found in upper Milford, Lehigh county, Pa.

LEA, ISAAC. 1855.

[Note on the tracks of crustaceans and other markings on the sandstone of Connecticut valley.]

In Boston Soc. Nat. Hist., Proc., vol. 5, pp. 276-277.

An extract from a letter referring to a slab of sandstone from Greenfield, Mass.

LEA, ISAAC. 1856.

Remarks on a tooth of a sauroid reptile, from near Phœnixville [Pa.].

In Philadelphia Acad. Nat. Sci., Proc., vol. 8, 1856, pp. 77-78.

Abstract in Am. Jour. Sci., 2d ser., vol. 22, pp. 122-123; also Neues Jahrbuch, 1857, p. 253.

Describes the tooth of a reptile to which a name is given. Names also two species of Posidonia, and a fossil footprint from the locality that yielded the reptilian remains.

LEA, ISAAC. 1857.

[Remarks on fossils from Phœnixville, Pa.]

In Philadelphia Acad. Nat. Sci., Proc., vol. 9, 1858, p. 149.

Brief abstract of remarks on a fossil bone and a coprolite from the tunnel at Phœnixville, Pa.

LEA, ISAAC. 1857a.

[Brief remarks on the identity of the rocks near Gwynned, Pa., with those at Phœnixville, Pa.]

In Philadelphia Acad. Sci., Proc., vol. 9, 1858, p. 173.

Brief record of remarks based on fossils from the localities named.

LEA [ISAAC]. 1858.

[Remarks on the age of the Newark system.]

In Philadelphia Acad. Nat. Sci., Proc., vol. 10, pp. 90-92.

LEA, I[SAAC]—Continued.

A brief statement of the opinions and conclusions of various geologists concerning the geological position of the Newark system.

LEA [I.]. Cited on the age of the Newark system (Lea, '58).

Cited on the age of the Newer Red sandstone of Prince Edward island (Leidy, '54, p. 330).

Cited on the age of the Red sandstone of Prince Edward island (Owen, '76, p. 361).

Cited on fossil crustaceans from the Newark system (Jones, '62, p. 86).

Cited on fossil plants from Turners Falls, Mass. (Emmons, '57, p. 134).

Cited on fossil reptiles from North Carolina (Emmons, '57, p. 73).

Cited on fossil reptiles from Pennsylvania (Emmons, '56, pp. 298, 308. Frazer, '77*a*, p. 497. H. D. Rogers, '58, vol. 2, p. 692-693).

Cited on fossil reptiles from Pennsylvania and New Jersey (H. D. Rogers, '58, vol. 2, p. 695).

Notice of the description of reptilian fossils by (Miller, '79-'81, vol. 2, p. 152).

Lead, at Berlin, Conn. (E. Hitchcock, '35, p. 232).

In Massachusetts, brief account of (E. Hitchcock, '41, p. 448).

Leakesville, Va. Boundary of the Newark near (W. B. Rogers, '39, p. 75).

Description of geology near (W. B. Rogers, '39, p. 78).

Leaksville, N. C. Analysis of coal from near (Chance, '85, pp. 64-65).

Boundary of the Newark near (Mitchell, '42, p. 134).

Brief account of the rocks near (Emmons, '52, p. 149).

Character and dip of rocks at (Emmons, '56, p. 255).

Coal at (Emmons, '57, p. 33. Kerr, '75, p. 145. Kerr, '75, p. 295. McGehee, '83, p. 77).

Conglomerate near (Emmons, '52, p. 152. Emmons, '56, p. 256).

Dip and strike at (Emmons, '56, pp. 257, 258).

Dip of coal at (McGehee, '83, p. 77).

General section of Newark rocks near (Jones, '62, p. 89).

Newark system near (Macfarlane, '77, p. 527).

Reference to fossil fishes from (E. Hitchcock, '41, p. 440).

Reptile remains from (Emmons, '56, p. 309. Emmons, '57, p. 81).

Section near (Emmons, '52, p. 149. Emmons, '56, p. 257).

Thickness of coal seams near (Chance, '85, p. 64).

Thickness of sandstone at (Emmons, '57, p. 22).

Lebanon, N. J. Analysis of trap near (Cook, '68, p. 218).

Boundaries of the Newark system near (Cook, '89, p. 11. H. D. Rogers, '40, p. 16. H. D Rogers, '40, p. 118).

Boundary of trap near (Cook, '68, p. 193).

LEIDY, [JOSEPH]. 1876.
Fish remains of the Mesozoic red shales [of Pennsylvania].
In Philadelphia Acad. Nat. Sci., Proc., vol. 28, p. 81.
Records the finding of obscure fish remains at Yerke's station on the Perkiomen railroad, in Montgomery county, Pa.

EIDY, J. Cited on character of certain footprints from Turners Falls, Mass. (Deane '56).
Cited of fossil reptiles from North Carolina (Emmons, '57, p. 60).
Cited on fossil reptiles from Pennsylvania and North Carolina (H. D. Rogers, '58, vol. 2, p. 695–697).
Notice of the description of reptilian fossils by (Miller, '79–'81, vol. 2, p. 152).

LEITH-ADAMS, A. Cited on Jurassic reptiles from high northern latitudes (Hull, '87, p. 95).

Lemer's ore pit, Pa. Report on (Frazer, '77, p. 225).

Leonia, N. J. Indurated shale near (Darton, '90, p. 52).

Leopard, Pa. Trap dike near (Lewis, '85, p. 444).

Lepreuce, N. B. Age of rocks at (Bailey, '65, p. 5).

LESCHARBOT. Cited on native copper from the bay of Fundy (Gilpin, '77, p. 749).

LESLEY, J. P. 1856.
Manual of coal and its topography. Illustrated by original drawings, chiefly of facts in the geology of the Appalachian region of the United States of North America.
Philadelphia, 12 mo, pp. i–xii, 1–224.
Contains a brief account of the origin of the trap ridges of the Newark system of Pennsylvania and New Jersey, pp. 132–133. Refers to lamination in the trap of East and West Rocks, Conn., p. 162.

LESLEY, J. PETER. 1863.
[On an asphalt vein in West Virginia.]
In Am. Phil. Soc., Proc., vol. 9, pp. 183–197, pl. 3–4.
Contains theoretical consideration respecting the deposition and erosion of the Newark system, pp. 188–189.

LESLEY, J. PETER. 1864.
[On the discovery of lignite in Franklin county, Pa., and its bearing on the determination of the age of the present surface of the land.]
In Am. Phil. Soc., Proc., vol. 9, pp. 463–482, and 4 plates.
Discusses the manner in which the Newark rocks of Pennsylvania were deposited.

LESLEY, J. P. 1873.
[Remarks on iron ores near Doylestown, Pa.]
In Am. Philo. Soc., Proc., vol. 13, p. 264.

[LESLEY, J. PETER]. 1874.
Notes on the geology of Lehigh county, Pa.
In Second Geol. Surv. of Pennsylvania, 1874. Report on the Brown Hematite ore ranges of Lehigh county, vol. D, pp. 57–66.
Contains brief observations on the Newark rocks of Lehigh county, pp. 61–64.

LESLEY, J. P. 1880.
Geological map of Cumberland county, Pa.
In Second Geol. Surv. of Pennsylvania, vol. D, 5, atlas. No text accompanying.

LESLEY, JOSEPH PETER. 1883.
The geology of Chester county after the surveys of Henry D. Rogers, Persifor Frazer, and Charles E. Hall.
In second geological survey of Pennsylvania, vol. C, 4, pp. 1–54, 63–214, 351–354, pl. 2.
Unconformity at base of the Newark system with hypothesis to account for it, p. 22. Folding of the Appalachians previous to the Newark, p. 132. A general statement of the character of the Newark of Pennsylvania, compiled principally from reports of previous observers, pp. 178–215.

LESLEY, JOSEPH PETER. 1885.
Second geological survey of Pennsylvania. Report of progress.
A geological hand atlas of the sixty-seven counties of Pennsylvania, embodying the the results of the field work of the survey from 1874 to 1884.
Harrisburg, pp. i–cxii, pl. 1–61, and 2 maps.
Presents brief sketches of the geology of each county, in explanation of accompanying maps.

LESLEY, J. PETER. 1886.
Geology of the Pittsburg coal region.
In Am. Inst. Min. Eng., Trans., vol. 14, 1885–1886, pp. 618–656, and on map op, p. 656.
General remarks on the deposition of the Newark rocks of Pennsylvania, p. 630. Area occupied shown on the map op. p. 656.

LESLEY, J. P. 1891.
On an important boring through 2,000 feet of Trias, in eastern Pennsylvania.
In Am. Philo. Soc., Proc., vol. 29, pp. 20–25.
Gives a record of strata passed through in boring a well in Bucks county, 18 miles north of Easton, Pa. In remarks on the paper, B. S. Lyman states the rocks penetrated belong in the central portion of the Newark system, which is 2,100 feet thick.

LESLEY, J. P. Cited on former extent of the Newark system (Macfarlane, '79, p. 41).
Cited on mode of formation of the Richmond coal field, Virginia (Clifford, '87, pp. 6, 29–30).
Cited on overflow trap sheets in Pennsylvania (W. M. Davis, '83, p. 298).
Cited on relation of trap and sandstone in Pennsylvania (W. M. Davis, '83, p. 287).
Cited on structure and mode of formation of the Richmond coal field, Virginia (Macfarlane, '77, pp. 510–514).

LESLEY, J. P., and PERSIFOR FRAZER. 1876.
Geological map of Adams county, Pa.
In second geological survey of Pennsylvania, vol. D 5, atlas. No text accompanying.

LESLEY, J. P., and E. V. d'INVILLIERS. 1885.
Report on the Cornwall iron ore mines, Lebanon county, Pa.

LESLEY, J. P., and E. V. d'INVILLIERS—Continued.

In Ann. Rep. of the Geol. Surv. of Pennsylvania for 1885; Harrisburg, Pa., 1886, pp. 491–570, and plates.

Gives a detailed description of the iron ore body at the Cornwall mines, and states its relation to the trap and sedimentary beds of the Newark system. A fault having a throw of several thousand feet is stated to exist at the junction of the Newark rocks with the bordering formations on the west; strikes and dip, character of the trap dike, etc., are given.

LESQUEREUX, L. 1876.

On the tertiary flora of the North American lignitic, considered as evidence of the age of the formation.

In annual report of the United States geological and geographical survey of the Territories, embracing Colorado and parts of adjacent Territories, being a report of progress for the year 1874. By F. V. Hayden. Washington (Interior Dep.), pp. 275–365, pls. 1–8.

Contains a brief reference to the age of the Newark system as indicated by fossil plants.

LESQUEREUX, LEO. 1879.

[A fossil tree trunk found at Belleville, N. J.]

In [Annual report on the geology of New Jersey for 1879], pp. 26–27.

A quotation from a letter in reference to a photograph of a fossil tree trunk supposed to be a Lepidodendron.

Lesser cross roads, N. J. Copper ores near (Cook, '68, p. 678).

Dip in shale near (Cook, '82, p. 29).

Dip near (Cook, '68, p. 198).

Leverett, Mass. Note on conglomerate near (Nash, '27, p. 247).

Stratigraphy in (Walling, '78).

LEWIS, HENRY CARVILL. 1880.

A new locality for lignite.

In Philadelphia Acad. Nat. Sci., Proc., vol. 32, p. 281.

Describes the occurrence of lignite in Montgomery county, Pa., in what the author seems to regard as Newark beds.

LEWIS, HENRY CARVILL. 1880a.

The iron ores and lignite of the Montgomery county valley.

In Philadelphia Acad. Nat. Sci., Proc., vol. 32, pp. 282–291.

Contains a few observations on the Newark system in the region referred to.

LEWIS, HENRY CARVILL. 1880b.

On a new fucoidal plant from the Trias [of New Jersey].

In Philadelphia Acad. Nat. Sci., Proc., vol. 32, pp. 293–294.

Abstract in Neues Jahrbuch, 1882, p. 138.

Describes and figures the cast of what is described as a fossil fucoid, under the name of *Palæophycus limaciformis*, from Milford, N. J.

LEWIS, H. C. 1882.

On a fault in the Trias near Yardleyville, Pa.

In Philadelphia Acad. Nat. Sci.. Proc., vol, 34, pp. 40–41.

Describes the occurrence of a dike of trap coincident with a fault between sandstone and conglomerate. Refers also to change in the dip of sandstone and shale produced by trap dikes.

LEWIS, H. CARVILL. 1882a.

The geology of Philadelphia.

In Franklin Inst. Journal, 3d ser., vol. 85, 1883 pp. 359–374, 422–427.

Includes a brief popular account of the general features of the Newark system near the locality mentioned, together with a reference to the reptilian fossils found in the same beds, and the mode of origin of the associated trap rock, pp. 426–427.

LEWIS, H. CARVILLE. 1884.

[Note on Newark fossils from near Phœnixville, Pa.]

In Science, vol. 3, p. 295.

States that two species of Unio, together with undetermined marine shells and remains of plants and animal, have been obtained near the town mentioned.

LEWIS, H. CARVILL. 1885.

A great trap dike across southeastern Pennsylvania.

Am. Phil. Soc., Proc., vol. 22, pp. 438–456, map op. p. 440.

Abstract in Science, vol. 4, p. 328; also in Am. Assoc. Adv. Sci., Proc., vol. 33, pp. 402–403, and in Neues Jahrbuch, 1887, p. 74.

Reviewed by Persifor Frazer in Am. Philo. Soc., Proc., vol. 21, pp. 691–694.

Describes in detail the course of a trap dike which enters Pennsylvania at Penmar at the southwest and extends nearly to the Delaware on the east. The course of the dike is shown on the map op. p. 440. The association of the dike with a great fault in Bucks county is discussed.

A criticism of this paper by P. Frazer is replied to, p. 456. For Frazer's rejoinder, see Frazer, 1884.

LEWIS, H. C. Review of a paper by, on a great trap dike across southeastern Pennsylvania (Frazer, '84).

Lewisburg, Pa. Contact metamorphism near (H. D. Rogers, '58, vol. 2, pp. 688–689).

Sandstone from (E. C. Hall, '78, p. 36).

Trap dikes near (H. D. Rogers, '58, vol. 2, p. 688).

Trap hills near (H. D. Rogers, '58, vol. 2, p. 688).

Leyden, Mass. Contact of Newark system and Primary rocks in (E. Hitchcock, '35, p. 223).

Description of the gorge and glen in (E. Hitchcock, '41, pp. 285–286).

Dip and strike at (E. Hitchcock, '41, p. 448).

Dip of sandstone in (E. Hitchcock, '35, p. 223).

Junction of Newark system and Primary rocks in (E. Hitchcock, '41, p. 448).

LOPER, S. WARD. 1891.
Two belts of fossiliferous black shale in the Triassic formation of Connecticut.
See Davis and Loper, 1891.

LOUGHRIDGE, R. H. 1884.
Report on the cotton production of the state of Georgia [etc.].
In Tenth Census of the United States, Washington (Interior Dept., Census Office), 4to, vol. 6, part 2, pp. 259-450).
States that the Newark system is probably represented in Georgia by trap dikes and by clay slates adjacent to the metamorphic region, p. 279.

LYELL, CHARLES. 1842.
On the fossil footprints of birds and impressions of raindrops in the valley of the Connecticut.
In London Geol. Soc., Proc., vol. 3, 1838-1842, pp. 793-796.
Republished in Am. Jour. Sci., vol. 45, 1843, pp. 394-397.

LYELL, CHARLES—Continued.
Describes the sandstone formation of the Connecticut valley and New Jersey, with its fossil tracks and other impressions. Considers the conditions of its deposition, relation to the hypogene rocks, age, etc.

LYELL [CHARLES]. 1842a.
[Remarks on the cause of the prevailing dip of the New Red sandstone of the Connecticut valley and of New Jersey and Pennsylvania.]
In Am. Jour. Sci., vol. 43, pp. 170, 172; also in Am. Assoc. Geol. and Nat., Proc., pp. 63, 64, 66.
Brief remarks on a paper by Edward Hitchcock.

LYELL, CHARLES. 1843.
Fossil footprints.
In lectures on geology, delivered at the Broadway tabernacle, in the city of New York. Lecture VI, pp. 37-43.
Contains a brief account of fossil footprints, fossil fishes, etc., from New Jersey and the Connecticut valley.

LYELL, CHARLES. 1845.
Travels in North America, with geological observations on the United States, Canada, and Nova Scotia.
London, 12mo, vol. 1, pp. i-xii, 1-316, pl. 1, 3-5, vol. 2, pp. i-viii, 1-272, pl. 2, 6-7.
Another edition of this work was issued in New York, 1845, in two volumes, 12mo, but without a number of the plates that accompany the edition mentioned above. A second English edition appeared in 1855. A German edition translated by Emil Th. Wolff, was published at Halle in 1846.
Reviewed in Quart. Jour. Geol. Soc., London, vol. 1, pp. 389-399, and by E. Emmons in Am. Quart. Jour. Agri. and Sci., vol. 2, pp. 265-267.
Refers briefly to the sandstone and trap near New Haven, Conn., vol. 1, p. 13, and to the same formation in New Jersey, p. 15. Describes also a visit to the Connecticut valley in Massachusetts, in company with E. Hitchcockpp, . 251-255. Mentions the occurrence of sandstone, trap, etc., at cape Blomidon, N. S., vol. 2, pp. 271-272. A colored geological map of the eastern portion of the United States forms the frontispiece of vol. 2. A geological sketch map of the United States forming plate op. p. 75, in vol. 1 of the New York edition, does not appear in the London edition. Mentions also the occurrence of sandstone, trap, amygdaloid, etc., at cape Blomidon, N. S., vol. 2, p. 271.

LYELL, CHARLES. 1847.
On the structure and probable age of the coal field of the James River, near Richmond, Va.
In Quart. Jour. Geol. Soc., London, vol. 3, pp. 261-280, pls. 8-9.

LYELL, CHARLES—Continued.

Abstract in Am. Jour. Sci., 2d ser., vol. 4, pp. 113–115.

Geological structure of the coal field, p. 261. Vertical calamites, p. 262. Thickness of coal, p. 263. Section showing the geological position of the coal-bearing rocks, p. 263. Section of Midlothian coal mine, p. 265. Junction of coal and granite in Blackheath mines, p. 266. Organic structure and mineral composition of the coal, p. 268. Vegetable structure of mineral charcoal from Clover hill mines, p. 268. Analyses of coals and coke, p. 270. Beds of coal changed to coke by the action of trap, p. 270. Natural coke, p. 272. Position of the trap, p. 273. Age of the coals as determined by organic remains, p. 274. Fossil shells, p. 274. Fossil fishes, p. 275. Whether the strata are of marine or fresh-water origin, p. 278. Fossil plants, p. 278. The coal measures probably of the age of the inferior Oolitic and Lias, p. 279.

LYELL, CHARLES. 1849.

A second visit to the United States of North America.

London, 1849, vol. 1, pp. i–xii, 1–368; vol. 2, pp. i–xii, 1–385.

Second ed. not seen.

Third ed., London, 1855, in two volumes, paged as in 1st ed. Contains an account of a visit to the Richmond coal field, Virginia, vol. 1, pp. 279–288.

LYELL, CHARLES. 1851.

On fossil rain marks of the Recent, Triassic, and Carboniferous periods.

In Quart. Jour. Geol. Soc., London, vol. 7, pp. 238–247.

Describes raindrop impressions from Newark and Pompton, N. J. Gives figures of raindrop impressions and of hail impressions from Pompton, copied from C. W. Redfield, pp. 238, 242–244.

LYELL, C. 1851a.

On the discovery of some fossil reptilian remains and landshells in the interior of an erect fossil tree in the coal measures of Nova Scotia, with remarks on the origin of coal fields and the time required for their formation.

In Roy. Inst. [London], Proc., vol. 1, pp. 281–288.

Gives a brief account of the area, remarks the absence of reptilian remains in, p. 283.

LYELL, CHARLES. 1851b.

[Origin of raindrop impressions.]

In Am. Assoc. Adv. Sci., Proc., vol. 5, p. 74.

Quotation from a letter in a paper by W. C. Redfield.

LYELL, C. 1851c.

On impressions of raindrops in ancient and modern strata.

Royal Inst. [of Great Britain], Proc., vol. 1, pp. 50–53.

Mentions raindrop impressions from New Jersey.

LYELL, CHARLES. 1852.

Inferences deducible from the raindrop impressions in the Triassic and Carboniferous rocks.

In Ann. Sci. Discov., p. 261.

Brief extract from a lecture in which the impressions of raindrops and associated impressions on certain rocks are interpreted.

LYELL, CHARLES. 1854.

Special reports on the geological, topographical, and hydrographical departments of the exhibition.

In general report of the British commissioners of the New York industrial exhibition in 1853, London, 4to, pp. 1–50.

Abstract in France, Geol. Soc., Bull., 2d ser., vol. 12, part 1, pp. 400–428.

Describes briefly the rocks of the Deep river basin, N. C., and of the Chesterfield basin (Richmond coal field), Va., referring to them as Oolite or Lias. The extent and characteristics of the Newark system in Massachusetts, Connecticut, New Jersey, and Pennsylvania, also receives attention, with special reference to their economic products. The character of the trap rocks in these states and their relation to associated stratified rocks is also treated.

LYELL, C. 1857.

[Remarks on the age of the Richmond coal field, Va.]

In geology of North America, by Jules Marcou, Zurich., 1858, 4to, p. 16.

In a letter to C. Marcou, states that C. Bunbury has changed his statement as to the age of the plants of the Richmond coal field, on account of a change in the determination of the age of the beds with which they were compared.

LYELL, CHARLES. 1866.

Elements of Geology.

New York, 6th ed., pp. i–xvi, 1–803.

Published previously as "A manual of elementary geology," several editions.

Contains a condensed description of the Richmond coal field, Va., the Deep river coal field, N. C., and of the sandstone, etc., of the Connecticut valley.

LYELL, C. 1871.

The Student's Elements of Geology.

London, 12mo, pp. i–xix, 1–624.

Contents relating to the Newark sandstone of the Connecticut valley, p. 361.

Coal field of Richmond, Va., p. 362. Mammalian remains, p. 364. Low grade of early mammals favorable to the theory of progressive development, p. 364.

LYELL, C. Cited on age of certain rocks in Nova Scotia (Dawson, '78, p. 109).

Cited on age of Newark system (Dewey, '57. Lea, '58. Newberry, '88, p. 10).

Cited on age of the Newark system of Virginia (Horner, '46).

Cited on age of the Richmond coal field, Va. (Hull, '81, p. 460. Marcou, '49, pp. 273–274.

LYELL, C.—Continued.
Marcou, '58, p. 16. W. C. Redfield, '56, pp. 185, 187).
Cited on coal mining in the Richmond coal field (Fontaine, '79, pp. 35, 36).
Cited on fossil crustaceans from the Newark system (Jones, '62, pp. 85, 86).
Cited on the fossil fishes of the Newark system (Newberry, '88, p. 20).
Cited on fossil footprints (Murchison, '43).
Cited on the fossil plants of the Richmond area (De La Beche, '48. Fontaine, '83, p. 25).
Cited on geology of the Richmond coal, Virginia (Greer, '71. Taylor, '48, p. 47).
Cited on intrusive trap sheets in Virginia (W. M. Davis, '83, p. 294).
Cited on natural coke in Richmond coal field, Va. (Clifford, '87, p. 12. De La Beche, '48).
Cited on Newark flora (Marcou, '90).
Cited on origin of certain raindrop impressions found in New Jersey (W. C. Redfield, '51*a*, pp. 73, 74).
Cited on Posidonia from the Richmond coal field, Va. (Lea, '56, p. 78).
Cited on relation of trap and sandstone in Massachusetts (Davis, '83, p. 285).
Cited on Richmond coal field, Va. (Clifford, '87, pp. 2, 5, 7, 8, 13, 14, 23, 24).
Cited on Richmond coal field (Clifford, '88. Emmons, '57, pp. 11-13).
Cited on section in the Richmond coal field, Va. (Emmons, '56, p. 339).
Cited on trap dikes in the Richmond coal field, Va. (W. M. Davis, '83, p. 293).
Fossil fishes obtained by, from Connecticut (Egerton, '49, p. 8).
Notice of work by, in Virginia (Miller '79-'81, vol. 2, pp. 149-151).

LYMAN, B. S. 1891.
[Remarks on bored well in Bucks county, near Easton, Pa.]
In Am. Philo. Soc. Proc., vol. 29, pp. 24, 25).
[Remarks on paper by J. P. Lesley. See Lesley, '91, in which the section passed through by the boring referred to is given.]

Lynchburg, Va. Brief account of sandstone near (W. B. Rogers, '36, p. 82).

MACFARLANE, JAMES. 1877.
The coal regions of America; their topography, geology, and development.
New York, 3d ed., pp. i-xvi, 1-696, and 29 maps.
2d ed., New York. Not seen.
1st ed., New York. 1873, pp. i-xvi, 1-676, and 25 maps.
Contains a general account of the Richmond, Va., Deep river and Dan river, N. C., coal fields. Compiled principally from the report of E. Emmons, H. D. Rogers, and J. P. Lesley. Contains geological sketch map of the United States, pl. op. p. 3; a geological map of Pennsylvania, frontispiece; and a map of the United States showing distribution of coal fields, pl. op. p. 626.

MACFARLANE, JAMES. 1879.
An American geological railway guide.
New York, pp. 1-216 and a geological map.
Contains a brief sketch of the Newark system, and indicates what railroad stations are situated on it.

MACFARLANE, JAMES. 1885.
An American geological railway guide. [Being advance sheets of a second edition, relating to the Dominion of Canada.]
New York, pp. 52-82.
Refers briefly to the Newark rocks of Nova Scotia, p. 56.

MACFARLANE, J. Cited on the coal production of the Richmond coal field, Va. (Heinrich, '78, p. 268).
Cited on the value of the Richmond coal field, Va (Hotchkiss, '80, pp. 91-92).

MACKIE, S. J. 1863.
The aeronauts of the Solenhofen age.
In The Geologist, vol. 6, pp. 1-8, pl. 1.
Refers briefly to the footprints of the Connecticut valley.

MACKIE, S. J. 1864.
Fossil birds.
In The Geologist, vol. 6, 1863, pp. 415-424, 445-455, pls. 22-24; vol. 7, 1864, pp. 11-24, 50-53, pls. 1-4.
Contains a brief account of the finding of fossil footprints in the Connecticut valley, followed by a "bibliography of Connecticut footprints," compiled principally from a similar list by Hitchcock in his Ichnology of New England. An extract is also given from Emmons's "American Geology" concerning a fossil bird bone from the Newark rocks of North Carolina.

MACLURE, WILLIAM. 1809.
Observations on the geology of the United States, explanatory of a geological map.
In Am. Phil. Soc., Trans., vol. 6, 1809, pt. 2, pp. 411-428. Republished in same, n. s., vol, 1, 1818, pp. 1-91, pls. 1-2; also as a separate volume, Philadelphia, 1817, 8vo, pp. i-ix, 10-130, pls. 1-2, and map. The map (as stated by Marcou) was reproduced in 1822 by P. Cleaveland as a frontispiece of an elementary treatise on mineralogy and geology, 2d ed., Boston, and also in 1843, in The Geologist.
Portions of the Newark rocks of New Jersey, Connecticut, etc., are considered in connection with other rocks west of the Appalachians, which are now known to be of much older date, under the head of "Secondary formation," and are so represented on the map.

MACLURE (—). Cited on the age of the coal fields of North Carolina (Emmons, '56, p. 271).

MACLURE [W.]. Cited on the age of the Newark system (Lea, '53, pp. 188, 189. Newberry, '88, p. 8. H. D. Rogers, '44, pp. 248, 251. H. D. Rogers, '58, vol. 2, p. 693).
Cited on the age of the Richmond coal field, Va. (Taylor, '35, p. 294).

McCara's Brook, N. S. Trap of (Dawson, '78, p. 316).

M'CLURE, WM. 1822.
Comparative features of American and European geology.
In Am. Jour. Sci., vol. 5, pp. 197-198.
An extract from a letter relating to the extent and general character of the trap rocks of the Atlantic slope. The former connection of several of the Newark areas between the Connecticut and the Rappahannock is suggested.

M'CLURE, W. Cited on the extent of the Dan river area, N. C. (Olmsted, '27, p. 128).
Cited on the former extent of the Newark system (Olmsted, '24, p. 18).
Cited on the Newark of North Carolina (Olmsted, '20).

McClure iron mine, Pa. Analysis of ore from (d'Invilliers, '86, p. 1513).

McCormick iron mine, near Dillsburg, Pa. Brief account of (Frazer, '76*d*).
Description of (d'Invilliers, '86, pp. 1511-1512).
Report on (Frazer. '77, pp. 214-217, 228-229).

McCREATH, ANDREW S. 1879.
Second geological survey of Pennsylvania, 1876-1878, MM. Second report of progress in the laboratory of the survey at Harrisburg.
Harrisburg, pp. i-xii, 1-438, and 2 plates.
Contains an analysis of coal from York co., Pa.

McCREATH, ANDREW S. 1881.
Second geological survey of Pennsylvania, 1879-1880. M3. Third report of progress in the laboratory of the survey at Harrisburg.
Harrisburg, pp. i-xx, 1-126, map in pocket.
Contains analyses of limestones from near Dillsburg, York county, Pa.

McCREATH, A. S. Analysis of coal from the Richmond coal field, Va. (Clifford, '87, p. 10).
Analysis of iron ore from Pennsylvania by (d'Invilliers, '86, p. 1507).
Analysis of iron ores (d'Invilliers, '83, pp. 324, 325, 331-333, 341).
Cited on the composition of coal from the Richmond coal field, Va. (Chance, '85, p. 19).

McGEE, W. J. 1884.
Map of the United States, exhibiting the present status of knowledge relating to the areal distribution of geologic groups.
In U. S. Geol. Surv., fifth annual report, 1883-1884, pl. 2, in pocket at end of volume.
A compiled map showing areas occupied by the Newark system.

McGEE, W. J. 1888.
Three formations of the middle Atlantic slope.
In Am. Jour. Sci., 3d ser., vol. 35, pp. 120-143, 228, 330, 367-388, 448-466, pl. 2, 6-7. Reviewed in Am. Geol., vol. 2, pp. 129-131.
States that the Potomac formation rests unconformably on the eroded surface of the Newark, pp. 134, 135.

McGEHEE, M. 1883.
Handbook of the State of North Carolina, exhibiting its resources and industries.
Raleigh, pp. i-vi, 1-154.
Contains a brief account of the Deep river and Dan river coal fields, pp. 24-25, 75-77, 82.

McKAY, A. W. 1866.
The red sandstone of Nova Scotia.
British Assoc. Adv. Sci., Rep., No. 35.
A brief summary of facts and conclusions concerning the distribution, lithological character, fossils, geological age, etc., of the Newark rocks of Nova Scotia, pp. 66-67.

McKay's head, N. S. Rocks of (Gesner, '36, p. 254).

McKnightstown, Pa. Sandstone, conglomerate, etc., from (C. E. Hall, '78, p. 42).

McLENAHAN, S. 1852.
[Observations and remarks on the Deep and Dan river coal fields, North Carolina.]
In report of Professor Emmons, on his geological survey of North Carolina (Executive document, No. 13).
Raleigh, 1852, pp. 168-173.
Describes briefly some of the local features of the coal fields mentioned, pp. 168-171.

Madison, N. C. Brief account of coal near (McGehee, '83, p. 76).
Coal near (Kerr, '75, p. 145).
Conglomerate near (Emmons, '52, p. 152).
Fossil tree-trunks found at (Emmons, '52, p. 148).
Section near (Emmons, '56, p. 259).
Sections with dips and strikes at (Emmons, '52, p. 151).
Thickness of sandstone at (Emmons, '57, p. 22).

Madison, N. J. Dip of sandstone near (H. D. Rogers, '40, p. 133).

Madisonville, N. J. Dip in shale at (Cook, '82, p. 30).

Magdalen islands. Mention of Newark rocks in (Marcou, '58, pp. 11, 65).
Possible Trias on (Richardson, '81, p. 8G).

MAHAN, D. H. 1871.
[Trap rock as a building stone.]
In an elementary course of civil engineering, New York, p. 3.
Refers to the uses of the trap rock of the Palisades of New Jersey, and mentions its mineralogical composition (criticized by G. P. Merrill, see Merrill, '89, p. 435). Refers also to the sandstone of the Newark, pp. 4-5.

MAHAN [D. H.]. Cited on the mineralogical composition of trap rock (G. P. Merrill, '89, p. 435).

Maidenhead coal mine, Va. Account of (Wooldridge, '42, pp. 2-3).
Analysis of coal from (Clemson, '35. Clifford, '87, p. 10. Macfarlane, '77, p. 515. Williams, '83, p. 82).
Brief account of (Macfarlane, '77, p. 507).
Depth of (Taylor, '48, p. 49).
Explosion in (Taylor, '48, p. 49).

MANTELL, GIDEON ALGERNON. 1843.
[On the footprints in the Connecticut valley sandstone.]
In Am. Jour. Sci., vol. 45, pp. 184–185.
Contains general observations regarding the fossils mentioned.

MANTELL, GIDEON ALGERNON. 1846.
Description of footmarks and other imprints on a slab of New Red sandstone, from Turners Falls, Mass., U. S., collected by Dr. James Deane, of Greenfield, U. S.

MANTELL, GIDEON ALGERNON—Continued.
In London Geol. Soc., Quart. Jour., vol. 2, pp. 38–40; also in London and Edinburgh Philo. Mag., 1843, vol. 23, p. 186.
Abstract in Neues Jahrbuch, 1844, p. 248.
Gives a general description of a small slab of sandstone bearing raindrop impressions and footprints.

Map, geological, of North Carolina—Continued.
Showing outcrop of coal near the Gulf (Chance, '85, p. 38).
Showing position of coal-bearing areas (Kerr, '79).
Of Nova Scotia (Dawson, '45. Dawson, '78, 1st ed. Dawson, '78, map 2d and 3d ed. Gesner, '36. Jackson and Alger, '33).
Minas basin and Cobequid bay (Dawson, '47, pl. 5).
Of Pennsylvania (Frazer, '82, pl. [3]. Lesley, '86, op. p. 656. Lesley and d'Invilliers '85, frontispiece of volume. Macfarlane, '77, frontispiece. Putnam, '86c, pl. op. p. 179. H. D. Rogers, 58, vol. 2, in portfolio).
Adams county (Lesley and Frazer, '76).
Chester county (Frazer, '83, in pocket).
Cornwall iron mines near Lebanon (Lesley and d'Invilliers, '85).
Cumberland county (Lesley, '80).
Distribution of Newark rocks (C. E. Hall, '80, pl. op. p. 442).
Franklin county (Sanders, '81).
Fritz island mine (d'Invilliers, '83, in atlas).
Indicating drainage, etc., in Jurassic time (W. M. Davis, '89*a*, p. 233).
Iron mines near Boyertown (d'Invilliers, '83, in atlas).
Iron mines of Cumberland and York counties (d'Invilliers, '86, pl. op. p. 1437).
Iron ore deposits at Cornwall (d'Invilliers, 86*a*, p. 874).
Iron ore mines near Dillsburg (Frazer, '76*d*, pl. 2).
Lancaster county (Frazer, '80).
Lehigh and Northampton counties and a part of Berks county (d'Invilliers, '83, in atlas).
Mining districts of Chester and Montgomery counties (H. D. Rogers, '58, vol. 2, op. p. 674).
Near Philadelphia (C. E. Hall, '81, in pocket. C. E. Hall, '81, p. 21).
Newark rocks (Lesley, '64, op. p. 476).
Ore deposits in York and Adams counties (Frazer, '76, op. p. 64).
Pickering creek copper and lead mines (Lesley, '83, p. 177).
Portion of Montgomery and Bucks counties (Hall, '81, in pocket).
Trap dike across southeast Pennsylvania (Lewis, '85, pl. op. p. 440).
Trap dike near Flourtown, Pa. (C. E. Hall, '81, p. 23).
York county (Frazer, '80. Frazer, '85, pl. op. p. 391).
York and Adams counties (Frazer, '76, op. p. 196. Frazer, '77).
Of Prince Edward island, scale 25 miles to 1 inch (Dawson, '78, map, 2d and 3d ed. Dawson and Harington, '71, frontispiece. Ells, '84, accompanying).
Of South Carolina, Chesterfield county (Tuomey, '48. Lieber, '56, pl. 6).

Map, geological, of the United States.
(Brewer, '90. C. H. Hitchcock, '74, pl. 12. C. H. Hitchcock, '86. Hitchcock and Blake, '74. Macfarlane, '79, pl. op. p. 216. McGee, '84. Marcou, '55. Marcou, '58, frontispiece. Marcou, '58, frontispiece. Marcou, '58, pl. 9. H. D. Rogers, '56, pl. 8).
Of the United States and the British provinces (Marcou, '53, on map in vol. 2. Marcou, '55*a*).
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Black heath coal mines (Clifford, '87, pl. 4).
Deep run coal mine (Clifford, '87, pl. 5).
Eastern part of, showing distribution of Mesozoic rocks (Heinrich, '78, pl. 5).
Midlothian coal mine (Heinrich, '76, pl. 3).
Piedmont coal fields (Daddow and Bannan, '66, p. 395).
The Richmond coal field (Clifford, '87, pl. 1).
The western part of (Benton, '86, pl. op. p. 261).
Of the world (Prestwich, '86, vol. 1, pl. 1).
Showing Newark area (E. Hitchcock, '56).
Geological sketch, of the United States (Foster, '69, pl. op. p. 273. Lyell, '45, pl. op. p. 75 in New York edition. Macfarlane, '77, pl. op. p, 3. Steel, '74, frontispiece).
Of coal fields of the United States. Indicates the position of the Richmond, Deep river, and Dan river coal fields (Macfarlane, '77, pl. op. p. 626).

Newark area in the United States (Chance, '85, pl. op. p. 66).

Marble hall, Pa. Trap dike near (C. E. Hall, '81, p. 75. Lewis, '85, p. 441. H. D. Rogers, '58, vol. 1, p. 214).

March's mill, Pa. Dip of conglomerate at (d'Invilliers, '83, p. 202).

Strike and dip (d'Invilliers, '83, p. 213).

MARCOU, JULES. 1849.
Note sur le houille du conté de Chesterfield, près de Richmond (État de Virginie).

In Bull. Soc. Géol. de France, 2d ser., vol. 6, 1848–1849, pp 572–575.

Reviews previous determination of the geological position of the Richmond coal field, and proposes a new correlation based on additional evidence furnished by fossil plants and fishes.

MARCOU, JULES. 1853.
A geological map of the United States and of the British provinces in North America; with an explanatory text, geological sections, and plates of the fossils which characterize the formations.

MARCOU, JULES—Continued.

Boston. [vol. 1], pp. i–viii, 1–92, pls. 1–8; [vol. 2], a geological map of the United States, etc.

For references to later editions of the geological map see Bulletin No. 7, 1884, of the U. S. Geological Survey.

Reviewed in Am. Jour. Sci., 2d ser., vol. 17, pp. 199–206; by W. P. Blake, ibid., vol. 22, pp. 383–388; by H. Agassiz, ibid., vol. 27, pp. 134–139.

Contains a list of synonyms of the Newark system and gives a brief account of the formation. A few characteristic fossils are figured, pp. 39–44, pls. 6–7.

Refers the Richmond area to the Trias, and the Newark rocks of North Carolina to the New Red sandstone.

MARCOU, JULES. 1855.

Résumé explicatif d'une carte géologique des États-Unis et des provinces anglaises de l'Amérique du Nord avec un profil géologique allant de la vallée du Mississippi aux côtes du Pacifique et une planche de fossiles.

In Bull. Soc. Géol. de France, 2d ser., vol. 12, pp. 813–936, pl. 21, and map.

Contains a general sketch of the characteristics, distribution, and stratigraphical relations of the Jura and Trias formations in North America. Discussion of the age of the Newark system.

MARCOU, JULES. 1855a.

Ueber die Geologie Vereinigten Staaten und der englischen provinzen von Nordamerika.

In Petermann's Mitth., vol. 1, 1855, pp. 149–159, and map 15.

Brief account of the extent and characteristics of the Newark system of North America.

MARCOU, JULES. 1858.

Geology of North America, with two reports on the prairies of Arkansas and Texas, the Rocky mountains of New Mexico, and the Sierra Nevada of California.

Zurich, 4to, pp. i–viii, 1–144, 1–8, pls. 1–9, and a geological map of the United States.

Contains many statements concerning the geological position of the Newark system.

MARCOU, JULES. 1859.

Reply to the criticisms of James D. Dana, including Dana's two articles, with a letter of Louis Agassiz.

Zurich, pp. 1–40.

A reply to certain criticisms in reference to Jules Marcou's observations on the geology of North America. Several reviews of Marcou's writings are reprinted.

MARCOU, JULES. 1875.

Explication d'une seconde édition de la carte géologique de la terre.

Zurich, 4to, pp. 1–222, pl. 1.

Contains a short sketch of general geology, in which brief references are made to the "Trias" and "Jura" of North America, pp. 43–55; and an account of the geology of North America in which brief notices are given of the writings of various geologists. On the small map at the end of the volume areas are indicated which are occupied by the "Trias" and "Dyas" combined.

MARCOU, JULES. 1888.

American geological classification and nomenclature.

Cambridge, Mass., pp. 1–75.

Refers briefly to the rocks of the Newark system, pp. 31–32, 73.

MARCOU, JULES. 1890.

The Triassic flora of Richmond, Va.

In Am. Geol., vol. 5, pp. 160–174.

A review of "Contribution to the knowledge of the older Mesozoic flora of Virginia," by W. M. Fontaine; "Sur la présence dans le grès bigarré, des Vosges, de l'Acrostichides rhombifolius, Fontaine" par René Zeiller; "Die Lunzen-(Lettenkohlens)-Flora in den "older Mesozoic beds of the coal field of eastern Virginia," by D. Stur; and "Fossil fishes and fossil plants of the Triassic rocks of New Jersey and the Connecticut valley," by J. S. Newberry.

MARCOU, J. Cited on the age of the Newark system (Dewey, '57. Jones, '62, p. 134. Lea, '58. Newberry, '88, p. 9. Zeiller, '88, p. 698).

Richmond coal field, Virginia (Hull, '81, p. 460).

MARCOU, J. Cited on extent of the Triassic rocks in America (Archiac, '60, pp. 633–638).

Geological map of North America (Marcou, '59, pp. 26–30).

Newark flora (Marcou, '90).

Reproduction of geological map of the world by (Prestwich, '86, vol. 1, pl. 1).

Review of geology of North America by (Agassiz, '59. J. D. Dana, '59).

Margaretville, N. S. Copper at (How, '69, p. 66. Willimott, '84, p. 20, L.? 25, 26 L.).

Margerum's, S., quarry near Princeton, N. J. Description of (Cook, '81, p. 55).

Maria furnace, Pa. Iron ore near (H. D. Rogers, '58, vol. 2, p. 690).

Trap dikes near (H. D. Rogers, '58, vol. 2, p. 690).

Mariner's harbor, Staten island. Newark outcrop near (Hollick, '89).

Marion, N. J. Trap rock at (Ward, '79, p. 150).

Marion, Pa. Boundaries of the Newark in (C. E. Hall, '81, pp. 83–84).

Marlboro, Conn. Description of trap dikes in primary rocks near (Percival, '42, pp. 423–424).

Marls in North Carolina. (Kerr, '75, p. 187).

MARSH, DEXTER. 1848.

[On the discovery of footprints in the sandstone of the Connecticut valley.]

In Am. Jour. Sci., 2d ser., vol. 6, pp. 272–274.

Describes the finding of footprints at several localities in the Connecticut valley.

MARSH, DEXTER. Cited on the discovery of fossil footprints in the Connecticut valley (E. Hitchcock, '58, p. 8).

MARSH, D. Footprints discovered by (Deane, '49, pp. 212–214. E. Hitchcock, '55*a*, p. 186).

Reference to specimens of footprints in the cabinet of (E. Hitchcock, '48).

Referred to in connection with fossil footprints (Macfarlane, '79, p. 63).

MARSH, O. C. 1863.

Catalogue of mineral localities in New Brunswick, Nova Scotia, and Newfoundland.

In Am. Jour. Sci., 2d ser., vol. 35, pp. 210–218.

Includes many Newark localities.

MARSH, O. C. 1867.

Contributions to the mineralogy of Nova Scotia; No. 1, Lederite identical with gmelinite.

In Am. Jour. Sci., 2d ser., vol. 44, p. 362–367.

Localities in the Newark are mentioned.

MARSH, O. C. 1877.

The introduction and succession of vertebrate life in America.

In Am. Assoc. Adv. Sci., Proc., vol. 26, 1878, pp. 211–258, pl. op. p. 211.

Contains a general summary of what is known concerning the reptilian life of the Newark system, pp. 218–220.

MARSH, O. C. 1887*a*.

American Jurassic mammals.

In Am. Jour. Sci., 3d ser., vol. 33, pp. 327–348, pls. 7–10.

Republished in Geol. Mag., n. s., vol. 4, decade 3, 1887, pp. 241–247, 289–299, pls. 6–9.

Classifies all known Triassic and Jurassic mammals for America, and describes several new genera and species.

MARSH, O. C. 1889.

Notice of new American Dinosauria.

In Am. Jour. Sci., 3d ser., vol. 37, pp. 331–336.

Contains brief descriptions of Dinosaurian remains from the Connecticut valley.

MARSH, O. C. Cited in reference to fossils of the Newark system (Newberry, '88).

Cited on Mormolucoides articulatus (Scudder, '68, p. 218).

Reptilian character of the footprints of the Connecticut valley (Hull, '87, p. 86).

Remarks on footprints collected by Winchell, '70, p. 186).

Marsh, Pa. Boundaries of the Newark in (C. E. Hall, '81, pp. 74–75).

Marshal corners, N. J. Copper ores near (Cook, '68, p. 679).

Dip in shale at (Cook, '82, p. 26).

Dip near (Cook, '68, p. 199).

Trap hill near (Cook, '68, p. 190).

Marshalton, Pa. Trap dike near (Lewis, '85, pp. 445, 446).

Marsh's quarry, Montague, Mass. Fossil footprints at (E. Hitchcock, '58, pp. 49 et seq.).

MARSTERS, V. F. 1890.

Triassic traps of Nova Scotia, with notes on other intrusives of Pictou and Antigonish counties, N. S.

In Am. Geol., vol. 5, pp. 140–145.

MARSTERS, V. F.—Continued.

Describes North mountain and cape Blomidon, N. S. Suggests that the trap rocks there exposed were formed by a submarine eruption. Compares the trap with similar rocks in the Connecticut valley, and describes its microscopical characters. Describes trap dikes outside of the Newark area in eastern Nova Scotia.

Marsters mountain, N. S. Character of, and height of (Marsters, '90).

Marthas Vineyard. Newark debris in Tertiary rocks of (Shaler, '85*a*, p. 21).

Martials cove, N. S. Description of (Gesner, '36, pp. 192–194).

MARTIN, B. N. 1870.

[Remarks on the metamorphic origin of the trap rock forming the Palisades of the Hudson.]

In New York Lyc. Nat. Hist., Proc., vol. 1, 1870–'71, pp. 132–133.

Describes personal observations on the stratification and lithology of the rocks of the Palisades, which tend to support the metamorphic origin of the trap of that ridge as suggested by Wurtz.

MARTIN, D. S. 1870.

[Celadonite (?) from the trap rock of Weehawken, N. J.]

In New York Lyc. Nat. Hist., Proc., vol. 1, 1870–'71, pp. 130–131.

Mentions the discovery of the mineral referred to.

MARTIN, DANIEL S. 1876.

On the rocks of New York island and their relation to the geology of the Middle states.

In Liverpool Geol. Soc., Proc., vol. 3, pp. 118–120.

Describes the belt of gneiss passing through New York, Trenton, Philadelphia, etc., and shows that it divides the earlier from the latter Mesozoic beds. The opposite dips of the beds on the sides of this axis are noted.

MARTIN, D. S. 1883.

[Remark on the Newark system in New Jersey.]

In New York Acad. Sci., Trans., vol. 2, 1882–'83, p. 120.

Refers to a possible origin of the arkose near Hoboken, N. J., and states that the Newark rocks of New Jersey and of the Connecticut valley were probably united at the time of their deposition.

MARTIN, D. S. 1885.

[Remarks on the former connection of the Newark areas of New Jersey and of the Connecticut valley.]

In New York Acad. Sci., Trans., vol. 5, 1885–'86, pp. 19–20.

Refers to the mineralogical character of the "tide-water gneiss" separating the two Newark areas referred to, and expresses the opinion that these areas were united at the time of their deposition.

Massachusetts sections—Continued.
Showing junction of trap and sandstone (W. M. Davis, '83, pp. 305-307, pl. 10).
Through (Walling, '78, pl. op. p. 192).
West Springfield, showing trap and sandstone (W. M. Davis, '83, pp. 305-307, pl. 10).

MATHER, W. W. **1834.**
[New locality for fossil fish in the Connecticut valley.]
In Neues Jahrbuch, 1834, pp. 531-532.
Describes a new locality for fossil fish 20 miles from New Haven, Conn., where the geological relations are the same as at Sunderland and Middlesex.

MATHER, W. W. **1838.**
Report of W. W. Mather, geologist of the first geological district of the state of N[ew] Y[ork].
In second annual report of the geological survey of New York.
Albany, pp. 121-183.
Contains a brief reference to the trap rocks near Tompkinsville, Staten island, N. Y., p. 140.

MATHER, W. W. **1839.**
Third annual report of W. W. Mather, geologist of the first geological district of the state of New York.
In third annual report of the geological survey of New York.
Albany, pp. 69-134.
Contains an account of the sandstone and associated trap of Richmond and Rockland counties, N. Y., pp. 116-117, 122-127, 132.

MATHER, WILLIAM W. **1843.**
Natural History of New York, Part IV. Geology, Part I. Containing the geology of the first geological district.
Albany, 4to, pp. i-xxxvii, 1-655, pls. 1-46.

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MATHER, WILLIAM W.—Continued.

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MATHER, WILLIAM W. **1845.**
On the physical geology of the United States east of the Rocky mountains and on some of the causes affecting the sedimentary formations of the earth.
In Am. Jour. Sci., vol. 49, pp. 1-20, 284-301.
Brief statement of hypothesis concerning the mode of formation of the Newark sandstone along the Hudson river, p. 14.

MATHER, W. W. Cited on the age of the Newark system (H. D. Rogers, '44, p. 250.
Cited on the cause of the tilting of the Newark (W. M. Davis, '83, p. 303).
Cited on the conglomerate of Rockland county, N. Y. (Lea, '53, p. 190).
Cited on the mode of formation of the Newark system (Lea, '53, pp. 191-192).
Cited on the Newark rocks on Staten island (Hollick, '89).
Cited on trap dikes under the Palisades, N. Y. (W. M. Davis, '83, p. 292).
Notice of work by (Miller, '79-'81, vol. 2, p. 148).

MATTHEW, G. F. **1863.**
Observations on the geology of St. John county, New Brunswick.
In Canadian Nat., vol. 8, pp. 241-259.
Contains a small map showing Newark rocks at Quaco Head, p. 248.
Notices briefly the unconformity of the Newark near Gardner's creek with the upturned Carboniferous rocks beneath, pp. 256, 258. Appended is a note by J. W. Dawson on fossil plants.

MATTHEW, GEO. F. **1865.**
[Report on the] New Red sandstone or Trias [of New Brunswick].
In observations on the geology of southern New Brunswick, made principally during the summer of 1864 by Prof. L. W. Bailey, Messrs. Geo. F. Matthew, and C. F. Hartt, prepared and arranged, with a geological map, by L. W. Bailey, pp. 123-125, 129, and map.
Some errors in reference to the age of certain rocks made by Abraham Gesner, in reports on the geological survey of New Brunswick, from 1839-1841, are pointed out. The localities of Newark rocks are described in detail, together with descriptions of lithological characters, dip, trap intrusions, etc., pp. 123-125. On p. 129 is a table giving a "classification of the sediments of southern New Brunswick on physical grounds."

MATTHEW, G. F. **1865a.**
On the Azoic and Paleozoic rocks of southern New Brunswick.
In London, Geol. Soc., Quart. Jour., vol. 21, pp. 422-433, and map.
The map accompanying this paper shows the location of several Newark areas along the southeast shore of New Brunswick.

MATTHEW, G. F. 1878.
Report on the slate formation of the northern part of Charlotte county, New Brunswick, with a summary of geological observations in the southeastern part of the same county.
In geological survey of Canada. Report of progress for 1876–'77.
Montreal, 1878, pp. 321–350.
A single paragraph on p. 339 refers to the relation of the Upper Silurian and Newark rocks of Grand Manan island, N. B.

MATTHEW, G. F. 1880.
Report on the geology of southern New Brunswick, embracing the counties of Charlotte, Sunbury, Queens, Kings, St. John, and Albert.
See Bailey, Matthew, and Ells, 1880.

MATTHEW, S. F. Cited on overflow trap sheets on Grand Manan island (W. M. Davis, '83, p. 297).
Cited on trap dikes on Grand Manan island, N. B. (W. M. Davis, '83, p. 291).
Notice of work done by, in New Brunswick (Miller, '79–'81, vol. 2, p. 156).

May, Pa. Trap dikes at (Lesley, '85, p. lxiv.

MEADE, WILLIAM. 1827.
Remarks on the anthracite of Europe and America.
In Am. Jour. Sci., vol. 12, pp. 75–83.
Refers to the supposed absence of coal in the Newark system.

Meads basin, N. J. Course of trap ridge near (Cook, '82, pp. 54–55).
Description of trap hill near (Cook, '68, pp. 185, 186).

Mechanic copper mine, N. J. Description of (H. D. Rogers, '40, pp. 163–164).

Mechanics grove, Pa. Description of trap dike near (Frazer, '80, p. 30).

Mechanicsville, Pa. Description of trap dikes near (C. E. Hall, '81, pp. 19–20, 84).
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Section from near, to near mount Holly (Frazer, '77, pp. 274–277, pl. op. p. 274).
Trap dikes near (C. E. Hall, '81, p. 19–20. Lewis, '85, p. 443).

Medford, Mass. Character of trap rock quarried at (G. P. Merrill, '84, p. 24).

Melick hill, N. J. Description of (Cook, '82, p. 65).

Melaphyre trap in New Jersey. Brief account of (Credner, '70).

Mendham, N. J. Boundary of the Newark near (H. D. Rogers, '40, p. 118).

Meriden, Conn. Ash bed near, popular account of (W. M. Davis, '91).
Brief account of trap near (E. Hitchcock, '23, vol. 6, p. 49).
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Description of geology near (W. M. Davis, '83, pp. 265–266).
Description of quarry near (Davis and Whittle, '89, pp. 112–113).
Description of trap ridges near (Percival, '42, p. 371).
Diagram showing geological structure near (W. M. Davis, '89, pl. 2).
Discussion of the origin of topographic features near (W. M. Davis, '89*c*).
Excursion to the Hanging hills of (J. D. Dana, '70).
Extrusive character of the Hanging hills near (W. M. Davis, '82*a*, pp. 122–123).
Faults near (W. M. Davis, '89*b*, p. 29).
Filling of fissures in trap (W. M. Davis, '90).
Map of trap ridges and faults near (W. M. Davis, 89*c*, p. 424).
Mines near (C. H. S. Davis, '70).
Notice of a bed of volcanic ash near (Chapin, '89).
Overflow trap sheets near (W. M. Davis, '88 p. 464).
Reference to exposure in quarry near (Davis and Whittle, '89, p. 121).
Reference to the origin of the trap sheets near (Nason, '89*a*, p. 66).
Scenery near (Chapin, '87).
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Section in quarry near (W. M. Davis, '89, pl. 5).
Sketch map of Hanging hills in (W. M. Davis, '83, pp. 305–307, pl. 10).
Sketch of the geology of (C. H. S. Davis, '70).
Special account of quarries at (Davis and Whittle, '89, pp. 127–133).
Topographic form of trap ridge near (Percival, '42, p. 304).
Trap ridges near (Davis and Whittle, '89, pp. 107–110. Percival, '42, pp. 348, 349, 364).

Meriden, New Britain district, Conn. Map of, with cross-section and distant view (W. M. Davis, '89, pl. 5).

Meridian Hill, Conn. Amygdaloid at (E. S. Dana, '75).

Meriwether, Ga. Brief account of trap dikes in (Henderson, '85, p. 88).

Meriwether county, Ga. Trap dikes in (T. P. James, '76, p. 38 and map. Loughridge, '84, p. 279).

MERRICK [S. V.]. 1851.
[Remarks on recent and fossil raindrop impressions.]
In Am. Assoc. Adv. Sci., Proc., vol. 5, pp. 74–75.
Compares recent raindrop impressions with fossil impressions which are believed to have had a similar origin.

MERRILL, FREDERICK J. H. 1890.
Some ancient shore lines and their history.
Abstract in New York Acad. Sci., Trans., vol. 9, pp. 78–82.

Milford, N. J.—Continued.
Detailed description of calcareous conglomerate near (H. D. Rogers, '40, pp. 140–141).
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Milford, Pa. Mention of reptilian remains from the Newark rocks near (Dewey, '57).

Milford to Trenton, N. J. Section from (Cook, '79, p. 28).

Milton, N. J. Synclinal axis near (H. D. Rogers, '40, p. 128).

Milton grove, Pa. Boundary of the Newark near (Frazer, '80, p. 13).
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Millbaugh hill, Pa. Boundary of the Newark near (H. D. Rogers, '58, vol. 2, p. 668).

Millbrook, N. J. Boundary of Newark along (Cook, '68, p. 175).

MILLER, S. A. 1879–1881.
North American Mesozoic and Cenozoic geology and paleontology.
In Cincinnati Soc. Nat. Hist., Jour., vol. 2. pp. 140–161, 223–244; vol. 3, pp. 9–32, 79–118, 165–202, 245–288; vol. 4, pp. 3–46, 93–144, 183–234.

MILLER, S. A.—Continued.
Published also as: North American Mesozoic and Cenozoic geology and paleontology; or an abridged history of our knowledge of the Triassic, Jurassic, Cretaceous and Tertiary formations of this country. Cincinnati, 1881, pp. 1–338.
Presents a brief abstract of a large number of reports and papers. Contains a hypothesis relating to the mode of formation of the Newark system, and also a brief summary concerning its fauna and flora, vol. 2, pp. 146–161, 223–244.

Millers falls, Mass. Brief account of copper ores at (E. Hitchcock, '35, p. 72).

Millers river, Mass. Conglomerate at the mouth of (E. Hitchcock, '35, p. 214).

Millington, N. J. Abandoned quarries near (Cook, '81, p. 55).
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Brief reference to trap hills near (H. D. Rogers, 36, p. 159).
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Philadelphia, 1836, 2d ed., pp. 1–188, pl. 1.
First ed., Philadelphia, 1836; each edition is paged the same up to p. 174.
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ROGERS, HENRY DARWIN. **1839.**
Third annual report on the geological survey of the state of Pennsylvania.
Harrisburg, Pa., 16mo, pp. 4–119.
Name Middle Secondary strata applied to the Newark, p. 12. Unconformity between the Newark and underlying rocks (other examples are mentioned on p. 21). General dip of the strata; former extension of the Newark beyond its present limits, p. 17. The area occupied by the Newark given by counties, and its northern and southern boundaries described. Occurrence of variegated conglomerate, Red

ROGERS, HENRY DARWIN—Continued.

sandstone, and trap. Localities where variegated conglomerate occurs along the northern border of the area. The hypothesis is here advanced that the sedimentary rocks of the Newark in Pennsylvania, New Jersey, etc., were deposited in their present inclined position by a river rising in Virginia and flowing northward, pp. 18–23.

Trap dikes with accompanying dislocation and metamorphism in the adjacent beds, together with the occurrence of ores of iron and copper along the lines of contact, pp. 18–23.

ROGERS, HENRY D. 1840.

Description of the geology of the state of New Jersey, being a final report.

Philadelphia, pp. 1–301, pl. 1, and map.

Contents relating to the Newark system:

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ROGERS, HENRY D. 1841.

Fifth annual report of the geological exploration of the commonwealth of Pennsylvania.

Harrisburg, pp. 1–156, pl. 1.

Describes the Newark rocks bordering the South mountain, Pa., pp. 16–17, 38–39.

ROGERS, HENRY D. 1841a.

[Remarks on the columnar structure of the trap dikes of Pennsylvania and on the magnetic iron ores of New Jersey.]

In Am. Jour. Sci., vol. 41, p. 173; also in Am. Assoc. Geol. and Nat., Proc., 1840–1842, p. 26.

Brief abstract of a remark on a paper by Prof. Mather concerning joints in rocks.

ROGERS, H. D. 1842.

[Remark on the independent origin of the New Red sandstone of the Connecticut valley and of New Jersey and Pennsylvania.]

ROGERS, H. D.—Continued.

In Am. Jour. Sci., vol. 43, pp. 170, 171, 172; also in Am. Assoc. Geol. and Nat., Proc., 1840–1842, pp. 63, 64, 66.

Brief abstract of remarks to the effect that the Newark rocks of the Connecticut valley and of the New Jersey-Pennsylvania area was formed in independent basins.

ROGERS, H. D. 1843.

[Remarks in reference to the age of the Newark system.]

In Philadelphia Acad. Nat. Sci., Proc., vol. 1, p. 250.

States that Posidonomia minuta, from Prince Edward county, Va., indicates that the rocks in which it occurs are the New Red sandstone.

ROGERS, HENRY D. 1843a.

On the physical structure of the Appalachian chain, as exemplifying the laws which have regulated the elevation of great mountain chains generally.

See Rogers, William B. and H. D. Rogers, 1843.

ROGERS, [H. D.] 1843b.

[Remarks on the age of the New Red sandstone of the Connecticut valley and New Jersey.]

In Am. Jour. Sci., vol. 45, p. 315.

Abstract of remarks on a paper by W. C. Redfield.

[ROGERS, H. D.] 1843c.

[On the crescent form of the trappean dikes of the Newark sandstone regions of New Jersey and Connecticut.]

In Am. Jour. Sci., vol. 45, p. 334.

Abstract of remarks on the cause of the topographic form of the trap ridges referred to.

ROGERS, HENRY D. 1844.

Address delivered at the meeting of the Association of American Geologists and Naturalists, held in Washington, May, 1844.

In Am. Jour. Sci., vol. 47, pp. 137–160, 247–278.

Reviews the progress made in the study of the Newark system up to 1844.

ROGERS, H. D. 1848.

[Altered shales and sandstones at New Hope, Pa.]

In Boston Soc. Nat. Hist., Proc., vol. 3, 1848–1851, p. 30.

A brief record of contact metamorphism.

ROGERS, HENRY D. 1853.

[On the thickness of the Connecticut valley sandstone.]

In Boston Soc. Nat. Hist., Proc., vol. 9, 1851–1854, pp. 379–380.

Remarks on a paper by Edward Hitchcock, states that the Newark strata may have been deposited in an inclined position. Refers to instances where the system is not so thick as might be inferred.

ROGERS, H. D. 1853a.

[Remarks on the age of Connecticut sandstone.]

In Am. Acad., Proc., vol. 3, p. 70.

ROGERS, H. D. 1854.

[Remarks on fossil footprints.]

ROGERS, H. D.—Continued.

In Boston Soc. Nat. Hist., Proc., vol. 5, 1854–1855, p. 30.

Brief remarks in discussion of a paper by Bouvé.

ROGERS, H. D. 1855.

[Remarks on footprints and raindrop impressions.]

In Boston Soc. Nat. Hist., Proc., vol. 5, 1854–1856, pp. 182–185.

In describing certain Carboniferous footprints, refers to those of the Newark system, suggests that the so-called raindrop impressions may have been made by spray from breaking waves, p. 185.

ROGERS, HENRY DARWIN. 1856.

Geological map of the United States and British North America.

In The Physical Atlas of Natural Phenomena by Alexander Keith Johnson. New and enlarged ed., pp. 29–32, pl. 8.

Contains a condensed account of the Newark system, including geographical extent, organic remains, and geological age, dip and physical conditions attending its origin, trap rocks, metalliferous veins, coal formation, etc., p. 32.

History of the literature of the Newark system, p. 32.*

ROGERS, HENRY DARWIN. 1858.

The geology of Pennsylvania.

Philadelphia, vol. 1, pp. i–xxvii, 1–586, pl. 36; vol. 2, pp. i–xxiv, 1–1046, pl. 51. Accompanied by an atlas containing a geological map of Pennsylvania in three sheets, a topographical and geological map of the anthracite fields of Pennsylvania in two sheets, and two sheets of sections.

In describing the crystalline and Paleozoic rocks of Pennsylvania, in vol. 1, several references are made to the relation of the Newark system to older formations, and also to its lithological character, strike, dip, trap dikes, ores, etc., pp. 86–87, 88, 89, 90, 92, 101–102, 103, 151, 160, 164, 204, 214.

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ROGERS, H. D. Cited on age of the Connecticut valley sandstone (C. H. Hitchcock, '55, p. 392).

Cited on age of the Newark rocks of Pennsylvania (W. C. Redfield, '56*a*, p. 357).

Newark system (Lea, '53. Lea, '58. Mather, '43, pp. 293–294. Newberry, '88, p. 9. W. C. Redfield, '56, pp. 181).

Richmond coal field, Va. (W. B. Rogers, '43, p. 301).

Cited on conglomerate in New Jersey (Cook, '89, p. 15). York county, Pa. (Frazer, '85, p. 403).

Cited on conglomerate of Virginia (W. B. Rogers, '36, pp. 81–82).

Cited on contact metamorphism in New Jersey (W. M. Davis, '83, p. 301).

New Jersey, at Rocky Hill (J. D. Dana, '43, pp. 113–114).

Cited on curved form of certain trap ridges (W. M. Davis, '83, p. 307. Silliman, '44).

Cited on deposition of the Newark system in inclined strata (W. B. Rogers, '42).

Cited on divisions of the "Middle secondary rocks" of the Atlantic slope (Lea, '53, pp. 191–192).

Cited on extent of Triassic rocks in North America (Archaic, '60, pp. 633–645).

Cited on fossil plants (Marcou, '90. Newberry, '88).

Cited on geological map of the United States (Marcou, '59, pp. 31–35).

Cited on geological position of the Newark system (E. Hitchcock, '41, p. 438).

Cited on intrusive trap sheets in Pennsylvania (W. M. Davis, '83, p. 294).

ROGERS, H. D.—Continued.

Cited on iron ores in Pennsylvania (Frazer, '77, p. 317).

Cited on mode of deposition of the Newark rocks of Pennsylvania (Frazer, '77c, p. 653. Lea, '53, pp. 191-192. E. Hitchcock, '41, pp. 527-529. Mather, '43, pp. 288-292. Mitchell, '42, p. 133).

Cited on monoclinal structure of the Newark (W. M. Davis, '83, p. 302. W. M. Davis, '86, pp. 342-343).

Cited on native silver in New Jersey (Darton, '85).

Cited on Newark system in New Jersey and Pennsylvania (Jones, '62, pp. 88-92).

Pennsylvania (Frazer, '77a, p. 995).

Cited on origin and deposition of Newark strata (W. M. Davis, '83, p. 287).

Cited on origin of the dip in the Newark rocks of Pennsylvania (Macfarlane, '79, p. 41).

Cited on origin of the trap rock of New Jersey (Hovey, '89, p. 376).

Cited on overflow trap sheets in Pennsylvania (W. M. Davis, '83, p. 298).

Cited on prevailing dip of the Newark (W. M. Davis, '83, pp. 305, 306).

Cited as prevailing dip of the Newark in New Jersey and Pennsylvania (W. B. Rogers, '39, p. 72).

Cited on relation of trap and sandstone in New Jersey (W. M. Davis, '83, p. 287).

Pennsylvania (W. M. Davis, '83, p. 287).

Cited on reptilian remains in Newark rocks at Phœnixville, Pa. (Wheatley, '61 p. 42).

Cited on structure of the Newark system (Cook, '87).

Cited on thickness of the Newark in Pennsylvania (Frazer, '77a, pp. 496, 498-499).

Cited on trap at Feltville, N. J. (Darton, '90, p. 26).

Cited on trap dikes in New Jersey (H. D. Rogers, '58, vol. 2, p. 685).

Pennsylvania (W. M. Davis, '83, p. 292. Lewis, '85, pp. 438-439, 441, 443).

Cited on "variegated calcareous conglomerate" of New Jersey (Lea, '53, p. 190. Russell, '78, p. 231-232).

Description of fossil Estheriæ, collected by (Jones, '62, pp. 123-126).

Discussion of hypotheses by, explaining the uniform dip (W. M. Davis, '82a, p. 118).

Hypothesis proposed by, to account for the general inclination of the Newark rocks of New Jersey (Russell, '78, p. 228).

Notice of work by (Miller, '79-'81, vol. 2, p. 147).

Reference to explanation of the structure of the Newark system, by (See Cook, '89a, p. 170).

ROGERS, HENRY D., LARDNER VANUXEM, RICHARD C. TAYLOR, EBENEZER EMMONS, and T. A. CONRAD. 1841.

Report on the ornithichnites or footmarks of extinct birds in the New Red sandstone of Massachusetts and Connecticut, observed and described by Prof. Hitchcock, of Amherst.

ROGERS, HENRY D., LARDNER VANUXEM, RICHARD C. TAYLOR, EBENEZER EMMONS, and T. A. CONRAD—Continued.

In Am. Jour. Sci., vol. 41, pp. 165-168; also in Am. Assoc. Geol. and Nat., Proc., 1840-1842, pp. 18-21, and in final report on the geology of Massachusetts, by E. Hitchcock, Amherst and Northampton, 1841, 4to, vol. 1, pp. 2a-3a.

Abstract in Neues Jahrbuch, 1841, pp. 739-740.

Report of a committee appointed from the members of the Association of American Geologists and Naturalists, and relates especially to the evidence of the animal origin of the footprints found in the sandstone of the Connecticut valley. The conclusion announced by Hitchcock as to the ornithic character of many of the footprints is sustained.

ROGERS, WILLIAM B. 1836.

Report of the geological reconnoissance of the state of Virginia.

Philadelphia. Pp. 1-143, pl. 1.

Reprinted in a reprint of annual reports and other papers on the geology of the Virginias, by the late William Barton Rogers. New York, 1884, pp. 21-122, pl. 1.

Contains a detailed account of the Richmond coal field, pp. 52-61, and a brief notice of the presence of sandstone suitable for building purposes in Orange, Nelson, and Amherst counties.

ROGERS, WILLIAM B. 1837.

Report on the progress of the geological survey of the state of Virginia for the year 1836.

[Richmond.] 4to, pp. 1-14.

Reprinted in a reprint of annual reports and other papers on the geology of the Virginias, by the late William Barton Rogers. New York, 1880, pp. 123-145.

Contains a brief account of the Richmond coal field, and also of the Newark area in northern Virginia, pp. 5-6, 7.

ROGERS, WILLIAM B. 1839.

Report of the progress of the geological survey of the state of Virginia for the year 1839.

Richmond, 1840. Pp. 1-161, pls. 1-2.

Reprinted in a reprint of annual reports and other papers on the geology of the Virginias, by the late William Barton Rogers. New York, 1889, pp. 285-410, pl. op. p. 276, and pl. 1.

Contains a description of the Newark areas in Pittsylvania, Campbell, Appomattox, Prince Edward, Halifax, Buckingham, and Cumberland counties, Va. The contents are as follows:

ROGERS, WILLIAM B.—Continued.

Igneous rocks, and associated metamorphism 81-83

ROGERS, WILLIAM B. 1840.

Report of the progress of the geological survey of the state of Virginia for the year 1840.

Richmond, 1841. Pp. 1-132.

Reprinted in a reprint of annual reports and other papers on the geology of the Virginias, by the late William Barton Rogers. New York, 1884, pp. 411-435.

Contains a description of the boundaries and principal characteristics of the Newark areas in northern Virginia, included in Orange, Culpeper, Prince William, Fauquier, Fairfax, and Loudoun counties, pp. 59-69; and also a description of the boundary of the northern part of the Richmond area, pp. 71-72. On p. 124 a short notice of the occurrence of coke in the Richmond coal field is given.

ROGERS, W. B. 1842.

[On the prevailing dip in the various areas of New Red sandstone of the Atlantic slope.]

In Am. Jour. Sci., vol. 43, p. 171; also in Am. Assoc. Geol. and Nat., Proc., 1840-1842, pp. 64-65.

An abstract of remarks on the prevailing dip of the Newark system, especially in Virginia, and the slight effect of intrusive rocks on the associated sedimentary beds. The hypothesis proposed by H. D. Rogers, in reference to the strata of sandstone and shale composing the system having been deposited in their present inclined position, is sustained.

ROGERS, W. B. 1842a.

[Observations tending to show that the footprints on the sandstone of the Connecticut valley were made on inclined surfaces.]

In Am. Jour. Sci., vol. 43, p. 173; also in Am. Assoc. Geol. and Nat., Proc., 1840-1842, p. 66.

Calls attention to the appearance in certain footprints of a slight sliding of the foot which made the impression.

ROGERS, WM. B. 1842b.

On the porous anthracite or natural coke of eastern Virginia.

In Am. Jour. Sci., vol. 43, pp. 175-176; also in Am. Assoc. Geol. and Nat., Proc., 1840-1842, p. 68.

Brief abstract of a paper describing the structure and mode of formation of the natural coke of Virginia.

ROGERS, W. B. 1842c.

[On the geological age of the Richmond coal field, Va.]

In Philadelphia Acad. Nat. Sci., Proc., vol. 1, p. 142.

A brief announcement that the rocks of the Richmond coal field are equivalent in time to the Lias of Europe.

ROGERS, WILLIAM BARTON. 1843.

On the age of the coal rocks of eastern Virginia.

ROGERS, WILLIAM BARTON—Continued.

In Am. Assoc. Geol. and Nat., Trans., 1840-1842, p. 298-316, pls. 13, 14.

Abstract in Am. Jour. Sci., vol. 43, 1842, p. 175; also in Am. Assoc. Geol. and Nat., Proc., 1840-1842, p. 68.

Republished in "A reprint of annual reports and other papers on the geology of the Virginias," by the late William Barton Rogers. New York, 1881, pp. 645-656, and plate.

Describes briefly the rocks of the Richmond coal field, discusses their probable age, and gives descriptions and figures of a number of fossil plants found in them.

ROGERS, W. B. 1843a.

Observations of subterranean temperatures in the coal mines of eastern Virginia.

In Am. Assoc. Geol. and Nat., Trans., 1840-1842, p. 532-538.

Abstract in Am. Jour. Sci., vol. 43, p. 176; also in Am. Assoc. Geol. and Nat., Proc., 1840-1842, p. 69.

Describes briefly the stratigraphy of the Richmond coal field, thickness of coal, dip of strata, etc., and gives observations of temperature in various mines, the depths of which are stated.

ROGERS, WILLIAM B. 1851.

[Difficulty of determining the age of the coal beds of North Carolina and Virginia.]

In Am. Assoc. Adv. Sci., Proc., vol. 4, p. 275.

Discussion of a paper by W. R. Johnson.

ROGERS, W. B. 1853.

[Age of the Deep river coal field, North Carolina.]

In Am. Acad., Proc., vol. 3, 1852-1857, pp. 69, 70.

Abstract of remarks in reference to the similarity of the Newark system in North Carolina, Virginia, and Pennsylvania. Followed by remarks on the age of the same system, by L. Agassiz and T. C. Jackson.

ROGERS, W. B. 1854.

[Remarks on fossils from the Middle Secondary strata of North Carolina, Virginia, Pennsylvania and Massachusetts.]

In Boston Soc. Nat. Hist., Proc., vol. 5, pp. 14-18; also in Am. Jour. Sci., 2d. ser., vol. 19, 1855, pp. 123-125.

Abstract in Ann. Sci. Discov., 1855, pp. 330-333, and in Am. Jour. Sci., 2d. ser., vol. 19, pp. 123-125.

Describes briefly several of the Newark areas and makes a comparison of their fossils. The conclusion is reached that the fossils indicate a Jurassic age.

ROGERS, WILLIAM B. 1854a.

[Observations on the occurrence of natural coke in the Richmond coal field, Va.]

In Boston Soc. Nat. Hist., Proc., vol. 5, pp. 53-56.

Reprinted in The Virginias, vol. 4, pp. 158-159.

Abstract in Ann. Sci. Discov., 1855, pp. 320-322.

ROGERS, WILLIAM B.—Continued.

Describes the occurrence of natural coke and its relation to igneous injections. The presence of baked fire clay associated with the coke is also mentioned.

ROGERS, W. B. 1854b.

[On natural coke in the Richmond coal field, Va.]

In Am. Acad.. Proc., vol. 3, 1852–1857, pp. 106–107.

Describes the natural coke and its relation to a trap sheet. The trap is supposed to have been extruded before the rocks above it were deposited.

ROGERS, W. B. 1855.

[On lignite from Lancaster county, Pennsylvania, and from the Richmond coal field, Va.]

In Boston Soc. Nat. Hist., Proc., vol. 5, pp. 189–190.

From the similarity of specimens of lignite from the localities mentioned in the title it is concluded that the rocks from which they were obtained are of the same age.

ROGERS, WM. B. 1855a.

[Remarks on the age of the coal-bearing rocks near Richmond, Va., and of the Newark areas in North Carolina.]

In Boston Soc. Nat. Hist., Proc., vol. 5, p. 186.

The age of the deposits mentioned is considered the same, judging from specimens of lignite from each.

ROGERS, WILLIAM B. 1855b.

[On a new locality for Posidonomaya in the Mesozoic rocks of Virginia.]

In Boston Soc. Nat. Hist., Proc., vol. 5, pp. 201–202.

From the discovery of specimens of Posidonomaya near the junction of the Bannister and Dan rivers, Virginia, the rocks containing them are correlated with the Mesozoic strata of Prince Edward county and other localities.

ROGERS, WILLIAM B. 1855c.

[Local metamorphism produced by trap dikes in Prince William county, Virginia.]

In Boston Soc. Nat. Hist., Proc., vol. 5, pp. 202–204.

Describes the character and general strike of the trap dikes of the region mentioned, together with the alteration they have produced on the adjacent shales and sandstones. From the evidences of alteration in sedimentary beds similar to that adjacent to the dikes, over a large area, the hypothesis is suggested that the rocks in question were formerly covered by a trap sheet which has been eroded away.

ROGERS [W. B.]. 1859.

[Who first discovered the footprints in the Connecticut valley sandstone.]

In Boston Soc. Nat. Hist., Proc., vol. 7, 1859–1861, p. 53.

Relates to the claims of Deane and Hitchcock to priority in the discovery of the footprints in question. Remarks in discussion of a paper by T. T. Bouvé.

ROGERS, W. B. 1860.

[Remark on the deposition of the inclined strata of the Newark system.]

In Boston Soc. Nat. Hist., Proc., vol. 7, 1859–1861, p. 274.

Refers briefly to the Newark system as an example of the manner in which inclined strata may be deposited.

ROGERS [W. B.]. 1860a.

[On a block of Red sandstone from Portland, Connecticut, containing impressions of bones, apparently ornithic.]

In Boston Soc. Nat. Hist., Proc., vol. 7, p. 396.

ROGERS [W. B.]. 1860b.

[On the age of the sandstone on the St. Croix, New Brunswick, and at Perry, Me.]

In Boston Soc. Nat. Hist., Proc., vol. 7, pp. 398–399.

The rocks at the localities mentioned in the title are not admitted to be of Newark age.

In discussion of a paper by C. T. Jackson.

ROGERS, WILLIAM B. 1879.

List of geological formations found in Virginia and West Virginia.

In American geological railway guide, by James Macfarlane, pp. 179–185.

Describes briefly the Newark (Jurasso-Cretaceous and the Jurasso-Triassic) rocks of Virginia, and indicates their position in the geological column, p. 180.

ROGERS, W. B. 1880.

The iron ores of Virginia and West Virginia.

In The Virginias, vol. 1, pp. 128–130, 138–140, 152–153, 160–161.

Contains an account of the Mesozoic iron ores of Virginia.

ROGERS, WILLIAM B. 1880a.

Table of the geological formations found in V[irgini]a and W[est] V[irgini]a.

In The Virginias, vol. 1, pp. 14–15. (Republished in The Virginias, vol. 3, p. 61.)

Indicates the position of the Newark system in the geological column.

ROGERS, WILLIAM BARTON. 1884.

A reprint of annual reports and other papers on the geology of the Virginias, by the late William Barton Rogers.

New York. Pp. i–xv, 1–832, with 7 plates in volume and 8 plates and 1 geological map in pockets.

Reviewed by J. L. and H. D. Campbell in Am. Jour. Sci., 3d ser. vol. 30. pp. 357–374, vol. 31, pp. 193–202.

The reports and paper in this volume which contain matter relating to the Newark system have been noticed in this index as originally published. The geological map of Virginia, and some of sections on pls. 7–8 were not published originally with the reports.

ROGERS, WILLIAM BARTON. Analysis of coal from the Richmond coal field, Va., Clifford, '87, p. 10).

ROGERS, WILLIAM BARTON—Continued.
Cited on age of the Newark system (Dewey, '57. C. H. Hitchcock, '71, p. 21. E. Hitchcock, '55*a*, p. 407. Hitchcock and Hitchcock, '67, p. 416. Lea, '53, p. 188. Mather, '43, pp. 293-294. Newberry, '88, p. 9. W. C. Redfield, '56, pp. 180-181. Stur, '88, p. 205. Zeiller, '88, p. 698).
Cited on age of the Newark in the Connecticut valley (E. Hitchcock, jr., '55, p. 25).
In New Jersey, Virginia, etc. (J. D. Dana, '56, p. 322).
In North Carolina (Emmons, '56, p. 272. Macfarlane, '77, pp. 517, 528).
In Virginia (Fontaine, '83, pp. 12, 15, 16, 28, 37, 89. E. Hitchcock, '58, p. 6. Horner, '46. Lyell, '47, pp. 261, 279, 280. Lyell, '49, pp. 280-281. Marcou, '49, pp. 273-274. Marcou, '58, pp. 13-15. Macfarlane, '77. W. C. Redfield, '56*a*, p. 357. H. D. Rogers, '58, vol. 2, pp. 693, 696).
Cited on faults in the Richmond coal fields, Va. (W. M. Davis, '83, p. 304).
Cited on footprints from Turners Falls, Mass. (Deane, '56).
Cited on fossils of the Richmond coal field, Va. (Heinrich, '78, p. 264).
Cited on a fossil crustacean from Va. (Jones, '62, pp. 123-126. H. D. Rogers, '43).
Cited on fossil crustaceans (Jones, '62, p. 85).
Cited on fossil plants (Marcou, '90).
Cited on geological position of the Newark system (E. Hitchcock, '41, p. 438).
Cited on intrusive trap sheets in Virginia (W. M. Davis, '83, p. 294).
Cited on mode of formation of the Newark system (E. Hitchcock, '41, pp. 527-529).
Cited on origin of the conglomerate "Potomac marble" on the west border of the Newark of Maryland and Virginia (Lea, '53, p. 189).
Cited on origin of the natural coke of the Richmond coal field, Va. (Hotchkiss, '83. Stevens, '73).
Cited on origin of the Newark system (Cook, '89, p. 13).
Cited on origin of the prevailing dip of the rocks of the Newark system (Newberry, '88, p. 6).
Cited on *Pecopteris whitbyensis* (Emmons, '56, p. 326).
Cited on relation of trap and sandstone in Pennsylvania (W. M. Davis, '83, p. 287).
Cited on Richmond coal field, Va. (Clifford, '87, pp. 4, 25. Taylor. '48, p. 46).
Cited on Tæniopteris from Richmond coal field (Bunbury, '47, p. 281).
Cited on temperatures in coal mines of Richmond coal field, Va. (Taylor, '48, pp. 49-50).
Cited on the tilting of the sandstone and trap of the Richmond coal field, Va. (W. M. Davis, '83, p. 302).
Cited on trap dikes in Virginia (W. M. Davis, '83, p. 292).
Geological map of Virginia (Hotchkiss, '80).
Notice of work by, in Virginia (Miller, '79-'81, vol. 2, p. 149).

ROGERS, WILLIAM BARTON—Continued.
Section of the Richmond coal field, Va. (Hotchkiss, '80).

ROGERS, WILLIAM B., and HENRY D. ROGERS. **1843a.**
On the physical structure of the Appalachian chain, as exemplifying the laws which have regulated the elevation of great mountain chains generally.
In Am. Assoc. Geol. and Nat., Trans., 1840-1842, pp. 474-531, pl. 3.
Describe an unconformity between the Newark system and the crystalline rocks on which it rests, p. 523.

Roger's head, N. B. Rocks of (Gesner, '40, pp. 16, 17).

Roger's mills, N. J. Synclinal axis near (H. D. Rogers, '40, p. 128).

Roger's point, N. B. Rocks of (Gesner, '41, p. 14).

Rogerstown, Pa. Boundary of the Newark near (H. D. Rogers, '58, vol. 2, p. 668),

Rosemont, N. J. Dip in shale at (Cook, '82, p. 26).

Rosstown, Pa. Contact metamorphism near (H. D. Rogers, '58, vol. 2, p. 679).
Trap dikes near (H. D. Rogers, '58, vol. 2, p. 688).
Trap ranges near (H. D. Rogers, '58, vol. 2, p. 679).

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Mention of various rock specimens from near (C. E. Hall, '78, pp. 39-69).

Rothville, Pa. Boundary of the Newark near (Frazer, '80, p. 44).

Round mountain, N. J. Description of (Cook, '68, pp. 193-194. Cook, '82, pp. 63-64. Darton, '90, pp. 62-65).
Diverse dips near (Nason, '89, p. 18).
Origin of trap of (Darton, '89, p. 138),
See also Pennington mountain (Cook, '68, p. 190).

Round Top, Pa. Analysis of trap from (Frazer, '77, p. 310).
Contact metamorphism at (H. D. Rogers, '58, vol. 2, p. 687).
Trap dikes at (H. D. Rogers, '58, vol. 2, p. 687).
Trap from (C. E. Hall, '78, pp. 29, 39).

Round valley, N. J. Dip in (Cook, '68, p. 199).
Dip in indurated shale at (Cook, '82, p. 28).
Small sandstone area near (Cook, '68, p. 75).

Round valley hill, N. J. Described briefly as a trap outcrop (H. D. Rogers, '36, p. 159).

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Character of the formation near (H. D. Rogers, '40, p. 132).
Description of (Cook, '68, p. 193. Cook, '82, pp. 64-65).
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Rowlet's coal mine, Va. Notes on (Taylor, '35, p. 285).

RUSSELL, I. C. 1877.
Concerning footprints.
In American Nat., vol. 11, pp. 406-417.
Contains a popular account of the fossil footprints of New Jersey and the Connecticut valley.

RUSSELL, I. C. 1878.
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In New York Acad. Sci., Ann., vol. 1, 1879, pp. 220-254.
Reviewed by P. Frazer, in Am. Nat., vol. 13, pp. 284-292, and by J. D. Dana in Am. Jour. Sci., 3d ser., vol. 17, pp. 328-330.
Indicates briefly the distribution of the various areas of Newark system, pp. 220-222. Describes the Red sandstones and shales, variegated conglomerate, and eruptive rocks of the New Jersey area, pp. 222-246. In treating of this division of the subject numerous details are mentioned, and the conclusion reached that the Newark rocks of New Jersey and of the Connecticut valley were united at the time of their deposition, upheaval and erosion having since separated the two areas.

RUSSELL, ISRAEL COOK. 1878a.
On the intrusive nature of the Triassic trap sheets of New Jersey.
In Am. Jour. Sci., 3d ser., vol. 15, pp. 277-280.
An attempt to prove that certain trap sheets in New Jersey are intrusive sheets and not interbedded overflows of igneous rocks.

RUSSELL, ISRAEL COOK. 1878b.
On the occurrence of a solid hydrocarbon in the eruptive rocks of New Jersey.
In Am. Jour. Sci., 3d ser., vol. 16, pp. 112-114.
Abstract in Am. Nat., vol. 13, pp. 198-199.
Describes the occurrence of a solid hydrocarbon in the trap of the First Newark mountain, N. J., and refers to previous discoveries of similar substances. See also pp. 130-132 of same volume.

RUSSELL, I. C. 1879.
Footprint in the Mesozoic rocks of New Jersey.
In Am. Jour. Sci., 3d ser., vol. 18, p. 232.
Brief record of the finding of a fossil footprint near Boonton, N. J.

RUSSELL, ISRAEL C. 1880.
On the geology of Hudson county, New Jersey.
In New York Acad. Sci., Ann., vol. 2, 1882, pp. 27-30, pl. 2.
Republished in part in Science (ed. by J. Mitchels), vol. 2, 1881, pp. 63-65.
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RUSSELL, I. C. 1880a.
On the former extent of the Triassic formation of the Atlantic states.
In Am. Nat., vol. 14, pp. 703-712.

RUSSELL, I. C.—Continued.
Assembles various observations which are considered by the writer as indicating that the various Newark areas were originally connected and have since been separated by erosion.

RUSSELL, ISRAEL COOK. 1885.
North Carolina coal fields.
In Science, vol. 6, pp. 548-549.
Notice of a report on the coal fields of North Carolina, by H. M. Chance.

RUSSELL, ISRAEL COOK. 1889.
Subaerial decay of rocks and origin of the red color of certain formations.
U. S. Geol. Surv., Bull. No. 52, pp. 1-65.
Reviewed by J. D. Dana in Am. Jour. Sci., 3d ser., vol. 39, pp. 317-319.
Discusses the origin of the prevailing red color of the sandstones and shales of the Newark system, pp. 44-55.

RUSSELL, I. C. 1889a.
The Newark system.
In Am. Geol., vol. 3, pp. 178-182.
Reviewed by C. H. Hitchcock in Am. Geol., vol. 5, pp. 200-202.
Gives a list of names and correlations applied to the Red sandstone, shale, etc., which occur in detached area along the Atlantic coast. Suggests that the name, Newark system, proposed by W. C. Redfield, in 1856, be used to designate the system of rocks referred to.

RUSSELL, ISRAEL COOK. 1891.
Has "Newark" priority as a group name.
In Am. Geol., vol. 7, pp. 238-241.
A reply to criticisms by C. H. Hitchcock.

RUSSELL, I. C. Cited on cause of the tilting of the Newark (W. M. Davis, '83, p. 303).
Curved form of certain trap ridges (W. M. Davis, '83, p. 307).
Fossil footprints in New Jersey (C. H. Hitchcock, '88, p. 123).
Former connection of the Newark system in New Jersey and Connecticut valley (Le Conte, '82, pp. 470, 600).
Former extent of the Newark system (Newberry, '88, p. 6).
Geology near Feltville, N. J. (W. M. Davis, '83, p. 275).
Intrusive trap sheets in New Jersey (W. M. Davis, '83, pp. 295, 296. Russell, '78, p. 243).
Newark of New Jersey (Miller, '79-'81, vol. 2, p. 235).
Origin of the red color of Newark sandstones (J. D. Dana, '90, p. 319).
Solid hydrocarbon in the igneous rocks of New Jersey (J. D. Dana, '78).
Structure of the Newark system (Cook, '87).
Trap at Feltville, N. J. (Darton, '90, p. 26).
Trap ridges (Frazer, '82, p. 141).
Discussion of the hypothesis by, explaining opposing dips (W. M. Davis, '82*a*, p. 119).

Ruth mine, Pa. Detailed account of (d'Invilliers, '83, pp. 350-352).

SHALER, N. S. 1871.
On the causes which have led to the production of cape Hatteras.
In Boston Soc. Nat. Hist., Proc., vol. 14, pp. 110–121.
Refers to the structure and age of the Richmond coal field, pp. 114–115, 117. Structure of the Connecticut valley area, p. 118.

SHALER, N. S. 1875.
Notes on the investigations of the Kentucky geological survey during the years 1873, 1874, and 1875.
In Kentucky geological survey, Reports of Progress, 2d ser., vol. 3, 4to, pp. 129–282.
Contains brief references to the structural features associated with the Newark system in Virginia and the Connecticut valley, p. 220.

SHALER, N. S. 1884.
Description of quarries and quarry regions.
In report on the building stones of the United States and statistics of the quarry industry for 1880, in Tenth Census of the United States, vol, 10, part 2, pp. 107–229, pls. 27–58.
Describes the Newark sandstone quarries of Connecticut, pp. 126–127; New Jersey, pp. 141–144; Pennsylvania, pp. 156–157; Maryland, p. 178; Virginia, p. 179; and North Carolina, pp. 181–182; the trap rock quarries of Connecticut, p. 177; New Jersey, pp. 145–146, and Virginia, p. 179; and the Triassic limestone quarries of Pennsylvania, p. 156, and Maryland, p. 177.

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A first book in geology.
Boston, 12mo, pp. i–xvii, 1–255.
Contains a brief account of the life of the Jurassic and Triassic periods, pp. 217–224).

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[Administrative report of Atlantic coast division of the U. S. Geological Survey.]
In U. S. Geol. Surv., Sixth Ann. Rep. of the, pp. 18–22.
States that the Tertiary strata of Martha's Vineyard are in part composed of Newark débris, p. 21.

SHALER, NATHANIEL SOUTHGATE, and WILLIAM MORRIS DAVIS. 1881.
Illustrations of the earth's surface. Glaciers.
Boston. Folio, pp. i–vi, 1–198, pls. 1–25.
Suggests that the Newark conglomerate of the Connecticut valley may be of glacial origin, pp. 95–96. Section showing ancient periods of glaciation, p. 102.

SHEPARD, C. U. 1832.
Datholite and iolite in Connecticut.
In Am. Jour. Sci., vol. 22, pp. 389–391.
Describes the occurrence of datholite, etc., in trap at Middlefield and Haddam, Conn., and compares these localities with similar localities in New Jersey.

SHEPARD, CHARLES UPHAM. 1837.
Report on the geological survey of Connecticut.
New Haven, Pp. 1–188.
Abstract in Am. Jour. Sci., 1st ser., vol. 33, pp. 151–175.
Devoted mainly to mineralogy, but contains a brief discussion in reference to the probability of finding coal in Connecticut, pp. 61–62; also a brief description of the building stones of the Newark area, including trap rocks, pp. 98–100. List of Newark specimens collected to illustrate the geology and mineralogy of the state, pp. 165–169.

SHEPARD, CHARLES UPHAM. **1867.**
On the supposed tadpole nests or imprints made by the *Batrachoides nidificans* (Hitchcock), in the red shale of the New Red sandstone of South Hadley, Mass.
In Am. Jour. Sci., 2d ser., vol. 43, pp. 99-104.
Discusses the origin of the markings referred to.

Shoolie, N. S. Relation of trap, conglomerate, and sandstone at (Gesner, '43).

Shooter's island, N. Y. Exposures of Newark sandstone and shale on (Britton, '81, p. 168).

Short Hills, N. J. Record of well bored in (Nason, '89*b*).

Short mountain, Conn. Description of (Percival, '42, p. 375).
Detailed study of the geological structure near (W. M. Davis, '89).
Sketch map of (W. M. Davis, '89, pl. 5).

SHRUMP, F. W. Stone quarry of, near Verona, N. J. (Cook, '81, p. 52).

Shuttle meadow, Conn. Detailed study of cross-section at (W. M. Davis, '89, pp. 64-69).

Shuttle meadow mountain, Conn. Anterior trap ridge of (Davis and Whittle, '89, p. 109).

Shuttle meadow reservoir, Conn. Sketch map of (W. M. Davis, '89, pl. 2).
View of fault gap near (W. M. Davis, '89, pl. 2).

Siccomac, N. J. Boundary of First mountain trap near (Cook, '68, p. 180).
Watchung mountain, end at (Cook, '82, p. 49).

Siddonstown, Pa. Trap dike near (H. D. Rogers, '58, vol. 2, p. 689).

Sidney church, N. J. Conglomerate at (Cook, '82, p. 41).
Deformed strata at (Cook, '83, p. 25).
Dip in conglomerate and shale near (Cook, '82, p. 28).
Faults and folds near (Cook, '79, p. 33).
Faults near (Cook, '82, p. 16).
Folds near (Cook, '82, p. 17).
Limestone at (Cook, '82, pp. 22, 42).

Sidney mills, N. J. Dip in shale near (Cook, '82, p. 28).

Sillery, J. Stone quarry of, near Prallsville, N. J. (Cook, '81, p. 59).

SILLIMAN, BENJAMIN. **1810.**
Sketch of the mineralogy of the town of New Haven [etc.].
In Connecticut Acad. Arts and Sci., Mem., vol. 1, pp. 83-96.
Contains a general account of the trap exposures near New Haven, Conn.

SILLIMAN, BENJAMIN. **1814.**
Mineralogical and geological observations on New Haven and its vicinity.
In Am. Min. Jour., vol. 1, pp. 139-149).
Abstract in Jour. de phys., de chim. [etc.] Par J. C. Delamétherie, Paris, Tome 75, 1812, pp. 75-79.
Notice in Am. Jour. Sci., vol. 1, 1818, pp. 55-56, and in Elementary treatise on Mineralogy and Geology by Parker Cleaveland, 1822, p. 555.
Describes the geology about New Haven, Conn., especially of east and west rocks. Records the finding of a large mass of native copper on the Hamden hills, Conn.

[SILLIMAN, BENJAMIN.] **1818.**
Native copper [found near Wallingford, Conn.].
In Am. Jour. Sci., vol. 1, pp. 55-56.
Describes the finding of a mass of native copper.

[SILLIMAN, BENJAMIN.] **1818a.**
New localities of agate, chalcedony, chabazite, stilbite, analcite, titanium, prehnite, etc.
In Am. Jour. Sci., vol. 1, pp. 134-135.
Describes the occurrence of minerals at Deerfield, Mass., and at East Haven and Woodbury, Conn.

SILLIMAN, BENJAMIN. **1820.**
[Note on the discovery of fossil bones in sandstone at East Windsor, Conn.]
In Am. Jour. Sci., vol. 2, p. 147.
Gives a brief account of the Newark (called Old Red sandstone) of the Connecticut valley; and remarks on the nature of the animal to which the bones referred to belonged.

[SILLIMAN, BENJAMIN.] **1820a.**
Sketch of a tour in the counties of New Haven and Litchfield, in Connecticut, with notices of the geology, mineralogy and scenery, etc.
In Am. Jour. Sci., vol. 2, pp. 201-235.
Describes West rock, Connecticut, pp. 202-203, and also the character of the small Newark basin in Woodbury and Southbury, Conn., pp. 231-233.

[SILLIMAN, BENJAMIN.] **1821.**
[Remarks on letters from Alexander Brongniart in reference to fossil fishes and native copper from near Middletown, Conn.]
In Am. Jour. Sci., vol. 3, pp. 221-222.
Refers to the finding of fossil fishes, and to the working of copper ore.

[SILLIMAN, BENJAMIN.] **1821a.**
[Note on the finding of fossil fish at Sunderland, Mass.]
In Am. Jour. Sci., vol. 3, pp. 365-366.
States that a large number of fossil fish were obtained by Edward Hitchcock, at Sunderland, Mass.

SILLIMAN, B. **1824.**
Remarks made on a short tour between Hartford and Quebec in the autumn of 1819.
New Haven, 2d ed., 12mo., pp. 1-443, and 9 plates.
First edition, New Haven, 1820, 12mo., pp. 1-407, and 9 plates.
Contains a general account of the scenery and geology of the Connecticut valley.

SILLIMAN, BENJAMIN. **1827.**
[Note on the presence of bituminous coal in the Connecticut valley.]
In Am. Jour. Sci., vol. 12, p. 76).
States that coal has been found at several places in the Connecticut valley.

[SILLIMAN, BENJAMIN.] 1830.
Igneous origin of some trap rocks.
In Am. Jour. Sci., vol. 17, pp. 119–132, and plate.
Describes the contact of trap with sandstone beneath, at Rocky Hill near Hartford, Conn. The effect of the heat of the trap on the sandstone is discussed, pp. 122–131, and plate.

[SILLIMAN, BENJAMIN.] 1837.
Bird tracks at Middletown, Conn., in the New Red sandstone.
In Am. Jour. Sci., vol. 31, p. 165.
Brief abstract from a letter stating that footprints as well as bones and fossil plants have been found at the place named.

[SILLIMAN, BENJAMIN.] 1839.
Fossil fishes in the sandstone of New Jersey.
In Am. Jour. Sci., vol. 35, p. 192.
Notice of the finding of fossil fishes in Morris county, N. J.
Further information regarding these fossils is given by "R." in Am. Jour. Sci., vol. 36, pp. 186–187.

[SILLIMAN, BENJAMIN.] 1842.
[Note on the Richmond coal field, Va.]
In Am. Jour. Sci., vol. 43, p. 14.
A brief reference concerning specimens received from the Midlothian coal mine, Virginia, value of the coal of that field, etc.

[SILLIMAN, B.] 1843.
Ornithichnites of the Connecticut river sandstone and the Dinornis of New Zealand.
In Am. Jour. Sci., vol. 45, pp. 177–188.
Publishes letters from J. Deane, G. A. Mantell, and R. Owen relative to the fossil footprints of the Connecticut valley.

SILLIMAN, BENJAMIN. 1844.
Dr. Percival, the original observer of the crescent-formed dikes of trap in the New Red sandstone of Connecticut.
In Am. Jour. Sci., vol. 46, pp. 205–206.
Relates to an omission to give credit to Percival in a report of a meeting of the Association of American Geologists and Naturalists, published in the Am. Jour. Sci., vol. 45, p. 334.

SILLIMAN, B. Cited on certain polygonal depressions in sandstone from Connecticut valley (E. Hitchcock, '56, p. 111).
Cited on curved form of certain trap ridges (W. M. Davis, '83, p. 307).
Cited on fossil fish from Connecticut (J. H. Redfield, '36).
Cited on fossil footprints (Deane, '45, p. 159).
Cited on metamorphism contact at Rocky hill, Mass. (E. Hitchcock, '35, pp. 422–423).
Cited on native copper in the Connecticut valley (Hoffmann, '22).
Cited on origin of the sandstones of the Connecticut valley (E. Hitchcock, '35, p. 241).
Cited on relation of trap and sandstone in Connecticut (W. M. Davis, '83, pp. 285–286).
Cited on trap rocks near Hartford, Conn. Davis and Whittle, '89, p. 121).

SILLIMAN, B., B. SILLIMAN, Jr., and JAMES D. DANA. 1847.
[Note on phalangeal impressions in fossil footprints.]
In Am. Jour. Sci., 2d ser., vol. 3, p. 276.
Calls attention to a statement by L. Agassiz in reference to the number of phalanges in the toes of birds, and cites similar observations by E. Hitchcock and J. Deane.

[SILLIMAN, B., and J. D. DANA.] 1847.
[Note on] ornithichnites.
In Am. Jour. Sci., 2d ser., vol. 3, p. 276.
Notes the observations of Hitchcock, Agassiz, and Deane on the number of joints in the toes of fossil footprints from the Connecticut valley. The names of certain fossil footprints found at Turners Falls, Mass., by James Deane, and described in the Am. Jour. Sci., 2d ser., vol. 3, pp. 74–79, are supplied by Hitchcock.

SILLIMAN [BENJAMIN], and [DOUGLASS] HOUGHTON. 1844.
On the connection of the metallic copper with the trap of Connecticut and Michigan.
In Am. Jour. Sci., vol. 47, p. 132.
A brief discussion of the origin of native copper, frequently associated with trap.

SILLIMAN, B., and O. P. HUBBARD. 1842.
Chemical examination of bituminous coal from the pits of the Midlothian coal-mining company, south side of James river, 14 miles from Richmond, Va., Chesterfield county.
In Am. Jour. Sci., vol. 42, pp. 369–374.
Gives in detail the result of an examination of a large sample of coal from the locality named.

SILLIMAN and HUBBARD. Analysis of coal from the Richmond coal field, Va. (Clifford, '87, p. 10).

SILLIMAN [B.], Jr. 1841.
[Remark on rhombic structure in the sandstone of the Connecticut valley.]
In Am. Jour. Sci., vol. 41, p. 173, also in Am. Assoc. Geol. and Nat., Proc., 1840–1842, p. 26.
Brief abstract of remark on a paper by Prof. Mather, concerning joints in rock.

SILLIMAN, BENJAMIN, Jr. 1842.
[On the cause of the prevailing dip of the New Red sandstone of the Connecticut valley.]
In Am. Jour. Sci., vol. 43, p. 171; also in Am Assoc. Geol. and Nat., 1840–1842, p. 64.
Refers the prevailing dip of the sandstone of the Connecticut valley to upheaval, connected with outbursts of trap. Brief abstract of remarks on a paper by Edward Hitchcock.

SILLIMAN, BENJAMIN, Jr. 1842a.
[Trap eruption causing upheaval of adjacent strata.]
In Am. Assoc. Geol. and Nat., Proc., 1840–1842, p. 64.
A brief remark in which the inclination of the sandstones of the Connecticut valley is referred to the eruption of trap.

SILLIMAN, BENJAMIN, Jr. 1844.
Report on the intrusive trap of the New Red sandstone of Connecticut.
In Am. Jour. Sci., vol. 47, pp. 107–108.
Abstract in Neues Jahrbuch, 1845, pp. 728–729.
An abstract of a report to the Association of American Geologists and Naturalists, concerning, 1st, the dip of the Connecticut valley sandstone; 2d, the manner in which the trap rocks were intruded, and 3d, the erosion of the formation. The age of the strata is stated to be the "period of the New Red sandstone."

SILLIMAN, B., Jr. 1847.
On fossil trees found at Bristol, Conn., in the New Red sandstone.
In Am. Jour. Sci., 2d ser., vol. 4, pp. 116–118.
Describes the finding of the trunk mentioned.

SILLIMAN, B., Jr. 1847a.
[Note on phalangeal impressions in fossil footprints.]
See Silliman, Silliman, jr., and Dana, 1847.

SILLIMAN, B., Jr., and J. D. WHITNEY. 1855.
Notice of the geological position and character of the copper mine at Bristol, Conn.
In Am. Jour. Sci., 2d ser., vol. 20, pp. 361–368.
Devoted principally to the economic importance of the mine, but describes also its geological position, section of the ore body, etc.

Silver, native, at the Bridgewater copper mine, N. J. (Darton, '85).

Silver Hill, N. J. Description of (Cook, '68, p. 194. Cook, '82, p. 65).
Dip in shale near (Cook, '82, p. 29).

Simsbury copper mine, Mass. Brief account of (E. Hitchcock, '35, pp. 71, 229).

Simsbury, Conn. Building stones in (Percival, '42, p. 439).
Description of sandstone ridge near (Percival, '42, p. 440).

Sindle's mill, N. J. Basaltic columns near (Cook, '68, p. 203).

Skillman station, N. J. Dip in shale at (Cook, '82, p. 25).

Slate, bituminous, in North Carolina (Emmons, '56, p. 268).
Black, in Dan river coalfield, N. C. (McLenahan, '52, p. 171).
With coal, near Leaksville, Va. (W. B. Rogers, '39, p. 78).

Slate Ridge, Pa. Description of trap dike near (Frazer, '80, p. 31).

Slickensides, at North Belleville, N. J. (Cook, '82, p. 16).

SMITH, ALFRED. 1832.
On the water courses, and the alluvial and rock formations of the Connecticut river valley.
In Am. Jour. Sci., vol. 22, pp. 205–231, and map op. p. 205.
Gives the extent and boundaries of the Newark rocks of the Connecticut valley, with a description of principal trap ridges. Refers briefly to the fossils that have been collected, and presents theoretical discussions as to the mode of formation of the sedimentary beds and the origin of the trap.

SMITH, A. Cited on the character of the rocks at Enfield Falls, Conn. (E. Hitchcock, '41, p. 447).

SMITH, EUGENE A. 1878.
Outline of the geology of Alabama.
In handbook of Alabama [etc.], by Saffold Berney, pp. 129–196.
Refers to igneous rocks which are considered as belonging to the Newark system of dikes, pp. 139, 142.

SMITH, EUGENE A. 1883.
Geological survey of Alabama. Report for the years 1881 and 1882.
Montgomery, Ala. Pp. i–xvi, 1–615, and 8 maps.
States that stratified rocks of the Newark system are not known in Alabama, but that the trap dikes of the metamorphic region are usually referred to that period, p. 556.

SMITH, NATHAN. 1820.
Fossil bones found in Red sandstone.
In Am. Jour. Sci., vol. 2, pp. 146–147.
Records the finding of fossil bones at East Windsor, Conn.

SMITH, O. R. Cited on depth of artesian well at Durham, N. C. (Venable, '87).

SMITH, THOMAS P. 1799.
Account of crystallized basalts found in Pennsylvania.
In Am. Philo. Soc., Trans., vol. 4, 1804, pp. 445–446.
A brief account of having seen basalt (trap) near Elizabethtown and Campbellstown, Pa.

SMITH, T. P. Cited on the presence of Jura-Trias in America (Lea, '53, p. 189).

SMITH, W. Discovery of saurian bones by, at Springfield, Mass. (E. Hitchcock, '58, p. 186).

Smith iron mine, N. C. Brief account of, with sketch (Willis, '86, p. 305).

Smith's Ferry, Mass. Brief account of a visit to (Lyell, '45, vol. 1, p. 252).
Dip of rocks at (Lyell, '42).
Fossil footprints at (E. Hitchcock, '58, pp. 50 et seq.).
Relation of conglomerate, trap, and sandstone at (Lyell, '42, p. 794).
Section of rocks at (Lyell, '42).

Smith's hill, N. J. Described briefly as a trap outcrop (H. D. Rogers, '36, p. 159).
Description of trap and sandstone near (H. D. Rogers, '36, p. 156).
Detailed description of (H. D. Rogers, '40, p. 151).
Quarries of trap rock at, mention of (G. P. Merrill, '89, p. 436. Cook, '79, p. 26. Cook, '81, p. 62).

Smithville, N. J. Description of sandstone outcrops near (H. D. Rogers, '36, p. 153).

TAYLOR, R. C. 1834.
[Richmond coal basin and its coal trade.]
In Pennsylvania Senate Journal, vol. 2, 1833–'34, p. 567.
Not seen.

TAYLOR, RICHARD C. 1835.
Memoir of a section passing through the bituminous coal field near Richmond, Va.
In Pennsylvania Geol. Soc., Trans., vol. 1, pp. 275–294, pl. 16–17.
Describes the general character of the Richmond coal field, together with the thickness and quality of the coal as exposed in a number of mines.

TAYLOR, RICHARD C. 1835a.
Review of geological phenomena, and the deductions derived therefrom, in 250 miles of sections in parts of Virginia and Maryland. Also notice of certain fossil acotyledonous plants in the secondary strata of Fredericksburg.
In Pennsylvania Geol. Soc., Trans., vol. 1, pp. 314–325, pl. 18–19.
Contains a brief mention of Newark sandstone and conglomerate on the Potomac river in Maryland, p. 320.

TAYLOR, RICHARD C. 1841.
Report on the ornithichnites or footmarks of extinct birds, in the New Red sandstone of Massachusetts and Connecticut, observed by Prof. Hitchcock, of Amherst.
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UNITED STATES GEOLOGICAL SURVEY

J. W. POWELL, DIRECTOR

CORRELATION PAPERS

ARCHEAN AND ALGONKIAN

BY

CHARLES RICHARD VAN HISE

WASHINGTON

GOVERNMENT PRINTING OFFICE

1892

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DEPARTMENT OF THE INTERIOR,
U. S. GEOLOGICAL SURVEY,
DIVISION OF GEOLOGIC CORRELATION,
Washington, D. C., January 30, 1892.

SIR: I have the honor to transmit herewith a memoir by Prof. C. R. Van Hise on the Archean and Algonkian of North America, prepared for publication as a bulletin.

The Division of Geologic Correlation was created for the purpose of summarizing existing knowledge with reference to the geologic formations of North America, and especially of the United States; of discussing the correlation of formations found in different parts of the country with one another and with formations in other countries; and of discussing the principles of geologic correlation in the light of American phenomena. The formations of each geologic period were assigned to some student already well acquainted with them, and it was arranged that he should expand his knowledge by study of the literature and by field examination of classic localities, and embody his results in an essay. The general plan of the work has been set forth on page 16 of the Ninth Annual Report of the Survey, and on pages 108 to 113 of the Tenth Annual Report, as well as in a letter of transmittal of Bulletin No. 80.

The present essay is the seventh of the series, having been preceded by essays on the Carboniferous and Devonian, the Cambrian, the Cretaceous, the Eocene, the Neocene, and the Newark systems; prepared severally by Messrs. Williams, Walcott, White, Clark, Dall and Harris, and Russell, and constituting Bulletins 80, 81, 82, 83, 84, and 85.

The voluminous literature of the pre-Cambrian rocks of North America is abstracted in a thorough manner, being classified for this purpose primarily by geographic districts and secondarily by dates. The division of the rocks into two great classes, the Archean and Algonkian, taxonomically coordinate with the periods under which the fossiliferous clastic rocks are classified, is then advocated and set forth at length. As these rocks do not contain faunas available for purposes of correlation, their classification, both major and minor, is necessarily based on physical characters and relations, and much attention is therefore given to the discussion of the possibilities and limitations of correlation by means of physical data. It is concluded that with present information the correlation of pre-Cambrian series and formations of different geologic provinces is impracticable.

Very respectfully, your obedient servant,

G. K. GILBERT,
Geologist in charge.

Hon. J. W. POWELL,
Director U. S. Geological Survey.

OUTLINE OF THIS PAPER.

This book is a review of the present state of knowledge of the general structure of the pre-Cambrian rocks of the United States and Canada. The material contained in the historical chapters is of two kinds: Summaries of all articles pertaining to the subject considered, and summaries of the conclusions which appear to be established. The first represents the substance of the literature; the second brings together the important ascertained structural facts, and oftentimes becomes a more or less extended discussion. The final chapter covers the same grounds as the historical chapters for the various pre-Cambrian general successions proposed by different authors, and also contains a discussion of results and the principles upon which they are based. Within the chapters, individual districts or regions are given separate sections, and the summary of literature for each is arranged in chronological order. As used in this volume, the term Cambrian is defined as delimited below by the base of the Olenellus fauna; Algonkian includes the pre-Olenellus clastics and their equivalent crystallines; while the Archean includes the completely crystalline rocks below the Algonkian.

The several chapters have the following scopes: Chapter I: The Original Laurentian and Huronian areas—treats of eastern Ontario and western Quebec, and the area from the north channel of lake Huron to lake Temiscamang. Chapter II: Lake Superior Region—summarizes the work of the official geologists of the Canadian Survey and associates, of the early United States geologists and associates, of the Michigan geologists and associates, of the Wisconsin geologists and associates, of the Minnesota geologists and associates, of the later United States geologists and associates, and gives a summary and discussion of results. Chapter III: The Great Northern Area—treats of the region about Hudson bay, northern Canada, and the lower St. Lawrence river region. Chapter IV: Eastern Canada and Newfoundland—treats of the Eastern townships, Gaspé peninsula, central New Brunswick, southern New Brunswick, Nova Scotia and cape Breton, and Newfoundland. Chapter V: Isolated Areas of Dakota, Missouri and Texas—treats of the Black hills, the pre-Cambrian of Missouri, and the central Mineral region of Texas. Chapter VI: The Cordilleras—treats of the many mountain ranges in the far west. Chapter VII: Eastern United States—treats of the New England, Middle Atlantic, and Southern Atlantic states. Chapter VIII: General Successions and Discussions of Principles—summarizes the various general successions proposed, suggests one, and discusses the principles of pre-Cambrian stratigraphy.

The more important conclusions of this chapter are as follows: The Archean is the basal complex of America. It has everywhere, if large areas are considered, an essential likeness. It consists mainly of granitic, gneissic and schistic rocks, among which are never found beds of quartzite, limestone, or any other indubitable clastics. One kind of rock may occupy considerable areas, but when different kinds are associated their structural relations are most intricate. These relations, as well as the completely crystalline schistose character of the rocks, the frequent broken and distorted forms of the mineral constituents, and their involuted foldings, are evidence that these most ancient rocks have passed through repeated powerful dynamic movements.

As to the origin of the Archean rocks, three different views are proposed: (1) They may be considered as metamorphosed detrital rocks. (2) They may be considered as igneous and later in origin than certain of the pre-Cambrian clastics. (3) They may be considered as igneous and representing either a part of the earth's original crust or else originally crystallized material which has now reached the surface as a consequence of inward crystallization and subsequent deep denudation. The Archean rocks have no limit below, but are limited above by the Algonkian. While structural methods have been applied to the Archean rocks, they have not thus far been successful, and the only subdivisions which are at present applicable are those of a lithological character.

In various parts of North America are one or more series of clastic rocks between the Archean and Cambrian. These occur in the Original Laurentian area, the Original Huronian area, in the lake Superior region, in the region about Hudson bay, in the Eastern townships, in southern New Brunswick, in Nova Scotia and cape Breton, in Newfoundland, in the Black hills, in Missouri, in Texas, in many ranges of the Cordilleras, in the Grand canyon of the Colorado, in British Columbia, in the Adirondacks, and in other areas. Within these rocks, in many localities, are evidences of abundant life, and in a few places are definitely recognized fossils. The U. S. Geological Survey, recognizing that it is too early to classify the great thicknesses of rocks between the Archean and the Cambrian in North America into systems coordinate in value with those of the subdivisions of the Paleozoic, has proposed the term Algonkian for the whole. The Algonkian system is then delimited below by the Archean and above by the Cambrian.

In many regions it is easy to differentiate the Algonkian from other rocks. This is especially true where they are separated from them by unconformities. In other regions it is difficult to separate them from the Archean and Cambrian rocks, as there sometimes appear to be gradations between them. In this respect the Algonkian system is in no way different from others.

Algonkian stratigraphy is more difficult than post-Algonkian stratigraphy; because the further back we go in the history of the world for any given region the more numerous and frequent have been the changes through which any given rock stratum has passed; and because as yet fossils have not been found in sufficient quantity to be of any assistance in stratigraphy. However, in many regions it has been possible to subdivide the Algonkian rocks into series and these series into formations. In different regions these formations and series differ widely in the degree of crystallization, in their lithological character, and in their order of succession. In this respect Algonkian rocks are not different from those of post-Algonkian age. Considering the continent as a whole, age is no guide to the chemical or mineral composition, texture, color, degree of crystallization, or any other property of a formation, or vice versa, although in a given district or region any one of them may become important guides in stratigraphy.

In certain regions it has been found possible to correlate series with a great degree of probability and in some cases formations which occur in different districts. In regions separated from each other by great distances, and which therefore may have had different physical conditions at the same period, it is not yet possible to make safe correlations of subdivisions of the Algonkian of America. If this conclusion be correct, it is evident that the application of such American terms as Keweenawan, Huronian, etc., to European rocks is not warranted. In working out the geology of a region, local names should be applied to formations and series. Later, with fuller knowledge, these may perhaps be correlated with series to which classical names have been applied.

Physical methods of correlation being the only ones at present available, it becomes necessary to closely scrutinize these methods, estimate their relative value, and point out the services that each may be expected to perform. Of these methods unconformity must be given the foremost place for major divisions within a region. Unconformity may be established by any one of the following phenomena, or by a combination of two or more of them: (1) Ordinary discordance of bedding; (2) difference in the number of dynamic movements to which the series have been subjected; (3) discordance of bedding of upper series and foliation of lower; (4) relations with eruptives; (5) difference in degree of crystallization; (6) basal conglomerates; (7) general field relations.

PREFACE.

In the preparation of this book great difficulty has been encountered because of the unequal value of statements of fact by different men. Oftentimes in regions with which the writer is not familiar it is impossible to discriminate surely between good and poor work. In certain cases in which reports have read plausibly, an examination of the purported facts in the field with the accounts in hand has shown the descriptive parts to be so inaccurate as to render the conclusions, while apparently well founded, wholly valueless. But in general, when an author of this class has written much, discrepancies between the statements of facts appear.

Those who change their opinions are of different classes. A man who progresses must change his views, but the descriptive parts, given while an old view was held, ought to be still more useful for support of the new position. The old view may have contained a large element of truth, and is perhaps included in the newer, larger position. In reports the part that purports to be facts should be wholly separable from the general theories held, just as detailed maps, if rightly constructed, indicate the observations made and the generalizations drawn. More frequently than not, facts and theories are so inextricably mingled that no independent judgment can be reached as to the correctness of the conclusions, and often the facts of a report can not be used even by one personally familiar with the districts of which the report treats. The conclusions of another class of geologists are a series of guesses, which generally serve no purpose except that when any one of the numerous guesses has been established by the patient work of an investigator, the conclusion is at once claimed as a prior discovery of the guesser. Sometimes the discoveries announced by a writer almost or quite simultaneously, are wholly inconsistent with one another and with the facts which are described; for as with other men, so with geologists, many opinions are held at the same time which logically are exclusive of one another. Still another group of writers early reach a general theory as to the definite order of the evolution of the world. A person of this group year after year repeats the old statements and conclusions without any reference to the establishment of their falsity. More often than not, he is one who has done little or no systematic detailed field work in any region. All facts and conclusions which bear in his direction are hailed as discoveries; "all is grist which comes to his mill;" while every adverse fact or conclusion is explained out of existence or dismissed as unworthy of consideration.

By following continuously the summaries of the writings of a geologist who has been long at work in a region it will generally not be difficult to get a fairly accurate idea of the value of the work done.

During the preparation of this review, I have visited many districts of North America, but I have not been able to see important districts which I hoped to study before the submission of this volume. With the United States side of the lake Superior country I am tolerably familiar, having for a number of years given nearly the full field seasons to work in various parts of this region. Besides doing general work, I have mapped in detail certain districts. From time to time various parts of the Canadian lake Superior region have been visited. While no systematic mapping work has been done in regions other than that of lake Superior, reconnaissances and occasional detailed sections have been made in many. In the far West these include the Black hills of Dakota, southwestern Montana, the Laramie and Medicine Bow mountains of Wyoming; the Uinta and Wasatch mountains of Utah; and the Quartzite mountains and Front range of Colorado. In the Mississippi valley the crystalline region of Missouri has been seen. In company with Raphael Pumpelly, Bailey Willis, J. A. Holmes, C. D. Walcott, G. H. Williams, R. W. Ells, or alone, more or less extended trips have been made in Georgia, east Tennessee, North Carolina, eastern Maryland, eastern Pennsylvania, northern New Jersey, southern New York, the Berkshire hills, Green mountains, Adirondacks, Hastings district of Ontario, and the area of the Grenville series constituting the Original Laurentian. For the most part this work has not been of such a detailed nature as to add greatly to previous knowledge of these regions. The aim has been rather to get such a familiarity with them as would enable the writer to judge accurately of the results already reached. This statement does not apply to a part of the Adirondacks, where a somewhat closer study was made; also, in North Carolina a nearly complete section was made from the eastern side of the Piedmont plain through the Blue ridge to the uncrystalline rocks of east Tennessee. The Original Huronian area has been seen at three different times. The first time, in company with the late Dr. R. D. Irving, the North channel was coasted in a small boat and the interior visited, so that all of Logan's members of this series were seen, as well as the underlying Laurentian. In a second trip, also in company with Prof. Irving, the Canadian Pacific railroad was traversed twice on a hand car from Algoma Mills to Sudbury, a distance of 100 miles. The third trip, with Prof. Raphael Pumpelly, was again along the North channel of lake Huron, the object of special study being the possible existence of two series within the Huronian, and the structural relations between the lowest Huronian and the Laurentian.

The labor involved in abstracting the pre-Cambrian literature of North America has been great. This is shown by the large number of books and articles actually summarized. These, however, give an imperfect idea of the volume of literature covered; for very numerous articles have been examined which repeat what had already been summarized from other papers. Also a vast amount of material from which nothing is taken has been looked through, in order to ascertain whether it contained anything which ought to be considered. In all cases summaries are made from the original articles, with the exception of a part of the section upon northern Canada. Nearly the entire literature of the geology of this region has recently been clearly compiled by Dr. George M. Dawson, and from this compilation the major part of the summary for this region is taken.

To a card catalogue of the Appalachians by N. H. Darton, to Azoic Rocks and other works by Hunt, to the Minnesota reports, to the Azoic System by Whitney and Wadsworth, to Irving's Copper-bearing Rocks, and also to many other works the writer is much indebted as furnishing guides to the pre-Cambrian literature. In this way Darton's catalogue and the Azoic System have been by far the most valuable. After independently preparing abstracts of papers and reports I have compared them with the abstracts contained in the Azoic System in order to discover omissions, and this book has thus enabled me to make the survey of literature more nearly complete than it otherwise would have been. To a certain extent other books have been used in the same fashion.

Mr. W. N. Merriam has drawn all the maps for the illustration of the volume. To Mr. George E. Luther the writer is indebted for most efficient clerical assistance from the outset, without which it would have been impossible to complete this volume within the time allotted.

To Sir Archibald Geikie, Dr. Hans Reusch, Dr. K. A. Lossen, Michel-Levy, and Dr. Johannes Lehmann I am indebted for summary statements of the condition of knowledge with reference to the pre-Cambrian of Great Britain, France, Germany and Scandinavia.

With Messrs. C. D. Walcott, G. H. Williams, Bailey Willis, and R. W. Ells I have been in the field and in consultation, and from them have received much useful information.

Mr. G. K. Gilbert has kindly read the manuscript, and has made many suggestions which have been of value.

To the late Prof. Roland D. Irving, and to Prof. Raphael Pumpelly I am indebted in a peculiar manner. With the former I was associated in work from my earliest studies in geology until his death. With the latter I have been much in the field for the last two seasons and have received many pregnant ideas. What part of the thoughts contained come from these two friends I am unable to specify in detail, but I am conscious that the debt is a heavy one.

No one else will feel so keenly the imperfections of this volume as the writer. Papers will be found to be overlooked of which summaries ought to have been made. Mistakes of interpretation will be found. Undue proportion in the summaries will be discovered. I can only say that I have attempted to reduce these defects to a minimum. It will be esteemed a great favor, with reference to a possible future edition, if all who discover such omissions and mistakes will communicate them to the writer.

C. R. V.

MADISON, WIS., *July, 31, 1891.*

A REVIEW OF THE PRESENT STATE OF KNOWLEDGE OF THE PRE-CAMBRIAN ROCKS OF NORTH AMERICA.

By C. R. Van Hise.

INTRODUCTION.

The purpose of this book is to give an account of the present state of knowledge of the general structure of the pre-Cambrian of the United States and Canada. It is not a bibliography of pre-Cambrian literature, nor a petrography of the pre-Cambrian rocks, nor a treatment of metamorphism, nor an account of economic facts. Mere occurrences of pre-Cambrian or crystalline rocks are not referred to unless the districts are new. Petrography, metamorphism, and economic geology are considered only so far as they have a direct bearing upon structural results, and then the substance of the established conclusions is given rather than the facts upon which they are based and the manner of reaching them.

The material contained in the historical chapters of this volume is of two kinds: First, a summary of all articles or parts of articles which have contributed knowledge upon the subject considered; and second, summaries of the conclusions which appear to be established in the various regions, while the final chapter covers the same ground for general successions proposed and also a discussion of these results and the principles upon which they are based. No summaries are made of writings based wholly upon the field work and reports of others. This report is not a review of reviews; neither is purely controversial literature noticed. When a paper is made up in part of an original investigation and of a discussion of the works of others, only the first part is summarized. When the same writer repeats the same facts and conclusions several times, summary is made of the most comprehensive article and references are made to the others in the footnotes.[1] Oftentimes a final report includes all found in several annual reports. In this case the final report only is summarized. In making summaries the conclusions reached by the various authors are always given, and as full an account of the facts upon which they are based as is possible without extending this book beyond bounds.

[1] At the end of each chapter.

The abstracts given have the defects of all summaries—a certain amount of inaccuracy, because all modifying and qualifying facts can not be given, and an undue amount of emphasis in the conclusions. In regions in which much work has been done these defects are not so serious as in little studied regions, for in the former the observations of independent observers confirm or neutralize each other.

So far as possible, in the summaries, the original language of the author is used, although a single sentence of the summary may be taken from several sentences of the original. Where the ideas can be conveyed in a briefer manner than in the original language other words are used. No quotations are made; for the ideas contained, whether in the original language or not, are wholly the ideas of the author—the whole is in fact really quoted. It might be thought that better results would have been reached by indicating through quotations what words are taken from the original, but this method would have necessitated an unpleasant and constant alternation from quoted to nonquoted phrases. It would have made it much more difficult to convey briefly the thoughts of the original; for the words which are adapted to complete expositions are often not the best adapted to a résumé. At first the plan of quoting was followed, but this was abandoned, because it was seen that carrying it out would add greatly to the size of this volume without enhancing, if indeed it did not diminish, the accuracy and comprehensiveness of the review.

Due proportion should be maintained between the abstracts of the various writings. Frequently a short article contains much more of structural importance than one of far greater length, although the longer article may contain much of interest which does not come within the scope of the paper. Into the summaries the editor enters only in so far that he must of necessity take what appears to him important and omit what appears unimportant. Undoubtedly in this respect many mistakes are made; future investigations will show that omitted facts and conclusions have greater importance than now appears; but a perfectly proportioned summary could be made only by perfect knowledge.

The necessarily brief summaries will perhaps serve the purposes of those who are interested in the general stratigraphy of the pre-Cambrian. They will not answer for those who wish to understand in detail the structure of any given region. For this local details are necessary. As the summaries are not made with reference to upholding any theory, they of necessity will fail to give all the facts which bear upon any particular hypothesis. But even for these special purposes it is hoped this volume may be found sufficiently full to be useful, and it certainly will assist in directing to the important literature.

In the discussion the aim has been, not to call attention to all that seems to be erroneous, but first to point out where there is harmony between the different authors, often veiled because terms are used with different significations; and, second, to note the important conclusions which have been clearly determined. Statements and conclusions with which the writer does not agree are in general not criticised nor is any refutation attempted, unless the point at issue is one of such a fundamental character that it can not be overlooked.

The maps are in all cases compiled from the original sources, and, like the summaries, have whatever excellence or defects the original work has. In many cases the editor feels assured that the maps will need to be materially modified, but he has not the detailed knowledge necessary to make the modifications. The generalized character of the boundaries is often indicated by the fact that they are straight lines. It need not be said that true geological boundaries are not of this nature in much disturbed regions. In the Appalachians the maps merely outline the crystalline rocks. Much of the area included is known to belong to the Paleozoic, but it is impossible either accurately to separate these areas or to subdivide the pre-Cambrian. All that can be done in many areas is to indicate that the rocks are pre-Cambrian, although it is oftentimes certain that Algonkian and Archean rocks both occur, which have not been separated in mapping. In a few regions, not only can the Archean and Algonkian be discriminated, but the latter has been subdivided into series and these into formations. There are then on the maps all grades of knowledge, from the eastern United States, where the pre-Cambrian is not outlined, to areas in which pre-Cambrian series are divided into formations. The maps, as the summaries, are a résumé of the present imperfect knowledge.

The order in which the districts are taken up is not consistently geographical or geological, but rather the order of the development of exact knowledge of the pre-Cambrian rocks. The great Canadian pre-Cambrian area in all its parts is a geological unit, yet the detailed study of it has been confined somewhat closely to particular regions; and of necessity the regions which have been units of work have to be followed rather than a strictly logical order. Chapter I is devoted to the original Laurentian and original Huronian areas. Chapter II is given to the lake Superior region. These regions are taken first because the exact knowledge of the pre-Cambrian rocks is here greater than in other areas. The Appalachian region, although the earliest to be studied, is reviewed last, for it is the area in which the conditions for obtaining exact knowledge are the least favorable, and about which comparatively little structural knowledge of the pre-Cambrian has been acquired.

In the summaries of the individual districts the order is that of appearance of the papers. By giving the entire summary of the literature of one district before taking up another, epitomes of parts of a single paper are necessarily dissociated. By this method something of correlation is lost; but purely general work is summarized in the general chapter and the subject of correlation is here treated.

In regard to regions like the Appalachians and California, in which post-Cambrian rocks have become completely crystalline and have been for many years and are yet confused with pre-Cambrian rocks, summaries unavoidably extend beyond the proper scope of this paper. Of series which were in the past supposed to be pre-Cambrian, but which have been demonstrated to be Cambrian or post-Cambrian, the fact is mentioned, but the literature which concerns them is not summarized, since it does not fall within the scope of this paper. The particular position which such formations shall take in Cambrian or post-Cambrian time is a subject for others to consider.

Of necessity the eruptives which have not been differentiated from the pre-Cambrian have to be considered. Oftentimes it is quite probable that eruptives noted belong to post-Cambrian time. No paper is summarized bearing upon the unmistakable Cambrian or post-Cambrian eruptives unless it has a direct bearing upon the character or relations of the associated rocks of pre-Cambrian age.

All references to literature are given at the ends of the respective chapters, the reference notes having continuous numbers. In the discussions closing sections or chapters and in the general chapter citations are not repeated. The original source of any statement attributed to an author may always be found by the aid of the index, where the name of each author is followed by references to the pages where his work is summarized.

The terms group, system, series, are used with the stratigraphical significance given them by the International Geological Congress. The corresponding chronological terms era and period are used. Formation is used as one of the members of a series, as quartzite formation or limestone formation of the Huronian series. The term "crystalline schist" is rigidly confined to rocks which have a "completely crystalline interlocked texture, which is possessed of a schistose parting due to a parallel or foliated arrangement of the mineral ingredients, or of aggregations of these ingredients." The finely banded gneisses are typical examples. All rock masses which within themselves show indubitable evidence of clastic origin are excluded from the crystalline schists and are regarded as semi or partially crystalline. A clastic or semi-crystalline formation may grade into a crystalline schist.

In the summaries of results and in the general discussion (Chapter VIII), unless otherwise stated, the term Cambrian is delimited below by the Olenellus fauna. The term Algonkian is a system term, covering all recognizable pre-Cambrian clastic rocks. The term Archean is a coordinate-system term, covering all pre-Algonkian rocks. It therefore includes only completely crystalline rocks, but does not include all rocks of this kind, as holocrystalline rocks of eruptive and sedimentary origin may occur in Algonkian or post-Algonkian time. The propriety of these usages will appear in what follows.

CHAPTER I.

THE ORIGINAL LAURENTIAN AND HURONIAN AREAS.

SECTION I. EASTERN ONTARIO AND WESTERN QUEBEC.

LITERATURE.

LOGAN,[1] in 1847, describes between the Ottawa and Mattawa rivers, a metamorphic series of rocks, which, in its highly crystalline character, belongs to the order named by Lyell Primary. They are called metamorphic, because their aspect is such as to lead to the theoretical belief that they may be ancient sedimentary formations. A red syenitic gneiss, in which hornblende and mica are arranged in a parallel direction, is the predominant rock. The thickness of the gneiss is not ascertained. South of the Mattawa and Ottawa are important beds of coarse crystalline limestone interstratified with the gneiss in a conformable manner, although this conformity would not be seen in a small area, because of the minor complicated contortions. One section at High falls, on the Madawaska, has a thickness of 1,351 feet, and consists of gneiss, crystalline limestone, with a small amount of micaceous quartz rock, the gneiss greatly predominating. The areas which bear limestone are so distinct that they are placed as a separate group of metamorphic strata, supposed from their geographical position and general attitude to overlie the syenitic group conformably. Both of the metamorphic groups are frequently traversed by dikes and veins, including those of a granitic and pyroxenic character. From the vicinity of Quebec the limestone group ranged along the St. Lawrence, a distance varying from 10 to 20 miles, reaches the seigniory of Argenteuil, where it makes a turn toward the valley of the Ottawa, is seen above Grenville, and is last seen about half way between Fort William and Joachim falls, and at Portage de Talon, on the Mattawa. In the vicinity of Grenville the limestone is plumbaceous.

LOGAN,[2] in 1852, finds a metamorphic and gneissic series of a widespread occurrence upon the river du Nord and the country to the westward. The Potsdam formation rests unconformably upon the metamorphic series.

MURRAY,[3] in 1852, describes a metamorphic series upon and north of the Upper St. Lawrence. On the Thousand isles are micaceous and hornblende gneisses. Crystalline limestones, quartzites, and conglomerates are all found upon the mainland, and the latter is cited as decisive evidence of the metamorphic character of the series as a whole.

[1] For notes see end of chapter, p. 48.

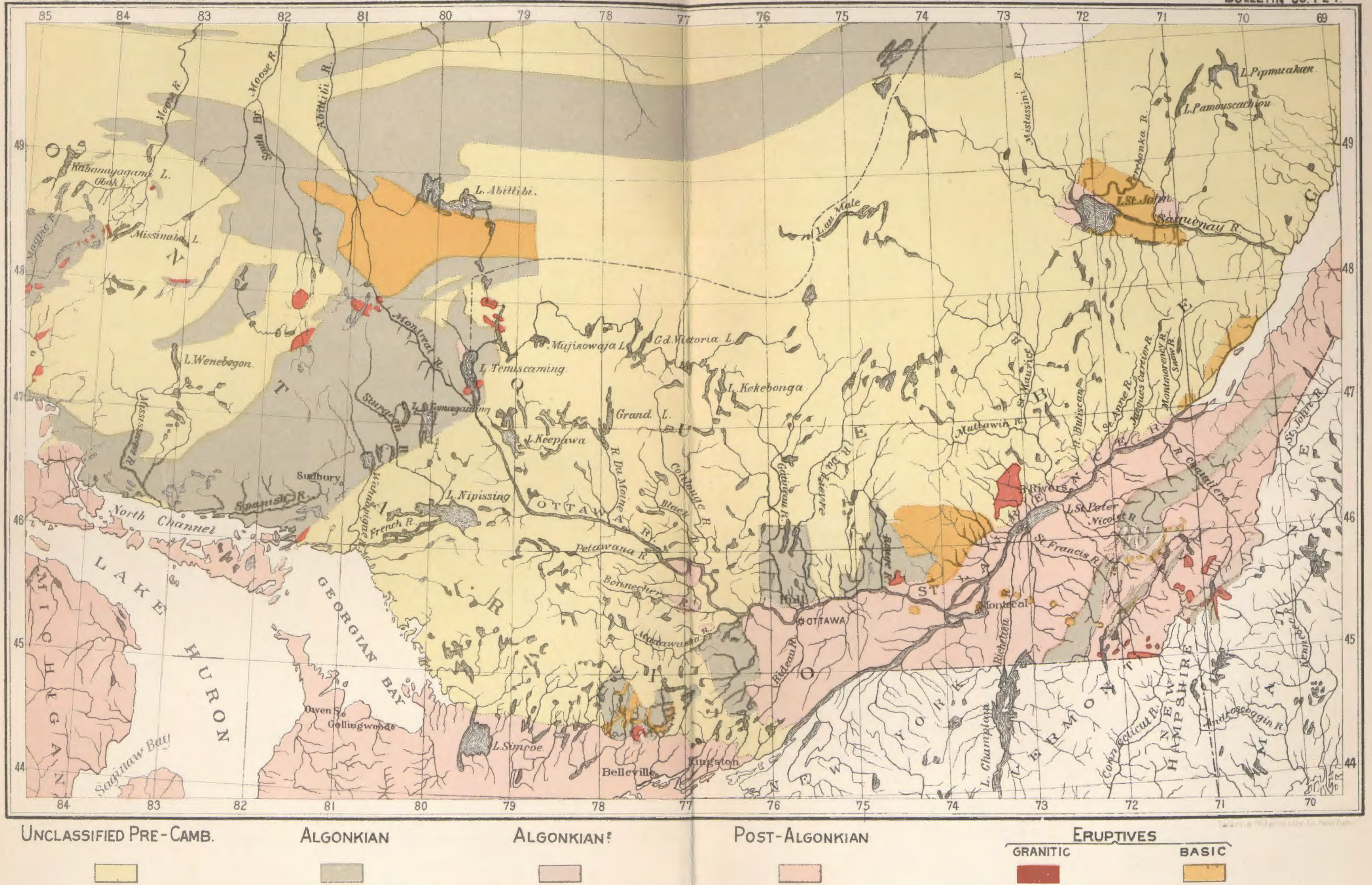
LOGAN,[4] in 1854, applies to the series before called "metamorphic" underlying the fossiliferous formations of Canada the name Laurentian series, because metamorphic is applicable to any series of altered rocks. The proposed name is founded on that given by Mr. Garneau to the chain of hills which they compose. Above the Laurentian series is the Potsdam sandstone.

MURRAY,[5] in 1854, remarks that south of the Laurentian series are the more recent fossiliferous rocks. The Laurentian series consists of masses of micaceous and hornblende-gneiss and masses of interstratified crystalline limestone. Intrusive granite is found in the gneiss. The magnesian crystalline limestone layers, one 700 feet thick, are persistent. A section of gneiss, mica-schist and quartzite, all sometimes garnetiferous, and two belts of limestone, together 140 feet thick, make up a succession 1,369 feet thick at Birch lake. In the series is a conglomerate, the matrix of which in one case is a limestone and the pebbles of quartz and feldspar. In another conglomerate are distinct pebbles in a talcose slaty matrix. These pebbles are sometimes distinctly rounded and flattened, the flat sides always lying parallel with the bedding. The pebbles vary from 5 or 6 inches in diameter to those so small as not to exceed the size of snipe shot.

LOGAN,[6] in 1857, describes the Laurentian formation for some distance north of the Ottawa river between rivers Rouge and du Nord. The rocks are found to be limestone, gneiss, and quartzite. The limestone formations are used chiefly in working out the structure, but even with this guide, on account of the repetition of layers by folding and lack of fossils, the work is very difficult. All of the above rocks are taken to be metamorphosed sediments. They are cut by eruptives, such as syenite, porphyry, and greenstone, which are older than the fossiliferous formations.

MURRAY,[7] in 1857, finds Laurentian rocks largely exposed between Georgian bay and the Ottawa river. The rocks are red and gray gneisses, micaceous and hornblendic schists, quartzite, and crystalline limestone. On lake Nipissing and its islands is found the Laurentian formation, consisting of gneiss, mica-schist, hornblende schist, crystalline limestone, and associated with this beds of specular ore. Limestones are also found along Muskoka river. The strata are everywhere more or less corrugated, in many places exhibiting sharp and complicated folding. They are intersected by quartzo-feldspathic and quartz veins. The Laurentian rocks of Georgian bay are separated from the Huronian north of lake Huron by a line running from the northwest side of Shibahahnahning to the junction of the Maskanongi and Sturgeon rivers, its course being in a northeasterly direction.

HUNT,[8] in 1857, states that stratified feldspathic rocks are closely associated with the crystalline limestones, which alternate with gneissoid and quartzose rocks of the Laurentide mountains. These rocks, besides containing pyroxene, which passes over into hypersthene and a triclinic feldspar, contain as accidental minerals, mica, garnet, and ilmenite.



GEOLOGICAL MAP OF A PORTION OF CANADA

SHOWING PRE-CAMBRIAN AND CRYSTALLINE ROCKS

Compiled from Official Maps of the Canadian Geol. Survey

Scale 5.449.000.

LOGAN,[9] in 1858, in describing the Laurentian of Ottawa thinks it probable that it can be divided into two great groups: that characterized by the presence of limestone and that without, and the latter of these groups also will be capable of subdivision. Often interstratified with the limestones are bands of quartzite which are heaviest near the junction of the limestone and the gneiss. The greatest mass of quartzite is beneath the limestone and is 400 feet thick. The limestones of the Laurentian are influenced in their strikes and dips by subsequent masses of igneous rocks. However, to these rocks as a whole, as well as to their equivalent throughout Canada, is applied the term Laurentian series, from the Laurentide range of mountains from lake Huron to Labrador, which are composed of this rock.

LOGAN,[10] in 1859, gives an elaborate description of the distribution of the limestones along the Rouge river. There are found to be two belts which are regarded as interstratified with the gneisses. This latter rock is sometimes garnetiferous and occasionally is spoken of as the quartzite. The total thickness of rocks exposed on the Rouge is over 22,000 feet, of which over 5,000 is limestone.

LOGAN,[11] in 1860, finds three belts of limestone, which are associated with massive orthoclase gneiss, mica-slate, hornblende rock, and quartz rock together 15,000 feet thick. The calcareous bands are largely associated with labradorite, and beds of hornblende rocks and quartz rocks often thickly studded with pink garnets. One of the beds of pure white quartz rock is a thousand feet thick. Certain fossil-like forms have been found which resemble Stromatocerium. The strata are very much folded.

LOGAN,[12] in 1863, gives a general account of the pre-Potsdam rocks, which are called Azoic and are divided into the Huronian series and the Laurentian system. In the Laurentian system are included anorthosite, orthoclase-gneiss, granitoid gneiss, quartzite, hornblende-schist, mica-schist, pyroxene and garnet rocks, limestones and dolomites. The anorthosites are composed of lime-soda feldspar, varying in composition from andesine to anorthite, and associated with pyroxene or hypersthene. The orthoclase-gneiss has a never failing constancy in the parallelism of its mineral constituents, which, however, is sometimes obscure. This rock is usually very feldspathic and often coarse grained. With the feldspar and quartz are often mica and hornblende. The gneisses appear to attain several thousand feet in thickness, but are divided at unequal intervals by hornblende and mica-schist in which the stratification is more distinct. The quartzites are in considerable volume, two layers of which, nearly pure, have one a thickness of 400 and the other a thickness of 600 feet. The masses of limestone are generally very crystalline and coarse grained, but sometimes are saccharoidal. The bands of limestone are sometimes of great thickness. They are usually not pure, but contain many other minerals, among which are very frequently mica and graphite. Among the rarer minerals is chondrodite. The iron ore, which is mostly magnetite, is interstratified with or not far removed from the limestone bands. Associated with the limestones are dolomites, which, however, compose distinct beds.

There is not any special order in the masses, but beds of hornblende rock and hornblende schists are more abundant near the interstratified bands of limestone than elsewhere, and in the same neighborhood there usually occurs a more frequent repetition of beds of quartzite than in other parts. Garnet is sometimes disseminated in the micaceous and hornblendic gneiss and quartzite and are commonly confined to the immediate proximity of the limestones. The limestones and gneiss beds as a whole are generally conformable to them. It often happens that a subordinate layer of gneiss will display contortions of the most complicated description. Notwithstanding the highly crystalline condition of the Laurentian rocks, beds of unmistakable conglomeritic character are occasionally met with. These generally occur in the quartzite or micaceous beds. The intrusives of the Laurentian consist chiefly of syenite and greenstones. The greenstone dikes are always interrupted by the syenite when they have been found to come in contact with it, and the latter is therefore of posterior date. A mass of intrusive syenite occupies an area of about 36 square miles in the townships of Grenville, Chatham, and Wentworth. It is cut and penetrated by masses of a porphyritic character which are therefore of a still later date.

The Laurentian series stretches on the north side of the St. Lawrence from Labrador to Lake Huron, and occupies by far the larger portion of Canada. Its strata probably possesses a very great thickness. To determine the superposition of the various members of such an ancient series is a task which has never yet been accomplished, and the difficulties attending it arise from the absence of fossils to characterize its different members. Bands of crystalline limestones are easily distinguished from the bands of gneiss, but it is scarcely possible to know from local inspection whether any mass of limestone in one part is equivalent to a certain mass in another part. They all resemble one another lithologically. The dips avail but little in tracing out the structure, for in numerous folds in the series the dips are overturned, and the only reliable mode of working out the physical structure is to continuously follow the outcrop of each important mass in all its windings as far as it can be traced, until it becomes covered by superior strata, is cut off by dislocation, or disappears by thinning out.

Several sections are described in detail. The general section is as follows, in ascending order: Orthoclase-gneiss, 5,000 feet; Trembling lake limestone, 1,500 feet; orthoclase-gneiss, 4,000 feet; Great Beaver lake and Green lake crystalline limestone, including interstratified beds of garnetiferous and hornblendic gneiss, 2,500 feet; orthoclase-gneiss, the lower part having several bands of quartzite, 3,500 feet; Grenville crystalline limestone, 750 feet; orthoclase-gneiss, 1,580 feet; Proctor's lake limestone, 20 feet; orthoclase-gneiss, including quartzite, 3,400 feet; anorthosite, thickness (wholly conjectural), 10,000 feet; total, 32,750 feet. In the limestones are fossil-like forms which resemble *Stromatopora rugosa.* Accompanying the account of the Laurentian is a detailed map of it in parts of the counties of Terrebonne, Argenteuil, and Two Mountains.

The anorthosite probably overlies the Grenville series uncomformably. It is remarked that if the two inferior limestone bands of the Grenville series disappear on reaching the margin of the anorthosite, it is conclusive evidence of the existence in the Laurentian system of two immense sedimentary formations, the one superimposed unconformably upon the other, with probably a great difference of time between them.

LOGAN,[12] in 1863, first describes a part of what was later called the Hastings series. In ascending order are found contorted gneiss and micaceous schists cut by red syenite veins. Above this comes crystalline limestone, and north of the village of Madoc, still in ascending order, occurs a somewhat micaceous schist, which contains numerous fragments of rock in character different from the matrix, some of them resembling syenite or greenstone. The pebbles are in places distinctly rounded.

BIGSBY,[13] in 1864, states that crystalline limestones occur in bands from 50 to 1,500 feet thick at Gananoque, on the lake of the Thousand isles, and on the Mattawa. The bands of marble are tortuous, and between them are sometimes found corrugated seams of gneiss. Conglomerates and grits occur at Bastard, on the Ottawa, and at Madoc, near lake Ontario. At the former place, between the beds of marble, is quartzose sandstone, with pebbles of calcareous sandstone and vitrified quartz. At Madoc village are interstratified marble and conglomerate, one being bluish micaceous schist, holding fragments of greenstone and syenite, the other being a dolomite with large pebbles of quartz, feldspar, and calcite. As proofs of life are the occurrence of limestone, carbon, phosphorus, sulphur, and iron ore. The Laurentian system as a whole consists of, (1) orthoclase-gneiss, sometimes granitoid, with quartzite, hornblendic and micaceous schists, pyroxene, and garnet rock; (2) white crystalline limestone and dolomites, in numerous thick beds, containing serpentine, pyroxene, hornblende, mica, graphite, iron ores, apatite, fluor, etc., and interstratified with bands of gneiss; (3) lime-feldspar rock, or anorthosite, containing hypersthene, ilmenite, pyroxene, horneblende, graphite, etc. These three groups are traversed by granitic and metalliferous veins.

MACFARLANE,[14] in 1866, describes the Laurentian rocks of several towns in the county of Hastings. The rocks here found include granite, granite-gneiss, gneiss, petrosilex, conglomerates, and limestones. At Madoc are conglomerates consisting of pebbles, generally of quartzite, in a schistose matrix, lithologically not unlike some of the Huronian rocks.

LOGAN,[15] in 1866, further describes the distribution and structure of the Ottawa Laurentian limestone. There are here three great conformable bands, which are termed the Grenville, Green lake, and Trembling lake bands. In these limestones Eozoon is found.

LOGAN,[16] in 1867, states that the Hastings series is arranged in the form of a trough, and that to the eastward, and probably beneath them, are rocks which resemble those of the Grenville, and it is supposed that the Hastings series is somewhat higher than the Grenville. The Madoc limestone is overlain unconformably at several places by the horizontal Lower Silurian limestone. In Tudor the limestone is suddenly interrupted for a considerable part of its breadth by a mass of anorthosite rock, rising 150 feet above the general plain, which is supposed to belong to the unconformable Upper Laurentian.

VENNOR,[17] in 1867, gives the ascending section of Laurentian rocks in Hastings county as follows: Red feldspathic gneiss, 5,000 feet thick; dark green chloritic slates, 200 feet; crystalline limestone, 2,200 feet; siliceous and micaceous slates, 400 feet; bluish and grayish mica-slates, 500 feet; pinkish dolomite, 100 feet; micaceous limestone or calc-schist, containing Eozoon, 2,000 feet; green diorite slates, 7,500 feet; reddish granitic gneiss, 2,100 feet; total, 20,000 feet.

DAWSON[18] (Sir William), in 1869, states that the graphite of the Laurentian is scattered through great thickness of limestones, and is found also in veins. In one bed of limestone 600 feet thick the amount of disseminated graphite must amount to as much as a solid bed 20 or 30 feet thick. The graphite is believed to be of organic origin because, first, it contains obscure traces of organic structure; second, its arrangement and microscopical structure corresponds with that of micaceous and bituminous matter in marine formations of modern date; third, if of metamorphic origin, it has only undergone the metamorphosis which is known to affect organic material of later age; fourth, it is associated with beds of limestone, iron ore, and metallic sulphides, presumably of organic origin.

VENNOR,[19] in 1870, in a report on Hastings county, describes the pre-Silurian rocks. The rocks are divided into three divisions, A, B, and C. A, the lower division, consists of syenite rock, granitic gneiss, 2,000 feet; fine-grained gneiss, sometimes hornblendic and passing into mica-schist, 10,400 feet; crystalline limestone, 400 feet. B, the middle division, is of hornblendic and pyroxenic rocks, including diorite and diabase, both massive and schistose, 4,200 feet. C, the upper division, consists of crystalline and granular limestone, 330 feet; mica-slates interstratified with dolomite, sometimes conglomeratic, with pebbles of gneiss or quartzite 1 to 12 inches in diameter, 400 feet; slate interstratified with gneiss, 500 feet; gneissoid micaceous quartzites, interstratified with siliceous limestone, 1,900 feet; gray micaceous limestone, 1,000 feet. Total, 21,130 feet. The syenite in certain localities has no apparent marks of stratification. Associated with the above rocks are deposits of iron ore. *Eozoon canadense* occurs in the topmost member of the upper division (C). Division B rests immediately upon A, but whether conformably or not is not determined, as the basal members of B are massive diorites and greenstones.

VENNOR,[20] in 1872, applies to the lowest division of the Hastings series (A), the term Laurentian, and the middle division (B) is placed as probable Huronian. The rocks of the upper group are found to lie unconformably upon the gneisses and crystalline limestones of the lowest, and it is probable that the middle group is unconformably below the upper and unconformably above the lower group.

VENNOR,[21] in 1872, reports on Leeds, Frontenac, and Lanark counties, Ontario. The granite of the gold-bearing rocks is believed to represent eruptions which took place probably toward the close of the Laurentian period, or at some time prior to the deposition of the rocks of divisions B and C, for, whenever these higher rocks are wanting, the Laurentian gneisses, quartzites, and limestone are cut by a network of veins.

VENNOR,[22] in 1873, gives an additional report upon the counties of Frontenac, Leeds, and Lanark. The area is divided into western, middle, and eastern sections. In the western section the main mass of rocks is of granite, syenite, and coarse and fine grained gneisses. The red granites sometimes appear to be of later date than the white mica-granites and even of the diorites of division B. Limestone was not observed. In a trough between two granite and gneiss areas are found diorite-slates, micaceous and chloritic schists, pyroxenic rocks, conglomerates, dolomites, and sandy crystalline limestones. In one conglomerate the pebbles of quartz in a matrix of sand and mica are flattened out along the plane of bedding, so that those which in cross measurement are not more than one-fifth of an inch broad have a length of from 5 to 10 inches. In places in the conglomerate, instead of pebbles, are layers of vitreous quartz or quartzite and mica-schist. The middle section is undoubtedly Lower Laurentian. The rocks met with include great thicknesses of gneiss, for the most part clearly stratified, with well defined strike and dip; masses of hornblende rock and diorite, graduating into slate or schist; large and important bands of crystalline limestones, and groups of calcareous strata associated with mica-slates, and workable masses of magnetic iron ore. These rocks are clearly interstratified. Apparently five distinct bands of crystalline limestone are met with, separated by reddish granitic and dark hornblendic gneisses. The rocks of the eastern section consist chiefly of gneiss, but associated with this are coarsely granular limestones. The horizontal limestones of the Lower Silurian by a fault are brought into abrupt vertical contact with the Laurentian gneiss.

VENNOR,[23] in 1874, further describes Frontenac, Leeds, and Lanark counties. The five belts of crystalline limestones mentioned in the previous report are described in detail. Eozoon occurs abundantly in places.

VENNOR,[24] in 1876, gives a further report on the rear portions of Frontenac and Lanark counties. Two sections are given, representing the limestones as interstratified with the quartzites and gneisses. The rocks are classified into five groups: I, Mica-schist group; II, Dolomite and slate group; III, Diorite and hornblende-schist group; IV, Crystalline limestone and hornblende-rock group; V, Gneiss and crystalline limestone group. A sixth group, described in a previous report, occupies the front portion of Lanark county. Each of the five groups have many subordinate phases of rocks; they occupy distinct and separate positions, but it is not known whether they represent one or more formations.

VENNOR,[25] in 1877, states that there is in eastern Ontario and the adjoining portions of Quebec an Azoic formation, consisting of syenite and gneiss(?), without crystalline limestone, in which there is but little indication of stratification. On it has been unconformably deposited a great system of gneisses, schists, slates, crystalline limestones, and dolomites, in the higher member of which Eozoon is found. The limestone occurs in four principal belts. Both Logan's Huronian and Upper Laurentian are considered to belong to the second division, which is for the present called the Upper Laurentian. Interstratified with several of the bands of limestone are labradorite rocks. No evidence is found for making these a distinct system. The Huronian and Hastings series are simply an altered condition in their westward extension of the lower portion of the upper system.

VENNOR,[26] in 1878, reports on the counties of Renfrew, Pontiac, and Ottawa. Referring to the work of previous years, it is said that the rocks of divisions B and C of the Hastings series are really the western extensions of the diorites, hornblende-schists, and mica-slates of Lanark and Renfrew counties, in other words, of groups I, II, and III; and these last have also been shown to be a low portion of the gneiss and limestone series, that is, groups IV, V, and VI; and these have always been looked upon as typical Laurentian. The conclusion is consequently reached that the Hastings series is not, as it has been considered to be, the most recent, but rather the oldest portion of this great system of rocks investigated. It is also clear that this great crystalline gneiss and limestone series rests upon a still older gneiss series, in which no crystalline limestones have yet been discovered. This series is the one referred to as division A, where limestones have been mentioned, but incorrectly. This occupies many hundreds of square miles between the St. Lawrence and Ottawa rivers, and is the rock which forms the backbone of eastern Ontario and the nucleus around which have been deposited all succeeding formations. This, then, is undoubtedly Archean and Lower Laurentian, and consequently the crystalline limestones and gneisses constitute a series which would come in beneath Logan's Upper Laurentian or Labradorite series. Whether this latter exists as a distinct formation is doubtful. In each instance in which the crystalline limestones have been found in the interior of the gneiss country, these have been proved to occur in the superficial condition of shallow troughs, and not as bands interstratified in the gneiss itself.

The lower noncalcareous Laurentian is a great series of crystalline rocks, not only highly metamorphosed, but most intricately contorted. In the entire area studied the gneiss and syenite are by far the most abundant rocks, while gneisses with interstratified crystalline limestones occupy but a comparatively limited area, and this only toward the margins of the former. The relative volumes of the two distinct sets of rocks, that is, the gneisses with the crystalline limestones, bear about the same relations to the volume of gneiss and syenite that the comparatively narrow belt of the Silurian does in this section of country to both of these together.

There is thus in these old crystalline rocks a great uncalcareous division and a smaller calcareous one. The first of these may be further subdivided into a stratified and unstratified portion, of which the latter is undoubtedly the lowest and oldest. As shown by the map, north and northwestward of the line, at the base of the gneiss and limestone series, there are numerous and repeated troughs of the lower member of this division which separate out over the great fundamental gneiss system in a most irregular manner, and it is these that have given rise to the supposition that the older gneiss and syenite is interstratified with the crystalline limestone. The three great subdivisions in eastern Ontario are, then, first, a great gneissic and syenitic series without limestone; second, a thinner gneissic series with labradorites and limestones; and, third, Lower Silurian (Potsdam to Trenton). The thickness of the upper series, exclusive of the fundamental gneiss, is placed tentatively as from 50,000 to 60,000 feet. No attempt is made to estimate the thickness of the underlying gneiss and syenite series.

BELL,[27] in 1878, reports on geological researches north of lake Huron and east of lake Superior, including lake Nipissing. He finds the rocks along the whole northeast coast of Georgian bay, a distance of 125 miles, to belong to the Laurentian series. They consist principally of varieties of gneiss, occasionally interstratified with bands of hornblendic and micaceous schists. The crystalline limestones are also found, as well as stratified diorites, trap rocks, and granite veins. The rocks have no uniform strike and are contorted into many anticlinals and synclinals. The crystalline limestones of Georgian bay and lake Nipissing are regarded as belonging in three and possibly more crystalline bands. Associated with the limestone are sometimes found chert, conglomerate, quartzite, and magnetic iron ore. A junction of the granite with the Huronian quartzite and hornblende-schist is mentioned.

WILKINS,[28] in 1878, describes near the Grand Trunk station of Shannonville, about three-quarters of a mile north of the village, a gray and green slate conglomerate which much resembles the slate conglomerate of lake Huron belonging to the Huronian system. The base of this rock is a schistose gray orthoclase with green hornblende and epidote, while the pebbles are of Laurentian gneiss, white and red micaceous and syenitic granite, syenite, felsite, dolerite, diorite, epidote, chlorite, and quartz, these masses being generally rounded, particularly the gneissic pebbles, and very rarely angular, while in size some exceed a foot in diameter, and others are not over 2 or 3 inches. At Gibson's mountain, 6 miles southwest of Belleville, occurs Laurentian porphyritic coarse grained granitoid syenitic gneiss.

SELWYN,[29] in 1879, states that it has been conclusively demonstrated that the Grenville and Hastings groups, consisting of limestones and calcareous schists holding Eozoon, with associated dioritic, felsitic, micaceous, slaty, and conglomeratic rocks, form one great conformable series, which rests quite unconformably upon a massive granitoid, syenitic, or red gneiss series, and are unconformably below the Potsdam or Lower Silurian rocks. The same may be said of the Huronian series of Georgian bay, which at lake Nipissing include some labradorite gneiss, and it is very probable that a connection will eventually be traced out between these supposed greatly different formations like that now proved to exist between the Hastings and Grenville series. The Norian series is thought to be a part and parcel of the great crystalline limestone series. These anorthosites are thought to represent the volcanic and intrusive rocks of the Laurentian period, and if so, their massive and irregular, and sometimes bedded appearance, and the fact that they interrupt and cut off some of the limestones, is readily understood. Chemical and microscopical investigations both seem to point to this as the true explanation of their origin. That they are really eruptive rocks is held by nearly all geologists who have carefully studied their stratigraphical relations.

SELWYN,[30] in 1884, finds from Pembroke to Wahnahpitae river on the Canadian Pacific railway, nothing but Laurentian, which consists of red, gray, and white orthoclase gneiss, black hornblende-schists and mica-schists, often garnetiferous, pyroxenic gneiss banded like Eozoon, and large bands of crystalline limestone. These rocks are all very distinctly stratified, and dip generally in an easterly direction at angles varying from almost horizontal to vertical.

SUMMARY OF RESULTS.

It is apparent that the great area, roughly bounded by Georgian bay, the Ottawa and St. Lawrence rivers. to which the term Laurentian is applied, is, as a whole, a very crystalline one. This is so far true that no attempt has been made over the greater part of the area to stratigraphically subdivide the rocks. The exceptions to this are a small area in Argenteuil and adjacent counties, and a strip of country running from Ottawa to Madoc. Even in the districts in which the detailed maps are given there is no estimate of the thickness of the layers of the more massive parts of the series.

In discussing the stratigraphical succession, large areas of the rocks, including syenite, granite, porphyry, etc., can be excluded, for it is certain, as was early recognized by Logan and Murray, that many of these rocks are eruptives of later age than the gneissic and schistose rocks with which they are associated.

Logan, Murray, and Vennor in his final comprehensive review, reached the same stratigraphical conclusions. Occupying the inferior position in this region is an immense thickness of syenitic, granitic, and gneissic rocks. For the most part this lower division is intricately folded, and if it has a stratigraphy, it is of so complicated a character that no estimate is made of the thickness. Where a structure is present there is no evidence that it is due to sedimentation. It contains no bedded limestones, no carbonaceous schists, no clastics, either volcanic or water-deposited. It is, then, a complex, devoid of any structure which has been shown to be bedding, devoid of any materials which may not be of other than surface origin. As described by Vennor, this lower non-calcareous Laurentian covers the larger part of the region. That limestones were at one time supposed to be contained in this series is explained by him to be due to the fact that overlying bands of the upper division are included as infolded troughs.

Upon these rocks rests a series of a very different lithological character. It includes great thicknesses of limestones, quartzites, conglomerates, hornblende-schists, mica-schists, and bedded gneisses. If the limestones, quartzites and the regularly bedded character of the gneisses are not sufficient evidence of a clastic origin, the presence of unmistakable conglomerates at numerous points is conclusive. This clastic series, as shown by the descriptions of it in the vicinity of Madoc, is in part clearly volcanic. The very great estimated thickness of this bedded series may be questioned, for evidently the study was not close enough and the structure well enough determined to decide this difficult question. The equivalence of the clastic rocks of the different districts has been assumed, but those more distant from the type area differ considerably from it in lithological character as well as from each other. That they are really equal has not been shown, although this is probable for certain of the districts.

As to the anorthosite series it may be excluded from the bedded succession. It is now believed by most geologists that this rock is an eruptive. The unconformity at its base is an eruptive one, in all probability caused by the outflowing of this rock at a later period than the formation of the underlying series.

The Laurentian clastic series of the type area resembles, to a remarkable degree, the bedded gneisses, limestones, graphitic schists, and quartzites of the Adirondacks, except that the latter have become more completely crystalline. The core of the Adirondacks is "anorthosite rock," really gabbro, and away from this the bedded series dips in a quaquaversal manner, so that the anorthosites apparently underlie the clastics. This is explicable by regarding the anorthosite as an intrusive which has pushed up the bedded clastics, causing the latter to dip away from it in every direction. In the Ontario area it appears that the "anorthosite" has actually burst through and overflowed the clastics.

Comparing the bedded clastic division of the Laurentian with the Original Huronian, the description of the latter by Bell at Nipissing approaches closely in lithological character that of the Huronian, to which division the series was referred by Selwyn. The clastic series in the vicinity of Madoc, before Vennor realized that it is probably a continuation of that to which the term Laurentian was applied at Ottawa by Logan, was considered as Huronian, and by Logan himself was supposed to be higher than the Grenville series.

These two districts are intermediate in position as in character between the type areas of upper Laurentian and the Huronian.

The clastics of the Laurentian nowhere come in contact with those of the Original Huronian area, so that we have no evidence whatever as to their relative age. The former are underlain by a banded and contorted gneissic and granitic series. The same is true of the Huronian of lake Huron. In this latter area the clastic series rests unconformably upon a lower gneissic one, but in eastern Ontario we have no positive evidence that similar relations obtain; but it is not improbable, as maintained by Vennor, that there is at the base of the clastic series a true unconformity. On the other hand, it is possible that the relations between the clastic series and the underlying completely crystalline series are those of sedimentary rocks and later intrusives.

Bearing in favor of an unconformity between the lower granite-gneiss and at least a part of the clastic series are several lines of evidence: (1) In Leeds, Frontenac, and Lanark counties the granites which cut the Laurentian gneisses in a network of veins never penetrate the series of quartzites, conglomerates, limestones, etc., although sometimes found in Vennor's middle or dioritic division. This indicates that the granite-gneiss not only existed but had been intruded by granitic eruptions before the clastics were deposited. (2) The abundant large pebbles and bowlders of granite and syenite found at many localities in the Laurentian region, and particularly about lake Nipissing and near Shannonville, show that earlier than the clastics existed gneisses and granites identical in character with those now designated as Laurentian. The probability is that these pebbles are, as supposed by Logan and Wilkins, derived directly from the Laurentian. If this is the case, between the two must have existed a great time gap, for these fragments when deposited show that the rocks from which they are derived were then at the surface in their present completely crystalline condition. (3) The rocks of plainly clastic origin are associated and occur in trough-like areas, although having interstratified with them comparatively thin belts of gneiss, which, however, may be meta-

Sackett & Wilhelms Litho Co N.Y.

ARCHEAN | ALGONKIAN (HURONIAN) | POST-ALGONKIAN

- a Gray Quartzite
- b Green Chlorite Slate
- c Lower White Quartzite
- d Lower Slate Conglomerate
- e Limestone
- f Upper Slate Conglomerate
- g Red Quartzite
- h Red Jasp. Conglomerate
- i Upper White Quartzite
- k Yellow Chert & Limestone
- l White Quartzite. Chert & Limestone

MAP OF THE ORIGINAL HURONIAN ROCKS

(After Logan)

Scale $\frac{1}{506.880}$

morphosed sedimentaries. That this series is newer than the granite-gneisses, is indicated by the fact that the intricate structure of the lower Laurentian is not simulated by the clastic rocks. Apparently the latter has undergone earlier and more intense orographic movements than the former.

SECTION II. FROM NORTH CHANNEL OF LAKE HURON TO LAKE TEMISCAMANG.

LITERATURE.

BIGSBY,[31] in 1821, gives the earliest geological account of the north shore of lake Huron. He found north of the North channel two series of rocks, one of granite, gneiss, and trap, which was placed by him with the Primitive; the other, without mentioning distinct characters, he called the Transition formation.

MURRAY,[32] in 1845, finds Primary and Metamorphic rocks to comprise the whole country to the north of lake Simcoe and the northeastern shores of lake Huron. The rocks are similar in appearance to the masses which compose the Thousand isles, and include granite, syenite, and gneiss, as well as a coarse micaceous sandstone, which at one place presents evidence of stratification.

LOGAN,[33] in 1847, finds, after passing over 63 miles of lower metamorphic or syenitic gneiss on the Ottawa, after leaving the Mattawa (nearing lake Temiscamang), a succession consisting of (1) chloritic slates and conglomerates, (2) greenish sandstones, and (3) fossiliferous limestones. The conglomerates often hold pebbles and bowlders, sometimes a foot in diameter, of the subjacent gneiss, from which they are chiefly derived. So indurated is the rock that the fracture breaks across the pebbles. The sandstone is of a sea-green color, and appears to be composed of quartz and feldspar, with occasional flakes of mica. The volume of (1) is probably not less and may be very much more than 1,000 feet, while that of the sandstone is between 400 and 500 feet. Formation (3), fossiliferous limestone, is often conglomeratic at its base, containing pebbles, fragments, and bowlders of the sandstone beneath in a calcareous cement. Some of the harder beds abound in chert and many of them are fossiliferous, the organic remains leading to the opinion that this rock is equivalent to the Niagara of New York. That these limestones are unconformable with the slates appears almost certain, but whether the intermediate sandstones are conformable with one or both of these can not be asserted, nor can it be asserted that the slates are conformable with the gneiss.

LOCKE,[34] in 1847, having visited Echo lake and the Bruce mine, finds the rocks of the North channel to consist of sandstone, talcose slate, limestone, all metamorphosed by trap rock. The slate contains some pebbles of primitive rock, and thus approaches a conglomerate. The limestone at Echo lake shows original stratification, and is traversed by seams of hard metamorphic slate, being nearly in the condition of a jasper. They are undulated, contorted, and pleated in a beautiful manner.

CHANNING,[35] in 1847, reports on an examination of Sugar island, Sailors Encampment island, St. Joseph island, and the main shore to Sault Ste. Marie on the American side. Metamorphic sandstone quartz, chlorite-slate quartz, feldspar rock quartz, chlorite, granite, syenite are all found, and are constantly intersected by the trap dikes. At Echo lake is a metamorphic sandstone quartz, containing a stratum of pebbles converted into jasper. On Sugar island is found metamorphic sandstone, containing fragments of metamorphic sandstone and gray gneiss.

MURRAY,[36] in 1849, describes the continuation of his work on the north coast of lake Huron west of French river, and upon the adjacent Manitoulin islands. The pre-Potsdam group of rocks consist, firstly, of a metamorphic series, composed of granitic and syenitic rocks in the forms of gneiss, mica-slate, and hornblende-slate; and, secondly, in ascending order, of a stratified series, composed of quartz rock or sandstones, conglomerates, shales, and limestones, with interposed beds of greenstone. The first of these series is in so highly a disturbed condition, and is so much contorted that it is impossible to ascertain its thickness. The second series occupies the whole north coast of lake Huron, with many of its neighboring islands between little lake George and Shebawenahning. The breadth of country this series occupies, and the thickness it attains, there was no opportunity of determining. The quartzites sometimes pass into a sandstone, and into a beautiful conglomerate, whose pebbles are chiefly of blood-red jasper. Besides the jasper conglomerates there are other conglomerates, the pebbles and bowlders of which are of syenite, varying from those of small size to those 2 feet in diameter; and these are sometimes in a greenish quartz rock as a matrix, and sometimes in a greenish slate, more frequently the latter. Numerous greenstone dikes traverse the stratified series, and greenstone masses are interposed among the sedimentary beds. On some small islands granite veins and trap dikes were found breaking through the quartz rock, on one of which the latter beds dipped in opposite directions on opposite sides of the granite, and on another the quartz rock was found reclining on the granite, the contact being seen. The fossiliferous series is supported unconformably upon the older rocks.

LOGAN,[37] in 1849, next gives a general account of the geology of the north shore of lake Huron. An area of rocks, 120 miles long, and from 10 to 20 miles wide, is placed in a single formation. This formation rests unconformably below the Silurian, as shown by the fact that the latter horizontal strata rest upon the uptilted edges of the quartz rock, fill the valleys between, and overtop the mountains. Upon account of the eruptive material which the formation contains it is placed as the probable equivalent of the copper-bearing group of lake Superior. The series is divided into rocks of sedimentary and rocks of eruptive origin. The sedimentaries consist of sandstones, conglomerates, slates, and limestones. The greenstones are of igneous origin, and are of two classes, intrusives and overflows. The intrusives are in part as sheets and in part as dikes. The various kinds of sedimentary beds grade into each other, while the greenstones do not thus grade into the sediments, and therefore present a strong contrast to the real sedimentary beds. The dikes and overflow sheets are lithologically alike, and the dikes reveal a history which has two or three episodes. The chief difference in the copper-bearing rock of lakes Huron and Superior seems to lie in the great amount of amygdaloidal trap in the latter, and of white quartz or sandstone in the former, but there are strong points of resemblance, so it is highly probable, if not almost certain, that they are equivalent and beneath the lowest fossiliferous deposits. On the east and west the series seems to repose on granite.

MURRAY,[38] in 1850, gives the result of a survey of the Spanish river. Upon this stream he finds exposed a granitic or metamorphic group and a quartz-rock group. The latter contains quartzites, slates, and conglomerates, holding sometimes pebbles of jasper, but more often of syenite or granite, as well as limestones and dikes and beds of intrusive greenstones, and can scarcely be less than 10,000 feet thick. The granitic group appears to rise from beneath the metamorphic group at two places.

LOGAN,[39] in 1852, states that on lake Huron the Lower Silurian group rests unconformably upon a siliceous series, containing one band of limestone about 150 feet in thickness, having leaves of chert, but without discovered fossils. The series is the copper-bearing rocks of that district, is interstratified with igneous masses, and has a thickness of at least 10,000 feet; it is supposed to be the Cambrian epoch. The gneissoid group is probably still older, and its condition is such as to make it reasonable to suppose that it consists of altered aqueous deposits.

MURRAY,[7] in 1857, describes several of the more important streams between Georgian bay and lake Nipissing. They embrace two of the oldest recognized geological formations, the Laurentian and Huronian; the rocks of the latter are more recent and have been observed to pass unconformably below the lowest of the fossiliferous strata of the Silurian system. The contorted gneiss of the Laurentian series, with its associated micaceous and hornblendic schists, spreads over the country to the south and east, while the slates, conglomerates, limestones, quartzites, and greenstones of the Huronian occupy the northern and western parts. The difference in lithological character between the two formations is always sufficiently apparent, but though both were found a short distance apart, the immediate point of contact was always obscure, and a mass of greenstone of rather coarse grain was usually the first intimation of the proximity of the higher rocks. Whether this greenstone is a contemporaneous flow or subsequent intrusion has not been ascertained. The lower slates stand nearly vertical on Sturgeon river near the gneiss. The following is the general succession within the Huronian, in ascending order: fine grained siliceous slates; slate-conglomerate, containing profuse syenite and occasional jasper pebbles; limestone; slate-conglomerate, like the first; green siliceous chloritic slate; and close grained quartzite of various colors running into a conglomerate, the pebbles of which include white quartz and red and green jasper. The thickness of the Huronian is calculated at 10,000 feet and corresponds with the determination of the thickness of the quartz-rock series on the Spanish river.

LOGAN,[40] in 1858, applies the term Huronian to the copper-bearing rocks of lake Huron. A limestone near the middle of the series is used to trace out the structure.

MURRAY,[41] in 1858, gives a continuation of his study of the rocks north of lake Huron. He places the rocks of French river, described in the report of 1857, as Laurentian. A belt of limestone 200 feet thick is used in working out the structure of the Huronian. The Huronian is also called the copper-bearing rocks.

LOGAN,[42] in 1858, gives a general description of the pre-Silurian Azoic rocks of Canada, which occupy nearly a quarter of a million square miles. These are a series of very ancient sedimentary deposits in an altered position. They are of great thickness and are capable of division into stratigraphical groups. In the formation about lake Temiscamang are sandstones, quartzose conglomerates, and slate conglomerates, the slate conglomerates holding pebbles and bowlders derived from the subjacent gneiss. The bowlders display red feldspar, translucent quartz, green hornblende, and black mica, arranged in parallel layers, which present directions accordant with the attitude in which the bowlders were accidentally inclosed. From this it is evident that the slate conglomerate was not deposited until the subjacent formation had been converted into gneiss, and very probably greatly disturbed; for while the dip of the gneiss, up to the immediate vicinity of the slate conglomerates, was usually at high angles, that of the latter did not exceed 9 degrees. A similar set of clastic rocks is found on the north shore of lake Huron, except that the series is here intersected and interstratified with greenstone trap, and pebbles of syenite and jasper are found. Eastward of lake Temiscamang, in an area of 200,000 square miles imperfectly examined, no similar series of rocks has been met with. Because this clastic series of rocks occurs in typical development on lake Huron it has been decided to designate it by the term Huronian.

MURRAY,[43] in 1859, in continuing his study of the Huronian, gives most of his time to the region adjacent to the Thessalon and Mississagui rivers. The Huronian is found to be in two main troughs and the thickness of the series of formations amounts to 16,700 feet. This thickness, greater than that given in the report of 1857, is due to the accidental existence here of intercalated greenstones.

BIGSBY,[44] in 1862, concludes that the Huronian is greatly older than the Cambrian because: (1) Its marked similarity, lithologically, to the fundamental gneiss formation. (2) The conformity of these two sets of beds. (3) The great interval of time which must have elapsed between the periods of laying down the fundamental formation and the Silurian, if we are to judge from the occasionally vast thickness of the Cambrian. Beyond all comparison, the Huronian is more widespread and extensive, as well as more uniform in its mineral constitution, than the Cambrian group. It is, perhaps, also more important economically.

LOGAN,[12] in 1863, gives a general summary of the information as to the Huronian series north of lake Huron. This area is mapped in detail. It extends along the entire North channel of lake Huron, with the exception of a short distance where the Laurentian occupies the shore. The full section on the north shore of lake Huron is as follows, from the bottom upward: (1) gray quartzite, 500 feet; (2) green chlorite slate, 200 feet; (3) white quartzite, 1,000 feet; (4) lower slate conglomerate, 1,280 feet; (5) limestone, 300 feet; (6) upper slate conglomerate, 3,000 feet; (7) red quartzite, 2,300 feet; (8) red jasper conglomerate, 2,150 feet; (9) white quartzite, 2,970 feet; (10) yellow chert and limestone, 400 feet; (11) white quartzite, 1,500 feet; (12) yellowish chert and impure limestone, 200 feet; (13) white quartzite, 400 feet; total thickness, 18,000 feet. Interstratified with certain of these layers, and particularly Nos. 4, 6, 7, 8, and 9 are considerable masses of greenstone. That these are contemporaneous overflows in places is indicated by the fact that they are amygdaloidal and are arranged in layers. There are, however, also present intrusive masses of greenstone and granite, which in the form of dikes cut the stratified rocks in many directions. The different sets of dikes are of at least three different ages, the granite being intermediate in age between two greenstone eruptions. Many of the pebbles of the red jasper conglomerate are banded, showing their derivation from a more ancient stratified rock. South of lake Pakowagaming is a considerable area of granite which breaks through and disturbs the Laurentian gneiss, and from which emanates a complexity of dikes, the whole being supposed to be of Huronian age. The immediate contact of the gneiss with the overlying rocks has not been observed. The gneiss between Mississagui and St. Marys rivers has been much disturbed by intrusive granite and greenstone, and it is difficult to make out how the stratified portions are related to each other. Near Les Grandes Sables, a gray quartzite, supposed to be the lowest Huronian, abuts against one mass of gneiss, and runs under another and appears to be much broken by and entangled among the intrusive rock. On lake Temiscamang the

Laurentian gneiss is followed by a slate conglomerate which contains pebbles and bowlders sometimes a foot in diameter of the subjacent gneiss. The Huronian of lake Huron is correlated with the lower copper-bearing rocks of lake Superior. Several detailed sections are described. The general sections represent the Huronian series as resting unconformably upon the Laurentian.

LOGAN,[45] in 1865, states that the horizontal strata, which form the base of the Lower Silurian in western Canada, rest upon the upturned edges of the Huronian series, which in its turn unconformably overlies the Lower Laurentian. The Huronian is believed to be more recent than the Upper Laurentian series, although the two formations have never yet been seen in contact.

SELWYN,[30] in 1884, west of Wahnahpitae river, on the Canadian Pacific railway, for 80 miles, finds Laurentian rocks, which consist of felsites or felsitic quartzites, thin bedded quartzites which hold angular fragments of granite and gneiss, diorite and diabase, with a series of coarse and fine fragmental beds varying in character from a fine ash to coarse agglomerate.

IRVING,[46] in 1887, summarizes the information of the Canadian Survey with reference to the Huronian of lake Huron, and describes a contact near Thessalon river between the underlying gneissic series and the overlying Huronian. Here a basal conglomerate, containing partly rounded and angular fragments up to 2 feet in diameter, largely derived from the immediately underlying gneiss, rests directly upon the upturned edges of the gneissic series. Such a contact indicates a great structural break, whether the underlying gneissic series is of eruptive or of sedimentary origin. If sedimentary, it must have been metamorphosed to its present crystalline condition and upturned before the fragmentals were deposited upon it; if eruptive, its coarsely crystalline character shows that it belongs to the deep-seated rocks which must have crystallized at depth, and therefore has been subjected to great erosion in order that this class of rocks may be found at the surface. Such a contact is also found at two or three other points on the Algoma branch of the Canadian Pacific railway, and particularly at the vicinity of the mouth of Serpent river. Logan's[2] green, chloritic slate is composed of diabase sheets and a little interleaved fragmental material, perhaps partly volcanic ash.

WINCHELL (N. H.),[47] in 1888, describes many localities within the Original Huronian. Logan's chloritic slates, as well as the greenstones, are regarded as accidental features, the former being a part of the basic eruptive rocks of the region. Vast outflows of greenstone cover many square miles in the Thessalon valley and constitute hill ranges as conspicuous as those of any hill rock in the region. This series is classified and parallelized with the Minnesota rocks, as follows:

Original Huronian.	Minnesota equivalents.
Otter Tail quartzite Thessalon quartzite	Pewabic quartzite (?). New Ulm, Pokegama and Wauswaugoning quartzites.
Black slate	Animikie black slate.
"Lithographic stone" and fine gray quartzite	Not known.
Red felsite	Felsites at Duluth and probably the Great palisades.
Mississagui quartzite	Not known.
Slate conglomerate	Ogishki conglomerate.

Chert and quartzite pebbles in the Thessalon quartzite lead to the inference that this is unconformably upon the black slate. The existence of granite bowlders in the slate conglomerate indicates another unconformity between it and the granites of the region. In this latter case the evidence is conclusive, and in the former it is inconsiderable.

WINCHELL (ALEX.),[48] in 1888, also gives many observations upon the original Huronian. In the Huronian system is a large volume of eruptive rock with a great thickness of rocks of undoubted sedimentary origin, with an equal volume of an obscure slaty character. The latter appear to constitute the green chlorite schist of Logan, which is either an ancient or much altered eruptive or highly altered sedimentary material. The quartzites contain angular fragments of such a character that they seem to be derived from this diabase schist; and this circumstance countenances the theory that the latter are older and probably sedimentary in origin. The Huronian of Canada, in descending order, is as follows: Otter Tail white quartzite, 4,000 feet; Thessalon red and gray quartzite, 5,000 feet; Otter Tail cherty limestone, 100 feet; Upper Plummer conglomeratic and siliceous argillite, 500 feet; red felsite, granulite, and quartzite, 100 feet; lower conglomeratic and siliceous argillite, 7,400 feet; Bruce limestone, 100 feet; Mississagui vitreous quartzite, 3,750 feet. This succession includes neither the lower nor the upper limit of the Huronian. At St. Joseph's island the Huronian is immediately overlain by a fossiliferous limestone, apparently the Chazy. It thus appears that the Huronian is a system following downward immediately below the Lower Silurian, and if no intervening terranes are wanting it occupies the position of the Taconic of Emmons and the Lower Cambrian of Sedgwick. The lower limit of the Huronian must be succeeded by a formation of vitreous quartz, red jasper, and graywacke, besides greenstones, red granulite, red gneiss, mica-bearing granite, since fragments of all these are found in the Huronian. It may be that the quartzite pebbles are derived from the Mississagui quartzite, but the red jasper and greywacke must have been derived from a terrane older than the Huronian and newer than the crystalline masses of the Laurentian.

BONNEY,[49] in 1888, discusses the development of the crystalline schists in the neighborhood of Sudbury. The semicrystallines can be easily separated from the thoroughly crystalline rocks of the Laurentian. In the Huronian rocks two groups may be distinguished, one of which is slightly altered and the other very much more extensively modified. The semicrystallines are compared with those of like character in Great Britain.

BARLOW,[50] in 1890, describes the relations between the Huronian and Laurentian north of lake Huron. At many localities the contact is found to be an irruptive one, the granite and gneiss intruding the Huronian clastics. Very often the Huronian strata dip into or under the gneiss, although often the Huronian beds are superimposed upon the gneiss in perfect conformity, and occasionally gneiss is seen dipping away from the vertical Huronian strata. Huronian rocks are also seen resting unconformably upon the upturned edges of Laurentian gneiss. The Huronian strata are often metamorphosed where in contact with the gneiss. These different phenomena are all explained by the later irruptive character of the gneiss. It is concluded that the Huronian system is the oldest series of sedimentary strata known in this region.

BELL[51], in 1890, states that stretching from lake Huron to lake Temiscamang is the greatest area of Huronian rocks in Canada. The most prevalent rock in this region is graywacke, often conglomeratic. Another rock of great abundance is a quartz-diorite. These two are the parent rocks of the Huronian. The quartzites and clay-slates are but phases of the graywacke. The rocks of this region show three ways by which gneiss may be formed, namely, by the direct conversion of the thin bedded or slaty varieties of graywacke, by the alteration of the mixed quartz and feldspar rock derived from other varieties of it, and by the alteration of the modified quartz-diorites. The dolomites are of a concretionary or segregated nature, derived from the hornblende and augite of the rocks with which they are associated. During the process of conversion from graywacke into syenite, strings and veins of magnetite have formed.

WINCHELL (ALEX.)[52], in 1890, gives further observations on the original Huronian region. Northwest of Echo lake is found a series of argillites, slates, quartzites, and schists, which are frequently conglomeratic and in one place contain outcrops of hematite. These strata are close to a vertical attitude, strike nearly east and west, and resemble the Knife lake series and Ogishki conglomerates of Minnesota. These rocks can not belong to the same system as the quartzites, upper slate conglomerates, and limestone of the Huronian, which dip at an angle of 20°. There is here a genuine discordance of stratification, and two series, not one, as mapped by Logan. The lower system is the formation which occurs at Gros cap, Goulais bay, and Doré river, which was identified by Logan with the Huronian of lake Huron. The author is convinced also of their identity with the vertical strata in Minnesota and Canada known as the Keewatin system. It is also clear that these gnarled, green pebble slates are the prolongation of the lower slate conglomerate of the Thessalon valley.

WINCHELL (ALEX.)[53], in 1891, maintains that the Original Huronian is divisible into two unconformable series, the break occurring between the upper and lower slate-conglomerates, and the limestone belonging with the upper series. The descriptions of this region by Murray indicate that near lake Wahnapitae there is a stratigraphic unconformity between the upper and lower divisions of the Original Huronian, as here the slate-conglomerates are in a nearly vertical attitude, while the newer members seldom have an inclination greater than 45°. In every instance in which the lower slate-conglomerate has been traced by Logan or Murray to the proximity of the gneiss these formations seem to be conformable in position, though the actual juxtaposition was concealed. At Murray hill the slate-conglomerate has a dip to the southward of 78°, while 2 miles south of this the slate-conglomerate has a dip of 40° toward S. 30° W. The first is regarded as the lower slate-conglomerate and the second as the upper slate-conglomerate. At the junction of the Sudbury branch of the Canadian Pacific railway with Vermilion river an arenaceous slaty rock, having a dip of 45°, rests on a different schist having a different dip. At this locality, according to Lawson, the unconformity is similar to that at Penokee gap, Wisconsin. The lower rock is a fine micaceous gneiss or mica-schist, and the upper rock is interbedded quartzite and gray argillite. At Echo lake is a series, in descending order, of slate-conglomerate and quartzite, with a dip of about 20°; after this is an interval of a third of a mile, and then appears a quartzose slate-conglomerate comparable with the Ogishki conglomerate; this is followed by quartzite, and this by alternations of quartzite, quartz-schist, and various slates, schists, and argillites, the series having a dip of 75° to 80° southwesterly, and being as a whole more crystalline than the upper system. It is concluded that the name Huronian must be restricted to the upper or lower system; and if restricted to the upper system it remains attached to the best known and most characteristic portion of the old complex Huronian. For the older system, not distinctly named until 1886 as Keewatin by Lawson, the term Kewatian is proposed.

BELL,[54] in 1891, describes the geology of the district of Sudbury. The main outlines of the great Huronian area of this region are given. Within this region are many inliers of gneiss and red quartz-syenite, which correspond with Laurentian types of rock, and it is uncertain whether they are protrusions of the older rocks from beneath or whether some of them may not be portions of the Huronian itself which have undergone further metamorphism. In the Sudbury district many of the areas consist of separate masses, like large and small bowlders, the interspaces being filled by a breccia with a dioritic paste, and suggesting that these rocks may be underlain at no great depth by diorite which was in a soft condition after the gneiss and syenite had been consolidated. At some places within the syenite area, as, for example, about two miles west of Cartier, a massive fine grained rock like some varieties of graywacke may be seen passing into thoroughly crystalline quartz-syenite. The rocks in greatest quantity, and those which constitute the lowest member of the Huronian series between lakes Huron and Wahnapitae, are quartzose graywackes and quartzites, with occasionally a little felsite. In this member of the series crystalline diorites occur as intruded masses, varying from a half a mile to ten miles in length. Also are associated obscurely stratified varieties of quartz-diorite and of dioritic and hornblendic schists, and also compact brown-weathering dolomite. The next member of the series in ascending order is a black volcanic glass breccia consisting of angular fragments crowded together. The highest rocks of the series, or those which occupy the center of the trough, are evenly bedded argillaceous sandstones or graywackes, interstratified with slaty belts and overlain at the summit by black slates. The stratified Huronian rocks, as well as the gneiss and quartz-syenite, are traversed by dikes of coarsely crystalline diabase, which are often large and can be traced for considerable distances.

WINCHELL (N. H.),[55] in 1891, gives further observations upon the Huronian. Northwest of Sudbury and eastward from Algoma there are two formations. In both, the slate and slate conglomerate constitute the upper formation. In the Sudbury region the underlying rocks are largely felsitic, but are also occasionally micaceous and hornblendic. In the section eastward from Algoma the underlying formation seems to be the Mississagui quartzite, with interbedded green fissile schist, with mica-schist varying into hornblende-schist. Logan's Mississagui quartzite is supposed not to be Logan's lowest gray quartzite, but is probably a constituent part of the Keewatin. It is concluded that the observations confirm, or at least do not contravene, the conclusion that the Huronian system of the Canadian reports embraces two or three formations, one of these the true Huronian, first described and mapped by Murray; another, the Keewatin of Lawson; and another, the series of crystalline schists styled the Vermilion series.

PUMPELLY and VAN HISE,[56] in 1892, describe the relations of the Huronian and Laurentian and also give evidence for the divisibility of the Huronian into two series as advocated by Winchell.

In reference to the latter point, at a limestone quarry about 2 miles northeast of Garden river, the upper slate conglomerate was found in actual contact with the limestone member. This conglomerate has a rough appearance of stratification and bears numerous fragments of limestone, many of them more than a foot in length and all in precisely the condition in which is now the original limestone. In this conglomerate are also numerous fragments of schist and granite. The line of contact could be traced only a short distance, and it appears to follow somewhat closely the lamination of the limestone. These relations clearly indicate that after the limestone was deposited, before the beginning of the time of the upper slate conglomerate, there was a considerable interval of erosion. The observations thus tend to confirm

Winchell's conclusion that the Laurentian is divisible into two discordant series, the break occurring above the lower limestone. If this break shall prove to be general at this horizon, it places in the Lower Huronian, using Logan's thicknesses for the formations, about 5,000 feet, and in the Upper Huronian about 13,000 feet.

Almost immediately below the limestone was found the lower slate conglomerate, which in lithological character is precisely like the slate conglomerate in contact with the granite below described.

As bearing upon the relations of the Huronian and Laurentian, one new locality was found, and the contact described by Irving east of Thessalon was again examined. About two miles northwest of Garden river the lower slate conglomerate of Logan was traced downward into a finely laminated semicrystalline quartzose schist, and this downward into a basal conglomerate and recomposed granite which rests almost directly upon the solid granite. The major part of the debris of the basal bowlder conglomerate is derived from the immediately subjacent granite. The evidence of erosive unconformability is thus of the clearest character. The likeness of the slate conglomerate at this locality to that below the limestone, the metamorphosed character of the quartzose schist and the steepness of the inclination of the rocks all bear toward the correctness of Logan's mapping, that this slate conglomerate is the lower one, and, if so, the unconformable contact is between the lower series of the Huronian and the granite.

At the contact between the lower quartzite of Logan and the Laurentian east of Thessalon, described by Irving, it was found that the relations could be much more clearly seen than at the time the locality was visited by Irving, because the water was very low, and two islands upon which the contact occurs were then submerged. The Laurentian area does not consist of simply granite or gneiss, as might be inferred from Logan's mapping, but is an intricate complex of granite, gneiss, and schist. The granite has intruded the schist and fine grained gneisses in the most intricate manner. In many places large roundish fragments of schist or gneiss are contained in granite, and these have a decidedly water-worn appearance. However, in any given area the fragments are always of material identical with that of the immediate adjacent gneiss or schist. In short, the rocks furnish one of the most beautiful illustrations of the relations described by Lawson between schists and gneisses and a later intrusive granite. Resting upon this complex was found a great bowlder conglomerate which differs radically in its character from the pseudo-conglomerates of the Laurentian. The pebbles and bowlders instead of being widely separated are packed closely together. Within a very small area, a square yard or square rod, may be found all varieties of the material to be found within the basement complex: that is, many phases of crystalline schist, gneiss, granite, and granite-gneiss. On one of the islands in which the contact was seen, the line of separation is perfectly sharp and irregular, bending at one place at an angle of 50°. Also the foliation of the granite-gneisses abuts almost at right angles against the line of contact at one place. The contact here, then, has all the characteristics of one of erosive unconformability. Upon the second island, instead of a clear line of contact between the conglomerate and the basement complex there is an apparent gradation, the change occurring within 5 or 6 feet. Here the solid granite-gneiss is first broken; then in passing upward the angular fragments have moved somewhat; in passing still farther upward they become roundish and are mingled with extraneous material, until a bowlder conglomerate is reached which is in every respect like that before described. This relation is not uncommon when an encroaching shore-line overrides a rock formation.

It is concluded that between the lowest members of the Original Huronian series and the granite-gneiss-schist basement complex which Logan has called Laurentian, there is the clearest evidence of a very great unconformity. Also, that the Laurentian series, instead of being a simple one, consists of rocks of many different kinds and has a most complex history.

SUMMARY OF RESULTS.

Bigsby's Transition formation is that to which the term Huronian was later applied by Logan and Murray, and his description of this series is hence the earliest. From the first it is plain that Murray does not consider the series as metamorphic, since it is excluded from the rocks to which that term is applied. It is also plain that the true nature of the interbedded greenstones was appreciated. Logan was distinctly a stratigraphical geologist, who believed in extreme metamorphism of sedimentary beds, yet he also clearly saw that the greenstones associated with the fragmental rocks could not be regarded as other than of igneous origin.

As to the relations of the Huronian and Laurentian north of lake Huron, Murray made the distinction in 1857 to rest upon age and upon lithological characteristics, the Laurentian being older and more completely crystalline than the Huronian. While the Huronian and Laurentian by Logan and Murray are not described at any definite locality as having unconformable relations, the former states that the Huronian is a stratified series and reposes discordantly upon the Laurentian system, and in 1858 he again clearly indicates the same thing by the statement that in the slate conglomerates are bowlders and pebbles derived from the subjacent gneiss and that the lower formation was consequently converted into gneiss and probably greatly disturbed before the upper series was laid down. In 1865, Logan further says that the Huronian unconformably overlies the lower Laurentian, and is believed, although not found in contact with it, to be more recent than the upper Laurentian. These statements are emphasized by his sections published in 1863, which represent the Huronian as resting unconformably upon the Laurentian. The first to describe an actual contact between the underlying gneissic series and the overlying Huronian was Irving, who in 1887 clearly showed that such an unconformity occurs. The observations of Pumpelly and myself reenforce this conclusion and show that between the lowest member of the Huronian and Laurentian complex is a very great discordance.

The facts given by Barlow, taken in connection with the foregoing, show that he has neglected to differentiate the clastic rocks of the Huronian, from the more ancient underlying crystalline gneisses. Also, he has failed to separate an earlier granite-gneiss from a later intrusive. That a part of the granite is eruptive, of later age than the Huronian, was as well known to Logan and Murray as to Barlow. These early geologists recognized both a later granite and a granite-gneiss basement complex upon which the Huronian was deposited, while the latter failed to make this fundamental discrimination. He saw the former and assumed that this covered the entire ground.

As to the position taken by Alexander Winchell, that the Original Huronian is divisible into two unconformable series, it may be remarked that the locality in which the strongest evidence for this is given, Echo lake, is on the outskirts of the area mapped in detail by Logan and Murray. Before accepting the conclusion that these geologists, in their careful work extending over several years in the area of the Original Huronian, have overlooked a great unconformity and have misunderstood what part of the area is covered by lower slate conglomerate and what by upper slate conglomerate, we ought to have the most decisive evidence. However, the observations of Pumpelly and myself tend toward the correctness of Winchell's first conclusion. At least between the limestone and the upper slate conglomerate, in places, there has been a considerable erosion interval. That with the Huronian in the more general work of later years Logan and Murray placed two discordant series is certain. The same was done by the geologists on the south shore of lake Superior, and in view of this very common reference it is stated in another place that for these two series the terms Upper Huronian and Lower Huronian are used. If it is really the case that in the Original Huronian of the north channel of lake Huron, in the area covered by the detailed map of 1863, two discordant series do exist, this suggestion is eminently appropriate.

Great indisputable results were reached by the early Canadian geologists, Logan and Murray. This district north of lake Huron was the first in which it was shown that an unmistakable detrital and little metamorphosed series of rocks rests unconformably under the upper Cambrian. Also it was shown that this series is of such a character that the ordinary stratigraphical methods apply, and Logan and Murray were able to subdivide it into formations upon a lithological basis in the same fashion as is done in fossiliferous series. This is so evident that it would not be emphasized if it had not been denied. Far more to the credit of Logan and Murray is the recognition of the character of the amygdaloids and the interbedded greenstones. No extreme metamorphic theory was applied to them, and they were distinctly regarded as an exception to the ordinary stratigraphical laws and separated both in descriptions and mapping. This is the more creditable because for many years afterwards similar rocks were supposed by many other writers to be parts of the stratified successions in a completely metamorphosed condition had caused them to become crystalline. Finally it was recognized that this Huronian series rests unconformably upon an older gneissic and granitic crystalline series, which has yielded abundant fragments to the overlying rocks.

To the person who hypothecates that all pre-Cambrian rocks are wholly crystalline and that all truly detrital rocks are Cambrian or post-Cambrian, these conclusions prove only that inferior to the Potsdam sandstone, and separated from it by a great unconformity, is a series of rocks of great thickness, having a number of persistent members of varying lithological character, which are lower Cambrian. But this position does not lessen the value of the work done; for it would still be true that the Huronian series was the first so low in the geological column in which the above facts were shown.

The only rocks in the Original Huronian area which Logan correlated with those of the Original Laurentian area are the unconformably underlying granitic and gneissic series. These were called lower Laurentian, the idea being evidently to correlate them with the lower noncalcareous division of the Original Laurentian. This correlation was plainly made on the ground of lithological likeness. That the Huronian is more recent than the upper Laurentian was stated only as a belief. This belief appears to have been based upon the "nonmetamorphic" character of the Huronian as compared with the upper Laurentian. It is also possible that the fact that there is a structural break on the north shore of lake Huron, between the Huronian and the gneissic series, whereas no such break was found between the upper and lower divisions of the Original Laurentian, had an influence in leading to this conclusion.

NOTES.

The following are the titles of papers and works cited in the foregoing chapter, reference marks to which appear in the text:

[1] On the Geology of the Ottawa and some of its Tributaries, W. E. Logan. Rept. of Prog. Geol. Survey of Canada for 1845–'46, pp. 40–51.

[2] On the Geology of the Counties of Beauharnois and the Lake of Two Mountains, W. E. Logan. Rept. of Prog. Geol. Survey of Canada for 1851–'52.

[3] On the Geology of the Region between the Ottawa, the St. Lawrence, and the Rideau, Alexander Murray. Ibid., pp. 59–65.

[4] W. E. Logan: Rept. of Prog. Geol. Survey of Canada for 1852–'53, pp. 8, 74.

[5] On the Geology of the Region between Kingston and Lake Simcoe, Alexander Murray. Ibid., pp. 75–133.

[6] On the Laurentian rocks of Grenville, Chatham, St. Jerome, etc., and the Economic Materials found in them, W. E. Logan. Rept. of Prog. Geol. Survey of Canada for 1853–'54–'55–'56, pp. 5–57. Accompanied by a sketch map.

[7] On the Topographical and Geological Features of the Region between the Ottawa river and Georgian Bay, as well as North of Lake Huron, Alexander Murray. Ibid., pp. 59–190. Accompanied by two maps.

[8] Reports of T. Sterry Hunt. Ibid., pp. 397–494.

[9] On the Probable Subdivision of the Laurentian Series of Rocks of Canada, Sir William E. Logan. Proc. Am. Assoc. Adv. Sci., part 2, 1857, 11th meeting, pp. 47–51.

[10] On the Distribution of the Laurentian Limestones, and of the Drift in the Grenville Region, W. E. Logan. Rept. of Prog. Geol. Survey of Canada for 1858, pp. 8–40.

[11] Contribution to the History of the Laurentian Limestones, Sir William E. Logan. Proc. Am. Assoc. Adv. Sci., 1859, 13th meeting, pp. 310–312.

[12] Report of Progress of the Geological Survey of Canada from its Commencement to 1863, W. E. Logan, pp. 983. Accompanied by an atlas.

[13] On the Laurentian Formation, its Mineral Constitution, its Geographical Distribution, and its Residuary Elements of Life, J. J. Bigsby. Geol. Magazine, 1864, vol. I, pp. 154–158, 200–206.

[14] On the Geology and Economic Minerals of portions of the County of Hastings, Thomas Macfarlane. Rept. of Prog. Geol. Survey of Canada for 1863 to 1866, pp. 91–96.

[15] Summary Report of Geological Investigations, W. E. Logan. *Ibid.*, pp. 10–19.

[16] On New Specimens of Eozoon, W. E. Logan. Quart. Jour. Geol. Soc., London, vol. XXIII, 1867, pp. 253–256.

[17] Ascending Section of Laurentian Rocks in the County of Hastings, Canada West, H. G. Vennor. Ibid., pp. 256–257.

[18] On the Graphite of the Laurentian of Canada, J. W. Dawson. Ibid., vol. XXV, 1869, p. 406. See also vol. XXVI, pp. 112–117.

[19] On the Geology of portions of Hastings, Peterborough, and Frontenac Counties, Ontario, Henry G. Vennor. Rept. of Prog. Geol. Survey of Canada from 1866 to 1869, pp. 143–171. Accompanied by a geological map.

[20] Abstract of a Report on the Geology of parts of the Counties of Frontenac, Leeds, and Lanark (Ontario), Henry G. Vennor. Rept. of Prog. Geol. Survey of Canada for 1870–'71, pp. 309–315.

[21] Progress Report of Exploration and Survey of Leeds, Frontenac, and Lanark, Henry G. Vennor. Rept. of Prog. Geol. Survey of Canada for 1871–'72, pp. 120–140.

[22] On Explorations and Surveys in the Counties of Frontenac, Leeds, and Lanark, Henry G. Vennor. Rept. of Prog. Geol. Survey of Canada, 1872–'73, pp. 136–179.

[23] Report of Explorations and Surveys in Frontenac, Leeds, and Lanark Counties, Henry G. Vennor. Rept. of Prog. Geol. Survey of Canada for 1873–'74, pp. 103–146.

[24] Progress Report of Explorations and Surveys in the rear portions of Frontenac, and Lanark Counties, Henry G. Vennor. Rept. of Prog. Geol. Survey of Canada for 1874–'75, pp. 105–165. Accompanied by a map; see also Rept. of Prog. Geol. Survey of Canada, 1875–'76, p. 4.

[25] Archean of Canada, Henry G. Vennor. Am. Jour. Sci., 3d ser., vol. XIV, 1877, pp. 313–316.

[26] Progress Report of Explorations and Surveys made during the years 1875 and 1876 in the counties of Renfrew, Pontiac, and Ottawa, Henry G. Vennor. Rept. of Prog. Geol. Survey of Canada for 1876–'77, pp. 244–320. Accompanied by a map.

[27] Report on Geological Researches North of Lake Huron and East of Lake Superior, Robert Bell. Ibid., pp. 193–220.

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CHAPTER II.

LAKE SUPERIOR REGION.

SECTION I. WORK OF THE OFFICIAL GEOLOGISTS OF THE CANADIAN SURVEY AND ASSOCIATES.

BIGSBY,[1] in 1825, describes in detail the rocks at many points along the north shore of lake Superior, between the falls of St. Mary and Grand Portage, an interval of 445 miles. The varieties of rocks are few in number when compared with a similar extent of country in Europe. Of mica-slate, clay-slate, etc., not a vestige was found, not even in débris, nor of any secondary deposits above the Mountain limestone. Sandstone, under various modifications, occupies the greatest space; in intimate connection with the next prevailing rocks, the amygdaloids, porphyries, and greenstone trap. The alternating granites and greenstones of the northeastern and eastern coasts are nearly equal in quantity to these. The granites and syenites are not stratified. The porphyry, amygdaloid, and sandstone are considered contemporaneous and newer than the granites, although not much, as indicated by the transitions and alternations occurring about Gargantua. The age and connections of the greenstone trap the author is not prepared to state. The sandstone is most probably Old Red, a conclusion reached from the materials composing it, and its direct superposition on inclined rocks in this and other great lakes of the St. Lawrence and because it supports a fossiliferous limestone full of productæ, turbinoliæ, caryophylliæ, trilobites, conulariæ, encrinites, and orthoceratites, etc. The granite and syenite seem to be of the same age and belong to the transition or to the youngest of the primitive.

On the old route from lake Superior to the lake of the Woods (for 430 miles) is an alternation of chloritic greenstone and amphibolitic granite, but at and toward the lake of the Woods the greenstone passes into gneiss, and mica-slate, traversed in many ways and in great quantities by graphic granite.

BAYFIELD,[2] in 1829, gives an outline of the geology of lake Superior. The rocks of the lake are divided into four divisions: First, the inferior order, comprising granites, which almost always contain more or less hornblende. In this division neither gneiss nor mica-slate was met with, although the granite by the abundance of its mica or lamellar structure may for a short distance assume the appearance of either. Second, the submedial order, which includes greenstones, common jaspery variety of greenstone slates, flinty chlorite, talcose slate, and in one place alone transition limestone, with perhaps traces of graywacke. Third, trap or overlying rock, the most of which is amygdaloid; various kinds of porphyry are next in quantity; then trap, greenstone, syenites, and pitchstone. Fourth, the medial order, the only rock of which is the Old Red sandstone. Then follows an account of the distribution of each of these orders. The amygdaloid with little doubt rests upon the syenite and granite, although the junction was never seen. The amygdaloid passes into greenstone on the one hand simply by being divested of its nodules, and into porphyry on the other. The Old Red sandstone may be traced from one extremity of the lake to the other. Its existence is noticed on both shores, and it is traced across the lake by many of the islands, so as to leave no doubt of its being a general formation throughout the whole of the basin of lake Superior. It is generally horizontally stratified or nearly so. There are many instances of the conjunction of the sandstone and granite, which serve to prove that the sandstone was deposited after the granite occupied its present position. The sandstone, when conglomeratic, as is very frequently the case, contains fragments of the trap as well as of the inferior order, which are rounded by attrition, and it is therefore plain that the sandstone is later than the trap rocks. Organic remains were sought in this rock, but never discovered. It is placed as the Old Red because of its position immediately on the granite, its structure, and component parts.

BAYFIELD,[3] in 1845, places with the Primary rocks most of the clastics on the north shore of lake Superior. These are cut by various greenstones. A red sandstone forms nearly the entire southern boundary of the lake. In places it is shattered by the upheaval of granite and by trap rocks which enter into the composition of its conglomerates. At Nipigon bay it is overlaid by an immense bed of greenstone. It is probable, although not certain, that this sandstone underlies the fossiliferous red sandstone of St. Marys.

LOGAN,[4] in 1847, in a report on the geology and economic minerals of lake Superior, gives an account of a rather detailed examination of the north shore of lake Superior from Pigeon river to Sault Ste. Marie. Michipicoten island was also examined. Lake Superior appears to be set in a geological depression, which presents formations of a similar character on both the north and south sides, dipping to the center. The series on the north, in ascending order, consists of the following: (1) Granite and syenite; (2) gneiss; (3) chloritic and partially talcose and conglomerate slates; (4) bluish slates or shales, interstratified with trap; (5) sandstones, limestones, indurated marls, and conglomerates, interstratified with trap. The gneiss is succeeded by dark green slates, which at the base appear to be occasionally interstratified with beds of the subjacent granite and gneiss. These slaty beds at times have the quality of a greenstone, at times a mica-slate, and a few are quartz rocks. Higher in the series are conglomerates, the pebbles of which

are all apparently from hypogene rocks. Formations 4 and 5 rest unconformably upon 1, 2, and 3, having sometimes basal conglomerates, the pebbles being of quartz, red jasper, and slate. The upper part of 3 strongly resembles the upper slates at lake Temiscamang. The succession of conglomerate and pebbly slates at Gros cap has a total thickness of 1,700 feet. In group 5 are the succession of rocks at Michipicoten island, a portion of those at Thunder bay, and at other localities. At Michipicoten the thickness of the interbedded volcanics and water-deposited clastics is not less than 10,000 or 12,000 feet. Group 5 exhibits an unconformity to the granite. The conclusion that the copper-bearing series is older than the Potsdam sandstone arrived at by Houghton in 1841, is thought to be probably true.

MURRAY,[5] in 1847, in an account of the Kaministiquia and Michipicoten rivers, divides the geological formation into three groups: (1) Granite, syenite, gneiss, micaceous and chloritic schist; (2) blackish argillaceous slates, with associated trap; (3) drift clays and sands. At the portage of the Kaministiquia a massive syenite passes into a gneissoid syenite, upon which rest conformably dark colored altered slates, one rock passing imperceptibly into the other. The junction of 1 and 2 was not observed.

LOGAN,[6] in 1852, finds the rocks of the north shore of lake Superior to have the following succession: Granite, syenite, and gneiss, or micaceous and hornblende-gneiss, which are succeeded by chloritic and talcose slates, interstratified with obscure conglomerates with a slaty base. Upon these rest unconformably bluish slates, with belts of chert and limestone toward the bottom, and thick flows of greenstone trap at the top. Above these are alternations of sandstones, conglomerates, amygdaloids and traps, the whole thickness of the upper series above the unconformity being not less than 12,000 feet. The conclusion is reached that this upper series is the equivalent of the Potsdam sandstone, which rests unconformably upon the tilted beds of the lake Huron series, and that both are contemporaneous with the Cambrian series of the British isles.

BIGSBY,[7] in 1852, finds the crystalline strata of the lake of the Woods to conform in strike with those several hundred miles southward on the river Mississippi. Granite occupies the axis in the northeast part of the lake of the Woods, and is always the lowest rock, the gneiss, mica-schist and greenstone dipping away from it on both sides. Greenstone is perhaps the most abundant rock in this part of the lake, and greenstone conglomerates are found which contain black masses of greenstone lying with their greater length parallel to the strike. The granites and mica-slates are intimately associated, and the granite includes greenstone in a thousand tortuous masses, tongues, and slender veins. Also the granite is cut by greenstone.

BIGSBY,[8] in 1852, divides the rocks about lake Superior into (1) Metamorphic, including greenstone, slates, schists, gneisses, quartzites, jaspers, and crystalline limestones; (2) aqueous, including the calciferous and Cambrian sandstones and conglomerates; (3) igneous, including granite, syenite, and trap. The lake is a trough or basin of Cambrian or Silurian sandstone, surrounded by two irregular and imperfect zones, the inner consisting of traps with conglomerates, the outer, of metamorphic, flanked by igneous rocks. The metamorphic rocks, with the exception of quartzite and jasper, the oldest in the lake, support unconformably the sandstone. These rocks have been upheaved and altered by the intrusion of igneous rocks. The sandstone is generally horizontal, except near the intrusive rocks, where it rises at high angles and passes into jasper, porphyry, gneiss, or quartzite. The conglomerate is of the same age as much of the sandstone, and is between it and the trap; and there is reason to believe that the sandstone is interleaved with trap. The igneous rock, granite, everywhere forms the nucleus of the anticlinal axes. The trap rocks are divided into crystalline mountain masses—sometimes anticlinal and syenitic; into bedded traps; and into dikes intersecting igneous and metamorphic rocks; but all are portions of one long series of volcanic operations.

BIGSBY,[9] in 1854, finds the geology of Rainy lake to be as follows: Chloritic and greenstone slates, gneiss and mica-slate, in proportional quantities in the order here set down, seem once to have occupied the lake basin, with an ENE. strike, and a NNW. dip, at a high angle usually. But subsequently a very extensive outburst of granite, with some syenite, has taken place, to the great disturbance of the stratified rocks, and penetrating them both in intercalations and crosswise. These intrusive rocks occupy a very large portion of the lake, most of the western shore, nearly all the eastern trough or arm, and much of the east end of the lake about Stokes and Hale bays. Intercalations of syenite and hornblende-greenstone are frequent, and so is the occurrence of veins of porphyritic granite traversing the gneiss in all directions. The chlorite-slate greenstone, gneiss, and mica-slate are conformable with each other.

DAWSON (SIR WILLIAM),[10] in 1857, finds between Sault Ste. Marie and Mamainse three of the oldest formations in America or the world. Beginning at the top are: (1) Potsdam sandstone; (2) an enormously thick formation of conglomerates, sandstones, slate, and trap, constituting the Huronian series of Logan; (3) a still older Laurentian series, represented here principally by syenitic rocks which have afforded the material of the Huronian conglomerates. The sandstones and conglomerates of the second series probably unconformably underlie the Potsdam sandstone, as is indicated by their high inclination and disturbed condition.

LOGAN,[11] in 1863, finds on the north shore of lake Superior crystalline stratified rocks which occur in extensive tracts about Rainy lake and lac la Croix, as well as adjacent to lake Superior, which are probably of Laurentian age. There are three areas of Huronian along the northeast coast of lake Superior, and a narrow strip of Huronian rocks are seen along Thunder bay.

The Laurentian gneiss is succeeded by green or gray slates, which at the base appear to be interstratified with feldspathic beds of the reddish color belonging to the subjacent gneiss. Rising in the series the dark green slates become interstratified with layers holding a sufficient number of pebbles of different kinds to constitute conglomerates. It often happens, unless the pebbles are of white quartz, that they are very obscurely distinguishable on fracturing the rock, both the pebbles and the matrix having a gray color, and showing very little apparent difference in mineral character.

The Doré section, composed of strata inclined only 10° or 15° from the vertical, 1,700 feet thick, consists mainly of green slate rock and a green slate conglomerate, the pebbles being of granite, gneiss, syenite, etc., and some of the bowlders of which are a foot in diameter. At the Doré the lower part of the section assumes more the character of a gneiss and becomes interstratified with feldspathic layers. The Laurentian appears to be conformable with and to grade into the Huronian on the Kaministiquia river.

The Huronian formation of lake Superior is unconformably overlain by a second series of copper-bearing rocks, which may conveniently be divided into two groups, the lower consisting of bluish slates or shales, interstratified with chert beds, sandstones and trap, and the upper consisting of a succession of sandstones, limestones, marls, and conglomerates, also interstratified with trap which is often amygdaloidal. At the top of the lower group is a crowning overflow of trap 200 or 300 feet thick and the whole of it has a thickness of 1,500 or 2,000 feet. The upper group contains a great quantity of trap layers and has an enormous trappean overflow, the total volume having a thickness of between 6,000 and 10,000 feet. Dike rocks, consisting of greenstone, porphyry, and syenite, are found to be of two ages. The lower group composes the whole country, both islands and mainland, between Pigeon river and fort William. The upper group occupies the coast and islands from the south side of Thunder cape to the east end of Battle islands east of Nipigon bay. It also covers a large part of isle Royale and Michipicoten, at which latter island the total volume of the formation is at the most moderate estimation 12,000 feet. Upon the east coast of lake Superior this group is found at cape Choyye, cape Gargantua, point aux Mines, Mamainse, where the breadth across the measures is sufficient to give a thickness not far from 10,000, and at three other places on the coast between the last point and Sault Ste. Marie.

As to the age of this series, the fact that the generally moderate dips of the red sandstone at Sault Ste. Marie contrasts with the higher inclinations of the copper-bearing rocks, while none of the many dikes are known to intersect the Sault Ste. Marie sandstone, leads to the suspicion that the latter may overlie unconformably the rocks which, associated with the trap, constitute the copper-bearing series. The affinities of the Sault Ste. Marie red sandstone appear to bring it into the position of the Chazy rather than the Potsdam formation, and, if this were established, the copper-bearing portion of the lake Superior rocks might reasonably be considered to belong to the Calciferous and the Potsdam formations.

MACFARLANE,[12] in 1866, gives observations on the Laurentian, Huronian, and Upper Copper-bearing rocks of lake Superior. The Laurentian series on lake Superior seems to differ somewhat from other parts of Canada. The rocks are all highly crystalline, seldom thoroughly gneissoid, and all are unaccompanied by crystalline limestone, which is such a marked feature in some Laurentian districts. The gneiss strata are much contorted and are intersected with granite in almost equal quantity with the gneiss itself; and although this latter occurs in irregular veins, at the point of junction it is as firmly cemented with the gneiss as any two pieces of one and the same rock could well be. On the Goulais bay fragments of hornblende rock or schist up to 3 feet in diameter are inclosed in a coarse grained syenitic granite. In this series the oldest rock is the most basic in constitution, and this is the case without regard to mineralogical composition or structure of the rocks associated together. The indistinctness of parallelism in the rocks renders it a matter of extreme difficulty to form any clear ideas as to their succession, even if such should exist. Besides the above rocks there are considerable areas of granite, syenite, dolerite, diorite, and melaphyre found in the Laurentian.

The rocks of the Huronian system consist in large part of diabase, amygdaloid, diabase-schist, greenstone, breccias, and slaty greenstones. Interstratified with these are slate, slate conglomerate and quartzite. The bowlders and pebbles of the conglomerate of Doré river are for the most part granite; they are elongated and flattened, the pebbles sometimes being scarcely distinguishable from the slate. Granitic veins or masses, like the Laurentian, are found in the schistose greenstones, which are regarded as belonging to the Huronian. As to the succession of the strata, the author is as much at a loss among the irregular schistose Huronian greenstones as among the gneissoid granites of the Laurentian.

The Mamainse section of Upper Copper-bearing rocks consists of interbedded basic lava flows, often amygdaloidal, sandstones, and conglomerates, the total thickness being more than 16,000 feet. The total thickness of the series at Mamainse and Michipicoten is believed to be at least 20,000 feet. As to the relations of the horizontal Sault sandstone to the upper copper bearing series, a place was found on the south of point aux Mines where the Mamainse series adjoins the Laurentian rocks. The lowest member of the former is unconformably overlain by thin bedded bluish and yellowish gray sandstone, striking N. 50° E., and dipping 18° NW. The lowest layer is a conglomerate with granitic and trappean bowlders, and is followed by thin bedded sandstones, and these by thin shaly layers.

MACFARLANE,[13] in 1868, describes the rocks of the north and east shore of lake Superior. He here finds four formations—the Laurentian, Huronian, Upper Copper-bearing rocks, and St. Mary sandstone. The most prevalent rocks of the Laurentian series are of a massive crystalline character, more of a granitic than of a gneissic nature. Almost equally frequent with the granitic and gneissic rocks are aggregates of rocks which can be described as brecciated and intrusive, gneissic, granitic, and syenitic rocks. In these the order of age is always from basic to acidic. In one case fragments of hornblende-schists are found inclosed in syenitic granite, which is cut by granite dikes of different ages. It is believed that these rocks are wholly of igneous origin, representing a single period of time—the basic rock first solidified; they were then rent off, broken up, and the crevices filled with more siliceous material, which gradually solidified, after which occurred another general movement with further intrusion of the most siliceous materials.

In the Huronian series is placed diabase, augite-porphyry, calcareous diabase, diabase schist, greenstone and greenstone slate, chlorite-schist, quartzite, hematite, greenstone breccia, and slate-conglomerate. The slate conglomerates frequently contains granite pebbles which are in roundish, lenticular, bent, long-drawn out masses, with a diabase-schist or greenstone-slate matrix. These rocks locally have a sedimentary appearance, but are believed to be due to the subsequent intrusion of the Huronian rocks, which have caught granite fragments in them, and, by movement and heat, have softened and much distorted the contained fragments. It follows that far the greater number of the Huronian rocks are regarded as purely igneous.

In the Upper Copper-bearing series are distinguished melaphyre of various kinds—melaphyre breccia, porphyrite, porphyritic conglomerate, felsite-tuff, polygenous conglomerate, and sandstone. The polygenous conglomerate contains, at Mamainse, fragments chiefly of granite, gneiss, quartzite, greenstone and slate, while some of the newer contain abundant bowlders of melaphyre and amygdaloid. The igneous rocks and sandstones are regularly interstratified with each other. In many places the trap lies unconformably upon the upturned and contorted edges of the sandstone.

Along the coast and upon many islands is found an almost horizontal red sandstone, which is supposed to be a continuation of the Sault Ste. Marie sandstone. Its relations to the copper-bearing rocks are not clearly made out, but the lowest members of the Mamainse series, are unconformably overlain by sandstones which may be the equivalent of the horizontal red sandstones, but their lithological character is different. It is suggested, on lithological grounds, that this red sandstone may be of Permian age.

MACFARLANE,[14] in 1869, describes at Thunder cape a series of interstratified argillaceous and white and red dolomitic sandstones, which had been disturbed and eroded before the flow appeared which forms the summit rock of the cape.

BELL,[15] in 1870, gives an account of the geology of the northwest coast of lake Superior and the Nipigon district. The copper-bearing rocks are divided into a lower group and an upper group, and each of these groups separated into several divisions. In the upper group only is found interbedded trap. Different portions of this series are found overlying unconformably in certain places the Laurentian and in others the Huronian; and the great trap overflow which crowns Thunder cape rests in various places unconformably upon different members of both the upper and lower groups of the Upper Copper-bearing series. On account of the great thickness of this series, the absence of fossils, the prevalence of marls and sandstones charged with red oxide of iron, and of basalts, amygdaloids, and trap rocks, and various zeolites and native copper, this series is considered as probably of Permian or Triassic age. Between the margin of the Upper Copper-bearing rocks on Thunder bay and the Laurentian range, all the country not occupied by the syenitic areas appear to be composed of rocks of the Huronian series, consisting of diorites, dioritic conglomerates, hornblendic and fine grained micaceous slates, with some quartzites.

BELL,[16] in 1872, finds in the country north of lake Superior, between Nipigon and Michipicoten rivers, both Laurentian and Huronian rocks. The former includes gneisses and granites, and the latter includes slates, conglomerates, massive and schistose diorites, fine grained gneisses, mica-schists, micaceous, hornblendic, chloritic, feldspathic and epidotic schists, slates, granites, and iron ore. The Huronian rocks dip in various directions. At White river hornblendic schist and light gray gneiss are interstratified with massive granitic gneiss, and similar schists appear to rest conformably upon massive gneisses for a long way north of the river.

BELL,[17] in 1872, finds in the country between lake Superior and the Albany river areas of Laurentian and Huronian rocks. Between Mousewake lake and Martins falls bands of gneiss are interstratified with the schists, and just at Martins falls the latter have become entirely replaced by red and gray gneisses, apparently showing a conformable passage from the Huronian into the Laurentian rocks. A similar blending of these formations was noticed last year in the neighborhood of White lake.

SELWYN,[18] in 1873, finds, between Mille Lacs and Separation lake and the lake of the Woods, a series of parallel bands of schistose and slaty layers where hitherto was supposed to be almost exclusively the Laurentian gneiss. The facts observed lead to the conclusion, as stated by Bell, that the two series are in conformable sequence; yet it is far from improbable that this apparent conformity is only local and that a more extended and detailed investigation of the structure would show that there is in reality a very considerable break between the Laurentian gneiss and the overlying schistose and slaty strata referred to the Huronian rocks. The evidence as to the age of these latter is not satisfactory. They resemble as closely the altered rocks of the Quebec group as they do the Huronian of lake Huron and Superior.

BELL,[19] in 1873, finds in the country between lake Superior and lake Winnipeg rocks belonging to the Laurentian, Huronian, and Upper Copper-bearing series. The southern shores of lake of Mille Lacs are composed of Huronian strata. The Laurentian gneiss and Huronian schists at many places alternate with each other. The junction of the Laurentian rocks on the north with the Huronian schists on the south occurs at Rat portage on the lake of the Woods. The two rocks are seen almost in contact with each other and have the same strike and dip. The rocks classified as Huronian consist principally of a great variety of crystalline schists in which a greenish color prevails. In addition to these are grayish quartzites and schists, sometimes with iron ore, diorites, imperfect gneisses. The areas of granite and syenite in the region, which vary from patches to areas many miles in length, are always more or less intimately connected with the Huronian bands. The distinction between the Laurentian and Huronian rocks is chiefly of a lithological character, the Huronian appearing to succeed the Laurentian conformably. The Upper Copper-bearing series, composed of slates, marls, sandstones, and traps, lie nearly horizontally on the edges of the Laurentian and Huronian rocks.

HUNT,[20] in 1873, applies the name Animikie group to the lower division of Logan's Upper Copper-bearing series of lake Superior as it occurs at Thunder bay, where it includes dark colored argillites and sandstones overlain with a slight discordance by red and white sandstones apparently the same as those of the Keweenaw district. The dark colored sediments of the Animikie group rest directly upon the edges of the crystalline Huronian schists and are cut by great dikes of diorite. The great Keweenaw group, with its cupriferous amygdaloids, is here absent, although met with a few miles to the eastward. This group, as shown by Brooks and Pumpelly, occupies a place between the Huronian schists and the nearly horizontal red and white sandstone of the region, which is itself below the Trenton limestone.

BELL,[21] in 1874, in the country between the Red river and the South Saskatchewan, finds extensively mica-schists and gneisses; but a broad band of schist, having the character of the Huronian formation, crosses the central part of Rainy lake. On the islands of the lake of the Woods the granites, gneisses, and Huronian schists are intricately mingled with each other.

DAWSON (G. M.)[22], in 1875, gives an account of the geology of the lake of the Woods, where the rocks are wholly Laurentian and Huronian. The Laurentian formation is represented by a great thickness of granitoid and thick-bedded gneisses, which pass upward into thin-bedded gneisses and highly crystalline micaceous and hornblendic schists.

The Huronian rocks are more variable in character. The lowest beds are, for the most part, hard green rocks, with little traces of stratification, but hold some well stratified micaceous and chloritic schists and also imperfect gneiss. On these rest a great thickness of massive beds characterized by the predominance of conglomerate, but including quartzites and dioritic rocks. Above these is an extensive series of schistose and slaty beds generally more or less nacreous and chloritic or talcose, but often hornblendic and micaceous. They inclose also conglomerates, quartzites, and diorite beds. It is believed two movements have conspired to form the present features of the region, both being post-Huronian. The first of these is connected with the post-Huronian granite eruptions; the second and more important is believed to have taken place later, and to it is supposed to be due the parallelism in the folding of the Laurentian and Huronian rocks. At Rat portage the junction of the Laurentian and Huronian is so sharply defined that the hand can be laid upon it. This sharp contact is believed to be due to faulting. Adjacent to the granite the Huronian slate series is metamorphosed, and the occasional gneissic aspect of the Huronian is attributed to the granitic intrusions. The large Y-shaped granite mass in the northwest angle, in contact with the altered sedimentary rocks, assumes a more basic character and a darker aspect, becoming blackish gneissic diorite and gray syenitic diorite. The conglomerate beds are of immense thickness and could perhaps be best described as slate conglomerates. The pebbles generally resemble the matrix, and best appear upon a weathered surface; for on a freshly broken surface no clear distinction appears between the fragments and the inclosing materials, and the rock differs from the more compact altered schists and slates only in its rougher surface of fracture and a somewhat spotted character. The greenstone conglomerates of Bigsby resemble roughly fractured pieces of diorite in a dioritic paste. The quartzites show a tendency to run into conglomerates, and certain of the conglomerates have an aspect of a volcanic breccia. There is an entire absence of any granitic or gneissic beds in the conglomerates and breccias, and in this respect these Huronian rocks differ from the typical area. It is suggested that this fact may mean that the formation of the whole Huronian series took place subsequent to that of the typical Huronian, and therefore are perhaps more nearly equivalent to those of the Quebec group. The granitoid gneisses and intrusive granites are universally cut by veins of red orthoclase feldspar associated with quartz; and basic diorite dikes cut both the granitic and altered Laurentian rocks.

BELL,[23] in 1875, describes on the north shore of lake Superior the Laurentian, Huronian, and Upper Copper-bearing rocks. The Huronian occupies a large extent of country, alternating with bands of Laurentian, on both the north and south shores of the lake. North of lake

Superior the Laurentian rocks consist for the most part of gray and reddish gneiss, with micaceous belts and mica-schists. In the same region the Huronian rocks are mostly of a schistose character, the most common of which are greenish schists and imperfect gneisses, which include micaceous, hornblendic, dioritic, porphyritic, siliceous, cherty, chloritic, felsitic, and argillaceous schists; more rarely dolomitic schists, and occasionally bands of magnetic iron ore and hematite. Connected with the Huronian rocks are various patches of granite and syenite which show no stratification. In the Nipigon basin the Upper Copper-bearing rocks have their maximum development in Canadian territory. The basin consists of marls, sandstones, often covered with trappean outflows. For this Upper Copper-bearing series the term Nipigon group is proposed.

BELL,[24] in 1876, finds on lake Winnipeg extensive areas of Laurentian gneiss and Huronian schist. The run of the stratification is pretty uniform, averaging from 50° to 60° south of east, being almost at right angles to the general strike of the Laurentian and Huronian rocks in the great region north and northwest of lake Superior.

BELL,[25] in 1877, describes the rocks from the head of Moose river to Michipicoten and lake Superior; also along the Goulais river. Before reaching lake Superior there are several broad alternating belts of Laurentian gneiss and Huronian schist. The Huronian hornblende and mica-schists are cut by granite veins of various sizes, one of them 100 feet thick. On the Goulais river there are again alternations of Laurentian and Huronian rocks.

BELL,[26] in 1878, gives observations on the geology of the east shore of lake Superior from Batchawana bay to Michipicoten river. The Upper Copper-bearing series of Mamainse is calculated to have a thickness of 22,400 feet. It consists of a great variety of amygdaloids, volcanic tufas, felsites, cherts, crystalline diorites, sandstones and coarse conglomerates, the latter forming one of the most striking features in the series as it passes into a bowlder conglomerate. The bowlders are sometimes crowded in a sandy matrix, the largest running as high as 3 feet 8 inches in diameter, but the majority are under 1 foot. Far the greater number consist of granite and crystalline schists like those of the Huronian series, but there are also found white quartz, amygdaloid and gneiss. Granites, gneisses and schists, as well as basaltic dikes, are found at many points. Cape Choyye is composed of Huronian rocks, which consist of mica-schists and hornblende-schists, slaty quartzite, and massive diorite. The rocks of Gros cap are mostly slaty diorite, interstratified with siliceous rock, in which occur exposures of purplish red hematite. A dioritic slate west of Gros cap holds layers and lenticular patches of felsite and also rounded pebbles of granite, the largest of which are 9 inches in diameter.

MACFARLANE,[27] in 1879, in discussing Selwyn's paper on the Quebec group, maintains that there is frequently found between the water and the Laurentian or Huronian hills narrow strips or patches of rocks of the Upper Copper-bearing group. Such localities are Gros cap, south shore of Batchawana bay, and cape Gargantua. The conglomerates are full of Huronian débris, and in Batchawana bay bowlders may be observed of red jasper conglomerate, the characteristic rock of the typical Huronian. On Michipicoten island the igneous and sedimentary strata of the Upper Copper-bearing rocks have a dip of 25° to the southeast, while the nearest Huronian rocks dip 34° to 55° northward.

BELL,[28] in 1883, gives a further account of the distribution of the rocks of the lake of the Woods and adjacent country. They are not different from those mentioned in his previous report for 1872–73. The line between the Laurentian and Huronian system crosses the Winnipeg river at Rat portage, keeps near the railway to a point between lake Lulu and Keewatin mills, where it crosses it diagonally and continues in a westerly direction on the south side of the track.

SELWYN,[29] in 1883, as a result of an examination of the north shore of lake Superior from Thunder bay to Sault Ste. Marie, and thence eastward to Echo lake, fails to find evidence of the supposed unconformability of the Huronian and Laurentian. The author can give no better reason for supposing that certain sets of beds belong to the so-called Laurentian and others to the Huronian systems than a considerable difference in the lithological characters. The Laurentian are essentially granitoid, gneissic and feldspathic, while the Huronian are quartzose, hornblendic, schistose and slaty. As a whole the latter have a somewhat altered aspect and contain pebbles of rocks—granite, gneiss, quartzite, etc.—similar to those which form the Laurentian strata beneath them, while others, however, are not recognizable as from any known Laurentian sources. Bands of limestone and dolomite, more or less crystalline, are found in both Laurentian and Huronian areas, and, if we except the disputed form, Eozoon, no fossil whatever. The Huronian follows and does not rest unconformably upon the Laurentian. The Nipigon or Keweenian is later in age than the Animikie. No definite opinion can be expressed as to the position of the crowning overflow of Thunder cape.

SELWYN,[30] in 1883, describes the trap and sandstone of lake Superior as unconformably upon and entirely distinct from the Huronian. The series is divisible on the Canadian shore into two, and perhaps three divisions, between which there may be slight unconformities, which are, however, no greater than might be occasioned by the intermingling of sedimentary strata with volcanic material. The groups in ascending order are (1) the shales, cherts, dolomites and sandstones interbedded with massive diabase or dolerite of Pie island, McKays mountain and Thunder cape. (2) Conglomerates, shales, sandstones and dolomites, interstratified with massive beds of volcanic material, amygdaloids, melaphyres, tuffs, etc., many thousands of feet thick, occupying the east shore of Black bay, Nipigon strait, St. Ignace, Michipicoten island, Gargantua, Mamainse, etc. (3) The Sault Ste. Marie sandstone, which may be only the upper part of 2 without any intermingling of volcanic material. The whole together is Lower Cambrian, there being no evidence whatever of their holding any other place in the geological series. The first of these groups is the Animikie series while the second is the Keweenian.

SELWYN,[31] in 1885, places the crowning overflow of McKays mountain, Thunder cape and Pie island, etc., as a part of the Animikie. There was found no evidence of unconformity from the base of the Animikie to the top of the Keweenian as developed on Thunder cape and the surrounding region.

LAWSON,[32] in 1886, gives a report on the geology of the lake of the Woods region, with special reference to the Keewatin (Huronian?) belt of the Archean rocks.

Comprising a large part of the lake of the Woods is a series of crystalline and semi-crystalline schists to which the term Keewatin is applied. The term Huronian is not used, because it is very doubtful if the series belongs to this period. The rocks are found to differ fundamentally in lithological character from Logan's Original Huronian.

In the Keewatin, quartzites are unimportant; there are no true basal conglomerates; and the fragmentals of the lake of the Woods are of volcanic origin. No bedded limestones were observed. Structurally, also, the two series are fundamentally different. The lake of the Woods schists are folded with the associated granite gneisses, which are referred to the Laurentian, while the Huronian series has not partaken of the folding to which the adjacent gneisses have been subject. Further, the large areas of granite are found to be intrusive in both the Laurentian gneiss and Keewatin schists, while in the Huronian of Logan such intrusions, if present at all, are mentioned at only one locality. The slate conglomerate of Doré river appears to resemble the lake of the Woods agglomerates, but this area is distant from the typical Huronian region and appears to differ from it lithologically, as well as being in a nearly vertical attitude. These differences between the Doré and Huron areas, with their geographical separation, may warrant the belief that possibly Logan embraced under one designation two distinct series. As to Prof. Irving's position that the Animikie series is probably the equivalent of the Huronian, it is considered exceedingly probable that the flat-lying unfolded Animikie is much later than the lake of the Woods schists.

The rocks of the region, including both the Laurentian and Keewatin, comprise gneiss, granite, felsite, schistose hornblende rocks, diabase, diorite, serpentine, coarse clastic rocks and agglomerates, mica-schists, slates, quartzites, clay-slates, felsitic schists, hydromica and chlorite-schists, carbonaceous schists and limestones. The massive granites sometimes grade into foliated gneisses. Dikes of granite have sometimes foliated structures parallel to their sides. The agglomerates are not ordinary clastics, but are of volcanic origin. Both paste and included fragments have evidently had a common origin and been laid down together, perhaps not even always under water. The fragments are usually more or less elongated or lens-shaped, due to pressure. The greatest planes in the fragments are parallel with the planes of schistosity, which are usually observably identical with those of bedding; at times the agglomerates merge into mica-schists on the one hand and into hornblende-schists on the other. The mica-schists, micaceous slates, clay-slates, and quartzites constitute a natural group of rocks intimately associated, both as regards their origin and their present relations in the field. They are all probably ordinary metamorphic clastics. The felsitic, sericitic and hydromicaceous schists are probably sediments, the material of which was probably volcanic. The mica-schists quite frequently pass into finely laminated mica-gneisses. The limestones are found only in small masses and seem to be vein stones rather than bedded strata.

The Keewatin schists and Laurentian granitoid gneisses are found oftentimes to be apparently interbedded. At other times the junction is of the most irregular sort, tongues of schists running into the granite, or masses of it being contained in the granite and gneiss. The gneiss acts in many places as though it had been in a fluid state intruding the schists, and the conclusion is reached that the junction, instead of being that of interlaminated sediments, is that of a set of schistose rocks which have been intruded by fluid ones, the fluid material often placing itself along the parting of the schist, at other times cutting across it or including fragments of it. If this conclusion is true the supposed conformable junction of the two series at certain localities is no proof of true conformity, because the foliation of the granitoid gneisses, if these rocks were once viscid or plastic, is quite independent of any arrangement due to sedimentation that they may have possessed. This conclusion does not imply that the gneisses and schists may not have been originally sedimentary and conformable. However, the author inclines to the belief that the granitoid gneisses of the Laurentian were never aqueous sediments.

The granitic intrusions of the lake of the Woods are grouped into ten main centers. The granite cuts both the granitoid gneiss (Laurentian) and the various rocks of the Keewatin series, and is therefore of later age than either. A granite, the intrusive character of which is undoubted, sometimes merges in the same rock mass into a granitoid gneiss. There is a marked association of felsites or micrograuites with the main granite mass, there being an apparent tendency on the part of the former to an arrangement concentric with the periphery of the granite. Upon various sections a certain periodic arrangement of the Keewatin is made out, upon which as a basis it is found that the maximum thickness of the series is in the neighborhood of 20,000 feet. As to the general stratigraphical relations of the Keewatin, the conclusion is reached that they have been laid down and folded within a trough in the Laurentian formation.

HERRICK, TIGHT, and JONES,[33] in 1886, find on the north shore of lake Superior three distinct groups of rocks with their respective intrusives, granitic, schistose, and conglomeratic. The granites are found underlying the schists in such a way as to suggest that they have been intruded beneath them, although similar granites constitute the pebbles of the basement conglomerates in the schists. The schists are metamorphosed at contacts with the granites; the schists and schist-conglomerates especially, in several places, have been altered to porphyry and felsite-porphyry by contact with the eruptives. The third group consists of basement conglomerates, consisting of fragments of all the varieties of rock included in the other two series. Periodic overflows of igneous matter have left vast sheets of diabase, and there is a strong interaction between the sedimentary and eruptive rocks.

MCKELLAR,[34] in 1888, describes the Animikie on the north shore of lake Superior as always resting unconformably upon the crystalline and schistose rocks to which the term Huronian is applied, the contacts being found at many points. In lithological characteristics these two series are fundamentally different. The original Huronian and the schists underlying the Animikie are compared, and it is concluded that they are the equivalent of these rocks rather than of the Animikie series; therefore the latter is later than the Huronian. The contacts of the Animikie and Keweenawan formations show that there is an unconformity by erosion between the two.

LAWSON,[35] in 1888, reports on the geology of the Rainy lake region. The pre-Cambrian rocks are divided into an upper and lower Archean, as at the lake of the Woods. The upper is a bedded schistose and metamorphic series, while the lower is granitic, gneissic or syenitic in character. In the upper division two groups are recognized, one the Keewatin of the lake of the Woods, and the other, inferior in position, is given the name Coutchiching. In the lower division distinctions of stratigraphical sequence and relationship, if any such ever existed, have been obliterated, and for this the term Laurentian is retained. These rocks can be classified only on a petrographical basis. The contacts of the Keewatin with the Coutchiching and Laurentian are very frequent. The relations between the Keewatin and Laurentian are exactly like those described as maintaining upon the lake of the Woods. The schists are intruded by the granite, fragments of the former being included in the latter, and they are sometimes fused at the contact. Very frequently near the point of junction the Keewatin rocks become more crystalline and are glistening hornblende-schists.

At two localities basal conglomerates are found between the Keewatin and Coutchiching. At the first of these, Rat-root bay, Keewatin conglomerate rests upon Coutchiching schists, the conglomerates containing water-worn fragments of quartz and bowlders of granite. The second is at Grassy lake, where there is a pebbly conglomerate at the base of the Keewatin. The contacts of the Keewatin and Coutchiching are usually in apparent conformity, and the mapping of the series is made to rest upon lithological characters rather than upon structural discordance, although it is recognized that the conglomerates at the two localities mentioned are indicative of erosion, at least in some places, between the two series. The apparent accordance affords little evidence as to the question of original conformity or unconformity, because the two formations have been squeezed together; but the marked contrast in lithological characters indicates an abrupt change in the conditions of formation.

The thickness of the Keewatin rocks is calculated to be about five miles. The rocks are found in the main to be of clastic origin, but probably in the nature of volcanic débris rather than water-deposited sediments, although a small quantity of the materials is of the latter character. The volcanic débris of the Keewatin has a basic and an acid division, the latter being higher in the series than the former. Microscopical study leads to the conclusion that the series has been subjected to great pressure, as is evidenced by the fracture of the grains as well as by the schistose structure. The granite bowlders found in the conglomerates may either be ordinary detritus or may have been brought up from beneath by volcanic forces, although the former is the more probable. All of the granites of the region appear to be in some degree later than the Keewatin rocks, but this does not imply that there was not a granite shore for the basin in which the Keewatin rocks were deposited. The author has no doubt that the original floor upon which the Keewatin and Coutchiching rocks were deposited was fused at the time of disturbance and appears now to us as the foliated granite of the Laurentian. The granite bowlders of the Keewatin agglomerates may have been derived from a granite basement now obliterated by subsequent plutonic fusion.

The Coutchiching series consists of mica-schists, or mica-schists in which feldspar is present. Hornblende has been observed only in one instance. No limestones or conglomerates have been discovered. The schistose structure is believed to represent original sedimentation. Calculating the thickness upon this basis, it is found that the formation has an average thickness of 4 or 5 miles. The relations of the Coutchiching series to the Laurentian are found to be precisely the same as between the Keewatin and Laurentian. In the Coutchiching series there are no intercalations of recognizable volcanic rocks such as are found in the Keewatin, the rocks being acid crystalline schists which are regarded as ordinary metamorphosed quartzose sediments, with perhaps also volcanic material, although in no place has it been possible conclusively to prove this.

The Laurentian gneiss is intermixed with granite in such a way as to make it impossible at times to separate them. Its structure, if it has any, is so complex that no attempt was made to work it out, and, while parts of the granite seem to belong to the Laurentian proper, it is certain that granitic eruptions have occurred in this series after the main mass of the rock had solidified. The belts of Keewatin rocks which encircle the Laurentian areas are anastomosing or confluent, forming a continuous retiform area, the meshes being occupied by the Laurentian gneiss. At their nodes or points of confluence, these belts have their greatest width. The Coutchiching schists dip away from the Laurentian bosses in all directions, so that the general anticlinal structure of the belt is made up of three anticlinal domes. These relations are taken to mean that the surrounding schistose rocks represent sedimentary beds which have been thrust aside by the entering granite. Along the contacts of the Laurentian and Coutchiching are found such minerals as andalusite, staurolite, and garnet. Besides the granite masses, which cut all three of the previous series and thus are later than all, are also numerous diabase and trap dikes, which cut the series mentioned and the granite besides.

INGALL,[36] in 1888, in describing the mines and mining of lake Superior, finds the rocks to consist of Laurentian gneisses and granite, within which are found considerable areas of plutonic and volcanic rocks and metamorphic slates, considered to be Huronian, while overlying these, chiefly about Thunder bay and lake Nipigon, are the sedimentary and volcanic rocks of the Animikie, Nipigon, and Keweenian groups, which are in approximately a horizontal position and contrast markedly with the steeply inclined or almost vertical older rocks. The Animikie formation is divisible into an upper and lower portion. The chief character of the lower division is the preponderance of siliceous rock, such as chert and jasper, which are often accompanied by ferruginous dolomite with magnetite; while the upper division is formed for the most part of black, soft argillaceous argillites, which are occasionally dolomitic and ferruginous, and sometimes contain silica in such proportion as to approach the character of the lower division. The thickness of the Animikie is placed at 12,000 feet. The traps of the Animikie are concluded to be intrusive, frequently breaking as they do across the beds. In one case a sheet is seen to divide into three tongues. The dark color of the upper division of the Animikie is due to the presence of carbon. Patches of basal conglomerates are occasionally found at the base of the Animikie, lying in hollows in the old Archean sea bottom, the fragments consisting in general of granitic material.

SELWYN,[37] in 1890, announces the discovery by Ingall of traces of a fossil in the Animikie rocks. A part of the impressions are pronounced by Matthew to be similar to Eophyton, while for others the names Taonichnites and Ctenichnites are proposed. A part of them are of similar origin with characteristic tracks of the Cambrian rocks of the St. John group of New Brunswick.

LAWSON,[38] in 1890, discusses the internal relations and taxonomy of the Archean of central Canada. The Keewatin and Coutchiching are again described and the characteristic contacts which they have with the Laurentian. To the upper division, the Keewatin and Coutchiching, since they are sedimentary rocks, the principles of stratigraphical geology apply, and to cover these two series is proposed the term Ontarian, of systemic value. The principles applicable to the lower division, the Laurentian, are those of eruptive geology, since these rocks are of igneous origin. In the Laurentian there are at least two generations of rocks which are distinguishable in the Hunter island district, but both are the result of the crystallization of a subcrustal magma.

BELL,[39] in 1890, gives the following as the chief Huronian areas about lake Superior, in Ontario. An important area lies around Michipicoten at the northeast angle of lake Superior, running for 60 miles west and 20 miles south of that point, and extending inland to Dog lake, a distance of 45 miles. Another large area stretches from the Pic river eastward or inland to Nottamasagami lake, and westward mingled with granites and greenstones, to Nipigon bay. Two extensive belts run eastward from lake Nipigon, one of which crosses Long lake. West of Thunder bay, and stretching to the international boundary line, there is a large area which gives off arms to the northeast and southwest; and several belts and compact and straggling areas occur between this and the lake of the Woods basin, one of which follows the course of the Seine river. The lake of the Woods area, which has been already alluded to, occupies the whole breadth of the northern division of that lake. An important belt starts between Rainy lake and lake of the Woods, and running northeastward has a breadth of 45 miles where it crosses the line of the Canadian Pacific railway. Minnietakie and Sturgeon lakes lie within this belt.

The Huronian is divided into a lower and upper division, although no horizon has been agreed upon at which to draw the line between the two even locally. There is no evidence whatever that the two divisions are unconformable or that the lower part of the upper division are basal conglomerates. Conglomerates are found indifferently throughout both lower and upper divisions.

The lower division includes the Keewatin of Lawson and its equivalents. It consists largely of a variety of crystalline schists, in which the prevailing color is dark green or gray. Among these may be enumerated micaceous, dioritic, chloritic, argillaceous, hornblendic, talcoid, felsitic, epidotic, siliceous, dolomitic, and plumbagenous. There are also crystalline diorites or diabases of various shades of gray and greenish gray (mostly dark), argillaceous and dioritic slate-conglomerates, granites and syenites, impure, banded, and schistose iron ores, dolomites and imperfect gneisses. Among the commoner of the rocks of this division are fine grained mica-schists and dark green dioritic or hornblendic schists. Two kinds of conglomerates are also abundant, one having an argillaceous matrix with rounded pebbles of syenite and granite of various kinds, and some of the other Huronian rocks, but very seldom of gneiss; the other with a dioritic matrix, and often with rounded pebbles also. But, in perhaps the majority of cases, what were formerly considered as pebbles are really concretions of a lenticular form, and differing but slightly from the matrix in color and composition. They are best seen on wetted surfaces of cross sections of the rock, where they appear as parallel elongated patches tapering to a point at each end. Both hematite and magnetic iron ores are common in these rocks. Gneiss is not common in the Huronian, and it differs from the ordinary Laurentian gneiss in being imperfect and slightly calcareous.

In the upper division of the Huronian probably the most abundant rock in Ontario is what may be called a graywacke, but which in the older reports was often styled a "slate conglomerate;" but it also includes clay-slates, argillites, felsites, quartzites, ordinary conglomerates, jasper conglomerates, breccias, dolomites, serpentine, etc. In some localities the nearly vertical bands of quartzite, having withstood denudation better than the other rocks, remain as conspicuous hills or ridges, and this circumstance has caused their relative volume in the series to be overrated by superficial observers. The materials forming the graywackes and the stratified quartzose diorites have been derived from volcanic sources. The igneous character of the Huronian is further shown by the large masses and areas of greenstone (diorites or diabases), granites, syenites, and other eruptive rocks which are so largely mingled with both the lower and upper portions of the Huronian system in all parts of their distribution, forming indeed one of its characteristic features. The crystalline greenstones occur either as compact areas, wide elongated masses, dikes, or thick interstratifying beds in nearly all the Huronian areas. In many cases the dioritic schists may have been originally massive, but assumed the cleaved structure by pressure when incorporated among stratified masses. The commonest position of the granite and syenite areas is within but toward the borders of the Huronian tracts; but they sometimes occur in the Laurentian country, in their immediate vicinity, or at a distance from them in the direction of the longer axis of the Huronian areas.

Unconformably above the Huronian is the Cambrian system, which comprises, in the ascending order, the Animikie, Nipigon, and Potsdam formations.

The Animikie formation, in ascending order, consists of arenaceous conglomerate, with pebbles of quartz, jasper, and slate, seen on the north shore of Thunder bay; of thinly bedded cherts, mostly of dark colors, with argillaceous and dolomitic beds; of black and dark argillites, and flaggy black shales, with sandstones and ferruginous dolomitic bands and arenaceous beds, often rich in magnetic iron, together with layers and intrusive masses of trap (diabase). The Animikie formation occupies a great triangular area north and west of lake Superior, the base of which is 60 miles in length and the arms 40 and 80 miles, respectively.

The Nipigon formation, resting with apparent unconformity upon the Animikie formation, is characterized by reddish marls, sandstones, and conglomerates, with a large proportion of variously colored trappean beds and masses, a considerable part of which is amygdaloidal. The Nipigon formation occupies a great area about Nipigon lake and considerable areas at the east end of lake Superior and on Michipicoten island.

On the east side of Hudson bay and on the islands off the coast volcanic and sedimentary rocks are largely developed, comprising conglomerates, sandstones, limestones, chert breccias, shales, quartzites, argillites, porphyries, crystalline traps, amygdaloids, tufas, etc. The upper part of these may correspond to the Nipigon and the lower to the Animikie.

The sandstones of Sault Ste. Marie, of the peninsula between Goulais and Batchawana bays, isle Parisienne, etc., seem to be of Potsdam age. These sandstones are mostly red, but, unlike the Nipigon formation, they appear to be free from local disturbance and lie almost flat. Although they resemble some of the sandstones of the Nipigon series at Mamainse in red color, they are believed to be newer and probably unconformable to them.

LAWSON,[40] in 1891, states that the granite of Saganaga lake is found with abundant and clearly observed evidences of eruption, breaking through the Keewatin rocks, including the upper Vermilion fragmental rocks of Ogishki lake with their associated slates and grits. It is concluded that the break between the upper and lower Vermilion, described by Van Hise, is within the Keewatin group, dividing it into an upper and lower series, and that this break is therefore below the Animikie. It is further said that the conglomerates of the upper Kaministiquia series come out close to the shores of Thunder bay and form the basement upon which the undisturbed Animikie rocks rest with strongly marked unconformity. The following succession for the region northwest of lake Superior is presented: Keweenawan or Nipigon group; unconformity; Animikie group (possibly Huronian); unconformity; upper Keewatin series, unconformity; lower Keewatin series; unconformity(?); Coutchiching group; eruptive unconformity; Laurentian system, the granites and gneisses of which cut both Keewatin and Coutchiching groups.

SMYTH (H. L.),[41] in 1891, describes the structural geology of Steep Rock lake, Ontario. The lake is roughly in the shape of a letter M, the top is to the north, and its arms conform to the strike of the rock series. The rocks are divisible into three principal groups. The lower consists of granites and gneisses, and is designated as the basement complex. Resting upon the basement complex is a series of rocks about 5,000 feet in thickness, composed of nine persistent formations, which together constitute the Steep Rock series. Lying across the edges of the Steep Rock series, at the southeastern part of the lake, is a later series of granites, porphyries, and hornblende rocks which pass upward into the schists of the Aticokan river and are designated the Aticokan series. The granites and gneisses of the basal complex are cut by various dikes, which are of three kinds, those which supplied pebbles to the conglomerate at the base of the Steep Rock series; those which traverse both the basement complex and the Steep Rock series but have been subjected to the folding; and, third, a single massive dike which is subsequent to the latest period of folding.

The formations of the Steep Rock series, in ascending order, are conglomerate, lower limestone, ferruginous horizon, interbedded crystalline traps, calcareous green schists, upper conglomerate, greenstones and greenstone-schists, agglomerate, and dark gray clay-slate. It is then a series of sediments and interbedded eruptives.

Along the whole course of the lake this series dips at very steep angles, ranging from 60° to 80° away from the basement rocks, upon which they hang as a time-worn fringe having no extension inland. The basal part of the Steep Rock series is a bed having a maximum thickness of nearly a hundred feet, presenting the various phases of a conglomerate, coarse and fine, and quartzite and quartz-schists with feldspar. The lowest member contains rounded and waterworn pebbles of quartz and greenstone, the largest being a foot in diameter. Near the junction of the Steep Rock series and basal complex both are sometimes very similar in composition, so that it is impossible to draw the lines between them by this criterion. There is an apparent transition from one rock into the other. The transition zone has a highly schistose structure in the regional direction, which crosses the course of contact and the bedding nearly at right angles and is traced from the transition zone into the undoubted granite into which it gradually dies out. This transition is explained as due to probable disintegration of the basement complex before the Steep Rock series was deposited, combined with subsequent powerful dynamic movements which have affected both series.

The Steep Rock series is folded into an eastern synclinal, a middle anticlinal, and a western synclinal, the latter being faulted. The axes of these folds have a high pitch to the southward, varying from 60° to nearly 90°. Throughout the whole area is a regional cleavage which has a nearly uniform direction transverse to all the members of the Steep Rock series and also the contact between this series and the basement complex. This has largely obliterated the original lamination of the sediments and is now the dominant structure. It is therefore the last force which has left its marks upon the rocks of the lake. Before this last force acted upon the rocks, the Steep Rock series had been folded into a southwestward dipping monoclinal which, under the action of the cleavage-producing force in a northeast and southwest direction, caused the present fluted outcrop of the formations of the Steep Rock series. That the basement complex itself yielded to this latter force is shown by the irregular outcrops of the dikes cutting it.

As a result of the study the following general conclusions are reached: The contact of the lowest horizon of the Steep Rock series with the basement complex is one of erosion. The complex at the time of the deposition of the Steep Rock series was made up of consolidated crystalline rocks, and there is no evidence whatever that it has since undergone fusion or recurred to the condition of a magma. The rocks of the Steep Rock series have been subjected at two periods, more or less distant from one another, to great orotechnic forces, which acted—the first in a northeast and southwest direction, and the second in a northwest and southeast direction. The latter force has imposed upon all the rocks of the region a northeast structure which has largely, but not entirely, obliterated preexisting lamination in the sediments and schists of the Steep Rock series. The two orotechnic actions have produced great developments of autoclastic schists, both in the granites and in the rocks of the Steep Rock series, the present structure of which was induced and determined in direction by the later force.

SECTION II. WORK OF THE EARLY UNITED STATES GEOLOGISTS AND ASSOCIATES.

SCHOOLCRAFT,[42] in 1821, in his Narrative Journal of Travels in the Northwest, makes various observations on the crystalline rocks. At Granite point is found a bluff of granite which is traversed by irregular veins of greenstone trap. The sandstone laps upon the granite and fits into its irregular indentations in a manner that shows it to have assumed that position subsequently to the upheaving of the granite. Its horizontality is preserved even to the immediate point of contact. All the rock along the south shore of Lake Superior is either red or gray variegated sandstone, which appears to be referable to one formation. On passing by the Porcupine mountains, the red sandstone is visible along the shore in a position nearly vertical, dipping under the lake toward the north. Red sandstone in a vertical position is found at the mouth of the Montreal river and for a few miles beyond it toward Chequamègon bay. On the St. Louis river, after passing red sandrock in a horizontal position, is found on the banks of the river a slate (argillite) in a vertical position traversed by greenstone and milky quartz. At the grand portage of the St. Louis the country is rough, consisting of slate in a vertical position. This continues for a long way and is succeeded by hornblende, which continues to the head of Grand rapids.

CATLIN,[43] in 1840, finds the red pipestone quarries of the coteau des Prairies to consist of a perfectly stratified rock in layers of light gray and rose or flesh colored quartz, the deposit being evidently sedimentary and of secondary age.

LOCKE,[44] in 1844, describes the rocks of Copper harbor as well as the whole of Keweenaw peninsula as decidedly metamorphic, showing every degree of change produced by igneous action, from unchanged sandstone to compact greenstone. The original stratification is generally more or less evident; some layers bear evidence of semifusion with a corresponding degree of induration, while others seem scarcely to have been altered.

CUNNINGHAM,[45] in 1845, SANDERS,[46] in 1845, CAMPBELL,[47] SANDERS,[48] GRAY,[49] in 1845, GRAY,[50] in 1846, give various detailed observations as to the mineral regions of lake Superior, but give little or nothing of structural interest.

ROGERS,[51] in 1846, describes the red sandstones and conglomerates of lake Superior as resting unconformably upon highly inclined slate rocks undoubtedly Primal, and the Potsdam sandstone of the New York survey at Chocolate and Carp rivers, and therefore of post-Paleozoic age.

OWEN,[52] in 1847, finds the horizontal sandstone to overlap the crystalline and metamorphic formations at the southern portion of the Chippewa land district near the falls of the streams flowing into the Mississippi. The region to the north is based upon crystalline, granitic, and other intrusive rocks. North of the summit levels of the Chippewa land district the peculiar formations of the lake Superior country commence. These are red sandstones, marls, and conglomerates, occasionally penetrated by intrusive ranges of hornblende, greenstone, trap, and amygdaloid similar in their general aspect to the contemporaneous ranges of igneous rocks which occur in the mining district of Michigan. Besides this trap formation, there is an entirely distinct trap system in immediate juxtaposition with which strata have been discovered which are as old as if not older than the Lingula beds of the Potsdam sandstone of New York.

LOCKE,[53] in 1847, speaks of the relation of the trap rock and sandstone at Presque isle, and submits a drawing of it.

WHITNEY,[54] in 1847, describes the wide band of trappean rocks commencing at the extremity of Keweenaw point as continuing its course uninterruptedly as far as the Montreal river. Its distance from the lake between Portage and Ontonagon is generally from 8 to 10 miles. The highest and most imposing cliffs are found north and east of Agogebic lake. Beyond Agogebic lake the trap range widens and forms several ridges, between which it is not impossible that there may be sandstone. The Porcupine mountains embrace a system of trappose rocks in three tolerably distinct ranges. All the country north of the northern edge of the trap range from the Ontonagon to the Montreal, with the exception of the trappose rocks of the Porcupine mountains, is covered by the red sandstone of lake Superior.

OWEN,[55] in 1847, gives many details of the formations of the interior of the Chippewa land district, and of the formation of lake Superior. In the first district are seen many varieties of granite, syenite, greenstones, hornblende-rock, gneiss, and mica-slate. Magnesian and magnetic slates are capped unconformably by pebbly sandstones for nearly a mile along Black river. The red sandstone of lake Superior on Raymonds creek is estimated by Randall to be 10,000 feet in thickness.

NORWOOD,[56] in 1847, describes various rocks on the St. Louis river in the district between Fond du Lac and the falls of St. Anthony, and from the mouth of the Montreal river to the headwaters of the Wisconsin river by way of lake Flambeau. On the St. Louis river a conglomerate is found to rest unconformably upon the lower slates, the junction of the slates and conglomerates being exposed.

ROGERS,[57] in 1848, remarks that the south shore of lake Superior is outlined by a series of east and west dikes.

WHITNEY,[58] in 1848, finds in the townships near the Anse fossiliferous limestone, which seems to be surrounded by and has been deposited on the lake Superior sandstone.

FOSTER,[59] in 1848, in passing from Copper harbor to L'Anse, finds that the trap, instead of being forced through the layer of sandstone, as on the northern slope of Keweenaw point, protrudes through a fissure in it, causing an anticlinal axis. A few miles farther south the sandstone is nearly horizontal, being in a series of gentle undulations. At L'Anse the sandstones overlie the talcose, argillaceous, and hornblendic slates unconformably, while 15 miles southeast of L'Anse the granites protrude through these schists.

Upon the Michigamme river were found in order beds of quartz and feldspar, hornblende, and specular oxide of iron, associated with talcose and argillaceous schists. On the left bank of the Michigamme (Sec. 1, T. 46 N., R. 30 W.) is a hill 170 feet high, which exposes a very large mass of nearly pure specular oxide of iron. About 40 feet from the escarpment is a metamorphic rock composed of rounded particles of quartz and feldspar with masses of ore intermingled like the pebbles of a conglomerate.

Iron ore and marble were observed along the Menominee, as well as various other kinds of rocks, including granite, hornblende-slate, talcose slate, etc. At Sandy portage, on the Menominee, is a class of plutonic rocks older than the traps of Keweenaw point, which were protruded among the slates and then denuded before the deposition of the sandstone; for the slates are intercalated among the igneous rocks with a vertical inclination, while the sandstone rests horizontally or nearly so upon them. This sandstone is regarded as the oldest of the Paleozoic rocks and is the equivalent of the sandstone on the northern slope of the upper peninsula. Resting upon this sandstone is a limestone which is sparingly fossiliferous.

JACKSON,[60] in 1849, describes the sandstone of Keweenaw point remote from the trap as horizontal or but slightly waving, while near the trap rock it is as high as 30°. The conglomerate is limited to the borders of the trap and is of the same age as the finer grained sandstone with which it alternates. At the line of junction of the trap rocks and sandstone the two are interfused, producing the metamorphic rock amygdaloid, which resembles the vesicular lavas of volcanoes, but has its cavities filled with a great variety of curious and interesting minerals. On isle Royale about one quarter of the area is sandstone and conglomerate and the remainder trap, which formed ridges extending the whole length of the island.

WHITNEY,[61] in 1849, describes the iron ore of the upper peninsula of Michigan as existing in the form of solid ridges and knobs interstratified with banded jasper, the whole evidently of igneous origin.

AGASSIZ,[62] in 1850, describes the outlines of the shore of lake Superior as largely due to six different sets of dikes of different mineralogical character, and each system running parallel to one of the main shores lines, although it would be a mistake to ascribe the form to any single geological event. Its position in the main is doubtless determined by a dislocation between the primitive range north and the sedimentary deposit south. The rocks of the north shore of lake Superior are extensively metamorphic. The new red sandstone passes into porphyries, into quartzite, granite and gneiss, the metamorphism being more or less perfect, so that the stratification is still sometimes preserved or passes gradually into absolutely massive rocks.

JACKSON,[63] DICKENSON, MCINTYRE, BARNES, LOCKE, FOSTER and WHITNEY, GIBBS, HILL, BURT, and HUBBARD, in 1850, report upon the mineral lands south of lake Superior in the state of Michigan.

JACKSON,[64] describes the red sandstones and conglomerates of Keweenaw point as existing there anterior to the elevation of the trap rocks, being derived from the deposition of fine sand and pebbles from preexisting Primary rocks, such as granite, gneiss, or mica-slate. Porphyry furnishes a large portion of the débris, but it is doubtful if this is not a semi-fused sandstone. There is no reason to believe that igneous agencies had anything to do with the origin of the pebbles of the conglomerate, for they are rounded by the action of water. From the circumstance that the conglomerate borders the trappean rocks it is supposed an ancient shore may have existed along that line. It is certain that the finer sandstone is more remote from the trap than the conglomerate is, and that it is less uplifted and inclined as it recedes from the trap band. Near the junction of the two rocks the strata dip 25° or 30°, while remote from it the sandstone is nearly horizontal. The mineral composition, association, and contents of the sandstone are identical with those of Nova Scotia, Connecticut, Massachusetts, and New Jersey, belonging to the new red sandstone series; and that the lake Superior belongs to this age has been confirmed by the discovery by C. F. Merion of a tract of limestone in the midst of the sandstone of Keweenaw point near the Anse. The limestone contains *Pentamerus oblongus*, and according to Whitney has a dip of 30°, while the overlying sandstone is horizontal and has been deposited around it. The sedimentary strata have undergone great change by the action of the trap rocks. Along the line of the junction a chemical combination of the materials of the sandstones and trap rocks took place, forming the vesicular trap called amygdaloid, while there has further resulted from this action a brecciated or trap tuff, consisting of broken pieces of amygdaloid and sandstone. At other times the sandstone is indurated into a flinty red rock resembling jasper. At the Copper falls mine is a case of what appears to be an *Orthocera* in the breccia of amygdaloids and altered limestones. May it not have been torn from a subjacent bed of Silurian limestone by the agency of the intruded trap rocks? At the coast off lac la Belle the sandstone in contact with trap has a dip to the south of 30°, while at point Isabelle the sandstone cliffs are nearly horizontal.

LOCKE[65] finds near L'Anse that the trappean rocks contain fragments of slate distributed through it and converted into a hornstone when in small pieces, like the eruptive granite of Pigwacket mountain, New Hampshire. At point No. 2, west of Presque isle, is a junction of red sandstone and syenite. The mass of syenite intersected by dikes of trap is under the sandstone and seems to have but slightly affected it.

FOSTER and WHITNEY[66] accompany their synopsis of their explorations by geological maps of the region between Portage lake and the Montreal river, Keweenaw point, isle Royale, and the region between Keweenaw bay and Chocolate river.

WHITNEY[67] finds the rocks in the district between Portage lake and the Ontonagon river to comprise the following: First, the red sandstone of lake Superior, the age of which can not be determined, as it is destitute of fossils. It lies directly upon the granitic rocks. Second, a bed of fossiliferous limestone of the Lower Silurian system, which occurs in an isolated position and has but a limited extent, and the relations of which to the sandstone have not been determined with certainty. Third, the trappean rocks. Fourth, granitic and syenitic rocks, with hornblende and greenstone. The farther the red sandstone is removed from the trappean rocks, so much nearer do its strata approach to the horizontal and also become lighter color and more fragile. The conglomerate of Keweenaw point occurs mixed and intercalated in such a manner with the sandstone as to leave no doubt of their common origin and identity of age. In general the beds of conglomerate increase in frequency in nearing the trap. The sandstone does not repose directly on the trap, but almost invariably a bed of coarse pebble rock is found interposed between. A trap breccia found at Cushman's seems to be a product of the interfusion of trap and sandstone. Compact quartz rock or jasper occurs abundantly in mountain masses in the Porcupine mountains.

Whitney describes a deposit of limestone which rises to a height of about 300 feet above the general level of the country near L'Anse.

The limestone is indistinctly stratified and dips from zero to 30° at various points. At certain places it contains numerous fossils, but the greater part of the rock seems to be destitute of them. Among the fossils are encrinites, orthoceratites, and others. The country around is low and swampy, but the indications are for nothing but sandstone horizontally stratified. As the limestone is apparently inclined at an angle of 30°, it seems evident that this is the oldest rock, though it can not be denied that the stratification of the limestone is very obscure and in some places it appears to lie nearly horizontal. On the data collected the author feels unwilling to pronounce which is the older formation.

FOSTER [68] finds at Copper harbor the junction of the trap and conglomerate. At the point of contact the trap is vesicular, but a few feet distant amygdaloidal. The conglomerate is made up of rounded pebbles of greenstone, porphyry, and rarely granite, cemented by a dark iron sand, with carbonate of lime among the interstices. Near the Quincy mine the conglomerate, or rather sandstone, containing quartz pebbles, forms the gorge of the stream below the falls, and differs essentially from that on the northern slope of Keweenaw point. Between the sandstone and compact trap is a bed of red slaty trap associated with amygdaloid. At L'Anse sandstone and conglomerate are found resting unconformably upon chlorite-slate, novaculite or siliceous slate. In the Chippewa land district is found granite, gneiss, hornblende, chlorite, argillaceous slates, and magnetic iron ore. In Sec. 1, T. 46 N., R. 30 W., is a bed of quartz composed of rounded grains, with small specks of iron disseminated, and large rounded masses of the same material inclosed, constituting a conglomerate. This bed is 15 feet in thickness and is succeeded again by a specular iron exposed in places to the width of 100 feet.

The author is disposed to place the sandstone of lake Superior at the base of the fossiliferous series. The unbedded traps of Keweenaw point and isle Royale have broken through this sandstone, forming continuous lines of elevation. In receding from the trap of Keweenaw point the inclination of the sandstone diminishes rapidly, and 5 or 6 miles away is nearly horizontal. In a fork of Torch river, on the Douglass Houghton mining company's land, the sandstone dips southerly, or away from the trap. On the north side of the stream it is seen resting on the trap in large blocks. On the south side of Keweenaw point, at Bête Grise bay, the sandstone is white and granular, destitute of pebbles, and dips southerly or away from the trap. In the bottom of the bay, when the water is calm, the bands of sandstone can be seen describing immense curves parallel to the direction of the Bohemian range of mountains, and affording conclusive evidence that their bearing and upheaval are due to the protrusion of the igneous rocks. On the east side of Sec. 14, T. 59 N., R. 29 W., the sandstone is nearly horizontal, although removed but a few miles from the trap.

BURT [69] finds on Keweenaw point and along the south shore of lake Superior to the mouth of Carp river and in the Porcupine mountains five principal groups of rocks: Primary, Slates, Trap, Conglomerate, and Sandstone. With the Primary rocks are placed syenite and granite. Flanking the Primary rocks is argillaceous slate; flanking the slates and resting upon them are red and variegated sandstones, and these also flank the Primary rocks. The Trap rocks have a much higher angle on the southeast than on the northwest side of the range, which runs from the northeast end of Keweenaw point and extends in a course generally to the southwest. The Conglomerate flanks the trap range on the northwest, and is made up of sand, pebbles, and small bowlders principally derived from the rocks of the trap family. Resting conformably upon the conglomerate rock are a series of alternating strata of sandstone and conglomerate.

HUBBARD [70] finds, in the district south of lake Superior, Primary and Metamorphic regions, consisting of granite rocks, between which are metamorphic rocks which graduate into clay-slate.

BURT [71] finds in the area bounded on the north by the Fifth Correction line and south by the Fourth Correction line and the Brulé river, between ranges 23 and 37, granite and syenite, talcose and argillaceous slates, greenstone and hornblende-slate, mica-slates, coarse sandstone, calciferous sand rock, encrinal limestone, red sandstone and red clay, and magnetic iron ore beds.

FOSTER and WHITNEY,[72] in 1850, give a systematic report on the geology and topography of the copperlands. On Keweenaw point these consist of trappean rocks associated with conglomerates and sandstones.

On this point are two trap ranges, the southern known as the Bohemian range. The conglomerates are volcanic friction rocks rather than the result of erosion. The pebbles may have received their rounded shape by being projected from fissures through water. The only instance in the district in which trap occurs remote from the lines of fissure is in the northeast corner of T. 49 N. R, 36 W., where Silver mountain rises as an isolated and dome-shaped mass to the height of 1,000 feet. The summit of the rock consists of labrador and hornblende, while the surrounding plain is covered with clay, resting on sandstone in a nearly horizontal position. The sandstones and interbedded traps of Keweenaw point and isle Royale dip in opposite directions and form a synclinal trough. Near L'Anse is a limited patch of limestone which has a dip to the eastward from 25° to 30°, the limestone being distinctly stratified. The sandstone about a quarter of a mile to the north is horizontal, and it seems evident that the limestone overlies the sandstone, although the position of the inclined beds of the more southerly portion of the limestone is difficult to explain, since the surrounding country is low and level and underlain by sandstone and horizontal beds. It seems evident that at this point the country has been disturbed and upheaved by igneous action beneath, which has raised the strata without any appearance of trappean rocks at the surface. This is indicated by the fact that at no great distance to the south an elevation occurs at which the strata of sandstone dip on all sides, although there is no igneous rock visible. From the fossils entombed in this limestone Hall concludes that the rocks may be regarded as the equivalent of any of the following: The Potsdam and Calciferous sandstones, the Chazy, Bird's-eye, and Black river limestones, perhaps of the Trenton or even Hudson river groups. In T. 47 N., R. 25 W., Michigan, is a conglomerate, the pebbles of which comprise granite, hornblende, slate, greenstone, and iron ore.

FOSTER and WHITNEY[73], in 1851, report on the iron region of lake Superior land district, and give and an account of its general geology. The older rocks are classified as follows:

Formations.	Igneous.	Of various ages.	Plutonic rocks.	Granite. Syenite. Feldspar and quartz rock.
			Trappean or volcanic rocks.	Greenstone, or dolerite, porphyry, basalt, amygdaloid, hornblende and serpentine rocks, masses of specular and magnetic oxide of iron.
	Metamorphic.	Azoic system...		Gneiss, mica and hornblende slate. Chlorite, talcose and argillaceous slate. Beds of quartz and saccharoidal marble.
	Aqueous.	Silurian system.		

The igneous rocks are found in all these sedimentary systems. The oldest igneous rocks, consisting of hornblende, feldspar, and serpentine rocks are contemporary with the Azoic system. The granites and syenites are intermediate in age between the Azoic and Silurian systems. These are traversed by two systems of greenstone dikes which are anterior to the purely sedimentary deposits. Contemporaneous with the lower portion of the Silurian system are the bedded traps and amygdaloids of Keweenaw point, isle Royale and the Ontonagon region, which are composed of nearly the same constituents as many of the older igneous rocks, although there is no difficulty from the diversity in external characters in drawing the line of demarcation between them.

Below all the fossiliferous groups of the region is a class of rocks consisting of crystalline schists, beds of quartz, and saccharoidal marble, which is denominated the Azoic system, a term first applied by Murchison and de Verneuil to designate the crystalline masses which preceded the Paleozoic strata. This term as here used is limited to rocks which are detrital in their origin and which have been formed before the dawn of organized existence. The general section shows the rocks of Keweenaw point to be the counterpart of those of isle Royale, except that the dip of the sedimentary rocks is reversed, thus rendering it highly probable that between these two points is a great curvature in the strata caused by the elevation along the line of two volcanic fissures. The sandstone on the southern slope of the axis, equivalent to the Potsdam, is seen dipping away from the crystalline trap at a high angle, but at a short distance from the line of igneous outburst it verges toward horizontality; and along the coast at the head of Keweenaw bay it is seen reposing unconformably on the slates of the Azoic system. From L'Anse to Chippewa island in the Menominee river, a direct distance of more than 80 miles, the country is occupied by rocks of the Azoic system, which include immense deposits of specular and magnetic oxide of iron, and are invaded at many points by igneous rocks, both granitic and trappean. At Chippewa island the Potsdam sandstone reposes upon the upturned edges of the slates.

The Azoic rocks have been so transformed by direct and transmitted heat as to exhibit few traces of their original character. Sandstone has been converted into massive quartz, limestone into saccharoidal marble, and shales into hard crystalline schists. These rocks are destitute of life, are a system of obscurely stratified rocks interposed between the Potsdam and the granite, and are unconformable to the former in dip. The Azoic series of the southern shore have not been capable of division into two groups as done by Logan on the north shore. The rocks are highly inclined and much contorted, and nowhere exhibit the characters of a purely sedimentary rock; but the evidences of metamorphism are more striking in approaching the lines of igneous outburst. Gneiss generally flanks the granite, succeeded by dark masses of hornblende, with numerous joints, but obscure lines of bedding, which often graduate into hornblende-slate or chlorite-slate in receding from the igneous products. The greenstones often form broad sheets, bearing the same relation to the slates that the trappean bands of Keweenaw point do to the conglomerates. Many of the slates appear to be composed of pulverulent greenstone, as though they might originally have been ejected as an ash and subsequently deposited as a sediment. They pass by imperceptible gradations from a highly fissile to a highly compact slate.

In Sec. 19, T. 49 N., R. 27 W., is found a talcose and chlorite slate, and quartzose rocks enveloping pebbles and displaying obscure lines of stratification. In Sec. 32, T. 48 N., R. 26 W., and near Jackson Company's forge are found quartzose conglomerates. On the line between Secs. 29 and 32, T. 47 N., R. 27 W., is a conglomerate forming an isolated rounded elevation, which is made up of coarse blocks of various sorts belonging to the neighboring trappean and slaty beds. Among them are found fragments of the rock associated with iron, and masses of the iron itself, and of the banded and jaspery varieties. Most of the fragments of the breccia are but slightly rounded and worn on their edges, having in this respect the appearance of a friction conglomerate. The blocks are cemented together by a hard ferruginous paste.

The granites belong to two different epochs: That of the northwestern coast and the vicinity of Pigeon river was elevated before the Azoic period, since the upper portion of the slates repose horizontally around it; while that of the northeastern coast, and that which forms the axis of the river systems of the two lakes, was elevated after the termination of the Azoic period and before the dawn of the Silurian, since the granite has disturbed the upper beds of slate, while the lower beds of the Potsdam rest undisturbed around it.

The masses of iron ore and jasper have none of the characteristics of vein deposits. They are intercalated among the metamorphosed sedimentaries and have an intimate association with the trappean, porphyritic, and serpentine rocks. If the trappean rocks were an invariable accompaniment, the ores would with little hesitancy all be assigned to a purely eruptive origin; but when they are found in the form of beds, in clearly metamorphic strata, having a common bearing and inclination, they are regarded as having been derived from the destruction of previously formed igneous masses, and their present association as having resulted from aqueous deposition. The Azoic period having been one of long continued and violent mechanical action, there is no reason to doubt that many of the strata of which it is composed may have been derived from the ruins of previously formed rocks of the same age, both sedimentary and igneous, as is shown by the case of the knob of conglomerate already mentioned. The minute banding of the ore and jasper can hardly be explained by any other than the action of segregating forces in an igneous rock. The authors are then disposed to regard the specular and magnetic oxide of iron as a purely igneous product, in some instances poured out, in others sublimed, from the interior of the earth. Where the ores are in a state of purity, in the form of irregular masses in preexisting depressions, or where the incumbent strata are metamorphosed or traversed by the dikes of ferruginous matter, they are without doubt eruptive. Where impregnating metamorphic products, such as jasper, hornstone, or chert, quartz, chlorite, and talc slate, not only between the laminæ but intimately incorporated with the mass, giving it a banded structure, they are regarded as the results of sublimation. The supposition that the ore may be a secondary product resulting from the decomposition of a pyrite, or the metamorphism of bog iron, is inadequate to account for the accumulation of such mountain masses and to explain the relations to the associated rocks.

The bed of lake Superior, embracing an area of about 32,000 square miles, is occupied almost exclusively by the Potsdam sandstone. The sandstone in the vicinity of the trappean rocks attains the enormous thickness of 5,000 feet, and often consists of conglomerates composed of trappean pebbles, and away from these lines of disturbance, where it abuts against the Azoic rocks, it is a purely siliceous sand. At Granite point masses of granite are overlain by horizontal sandstones. The granites are cut by dikes of greenstone, which in no case penetrate the overlying rock. The same phenomena are seen at Presque isle, at Middle island below Presque isle, and at Carp river. On the Menominee river, near the foot of Chippewa island, layers of sandstone are found on the upturned edges of the Azoic slates.

Whitney does not find the *Pentamerus oblongus* referred to by Jackson, nor any other form characteristic of the Niagara formation; but, on the other hand, they are pronounced as belonging to Lower Silurian types.

FOSTER and WHITNEY,[74] in 1851, repeat the general conclusions contained in their report on the iron region, and remark that the Azoic system is characterized by such immense deposits of specular and magnetic oxide of iron that it might with propriety be denominated the Iron Age of geology, while the Silurian epoch with equal propriety might be designated the Copper Age.

FOSTER and WHITNEY,[75] in 1851, farther speak of the age of the lake Superior sandstone. The sandstone of the St. Marys river is traced to the south shore of Keweenaw point and is found to increase in thickness gradually, until in the vicinity of the trappean rocks it becomes of great thickness, accompanied by wide belts of conglomerate. The conglomerates of Keweenaw point are the result of igneous rather than aqueous forces, being caused by friction and mechanical volcanic action along the line of fissure. The mural faces of the trappean ranges are almost without exception turned toward the south, and the sandstone on that side is elevated at a high angle, sometimes dipping almost vertical at the junction of the two formations, but in proceeding southward becoming almost immediately horizontal. The appearance is as if the strata had been broken and elevated just as the southern edge of the igneous mass. Where the sandstones and traps are interlaminated it is difficult to determine the junction when the sandstone lies upon the trap, but when below it the line of separation is sharp. As further showing that the sandstone is Lower Silurian, a small deposit of Lower Silurian limestone resting upon the sandstone effectually completes the chain of evidence.

OWEN,[76] in 1851, mentions various metamorphic slates, quartzites, and other crystalline and trappean rocks as occurring on the south shore of lake Superior. On the north shore, in Minnesota, between Fond du Lac and the British possessions there is a repetition in inverse order of the same formations, forming a synclinal trough with the red sandstone nearest the lake, while the slates, conglomerates, and associated traps are crossed in succession in proceeding into the interior, and these are followed by the metamorphic slates and granitic rocks.

OWEN,[77] in 1852, discusses the age of the red sandstones of lake Superior. The test of lithological character, if alone applied, is in favor of the view that they are of the same age as the red sandstones of New Jersey and Nova Scotia. On the St. Croix river, in Wisconsin, the white and buff quartzose sandstones belonging to the lowest Protozoic formation are succeeded by red sandstones similar to those of lake Superior, and, like them, associated with coarse red conglomerates and trap. The same phenomena are seen at other points south of lake Superior. It is, however, conceivable, as a result of the upthrust of igneous rocks, which sometimes break through the fossiliferous strata, entangling and partially indurating the fragments without altering or tilting the adjacent beds, that tilted red sandstones dipping to the south really may never rest conformably under the white and buff sandstones, but merely abut against them and not in fact overlie them at all; but the natural and reasonable inference is that the white and buff sandstones do actually rest conformably upon the red sandstones in question.

NORWOOD,[78] in 1852, gives a great number of details as to the geology of middle and western Minnesota and the country adjacent to the southwest shore of lake Superior, illustrating the relations of the shales, trap rocks, granites, etc., and showing the manner of intrusion of the eruptives and the complicated folding to which the strata have been subjected. At the St. Louis and Black rivers the sandstone rests unconformably upon the underlying argillaceous and siliceous slates.

WHITTLESEY,[79] in 1852, gives geological descriptions of part of Wisconsin south of lake Superior. Passing from the lake southerly four great classes of rocks are seen in each section: (1) Sedimentary, including red sandstone, black slate, conglomerate. (2) Trappose rocks, or those of volcanic origin, including amygdaloid, greenstone, augitic, hornblendic, and feldspathic rocks, embracing syenites and granites of the same age. (3) Metamorphosed rocks, including hornblende slates, iron slates, black slates, talcose slates, slaty quartz. (4) Granitic, including syenite and granite. The granites and syenites of the interior are the most ancient rocks of the district. After the protrusion of these granitic masses many changes have occurred. The sandstone deposits of lake Superior must have been subsequent to the granites of the Wisconsin, Chippewa, and Montreal rivers; since that period has been one of long and intense igneous action in which the trap, hornblendic, and greenstone masses have been ejected, and also with them protrusions of recent granites and syenite. The metamorphic slates have been elevated during these convulsions, and the sedimentary rocks thrust away to the northward and tilted up at high angles. The old granites and syenites have been rent with fluid matter, such as quartz and hornblende. The northern part of the Penokee range shows evidence of four formations of trappose rocks, which fill a geological epoch of no great duration between the area of the red sandstone deposits and the metamorphic uplifts. There are cases where the trap, instead of being forced across the stratification, has spread out between the beds, forming alternate strata of trap and sandstone without any visible conglomerate.

SHUMARD,[80] in 1852, mentions the quartzite ranges of Sauk county, near Baraboo. The quartzites are surmounted by sandstone, and all are included in the great sandstone formation of southern Wisconsin.

JACKSON,[81] in 1853, maintains that the red and gray sandstones of lake Superior are above the rocks of Devonian age. They rest horizontally around Silurian limestone, which has an inclination on Sturgeon river near Keweenaw point of 30°. In point of fact the sandstones of lake Superior are the exact equivalents of those of Nova Scotia, where trap rocks of the same age as those of lake Superior pass through them. The amygdaloidal trap of Keweenaw point and isle Royale is a vesicular rock formed by the interfusion of sandstone and trap rock.

MARCOU,[82] in 1853, after having made a complete tour of lake Superior, places the red sandstone and traps bearing copper as the new red sandstone, and correlates it with the new red sandstones of Nova Scotia, New Brunswick, Connecticut, New Jersey, Maryland, and Virginia.

WHITNEY,[83] in 1854, states that the basin of lake Superior is a great synclinal trough caused by a depression of the sandstone, which appears to form its bed. The northern and eastern shores for much of their distances are faced by perpendicular cliffs, while the southern shore is comparatively low. The reason for this difference is that on the east and north the sandstone which originally existed there has been worn away and the more enduring granitic and trappean rocks only are left. The age and relations of the sandstones of lake Superior to the trappean rocks and Azoic slates are again described as before.

SCHOOLCRAFT,[84] in 1855, states that the granitic strata of the Thousand isles reappear on the north shore of lakes Huron and Superior, underlie the bed of the latter, and are found on the rough coast between Chocolate river and Keweenaw, and cross the Mississippi near the falls of St. Anthony. The straits of St. Mary's appears to be the ancient line of junction between the great calcareous and granitic series of rocks on the continent. The island of St. Joseph is chiefly primitive rocks and at its south end is largely loaded with granitic, porphyritic and quartzitic bowlders. The north shore of the river, opposite the island, is entirely of the granitic series, which continues to Gros cap on lake Superior. The red sandrock of lake Superior is regarded as the Old Red sandstone. The formation of red jasper in white quartz exists on the southern foot of Sugar island. In the granitic conglomerates are seen red feldspathic granite, black shining hornblende rock, white fatty quartz, and striped jasper, all held together firmly. Volcanic action appears to have thrown up the trap rocks of the Pic, of the Porcupine chain, of isle Royale, and the long peninsula of Keweenaw. The sandstone of the southern coast exhibits undulations of 8° or 10° at several places. Two instances of this are the point des Grands Sables, beginning with the horizontal strata of the Pictured rocks, and the second is at Grand island.

WHITNEY,[85] in 1856, describes the northeastern side of lake Superior, from Gros cap to Nipigon bay, as consisting of rocks of the Azoic system. On the south shore of the lake, and along the northwest shore as far as the northeastern extremity of Nipigon bay, are found the shales, sandstones, conglomerates, and trappean rocks of the Potsdam system, except at Thunder bay and Carp river, where the Azoic appears. The south side of the Azoic on the north side of the lake runs from Kakabikka falls on the Kaministiquia in an almost straight line southwest, keeping a few miles from the lake. Thunder cape consists of thinly bedded slates for 800 feet of its thickness, above which is a sheet of trappean rock 200 or 300 feet thick.

WHITNEY,[86] in 1856, maintains that the iron ores of lake Superior, Scandinavia, Missouri, and northern New York, form a class by themselves belonging to the Azoic age, and they have been poured out like other igneous rocks from the interior in a molten or plastic state. Besides the purest ores are others interlaminated with bands of quartz which are distinctly bedded and probably are of sedimentary origin. The iron ore in these may have been introduced either by sublimation during the deposition of the siliceous particles, or by precipitation from a ferriferous solution at the time of formation of the stratified rocks.

WHITNEY,[87] in 1857, again maintains the Potsdam age of the sandstones of the Cupriferous series. Underlying this series unconformably on the south shore is the Azoic series, which is identical in character with the rocks of Thunder and Black bays. The rocks on the north shore of lake Huron and in the north and east of Canada are identical in position and lithological character with the Azoic system.

JACKSON,[88] in 1860, again asserts that the red sandstones of Keweenaw point are certainly coeval with the sandstone of Nova Scotia, Connecticut river, and New Jersey, as proved by identity of composition, mode of disruption, character of associated minerals, and above all, by the fact that they rest upon Devonian limestones. *Orthoceratite* at Copper Falls mine and *Pentamerus* in the underlying limestone of Sturgeon river show that the sandstones are not Potsdam. This is also shown by the occurrence of pitchstone porphyry upon isle Royale such as are found in the isle of Arran of Triassic or Devonian age. The author is not disposed to place the sandstones of the Pictured rocks in the same formation with Keweenaw point and isle Royale.

ROGERS,[89] in 1860, maintains that the argillaceous shales and conglomerates of a part of the southern shore of lake Superior are the equivalent of the Primal series. The Cupriferous series is in direct association with the Potsdam, and therefore the argument for Triassic age on account of texture and color is entirely valueless.

WILLIAMS and BLANDY,[90] in 1862, describe the trap ranges of Portage lake as being about 3 miles wide and consisting of amygdaloidal trap, occasionally intercalated with sandstones and conglomerates. The dips vary from 60° to 75°, becoming nearer horizontal toward the northwest, until finally the sandstone which succeeds it becomes absolutely so.

KIMBALL,[91] in 1865, divides the rocks of the Marquette region into two formations, Laurentian and Huronian; the former including the granite ridges, while the latter nearly agrees with Foster and Whitney's limits for the Azoic. The crystalline rocks south of Keweenaw point are pre-Paleozoic, while the greenstones of that point are intercalated conformably with the Paleozoic. The specular iron ore and beds of specular conglomerate are heavy bedded strata and schists in which none of the phenomena of aqueous deposits are wanting. They exhibit not only stratification, but anticlinal and synclinal folds. From a stratigraphical point of view the Huronian greenstones, schists, and iron ores of Marquette exhibit characters which render quite untenable the theory of the exotic character of any portion of them.

AGASSIZ,[92] in 1867, finds at two ravines near Torch lake—one the Douglass Houghton—that the sandstone rests unconformably upon the trap. The trap dips N. 42°, while the sandstone, 100 feet distant, lies nearly horizontal, with no trace of an anticlinal axis between. The sandstone contains water-worn fragments of the trap. The sandstone north of the range is conformable with the trap, but the sandstone south is plainly of a different age.

WHITTLESEY,[93] in 1876, finds nowhere on the American side of the boundary, except at Vermilion lake, rocks which are like the Laurentian of Canada. The great masses of granite and syenite around which the Huronian is formed do not resemble the Laurentian of the Canadian geologists. Between the Canadian and American Huronian there is a very close resemblance. The conclusion of Foster and Whitney that the traps of lake Superior are of Potsdam age is adopted. The Bohemian range resembles more nearly the Huronian than it does the trap series. In this range are bands of friction conglomerates with the evidences of metamorphic sandstone passing into jasper, vesicular trap, and breccia. A friction conglomerate also occurs at Aminicon, Douglas county, Wisconsin.

WADSWORTH,[94] in 1880, gives notes on the geology of the iron and copper districts of lake Superior. The contacts of the jasper and ore, which are interlaminated and have a common origin with the associated schists, are described, and at numerous points the contacts are found to be those of eruptive and sedimentary. The schistose structure is regular, while the jasper and ore is exceedingly contorted, breaks across the schistose and other rocks, and contains fragments of the schists. Not the slightest sign of plasticity or intrusion of the schists relative to the ore and jasper was seen. The present lamination of the schists existed prior to the intrusion of the ore. At the School-house, New York, and Jackson mines the overlying rock contains débris of the underlying ore and jasper. The diorites, felsites, and diabases are intrusive rocks. The soft hematites differ only from the hard ore and jasper in that they have been leached by thermal waters and changed to their soft condition. The granite is found at numerous points to cut the schists and gneisses. At several places, also, it cuts a quartzite, one of which resembles the ordinary Huronian quartzite. The crystalline rocks of Presque isle are peridotite and serpentine which has resulted from the alteration of the peridotite.

The only evidence that the Huronian unconformably overlies the Laurentian is the fact that the foliation of the latter does not conform in its dip to that of the former. However, no point was found in which it was possible to trace the rock continuously from well marked and mapped Laurentian into the Huronian. The general structure of the iron region seems to be as follows: The schists and sandstones were laid down in the usual way; were then disturbed by the eruption of the jasper and ore. Much of the original rock still remained horizontal, and new sedimentary deposits continued to be formed out of the jasper and other rocks. Next came the eruption of the diorite, which completed most of the local folding and tilting of the strata. Finally the granite eruption took place on both sides of the Huronian, uplifting and contorting the strata near it, and perhaps laterally compressing the inclosed iron-bearing rocks.

The conclusion reached by Foster, Whitney, and Marvine that the traps and lava flows and were successively laid down one upon the other, are covered by sandstones and conglomerates, is agreed with. The sandstones and conglomerates when overlain by traps are usually baked and indurated. At the Douglass Houghton ravine and Hungarian river the eastern sandstone, which has been maintained to rest against the trap and sandstone series unconformably, is found interlaminated with the melaphyres, and therefore settles the long-disputed question of the relative age of the traps and Eastern sandstone of lake Superior. The last melaphyre sheet which underlies the sandstone has a dip to the northwest of 20°. As the Douglass Houghton ravine is followed downward the dip gradually declines in steepness, although still to the northwest, the last dip measured being 5°. The junction between the Eastern sandstone and the trap, described by Agassiz and Pumpelly, is not the junction at all, it being some distance below instead of at the falls. In the Torch lake sandstone quarry the sandstone layers, instead of being horizontal as they have been regarded, have a dip of 15°, the former supposed bedding being due to joints. As the Eastern sandstone conformably underlies the traps, the Eastern and Western sandstones and the traps lying between them are of the same geological age.

WADSWORTH,[95] in 1884, as a result of an examination of a supposed fossil from the copper-bearing rocks of lake Superior, described by Hall as being very like the Huronia or siphuncles of Orthoceratites, finds it to be of inorganic origin, having probably been formed by the flowing of a pasty lava in such a manner as to raise a series of ridges, giving an appearance closely like that of some cephalapods. The interior of the specimen is in all respects that of an ordinary volcanic rock.

SECTION III. WORK OF THE MICHIGAN GEOLOGISTS AND ASSOCIATES.

HOUGHTON,[96] in 1840, divides the rocks in the south and southeastern part of the Upper Peninsula into primary and sedimentary. The primary region stretches continuously in a northwestward direction for many hundreds of miles, skirting portions of the shores of lake Superior, and constituting the highlands between that lake and the lake of the Woods. From these highlands it stretches a little east of lake Winnipeg, far to the northwest, finally constituting the immense "barren grounds" of the British Possessions. The rocks of St. Marys river and adjacent region comprise greenstone, argillite, and granular quartz rock, which passes into an almost conglomeratic quartz rock. In this occur small quantities of hematitic iron ore. The sedimentary rocks include the lake Superior sandstone and lime rock and shales. The lake Superior sandstone is nearly continuous on the southern shore of lake Superior, and in its easterly prolongation rests against and upon the primary range of St. Marys river, where it passes conformably below the limestone above. The lake Superior sandstone, in its easterly prolongation, does not attain a very great thickness, but in proceeding westerly this thickness is vastly increased, attaining on the south shore of lake Superior to several hundred feet. A careful search for fossils in this sandstone has failed to reveal a single one.

HOUGHTON,[97] in 1841, divides the older rocks of the upper peninsula of Michigan into (1) Primary, (2) Trap, (3) Metamorphic, (4) Conglomerate, (5) Mixed conglomerate and sandstone, (6) Lower or red sandstones and shales, (7) Upper or gray sandstone. The Primary rocks are in a broad sense granite. The granitic rocks are largely traversed by greenstone dikes. The trap rocks of the district in a chronological order would follow the metamorphic slates and quartz rocks, but the granitic rocks pass by almost insensible gradation into the greenstones of the trap formation.

The sedimentary rocks on the south and southeast of the main trap range are scarcely disturbed, while those on the north and northwesterly sides are invariably tilted to a high angle near the range of hills. The sedimentary rocks on the north are traversed by frequent dikes, varying in thickness from 50 to 400 or 500 feet. The rocks on this northwestern escarpment were in an intense state of ignition while in contact with the sedimentary rocks, as shown by the great changes which these rocks have undergone. The author is disposed to regard the amygdaloid as due to the fusion of the lower portions of the sedimentary rocks.

At Presque isle is a little isolated knob of trap which has been uplifted, as is shown by the way in which the stratification of the adjacent sedimentary rocks has been disturbed. They invariably dip at a high angle in all directions from the trap. At the immediate line of junction the character of both rocks is lost, and the sedimentary rocks for a distance of several hundred feet have been shattered while retaining their original position, and were again cemented by an injection of calcareous matter.

The area of country occupied by the metamorphic group is less than by the Primary or Trap. The group is made up of an alternating series of talcose and mica-slates, graduating into clay-slates, with quartz and serpentine rocks, the quartz rocks being by far the most abundant. The metamorphic rocks are occasionally traversed by trap dikes.

The conglomerate rock, the lowest of the sedimentary rocks, is invariably connected with or rests upon the trap rock. It is very variable in thickness and is without doubt a trap tuff which has accumulated or deposited around the conical knobs of trap during their gradual elevation. The pebbles of the rock consist of rounded masses of greenstone and amygdaloid. They are usually firmly cemented by calcareous and argillaceous material. Resting conformably upon the conglomerate is a mixed conglomerate and sandrock. This mixed rock occurs upon isle Royale and was seen to be very widespread upon the south shore. The conglomeratic part of the mixed rock has the same character as the conglomerate rock. Dikes of greenstone are found in this mixed rock, but less frequently than in the rock below. The red sandstone is the chief rock that appears upon the immediate coast of the south shore of lake Superior. The primary, metamorphic, and trap rocks are almost invariably surrounded or flanked at their bases by this sandrock. The material of this sandrock differs widely from the conglomerate rocks, for these are made up of materials clearly of trappean origin and very rarely of quartz; while the red sandstone is composed of materials derived from the granitic and metamorphic rocks, in which quartz occurs abundantly. The red sandrock is less frequently traversed by dikes than the rocks before described, although they are sometimes noticed traversing the whole of the several rock formations, including the red sandstone. The upper or gray sandrock conforms to the limestone above it, and rests conformably upon the uptilted edges of the red sandrock below.

WINCHELL (ALEXANDER),[98] in 1861, gives a general sketch of the geology of Michigan. Among the stratified rocks are placed the Azoic, while the unstratified rocks are divided into Volcanic, including lava, trap, etc., and Plutonic, including granite, syenite, etc. The Azoic rocks are of immense thickness and are interposed between the crystalline, plutonic, and volcanic rocks and the lake Superior sandstone. The rocks in this system in Michigan consist of talcose, chloritic, and siliceous slates, quartz, and beds of marble. In it are found the specular and magnetic ores of lake Superior. The Lake Superior sandstone is placed in the lower Silurian system. The solid quartzose character of the rock of St. Joseph's and Sulphur islands suggests the idea of its being Azoic; but the gradual transition from the unaltered sandstone of the Sault to the altered sandstone of Neebish rapids and jasper conglomerates of the western shore of Campement d'Ours, favors the idea of the equivalency of the sandstone and quartzite, as it is also the fact that the fossiliferous Chazy limestone is found directly upon the quartzite at Sulphur island.

CREDNER,[99] in 1869, describes in the upper peninsula of Michigan the Laurentian and Huronian systems. The Laurentian system is the gneiss-granite formation, which includes many varieties of massive rocks, as well as hornblende, chlorite, and other schists, and also thin layers of dolomitic limestones.

The Huronian system is the iron-bearing formation. The general succession, beginning at the base, is quartzite, in its upper parts often iron stained, 2,500 feet; crystalline dolomitic limestone, containing argillite, chlorite-schist, and layers of quartz, seldom conglomeratic, 2,500 to 3,500 feet; more or less siliceous hematite, 600 to 1,000 feet; ferruginous chlorite-schist, 1,200 feet; dark clay-slate, with beds of hard quartzite, 8,500 feet; chlorites-chist, with beds of diorite, 1,300 feet; talc-schist, with various impurities, 100 feet; aphanitic to granular diorite, 2,300 feet; talc-schist, with various impurities, 1,500 feet.

In the iron group is a granite dike on the Sturgeon river 12 feet wide, which breaks through the iron ore and jasper at a right angle to the schist. Over the iron formation, at the Michigamme mine, is found a conglomerate of jasper and fragments of quartz in an iron and quartz base. There is a discordance between the Laurentian and Huronian. The Potsdam sandstone rests upon the Huronian and Laurentian unconformably.

BROOKS and PUMPELLY,[100] in 1872, maintain that the copper-bearing rocks of lake Superior are unconformably below the Lower Silurian sandstone. This is shown by the fact that the horizontal strata abut against the steep faces of the cupriferous series on Keweenaw point, the latter dipping away from the sandstone at an angle of from 60° to 40°. Also for a long distance between the Montreal river and lake Gogebic the cupriferous series conform in strike and dip to the Huronian schists, dipping steeply to the north at an angle of from 50° to 70°, while the Silurian sandstone to the north, in a flat-lying condition, covers an extensive country. In Sec. 13, T. 46 N., R. 41 W., the Silurian sandstone is found in a nearly horizontal position, while 4 miles distant the cupriferous series dip to the north at an angle of 50°.

It is concluded that the cupriferous series was formed before the tilting of the Huronian beds upon which it rests conformably, and consequently before the elevation of the great Azoic area. After the elevation of these rocks, and after they had assumed their essential lithological characters, came the deposition of the lake Superior sandstone and its accompanying shales as a product of the erosion of the older rocks, and containing fossils which show them to belong to the Lower Silurian. At several places have been detected a lack of conformity between the Laurentian and Huronian in the upper peninsula of Michigan, but when the Huronian and Cupriferous are seen in contact there seems to be a well marked concordance between them.

BROOKS,[101] in 1873, divides the rocks of the upper peninsula in descending order into Lower Silurian, Copper-bearing rocks, Iron-bearing rocks, and Granitic rocks, and gives a systematic account of the last two, and especially of the economic geology of the iron-bearing series. The copper-bearing rocks correspond with the Upper Copper-bearing rocks of the Canadian geologists and occupy a narrow belt on the northwestern edge of the upper peninsula. This series includes sandstones, which are nearly or quite identical with the Silurian in appearance, but their great mass is made up of different varieties of trap, often amygdaloidal, interstratified with beds of peculiar conglomerates. The layers of these rocks are inclined, dipping northwest and north toward lake Superior, from vertical to as low as 23° on Keweenaw point. The iron-bearing rocks are assumed to correspond with the Huronian system of Canada. They may have a thickness of 5,000 feet and consist of a series of extensively folded beds of diorite, quartzite, chlorite-schists, clay-slate, mica-slate, and graphitic shales, among which are intercalated extensive beds of several varieties of iron ore. The most abundant rock is greenstone or diorite, in which the bedding is usually obscure, but the intercalated schists and slates usually bear strong marks of stratification. The dips are usually at a high angle and are more apt to be north or south than any other direction. The granitic rocks are believed to be the equivalents of the Laurentian of Canada. In these the bedding indications are still more obscure and often entirely wanting. Also, if possible, there is more irregularity in strike and dip than in the Huronian.

A full lithological description of the different phases of rocks found in the Huronian system, and the various sections at the many mines in the upper peninsula are given in detail.

The formations of the Huronian system in the Marquette region comprise nineteen members, numbered from the base upward. I, II, III, and IV are composed of beds of siliceous ferruginous schist, alternating with chloritic schists and diorites, the relations of which have not been fully made out; V is a quartzite, sometimes containing marble and beds of argillite and novaculite; VI, VIII, and X are siliceous ferruginous schists; VII, IX, and XI are dioritic rocks, varying much in character; XIII is the bed which contains all the rich specular and magnetic ore, associated with mixed ore and magnesian schist; XIV is a quartzite, often conglomeratic; XV is argillite or clay slate; XVI is uncertain, it contains some soft hematite; XVII is anthophyllitic schist, containing iron and manganese; XVIII is doubtful; XIX is mica-schist, containing staurolite, andalusite, and garnets. The total thickness of the whole Marquette series may have an aggregate of 5,000 feet.

The beds appear to be metamorphosed sedimentary strata, having many folds or corrugations, thereby forming in the Marquette region an irregular trough or basin, which, commencing on the shore of lake Superior, extends west more than 40 miles. The upturned edges of these rocks are quite irregular in their trend and present numerous outcrops. While some of the beds present lithological characters so constant that they can be identified wherever seen, others undergo great changes. Marble passes into quartzite, which in turn graduates into novaculite.

Near the junction of the Huronian and Laurentian systems, in the Marquette region, are several varieties of gneissic rocks, composed in the main of crystalline feldspar, with glassy quartz and much chlorite. Intersecting these are beds of hornblendic schist, argillite, and sometimes chloritic schist. These rocks are entirely beneath all of the iron beds, seem to contain no useful mineral or ores, and are of uncertain age. No attempt is here made to describe or classify them.

The diorites, dioritic schists and related rocks range in structure from very fine grained or compact (almost aphanite) to coarsely granular and crystalline, being sometimes porphyritic in character. The rock passes on the one hand into a hornblende rock, and on the other into a rock resembling a diorite. It is eminently schistose in character, splitting easily, and appearing more like chloritic schist than any other rock. At several points dioritic schists, semi-amygdaloidal in character, were observed, and in one instance the rock had a strong resemblance to a conglomerate. The bedding of the rocks is generally obscure and sometimes entirely wanting. It is only by a full study of the rock in mass and its relations to the adjacent beds that one becomes convinced, whatever its origin, that it presents in mass precisely the same phenomenon as regards stratification as do the accompanying schists and quartzites. Chloritic magnesian schists are associated with the pure and mixed ores. Oftentimes these magnesian schists several feet in width cut across the stratification and are called slate dikes. It is difficult or impossible to draw the line between these magnesian schists and the dioritic schists. It is suggested that on the New England-Saginaw range and at the lake Superior mine, tepid alkaline waters have penetrated the formation and have dissolved out the greater portion of the siliceous matter, leaving the iron oxide in a hydrated earthy condition.

At the S. C. Smith mine and along Plumbago brook is found carbonaceous matter. These carbonaceous shales burn white before the blowpipe and mark paper like a piece of charcoal.

Above the Cascade ore is a bed of coarse conglomerate. The upper quartzite of Republic mountain, near its base, is a conglomerate containing large and small fragments of flaggy ore. At the New England mine between the ore and the quartzite is a mass of specular conglomerate similar to that at Republic mountain.

The iron-bearing series is unconformably above the older Laurentian rocks. The contact is observed in Plumbago brook, where a talcy red rock, unmistakably belonging to the Huronian, dipping at a low angle to the northwest, is in contact with the Laurentian chloritic gneiss, which dips at an angle of about 35° SSW. The same phenomena can be seen near Republic mountain, where the Huronian schists strike nearly at right angles to the Laurentian gneiss only 50 feet distant; both series dipping at high angles, the Laurentian east of north, and the Huronian about 45 degrees west of north. The non-conformability is further shown by the fact that the Laurentian generally abounds in dikes of granite and diorite, which are almost entirely absent from the Huronian.

Many details are given as to the Menominee and Felch Mountain districts. The rocks of these ranges are parallel with those in the Marquette district. At many places the Silurian rocks unconformably cap the iron-bearing rocks.

The lake Gogebic and Montreal river iron range is regarded as an eastern prolongation of the Penokee range of Wisconsin. The northern geological boundary is the south copper range, consisting of massive and amygdaloidal copper-bearing traps, the bedding of which is exceedingly obscure, with occasional beds of sandstone and imperfect conglomerates. The strike of these rocks is east and west, with a dip to the north at a high angle, thus conforming with the Huronian rocks underneath. On the south of the iron-bearing rocks is a series of granites, gneisses, and obscure schists, which are unmistakably Laurentian in their lithological character, and they are unconformably overlain by the Huronian rocks. The horizontal Lower Silurian sandstones occupy a broad belt of country north of the copper range. Their actual contact with the highly tilted copper rocks was not seen, but they show not the slightest evidence of disturbance within a few miles of these steeply inclined rocks, and are regarded as unconformably above them.

PUMPELLY,[102] in 1873, gives a systematic account of the copper-bearing rocks. These on Keweenaw point consist of an immense development of alternating trappean rocks and conglomerates dipping to the northwest at an angle running from 60° to 23°. The red sandstone and shales of lake Superior are everywhere nearly horizontal on the south shore of lake Superior between the Sault Ste. Marie and Bête Grise bay. At the western edge of this belt its nearly horizontal strata abut against the steep face of a wall formed by the upturned edges of beds of the cupriferous series of melaphyre and conglomerate, which dip away from the sandstone at angles of from 40° to 60°. This sharp line has been explained as due to a fault, the horizontal sandstone being regarded as of the same age as the conformable overlying sandstone of the cupriferous series. One objection to this explanation is the enormous amount of dislocation required, amounting to several miles. Again, near Houghton there are two patches of sandstone lying on the upturned melaphyre beds. In the horizontal sandstone near the so-called fault are abundant pebbles of melaphyre and conglomerate of the cupriferous series. But the most decided facts found by Maj. Brooks and the author are in the country between the Bad river in Wisconsin and the middle branch of the Ontonagon, east of lake Gogebic. Here the quartzites and schists of the Huronian formation are bordered on the south by the Laurentian gneisses, and are overlain conformably by the bedded melaphyres and interstratified sandstones of the cupriferous series. Between these ridges forming the south mineral range and the main range of Keweenaw point is the horizontally stratified Silurian sandstone, forming a generally level country. The conformable cupriferous and Huronian schists dip to the northward at angles from 50° to 70°, but in approaching Gogebic lake from the west the pre-Silurian erosion has made a deep indentation across the cupriferous series and the Huronian, as well as into the Laurentian, so that a short distance west of the lake these rocks end in steep and high declivities, at the base of which lies the level country of the Silurian sandstone. On the Ontonagon river the Silurian sandstone is nearly horizontal, while about 150 steps from the base of the cliff are outcrops of Laurentian schists having a dip of 45° to 60° southeast. The nearest outcrop of the cupriferous series is about 4 miles distant, and it strikes nearly east and west and dips 50° to the north. The lithology of the copper-bearing rocks of the Portage lake district is fully given. The rocks are melaphyres and amygdaloids, interstratified with conglomerates. The paragenesis of the minerals associated with the copper is worked out. Several detailed cross sections are given at Portage lake, and one cross section at the Central mine describing the thickness and character of the alternating rocks in great detail.

MARVINE,[103] in 1873, gives in the greatest detail the structure and lithology of the alternating trappean and detrital beds of the copper-bearing rocks on the Eagle river section. The correlation of the Houghton and Keweenaw rocks is fully discussed. The Albany, Boston, and Allouez conglomerates are regarded as the same bed. Stratigraphically eleven out of fifteen conglomerates have equivalents in both the Houghton and Keweenaw regions. The conglomerate beds of Keweenaw point are not mere local deposits, but are unusually persistent, and while a bed may thin out and lose its character as a conglomerate, it may still exist as a mere seam. In one instance a band extends for at least 50 miles, varying in thickness from a few to over 75 feet. It is therefore concluded that the changes which formed the melaphyres ceased to act over extended areas during the time of the formation of the sandstones and conglomerates. The abundance of acid rocks among the conglomerates was noted, and opposite Calumet the former presence of predominant quartz-porphyry was inferred.

ROMINGER,[104] in 1873, places the lake Superior sandstone as Potsdam, finding it directly overlapped by the calciferous formation. At Presque isle and Granite point the horizontal sandstones are found resting upon the crystalline rocks, there being at the former place a conglomerate which rests unconformably upon the dolomite of Presque isle. The sandstones on the eastern shore of Keweenaw point retain their horizontal position and lithological character to such a degree that the different strata can be parallelized without difficulty with those of the more eastern localities. Near the center the horizontal sandstones are found abutting against the uplifted edges of a different rock series, the copper-bearing rocks. The abrupt edges of the strata look to the southeast, and their dip is in the opposite direction under angles varying from 70° to 40°. The unconformable abutment of the sandstones against the trappean series is plainly observed at several places near Houghton, on the property of the Isle Royale company, near the stamp works of the Calumet and Hecla mines, on the railroad coming down from the mines to the stamp works, and on the Sheldon and Columbia property.

ROMINGER,[105] in 1876, describes the red lake Superior sandstone as unconformably abutting against or overlapping the trap rock with horizontally disposed layers. On the western slope of the ridge the trap rocks are conformably overlain by sandstones, conglomerates, and slates, the age of which is intermediate between the trap and the horizontal sandstone, but between all three there are such great lithological affinities that it is natural to regard them as consecutive products of one and the same epochs. The absence of trappean rocks distinguishes the upper division from the lower.

The Huron mountains are a crystalline granitic and dioritic Laurentian rock series. These granitic rocks are surrounded by a narrow belt of the horizontal red sandstone of lake Superior, which abuts unconformably against them. The Huronian rock series, with uplifted beds alternating with slate rocks, quartzites, diorites, and jaspery strata, with seams of iron ore, lean unconformably against the granitic series.

BROOKS,[106] in 1876, places granite as the youngest Huronian rock south of lake Superior. This granite occurs as the uppermost member of the Menominee and Penokee series, but in the latter it thins out and disappears before reaching the Gogebic region. The lithological character of this granite belt bears a general resemblance to the Laurentian rocks. This granite, from the fact that it does not give off dikes cutting the copper-bearing series, is believed to be earlier than the latter. Although there is approximate conformability in strike and dip, there is probably an unconformity between the copper-bearing rocks and the

Penokee-Gogebic Huronian, as shown by the fact that the former series is in contact in different places with various members of the Huronian. There is also an unconformity between the Huronian and Laurentian.

As supporting the view that the pre-Silurian systems are distinct periods, attention is called to the lithological differences between the three series, as well as to the intensity of folding to which they have been subjected. The detrital members of the copper series consist of friable sandstone showing no greater metamorphism than the Silurian, and it is folded only in regular magnificent sweeps, the same strike and dip continuing in some cases for about 150 miles. The Huronian series consists of greenstones, various schists, clay-slates, quartzites, marbles, with gneisses and granites containing no copper, and having conformable beds of the various oxides of iron, and is everywhere sharply folded into narrow troughs and irregular basins trending in every direction. The Laurentian is still more plicated and metamorphosed, the stratification often being entirely obliterated. Whether the Laurentian rocks can be separated into two or more nonconformable systems, as in Canada, no opinion is ventured. Since Keweenaw peninsula is a striking geographical feature in lake Superior, and is the locality where the copper series is best exposed, the name Keweenawian is suggested for this period.

BROOKS[167], in 1876, gives a list of the rocks of the Huronian series in order of their abundance and as they occur in stratigraphical succession in the Marquette, Menominee, Penokee, and Gogebic series. Lithologically the rocks are divided into (1) Fragmental rocks, exclusive of limestone; (2) Metamorphic rocks, not calcareous; (3) Calcareous rocks; (4) Igneous rocks.

The Fragmental rocks include quartz-conglomerates, which occur in the middle horizon, both in the Marquette and Menominee and in the latter at the base of the series where it holds pebbles of granite, gneiss, and quartz. In the Metamorphic rocks not calcareous are included many varieties; the mica-bearing series includes granite, syenite, gneiss, mica-schists, hornblende-schists, mica-slates, clay-slates, diorites, diabases, quartzites, siliceous schists, chert and jasper rocks, iron ores, as well as many others. Among the eruptive rocks is a feldspathic series, including granite dikes; hornblendic and pyroxenic series, including diabase and similar rocks, and hydrous magnesian schistose rocks which are found in dike-like forms crossing the quartzites, iron ores, and greenstones.

The succession in the Marquette region from the base upward is (*a*) syenite, diorite, diabase, hornblende-schists, slates, conglomeratic quartzites, and various quartzose iron ores; (*b*) quartzite graduating into protogine, and containing interstratified beds of dolomitic marble; (*c*) ferruginous quartzose schist; (*d*) hornblendic rocks with greenstones; (*e*) ferruginous quartzose flags, clay-slates, and quartzites; (*f*) hornblendic rock, related to diorite and diabase; (*g*) siliceous hematitic and limonitic schistose ores; (*h*) diorite, hornblende-schist, and chlorite-schist; (*i*) arenaceous quartz-schist, banded with micaceous iron and quartzose limonitic ore; (*j*) pure specular hematite and magnetite, with banded jaspery schists and interstratified beds of chloritic and hydromica-schist; (*k*) an arenaceous quartzite, often semischistose and conglomeratic; (*l*) argillaceous slate; (*m*) quartz-schists; (*n*) anthophyllitic schist; (*o*) mica-schist. Similar successions are given in the other regions mentioned and correlated with that in the Marquette region, and all of these successions are compared and correlated with Logan's succession in Canada.

The Huronian in the Marquette, Menominee, and Gogebic regions is nonconformable with the Laurentian.

PUMPELLY,[108] in 1878, describes lake Superior as divided into two distinct basins by Keweenaw point, the western basin being a geosynclinal trough. The southeastern lip of this trough consists of an immense development of volcanic rocks in the form of great beds and flows associated with conglomerates and sandstones, both of which consist essentially of porphyry detritus. This Keweenaw series is more nearly conformable with the underlying highly tilted Huronian schists than with the Potsdam sandstone. The prominent eruptive rocks of the Keweenaw series fall under the two heads, diabase and melaphyre. The changes which have taken place in the interior of the rock masses since eruption, that is, the metasomatic development of these rocks, is traced out in great detail.

WRIGHT,[109] in 1879, describes the Laurentian series as consisting of coarsely crystalline massive granites, passing into gneissoid rocks, and these graduating into mica-schists, and the latter even as imperceptibly into slates. The Laurentian granite is regarded as a metamorphic sedimentary rock, because the quartz grains contain cavities filled with liquid, while igneous granites never contain such cavities, but rather those filled with glass or stone. The lower Huronian strata have been chiefly derived from the ruins of the Laurentian rocks. The nonconformity between the Laurentian and Huronian may be seen at Penokee gap. Here the dip of the gneissoid granite is about 70° to the south, while the plainly bedded Huronian strata in direct contact have a dip of 65° to the north. At the Macomber mine, near Negaunee, is found a bed of manganiferous hematitic shale bearing the impression of some fossil which Profs. Brush, Verrill, Dana, and Smith pronounce to belong to the lower forms of life. The Lower Silurian sandstone about the city of Marquette is nearly horizontally bedded, and rests unconformably on and against the Huronian.

ROMINGER,[110] in 1881, gives a general account of the Marquette and Menominee iron region, with very voluminous details as to particular localities.

The Marquette region.—In general remarks on the geology of the Marquette district the succession is (1) Granitic group; (2) Dioritic group;

(3) Quartzite group; (4) Iron group; (5) Arenaceous Slate group; (6) Mica-schist group; and (7) Serpentine group; but later it is seen that the Quartzite group reposes upon the Iron group, so that the order of 3 and 4 is reversed. The Silurian sandstones rest horizontally on the other rock formations and frequently contain fragments of the underlying formations. The crystalline granitic masses are directly confined to the northern and southern limits of the Marquette district. The dip of the strata on the south part of the trough is usually to the north, and on the north side to the south, so that we may consider this area as a synclinal caused by the upheaval of its northern and southern margins. The granitic and sedimentary rock masses are traversed by rock belts of a crystalline character, which represent lava streams intruded at different periods subsequently to the rocks cut.

In the Granitic group the granites are found interstratified with the Huronian schists of the Dioritic group. The granites are usually middling coarse grained and in the main are massive, although distinct gneissoid rocks have a limited occurrence. Besides the dioritic dikes there are in the granites crystalline non-stratified masses resembling eruptive dikes. In several instances granite dikes show a laminar arrangement of the mica scales. Also syenites are associated with the ordinary granites. The hornblende rocks associated with the granites are distinguished from those occupying a higher position in the series by the brighter luster of the hornblende crystals. Dioritic rocks occur interstratified with the granites, which are probably of the same origin as the volcanic eruptives. In the Laurentian rocks no limestones, layers of quartzite, nor beds of iron ore are found. The granitic rocks in their present position are actually the younger rocks, as shown by the intrusion of large masses of granite between the stratified sediments of the Dioritic group.

The dioritic group is regarded as remelted, completely metamorphosed Huronian sediments, their more crystalline character being due to their closer proximity to the volcanic forces. The rocks of the Dioritic group include a large succession of schistose beds of uniform character, interstratified with massive diorite. In the dioritic rock chlorite frequently replaces the hornblende and often seems to be a product of its decomposition. The massive diorites are usually conformably bedded with the schists and often insensible gradations from the schistose conditions to the massive diorite can be seen. The exposures of massive diorite generally form a nucleus around which the inclosing rock masses are arranged concentrically with a more perfect schistose structure. In the Dioritic group are conglomerates. One variety is well exposed at Deer lake furnace, where the pebbles are of a feldspathic substance which on fresh fracture contrasts little with the surrounding schistose mass. Also extensive conglomeratic masses are found full of granite pebbles of large size in Sec. 2, T. 48 N., R. 26 W., and in Sec. 29, T. 48 N., R. 25 W. In opposition to Brooks it is maintained that there is but one iron-group formation.

The Quartzite group is in places interstratified with ferruginous and siliceous seams, as well as novaculitic strata and siliceous limestones. Frequently in the quartzite is a conglomerate containing abundant quartz fragments, and also not infrequently containing granite and slate fragments. Oftentimes these conglomerates containing the granite fragments are very close to the massive granite, while it not infrequently underlies them. At one place in which the quartzite is in contact with the granite the one rock is seen to graduate by imperceptible stages into the other, in which case the sedimentary strata are changed into the granite-like rock by being exposed to the contact with the eruptive granite. In another place a granite breccia containing large fragments of granite is found in connection with such large masses of granite as to be too great to be fragments of a breccia, and this suggests that the nucleus of the hills are solid granites, whose shattered portions are recemented on the spot by sedimentary débris washed into the interstices. In the next hill to the south the inclosed water-worn pebbles are in part granite and in part slate. Above the ore-bearing rock beds is generally a very coarse quartzite conglomerate which often has the characters of a coarse grained ferruginous quartzite and grades down into a brecciated ore. The fragments are chiefly ore, jasper and quartz, and the cement is arenaceous or ferruginous. This occurrence is so general as to suggest that great disturbances not of a local extent must have occurred at the end of the era of iron sediments. The number of localities and mines at which this conglomerate or breccia occurs is very great. Among the latter are the Home, Gibbon, Jackson, Cleveland, Cascade, Gribben, Salisbury, Lake Superior, Champion, Saginaw and Goodrich, Keystone, Republic, and Michigamme.

The Iron group occupies a position inferior to the Quartzite group, and there are not two horizons here, as supposed by Brooks. It is composed of banded jasper, conformable chlorite-schist, and ore. The ore-deposits are not regular sedimentary layers, but the product of the decomposition of the impure ledges by percolating waters, leaching out the siliceous matter and replacing it with iron oxide, and are therefore very irregular in form. The strata are in a much disturbed condition, folded and distorted in every possible way, usually without fault. These disturbed beds lie in every instance directly, but often unconformably, on chloritic or hydromicaceous schists, or on crystalline dioritic masses, which are constant associates of the chlorite schists, or on dioritic schists. At the Jackson mine are knobs of diorite associated with schists surrounded by the banded jasper rocks, which are evidently corrugated by the intrusion of this mass. In places the ore-bearing formation is not found incumbent on the Dioritic group. At Teal lake the quartzite is found under the ore and the diorite over the ore, which leads to the conclusion that these strata are in an overturned position.

The Arenaceous Slate group of great thickness is so designated because a large portion of the rocks here included consist of sandy siliceous layers, alternating with slaty argillitic rock beds and occasionally with compact quartzite. The strata in different localities quite often differ considerably. The rocks of this group are incumbent on the quartzite formation, but also sometimes rest upon the ore-bearing rocks, and quite often are found in direct contact with the dioritic series. The rocks are sometimes conglomeratic or brecciated, the fragments consisting of different kinds of rocks. In the black roofing slates of Huron bay the cleavage is discordant with the bedding. Occupying a position above the black slates are the ore deposits of the Taylor mine, near L'Anse, and of the Northampton and D'Alaby, north of Champion; also the S. C. Smith and other mines. These ores are contemporaneous and equivalent to that of the Commonwealth in the Menominee district.

The Mica-schist group is found exposed for the most part about Michigamme village. The Serpentine group includes the rocks of Presque isle and those of similar class. The Silurian sandrock reposes unconformably upon the Serpentine formation at Presque isle. Besides the serpentine and other magnesian silicates, limestone comprises an important share of this group.

The seven previous groups, considered to be a succession of sedimentary strata, are intersected by various dikes, among which are a dioritic rock and dolerite dikes, the latter of which are later in age than the former. No proof has been found of any discordance between the granites of Marquette and the adjoining Huronian beds. On the contrary, outcrops of the two kinds of rocks exhibit a remarkable parallelism in strike and dip, and in many localities the Huronian schists and belts of granite are interlaminated in perfect conformity. The granite is, however, regarded as intrusive masses. The granites are therefore, with reference to the stratified sedimentary rocks, actually the younger rock.

The Menominee region.—Many localities and sections in the Menominee iron region are described in detail. The Silurian sandstone is found to rest unconformably upon the nearly vertical Huronian strata. Near Sturgeon river falls, in the river, the quartzite formation reposes unconformably on the granite. Thick layers of limestone are found in the series, and this is sometimes conglomeratic. The fissile phyllite schists are found in discordance with the dioritic schists at lake Hanbury. The granitic and gneissic rocks south and north of the Felch mountain ore formation are found to be absolutely identical. The dioritic rocks are found generally and play the part of an intrusive with regard to the strictly sedimentary rock beds of the Huronian series. The dioritic group is held to be older than the iron-bearing group because it exhibits a greater degree of metamorphism and on the ground that it is lithologically like the equivalent dioritic group of the Marquette district. It has evidently been transformed under the cooperation of heat and partially brought into a plastic condition.

In the eastern part of the Menominee region the rocks found comprise, in descending order, the lake Hanbury slate group, perhaps 2,000 feet in thickness; the Quinnesec ore formation, which comprises micaceous and argillitic strata, containing ore bodies, not less than 1,000 feet thick; and the Norway limestone belt, at least 1,000 feet thick. The Commonwealth mine, in the western part of the Menominee district, represents a higher horizon than the Quinnesec ore formation.

WINCHELL (N. H.),[111] in 1888, describes in the Marquette district the conglomerate overlying the ore and jasper formation at several mines, and places the overlying quartzite in the Potsdam. North of Bessemer is a basal conglomerate of the Cupriferous series which is inferred to lie unconformably upon the Gogebic iron-bearing rock. This conglomerate appears to be the equivalent of the overlying Potsdam conglomerate of the Marquette region, which makes the Gogebic series pre-Potsdam. The granite underlying the Huronian slates at the Aurora mine was originally a conglomerate, but it has acted the role of an eruptive rock and has flowed over the adjoining sedimentary strata. This granitic conglomerate is parallelized with the Ogishki conglomerate of Minnesota, and the overlying sedimentary rocks are the equivalent of the Animikie.

WINCHELL (ALEX.),[112] in 1888, finds the Marquette iron-bearing rocks to have the same geological position with respect to the crystalline schists and gneisses and to consist of sediments of the same character as those of the Vermilion range. At Deer lake furnace is a peculiar conglomeratic rock which appears sedimentary, but is much altered and has a quasi-eruptive aspect. This conglomerate is like that of Stuntz island in Vermilion lake. Near Negaunee is an argillite which has a lower dip than a greenish chloritic quartzose rock across a railroad from it, and the two are therefore unconformable.

The rocks of Marquette are older than the Huronian because they differ from them lithologically; because the Canadian Huronian is immediately succeeded by the Paleozoic system, while the Marquette strata is not; because some evidences are found that in the Marquette district there is an overlying unconformable sub-Paleozoic system; and because the Marquette series, being the equivalent of the Vermilion, is older than the Animikie slates, which are the equivalent of the Huronian.

The rocks of the Gogebic range are regarded as the equivalent of those of the Marquette region because they resemble them lithologically, and because they are in an analogous position to the crystalline rocks. Between the Penokee series and the underlying schists there is a marked unconformity, the Penokee rocks dipping to the north, while the hornblende-schists dip to the south. The Penokee series strata are lithologically unlike the ore-bearing strata of Gogebic, Marquette, and

Vermilion regions, but resemble those of the Animikie series and are therefore perhaps Huronian, while the Gogebic iron-bearing strata are not.

WADSWORTH,[113] in 1890, gives a general account of the geology of the Marquette and Keweenaw districts based upon his own and other works. The Azoic system includes fragmental and eruptive rocks. Among the former are various argillites and schists of the Marquette district. Among the eruptive rocks are placed the jaspilites and their associated ores, with the exception of certain soft iron ores of chemical origin. The Keweenawan is again placed as a part of the Potsdam, since the first lava flow found on Keweenaw point flowed over the Eastern sandstone. Subsequently there has been a fault line or fissure running near the contact of the sandstones and lavas. This fault is regarded as normal and it accounts for the fact that sometimes the lavas and sometimes the associated conglomerates are brought in contact with the Eastern sandstone along the fault line.

WADSWORTH,[114] in 1891, modifies somewhat the foregoing account of the Azoic system. A portion of the jaspilites and associated iron ores are still held to be eruptive, but it is suggested that even for these supposed nonfragmental jaspilites of Ishpeming and Negaunee, their present relations may be due to sedimentary and chemical action and the squeezing together of the jaspilite and schist. The jaspilite and ore, with the associated quartzites, occurring at Cascade, Republic, Humboldt, and a part of those at Ishpeming and Negaunee, as well as those of the overlying quartzites and schists, are sedimentary. In the Marquette district there are three distinct geological formations or ages in ascending order as follows: First, the hornblende-schist and granite of Cascade or Palmer and the nonfragmental jaspilite and ore of Ishpeming and Negaunee—the Cascade formation. Second, the fragmental jaspilite and ore, with their associated quartzites and schists of Cascade, Republic, Humboldt, Ishpeming, Negaunee, and elsewhere—the Republic formation. Third, the overlying conglomerates, quartzites, and schists of Cascade, Republic, Holyoke, and elsewhere—the Holyoke formation.

Above the detrital Republic formation at the Cascade range is another detrital formation which contains water-worn débris derived from the underlying deposits of jaspilite and ore, and is therefore uncomformably above it. At present it is not possible to determine positively whether there are really three formations as given, or from four to six different ones, or whether the three may be reduced to two.

WADSWORTH,[115] in 1891, finds that the Lower Silurian, containing Trenton fossils near L'Anse, overlies the sandstone conformably, both having a synclinal structure; which tends to confirm the commonly received view of the Potsdam age of the Eastern sandstone.

WADSWORTH,[116] in 1891, gives observations upon the South Trap range and adjacent sandstones. Various places are mentioned, including Silver mountain, which are composed of lava flows. These traps sometimes have a dip not higher than 9° to 20°. In Secs. 11, 13 and 14, T. 46 N., R. 31 W., sandstone is found overlying the lava flows. The Eastern sandstone on Traverse island, in Keweenaw bay, is said to have an inclination of from 5° to 14°, while in the vicinity of Torch lake it has a dip of from 5° to 23°. It is concluded that the above observations go to show that the lava flows of the South Trap range east of lake Gogebic do not dip at a high angle, as has been generally asserted, and further that the Eastern sandstone is not horizontal, as has been generally stated, but that the two dip at a low angle, generally 5° to 20°. These observations also indicate that the Eastern sandstone and the lava flows of the South Trap range are one formation, and are as conformable as eruptions of lava can be with a contemporaneous sedimentary deposit.

ROMINGER,[117] in unpublished manuscript of the Michigan Survey for 1881 to 1884, further reports upon the complex described in the former volume as the Huronian system. The lower granite and gneissoid portion of the rock groups in the Marquette region exhibits the characters of an eruptive and not of an altered sedimentary rock. Generally a solid crust of granite probably served as a substratum on which the Huronian sediments were laid down, but an opportunity is not often afforded to see the rocks in contiguity well enough exposed to allow a discrimination as to whether such contact is an original primary one or resulted from dislocation. The existence of granite as a surface rock at the time the Huronian sediments formed is proved by the occurrence of belts of granite, conglomerate and breccia in different horizons of the series.

A large belt of conglomerate formed of rounded weather-worn granite pebbles and schistose rock fragments, cemented by a matrix of similar schistose material, is seen in contact with a granite belt in the south half of Sec. 2, T. 48 N., R. 26 W.; in the SE. ¼ Sec. 22, T. 47 N., R. 26 W.; and in the north half of Sec. 29, T. 48 N., R. 25 W. In the first of these localities the fragments are different from the underlying granite. The second locality furnishes a better proof of the deposition of Huronian sediments on a base of granite. Here several knobs centrally composed of massive granite are surrounded by a mantle of coarse granite breccia, with a well laminated quartzose material as a cement. This breccia is conformably succeeded by hydromica-slates, interlaminated with heavy belts of compact quartzite. At the third locality granite conglomerate is interlaminated with dioritic schists, but is remote from granite outcrops. The gradation of the quartzite formation into the granite, described in the previous report as occurring in the north part of T. 47 N., R. 25 W., is now considered as a recemented mixture of granite fragments mingled with arenaceous material, although it is singular that the orthoclase crystals copiously found in the mass have all sharp outlines and are quite fresh.

The upheaval of the granite and its intrusion into the overlying strata occurred in all probability near the termination of the Huronian period, as we find the granite in contact with all the Huronian strata up to the youngest, and these always in a dislocated position. Intrusive belts of granite are usually never found to intersect beds higher than the iron-bearing group, except in the country north of the Penokee range in Wisconsin, and in the vicinity of Duluth, Minnesota, where granite or granite-like rocks cut across eruptive belts of gabbro which are themselves more recent than any of the sedimentary strata of the Huronian. These granites differ from the ordinary granites at the base of the Huronian, and are most likely younger. The dislocation of the Huronian beds is not exclusively due to the upheaval and intrusion of the granite, but has been caused in part by diorite and diabase intrusives which intersect the granite as well as the incumbent beds. The diorites intersecting the granite are identical with similar rocks interstratified with the schists of the Huronian group conformably or transversely intersecting them, and they therefore represent one and the same volcanic injection. From the massive forms of diorite a gradation exists into a schistose condition. This led to the conclusion in the former report that the massive diorites had suffered secondary fusion; but as the author is now convinced that schistose structure is not necessarily the result of aqueous sedimentation, it is concluded that the dioritic group does not belong in the sedimentary succession. Dolerite or diabase rocks intersect in dike-like-form all the Huronian rocks, as well as the granites. As they are like those of the copper-bearing series, these rocks, as well as the contemporaneous flows, are regarded as belonging to the same geological period. In the Felch mountain region one dike (15 or 16 feet in thickness) of holocrystalline granite cuts across the iron-bearing series. In Sec. 33, T. 42 N., R. 28 W., another granite dike cuts through the iron-bearing rocks.

Above the iron-ore group of the Marquette and Menominee districts before described is found at many localities important deposits of iron in both these regions which belong in the Arenaceous Slate group. There are, therefore, two iron horizons instead of one, as before supposed. The mica-schist formation, supposed to belong above the Arenaceous Slate group, is found to dip conformably below it in some places, and therefore is really a part of the Arenaceous Slate group, and is believed to represent its middle horizon. The slate group about L'Anse and Huron bay is black and often graphitic. The slate beds at Plumbago creek are succeeded by schistose beds richer in red feldspar and containing little quartz, which might by superficial examination be mistaken for granite, but which is evidently a fragmental rock formed by the detritus of the granite which near by forms large mountain masses, and the granite of which is very rich in red feldspar and contains comparatively little quartz.

The Gogebic region is described and the rocks are divided into granitic, dioritic, iron ore, and upper slate groups, which are analogous to the similar groups in the Marquette country. Granite seams were found here cutting across the dioritic schists, but were not found to cut the truly sedimentary strata. Locally, in contiguity with the granite, are heavy quartzite strata which are often conglomeratic, and are filled with rounded granite pebbles. The dioritic rocks above the granite often have a brecciated or conglomeratic structure, the fragments being various kinds of diorite cemented by the same material. The diorite is of eruptive character, as is shown by the occurrence of belts of it cutting transversely through the ore-bearing series. Limestones are also found, which occupy the same position as the limestones below the ore-bearing strata in the Menominee district.

The succession in the Felch mountain, from the base upward, is (1) granitic or dioritic rocks; (2) quartzite beds; (3) fissile quartz schists; (4) micaceous argillite; (5) crystalline limestone with siliceous seams; (6) ferruginous quartzites, containing the ore beds.

SECTION IV. WORK OF THE WISCONSIN GEOLOGISTS AND ASSOCIATES.

PERCIVAL,[118] in 1856, describes the quartzite ridges of Baraboo and Portland. The rock is a hard granular quartz, which has more or less distinct lines of stratification, and resembles much a Primary granular quartz. In the Baraboo rock are layers more or less filled with rounded pebbles of quartz, resembling layers of the same kind in the lower sandstone, and oblique cross lines between the regular lines of stratification, which occurrences appear to connect it with the lower sandstone. The dip of these ranges is at a moderate angle to the north, and if the rock is formed from the sandstone by igneous action from beneath, the metamorphic change has not been accompanied by much disturbance of the strata. The localities in which Primary rocks are found are all within the limits of the lower sandstone, and most of them occur at the falls of the northern rivers. These rocks are mainly hornblendic and syenitic, although trap rocks resembling the intrusive traps of Connecticut are seen, but these are believed to be rather Primary greenstones. Descriptions are given of the rocks of Marquette and Waushara counties, of those of Black, Wisconsin, St. Croix and other rivers. On Black river the rocks are syenite, greenstone and chlorite slate, the latter accompanied by iron ores.

DANIEL,[119] in 1858, describes the iron ores of Black river falls as associated with the chloritic and micaceous slates of the Azoic system. Syenite is also found adjacent. The fossiliferous horizontal sandstone rests upon the upturned edges of the Azoic slates, and at the base of it is a brecciated conglomerate consisting of sand, ore and slate. In the lower part of the Baraboo valley are lofty ranges of hard quartzite which are the soft crumbling Potsdam sandstone violently disturbed and changed.

LAPHAM,[120] in 1860, describes the Penokee iron range. Here is found a mountain mass of iron ore in an ancient chloritic slate, which rests upon a light colored quartz rock. Above and north of the ore the slate is hardened, probably by some volcanic agency. The whole series dip to the north.

HALL (JAMES),[121] in 1861, describes the quartzite ranges of northern Wisconsin, and particularly those of Spirit lake, as having been original stratified sandstones which have undergone subsequent metamorphism. These rocks are folded with their axes lying in an east and west direction and had become uplifted and metamorphosed before the commencement of the Potsdam era. In the quartzites in two or three localities are found beds of conglomerates. These metamorphic masses are in all probability the extension of the Huronian formation of Canada.

HALL (JAMES),[122] in 1862, describes the central and northern areas of Wisconsin as consisting of the Azoic rocks. These are hard and crystalline, are often destitute of lines of bedding, though they are in reality as regularly stratified as the more modern formations. Notwithstanding their crystalline character, their alternation of beds of different texture indicates their original different mechanical conditions as clearly as in any of the unaltered strata. They were deposited precisely as clay, sand, and limestone strata of more recent geological periods, and owe their present character to metamorphism. These rocks are granitic, syenitic, gneissoid, or hornblendic. In the southern part of the area of the crystalline rocks are numerous elevations of them appearing within the limits of the succeeding stratified rocks, so that we know that these latter are of later date. North of the Azoic rocks is the range of trap, conglomerate and sandstone bordering Lake Superior and known as the copper region. The quartzite ranges of Baraboo and Necedah hold the same position relative to the Potsdam sandstone as the Huronian system of the Canadian survey.

WHITTLESEY,[123] in 1863, describes the copper-bearing strata of Keweenaw point as extending southward across the boundary of the state of Michigan into Wisconsin, a distance of 160 miles. The order of rocks along the line is everywhere the same. Beyond the copper range, which is nearer to lake Superior, is a second range known as the iron range, and to this the name Pewabik was applied, although by a misprint it was transformed to Penokee.

Passing from lake Superior to south of the iron range, the structure in descending order is as follows: Formation No. 1, Potsdam sandstone, consisting of sandstones, conglomerates, black slates, and alternations of trap and sandstone; No. 2, Trappose, in two members; No. 3, Hornblendic; No. 4, Quartz, with slaty layers, separated into two members by a bed of magnetic iron and iron slate; No. 5, Granites and syenites of central Wisconsin. This system is everywhere stratified and conformable throughout. On the Bad and Montreal rivers are found no masses of crystalline limestone.

Irving,[124] in 1872, maintains that the quartzites of Sauk county are unconformably below the Potsdam, because they are uptilted at a high angle, while the Potsdam is horizontal, and the horizontal sandstone abuts against the quartzite and holds fragments derived from it. These quartzites are either Laurentian or Huronian.

Murrish,[125] in 1873, describes the quartzite ranges of Baraboo as a metamorphic sandstone of the Potsdam age. On the Black and Yellow rivers are found granitic and hornblendic Azoic and plutonic rocks. At Black river falls are knobs of magnetic ore in a series of elongated knobs or mounds, associated with quartz and micaceous slate. At Grand rapids, on the Wisconsin river, Azoic rocks similar to those on Black river are found. A quartzite mound at Necedah occupies a geological position similar to the iron ores at Black river falls.

Eaton,[126] in 1873, maps the quartzites of the Baraboo river. At Ableman's the highly tilted quartzites are flanked on both sides by horizontal sandstone and conglomerate, the latter having angular fragments of the quartzite of varying magnitudes. The overlying sandstone is exactly like that described by Irving at Devil's lake as containing Potsdam fossils. The sandstone is above horizontal limestone containing Pleurotomaria. The quartzite is then an old Azoic reef of tilted rocks which has suffered enormous erosion before washed by the waves of the Potsdam sea.

Irving,[127] in 1873, maintains the pre-Potsdam age of the Portland quartzite on the same ground as the pre-Potsdam age of the Baraboo ranges. There is a close similarity between the Baraboo and Portland quartzites and the rocks in northern Wisconsin and Michigan which are now regarded as Huronian.

Irving,[128] in 1874, describes as occurring in northern Wisconsin four distinct groups of rocks, the Laurentian, Huronian, Copper-bearing, and Lower Silurian. The Laurentian consists of granites, gneisses, and syenites for the most part, although there may be various schist beds present. The Huronian rocks consist of siliceous schists, quartz rock, and black slates, magnetic and specular schists and slates, metamorphic diorite and diorite-schists. Its lowest portion is of simple siliceous schist with some granular white quartz, gray quartzite, and black slate. The central portion consists of magnetic and specular slates and schists in which all the ores are found, and the highest and northernmost portion consists of diorites, diorite-slates, diorite-schists, and quartz-slates. The Copper-bearing series is next north of and immediately overlies the Huronian, and is of enormous thickness, never less than 4 miles. The lower portions of the group are probably in part of igneous origin, but the upper portions are beyond all doubt exclusively the results of sedimentation. The group consists of shales, sandstones, conglomerates, amygdaloids, and traps. The sedimentary series do not altogether overlie the trappean beds, but are near their junction directly and unmistakably interstratified with them. The Silurian rocks in Ashland county are in a horizontal position in a trough between two lines of highly tilted beds of the Copper-bearing series. At one place the horizontal sandstone is found within a few hundred feet of the copper-bearing trap and within 2 miles of vertical sandstones of the same group.

In Douglas county the horizontal sandstone is traceable to within a short distance of the trap, and sometimes to actual contact, the trap dipping, whenever it is observable, always to the southward, and having no tilted sandstones and conglomerates associated with them. As the Huronian and Copper-bearing series are in apparent conformity it is concluded that they were once spread out horizontally one over the other, and owe their present highly tilted position to one and the same disturbance; and subsequently, after a long period of erosion, the horizontal Silurian sandstones were laid down over and against the upturned edges of the Copper-bearing series; and that hence the Copper-bearing series is more nearly allied to the Archean than to the Silurian rocks. One fact is, however, difficult of explanation on this hypothesis. In Douglas county at several places the horizontal sandstones, when traced to their junction with the southward dipping trap, present a remarkable change; the horizontal layers are suddenly seen to change from their ordinary position to a confused mass of broken layers, dipping in every conceivable direction and increasing in confusion as the trap is approached, until finally the whole changes to a confused breccia of mingled trap and sandstone fragments. It is suggested that this appearance is due to the movement of the solid trap northward against the sandstone since the deposition of the latter rock. The great lake Superior synclinal of Copper-bearing rocks is found to extend west into northern Wisconsin.

SWEET,[129] in 1876, describes the junction of the Laurentian and Huronian rocks on Bad river. Here at the base of the Huronian series is a siliceous marble dipping to the northward at an angle of 66°, while 100 feet to the south is a ledge of gneissoid granite showing a well defined dip of 77° to the south. There can be no doubt of the unconformability of these formations. The Penokee series is found to be about 5,000 feet thick, to be everywhere conformable, and to dip about 66° to the north.

On the Chippewa is found a quartzite which has a layer the lowest stratum of which is a reddish metamorphic conglomerate having a thickness of 300 feet. The pebbles of this conglomerate are either jasper or amorphous quartz. The conglomerate and quartzite are distinctly and heavily bedded. South of this quartzite are syenitic granites which are assumed to be of Laurentian age, and the quartzites and conglomerates are assumed to overlie them unconformably. A short distance north of the mouth of Snake river cupriferous melaphyres and amygdaloids are overlain by horizontal beds of light colored Potsdam sandstone, while a few miles to the north conglomerates and shales conformably overlie the cupriferous strata. The conglomerate is heavily bedded, but does not cover the melaphyres and amygdaloids at all points, appearing to fill pockets and depressions in them rather than being interstratified. At St. Croix falls on the St. Croix river Potsdam sandstone containing fossils are found in a horizontal position within a few feet of the cupriferous rocks. Depressions and pockets in the surface of the cupriferous rocks are filled with horizontal layers of the sandstone, and detritus from the crystalline rocks are found in its layers. The lake Superior synclinal is traced westward across the state of Wisconsin and enters the state of Minnesota. It is then over 300 miles in length and from 30 to 50 miles in width.

IRVING,[130] in 1877, summarizes the facts proved as to the older rock series of Wisconsin. There are here four series: The oldest (1) are gneisses and granites with other rocks; these are overlain unconformably by (2) a series of quartzites, schists, diorites, etc., with some gneiss and granite; these in turn are overlain—probably also unconformably, but this is not certainly proved—by (3) the Copper series, which includes greenstones and melaphyres and also great thicknesses of interstratified sandstone, melaphyres, amygdaloids, and shales, the whole having a thickness of several miles; these finally are unconformably covered by (4) a series of unaltered horizontal sandstone including numerous fossils, many of which are closely allied to those of the Potsdam sandstone of New York, and all of which have a marked Primordial aspect. To the Laurentian and Huronian systems of Canada are referred (1) and (2) because they bear the same relations to one another and to the Copper series that these systems do.

The exact junction between the Potsdam sandstone and the Huronian quartzite is seen at numerous places. The Potsdam, containing fossils and numerous fragments from the older rocks, lies upon and wedged in between the tilted ledges of the Huronian. Exactly similar unconformability is to be seen at the Dalles of the St. Croix between the Potsdam and Copper series.

WIGHT,[131] in 1877, describes the horizontal Potsdam sandstone as resting on the uneven and tilted surface of the underlying igneous or crystalline rocks at St. Croix falls. Almost in contact with the trap the sandstone contains numerous well preserved fossils. At Pine island in Kettle river the Superior red sandstone contains abundant fragments of the adjacent trap, forming a brecciated conglomerate kindred to the conglomerate which extends from Keweenaw point along the northern base of the Porcupine and Penokee mountains. Everywhere this conglomerate is composed of fragments of the more elevated Huronian or trap ridges. The Superior red sandstone, wherever it borders the trap ridges, shows that it has been tilted, broken up, or crushed. It appears that the trap, whether erupted or upheaved convulsively or slowly, encountered this formation in its ascent. On the contrary, the Potsdam sandstone everywhere rests in a horizontal undisturbed position on the bedding of the trap. Either the Superior red sandstone is older than the Potsdam or the trap rocks in conjunction with the Superior red sandstone are younger than those in conjunction with the Potsdam.

CHAMBERLIN,[132] in 1877, describes the Archean rocks which in the eastern part of Wisconsin protrude but are not intrusive in the Paleozoic formations. These are the Mukwa granite, the Berlin porphyry, the Pine bluff quartz-porphry, the Marquette quartz-porphyry and the quartzites of Portland and Waterloo. The porphyries are found to have obscure but distinct bedding. The metamorphosed quartzites show ripple marks and contain conglomeratic layers. The Potsdam sandstone and Lower Magnesian limestone rest in a horizontal position against and contain fragments from the crystalline rocks. The quartzites are regarded as originally sandstones and conglomerates which were metamorphosed before the deposit of the neighboring horizontal rocks, and which have been tilted and eroded before the stratified rocks were deposited. These quartzites are regarded as a portion of the Baraboo quartzite series.

IRVING,[133] in 1877, describes the Archean rocks which cover all of Marathon, most of Wood, and much of Clark, Jackson and Portage counties, in Wisconsin. The Laurentian is a great mass of crystalline rocks, granite, gneiss, chloritic, micaceous and hornblendic schists which are folded and eroded so as to offer the greatest obstacles to their detailed study. On the south side of the Laurentian core, on Black river, and in isolated masses, are ferruginous schists, quartzites, and quartz-porphyries, which are probably Huronian. The presence of these rocks on the south, the quartzites of Chippewa and Barron counties on the west, and the Huronian rocks of the Penokee range on the north leads to the suggestion that the Huronian rocks entirely surround the Laurentian core of northern Wisconsin. The line of junction between the Archean area and the Potsdam formation to the south is exceedingly irregular. The latter always rests in a horizontal position upon the crystalline formations with the most marked unconformability, the exact contacts being found at several places. The most abundant of the crystalline rocks is gneiss, and the original bedded condition of the whole series is evident, not only by a prevailing gneissoid and schistose character, but also by the existence of distinct bedding planes which can generally, even in the granitoid kinds of rocks, be readily made out. The processes of metamorphism and disturbance have been carried to the last extreme, as shown by the highly crystalline character of the rocks and the fact that the gneiss grades into granite, as well as by the greatly contorted condition of the gneiss laminæ and the close folding of the whole series. While the series as a whole is bedded, distinctly intrusive granite occurs, as shown by the way in which it joins and penetrates the bedded rocks. The main area of the crystalline rocks certainly belongs to the Laurentian, and a small area only on the south of the district is doubtfully Huronian.

Very numerous details are given as to particular localities, showing the manner of occurrence and relations of the different varieties of rocks and the unconformities which exist between them and the Silurian. On Mosinee and Rib hills are found large exposures of quartzite. At Black river falls the regularly bedded succession of highly tilted strata of many members consists in large part of regularly laminated schistose rocks, such as ferruginous quartz-schist and magnesian schist or slate, having together an approximate thickness of at least 5,000 feet. Gneiss and granite are also here found.

Isolated from the main Archean area are quite numerous exposures of crystalline rocks which protrude in mound-like forms from beneath the horizontal strata. The largest of these are the quartzite ranges of Baraboo. About many of these areas are found horizontal sandstone lying immediately against the tilted crystalline rocks and carrying pebbles and bowlders derived from them, proving that they are all of greater antiquity than the surrounding sandstone layers. These relations are particularly well shown in the Baraboo quartzite ranges. Aside from these ranges, the more important areas are the Marcellon, Observatory hill, Moundville, Seneca (Pine bluff), Marquette and Berlin quartz-porphyries, the Montello and Marion granites, and the Necedah quartzite.

IRVING,[134] in 1878, describes at Potato river the siliceous slate, one of the lower members of the Huronian, as in contact with the chloritic gneiss of the Laurentian. The slate inclines at a high angle to the north, while the gneiss layers dip to the south and strike in a direction oblique to that of the slate layers.

CHAMBERLIN,[135] in 1878, describes on the Gogogashugun, in the Penokee district, the exact junction between the Laurentian and Huronian series. The Laurentian member consists of a peculiar gneissoid rock like that which occupies a similar relation at Penokee gap. The Huronian lies in absolute contact with this. Its siliceous material at the time of its deposition so insinuated itself into the irregularities of the surfaces of the gneiss that the two formations are interlocked, and a hand specimen was obtained, one portion of which is Laurentian gneiss and the other Huronian schist, the two being unconformable. The Huronian siliceous schists are overlain by beds of white and red quartzite, and these graduate into alternating layers of quartzite and iron ore. The iron ore horizon is here hematitic and soft, but is the equivalent of the hard magnetic horizon to the west. In this part of the belt is presented the greatest probabilities of the existence of workable ore.

IRVING,[136] in 1880, gives a comprehensive account of the general structure of northern Wisconsin. Here are found four great systems, the Laurentian, Huronian, Keweenawan, and Lower Silurian, all of which are unconformable with each other. The rocks of the crystalline nucleus are correlated with the Laurentian of Canada because they sustain the same structural relations to the Huronian, Keweenawan, and Lower Silurian as does the typical Laurentian of Canada, and because they have the same general lithological peculiarities. There can be no reasonable doubt that they are directly continuous with the Canada Laurentian. The prevailing rocks are granite and gneiss. These rocks are greatly folded and have certainly an enormous thickness. It is evident that these rocks are of true sedimentary origin. The granites are generally without distinct bedding, but no eruptive granite recognizable as such has been observed.

Lying immediately against the Laurentian, and sharply defined from it, extending from Montreal river to lake Numakagon, is a belt of schistose rocks which are beyond question the westward extension of the iron-bearing series of the upper peninsula of Michigan. This belt has an aggregate thickness of strata of 13,000 feet. The subdivisions, beginning below, are (1) crystalline limestone; (2) quartz-schist and argillitic mica-schist; (3) tremolitic magnetite-schists, magnetic and specular quartzites, lean magnetic and specular ores; (4) alternations of black mica-slate with diorite and schistose quartzites; (5) mica-schists with coarse intrusive granite. These major divisions are again subdivided at Penokee gap and vicinity. The system always dips north, usually at a high angle, the strikes are oblique to the underlying Laurentian gneiss, proving the unconformability of the two systems, the actual contact of which can be seen in several places. These rocks are regarded as the equivalent of the Huronian of Canada, because they are the direct continuation of the iron-bearing system of Marquette, because the grand divisions of the Bad river and Marquette system are similar, because they show the same relations to the Laurentian and Keweenawan systems as found in the Huronian of Canada, i. e., newer than the former and older than the latter, and because the Marquette and Menominee sediments are in unconformable contact with the Lower Silurian sandstone.

The Keweenawan system is a distinctly stratified one, in large measure made up of eruptive rocks in the form of flows. These constitute the lower 10,000 feet of the system, and above these are found the detrital rocks, increasing in frequency, until they wholly exclude the igneous rocks in the upper 15,000 feet. The eruptives of the system are chiefly diabase, melaphyre, and gabbro. The succession on the Montreal river is (1) chiefly diabase and diabase amygdaloid, with little satisfactory appearance of bedding and having a width of about 33,000 feet; (2) alternations of (1) with red sandstone and shale, 1,200 feet; (3) bowlder conglomerate, 1,200 feet; (4) alternations of shale and quartzless sandstone, 350 feet; (5) red sandstone and shale, 12,000 feet. If the series is regarded as a continuous one it is at least 50,000 feet thick. There are two prominent belts of the Keweenaw rocks in northern Wisconsin lying parallel to each other and having between them a synclinal depression which is occupied by Chequamegon bay. The Keweenawan system is evidently newer than the Penokee system. That the two systems are actually nonconformable in these regions is not evident, for in sections the dip in passing from one to the other is generally nearly the same. That there is a real unconformity is indicated by the facts (1) that in passing westward from Penokee gap the uppermost beds of the Huronian are gradually cut off by the gabbro that forms the base of the Keweenaw series; (2) that there is not an absolute conformity in dip between the Huronian and Keweenawan rocks; (3) west of lake Numakagon the diabases and other eruptive rocks of the Keweenaw series appear completely to cover the Huronian.

The lake Superior sandstone is always in a horizontal position and is more highly siliceous than the sandstones of the Keweenawan system. At the St. Louis river it overlies unconformably the Huronian schists. In Douglas county are several junctions of the sandstone with the Keweenawan rocks. Here the horizontal sandstones in approaching the eruptive rocks of the Keweenawan system are found to be brecciated and tilted, the original lines of deposition being sometimes entirely obliterated. These peculiar appearances are regarded as due in part to the naturally confused mode of deposition on the cliffy shore in which the sandstone was originally deposited; but a slight movement of the deep-seated crystalline rocks against the more superficial sandstones would also account for much of the phenomena. That the sandstone formation rests unconformably upon th Keweenawan system is further shown by the fact that in the Dalles of the St. Croix the horizontal sandstone and shales, with characteristic Primordial fossils, lie upon the irregular and eroded surface of a Keweenawan melaphyre.

The Penokee series is compared with the Marquette Huronian and there is found to be a general likeness in the rock succession in the two regions. Very numerous detailed sections and outcrops at particular localities are fully described and mapped.

WRIGHT,[137] in 1880, describes the Huronian series west of Penokee gap. The succession here found is limestone, chloro-silicious schists, quartzites, magnetic schists, Keweenawan; the magnetic schists being occasionally interstratified with greenstone. At Penokee gap is found a dolomitic limestone overlain with quartzite and chloro-siliceous schists, which rest unconformably upon the Laurentian rocks. The Huronian rocks here have a dip of 66° to the north, while the Laurentian rocks have a southern inclination from 65° to 80°. West of Numakagon lake the magnetic attractions are found to cease and the Copper-bearing series and granite belonging to the Laurentian are found in direct contact. This appearance is regarded as being due to the covering up of the Lower Huronian by the Copper-bearing rocks.

SWEET,[138] in 1880, describes the geology of the western lake Superior district. The geological formations here found comprise the Laurentian, Huronian, and Keweenawan systems. The Keweenawan rocks are found in a great synclinal. In northern Wisconsin, below the Keweenawan, no southward dipping rocks are found referred to the Huronian, but in

Minnesota, along the St. Louis river are strata which occupy a position inferior to the Keweenawan series, are lithologically like the slates of Ashland county, and are cut by numerous dikes in lithological character precisely like the rock at the base of the Copper-bearing series. They are hence regarded as Huronian. The Copper-bearing strata consist of a detrital upper portion of sandstones, conglomerates, and breccias, having a maximum thickness of 9,000 feet, and of eruptive strata, consisting of melaphyre, diabase, porphyry, gabbro, etc., having an apparent maximum thickness of over 36,000 feet. The quartzites, siliceous schists and chloritic slates along the St. Louis river, referred to the Huronian, are many thousand feet thick. Upon the St. Louis slates at one place the lake Superior red sandstone and conglomerate repose unconformably. The Keweenawan eruptive rocks are bedded. They have a very persistent and quite uniform dip and strike in any given locality. The layers are seldom less than a foot or two in thickness and are more often many feet thick, so as to give an exposure an unstratified appearance. On one side of each layer is a precipitous and somewhat jagged ridge, owing to the exposure of the edge of the layers, while on the other side the soil descends with the inclination of the bedding.

As to the age of the Copper-bearing series, it can be only said that they are older than the lake Superior red sandstone; for when the latter is conglomeratic the pebbles are almost invariably derived from the Keweenaw series. Also the perfectly horizontal sandstones approach in that condition within 15 or 20 feet of the dipping crystalline rocks; and from this it is assumed that they unconformably overlie them. At Black river falls on the lower Black river, at the gorge of Copper creek, and along the west bank of Middle river, the horizontal sandstones are found, in approaching the eruptives of the Copper-bearing series, to become uptilted, brecciated, and in some cases conglomeratic, and sometimes wholly lose their structure. The eruptives in all these cases dip away from the uptilted sedimentary rocks.

CHAMBERLIN and STRONG,[139] in 1880, describe the geology of the upper St. Croix district. The Keweenaw series is composed of two classes of rocks, massive crystalline beds which owe their origin to the succession of outflows of molten rocks, and conglomerates, sandstones and shales derived from the wear of these igneous rocks and from the older formations. They are in part interstratified with the igneous rocks and in part overlie them. The eruptives are mainly diabase and diabase amygdaloid, although melaphyre is found. The Keweenawan beds were deposited in essentially a horizontal condition, were bent into their present trough-like form, and eroded, and upon their upturned edges was deposited the Potsdam sandstone. This is shown by the fact that at St. Croix falls the horizontally stratified sandstone is found within a few feet of an exposure of highly inclined Keweenawan melaphyre containing numerous fragments derived from it. This sandstone has characteristic Potsdam fossils. At one place near the falls the Potsdam is found directly superimposed in a small gorge upon the melaphyre. The melaphyre is cut by vertical planes of division which are quite smooth and uniform; but there is another persistent set which is much less smooth, but persistent and constant in direction. These planes are usually in detail slightly uneven and undulatory, and separated by several feet. They are believed to represent the dip of the igneous beds. It is upon the persistence of these inclined beds, taken in connection with their parallel lithological habit, that the determinations of dip are made. Outside of the district the northward dipping diabase is found on one side of the Numakagon river, while upon the other is seen the Laurentian granite.

BROOKS,[140] in 1880, gives the geology of the Menominee iron region. The Lower Silurian sandstone is found capping the older rocks near lake Eliza. The Laurentian granite, gneiss, and crystalline schist series is not subdivided. No limestones, dolomitic marbles, conglomerates, calcareous or arenaceous chloritic schists are considered as belonging to the Laurentian system. It is not certain whether this series occurs in Wisconsin within the area surveyed.

The Huronian series is divided into lower, middle, and upper divisions. The lower division comprises the lower quartzite of great thickness, the great marble formation, and the great iron ore horizon containing magnetic, hematitic, and jaspery schists as well as deposits of iron. The middle Huronian comprises quartzites, clay-slates, and obscure soft schists. The upper Huronian includes mica-schists, gneisses, and granite, the last of which may possibly be eruptive, but is the topmost member of the Huronian succession. Interstratified with the Huronian are diorites, diabases, gabbros and greenstones, and greenstone schists, which are believed to be conformable beds of metamorphosed sediments. They are never found in the form of dikes. The thickness of the Huronian in the Menominee is not far from 10,000 to 15,000 feet. There is great difficulty in ascertaining exactly the thickness on account of the sharp folds, where thick beds double back upon themselves. This especially affects the quartzites, clay-slates, and greenstones. The relative proportions of the different kinds of rocks of the Huronian and a correlation of the successions in various districts of the Menominee are given, and the twenty members (including the upper granite) are correlated in detail with successions north of lake Huron, and in the Marquette, Gogebic, Penokee, and central Wisconsin regions. The resemblance between the Marquette, Menominee, Sunday Lake, and Penokee series are so numerous as to point unmistakably to their having been formed in one basin under essentially like conditions. Detailed sections and maps of the rock exposures are given at numerous points. The youngest Huronian member, the granite, has a wide extent. While this is true, granite dikes are rare in the Menominee Huronian and have never been observed in the Marquette series. No rocks affording the slightest suggestion of conglomeratic structure have been found in the Laurentian, its rocks always being much metamorphosed and often so much as to destroy all traces of bedding. Underlying the quartzite at Sturgeon river falls is a schist-conglomerate which has numerous pebbles of what appear to be granite and gneiss from the adjacent Laurentian. In the Pine and Poplar river regions is found conglomeratic quartz-schist containing micaceous iron and magnetite. In the Commonwealth section are included quartz-schists which are conglomeratic, containing pebbles of white quartz and jasper. There are also found in the upper beds of the Huronian, conglomeratic micaceous quartz-schists. At various places granites and gneisses overlie conformably the younger Huronian schists, into which they send dikes. As the evidence of bedding is rare, it is possible that toward the end of the Huronian period there was a great eruptive overflow of these rocks. Cutting the Laurentian rocks in all directions are dike-like masses of granite and greenstone. The abundant greenstone dikes of the Laurentian are much more common than in the Huronian, and resemble the Huronian bedded diorites. It is suggested that these dikes have afforded the material for the greenstones and related schists of the Huronian. May not also considerable of the magnetite come from the same source?

WRIGHT,[141] in 1880, in describing the western and southern extension of the Menominee range, states there can be no doubt that the granite is younger than the lower Huronian. This latter dips under the former, and veins of the former penetrate the latter, but whether it belongs to the lower Huronian is an open question.

STRONG, SWEET, BROTHERTON and CHAMBERLIN,[142] in 1882, further describe the quartzites of Barron and Chippewa counties. They are found in several localities to contain beds of conglomerate, to have not infrequently distinct bedding, and to contain locally beds of pipestone.

KING,[143] in 1882, describes the rocks of the upper Flambeau valley. They are found to be mainly granite, gneiss, hornblende-schist and mica-schist, and are all referred to the Laurentian.

IRVING and VAN HISE,[144] in 1882, describe the crystalline rocks of the Wisconsin valley. The crystalline rocks here found are a great series of schistose gneisses. Alternating with these are finer grained and more highly lamellar schists. Intersecting the gneiss are dikes of various basic rocks, while structureless masses of granite, presumably intrusive, are also found. In the vicinity of Wausau are argillaceous quartz schists and quartzites, which on lithological ground may be referred to the Huronian, although of the structural relations of these rocks with the Laurentian gneisses nothing is known.

CHAMBERLIN,[145] in 1883, gives a systematic account of the geology of Wisconsin. The rocks of Laurentian age are mainly of the granitic type, consisting largely of granites, gneisses, syneites, hornblendic, micaceous, and chloritic schists, with allied rocks. These are associated with igneous diabase, diorites, and similar rocks. This series is regarded as a sedimentary accumulation, on the grounds (1) of foliation and stratification; (2) of the alternating bands of varying chemical constitution; (3) of the verging of one kind of rock into another laterally; and (4) of the presence of kinds of rocks not known to be produced by igneous agencies. The thickness of these sediments is enormous. An estimate of 30,000 feet is probably not too great.

The calcareous and carbonaceous beds of the Laurentian of Canada, as well as the Archean limestones and iron ore beds of New York, are considered to be Huronian rather than Laurentian, and if this is so, there is present in the Laurentian no positive evidence of life, although investigations in the future may reveal evidences of organic beings. The development of life in the Primordial is so abundant as to lead to the conclusion that for its evolution to this degree of perfection a vast prior period of time was required which probably would carry the life well down into the Laurentian series. It is further suggested that the abundance of alkaline rocks in the Laurentian may be due to the effects of life in the Laurentian ocean.

Between the Laurentian and Huronian periods the Laurentian beds were closely folded; the sediments were changed by metamorphism to a thoroughly crystalline condition, and the series was profoundly eroded. About the thus formed Laurentian isles was deposited the Huronian. This comprises the Penokee series, the Menominee series, the Baraboo quartzites, the quartz-porphyries of central Wisconsin, the quartzites and catlinite of Barron and Chippewa counties, and the iron-bearing series of Black river falls. These series consist for the most part of limestones, slates, sometimes heavily carbonaceous, quartzites, hematitic and magnetitic schists, mica-schists and diorites. The presence of limestones, carbonaceous shales, and iron ore are taken as the evidence of life. After the deposition of the Huronian it was upheaved, metamorphosed and eroded before the beginning of Keewenawan time, although the unconformity between the two series in Wisconsin is but slight and the above changes were only partially accomplished when the Keweenawan eruptions began. The metamorphism was less in degree than that which has affected the Laurentian strata, but is more intense than that which the Keweenawan series has suffered. It was not in general sufficient to obliterate the original grains and pebbles, nor to destroy ripple and rill marks. In the Huronian strata are igneous beds and dikes of gabbros, diabases, and diorites, the age of which is not certain. They may be, so far as yet known, in part contemporaneous and in part subsequent, or wholly the one or the other.

The rocks of the Keweenawan period consist of interstratified igneous and sedimentary beds; the former mainly diabases, with some gabbros, melaphyres, and porphyries; the latter conglomerates, sandstones, and shales, derived mainly from the igneous rocks. The maximum thickness is about 45,000 feet, of which the upper 15,000 feet is sedimentary. The bottom of the lake Superior basin was gradually subsiding during the time of the formation of these beds. While tilted, they are not contorted or metamorphosed. There is in this period no direct evidence of the existence of life. Over the great conglomerate of the Penokee and Porcupine mountain regions is a black shale that simulates those of later ages formed in association with life. After the close of the Keweenawan period, before the Potsdam sedimentation began, there was a period of erosion. How great this interval was has not yet been determined; quite possibly the lower Cambrian formations of Great Britain and Bohemia bridge the entire interval.

IRVING,[146] in 1883, gives a systematic account of the lithology of Wisconsin. Among the eruptive rocks are placed diabase, melaphyre, gabbro, norite, diorite, peridotite, syenite, porphyry, and granite. Among the schistose rocks are gneiss, mica-schist, hydromica-schist, actinolite-schist, tremolite-schist, hornblende-schist, augite-schist, chlorite-schist, talc-schist, magnetite-schist, hematite-schist, quartz-schist, quartzite in part, chert-schist, and jasper-schist. Among the half fragmental rocks are quartzite, clay-slate, and novaculite. The explanation of the origin of gneiss or lamellar granite by metamorphism, the structure being regarded as residual sedimentation, is regarded as unsatisfactory. Many rocks which have been called metamorphic are placed as eruptive, and it seems not improbable that the same origin is to be attributed to some rocks with a strongly developed schistose structure. The hornblende-schists are regarded as altered forms of augite-schists.

WOOSTER,[147] in 1884, describes, upon the St. Croix river near Osceola mills, the Potsdam sandstone carrying fossils, which grades down into a conglomerate containing pebbles from the Keweenawan, Laurentian, and Huronian series. The sandstone and conglomerate rest unconformably upon the underlying Keweenawan rocks.

FULTON,[148] in 1888, describes the Huronian rocks of the eastern Menominee region as consisting of three formations. The basal formation is a crystalline siliceous limestone at least 1,200 feet thick, which outcrops at many localities along the range, especially north of the Norway, Quinnesec, and Chapin mines. The next group, estimated at a thousand feet in thickness, is the Quinnesec ore formation. It consists of siliceous or jasper slates, largely impregnated with iron oxides. These are succeeded by argillaceous hydromica slates and flesh-colored slates. This formation embraces the deposits of iron ore. The third formation is a series of dark gray, slaty, or schistose rocks, with occasional quartzose bands, having a thickness of 2,000 feet, and is called the lake Hanbury slate group. Detailed sections at the East Vulcan, Curry, Norway, Cyclops, and Quinnesec mines are described. In some cases the ore is associated with the Potsdam sandstone, which rests unconformably in a horizontal position upon the flexed and denuded Huronian rocks. The iron ore beds in the Huronian are generally associated with aluminous slates or soapstones.

SECTION V. WORK OF THE MINNESOTA GEOLOGISTS AND ASSOCIATES.

EAMES,[149] in 1866, mentions different crystalline rocks as occurring at many points in northeastern Minnesota.

EAMES,[150] in 1866, describes in Minnesota various granitic, igneous, and metamorphic rocks. The most prevalent rocks found in the northern part of the state are granite, porphyry, hornblende slates, siliceous slates, trap, greenstone, talcose slate, primitive schistose rock, gneiss, and Potsdam sandstone. The rocks of the Upper Mississippi river are described. At Pokegama falls the rock is a quartzite belonging to the Potsdam. There is also found along the river jasperoid rock with iron ore and argillaceous slate. In Stearns county are numerous exposures of granite. The varieties of rocks in the Vermilion lake district are found to be very numerous.

HALL (JAMES),[151] in 1869, finds in the vicinity of New Ulm, on the Big Cottonwood river and on the Little Cottonwood, extensive exposures of quartzite. At New Ulm the rock is shown to be a metamorphosed quartz rock or conglomerate. This rock is succeeded below by compact quartz rock, with beds of syenite, which graduate still lower into purple or reddish quartz rock in distinct layers, alternating with shaly seams. The quartzite of this region has a thickness of not less than 1,500 feet. At Redwood falls are found gneiss and granitic rocks of Laurentian age. The quartzites are regarded as of the age of the Huronian of Canada and equivalent to the quartzites of Wisconsin.

WHITE,[152] in 1870, describes the quartzites of Iowa, Minnesota, and Dakota. They are completely metamorphosed, intensely hard rocks, although the lines of stratification are distinct and there are frequently seen distinct ripple marks upon the bedded surfaces. Not infrequently the quartzite is conglomeratic. In them no fossils have been found. They are, however, regarded as belonging to the Azoic age because of their complete metamorphic character, because of their disturbed condition, and because the Lower Magnesian limestone at New Ulm rests upon the quartzites unconformably, and in this part of North America no disturbances are known to have occurred between the commencement and close of Paleozoic time.

WINCHELL (N. H),[153] in 1873, states that the granitic and metamorphic rocks occupy a great portion of the state of Minnesota These are regarded as Laurentian and Huronian. Their lithological and mineralogical characters are complex and variable. The original nucleus was granite and syenite, and around these are arranged the metamorphosed slates and gneisses in upturned or even vertical beds, while intercalated with them are numerous injected beds or dikes of trap. The Sioux quartzite and those of New Ulm are placed as a part of the Potsdam sandstone. The Potsdam was laid down before the close of the volcanic disturbance, for the St. Croix beds of later age rest unconformably upon the Laurentian as well as upon the upturned beds of the Potsdam. In lithological character the Potsdam beds differ from those of the St. Croix, being hard and vitreous and usually of a red color. The Potsdam has a thickness of at least 400 feet.

WINCHELL (N. H.),[154] in 1874, gives details as to the geology of the Minnesota valley. The quartzites in the vicinity of New Ulm and Red stone, referred to the Potsdam, are conglomeratic in places. In the valley there are quite numerous outcrops of granite which are sometimes cut by trap dikes. At Granite falls there are sudden changes from real granite to hornblende-schist.

STRENG and KLOOS,[155] in 1877, describe in the Upper Mississippi a set of granitic, syenitic, dioritic, and gabbro-like rocks which are referred to the Laurentian, while north of these is a zone of metamorphic schist—mica-slate, talc-slate, and clay-slate—with gneiss-like rocks, which may be Huronian. South of Vermilion lake is a region of granite, gneiss, and crystalline slate which belong to the Laurentian formation, while occupying a wide extent of country about the St. Louis river are roofing slates and quartzites which are probably the representative of the Huronian. The igneous rocks at the west end of lake Superior are without doubt of Potsdam age. On the St. Croix river is a melaphyre which lies unconformably below a sandstone and conglomerate bearing fossils of Lower Silurian age, which relation points to the Huronian age of the melaphyre.

WINCHELL (N. H.),[156] in 1878, describes the crystalline rocks along the Northern Pacific railroad. Syenites and granites occur at Little falls on the Mississippi, and at Thompson on the St. Louis river are slates, the former varying into a mica-schist. In Pipestone and Rock counties are large exposures of quartzite which are lithologically like those of New Ulm, and like them are placed in the Potsdam.

WINCHELL (N. H.),[157] in 1879, gives the geological results of an examination of the northeastern part of the state of Minnesota. The formations that compose the coast line of lake Superior include, in descending order, (1) metamorphic shales, sandstones, and quartzites cut by dikes and interbedded with igneous rocks, perhaps Sir William Logan's Quebec group. (2) Sandstones, metamorphosed into basaltiform red rock, interstratified with igneous rock along the Palisades and at Black point. (3) A quartzose conglomerate at the Great Palisades and at Portage bay island. (4) The quartzites and slates of Grand Portage bay. (5) The jasper, flint, and iron-bearing belt of Gunflint lake, Vermilion lake and Mesabi. (6) The slates and schists which the Canadian geologists designate Huronian. (7) Syenites, granites and other rocks which have been classed as Laurentian. (8) The igneous rocks known as the Cupriferous series. The Cupriferous series seems to overlie several formations unconformably, and is interstratified with some of the later, and especially with Nos. 1 and 2.

WINCHELL (N. H),[158] in 1880, describes the Cupriferous series of Duluth. At Duluth the most important rock is the gabbro. This is intimately associated with a syenitic granite which is a metamorphic rock, all stages being seen, from the perfectly crystalline granite to the unchanged sedimentary layers. The Cupriferous series is regarded as Potsdam.

UPHAM,[159] in 1880, describes granites and gneisses at numerous localities in the Minnesota valley. In the conglomerate opposite New Ulm and in the quartzite at Red stone are found numerous pebbles of quartz and jasper, but no granite pebbles are seen, although it outcrops close to the west.

HALL (C. W.),[160] in 1880, describes the rocks between the mouths of Poplar and Devil's track rivers on lake Superior to be dark colored basic rocks of igneous origin belonging to the Cupriferous series, with the exception of a few beds of sandstone and conglomerate interbedded with the igneous rocks. The Sawteeth mountains are formed as a result of combined igneous action and the folding of sedimentary strata and erosion.

WINCHELL (N. H.),[161] in 1881, gives many details as to the rocks of northeastern Minnesota. At Pigeon point is a massive bedded or jointed formation like that at Duluth, with which it may be parallelized. The latter belongs to the Cupriferous series and the former to the Animikie, so that the Animikie appears to be a downward extension of the Cupriferous. At Mountain lake the hills are short monoclinals of gray quartzite, with beds of argillaceous and black slate, dipping to the southward usually at an angle of 8° or 10°, and covered with a greater or less thickness of trap rocks. In beds generally less than 50 feet, but sometimes 150 feet thick, the trap and slate dip together, so that the hills have gradual slopes toward the south, and steep or perpendicular slopes toward the north. The quartzite must be an immense formation, as it is seen at Grand portage and all over Pigeon point, and on the islands of the point. The quartzite formation of Gunflint lake seems to graduate downward into the irony and carbonaceous Gunflint beds. A greenish, schistose, porphyritic rock cut by veins of milky quartz is found in nearly a vertical attitude on Gunflint lake. This is supposed to be the Canadian Huronian, and underlies the quartzite and Gunflint beds apparently unconformably; at least, it is a distinct formation from the Grand portage slates. The quartzite is locally a quartzite conglomerate. The Knife lake serpentinous quartzite is regarded as Huronian. On the south side of Vermilion lake are beds of jasper and iron which are regarded as the equivalent of the Gunflint beds. These are conformable with the magnesian schists and slates, which are in a vertical attitude. They pass down into the schists, and in places the schists and schistose structure penetrate the jasper and iron. It is suggested that the apparent conformity between the ferruginous beds and underlying slates and schists is only a superinduced one, the original bedding, which may have been nearly horizontal, having been obliterated by the change.

WINCHELL (N. H.),[162] in 1881, describes the Cupriferous series of Minnesota as having a wide extent. In passing from the shore of lake Superior it gradually becomes more changed and crystalline. The tilted red shales, conglomerates, and sandstones at Fond du Lac are the same as those associated with the igneous rocks all along the shore. At Fond du Lac they lie on a white quartz pebbly conglomerate a few feet in thickness, which rests unconformably on the roofing slates of the Huronian, the same formation that succeeds to the red rock formation at Ogishki Manissi and Knife lakes, northwest of Grand Marais. The Cupriferous series differs from the Upper Laurentian or Norian only in the absence of beds of limestones, but, as the lake Superior Cupriferous is Cambrian or Lower Silurian, it is inferred that the so-called Upper Laurentian, containing *Eozoon canadense*, is really Cambrian or Lower Silurian.

WINCHELL (N. H.),[163] in 1882, continues his description of localities. At Fond du Lac the detailed succession of sandstones and shales is given. The flint and jasper formations of Gunflint lake appear to be in apparent unconformity with the underlying slates and syenites. On Ogishki Manissi lake is found a great conglomerate. This conglomerate carries large rounded pieces of the Saganaga granite, which proves the greater age of that granite and the unconformability to it of the conglomerate. The conglomerate also contains red jasper.

The descending succession in northeastern Minnesota is (1) the horizontal quartzites and slates running from Grand portage to Gunflint lake; (2) the conglomerate; (3) jaspery and calcareous Gunflint beds; (4) gray marble; (5) the tilted slaty Ogishki Manissi conglomerate; (6) amphibolitic and chloritic slates; (7) mica-schists alternating with syenite; (8) syenites and granites of Saganaga and Gull lakes. As to whether the Gunflint beds belong with the schistose and tilted slates and conglomerates of Ogishki Manissi lake is an open question, although there are several things which indicate that they belong to the same series. The gabbro is found to have a widespread extent. It is suggested that if this gabbro and the associated red gneisses belong to the Cupriferous, the Minnesota and Wisconsin quartzites, as well as the red gneisses of the Upper Mississippi valley, may also belong to this series. The red syenite of Beaver bay is a metamorphosed conglomerate which was brecciated and mingled with the trap. This red rock was fluidized so as to intrude itself in the form of belts and veins. A conglomerate at Taylors falls, on the St. Croix, contains water-worn bowlders and traps of the region, but the superposition of the conglomerate on the trap can not actually be seen. This sandstone is fossiliferous. It is concluded that the Potsdam is represented by the copper-bearing series, while the underlying Animikie is equivalent to the Taconic of Emmons.

UPHAM,[164] in 1884, describes the crystalline rock outcrops in central Minnesota.

CHESTER,[165] in 1884, describes the rocks of the Mesabi and Vermilion iron ranges. The slates and schists on the south side of the Mesabi range are nearly horizontal. The rocks here found are precisely like those of the Penokee region of Wisconsin, and the two series bear the same relation to the Huronian series. The iron ore at Vermilion lake is found in connection with jasper and quartzite and is intimately bedded with the country rock, chiefly sericite-schist, standing in nearly a perpendicular position. These rocks are the representative of the Michigan and Wisconsin iron deposits, and there is no doubt that they belong to the Huronian. The Vermilion deposits bear the same relations to the granite as do those of Mesabi, and they are regarded as the same formation.

WINCHELL (N. H.),[166] in 1884, gives the general succession of rocks in northeastern Minnesota, in descending order, as follows: (1) Potsdam, including the Keweenawan sandstones, shales, and conglomerates, changed by igneous gabbros and dolerites locally to red quartzites, felsites, quartz-porphyries, and red granites. (2) Taconic group, including the Animikie series, the Gunflint beds, the Mesabi iron rocks, the Ogishki Manissi conglomerate (?), the Thompson slates and quartzites, and the Vermilion iron rocks. (3) Huronian group (?), including magnesian soft schists, becoming syenitic and porphyritic, found on the north side of Gunflint lake, along the national boundary, and at Vermilion lake. (4) Montalban (?), including mica-schists and micaceous granites about Vermilion lake and on the Mississippi river. (5) Laurentian, including massive hornblende-gneiss and probably the Watab and St. Cloud granites. This succession is parallelized with those of other writers given for the northwestern States.

WINCHELL (N. H.) and UPHAM,[167] in 1884 and 1888, give detailed geological maps and descriptions of many of the counties of Minnesota, which include the Laurentian gneisses and granites of the Mississippi and Minnesota rivers, the slates of the Upper Mississippi, the quartzites and conglomerates of Cottonwood, Pipestone, Rock, Brown, and Nicollet counties, which are regarded as Potsdam sandstone. The copper-bearing traps and conglomerates of Chisago and Pine counties are placed as Lower Cambrian. These reports contain nothing as to structural relations not found in the annual reports.

WINCHELL (N. H),[168] in 1885, finds between Two harbors and Vermilion lake two rock ranges, the first being Mesabi proper and the second the Giant's range. Resting unconformably upon the syenites of Giant's range are the Huronian conglomerates and greenstones of Vermilion lake, while south of this range are the slates and quartzites of the Animikie, overlain by the gabbro and red granite of the Mesabi range, which is in turn overlain by the trap rocks of the Cupriferous series. The Huronian is represented as resting conformably below the Animikie, although not appearing at the surface. There are three iron-ore horizons, the titanic iron of the gabbro belt, the iron ore of the

Mesabi range belonging in the Animikie, and the hematite of the Vermilion mines, which seems to be the equivalent of the Marquette and Menominee iron ores.

WINCHELL (N. H.),[169] in 1885, finds in the red quartzite at Pipestone two fossils, *Lingula calumet* and *Paradoxides barberi*, which are taken as indicative that this formation, as well as the Sioux quartzite of Iowa and Dakota, the Baraboo quartzites of Wisconsin, the quartzites of southwestern Minnesota, as well as the associated red gneisses, felsites, and felsite-porphyries, are all Primordial.

UPHAM,[170] in 1885, gives descriptions of the quartzites of Minnehaha county, Dakota. These are not infrequently ripple-marked and conglomeratic; they are like the quartzites of Pipestone county in Minnesota, and, like them, are placed in the Potsdam.

WINCHELL (N. H),[171] in 1885, divides the crystalline rocks of the northwest into six groups, in descending order: (1) A granitic and gabbro group, which is a part of Irving's Cupriferous, and is by Hunt parallelized with the Montalban. It includes rocks which have passed for typical Laurentian; while the gabbros are eruptive and are like the Upper Laurentian or Norian of Canada. The granites and gneisses show evidence of metamorphic origin. Below the granite and gabbro is (2) a mica-schist group. This is penetrated by biotite-granite. (3) Is the black mica-slate group, which often contains graphitic schists, in which are such ore deposits as the Commonwealth mine of Wisconsin. (4) Is a series of obscure hydromicaceous and greenish magnesian schists, along with quartzites and clay slates, with which are the more important bodies of hematitic iron ores, including those at Marquette and the magnetic belt at Penokee. (5) Is the great quartzite and marble group. It includes the marble of Menominee and marble and lower quartzite of Marquette, the great conglomerate of Ogishki Manissi lake and the lower slate-conglomerates of Canada. In (6) are the granites and syenites with hornblende-schists. This is the lowest recognized horizon of the Laurentian. Nos. 3, 4, and 5 together are the equivalent of the Taconic system, 3 being the equivalent of the Animikie, while 5 is the equivalent of the Huronian of Canada. This succession is compared with the successions of Brooks and Irving in Michigan and Wisconsin.

WINCHELL (ALEX.),[172] in 1887, gives detailed observations made on an extensive trip in northeastern Minnesota. The region presents a series of schists flanked on the north and south by massive crystalline rocks. In the western part of the district these rocks are gneissic on both sides, but to the east the gneissic rocks on the south are replaced by gabbro and greenstone. The schists and bedded crystallines stand in a nearly vertical attitude, having a persistent and uniform strike and dip, the latter oscillating from 80° to the north to 80° to the south. The rocks are sericitic, chloritic, micaceous, and hornblendic schists, and argillites and graywackes. The schists grade into the gneissic rocks, there being nowhere an abrupt passage from one class to the other. In the passage from the schists to the gneisses there is first an increase in frequency of ramifying veins, then lumps of gneiss or granite in the schists, and next interstratification of the schists and gneisses. The conglomerate at Ogishki Manissi lake, which attains an enormous development and contains varieties of granitic and quartzose bowiders, as well as flint, jasper, and other substances, is regarded as a local phase of the schists, as the bowlders are interbedded with the flinty argillites and sericite-schists. The entire system of gneisses and schists is regarded as belonging to one structural system, as they all possess a common dip and pass by gradations into each other. The iron-bearing rocks are interlaminated with the country schists, and while they exhibit much persistence, they do not persist without interruption. In structure the region is a simple synclinal fold, the strata of which have a thickness of 106,204 feet. The succession from the bottom upward is granite, gneiss, micaceous and hornblendic schists, graywacke, argillite-schist bearing conglomerates, and sericitic and chloritic schists bearing iron ores. As the plainly fragmental rocks grade by imperceptible stages into the gneiss and granite, the whole is regarded as a sedimentary series. While granite pebbles are found in the conglomerates, this is not the underlying granite, as many of the fragments differ in character from the inferior granite.

WINCHELL (N. H.),[175] in 1887, gives very numerous details as to the geology of northeastern Minnesota. At several places there are transitions between the granite gneiss and a fine grained mica-schist. In the syenite are sometimes found angular fragments of micaschist. The Vermilion group is defined as including the lower portion of the complex series of schists designated as Keewatin by Lawson. It embraces the mica-schists and hornblende-schists of Vermilion lake and their equivalents, and lies between the graywackes on the one side and the basal syenites and granites on the other.

The iron ores of Minnesota are at three horizons. At the top are the titaniferous ores, which are associated with the gabbro and constitute what is locally known as Mayhew Iron range, and is found from this range at many points all the way to Duluth. The nontitaniferous magnetic ores occur at several localities associated with hematite ores and included in a quartz-schist. These ores are comparable to those of the Penokee-Gogebic Iron range on the south side of lake Superior, and those of Black river falls in Wisconsin. Adjacent to Vermilion lake are hematite ores associated with jasper, which are inclosed in a schist, the bedding of which stands vertical. This schistose rock is probably of igneous origin, and in its relations to the jasperoid rocks it fills all their cavities, overlying them unconformably, and holding fragments of the jasper; all indicating its later origin. This igneous rock passes into a chlorite-schist, and this into the sericite-schists and graywackes, which show unmistakable evidence of an aqueous arrangement. The jasperoid hematite is a sedimentary rock and not an eruptive as has been supposed by Wadsworth. The rock was not, however, deposited in its present condition. The beds have been upturned, folded, crushed, and affected by intense chemical action. The ore is regarded as a result of chemical or metasomatic change. The general succession from above downward is as follows: (1) gabbro; (2) diabase dolerite. These rest unconformably upon the lower members. (3) Reddish gneiss and syenite, which includes the Misquah hills, White Iron lake, and the Giant's range (Mesabi heights). This is a case of a fusion of sedimentary beds in situ, although it is not generally complete. (4) Graywacke, sericite-schist, argillite, quartzite, and jaspilite, which occur about Vermilion lake. (5) Mica-schist, hornblende-schist, and diorite. The Vermilion group. (6) Mica-schist and granite veined with syenite and granulite. (7) Lower syenites and gneisses, generally regarded as Laurentian. Nos. 3 to 7 are conformable, and Nos. 4 to 7 graduate into each other.

There is reason for believing that the Animikie rocks overlie the greenstone No. 2 and underlie the gabbro, No. 1, of the above succession.

WINCHELL (N. H.),[174] in 1888, finds the Upper Huronian quartzites to be so similar to those of Pipestone, Cottonwood, and other counties in Minnesota that the former are regarded, with the latter, as Huronian. The Animikie on Gunflint lake, while not found in exact superposition on the Keewatin, bears such relations as to render it probable that the two formations are discordant. A short distance north of the Animikie the Keewatin rocks are found with a dip of 80°, and these a little farther to the north grade conformably into the crystalline schists of the Vermilion group, and these still farther to the north by transition pass into the gneisses and syenites of the Laurentian. The Animikie rocks are found resting unconformably on the gneiss west of Gunflint lake. The gabbro is observed overlying the Animikie at many places, the Pewabic quartzite, the Keewatin rocks north of Gunflint lake, and the syenite-gneiss north of Flying Cloud lake.

In passing from Gunflint lake the Animikie is found to have a dip as high as 30°. Near Gobbemichigomog lake there is a gradation from the flat-lying Animikie to rocks in a broken and tilted condition, and from these into the Ogishki Manissi conglomerate, with which they are interstratified. There is also extending from Stuntz island in Vermilion lake past Ely to near Ogishki Manissi lake an older schistose eruptive-looking conglomerate associated with the Keewatin schists, and therefore older than the Ogishki conglomerate. The beds on the north side of Gunflint lake resemble those on the south side of the Giant's range and belong in the same stratigraphical position near the beds of the Animikie. The gneiss is regarded as a metamorphosed sediment, because of the gradation of the Keewatin beds into it, and because it cuts through and is interstratified with the Keewatin. The Keewatin schists are interstratified eruptives and sedimentaries, as is the Cupriferous series. On Kékékabik lake there is an extension of the Ogishki Manissi conglomerate westward. The green schist conglomerates here found are apparently of about the same date as the Ogishki conglomerate or else its immediate conformable successor. The Animikie slates associated with this green schist conglomerate are also in conformable succession to the green schists, but it is likely that this conformity would not be found in the vicinity of the old volcanic vents.

WINCHELL (ALEX.),[175] in 1888, finds upon Wonder island in Saganaga lake a conglomerate which contains abundant rounded pebbles in a groundmass of syenite. The lower limit of the conglomerate is quite abrupt, and whether it overlies the syenite or grades into it is uncertain, but it is figured as overlying the syenite. The syenite is regarded as erupted after the conglomerate existed and the conglomerate was not laid down on the solidified syenite. The Animikie slates are found resting unconformably upon vertical schists, gneisses, and syenites at several points on Gunflint lake, 2 miles west of Gunflint lake, and on the north side of Epsilon lake. On the west side of Sea Gull lake the conglomerate and syenite are interbedded. This conglomerate is thought to be comparable with that of Wonder island. On the north side of the same lake the syenite contains sharply limited rounded pebbles and irregular masses of hornblendic and diabasic material. On Epsilon lake the argillite has schistic planes standing vertical, while the bedded structure has a dip of only 23°.

Summing up the succession: At the base are the granitoid and gneissoid rocks in three areas, the Basswood, White Iron, and Saganaga lakes. These granitic masses everywhere have a bedded structure more or less distinct. They are traversed by quartzose and granulitic veins, as well as dikes of diabase. The gneisses and granites are flanked by vertical crystalline schists of the Vermilion group. The transition from the gneisses to the crystalline schists is never abrupt, but is a structural gradation, near the line of junction the beds of gneisses and schists occurring in many alternations. Above the Vermilion group are the Keewatin semicrystalline schists, the two series being everywhere conformable; but there is a somewhat abrupt change from one group to the other, and there is a possibility that the original unconformity has been destroyed by lateral pressure, although such an unconformity is thought improbable. There has been no actual connection traced between the Keewatin schists north of Gunflint lake and those of Knife lake. The Keewatin schists are almost everywhere vertically bedded. When the bedding is obscure this is sometimes due to the action of erupted masses, but more often the cause of the metamorphosed condition of the strata is not ascribable to any visible cause. The Keewatin schists include graywacke, argillite, sericite-schist, chlorite schist, porphyrellyte schist and hematite.

The Ogishki conglomerate is placed as a part of the Keewatin system as it is traced by actual gradations into the adjoining argillites. These argillites and associated schists are in continuity with the argillites and schists of Vermilion lake, while in the conglomerate itself are local developments of sericite-schist. The bedding of the conglomerate is nearly vertical; its pebbles are metamorphosed; they include numerous varieties, among which are syenite resembling the Saganaga syenite, greenstone, porphyry, red jasper, flint, quartz, petrosilex, ordinary syenite, diorite, porphyroid, siliceous schist, and carbonaceous siliceous argillite. On structural as well as lithological grounds the Ogishki conglomerate seems to be a part of the Keewatin, although there are some reasons for suspecting it to grade into the Animikie. That the Keewatin schists are eruptive is regarded as improbable.

The Animikie series, resting unconformably upon the Keewatin, stretches from Thunder bay as far as Duluth and still beyond to the Mississippi river, and perhaps includes the slates as far west and north as Knife lake. The Animikie formation is generally in a nearly horizontal position, the dip not being more than from 5° to 15°. The formation is essentially an argillite, which embraces jaspery, magnetitic, hematitic, and sideritic beds. At Gobbemichigomog lake the Animikie, represented by the "muscovado," is in its characteristic horizontal position, while the vertically bedded terrane underlies it.

For the system of semicrystalline schists subjacent to the Animikie, to which the term Keewatin has been applied, Marquettian is proposed. The succession of terranes in northeastern Minnesota is, in descending order, then as follows: (1) Huronian system, over 4,082 feet thick, including the magnetic group, siliceous group, and argillite group; (2) Marquettian system, 27,500 feet thick, including the Ogishki group, 10,000 feet thick, the Tower group (earthy schists), 15,000 feet thick, and the graywacke group, 2,500 feet thick; (3) Laurentian system, 89,500 feet thick, including the Vermilion group, over 1,500 feet thick, and the gneissic group, over 88,000 feet thick. Total, more than 121,082 feet.

WINCHELL (H. V.),[176] in 1888, gives detailed observations about many localities in northeastern Minnesota. The mica-schist and interbedded gneiss are cut by granite veins at numerous places.

WINCHELL (N. H.),[177] in 1888, maintains that there is a great Primordial quartzite extending from New England through Canada, Wisconsin, and Minnesota to the Black hills of Dakota. It includes the Taconic quartzite of Emmons, that of Sauk and Barron counties in Wisconsin, the Sioux quartzite of Dakota, the quartzites of Minnesota, and those of the Black hills of Dakota. At the exhibition in New Orleans in 1884 was seen a block of the Potsdam sandstone of the state of New York exactly similar to the Pipestone quartzite of Minnesota, and as the latter bears Primordial fossils there is no lack of evidence to parallelize these outcrops. An examination of the quartzites of the

Original Huronian convinced the author of the parallelism of the great quartzite there displayed with those of Wisconsin and Minnesota. But things that are equal to the same thing are equal to each other, hence the Huronian quartzite is no other than the Potsdam sandstone of New York, the Red sandrock of Vermont, and the granular quartz of the Taconic.

WINCHELL (N. H.),[178] in 1889, gives a summary of the results of work on the crystalline rocks of northeastern Minnesota. In many points the conclusions and facts are the same as in the previous reports. The Laurentian age is made to include the gneiss, granite, and syenite, but excludes the crystalline schists. It is the fundamental gneiss of Minnesota. Associated with this fundamental gneiss are areas of massive eruptive syenite which are regarded as due to the hydrothermal fusion of the gneissic belts. The gneisses grade into the Vermilion schists, which are the equivalent of Lawson's Coutchiching. Along their contact the Laurentian plays the part of intrusive rocks, which is indicative that the opening of Vermilion age was one of violent volcanic action. The beds have subsequently been affected by hydrothermal fusion, which has tended to unify the Laurentian and Vermilion systems.

The Vermilion group passes by conformable transition into the Keewatin. The character of the Keewatin rocks indicates that there was active volcanic action during the whole period and that the ejectimenta were received and distributed by the waters of the surrounding sea. This is indicated by the alternation of breccias and volcanic material with truly sedimentary strata. The Keewatin is the iron-bearing formation. The iron ore is associated with the jaspilite, which is of a sedimentary origin. Parallel with the Keewatin of Minnesota is the serpentine and dioritic group of Rominger in the Marquette region. Above this group in both regions is a profound unconformity.

The Animikie series of Minnesota, bearing iron at one horizon, is the equivalent of the Marquette series bearing the iron group of Rominger, of the Penokee-Gogebic series of Michigan and Wisconsin, of the Mesabi range in Minnesota, of the Black river iron-bearing schists in Wisconsin, and of the quartzites of the Black hills. All are of Taconic age, for the Lower Cambrian is equal to the Taconic, the Huronian is equal to the Taconic; therefore the Lower Cambrian is equal to the Huronian.

In the Potsdam sandstone, which is unconformably on the Taconic, is included the upper quartzites of the Original Huronian, certain of the quartzites of Marquette, the Sioux quartzites of Dakota, and the quartzites of Minnesota and Wisconsin. This is also the age of the Copper-bearing rocks, which are an alternation of basic and acid eruptions with interbedded sandstones and conglomerates. The great gabbro eruption is later than the beginning of the Potsdam age. Unconformably above the Potsdam is the St. Croix sandstone.

The general succession in descending order is then as follows:

Calciferous	Magnesian limestones and sandstones	Dikelocephalus horizon
St. Croix	Sandstones and shales	
	Overlap unconformity.	
Potsdam	Quartzite, gabbro, red granite, and Keweenawan	Paradoxides horizon.
	Overlap unconformity.	
Taconic	Black and gray slates and quartzites, iron ore (Huronian, Animikie)	Olenellus horizon.
	Overlap unconformity.	
Keewatin	(Including the Kawishiwin or greenstone belt, with its jaspilite), sericitic schists and graywackes	Archean.
Vermilion	(Coutchiching) crystalline schists	
	Eruptive unconformity.	
Laurentian	Gneiss	

WINCHELL (H. V.),[179] in 1889, gives further observations on the iron regions of Minnesota. On the Giant's range the Animikie is found to rest upon the syenite. Here is a semicrystalline rock between the two, which grades into the syenite. The character of the transition is not metamorphic, but rather fragmental, there appearing to be a certain amount of loose crystalline material which has resulted from the decay and erosion of the syenite lying on top of this rock in the bed of the sea upon and around which the Animikie sediments were deposited. The coarse detritus grades up into the fine detritus of the Animikie. The Animikie beds are found also to rest unconformably upon the upturned edges of the Keewatin schists. The same relations are found to prevail in the Birch lake region. The gabbro containing ores in the vicinity of Kawishiwi river are found to contain fragments of the Animikie slates and quartzites, and is, therefore, of later origin. At Gunflint lake the Animikie rests uncomformably upon the Keewatin, and is found upon greenstone. The Keewatin schists are largely of eruptive origin. The contacts of the jaspilite with the basic schists are abrupt and angular, and numerous fragments are found contained in the schists. The jaspilite is regarded as a sedimentary formation which was broken up and involved in the eruptions of Keewatin age. The Huronian quartzite associated with the magnetite, lying unconformably upon the syenite, is believed to lie conformably upon the Animikie slates.

GRANT,[180] in 1889, gives geological observations made in northeastern Minnesota. North of Gunflint lake the vertical Keewatin and crystalline schists, with an east and west strike, strike directly across a range of immediately adjacent gneisses, the schists showing no evidence of being twisted or bent within 200 feet of the gneiss. In the syenites of Gunflint lake are found fragments of schist, which indicate that the syenite is eruptive later than the schists. At Winchell lake the syenite upon the top grades down by an apparent transition into gabbro. The gabbro is sometimes cut by veins or dikes of syenite, which indicates that the latter is of later age, although the syenite is generally below the gabbro.

WINCHELL (ALEX.),[181] in 1889, maintains that the Saganaga and West Sea Gull granite conglomerate before described is produced from a fragmental rock by selective metamorphism, the completely crystalline gneissoid rocks retaining rounded fragments which are residual clastic material. The conglomerate of Wonder island is not one consisting originally of a mass of pebbles over which a fluid magma has been poured, for the pebbles are not in contact; they could not have lain where they are before the gneissic magma existed. The gneissic magma was present, and it was this which supported the pebbles and prevented their contact. It is, then, contemporaneous with the pebbles. The magma must have been plastic, but it was low temperature igneo-aqueous plasticity.

WINCHELL (N. H.),[182] in 1889, in a general discussion of the origin of the eruptive rocks, maintains that there are four epochs of basic eruption in Minnesota: first, the Vermilion group; second, those succeeding the graywackes; third, those succeeding the Animikie; and fourth, those of the Cupriferous formation.

MEADS,[183] in 1889, describes the Stillwater, Minnesota, deep well. The well, after passing through about 700 feet of St. Croix and Potsdam sandstone, passes into rocks which are in every respect identical with those of Keweenaw point; hence the Keweenaw rocks are below the light colored sandstones of the northwest. For the first 1,500 feet these are brown shales and brown feldspathic sandstones, and these gradually assume the characters of a volcanic detrital tuff—amygdaloid—and finally at a depth of 3,300 feet unmistakable beds of trap were encountered alternating with sandstone beds. At this depth grains of native copper were seen in the drillings.

WINCHELL (N. H. and H. V.),[184] in 1889, maintain that the iron ores of the Keewatin of Minnesota are not derived from a carbonate, but are probably a direct chemical precipitate; for there is no evidence of the existence of carbonate of iron at any time, and the nature of the country rock is such as to imply that no carbonates in amounts required could have been deposited at the time the rocks were formed.

WINCHELL (ALEX.),[185] in 1890, repeats his general conclusions as to the stratigraphy in northeastern Minnesota and gives in descending order a succession, as follows:

V. The Uncrystalline schists (Animikie, Huronian).
IV. The Semi-crystalline schists (Keewatin).
III. The Crystalline schists (Vermilion).
II. The Gneissoid rocks.
I. The Granitoid rocks (Laurentian).

WINCHELL (N. H. and H. V.),[186] in 1890, state that the iron ores of Minnesota are at five different geological horizons, in descending order, as follows: (1) The hematites and limonites of the Mesabi range, the equivalents of the hematites of the Penokee-Gogebic range in Wisconsin; (2) the gabbro titaniferous magnetites near the bottom of the rocks of the Mesabi range; (3) Olivinitic magnetites, just below the gabbro in the basal portion of the Mesabi rocks; (4) the hematites and magnetites of the Vermilion range in the Keewatin formation; (5) the magnetites of the crystalline schists of the Vermilion formation. It is maintained that the upper iron deposits of the Mesabi and those of the Penokee-Gogebic are the equivalents of the Taconic ores of western New England.

WINCHELL (N. H.)[187], in 1891, gives numerous additional field observations. The relations of the jaspilite, argillite, and green schist are considered, and the argillite at least is regarded as a sedimentary rock. The position of the Pewabic quartzite is left uncertain. It is considered, however, to overlie the Animikie black slate, unless there are two great quartzites. This quartzite has heretofore been made the parallel of the great quartzite that overlies the Animikie unconformably, but it is possible that it runs below it conformably. In the Stuntz conglomerate is found a large bowlder which contains pebbles of chalcedonic quartz and quartzose felsite and the porphyrel at Kekekabik lake. A study of the ore formation leads to the conclusion that al three of the known agencies for rock-forming were intermittently at work and concerned in the formation of the iron ore, viz: *Eruption*, to afford the basic eruptive material; *sedimentation*, to arrange it (in the main), and *chemical precipitation* in the same water, to give the pure hematite and the chalcedonic silica. The great gabbro of the Cupriferous formation is regarded as lying below the Animikie, among other reasons, because it lies next to and immediately south of the gneiss of the Giant Range without the appearance of any black slate between them; and because bowlders of characteristic gabbro, red syenite, and quartz-porphyry occur abundantly in the later traps of the Cupriferous.

WINCHELL (N. H and H. V),[188] in 1891, give an extended treatment of the iron ores of northeastern Minnesota and the rocks in which they are contained. Excluding the Cretaceous, the rocks here found are divided in descending order, as follows: Keweenawan—trap rocks, tuffs, red sandstones, and conglomerates (Potsdam?); Animikie—black slates, gray, feldspathic sandstones and limestones; Norian—gabbro of the Mesabi hills, red granite, quartz-porphyry, red felsite; Pewabic quartzite (Granular quartz, Potsdam?); Keewatin—sericitic schists, graywackes, greenstones, agglomerates, jaspilite; Vermilion—mica-schists and hornblende-schists (Coutchiching?), Laurentian—sedimentary, gneissic and eruptive, massive or porphyritic. The Keweenawan to the Pewabic inclusive are placed in the Taconic, and the Keewatin to the Laurentian inclusive in the Archean or Azoic.

The jaspilite and schist of the Keewatin are found to occur sometimes minutely interlaminated; at other times the jasper is in irregular layers, which never have any great extent and always finally pinch out; at other times it is in oval forms, the greater lengths being parallel with the schistose structure. Again, the jaspilite is in great fragments within the green or massive diabasic schists, the masses having sometimes such relations with each other as to show that they are a broken continuous layer. The branches from the large bodies of jaspilite are supposed to be caused by the crumpling, breaking, and squeezing of the entire rock structure by which the thinner sheets have been buckled out and thrust laterally among the inclosing schists. The ore always occurs associated with the jaspilite, the forms of the deposits being exceedingly irregular. The ore and jasper are regarded as a direct chemical deep-sea precipitate, accompanied and interrupted by repeated ejections ot basic volcanic rocks from which the iron for the ore is extracted.

The rocks of the Animikie equivalent to the Huronian and included in the Taconic consist chiefly of carbonaceous and argillaceous slates with siliceous slates, fine-grained quartzites, and gray limestones. At the bottom of the series is a fragmental quartz sandstone 300 feet in thickness, which is named the Pewabic quartzite. The slates, conglomerates, and quartzites are profoundly affected and intermingled with eruptive material which is similar to that found so abundantly in the Keewatin. These beds have the appearance of consolidated beds of basic lava or of porous tuff, but where this prevails there is a sensible gradation from the dark trap-looking beds to thin beds of slate. At Ogishki lake there is a slate conglomerate similar to that on the north shore of lake Huron. This conglomerate is not the same as the agglomerates of the Keewatin such as that on Stuntz island, at Vermilion lake and Ely. The Keewatin is always nearly vertical while the dip of the Taconic rarely exceeds 15°. The iron-ore beds of the Taconic are the quartzose, hornblendic, magnetitic group of the Pewabic quartzite; an impure jaspilite, hematite, and limonite group; a carbonated iron group; and a gabbro titanic iron group. The jaspilitic hematite group has the same lithological peculiarities as the jaspilite beds of the Vermilion range. The gabbro in which the titanic iron occurs constitutes the Mesabi range. This has been before regarded as the base of the Keweenawan, into which it fades upwardly, but it has been found that this great gabbro flow was outpoured at an earlier date, and it is placed at or near the bottom of the Animikie.

WINCHELL (H. V.)[199], in 1891, states that the syenite of Saganaga lake is conglomeratic in places and contains pebbles which are similar to each other, being mostly composed of lamellar augite, with or without grains of feldspar, but there are no pebbles of syenite or jasper such as occur in the Keewatin conglomerates. In the Saganaga granite, at the end of the portage on Granite river, is a band of silica 1½ inches in diameter and 3 feet in length. North of Saganaga lake the syenite grades into chloritic syenite-gneiss, and this into thick bedded to massive Keewatin rocks. From these facts it is concluded that the syenite is simply a result of locally intense metamorphism.

SECTION VI. WORK OF THE LATER UNITED STATES GEOLOGISTS AND ASSOCIATES.

HAYDEN,[190] in 1867, in his sketch of the geology of northeastern Dakota, describes quartzites along the James river, Vermilion river, and at Sioux falls. These quartzites are sometimes conglomeratic. On the James river the lines of stratification are nearly obliterated, but the rock appears to be metamorphic. The pipestone bed on Pipestone creek is associated with the quartzites already mentioned and this rock is undoubtedly of the same age. At Sioux falls, while no well defined fossils were discovered, upon the outer surfaces of the rocks are rounded outlines of what appear to be organic remains, but the peculiar character of the quartzite points toward the Azoic series. The formation is tentatively referred to the Super-Carboniferous, Triassic, or downward extension of the Cretaceous; but Hall's opinion that this rock is Huronian is entitled to great weight.

IRVING,[191] in 1883, gives a systematic account of the Copper-bearing rocks of lake Superior. From this group is excluded the so-called lower group of Logan, the Animikie group of Hunt, and also the horizontal sandstones known as the Eastern and Western sandstones; although it includes the dolomitic sandstones, with accompanying crystalline rocks between Black and Thunder bays, and occupies the valley of the Black Sturgeon and Nipigon rivers, as well as lake Nipigon. The Keweenaw or Copper-bearing series then includes the succession of interbedded traps, amygdaloids, felsitic porphyries, porphyry-conglomerates, and sandstones, and the conformable overlying sandstone typically developed in the region of Keweenaw point and Portage lake. These rocks have their most widespread extent about the west half of lake Superior, but also occur in the eastern part of the lake. The entire geographical extent in the immediate basin of lake Superior is about 41,000 square miles.

The eruptive rocks include basic, intermediate, and acid kinds, but there is no such chronological relations between these three kinds as is found to be the rule in Tertiary and post-Tertiary times. In the Palisades of the Minnesota coast quartz-porphyries are found both overlain and underlain by basic rocks with abundant evidence that the porphyry is a surface flow. The same phenomena are seen at other places. Acid flows are superimposed upon basic flows, flows of intermediate acidity immediately overlie acid flows, flows of intermediate acidity overlie porphyritic conglomerates, flows of intermediate acidity are superimposed upon basic flows, basic rocks are intersected by acid rocks, basic flows overlie acid rocks, basic flows overlie those of intermediate acidity, acid rocks are intersected by basic rocks. There is a complete absence from the series of anything like volcanic ash. The detrital rocks of the series are composed of fragments broken for the most part from the acid rocks of the series—that is, such material as porphyry, both non-quartziferous and quartziferous, felsite, augite-syenite, granitell and granite, but there are also often found pebbles of the basic rocks, and in some cases particles of gneiss and granite from the underlying series. This is thought to be due to the fact that such viscous material would solidify into more or less bulky erect masses of relatively small area, and thus be most favorably situated for degradation. Between the several kinds of original rocks there are no sharp lines, but a continuous series of kinds from the most basic to the most acid.

The lithology of the different members of the series is given in detail. The basic original rocks include granular, porphyritic, and glassy kinds, the most abundant of which are gabbro, diabase, melaphyre, and porphyrite. The acid original rocks include quartzless porphyry, quartziferous porphyry, and felsite, augite-syenite, granite-porphyry, and granite. Here is included the so-called "jaspers," which have been regarded by many as metamorphosed sedimentary rocks. The basic crystalline rocks make up the greater part of the thickness of the series, the beds varying from a few feet to several hundred feet in thickness. Each of these beds often has a twofold division, an upper amygdaloidal portion, and a lower compact portion, which, however, grade into each other. The amygdaloids not infrequently resemble beds of sedimentary origin, but they never show any trace of fragmental character, and the stratiform condition is seen to be due to a succession of thin flows and two fluidal structures. Laterally the beds are not of indefinite extent, and are far less extensive than sedimentary beds of the same thickness. It is generally, however, difficult to prove the continuity or noncontinuity of a single flow over a great distance, but on the Minnesota shore individual layers were traced with certainty for 10 or 15 miles, while other beds almost certainly have an extent of nearly 30 miles, while groups of layers of allied characters are recognizable over much longer stretches. The more massive, thicker beds generally occur in the lower part of the series. Numerous dikes cut the basic rocks. These are generally small, commonly not more than 10 feet in width, but in the immediately underlying series on the north shore, the Lower Copper-bearing or Animikie group, are dikes of great magnitude. Of the original acid rocks true granite has been observed only in the Bad river region of Wisconsin intersecting the coarse gabbro at the base of the series. Quartz-porphyry and allied acid rocks have a widespread occurrence, two of the largest masses being the palisades of Minnesota and the core of the Porcupine mountains of Michigan. The detrital members have often a great extent. The outer conglomerate of Keweenaw point, for instance, is traced from the eastern extremity of the point to the Bad river in Wisconsin, a distance of at least 170 miles, although its thickness in this distance varies from less than 100 to as much as 4,000 feet. Thinner conglomerates have been traced for as great a distance as 50 miles.

The Keweenaw series is stratigraphically separated into two grand divisions, an upper member, made wholly of detrital material, for the most part red sandstones and shale; and a lower division, made chiefly of a succession of flows of basic rocks, but including layers of conglomerate and sandstone nearly to the base, and also original acid rocks. The line of separation between the two divisions is somewhat arbitrary, for the sandstone gradually increases in quantity upward, but above the highest known eruptive member is a maximum thickness of 15,000 feet of detrital material. The chief characteristics of the lower division are, first, that coarse grained basic rocks in very heavy beds are much more common at lower horizons; second, amygdaloidal texture is more frequent and highly developed at high horizons, this being more characteristic of the thinner beds; third, the gabbros are more often found at lower horizons while the ordinary diabases and melaphyres affect higher horizons; fourth, the acid rocks are found especially in low horizons, rarely reaching above the middle of the lower division; and, fifth, the detrital beds, although seen all the way to the base, are rare in the lower third of the series and increase in thickness and frequency toward the top. The thickness of the lower division is placed in round numbers at 25,000 to 30,000 feet, while at the Montreal river its apparent thickness is 33,000 to 35,000 feet, but a part of this may be due to the westward continuation of the Keweenaw fault.

Detailed descriptions are given of the rocks of Keweenaw point, of the region between Portage lake and the Ontonagòn river, of the South range, of the region between the Ontonagon river and Numakagon lake including the Porcupine mountains, of northwestern Wisconsin and the adjoining part of Minnesota, of the Minnesota coast, of isle Royale and Nipigon bay, of Michipicoten island and the east coast of lake Superior. Silver mountain, belonging to the South range, is composed of diabase, dipping at an angle of 30°, and appears to be surrounded by horizontal sandstone. On the west branch of the Ontonagon are found cliffs of horizontal sandstone almost in proximity with ferruginous slate supposed to belong to the Huronian, and but a short distance from diabases regarded as Keweenawan. The isolated position of the South range is regarded as due to a fault, as there is no evidence whatever of a fold, and to regard this part of the series as a continuous conformable succession with the Keweenawan rocks to the north would give the series an incredible thickness. The Porcupine mountains are found to be due to a subordinate fold in the series, the core being a quartz-porphyry.

All the known facts with reference to the relations of the horizontal sandstone to the Copper-bearing rocks of northwestern Wisconsin and the adjoining part of Minnesota are recapitulated. The unconformity between the fossiliferous Cambrian of the St. Croix valley and the bedded melaphyre and amygdaloids described by Sweet, Strong, and Chamberlin is indisputable, and the latter rocks are identical in nature and in structure with the similar rocks of Keweenaw point and have been shown to be in actual continuity with them. At Snake and Kettle rivers the diabase and diabase-amygdaloids with interbedded porphyry conglomerates are in all respects like those of Keweenaw point, and here, as shown by Chamberlin and McKinlay, the horizontal Cambrian sandstone overlies these beds unconformably. Sweet's examination of the Kettle and St. Croix rivers shows that here are cupriferous rocks which are identical with those of Keweenaw point, upon which the red sandstone of lake Superior west of the Montreal reposes unconformably, at Black river, Copper creek, Aminicon river, and Middle river. The disturbances of the overlying sandstone described by Sweet are due in part to the irregularities of an unconformable contact and to the pressure of the deep-seated Keweenaw rocks against the more shallow sandstone, but also in large measure to a faulting that has taken place along the contact line. The phenomena if not explained as above may be regarded as due to the intrusion of disturbing masses or dikes, as suggested by Whittlesey and Norwood, or the sandstone may be supposed to belong to the upper division of the Keweenaw series let down by a great fault. The first of these suppositions is forbidden by the bedded structure of the rocks, and the second is shown by the general structural features of lake Superior to be a physical impossibility.

The amygdaloidal and porphyritic rocks, and the granite, granitic porphyry, and felsite of the Duluth gabbros and the Minnesota coast are found in every case to be original eruptive rocks having all the evidences in their structure of this origin and none whatever of being metamorphosed shales and sandstones resulting from the red sandstones of Fond du Lac, as supposed by Prof. N. H. Winchell.

It is concluded that the Eastern sandstone along the south face of Keweenaw range is both a fault cliff and a shore cliff against which the newer sandstone was laid down, but not until after a large erosion, and that faulting again took place during or after the deposition of the sandstone; that this original faulting is demanded along this line by the relations of the Keweenaw and South ranges, without which the Keweenaw rocks would have an enormous thickness.

The relations of the Eastern sandstone and Keweenawan traps are described at Bête Grise bay, along the Hungarian river and Douglass Houghton ravine, and sections given showing the sandstone to rest unconformably upon the eruptives. At the Torch lake quarry the Eastern sandstone is found horizontally disposed in heavy layers, containing no fragments of porphyry such as are distinctive of the Keweenawan sandstones. No evidence of a northwesterly dip described by Wadsworth was here found. The sandstone adjacent to the trap is of the ordinary quartzose character. It is remarked that Wadsworth's statement that the feldspathic constituents have been leached from it, thus accounting for its differences from the Keweenawan sandstone, is a pure supposition. Farther west on and near the Ontonagon river, as at Bête Grise bay, the sandstone dips away from the north-dipping Keweenawan diabases at quite a high angle near the contact, which rapidly flattens as it is receded from. Finally along the north face of the South range eastward from lake Agogebic the sandstone is not infrequently met in a flat-lying position, and at one place lies directly across the course of the Keweenawan belt.

As to the age of the Eastern sandstone, it is regarded as demonstrated that it is older than the Trenton; hence its Triassic age is not discussed. The Western sandstone is regarded as the equivalent of the Eastern sandstone, although they are not found connected, nor is the Western sandstone at any point connected with the Mississippi valley Cambrian sandstone. It has, however, already been shown that the Keweenawan rocks rest unconformably under the Cambrian sandstone of the Mississippi valley in western Wisconsin.

The Animikie series in the Thunder bay district is of great thickness, probably upward of 10,000 feet, comprising quartzites, quartz-slates, clay-slates, magnetitic quartzites, sandstones, thin limestone beds, and beds of cherty and jaspery material. With these are associated in great volume both in interbedded and intersecting masses coarse gabbro and fine grained diabase, like those well known in the Keweenaw series. A broad examination of the region shows that there is little ground for the belief in one crowning overflow. The Animikie series is lithologically like the Penokee range in Wisconsin; both series bear the same relations to the newer Keweenawan rocks and the older gneisses, and the two groups are regarded as the same.

The Animikie rocks are also the equivalent of if not actually continuous with the Mesabi iron range running to Pokegama Falls and the slates of the St. Louis river, although these latter are affected by slaty cleavage.

The Original Huronian of Logan is compared with the Animikie slates of Thunder bay and the two are regarded as equivalent. The Marquette and the Menominee Huronian, with minor exceptions due perhaps to metasomatic changes, are lithologically like the Animikie and Penokee series, and are also regarded as belonging to the same horizon. The Original Huronian, the Animikie slates, the Penokee iron rocks, and iron-bearing rocks of Marquette and Menominee appear then to belong together and may hence properly be called Huronian. The Huronian schists in each of these areas are limited by granite and gneiss. There are, however, considerable areas of crystalline schists the relations of which are doubtful, and it is suspected that in several of the iron regions there are two distinct kinds of schists, those belonging to the Huronian and a schistose greenish phase belonging with an older series. It is also possible that a portion of the granites are eruptive and relatively new, while others, and especially those connected with the gneisses, may be of some sort of metamorphic origin not understood. The iron-bearing schists of Vermilion lake are, however, so like the Huronian that they are regarded as a folded continuation of the Animikie beds.

That the Animikie Huronian is beneath the Keweenawan rocks is shown by the fact that the Keweenawan beds along the Minnesota coast are passed in descending order until the Animikie slates are reached at Grand portage bay, but there is not a direct downward continuation of the Keweenawan into the Animikie, for between the two there has been an intervening period of erosion. This is shown by the fact that at Grand portage bay where the two formations come together the underlying slates suddenly rise entirely across the horizon of 600 or 700 feet of the Keweenawan sandstone. Also in northeastern Minnesota and in the Penokee district the overlying Keweenawan now is in contact with one member of the underlying series and now with another. Further, in the Keweenawan sandstones of Thunder bay are found chert and jasper pebbles from the Animikie, while in the Wisconsin Keweenawan are quartzite pebbles apparently from the underlying Huronian. More abundant than these, in the Keweenawan conglomerates are pebbles of older gneiss and granite. Lithologically the Keweenawan rocks are also unlike the Huronian. The bedded and sedimentary series of the two groups are in strong contrast. The shales and sandstones of the Keweenawan have nothing in common with the quartz-slates and quartz-schists of the Huronian. Also in the Huronian there is nothing like the acid eruptives of the Keweenawan. They have the common feature only of basic eruptive rocks, and of these in the Huronian there are no amygdaloidal or vesicular layers. A further difference between the Huronian and Keweenawan is in the degree of metamorphism. The Keweenawan sediments are unaltered, while the Huronian sediments are metamorphic. Whether this metamorphism took place before or during the period of Keweenawan eruptions and deposition is uncertain.

That the closely plicated Huronian rocks were folded before Keweenawan time is indicated by the fact that the troughs of Huronian schists adjacent to lake Nipigon lie directly athwart the flat-lying Keweenawan beds. If these schists are truly Huronian and equivalent to the unfolded rocks, as supposed by Bell, there can be no doubt of the existence of a genuine unconformity between the two systems. The Keweenawan synclinal forming the bed of lake Superior is found to comprise the whole basin, as well as a considerable area in northern Wisconsin and Minnesota. Not only the form of the lake as a whole, but its chief bays are due to subordinate folding or faulting of the Keweenawan series. In the great synclinal movement the underlying Huronian has partaken.

CHAMBERLIN,[192] in 1883, gives a summary of the arguments for regarding the copper-bearing series of lake Superior as pre-Potsdam: (1) The weakest argument of all, the general stratigraphical relations, indicate this. The Potsdam sandstone throughout the entire basin of lake Superior is always horizontal, or nearly so, while the Keweenawan series at many points immediately adjacent have suffered extensive disturbance. (2) The difference in thickness is enormous; the Potsdam rarely reaches 1,000 feet thick, while the Keweenawan series has, in addition to a vast thickness of interstratified eruptives and detrital rocks, an upper portion free from igneous matter 15,000 feet in thickness. (3) The sandstones of the Keweenawan series are largely composed of silicates, while the Potsdam sandstone is mainly quartzose. (4) At numerous points the Potsdam is found to rest against or upon the upturned edges of the Keweenawan series unconformably. Strong has found fifty-five places on the St. Croix where the unconformable contact occurs. In Douglas county are four sections in which the Potsdam sandstones become conglomeratic, bearing material from the Copper-bearing series, but here the contacts are complicated by subsequent disturbances. There are several other districts, such as the upper St. Croix river, the Snake and Kettle rivers in Minnesota, and the vicinity of lake Agogebic in Michigan, where the quartzose Potsdam sandstone is in a horizontal position and lying near the upturned igneous and detrital rocks of the Keweenaw series. (5) The foregoing facts are all consistent with each other. (6) The view is dynamically simple, whereas any other explanation implies an extraordinary amount of local faulting and disturbance. (7) In the Grand canyon of the Colorado is a series of rocks remarkably similar to the Keweenawan, which lie directly and unconformably below the Cambrian.

IRVING and VAN HISE,[193] in 1884, describe quartzites of many localities belonging to the rock series referred to the Huronian in the Northwest, and find that their supposed metamorphism is due to the deposition of interstitial silica, which has for the most part coordinated itself with the original grains, the forms of the latter being as perfect as at the time of deposition. The list of rocks given include those from the Original Huronian, from the various iron-bearing regions of Michigan and Wisconsin, from the Baraboo and Chippewa quartzites, from the Minnesota, Iowa, and Dakota quartzites, and from other localities.

IRVING and CHAMBERLIN,[194] in 1885, give a systematic account of the junction between the Eastern sandstone and Keweenaw series on Keweenaw point. Detailed descriptions are given of the relations of the two series at Bête Grise bay, at the Wall ravine, at the St. Louis ravine, at the Douglass Houghton ravine, at Torch lake quarry, at Hungarian ravine, and at other points. The conclusions, and the grounds upon which they are based, of Jackson, Foster and Whitney, Agassiz Rominger, Credner, and those who have followed them, are discussed in detail.

At Bête Grise bay the horizontal sandstone is found upon approaching the melaphyre to become tilted upward, and along the junction is found the evidence of faulting, both in the fluccan of the sandstone and in the broken character of the melaphyre at the contact. At the

Wall ravine the sandstone and conglomerate bearing fragments of the porphyry-conglomerate, with which rock the contact here occurs, are found to dip at a considerable angle away from the eruptive rock and to rest directly upon it. At the St. Louis ravine the sandstone is found upon approaching the Keweenaw series to become rapidly tilted upward, and before reaching the Keweenawan rocks to become vertical, while the interstratified eruptives and detrital rocks of the Keweenaw series dip away from the sandstone. At the Douglass Houghton ravine the horizontal sandstone is found upon approaching the Keweenaw series to become bent into a series of folds and to dip downward under the traps and porphyries, which dip at a steeper angle in the same direction. Along the contact the trap is shattered. At Torch lake quarry the sandstone is found to be in a horizontal position, there being no evidence whatever found that this structure is jointing or that the real dip has an inclination, as described by Wadsworth. The crystal outlined grains of sand here contained are found to be produced by secondary growth rather than crystals derived from quartz-porphyry. At the Hungarian ravine the relations are much the same as those at the Douglass Houghton ravine, except that the Keweenawan diabase is interstratified with conglomerate instead of quartz-porphyry. Along the contact the sandstone is broken.

In getting at an explanation of the facts there must be taken into account the bedded nature of the Keweenaw series; the uniformity and steadiness of dip; the enormous thickness of the Keneenaw series; the general horizontality of the Eastern sandstone; the quartzose character of the Potsdam sands in distinction to the silicate nature of the Keweenawan sands; the mutual relations and distribution of the two series; the relations to topography; the relations of the two series to drainage; the comparative straightness but gentle undulations of the junction line throughout its course of nearly 100 miles; the coincidence of the line of escarpment with the line of junction of the two series; the disturbance along the line of contact; the special character of the distortions; the character of the junction; the junction debris; the irregular and broken contact faces of the two series; the fact that the contact occurs between the Eastern sandstone and different members of the Keweenaw series; the discordance of strike; the derivation of the pebbles of the Eastern sandstone from the Keweenaw series; the distribution of the pebbles, those of the Keweenaw series being found only near the immediate junction; the imperfect assortment of the pebbles and matrix near the junction; the angularity of the pebbles at this place; the absence of large fallen masses of trap in the Eastern sandstone; and the proximity and relations of the Trenton limestone, resting as it does upon the Eastern sandstone within a short distance. These specifications are taken to point with distinctness to the conclusion that the Keweenaw series is much older than the Eastern Potsdam sandstone, that it was upturned, faulted along the escarpment and much eroded before the deposition of the Eastern sandstone, that the latter was laid down unconformably against and upon the former, and that subsequent minor faulting along the old line ensued, disturbing the contact edge of the sandstone.

IRVING,[195] in 1885, discusses the divisibility of the Archean in the Northwest. The relations of the Penokee-Gogebic series to the overlying Keweenawan and to the underlying complex are first discussed. The area south of the Penokee-Gogebic series is found to consist of crystalline hornblendic, chloritic and micaceous schists which locally show unmistakable evidence of fragmental origin, but which as a whole are intensely metamorphosed. The granites, however, are considered as of eruptive origin as they intersect intricately the associated schists at their contacts with them, but the granite is never found to cut the overlying slates. Above this granite-gneiss-schist area is, first, a belt of slate 500 feet thick, over this a belt of iron-bearing rocks of various kinds, and above this quartzites and slates, all having a dip to the north and extending for many miles east and west. None of these rocks are metamorphic.

North of this succession of layers, the Penokee series, is the Keweenawan series, which appears at first to be conformable, but a closer inspection shows that it is now in contact with one member of the underlying series and now with another, even lying against the lowest member of the Penokee series. These relations are taken to imply that between the Keweenawan and Penokee series there was a long period of erosion. There is also an unconformity between the granite-gneiss-schist complex and the Penokee Gogebic series. This is shown in the manner in which the regularly succeeding belts of the iron series traverse the courses of the lower; in the strong contrast between the two series in degree of crystallization, the lower series being nearly completely crystalline while the higher is little altered; in the highly folded and contorted condition of the lower series as contrasted with the unfolded condition of the higher; in the contrast between the contacts of the granite with the lower schists and with the higher slates, the former being invaded by it in an intricate manner, the latter never; in the discordant lamination of the two sets of rocks when in contact or close proximity; in the occurrence in the upper series, not only at horizons above the base, but also at points on the contact line, of abundant detrital material from the lower series.

In the Marquette district is found a slaty iron-bearing series which by common consent is regarded as the equivalent of the Penokee-Gogebic series; but the two have one point of contrast, the Marquette is highly folded. Here intervenes between the iron-bearing slates and the granites and gneisses a set of greenish hornblendic rocks, called by Rominger a dioritic group, which at their contact with the bounding granite are penetrated by them in the most intricate manner, so that one can not resist the conclusion that the granite is the more recently formed rock. These green schists are regarded as the equivalent of those cut by granite in the Penokee-Gogebic district. On this view the slate series of the Marquette district, consisting in the main of little altered rocks, was built up on a basement composed of granite and gneiss and greenish schist, and subsequently pushed into trough-like forms. In support of this view is cited the failure of the granite to penetrate the slates and quartzites associated with the iron, and the occurrence in the higher series of fragments from the lower, recomposed rocks occurring at points where the quartzites come in contact with the basement rocks.

The Archean in these regions is then divisible unless the upper series are called Cambrian, for which there is no ground until in them fossils have been discovered. These upper series are compared with the Huronian of lake Huron, and are found to be lithologically like them, and to bear the same relations to the underlying rocks, and to them the term Huronian is applied, while the underlying complex is regarded as Laurentian.

IRVING [196], in 1885, gives a preliminary account of an investigation of the Archean formations of the Northwestern States. The problems to be solved are discussed. An examination of the Original Huronian area of Murray and Logan shows that it is a series of rocks which is bent into gentle folds and which is composed for the most part, excluding eruptive material, of quartzites and graywackes, with a subordinate proportion of limestone and chert. The rocks as a whole are very little altered and resemble more the fossiliferous formations than the crystalline schists.

The Marquette and Menominee iron-bearing series are highly folded and the metasomatic changes which the crystalline members of the series have undergone are often extreme. Excluding the greenish schists of the lower part of the series, which may belong to an older formation, the rocks are mainly fragmental slates and quartzites, including a large proportion of basic eruptives, and also iron ores, limestones, etc., the whole having a distinctly Huronian aspect. The various greenstone layers of Brooks' scheme are regarded as eruptive, either contemporaneous or subsequent, as are also many of the greenish schists which by gradation pass into the massive greenstones. The iron ore and jasper are regarded as of sedimentary origin, being remarkably like similar material in the Penokee-Gogebic and Vermilion formations where there can be no doubt of their water-deposited character. In the Marquette district, as well as in the Vermilion lake district in Minnesota, are conglomerates overlying the iron belt which sometimes contain fragments of the underlying formation several feet in length. These fragments prove the existence of the the jaspery and chalcedonic material in its present condition before the formation of the overlying quartzite.

The Penokee-Gogebic iron belt is regarded as continuous with the

Huronian of the Marquette district. The slate belt of the St. Louis and Mississippi rivers is undoubtedly the equivalent of the Animikie series and of the Huronian. Equivalent with those are also the quartzites of Chippewa and Barron counties, the ferruginous schists of the Black River, the Baraboo quartzites, and the quartzite series of southern Minnesota and southeastern Dakota.

At New Ulm and Redstone in Minnesota the quartzites and conglomerates plainly uncomformably overlie the gneiss. The thickness of this formation here exposed is probably about 5,000 or 6,000 feet, a continuous section being found by Merriam at Sioux Falls, South Dakota, having a thickness of not less than 3,000 to 4,000 feet. The tilted position of these quartzites, their great thickness, their lithological contrast with the Potsdam sandstone, make it evident that between these series and the overlying Potsdam sandstone is a great unconformity.

In the Animikie series is a strongly marked continuous horizon of cherty and jaspery magnetitic schists and quartzites. The series as a whole is quite flat-lying, although having subordinate irregularities. The series having ferruginous schists north and west of lake Superior are regarded in part as having been once continuous with the Animikie series and are now separated merely because of erosion on the crowns of the folds, the close folding of the Vermilion schists being produced concomitantly with the broad simple trough of lake Superior. In support of this position is the fact that the great conglomerate of Ogishki Manissi, with the alternating quartzites and slates of Knife lake, is strikingly like the Huronian rocks. It is also the case that in the vicinity of Agamok lake the Animikie quartzites appear gradually to take on a folded condition.

In these various Huronian areas quartzites, graywackes, and clay slates, with intermediate phases, make up the most of the clastic series. As has been seen, these are rocks which have been indurated by metasomatic changes, and it follows that the bulk of the rocks which form the Huronian do not properly fall under the head of metamorphic rocks. The various augitic and hornblendic greenstones, peridotites, and felsitic porphyries are regarded as eruptives, while many of the schists are modified rocks of the same character. The cherty and jaspery rocks are supposed to be some sort of original chemical sediment, certainly not the result of metamorphism of sedimentary material. The limestones are in no essential respect different from many met with in the formations of later date.

IRVING,[197] in 1886, discusses the origin of the ferruginous schists and iron ores of the lake Superior region. An examination of the Animikie, Penokee, Marquette, Menominee, and Vermilion districts reveals the fact that in all of them is found abundant carbonate of iron, which oftentimes grades into the other forms of the iron-bearing formation. The silica of the jasper, actinolite, magnetite schists, and other forms of the iron belt never shows any evidence of fragmental texture, so easily discovered in the case of the ordinary quartzites and graywackes, and is therefore of chemical origin. Associated with the iron-bearing beds is often a considerable quantity of carbonaceous or graphitic schists. It is concluded, (1) That the original form of the iron-bearing beds of the lake Superior region was that of a series of thinly bedded carbonates, interstratified with carbonaceous shaly layers in places, which were more or less highly ferriferous. (2) That by a process of silicification these carbonate-bearing layers were transformed into the various kinds of ferruginous rocks now met with. (3) The iron thus removed from the rock at the time of silicification, passed into solution in the percolating waters, was redeposited in various places, and thus formed the ore bodies and bands of pure oxide of iron. (4) That in other places, instead of leaching out, the iron has united with the silicifying waters to form the silicates now found, such as actinolite. (5) That some of the silicifying process went on before the folding, but some afterwards, and to the latter period belong probably the larger bodies of crystalline ore.

WILLIS,[198] in 1886, describes the rock occurrences at several iron districts in northeastern Minnesota. At Pokegama falls on the Mississippi are found outcrops of red quartzite, coarse grained sandstone, sometimes metamorphosed to a quartzite and irregularly interstratified with hard specular ore. On Prairie river is found granite, southeast of which are quartzites, sandstone, and ore.

At Vermilion lake the iron-bearing series has a dip of between 85° and 90°, the structure being regarded as an anticline, upon the north side of which is the Vermilion range and on the south side that of Two rivers. The succession from the base upward is as follows: (1) Light green, thinly laminated, chloritic schist. (2) Jasper of white, gray, brown, and bright red colors, interstratified with layers of hard blue specular ore, which also occurs in ore-bodies of considerable extent running across the bedding; thickness 200 to 600 feet or more. (3) Chloritic schist, similar to 1; original thickness probably about 150 feet. (4) Quartzite, dark gray, white, or black, of saccharoidal texture, containing grains of magnetite which make it a readily recognized magnetic formation; probable thickness 200 feet. (5) Conglomerate, consisting of sandstone pebbles and traces of black slate inclosed in siliceous chloritic schist. (6) Compact homogeneous rock, composed of quartz grains, chlorite, hornblende, plagioclase feldspar, and calcite. This rock may be an eruptive quartz-diorite, but is considered a metamorphosed sedimentary transition bed between 5 and 7. (7) Black clay slate, fissile and sonorous. It occupies a broad area north of Vermilion range. In section 28 huge masses of jasper form the crown of the arch and are imbedded in green schist, with which they agree in strike and dip. The jasper blocks are rectangular and several hundred feet long; the ends of the bands come out squarely to the contact with the schist as to a fault.

IRVING,[199] in 1887, discusses the separability of a Huronian group from an underlying series. The character of the Original Huronian area is again fully discussed. When two series of rocks are in contact, one of which is crystalline in character and the other unquestionably of sedimentary origin, there is presumptive evidence of a discordance between them, as, whatever the origin of the crystalline schists, their present condition indicates the action of long-continued and deep-seated processes of alteration and profound erosion before the deposition upon them of the overlying detritals. In the Original Huronian area there is not only this distinction in its most marked form, but also the actual contact between this series and the Archean complex is found near the mouth of Thessalon river, the upper series having at its base a basal conglomerate, the fragments of which are plainly derived from the foliated crystalline underlying series. Allied phenomena are also seen on the Canadian Pacific railway between Algoma mills and Sudbury. It is concluded that the Huronian has a group value because it is essentially noncrystalline, because it is truly clastic and sedimentary, and because it has an immense volume. There is reason to believe that the area which stretches from the north shore of lake Huron to the Mississippi river, including the basin of lake Superior, is one geological basin.

In the Marquette district the contradictory conclusions reached by older writers are regarded as due to the fact that the stratiform rocks themselves are made up of two entirely distinct sets; an older series of intensely altered and crumpled crystalline schists, in the main of greenish color, which are intricately invaded by the granite, and a newer, little altered, mainly fragmental series whose contacts with the granites and the schists of the older basement are such as to render an intervening structural break evident. The peculiar granitoid quartzites which Rominger regards as having been produced by the metamorphosed action of granite are plainly detrital derivatives from the granite, and often run into coarse bowlder conglomerates, particular occurrences of which are described. Here, as north of lake Huron, as proof of distinctness of the newer series, is a general lithological contrast between the two; visible discordances; the penetration of the lower strata of the lower series by granite veins which fail to penetrate the higher detrital rocks, but yield fragments to them; the development of true basal conglomerates at the contacts of the two series; and the fact that the higher detrital rocks are in contact with different members of the lower series. The most abundant of the upper series detrital rocks are quartzites, but there are also present clay-slates, shales, mica-schists, and various calcareous and dolomitic rocks, with jasper and ferruginous schists and iron ores which are regarded as chemical sediments.

In passing southward from Marquette great areas underlain by the granites, gneisses and schists of the older formation are passed, but before the Menominee river is reached at least four distinct belts are crossed occupied by the newer iron-bearing series. These belts of newer rocks are more closely folded than the Marquette district, but the relations between the newer and older series are identical with that district.

Passing now to the Penokee district of northern Wisconsin and Michigan, the iron-bearing series is highly tilted but unfolded, and the relations are therefore particularly plain. Here the lower of the two unconformities is established (1) by the fact that the iron-bearing series traverses lithologically distinct areas of the older or basement formation; (2) the intersection of the older schistose rocks by granite which never cut the higher series; (3) the occurrence in the higher series of basal conglomerates, fragments of which are from the underlying gneiss, granite, and schist; (4) the lithological contrast of the two sets of rocks, the lower being completely crystalline, folded and foliated, while the upper is but little altered and regularly bedded. The upper unconformity is shown by the manner in which the flows of the Keweenaw series are found in contact with all members of the iron series at different places along the contact line.

The Animikie series is gently tilted, and rests in palpable unconformity upon a folded series of schists, granites, and gneisses. Above it is the Keweenaw series, which bears the same relations to the underlying rocks as they do to the Penokee series.

North of the Animikie beds are schistose iron-bearing rocks, which extend from Vermilion lake to the vicinity of Knife and Saganaga lakes. These are flanked by gneisses and granites, and on account of their lithological similarity to the Animikie rocks are taken to be their folded equivalent. While there is not here the same palpable unconformities as in the other regions discussed, it is believed that there are two groups of rocks, the apparent conformity being due to the intense folding.

There is then a graded series in the structural relations of the older and newer rocks from the Animikie, which lie upon the older formations with a slight inclination through the Penokee, which is unfolded, although deeply inclined; the typical Huronian, which is gently folded without schistose structure; the Marquette, which is crumpled between walls of older schists; the Menominee district, where the folding is so close that the discordances are no longer distinct; to the Vermilion lake district, where extreme pressure has produced a general community of inclination between the two groups of rocks. There is then in all these regions a great basement complex of crystalline schists, gneisses, and granites, above which, separated by a great structural hiatus, is the Huronian group, mainly of detrital rocks, which is followed in turn, after a severe structural break, by the Keweenaw group, upon the eroded edges of which rest the Potsdam or Upper Cambrian sandstone. For the combination of clastic series above the basement complex and below the Potsdam sandstone the system name Agnotozoic is proposed.

IRVING,[200] in 1888, discusses the classification of the early Cambrian and pre-Cambrian formations, and particularly those of the northwestern states. The relations of the Baraboo quartzites to the Potsdam sandstone, the relations of the Potsdam to the Keweenaw series, the relations of the Animikie, Penokee, Marquette, Menominee, and Vermilion lake iron-bearing series to the underlying and overlying series are again fully discussed. The Keweenawan is held to overlie the Huronian everywhere by a very considerable unconformity. Evidence before given is repeated, and important additional evidence of the break is found in northeastern Minnesota. At the base of the Keweenawan is a great mass of gabbro, which extends from Duluth northeast to the national boundary, more than 100 miles, and at its maximum is more than 20 miles wide. This basal gabbro is now in contact with one member of the Animikie, and now with another, while in other places it is in contact with the lower crystalline schists or granite. In the Huronian are placed the Original Huronian, the iron-bearing series of Michigan and Wisconsin, the Black river falls iron-bearing series, theAnimikie series, the St. Louis and Mississippi slate series, the Vermilion lake iron-bearing series, the Baraboo quartzite series, and the Sioux quartzite series. Under the Huronian is the Laurentian, separated from it by a great unconformity. This is a series of granites, gneisses, hornblende-schists, mica-schists, and other green schists.

These correlations are held to be warranted both by the lithological ikenesses of the rocks in the different districts referred to the same grand division, and the lithological contrasts between the divisions, as well as by the fact that such unconformities as exist between the series must necessarily have a very wide extent. That one or two organic forms have been found in the rocks referred to the Huronian is not sufficient evidence for extending the term Cambrian down to cover this and the Keweenawan groups. In the Huronian are shales and slates which have abundant organic matter and important beds of ferruginous strata which were probably accumulated because of the existence of organic matter. The fossils discovered are of types which have a great vertical range above the Cambrian and may have as great a vertical range below it. That a pre-Cambrian fauna existed is evident, while it is probable that this fauna had affinities with the Cambrian itself. Such weak paleontological evidence is not sufficient reason to disregard the enormous thickness of the formations to be included in the Cambrian in case the Keweenawan and Huronian are here placed, as well as the two great unconformities below the Potsdam which must also be covered by this term. Archean is restricted to the pre-Huronian rocks. The volume of the clastic series between the Cambrian and the Archean is such as to demand a term of value equivalent with Paleozoic, and Agnotozoic or Eparchean is proposed as this term.

VAN HISE,[201] in 1889, finds the iron ores of the Penokee-Gogebic series to be of sedimentary origin and to have been derived from an original cherty carbonate of iron which is yet abundantly present in the upper horizons of the ore-bearing formation.

HALL[202] (C. W.), in 1889, describes the distribution of the granites of the Northwestern states, and particularly those of Minnesota. They are found to be either intrusive or granitic veinstones, the latter being insignificant in quantity. The granites of Minnesota as to age are probably later than the Laurentian floor of the continent but earlier than the close of the Agnotozoic era. There are three or four grand periods of eruptive activity.

WILLIAMS,[203] in 1890, as a result of an extended examination of the field relations and microscopical characters of the widespread greenstones, greenstone schists, and agglomerates of the Marquette and Menominee districts, concludes that they are all of eruptive origin. This conclusion is reached from a consideration of the field evidence, the schistose phases being frequently traced by continuous gradations into massive forms; and from the microscopical evidence, these unaltered forms having all the characteristics of eruptive rocks. The original rock types were rather numerous, including gabbro, diabase, diabase-porphyry, melaphyre, diorite, diorite-porphyry, and tuffs. These rocks have been compressed, faulted, and crushed, as a result of which, combined with metasomatic changes, their present condition is produced.

IRVING,[204] in 1890, discusses the field relations of the greenstones and greenstone schists of the Marquette and Menominee districts. A field study of these rocks, heretofore generally considered sedimentary, led to the conclusion that they are largely of eruptive origin, and the detailed study of Williams has shown this conclusively. In the Marquette district the line of demarcation between the schists and granites is not a sharp one, the granites intricately intruding the schists, often in such a manner as to render it certain that the granite is the later rock. Also the basic dikes which cut the greenstone schists are of wholly subsequent date to the schists themselves, and are equivalent in age to those which have intruded the overlying detrital iron bearing series. On the other hand, it is concluded that the greenstone schists themselves do not belong within the same geological period as that which holds the remainder of the stratiform rocks of the region; that is, the greenstone schists are placed along with the granites and gneisses to form the basement upon which the overlying detrital iron-bearing series was horizontally and unconformably spread. This is shown by the fact that at a number of points the detrital beds which form the basement member of the iron-bearing series proper bear numerous waterworn fragments of the granite when in contact with that rock, and, when in contact with the greenstone schists, fragments of those rocks. In some cases the basal quartzite appears to grade into the granite, but a study of this quartzite in the thin section shows its completely fragmental character. These contacts or basal conglomerates are described in Secs. 1, 2, 3, 4, 5, T. 47 N., R. 25 W., Mich.; in Secs. 21 and 22, T. 47 N., R. 26 W., Mich.; in Sec.

29, T. 48 N., R. 25 W., Mich.; in Sec. 20, T. 48 N., R. 27 W., Mich.; in Sec. 17, T. 48 N., R. 26 W., Mich.; in Sec. 21, T. 48 N., R. 27 W., Mich.; and at various points in T. 49 N., R. 28 W., Mich.

From these occurrences it does not appear possible to escape the conclusion that the greenstone schists, together with the granite, are greatly older than the detrital rocks, and before the latter were formed had already suffered disturbance and deep denudation. This is certainly true if the underlying rocks are fragmental, and the conclusion can not be escaped if they are eruptive, for both the greenstone schists and the gneissoid granite must have received their schistosity before yielding the fragments; and, moreover, their character is such that it is generally believed that they must have crystallized in depth, and must therefore have had removed from them great masses of material before yielding the discovered fragments to wave action. There are evidently granitic rocks of two different ages in the Marquette district, because dikes of a fine grained reddish granite frequently cut the other granite. This later granite, of relatively small extent compared with the main masses, may have perhaps been later in time of formation than the detrital rocks themselves, as indicated by the presence of rare quartz-porphyry dikes and rare granitic dikes in the Felch mountain district intersecting a ferruginous schist of the iron-bearing series.

The above conclusions are further confirmed by the fact that the later greenstones interstratified with sedimentary layers, as shown by Prof. Williams, are precisely like the corresponding dikes in the greenstone-schist area, which were evidently intruded subsequent to the production of a schistosity. Also the schistosity of the greenstone schists corresponds at times with the bedded structure of the iron series, while at other times there is no such correspondence. A similar examination of the facts in the Menominee district leads to identical conclusions; that is, that the granite both south and north of the iron-bearing series and the associated green schists and gneisses constitute a complex upon which the newer series was deposited.

IRVING and VAN HISE,[205] in 1890 and 1892, give a detailed description of the Penokee series of Michigan and Wisconsin, of the complex of rocks south of this series, and discuss the relations which the Penokee rocks bear to the underlying and overlying series, as well as to the Eastern sandstone.

South of the Penokee series is the Southern Complex, an area of fine grained green hornblende-schists and mica-schists, gneisses, and granites. There is often no proper contact between the granite, gneiss, and schist, but an apparent gradation through a considerable distance from one to the other, while the granite often also cuts the schist, playing the part of a later intrusive. Distant from the lines of contact the schists occupy considerable areas. In none of these rocks is discovered any evidence of clastic origin. If the massive granites and syenites are regarded as eruptive, it must be concluded that many of the schists also have a like origin, because of the gradations between them.

The Penokee series proper is made up of three members, Quartz-Slate, Iron-Bearing, and Upper Slate, and these rest unconformably upon a Cherty Limestone member.

The Cherty Limestone below the base of the Penokee series proper varies in thickness from nothing to 300 feet and is not continuous. This member shows no evidence as a whole of mechanical origin, although occasionally a small amount of detrital material is found in it. It is regarded either as a chemical or organic sediment, and is called the Lower Penokee formation.

The Quartz-Slate member, resting upon the Cherty Limestone or upon the Southern Complex, is a continuous persistent layer of very constant thickness for many miles. It is for the most part in the neighborhood of 450 feet thick, although at one locality it reached 800 feet in thickness. The rocks of which it is composed comprise feldspathic quartz-slates, biotitic and chloritic quartz-slates, and vitreous quartzite, the latter being a persistent phase at the uppermost horizon. All these rocks are plainly fragmental and for the most part little altered, although occasionally by metasomatic changes they have become semicrystalline. The lowest horizon of the Quartz-Slate in the Penokee series proper was found at times to be a vitreous quartzite and other times to be a conglomerate. The débris of this conglomerate is usually derived chiefly from the Southern Complex, but at several localities contains a large quantity of chert from the Cherty Limestone member, and also includes a considerable amount of red jasper pebbles, and occasionally contains pebbles of white vitreous quartzite.

The next overlying formation is the Iron-Bearing member, which is longitudinally coextensive with the underlying Quartz-Slate. The thickness of this formation is surprisingly uniform, varying for the most part between 800 and 1,000 feet, although at its eastern extremity it apparently becomes thicker. The main phases of rocks here included are slaty and cherty iron carbonates, ferruginous slates and cherts, and actinolitic and magnetitic slates, none of which show any evidence of being of mechanical origin. The original form of the entire formation is taken to be an impure cherty iron carbonate, also bearing magnesium and calcium carbonate. From this condition the many phases and varieties of rocks now found are traced by minute stages. These transformations are mainly produced by secondary chemical changes. A comparison with the iron-bearing formation of the Animikie shows that it consists of the same kind of rocks, which have been derived from an iron carbonate in the same manner as those of the iron formation of the Penokee series. The iron ores are found to rest for the most part upon the underlying quartzite and upon a series of dikes which have cut the stratified layers. The ores in this position are secondary concentrations regarded as produced at the same time as the modifications of the Iron-Bearing member and due to downward percolating water, which has removed silica and has substituted iron oxide.

The Upper Slate member follows above the Iron-Bearing member. It is of great and variable thickness, the maximum being over 12,000 feet, and it varies from this to entire disappearance, the overlying series coming in contact with the Iron-Bearing or lower members. The rocks here comprised are mica-schists and mica-slates, graywackes and graywacke-slates, clay-slates or phyllites, and quartzites and conglomerates, all of which are of original mechanical detrital origin. The mica-schists and mica-slates are traced by imperceptible stages back to their original little altered or unaltered condition.

These three members constitute the Penokee series proper. The Eastern area of the series is found to differ in many respects from the main area already described. This was the center of great contemporaneous volcanic activity, and consequently the succession includes large thicknesses of lava flows and volcanic tuffs, which are not paralleled by the rocks found in the western area, and as a result of this disturbing force the detrital succession is not so simple and regular.

With the Penokee series are found eruptives of two classes, dikes cutting the formation and interbedded sheets, which are probably intrusions of the same age as the dikes. These eruptives are usually diabases, which are like the dikes found in the complex below the Penokee series, and which chemically are like the overlying Keweenaw series.

The Penokee series has approximately an east and west strike, is unfolded, and dips to the north at an angle varying usually from 60° to 80°. There are sharp flexures at a few points and small faults at only two localities.

While the strikes and dips of the Penokee series are persistent, those of the underlying schists are variable and often are at marked discordance with the Penokee succession. The granites which cut the fine grained schists of the underlying complex are never seen to intersect the limestone or quartz-slate. At quite a number of places the limestone or quartz-slate is found immediately adjacent to or in actual contact with the underlying complex, when it is always found to bear numerous water-worn fragments from the Southern Complex, the condition of which is that of the rock from which it is derived. When the contact is with the green schists the schistose structure of the underlying rocks abuts against the strike of the quartz-slate, while the fragments, with their greater length parallel to the schistose structure, are found with their longer diameters in the direction of the bedding of the slate, showing that their schistosity was produced before they were broken from their original position. It is then concluded that the Southern Complex is separated from the Penokee series by a great unconformity, and that as the quartz-slate is persistent for a distance of many miles, that the underlying complex had nearly reached a base level before the overlying series was deposited.

Above the Penokee series are the Keweenawan rocks, which are found at Tyler's fork above a thickness of at least 13,000 feet of sediments belonging to the Penokee series. In passing east or west from this point the Keweenawan rocks come in contact with lower and lower horizons of the Penokee series. At one place the entire succession appears to be cut off by it. This is taken to imply that between the deposition of the Penokee series and the outflows of Keweenawan time there lapsed a sufficient time for erosion to remove at least this thickness of sediments, and consequently that between the Keweenawan and Penokee series is a very considerable unconformity.

This unconformity is not, however, evident in single cross-sections. The bedded Keweenawan traps have a high inclination which is not markedly different from that of the Penokee succession. The inclination of this bedding is ascertained by the contacts of the different flows, by the inclination of their amygdaloidal horizons, and, north of Bessemer, by the contact between the traps and an interleaved sandstone.

At lake Gogebic the Eastern sandstone is found in a horizontal position to rest against the upturned edges of the Southern Complex and Penokee series alike, and to contain numerous characteristic fragments which can have been derived only from these series. Also very numerous fragments are found equally characteristic of the Keweenaw series, and it is therefore concluded that after the deposition of the Penokee and Keweenawan series, before the Eastern sandstone was laid down, that the two former were upturned and suffered great denudation.

A comparison of the Penokee series proper and the Animikie series shows that they are made up of like succession of rocks, occupying the same relative positions with reference to overlying and underlying rocks, one dipping northward under the basin of lake Superior and the other dipping southward under the same body of water. They are therefore regarded as equivalent. As probably equivalent with the Penokee series are also placed the various areas of rocks in the lake Superior basin referred to the Upper Huronian.

A comparison of the Penokee with the Marquette succession shows that there is a very close correspondence. Unconformably below the Marquette and Pénokee clastics is a crystalline basement complex. Within the pre-Keweenawan clastics in each district is a second physical break. Below this break, in the Penokee district, the formations of the lower Marquette are now represented only by the Cherty Limestone. That other members once existed is indicated by the presence of fragments of jasper and quartzite in the lowest horizon of the Quartz-Slate. Formations composed of these rocks and a cherty limestone are the characteristic members of the lower Marquette.

The correspondence of the members of the Penokee series proper with those of the upper Marquette is complete. The upper Marquette and Penokee series, looked at broadly, are great slate formations, both of which contain, near the base, an iron-bearing horizon. In the Penokee series that portion of the slate overlying the ore formation has been called the Upper Slate member, and that below it the quartz-slate member. The lower part of the quartz-slate is a quartzite and conglomerate, which corresponds to the quartzite and conglomerate forming the base of the upper Marquette series. The uppermost horizon of the Penokee quartz-slate is a narrow layer of persistent quartzite, which does not appear to be represented in the Marquette district. The character of the ore-bearing member is identical in both districts, being unquestionably derived from a lean, cherty carbonate of iron. The characteristic rocks of both are now the iron carbonates, ores, and cherts containing bands and shots of ore. The chief difference between the two is that in the Penokee district the actinolite-magnetite-schists are more prevalent, and that the iron-bearing formation is more persistent. Connected with this fact is perhaps the presence of the upper horizon of quartzite, which shows that a clearing up of the waters occurred before the beginning of deposition of the iron-bearing sediments. A still further analogy between the Penokee and Upper Marquette series is the presence in both of abundant surface volcanics. We have then in the two districts the following parallel descending pre-Keweenawan succession.

PENOKEE.	MARQUETTE.
Upper slate, locally mica-schist.	Upper slate, rather extensively mica-schist.
Iron-bearing formation.	Iron-bearing formation.
Quartz-slate; upper horizon persistent quartzite; central mass a slate; lower part often conglomeratic, bearing fragments of lower series, and locally a quartzite.	Lower slate; lower part quartzite or quartzite-conglomerate, bearing fragments of lower series, either lower Marquette or Archean.
Unconformity.	Unconformity.
Eroded away.	Iron-bearing formation.
Limestone.	Limestone and lower quartzite.
Unconformity.	Unconformity.
Basement complex.	Basement complex.

VAN HISE,[206] in 1891, describes the physical break between a Lower and an Upper Huronian series. In the Marquette district the Lower series includes the lower quartzite and novaculite of Brooks, the limestone formation as well as the chief iron-bearing formation containing the hard ores, which is composed chiefly of jasper and actinolitic and magnetitic slates. The Upper series has at its base a vitreous quartzite, but is chiefly composed of black slates sometimes carbonaceous, graywackes, and mica-schists, together of great thickness, and locally contains belts of ferruginous cherts and slates, including ore-bodies, which are, however, of a different character from the ores of the Lower series. The area occupied by the Upper series is equal to or greater than that of the Lower series. That the two series are separated by a great unconformity is shown by numerous contacts. At these contacts the lower quartzite of the Upper series contains abundant fragments of the Lower series which had reached their present condition before being deposited in the former. That the Lower series has been greatly folded and deeply truncated before the Upper series was deposited, is further shown by the much banded and contorted jasper abutting at all angles against the beds of the uptilted but simply folded Upper series, and also by its more crystalline character.

Since great belts of conglomerates containing abundant fragments of ore and jasper are found in the Upper Vermilion, at Ogishki lake, and in the Upper Kaministiquia series, it is argued that the source of this material is the great belts of iron ore and jasper contained in the Lower Vermilion, Hunters island, and Lower Kaministiquia series. That the Vermilion lake conglomerate is unconformably above the schists in vertical attitude, bearing ore and jasper, is further indicated by the fact discovered by Merriam that on the islands of Vermilion lake the conglomerate is found to be in a series of gentle folds although having a vertical cleavage developed. Merriam regards the conglomerate as a comparatively thin formation overlying and overlapping the Lower series. The presence of red jasper conglomerate in the Original Huronian suggests that in this district will be found in the future a Lower series similar to the Lower Vermilion bearing jasper and ore.

It is concluded that the confusion in correlation of the formations about lake Superior is due to the failure to recognize this general unconformity. Once recognized, the structural conclusions to which the various writers have most steadfastly held are found to be in general harmony. Above the physical break, and constituting the Upper Huronian (equivalent to the Original Huronian) are the Animikie and Upper Kaministiquia, Upper Vermilion, Upper Marquette, Western Menominee, Penokee-Gogebic proper, the Dakota, Iowa, Minnesota, and Wisconsin quartzites surrounded by the fossiliferous series. In the Lower Huronian is the Keewatin (in part at least), the Lower Kaministiquia, Lower Vermilion, Lower Marquttte, Felch mountain iron-bearing series, Menominee proper, and the Cherty limestone at the base of the Penokee series, and the Black river falls iron-bearing schists.

BAYLEY, [207] in 1892, concludes, after a microscopical examination of the specimens obtained in the neighborhood of Akeley lake, from the formation designated Pewabic quartzite by the Minnesota geologists, that they are granulitic and quartzose phases of the gabbro, and that none of them are sedimentary rocks. These granulitic and quartzose gabbros are traced into ordinary gabbros; consequently the Pewabic quartzite is a part of the gabbro. The ore beds of the Akeley lake series, interstratified with these granulitic gabbros, also belong with the overlying gabbro and not with the Animikie. This conclusion agrees with that of Chauvenet reached in 1883 and 1884. This iron-bearing silicified gabbro has been traced by this geologist southwest through secs. 25, 35, 34, T. 65 N., R. 5 W., to Mitchigamme lake. The same silicified gabbro belt has been found by Merriam at lake Gobbemichigomog.

MERRIAM,[208] in 1888 and 1889, in a detailed systematic study of parts of the Marquette district, ascertained that about many of the masses of basic eruptives the clastic rocks bow in a quaquaversal manner, indicating that many of the diabases, gabbros and diorites are intrusive subsequent to the formation of the Marquette series, and that the local strikes and dips are often due to this cause.

VAN HISE,[209] in 1890, examined the rock succession at Iron mountain, Michigan. Overlying the ore formation of the Ludington and Chapin mines is a conglomerate which bears fragments of ore and jasper. It therefore appears that after this material reached its present condition in the ore-bearing series it was eroded and furnished débris for a newer series.

PUMPELLY and VAN HISE,[210] in 1891 and 1892, find that in places the ore formation of the Menominee and Felch mountain districts passes down into the limestone. This gradation may be well seen in the Menominee district at a quarry east of the Chapin mine. Also in the deeper workings of the Chapin, the ores resting almost directly upon the limestone are found to bear a considerable percentage of carbonates, including iron, calcium, and magnesium. The Metropolitan ore deposits in the Felch mountain district are found associated with or within the limestone. At one pit the ore and jasper may be seen interlaminated with and grading down into a limestone. It is therefore probable that the ore formation of these districts, in part at least, is but an upward continuation of the limestone formation, perhaps differing from it originally only in that the upper part contained a greater quantity of original carbonate of iron.

Above the ore formation at Quinnesec, test pits show the presence of a typical chert and jasper conglomerate, in every respect like the basement conglomerates of the Upper Marquette.

SECTION VII. SUMMARY OF RESULTS.

The lake Superior region is the one in America about which most has been written and which has furnished the most definite knowledge of the structural relations of the pre-Cambrian rocks. Contained in the foregoing summary of literature is potentially much that follows, but it seems desirable to put together the conclusions which may be considered as determined and see how far the various positions taken by the different writers are really in harmony. Unless otherwise stated, the cited positions of the various authors are their later expressions; oftentimes earlier and different views have been held. For the sources from which the conclusions are drawn it will be necessary to turn to the literature, from which, by means of the footnotes, the material may be traced to the originals.

The four series to be arranged are those known as the lake Superior sandstone, the Keweenawan, the Huronian, and the Laurentian. The last two have by certain later writers been again subdivided.

LAKE SUPERIOR SANDSTONE.

The horizontal red sandstone of lake Superior was recognized as the most extensive formation of the lake by the earliest geological voyageurs, and in what follows this formation will be called the lake Superior sandstone. The early travelers, Schoolcraft, Bigsby, and Bayfield, regarded it as the Old Red sandstone, although Bayfield later considered it to probably underlie the fossiliferous red sandstone of St. Marys river. It was placed by Jackson, Marcou, and for a long time by Bell, as the New Red sandstone. Very early others, including Dawson (Sir William), Foster, Houghton, Logan, Owen, Whitney, and Rogers, regarded the sandstone as Lower Silurian or Potsdam. In 1873 Rominger finally demonstrated what Houghton had long before stated, that the horizontal sandstone is directly overlapped by the Calciferous formation. The sandstone was therefore placed as Potsdam, which position it has held since that time without dispute by anyone acquainted with the region.

It was very early seen that the horizontal sandstone is newer than the granites and slates of lake Superior, which occupy a lower position than the Keweenawan. Schoolcraft saw, as early as 1821, the unconformity between the granite and sandstone at Granite point, and that between the latter and the slates on the St. Louis river at the head of lake Superior. Bayfield recognized this unconformity in 1829, saying that the many instances of the conjunction of the sandstone and granite proved that the sandstone was deposited after the granite occupied its present position. Rogers saw the same relations between the sandstone and the slates of Chocolate and Carp rivers, although at first he regarded the latter as Primal. Owen, in 1847, described in northern Wisconsin like unconformable relations between the horizontal sandstone referred to the Potsdam and the crystalline rocks. Norwood, in 1847, again saw the unconformity between the lake Superior sandstone and St. Louis slates at Fond du Lac, described by Schoolcraft many years before. Foster, in 1848, saw the same unconformable relations between the sandstones and slates at L'Anse. Since these early discoveries of the relations between the sandstone and the crystalline rocks were announced they have been confirmed at these original localities and at numerous other localities by many observers.

As to the relations of the lake Superior sandstone with the sandstones interstratified with the trappean rocks, i.e., the Keweenawan, there has been the greatest diversity of opinion, and the question is one in which there is not yet entire unanimity, although the weight of the evidence is so strongly in favor of the inferior position of the Keweenaw series that this conclusion is doubted by but few geologists.

Bayfield, Bigsby, Burt, Rogers, Schoolcraft, and Whittlesey made no distinction between the lake Superior and Keweenawan sandstones, apparently not recognizing that there was any question of their not being equivalent. Jackson, followed by Bell, for many years apparently regarded the Keweenawan sandstones as later than the lake Superior sandstone. Jackson places the former as New Red, and states that the sandstone of the Pictured rocks may not be of the same age. Bell at first thought the Keweenawan Permian or Triassic, while cognizant of the fact that the lake Superior sandstone is older than the Triassic, but recently this writer places the sandstone as probably unconformably above the Keweenawan. Foster, Wadsworth, Whitney, and Winchell (N. H.), after comparisons and studies of the problem, have maintained that the lake Superior and Keweenawan sandstones belong to the same series. Agassiz, Brooks, Chamberlin, Dawson, Houghton, Irving, Logan, Macfarlane, Bell, Owen, Pumpelly, Rominger, Selwyn, Strong, Sweet, and Wooster have held as their latest view that the Keweenaw series is older than the lake Superior sandstone. Agassiz at first regarded all the sandstones of the same age, but came to the conclusion afterwards that the sandstone was deposited against the upturned Keweenaw series. Agassiz, Brooks, Chamberlin, Dawson, Irving, Owen, Pumpelly, Rominger, Strong, Sweet, and Wooster maintain a great unconformity between the two. Macfarlane held that there was a doubtful unconformity between the Keweenaw series and the lake Superior sandstone, the former occupying an inferior position. Houghton's, Logan's, and Selwyn's position is that the Keweenaw series is a downward extension of the lake Superior red sandstone. The latter is regarded by Logan as probably Chazy, and the Keweenawan therefore Calciferous or Potsdam. Selwyn and Bell now place the Keweenawan as Cambrian.

The relations of the horizontal sandstone in northern Wisconsin to the melaphyres and traps regarded as Keweenawan have been described by all observers to be those of unconformity, the horizontal sandstone resting upon the upturned edges of the Keweenaw series. The only point of difference has been whether this sandstone is Potsdam or not. It is so regarded by the Wisconsin geologists and by Owen, but is by N. H. Winchell called St. Croix and is placed above the Potsdam. The true position of this sandstone another will discuss, but no one doubts that it belongs near the base of the Northwestern Paleozoics. The extensive area of horizontal sandstone about Agogebic lake between the two highly tilted trap ranges was long ago cited by Brooks and Pumpelly as evidence that the lake Superior sandstone is far later in age, it being found not distant from the highly tilted Keweenawan eruptives.

The controversy has been most extended as to the relations of the two series on Keweenaw point. A part of what has been regarded as the lake Superior sandstone, adjacent to the trap range, has been shown by Wadsworth to belong with the Keweenaw series, and it is even yet a debatable question as to just where at certain places the lake Superior sandstone begins and the Keweenaw series ends; because by all it is now agreed that near this contact is an ancient fault of great magnitude, along which post-Potsdam slipping has taken place.

In considering the question whether the lake Superior sandstone is a part of the Keweenawan, the general field relations are more significant than all else. Wherever the Keweenaw series appears in its characteristic development about lake Superior, from Michipicoten on the east to Duluth on the west, from Thunder bay on the north to Keweenaw point on the south, it is a titled series, the inclinations rarely being less than 30°, never less on the south shore, while more commonly they are much higher, running often to 80°. The lake Superior sandstone, on the other hand, wherever found, is horizontal, except along lines of contact with Keweenawan or other rocks, and here the tilting has been explained to be due to faulting. The only locality remote from a contact at which the sandstone is said not to be horizontal is Traverse island, and at this place the facts upon which the statement is based have not been published. The lake Superior sandstone runs as a long tongue for a distance of more than 50 miles, always in horizontal attitude, gradually narrowing to the west; between the north and south highly inclined Keweenawan trap ranges to near the Montreal river. Nowhere is it interlaminated with or cut by a single eruptive rock of any kind. The finding of detrital rocks between the lava flows of the South range of the Keweenawan has no bearing against this assertion any more than does the existence of such rocks in the main trap range. Before it can be concluded that such tilted interlaminated detritals are a part of the horizontal Eastern sandstone the two must be traced together in continuous exposure.

These broad field relations and the absence of trap point with irresistible force to the conclusion that the lake Superior sandstone is a far later formation, laid down since the Keweenawan was deposited, uptilted, and eroded. If this is not the case, that it in broad areas should have wholly escaped the dynamic movements which upturned the Keweenaw series everywhere about lake Superior is absolutely inexplicable. Equally strange is the fact that it has everywhere escaped intrusive material. It is not a common thing for eruptive activity which extends over distances of 300 miles east and west and 100 miles north and south to continue in full force up to and stop along a ruled line 100 miles long. That this occurred must be believed if the lake Superior sandstone is regarded as belonging to that part of the Keweenaw series, interbedded with the traps, as advocated by Wadsworth. The absence of eruptive material in the horizontal sandstone on the theory that it is a part of the Keweenawan can be explained only by regarding it as the equivalent of the upper members of the Keweenawan, and even this hypothesis would leave wholly unexplained the strange field relations. The amount of positive evidence, based upon contact relations, necessary to establish the conclusion that the lake Superior sandstone is interstratified with the Keweenaw series, considering these general relations (mentioned by Logan as early as 1863), would need to be very great indeed.

However, the great mass of the evidence of contacts bears toward the later age of the sandstone. At the very numerous localities in Wisconsin in which the contacts are not obscured by faulting, all who have examined the district are agreed that the sandstone there found does rest unconformably upon melaphyres and traps in every respect identical with those of the Keweenawan. Also the order of superposition of the Potsdam sandstone and the Keweenawan are shown by the deep well at Stillwater, Minnesota, described by Meads. This well passed through 700 feet of St. Croix and Potsdam sandstone and then went into the characteristic interbedded sandstones and eruptives of the Keweenaw series. This occurrence alone would seem to demonstrate the inferior position of the Keweenawan, although from the nature of the case it can not determine whether there is an unconformity between the two. The only district in which anyone has maintained that the lake Superior sandstone does pass in continuous exposure between the traps is along the southern border of the Keweenawan of Keweenaw point, and, as already said, it is now not denied that there has been faulting here both before and since the deposition of the Eastern sandstone. Moreover, the fault is probably an overthrust. It is, then, a district in which the contacts and relations are particularly liable to be confusing and misleading. Even here, however, examinations by Agassiz, Chamberlin, Irving, Rominger and Pumpelly, have led them all to the conclusion that the Eastern sandstone is newer than and overlies the trap, while only Foster and Whitney and Wadsworth maintain the contrary.

Nearly all of the positive evidence as to the relations of what is known to be the lake Superior sandstone to the Keweenaw series is that the former is far later than and was deposited upon and against the upturned edges of the Keweenawan; that between them is a great unconformity; and, as has been seen, this conclusion is the one reached by the greater number who have studied the question critically. As the lake Superior Sandstone is Potsdam, it follows that the Keweenawan is pre-Potsdam; and since the unconformity separating the two is so great, the latter is probably pre Cambrian.

THE CHARACTER OF THE KEWEENAW SERIES.

Of the forms of the word proposed for this series, Keweenawian, Keweenian, and Keweenawan, the last is apparently preferable as being most directly derived from the geographical term Keweenaw.

Bayfield, in 1829, recognized the detrital character and source of the débris of the Keweenawan conglomerates, and concluded that they must be later than the traps.

The existence of a succession of interbedded clastics and volcanics 12,000 feet thick about lake Superior was recognized by Logan as early as 1847, while in 1852 the same author accurately characterized the series as an alternation of sandstones and conglomerates, amygdaloids and traps. The work of Foster and Whitney on the south shore established about the same time the existence of a similar great succession on Keweenaw point, although the conglomerates were by these authors regarded as friction conglomerates caused mainly by volcanic action upon the earlier sandstones. Jackson recognized that the conglomerates are of true detrital origin. The first clear appreciation of the contemporaneous interstratified relations between the volcanics and detrital rocks on the south shore was reached by Pumpelly and Marvine. Their work was much fuller on this series of rocks than any that had gone before, and as a consequence of this the rocks were recognized as a distinct system to which the term Keweenaw group was applied. Logan, on the north shore, included in his Upper Copper-bearing rocks what is here called Keweenawan and the uncomformably underlying Animikie. He however recognized that the two have a very different lithological character. The felsites, quartz-porphyries, and other acid rocks—in the earlier reports frequently called jaspers—and amygdaloids were by many of the earlier authors supposed to be metamorphosed sandstones. This position is, I believe, for the acid rocks, held by no writer at the present time, with perhaps one exception, and for the amygdaloids by none. The work of Wadsworth, Pumpelly and Irving has demonstrated beyond all doubt that these rocks are original eruptives. The Keweenawan is now generally recognized as a series many thousands of feet thick, consisting of interbedded lava flows and water-deposited detrital material, derived chiefly from the contemporaneous igneous rocks. The volcanics are predominant in the lower part of the series, the interstratifications of the two are most frequent in the middle portion, and the upper part of the series is free from volcanics.

RELATIONS OF KEWEENAW AND UNDERLYING SERIES.

Coming now to the relations of the Keweenaw and next underlying series, opinion is nearly unanimous. As these two series were folded together to form the basin of lake Superior, the earlier writers regarded them as conformable. That they are really discordant was first recognized by Brooks and Pumpelly, who found that the base of the Keweenawan is now in contact with one formation of the underlying series and now with another, and from this general relation they argued an erosion interval. Brooks also brought forward as evidence of this conclusion the wholly unaltered character of the Keweenawan detritals and the simplicity of its folding as compared with the Huronian. The Wisconsin geologists corroborated Brooks's and Pumpelly's results. When the relations of the series on the north shore were closely examined actual evidence of the erosion interval was found by Irving at Thunder bay. The same was seen by McKellar, and upon mapping the two series in northeastern Minnesota, Irving and Merriam found that the same discordance which was found on the south shore appeared, that is to say, the base of the Keweenawan is now in contact with one member of the underlying series and now with another. Selwyn finds at Thunder bay no evidence of this erosion interval, but this testimony is negative and stands alone. The great mass of evidence from many localities agrees that there is a physical break at the base of the Keweenawan.

The last point to consider in this connection is the reality of the existence and the position of the so-called crowning overflow of the northwest shore. This was described by Logan, Bell, Selwyn and others, and some were inclined to place it with the Animikie and others with the Keweenawan. Irving, in his general treatise on the copper-bearing rocks, does not recognize this overflow as a general formation, but places the more important flows to which this term has been applied at the base of the Keweenawan. Later work in northeastern Minnesota shows that at the base of the Keweenawan is a great area of gabbro, the thickness and magnitude of which is incomparably greater than the so-called crowning overflow of Thunder bay. This great mass of gabbro extends from Duluth northeast to the National boundary, a distance of 100 miles or more, and is at its maximum outcrop more than 20 miles in width. There is no question, unless it be considered a subsequent intrusion, that this great gabbro is the base of the Keweenawan, for it now comes in contact with one member of the Animikie and now with another. At other times it is in contact with the crystalline schists of the Lower Huronian, and again with the granite and gneiss of the Laurentian, so that it is evident, if it is a part of the regular succession, that all of these rocks have been deeply eroded before its appearance. This gabbro has been, however, too little studied to venture an opinion as to whether it is a great surface flow or succession of flows, or, as suggested by Bayley, an immense reservoir in the nature of an early laccolite or batholite which furnished material for the subsequent diabase dikes and sheets of the Animikie and for basic surface flows of the Keweenawan. Recently N. H. Winchell, contrary to all previous work, places this gabbro as older than the Animikie. Little evidence is given to support this change of view. No section is given illustrating the supposed structure. To the writer there appears to be great if not insuperable difficulties in the way of the correctness of this conclusion.

GENERAL SUCCESSION ACCORDING TO DIFFERENT WRITERS.

In taking the next step downward, we come to the complex about which there has been great diversity of opinion and about which it is difficult even yet to see clearly all the results which legitimately follow from the work done. The crude notion that the sandstones, traps, jaspers, gneisses, granites, and all other rocks of lake Superior represent one great formation, the crystalline phases being more metamorphosed materials, as maintained by some of the earlier geologists, would now hardly be held by any one. Also it is doubtful if any would deny that the rocks below the Keweenaw series are divisible on a structural basis, if the Animikie series is here included. The successions deduced by the geologists who have made the most extended study of the lake Superior region are as follows:

Logan makes the Keweenawan a downward extension of the lake Superior sandstone. Below the Keweenaw series, as before defined, is a set of slates (the Animikie) of very considerable thickness, which are, however, a part of the Upper Copper-bearing group, and therefore superior to the Original Huronian or Lower Copper-bearing group. The Animikie rests unconformably upon the Huronian. As to the relations of the Huronian and Laurentian about lake Superior little is said, except that at one place they appear to be conformable and grade into each other. We thus have Logan's succession, lake Superior sandstone; Keweenawan; Animikie; unconformity; Huronian; Laurentian. The Animikie, as well as the Keweenawan, is regarded as a part of the Cambrian series.

Selwyn's succession differs from Logan's only in that he maintains that all of the rocks underlying the Animikie in Canada constitute one general conformable succession, but divisible into two systems upon lithological grounds and the superior position of the second. These are the Laurentian and Huronian. This order is also that of Bell. With these authors the Laurentian is granitoid and gneissic, while the Huronian is quartzose, hornblendic, schistose and slaty.

Foster and Whitney's succession is Keweenawan, which includes the lake Superior sandstone; unconformity; Azoic—the latter said to be indivisible except on the north shore, and the granites are intrusive rocks later than the Azoic slates. On the north shore the Animikie reposes upon the granite. Until recently Wadsworth has held to the same succession as Foster and Whitney. In his last paper, however, he states it is probable that in the Marquette Azoic there are three distinct geological formations or ages to which he applies, beginning at the base, the terms Cascade, Republic, and Holyoke formations. The last two are unconformable with each other.

Macfarlane recognizes a Huronian and a Laurentian, but regards both series as wholly of igneous origin and the distinction between the two a lithological one, the basic green schists referred to the Huronian being newer than the granite and gneiss, and the pseudo-conglomerates found in the Huronian a consequence of the intrusion of the latter, in which process fragments of granite and gneiss were caught. The Keweenawan is full of débris from the Huronian.

Brooks, Pumpelly, Irving, Chamberlin, Sweet, and Wright recognize about the same general succession; lake Superior sandstone; unconformity; Keweenawan; unconformity; then a great system of rocks included in the Huronian; another unconformity; and then a complex of granites, gneisses and schists. Irving in his later work separates from the Huronian and puts in the Laurentian the formation of dioritic schists, obscure green conglomerates, chloritic schists, etc., cut by granite veins in the Marquette district, which Brooks placed as the lowest part of the Huronian, but the relations of which are said not to have been fully made out. There is the further resultant difference between Brooks and Irving that Brooks regards very considerable masses of granite in the Menominee district as the highest member of the Huronian. As this granite is said to overlie conformably the Huronian schists and to send dikes into them, it is suggested that toward the end of the Huronian period there was a great eruptive outflow of granite. As has been seen, these facts are explained by Irving by excluding from the Huronian the granite and the schists cut, although it is recognized that lesser granitic intrusions have occurred since Huronian time.

Rominger, in his earlier work on the south shore, seeing that his dioritic group of Huronian rocks is cut by granite, and considering the former as a sedimentary rock, and finding also, as he believed, actual transitions between the fragmental quartzites and granites, placed the whole complex as Huronian and regarded the granite as the youngest member. These positions are, however, very largely abandoned in his later unpublished work. The existence of granite and gneiss prior to the deposition of, and which have yielded débris to, the lowest members of the Huronian, is recognized, although contacts are said to be not often sufficiently frequent to enable a discrimination to be made between the original primary granites and gneisses and those of later eruptive origin. The recomposed character of the detrital rocks which repose upon and have derived débris from the granites and gneisses, instead of grading into them, is now seen. It is, however, still maintained that the great mass of the granite and gneiss is an eruptive of later age than the detrital rocks. The dioritic group, which is so frequently cut by granite veins, before considered as the bottom of the Huronian, is recognized as an igneous rock which must be excluded from the sedimentary series. Rominger's succession is, then, lake Superior sandstone; unconformity; Keweenawan; unconformity; Huronian sedimentary series, which has, however, been disturbed by great intrusions of granite and gneiss, with also basic rocks; unconformity; granite-gneiss-schist complex.

It is therefore to be noted that Brooks, Irving, and Rominger, who have done the most work in the detailed mapping of the rocks of the south shore, reach an identical conclusion as to the succession, the only difference being one of emphasis. Rominger insists on the great importance of the later granite-gneisses, but does not emphasize the presence of the granite-gneiss-schist complex; Irving, on the other hand, reverses the emphasis; while Brooks occupies an intermediate position. It is most significant that these three men, starting with different views, have finally reached like conclusions. For a long time Rominger denied the existence of the basement granite-gneiss-schist complex. Irving was slow to recognize the presence of later intrusive granite. In Brooks's earlier work in the Marquette district he did not find the evidence of intrusive granite-gneiss which he found later in the Menominee district.

Lawson recognizes a physical break at the base of the Keweenawan and a great break at the base of the Animikie, and divides the underlying complex about the lake of the Woods and Rainy lake, Ontario, into Keewatin, Coutchiching, and Laurentian, this being the order of occurrence downward, but in age the granitic and gneissic rocks are later than and intrusive in the schistose rocks. In this matter Lawson agrees with the earlier work of Bigsby upon Rainy lake and that of Dawson upon the lake of the Woods, except that Dawson did not regard all of the granite-gneiss of the lake of the Woods as later igneous material. These relations are the same as those described by Foster and Whitney, and by Wadsworth between the granite-gneisses and the Azoic slates on the south shore. With Dawson, Lawson agrees that the Laurentian gneiss and granite and the overlying schists are conformable. By both of these writers the schistose rocks of the lake of the Woods are regarded as sedimentary and largely of volcanic origin. There is the further agreement between Lawson and Dawson on the north shore and Foster and Whitney, Wadsworth, Irving, and Williams on the south shore that they regard the greenstone slates as largely in the nature of volcanic ash. Lawson gives the schistose rocks about Rainy lake a twofold division, both series being regarded as sedimentary and in apparent conformity, but there are great differences in the materials of which the series are composed as well as in degree of crystallization, and basal conglomerates are found at the bottom of the upper series. Between the two there is believed to be a considerable geological break. The upper is the equivalent of the schistose series of the lake of the Woods. To cover the two series is proposed the system name Ontarian. Lawson's succession is therefore Keweenawan, unconformity, Animikie, unconformity, Keewatin, unconformity, Coutchiching, irruptive unconformity, Laurentian cutting both Keewatin and Coutchiching.

It is of interest to note that Rominger's early conclusions as to the general relations of the rock series on the south shore were almost identical with those reached by Lawson as to the relations of the different series on the north shore; that is, the dioritic group, the lowest Huronian, is regarded as remelted metamorphosed Huronian sediments, the more crystalline character of the rocks being due to their closer proximity to the volcanic forces, and while the great masses of granite-gneiss are below the dioritic group, these rocks are also interstratified with and cut the dioritic rocks, the whole granitic group being regarded as of igneous origin, and later in age than the sedimentaries. The likeness of the dioritic group and Lawson's Keewatin at once suggests itself. As has been seen, Rominger's later studies led him materially to modify his opinions and to bring them more nearly in harmony with the conclusions of Brooks and Irving.

N. H. Winchell's succession is: Keweenawan, Animikie, Norian, Pewabic quartzite (all of which are included in the Taconic), Keewatin, Vermilion, Laurentian (which are included in the Archean or Azoic). The Keweenawan is doubtfully called Potsdam, and is, with the Animikie, placed as the Georgia formation; and the Pewabic quartzite is provisionally placed with the Potsdam granular quartz. Included in the Taconic are the quartzites of Minnesota, Iowa, Dakota and Wisconsin. The part of the succession placed in the Taconic differs from Irving's succession for this part of the column in that the formations which Winchell includes in the Norian and Pewabic are regarded as the great basal gabbro mass of the Keweenawan, between the upper Keweenawan and the Animikie instead of below the Animikie. It is not necessary to say that Irving regarded all of these members as pre-Cambrian. The succession within the Archean is the same as that of Lawson, the difference being only that Vermilion is substituted for Coutchiching. Also the Keewatin clastics, Vermilion schists, and Laurentian gneiss are regarded as in complete conformity, all detrital, and the lower members but more metamorphosed than the upper.

Alexander Winchell's succession below the Keweenawan is Huronian, Keewatin, Vermilion and Laurentian. At the base of the Huronian is a great structural break. The three lower series are in conformity and grade into each other. This is much the same as this part of the succession given by N. H. Winchell, except that one great series, the Ogishki conglomerate, is placed by the latter as a part of the Animikie (Huronian) while by Alexander Winchell it is placed with the Keewatin.

Doubtless to the minds of many the great thickness of the combined Keewatin and Coutchiching of Profs. Winchells and Lawson will be presumptive evidence against the structure which they have worked out. This thickness as given by Alexander Winchell is more than 30,000 feet, while Lawson gives the Keewatin a thickness of 5 miles and the Coutchiching a thickness of 4 or 5 miles, or in the neighborhood of 50,000 feet. The manner in which the structure of the Keewatin and Coutchiching schists always strike parallel to and encircle the adjacent granite masses suggests that these intrusives have developed slaty cleavage or schistose structure which has been mistaken for bedding. Lawson supposes the intruding granite has upthrust the beds until they now stand on end. That both schistose structure and bedding, with marked discordance to each other, exist east of Rainy lake is positively maintained by Pumpelly and Smyth.

If the objection of great thickness for the Keewatin and Coutchiching has weight, the enormous thickness of over 120,000 feet given for the conformable system in northeastern Minnesota, on the theory that the Keewatin and Coutchiching are conformable and grade into the gneissic series, and that all are of sedimentary origin, now folded into a simple synclinal structure, will be still more weighty evidence against the correctness of the conclusion reached. It is notable that Willis's explanation of the structure at the center of this supposed syncline, Vermilion lake, reverses this and makes it an anticline. Lawson does not have to meet this difficulty because he regards the granite and gneiss as irruptive and consequently a series to which the principles of ordinary stratigraphical geology do not apply.

From the foregoing statements it might be concluded that lake Superior stratigraphy below the Keweenawan is in a greater state of confusion than is really the case, for a closer examination of the various successions shows that many apparent discrepancies are not real, if conclusions are not extended beyond the field studied in each case. Confusion has resulted because the conclusions built up from a study of a small part of the region have been assumed to apply to the whole, and because different names are used for the same thing. The lake Superior region is so large that no one has had or can have a detailed personal knowledge of more than a small part of it.

LITHOLOGICAL CHARACTERS OF AZOIC, LAURENTIAN, HURONIAN, ETC.

Before going farther it will be well to summarize the lithological characters of the pre-Keweenawan rocks included by the various writers under the terms applied to the different series in different districts, although to a certain extent this will repeat the preceding paragraphs. It is here much less easy to make definite statements than in the case of the lake Superior sandstone and Keweenawan.

Azoic, as used by Foster and Whitney and those who followed these authors, was made to include everything below the Keweenawan, with the exception of the rocks which are plainly igneous. It covered conglomerates, quartzites, slates and marble, as well as the gneisses, mica-schists, hornblende-schists, etc.; that is, rocks which vary in their character from those which are plainly clastic, as conglomerates, to those which are completely crystalline. The granites, syenites, greenstones, greenstone slates, iron ore, jasper, etc., were regarded as igneous rocks, in part contemporaneous with and in part newer than the rocks of the Azoic system, all of which were supposed to be of detrital origin, but in age earlier than the Keweenawan.

Laurentian, as used by most of the earlier Canadian geologists, covers the most of the light colored granites and coarse grained gneisses. It was recognized that these rocks are cut by basic eruptives. This usage was followed by many of the American geologists up to the time of Brooks, who excluded a large part of the granite and gneiss from the

Laurentian, believing this part to be of later age and intrusive. Dawson about the lake of the Woods made the same discrimination. Irving, in his later work, differed from those who preceded him in that he included in the Laurentian all the thoroughly crystalline schists, with some of the obscure green schist-conglomerates; that is, he placed as a part of the Laurentian a large group of finely schistose rocks cut by granite veins which had heretofore been taken to be greatly metamorphosed detrital material and had been placed in the Huronian. He also regarded as belonging here many of the fine grained crystalline schists of a similar character on the north shore, placed by the earlier Canadian geologists with the Huronian. For this Laurentian increased in magnitude he used the term Archean. Lawson and the Profs. Winchell use the term Laurentian to cover practically the same class of rocks as the earlier Canadian geologists, although Lawson differs from them in regard to their origin and age. It was early remarked by Macfarlane and later by Whittlesey, Brooks and Rominger that the Laurentian of lake Superior differs from that system in eastern Canada in containing no limestones, quartzites, iron ores, or other rocks of the plainly detrital class. Brooks and Chamberlin remark that it is doubtful whether the lake Superior Laurentian is the equivalent of the eastern Laurentian of Canada.

The lake Superior Huronian of the larger number of the Canadian geologists includes the quartzites, slates, fine grained green schists, all of which are sometimes conglomeratic, and the pebbles often distorted and metamorphosed. It also includes the mica-schists, hornblende-schists and fine grained gneisses bearing calcite, with certain ferruginous schists and basic and acid volcanic products. The attitude of the Huronian schists is either vertical or steeply inclined. The Animikie is not included in the Huronian. On the south shore Brooks and Pumpelly in their earlier work included in the Huronian all the rocks in character like those placed in this system on the north shore, with also large areas of rocks the clastic character of which is evident, such as limestones, ferruginous beds, slates, graywackes, etc., which while always tilted or gently folded have not the schistose structure of the Huronian of the north shore, but rather resemble the Animikie. Later, Brooks placed as the upper member of the Huronian large areas of gneiss and granite which had earlier been regarded as Laurentian. Rominger went a step farther and recognized in his published report on the south shore the Huronian only, seeing as he did that a part of the granite-gneiss certainly cuts a portion of the schistose rocks which had been regarded as Huronian. He thus included in the Huronian the granite-gneisses which are equivalent to Lawson's Laurentian, and reverted to the position of Foster and Whitney, making his Huronian the equivalent of their Azoic, one indivisible system. In Rominger's later unpublished manuscript he, however, distinctly recognizes besides a later intrusive granite an earlier granite-gneiss upon which the lowest detrital beds were deposited, although he nowhere states whether this is considered Laurentian or not. Irving excludes from the Huronian on the south shore large areas of green crystalline hornblende schists, chlorite-schists and green schist-conglomerates cut by granite veins heretofore called Huronian; that is, he included in the Huronian only those detrital rocks the clastic character of which is apparent or which can be traced into the clastic rocks, such as the quartzites, limestones, ferruginous beds, argillaceous slates, the metamorphic mica-schists, etc. In his Huronian he included the Animikie on the north shore, placed above the Huronian by the Canadian geolgists.

Lawson abandons the term Huronian and divides the schistose rocks included under this term by the earlier Canadian geologists into two series the Coutchiching and Keewatin. The Coutchiching includes the lowest rocks in contact with the Laurentian gneisses and granites and comprises mica-schists and fine grained, evenly laminated gneisses; that is, thoroughly crystalline finely laminated rocks. The Keewatin includes fine grained green schists, both basic and acidic, with volcanic tuffs, agglomerates, peculiar altered conglomerates with intersecting eruptives, and jaspery iron ore beds. It does not include the unaltered slates, graywackes and ferruginous beds of the Animikie. The position of the Profs. Winchell is practically the same as that of Lawson, except that instead of using Coutchiching, Vermilion is used, and both the Keewatin and Coutchiching are held to be inferior to all of the Huronian.

The Animikie includes the unaltered, or little altered, gently inclined or folded slates, graywackes, and ferruginous beds on the north shore and in northeastern Minnesota.

Belonging to the series designated by the foregoing terms are recognized by all writers interbedded and cutting basic and acid eruptives of various sorts, only in the Animikie and in the Huronian of Irving the acid eruptives are insignificant in amount. Many of the fine grained green schists, with some exceptions, in early days regarded as much metamorphosed sedimentary Huronian rocks, are now considered by all to be much altered eruptives, either of surface or deep-seated origin, their present structure being due to secondary causes. That acid eruptive material should be found plentifully cutting the clastics series is not at all surprising. Acid eruptions were abundant and widespread in the lake Superior region as late as Keweenawan time, as is attested by the original acid rocks of the copper-bearing series, and still more emphatically by the vast amount of débris from felsites, quartz-porphyries, etc., found in the interlaminated detrital beds. That so few acid dikes are found in the upper Huronian of the south shore can be explained only by the fact that the acid eruptives of the Keweenawan are mostly remote from the Marquette, Menominee, and Penokee series. A closer study in the future will probably show in these districts a greater abundance of acid eruptives than has been supposed. The deep-seated pipes and bosses formed by the eruptions of the Keweenawan felsites and porphyries perhaps crystallized in the form of granite. It may well be that large masses of intrusive granite may be of Keneewanan or Animikie age. Even if this were the case and there are two epochs of granitic eruptives later than the upper Huronian clastics, this would be no evidence of the absence of an ancient floor composed mainly of granite-gneiss upon which the oldest Huronian has been deposited.

ORIGIN OF THE IRON ORES.

Before taking up the correlation of the pre-Keweenawan lake Superior series, one further point remains to be considered, whether the iron ores and associated rocks are eruptive or are sedimentary, for upon this point depends the correctness of many structural determinations. If, as believed by Wadsworth and Foster and Whitney, the iron ore is partly igneous, and by the first named that a part of the jasper has the same genesis, they may occur at any horizon up to that of their eruption and can not be used as guides in working out the structure. Those who believe the iron-bearing formations are sedimentary have regarded them as persistent members, and the striking and peculiar lithological characters of these belts have furnished key horizons to which to refer the associated clastics.

Foster and Whitney saw that the masses of iron ore and jasper have none of the characteristics of vein deposits, and believed that the supposition that they resulted from the decomposition of pyrites or the metamorphism of bog ore is wholly inadequate to account for the accumulation of such vast masses as occur, or to explain the relations to the associated rocks. If not of this origin, they could only conceive that they are igneous. The frequent association of the ore with eruptives and the fine banding led to the conclusion that these facts can hardly be explained except by igneous action. These writers saw, however, that when the ore is found in beds in clearly metamorphic strata having a common bearing and inclination they must be sedimentary, and such deposits are regarded as having been derived from the destruction of previously formed igneous masses and their present association to have resulted from aqueous deposition, so that even in this case the iron has an igneous source. At the present time few would assert that the iron ores are vein deposits, or the result of decomposition of pyrites, or the metamorphism of bog ores; but there are other explanations overlooked by Foster and Whitney which may apply before being driven to the igneous hypothesis.

The reasons given by Foster and Whitney for an igneous origin of the ore-bearing formations are of a negative character, and the only case in which positive evidence is given the rocks are recognized as detrital. But Wadsworth brings forward positive evidence as to the origin of the ores. Many instances are cited showing the way in which the jasper and ore have eruptive contacts with the associated schists. The facts, however, indicate the eruptive character of the ore and jasper only if the schists are of sedimentary origin. The investigations of Irving, Williams, and the Profs. Winchell, as well as our own later work, have shown that the lower Vermilion and lower Marquette iron-bearing members contain many schistose dikes, and also that in many cases the massive greenstone knobs found in these districts vary by imperceptible stages into the finely laminated schists associated with the iron ore and jasper. The schists are, then, in part at least, of eruptive origin. Brooks noted the dike-like character of certain magnesian schists associated with the ore formation, between which and the dioritic schists, believed to be of sedimentary origin, it was said to be impossible to draw the line. That these well laminated schists should not at first be regarded as eruptive is natural, but the variation of massive igneous rocks into those which are well laminated as a result of dynamic action and metasomatic changes is now so well known that new cases of it excite no surprise. I would by no means assert that all of the schistose rocks associated with the iron ores and jaspers in the Marquette and Vermilion districts are of eruptive origin, but this is certainly the case at many localities. This view reverses Wadsworth's and makes his sedimentary rocks eruptive and his eruptives sedimentary. It will, however, be seen that this position harmonizes Irving's conclusion as to the sedimentary origin of the ores and jaspers and the point upon which Wadsworth places most emphasis, that there are eruptive contacts between these rocks and the associated schists.

It is to be noted that the eruptive theory has been applied only to the Marquette and Vermilion jasper and ore. No one has asserted such an origin for the iron-bearing horizon of the Penokee and Animikie series. This is an independent question, as will be seen by what follows; for these formations probably occupy a higher position than the lower Marquette and lower Vermilion ores. We have, then, to answer two questions: "What is the origin of the iron-ore formations of the Penokee, Animikie, and equivalent iron-bearing formations?" and, second, "What is the origin of the great masses of ore and jasper of somewhat irregular shape, apparently not continuous formations, although probably at rather persistent horizons, in the Lower Vermilion, Lower Marquette, Kaministiquia, and similar areas?"

Upon the first of these questions there is practically no dispute. The iron-ore formation in the Penokee district has been found to extend for many miles as a simple belt of very uniform thickness between two readily recognized detrital formations, all with a common strike and dip varying within very narrow limits. A precisely similar condition of affairs is found in the Animikie district. These formations have been shown by later work to have been originally altogether what they still are largely, thinly laminated impure cherty carbonates of iron, in every way analogous to similar earthy carbonates of later geological periods. The other forms of material now associated with them, such as jasper, actinolitic and magnetitic schists, ore bodies, etc., are the consequence of subsequent changes. The ore bodies, for instance, are secondary concentrations, generally in troughs, due to the action of percolating water. The same facts are apparent as to the Upper Marquette and Upper Menominee ores and jaspers.

In the case of the iron formations of the Lower Marquette, Lower Vermilion, and similar districts the question can not be so decisively answered. The Lower Marquette iron-bearing formation is generally, if not always, the uppermost member found in the lower series, when erosion has not carried it away, and therefore apparently occupies a definite horizon, although as the structure of this district has not been worked out in detail this can not be positively asserted. In the Vermilion lake district the great masses of ore and jasper of immense thickness seem to extend only for a short distance along the strike of the rocks, then disappear and reappear at intervals to the northeastward at Long lake, at Hunter's island, and other points, probably also north of Port Arthur in the Kaministiquia district. This lack of persistence may be due to the fact that the fold or folds are not horizontal, but have a varying pitch. The ore formation at the swells of the pitching folds may have been removed by erosion. While it is not proved, it is probable that the ore formation is at a definite horizon, since the different outcrops appear to be in the same part of the series and along the same general line of strike for considerable distances. These ore and jasper formations contain abundant iron carbonate, are interlaminated with graphitic schists containing iron carbonate, the graphite of which is so abundant and widely disseminated in minute particles that it can hardly be believed to be other than of organic origin, and from these forms there are gradations to the other forms of rock found in the iron-bearing formation. In the deeper workings of some of the larger mines of the Marquette and Menominee districts, the ore bears much residual carbonate of iron and also carbonates of calcium and magnesium. At Iron Mountain and Metropolitan the iron formation grades downward by insensible degrees into the limestone. All of these points, and the remarkable lithological likenesses between the phases of rocks found at these horizons and those occurring in the iron formations of the Penokee and Animikie, demonstrably of detrital origin, are cited as evidence that these ores are derived from an originally impure cherty carbonate of iron. A study of the Vermilion iron formation by N. H. and H. V. Winchell has led them to the conclusion that it is of direct chemical detrital origin rather than derived from an impure cherty carbonate. Which of these views is the correct one does not concern the present question, for if the ore-bearing formation is detrital it may be used for the purposes of stratigraphy. We thus have in favor of an origin for these lower ore formations similar to those of the Penokee and Animikie a large amount of positive evidence, while the only adverse positive facts are those cited by Wadsworth, and these, as has already been said, may be brought into accordance with the sedimentary theory by considering the schistose rocks having eruptive contacts with the ores and jaspers as the intrusives, which in many cases they demonstrably are. In his most recent paper Wadsworth himself suggests that the supposed eruptive jasper and ore may be "truly fragmental, their present relations being due to sedimentary and chemical action and the squeezing together of the jaspilite and schist."

It was suggested by Brooks that the ore deposits of the New England-Saginaw range and of the lake Superior mine in the Marquette district are secondary concentrations due to the removal of silica and the deposition of iron oxide. The same position was taken by Rominger for the entire Marquette district. Later I have shown that it is a general truth for the lake Superior region that the iron ore deposits are secondary concentrations, produced by downward percolating waters along the paths of great water channels, and particularly at places where the waters are converged by tilted impervious basement formations.

THE BASIC ERUPTIVES AND STRATIGRAPHY.

At one other point the problem of lake Superior stratigraphy has been made more difficult by certain of the geologists than was necessary. The diabases, diorites, and gabbros were by several writers in early days regarded as metamorphic sedimentary rocks. Logan, Murray, and Foster and Whitney are notable exceptions. Partly as a consequence of this fact came the minute subdivision of the Marquette, Menominee, Penokee, and other series. All now regarding these rocks as intrusives, the facts that they are often in boss-like masses, and when interleaved do not necessarily continue for any considerable distance, present no difficulty; while a great formation like the Upper Slate of the Penokee and Marquette districts is left as a whole rather than divided into a number of members separated by layers of greenstone. Also it is now known that the "dioritic schists" are ancient eruptives, in part contemporaneous and interbedded with the sedimentary rocks. The volcanic character of these rocks was suggested by Foster and Whitney, and their igneous origin was appreciated by Rominger. Later investigations by Wadsworth and Williams, with the microscope, lead to the same conclusion.

The intrusions of the diabases, gabbros, and diorites, as suggested by Rominger, Wadsworth, and Merriam, have oftentimes had an important influence upon the structure of the sedimentary beds, although Rominger holds that the folding is primarily due to the intrusive granite. Strong and Rominger also suggested, in the St. Louis river district, that the eruptives were the pipes which furnished the outflows of Keweenawan time. This idea is not only plausible for this district, but is probably true for the entire lake Superior region. A closer study will probably demonstrate that the fresher eruptives in both the upper and lower Huronian, including the great intrusive beds of the Animikie, are really Keweenawan in age. Also the numerous dikes of like character cutting the fundamental complex doubtless represent in other series the same manifestation of igneous activity.

UNCONFORMITY AT BASE OF CLASTIC SERIES.

In attempting to determine how far the different views held as to lake Superior stratigraphy are really in harmony, it is desirable to have, if possible, as starting planes upper and lower horizons. From the preceding pages it is evident that for the first of these we have the base of the Keweenawan. Nearly all are agreed that below this series is a break more or less considerable, and all are agreed that it is a recognizable plane. It appears to the writer that the evidence shows the existence of another general plane for the lake Superior region at the horizon elsewhere defined as separating the Archean from the Algonkian—that is, the plane between the basement granite-gneiss-schist complex and the overlying clastic series with their equivalent crystallines. The failure generally to recognize this plane is due to the fact that the banded and contorted gneiss, which is the most prominent rock of the basal complex, does not differ greatly in lithological character from areas of later granite-gneiss which have intruded the clastics. This later granite-gneiss is, however, usually somewhat nearer the normal form of an eruptive rock, not having suffered so many vicissitudes in its briefer history. Those whose attention has been mainly directed to the contact phenomena of the intrusive granite-gneisses have generally refused to believe in an earlier granite-gneiss, although recognizing, at least in some cases, that the lowest detrital rocks bear numerous fragments of a granite-gneiss. On the other hand, those whose attention has been directed to the unconformities, as indicated by basal contacts and other phenomena between the basal complex and the clastic series, have sometimes been disinclined to believe in the existence of important areas of granite-gneiss which are intrusives later than the clastic series. Generally, in the districts which have been studied by individual writers the phenomena of the one class are conspicuous while those of the other class are unimportant or perhaps lacking altogether. Naturally this has engendered an inclination in each observer to conclude that the relations which have strongly impressed him are true of the entire lake Superior region.

Bell and Selwyn find no evidence of discordance between their Laurentian and Huronian. Bell, in 1873, says the distinction between the Laurentian and Huronian is chiefly of a lithological character, while Selwyn, in 1883, states that he can give no better reason for supposing that certain sets of beds belong to the Laurentian and others to the Huronian than a considerable difference in lithological character, the former being essentially granitoid, gneissic, and feldspathic, while the latter is quartzose, hornblendic, schistose, and slaty.

There is, however, much evidence that the plane between the Algonkian and Archean is definitely fixed over much of the lake Superior region by a great unconformity.

That below the Cherty Limestone of the Penokee series there is a great physical break would, in the face of the evidence at present known, be hardly doubted by anyone. The cherty limestone, forming a single line of outcrops, although not continuous, now rests upon granite, now upon gneiss, now upon the green crystalline schists. The granite is definitely known to be later than the schists because it intricately intrudes them, but it never intersects the cherty limestone. This basement is clearly a complex upon which the limestone has been deposited.

Turning now to the Marquette district: Unconformable contacts have been found at many localities, but here the clastic series are folded, and certain of the contacts between the clastics and crystalline complex, by overlapping, are below upper members of the clastic series rather than truly basal contacts. Of the two localities cited by Brooks for the unconformity between the Huronian and Laurentian, that at Republic mountain is clearly between the lower part of the Marquette series and the granite-gneiss-schist complex, while that at Plumbago creek, in the L'Anse district, is certainly below a high horizon. Of the many localities cited by Rominger and Irving in which there are contacts between the granite-gneiss-schist complex and the overlying clastics, if Brooks's succession be accepted, several belong well down in, if not actually at, the base of the Marquette series. At these contacts the clastics are generally conglomerates, built up chiefly of the débris of the underlying rocks, and oftentimes so thoroughly cemented as closely to resemble them and to lead to the conclusion, if not carefully examined, that there is a real transition between the clastic and crystalline rocks. As already indicated, this was at first Rominger's opinion, and the apparent transition was taken to indicate a gradual metamorphism from the conglomerates to the granite or schists as the case might be. But Rominger's later studies led him to see, as did also Irving, that these basal conglomerates are recomposed rocks resting upon an earlier formed crystalline and often granitic base. In the Menominee district Brooks, Rominger, and Irving all hold that contacts are found between very low, or the lowest members of the clastic series and the granite-gneiss complex, the relations being those of profound unconformity. The actual contact described by Smyth (too late to summarize in the literature) between the lowest formation of the lower Marquette and the granite-gneiss at Republic mountain is the clearest case on the south shore. Here is a basal conglomerate containing numerous water-worn bowlders and pebbles of granite, resting directly upon the granite from which the fragments are derived.

As shown by Irving, the magnitude of the break in the Penokee, Marquette, and Menominee districts is not lessened whether the underlying schist, gneiss, and granite are igneous or sedimentary, for they had reached their present crystalline condition before the overlying rocks were deposited upon them, a condition which a part or all could not have had as surface rocks; and which shows, whether igneous or aqueous, profound induced structures and deep erosion, and therefore a system of rocks which had an intricate history before the clastics were deposited. In this connection the physical break at the base of the Animikie and its equivalents is not cited, because this series occupies a higher position than the series overlying the break just considered.

As further evidence for a great physical break between the basement complex and the lowest overlying clastics are cited by Brooks and Irving (1) the strong contrast in the lithological characters of the two, the fundamental complex being thoroughly crystalline, while the overlying rocks are mainly plainly detrital, or such as may have been derived from detritals; (2) the fact that the complex is cut by very numerous granite dikes, which are but rarely found in the clastics; and (3) their general field relations, the complex having most obscure structures and very great variability in strike and tip, while the clastics are less intricately folded, showing that the older series has been subjected to orographic movements prior to the newer.

As before stated, Brooks, Rominger, and Irving—the three who have done the most detailed and continuous work on the south shore—had at the outset different opinions as to the relations of the clastics to a basement granite-gneiss, but they all came to the same final conclusion, that between the two is a great structural break. Pumpelly and Chamberlin, who have also done much general work in this region, agree with this conclusion. While this is true, all of these writers do not agree in every district as to the position at which this plane is found.

Whether the physical break which exists below the clastic series on the south shore is paralleled by a widespread unconformity on the north shore is less certain, although such an unconformity is found locally. Lawson, who has done the most work in this region, maintains that between the Keewatin and Coutchiching a profound physical change took place in the conditions of deposition, consequent upon which are great differences in lithological characters and a prevalent more crystalline condition in the inferior series. He also describes conglomerates in two places at the base of the Keewatin which bear both granitic fragments and fragments from the Coutchiching. From these facts Lawson believes that there is a real unconformity between the two series, although at the present time they have been so squeezed together and secondary structures formed as to be usually in apparent conformity, and the separation in mapping is based for the most part upon lithological grounds. Lawson, however, believes that the Coutchiching is a bedded sedimentary series, rather than a part of the basal complex, as here defined. If this be true, this unconformity does not bear on the question under discussion.

Pumpelly and Smyth, who have recently made a rather extended trip in western Ontario, acquiesce in Lawson's conclusion in so far as the unconformity is concerned, but differ from Lawson in that they find a great structural discordance between the basal clastic series east of Rainy lake and a fundamental complex consisting of granite, gneiss, and schist, while finding the superinduced foliation of both series parallel.

In Minnesota the Profs. Winchell, although recognizing the plane between the clastics and crystallines as a boundary between two groups of rocks, maintain conformity and gradations, although Alexander Winchell suggests that it is a possibility that the apparent conformity is superinduced by subsequent dynamic action.

The probability of an unconformity here follows from the same line of reasoning as that applied to the lake of the Woods and Rainy lake districts, and is further indicated by the descriptions of conglomerates at Saganaga and Epsilon lakes in northeastern Minnesota by Alex. Winchell. In the published note-books these conglomerates are described and figured as sharply separated from the underlying syenite and containing rounded pebbles of it, although it is said the conglomerates were not laid down on the solidified syenite. Later these occurrences are interpreted to mean that the syenite and gneiss are of sedimentary origin, being completely metamorphosed. However, I am not sure that I understand the descriptions well enough to be certain that these so called conglomerates are not really due to the intrusion of the later irruptive syenite, as was suggested by Winchell himself. In the earlier work on the north shore of lake Superior done by Bell, no distinction was made between the fine grained clastics and the crystalline schistose rocks, although it is not improbable that closer work will make it possible to extend the structural subdivisions of Pumpelly and Smyth. Macfarlane noted that the squeezed Huronian slate-conglomerates frequently contain granite fragments, although he did not consider them to be of sedimentary origin. Herrick found in his schistose group on Michipicoten bay basement conglomerates, the pebbles of which are like the granite below, although the relations between the granite and schists are such as to suggest to him that the granite had been intruded beneath the schist. Dawson (Sir William), Logan, and Bell all mention granite and gneiss fragments in the Original Huronian east of lake Superior, and Logan clearly believed the two to be unconformable. Irving found additional evidence in favor of this unconformity. Recent work of Pumpelly and myself has shown that the lowest member of the Original Huronian, as mapped by Logan, rests with a great unconformity upon the basement complex, the Laurentian of Logan. Selwyn, although thinking the Huronian and Laurentian conformable, states that Laurentian pebbles occur in the Huronian.

As shown in another place, the gradation described by the Profs. Winchell in northeastern Minnesota, and which appears to occur in other places, is wholly consistent with a real structural break between the basal complex and the clastics. When a clastic series grades down into a crystalline one, this may be caused by progressive metamorphism; by contact action of a subsequent intrusive, or by later folding, which destroys the original bedding of both series and produces a common secondary structure, at the same time causing the newer series to assume a crystalline character. Such induced conformity and transition are the more likely to occur when the materials of the newer series are chiefly derived from the older, and, as shown by Pumpelly, will be particularly likely to be perfect when the earlier series has suffered atmospheric disintegration before the deposition of the later. Future study may show still other causes of gradations between unconformable series.

Evidently north and east of lake Superior we are not without positive evidence that a great physical break occurs at certain points between an ancient granite-gneiss-schist complex and the clastic series, which, however, are often cut by recent intrusive granite-gneisses. Also at many localities in which an unconformity has not been positively shown the evidence at hand points in this direction. When the conditions are considered which are necessary to produce an unconformity it is difficult to see how one can really be of a local nature. Thus while it can not be asserted that a universal structural break north and east of lake Superior exists between the Algonkian and Archean, there is a probability that such is the case.

The foregoing evidence combined gives a strong case of probability for a general structural break in the lake Superior region between the lowest clastic series and a basement crystalline complex. However, it can not be denied that certain of the contacts, cited as showing this unconformity, although unquestionably beneath the lowest clastic series for particular districts, may be at higher stratigraphical positions than the base of the lowest clastic series of the whole lake Superior region. Before the question of a break at this position can be considered as settled beyond all question for the entire lake Superior region much more detailed mapping must be done. However, the existence of this break for many districts is so strongly supported, that it gives for the present the best available guidance as to one fixed horizon for comparisons of the rock series of the different districts. The recognition of this break does not imply that the lowest clastic series at certain localities are not penetrated by, and now rest upon, intrusive granite-gneiss, but in such cases the evidence of this break, if it once existed, has been destroyed.

We have, then, for structural work two starting planes, the base of the Keweenawan and the base of the clastics, included between which are the larger part of the series of rocks placed in the Huronian by the earlier Canadian geologists, the Animikie, Lawson's Keewatin the Profs. Winchell's Keewatin and Animikie, Irving's Huronian, and perhaps in part the Profs. Winchells' Vermilion and Lawson's Coutchiching.

UNCONFORMITY WITHIN CLASTIC SERIES.

It is believed that many of the further difficulties as to correlation in the districts about lake Superior have arisen from the failure to recognize a third physical break which has a very wide, if not universal, extent in this region. The early Canadian geologists found a break at the base of the Animikie, and while this series was first placed with the Huronian, the fact that unconformably below it was another series which also resembled the Huronian led the later Canadian geologists to exclude the entire Animikie from the Huronian, and they have thus restricted the term in this district to the pre-Animikie Huronian rocks. The Michigan and Wisconsin geologists include in the Huronian the equivalents of both the Animikie and pre-Animikie Huronian, and while facts were clearly contained in their reports pointing to a discordance within the rocks referred to the Huronian no attempt was made to carry these facts to their conclusion and to subdivide the series. But as early as 1883 Irving saw that there is a series of green schists and schist-conglomerates which must rest discordantly below other rocks recognized as Huronian, as shown by their attitude and degree of crystallization, as well as by the fact that they had yielded fragments to the newer formations. As a consequence of this he was led to exclude from the Huronian these lower schists, which had before been everywhere accepted as Huronian. Lawson, in 1886, saw that his Keewatin series is fundamentally different from parts of the original Huronian, and especially from the Animikie series, and was led to refer it to the Huronian series only doubtfully; at the same time he saw that the Keewatin is like the Doré river series at the east end of lake Superior, and suggested that possibly Logan and Murray had placed in the Huronian two discordant series. Alexander Winchell, in his last paper, which appeared almost simultaneously with his death, announced definitely that two series had been confounded in the Huronian.

We will now consider the evidence for a physical break within the rocks which have generally been referred to the Huronian.

Evidence of this break in the Marquette district was first noticed by Foster and by Foster and Whitney, who found over the ore horizon at what has since become the Republic mine, and one or two other localities, a conglomerate bearing fragments of the ore, jasper, and other rocks associated with the iron ore. It was next noted by Kimball, who mentions beds of specular conglomerate. Credner describes, over the iron formation at Michigamme mine, a conglomerate, the fragments of jasper and quartz being in an iron and quartz base. Brooks describes the upper quartzite of Republic mountain and that at the New England mine as a conglomerate containing fragments of ore. By Rominger the break was noticed at so many places that he remarked that above the iron-bearing rock is generally a very coarse quartzite-conglomerate which often has the character of a coarse-grained ferruginous quartzite, the fragments of which are chiefly ore, jasper and quartz. This occurrence is so general as to suggest to this author that great disturbances not of a local extent must have occurred at the end of the era of iron sediments. Wadsworth says that these conglomerates mark old water-worn beaches after the jasper and ore were in situ in nearly their present condition. Believing in the eruptive origin of these rocks, Wadsworth did not regard the conglomerates as evidence of the existence of more than a single series. Recently this author has changed his opinion in this particular. Irving recognized the break, and the fragments included in the conglomerate overlying the iron belt are said to prove the existence of the jaspery and chalcedonic material in its present condition before the formation of the upper quartzite. Lately the break was noticed by the Profs. Winchell, and N. H. Winchell regarded it as so great that the rocks above the break were provisionally referred to the Potsdam. The writer has described the break as of universal extent and as representative of a great unconformity, for the banded and contorted jasper and ore are found to abut perpendicularly against a quartzite bearing abundant fragments of the underlying formation, which are in exactly the condition there found. The lower series is a semicrystalline, much folded one, while the upper series has usually not become crystalline nor closely folded. Before the upper series was deposited the lower series was folded and truncated.

It is, then, plain that in the Marquette district, within the rocks which have heretofore been referred to the Huronian, are two series. Below the break which separates them are the lower quartzite of Brooks, the associated novaculite and limestone, and the lower ore-bearing formation, including the hematitic, magnetitic, and actinolitic schists and jaspers, which contain the larger number of great mines. Above the physical break are Brooks's upper quartzite, the base of which is generally the conglomerate already described. Over the upper quartzite follow the black slates, sometimes carbonaceous, graywackes, and mica-schists, together of great thickness, and occupying an area as large as or larger than the Lower Marquette series. In these upper slates, apparently at rather persistent horizons, are locally belts of chert and iron carbonate associated with ore bodies of considerable size. These ores are, however, of a very different character from those which occur in the lower ore formation.

In the Menominee district as evidence in favor of a physical break within the clastic series are the conglomerates described by Brooks at the Pine and Poplar rivers district, and in the Commonwealth section. At the first is found conglomeratic quartz-schists, containing micaceous iron and magnetite; in the second are included conglomeratic quartz-schists, containing pebbles of white quartz (chert) and jasper. Similar jasper conglomerates have been found by Pumpelly and the writer over the ore at certain of the mines. The relations here are, then, exactly like those in the Marquette district. Also, the structural break indicated by these conglomerates is supported by Brooks's major divisions of the Menominee rocks. His inferior Huronian comprises the lower quartzite of great thickness, a great marble formation, and the great iron-ore horizon, consisting of magnetitic, hematitic, and jaspery schists, with deposits of iron ore. In this formation are the Norway, Quinnesec, Ludington, Chapin mines, etc. Brooks's middle Huronian, presumably above the unconformity, includes quartzites, clay-slates, and obscure soft schists. Within these soft slates is the upper iron-bearing horizon, including such mines as the Commonwealth, those at Crystal falls, etc.

In the Penokee district this unconformity is represented by the basal conglomerates of the Quartz-Slate member, containing numerous fragments of chert and a few of jasper, which were in their present condition when derived from the Cherty Limestone and Iron-bearing members. The lower series is now represented by the Cherty Limestone member alone, while the upper series includes the Quartz-Slate, Iron-bearing, and Upper-Slate members.

That there is a similar unconformity within the clastic series between the Lower Vermilion, Hunters island, and Lower Kaministiquia series and the conglomerates at these places bearing abundant material derived both from the ore-bearing formation and from the green schists, is inferred because the water-worn fragments of schist, jasper, and ore are in precisely the same condition in the conglomerates that they are in their original position. In none of these places have actual contacts been described. The unconformity is further indicated in the Vermilion lake district by a strongly developed schistose structure in a nearly vertical position in the Lower Vermilion series, while the overlying conglomerates at places on the islands of Vermilion lake are found to be gently folded.

The work of the Profs. Winchell also gives evidence of this unconformity. N. H. Winchell, in tracing the flat-lying Animikie series to the westward from Gunflint lake, finds that it becomes more steeply inclined and takes on, at times, a slaty cleavage. It is traced as far as Agamok lake, near the great Ogishki conglomerate, and the latter is consequently placed with the Animikie. To these statements Alexander Winchell agrees so far as to Agamok lake, but places the Ogishki conglomerate as a part of the Lower Vermilion series, for he traces this conglomerate all the way to Vermilion lake and he recognizes no break between the Vermilion lake conglomerate and the Lower Vermilion. Taking the positive evidence given by Profs. Winchell and disregarding their partial conclusions, it would seem to indicate that there is a gradation and actual continuity between the flat-lying Animikie and the conglomerates with a vertical superinduced structure at Ogishki and Vermilion lakes. That between the Animikie and the Lower Vermilion there is a great physical break is now denied by no one, and if the foregoing reasoning is true, it shows that this break is a continuation of the one between the Lower Vermilion and the Upper Vermilion which bears fragments of the lower series. The only published detailed succession of the Vermilion series is that by Willis. His chloritic schists and jasper (I, II, and III) belong in the lower series, while his conglomerate and black clay-slate (V and VII) belong in the upper series. The position of the magnetitic quartzite (IV) is uncertain, while the quartz-diorite (VI) is probably an eruptive rock.

It has been long well known that near Port Arthur, Ontario, the Animikie and underlying Kaministiquia series are unconformable. McKellar, who for many years has been familiar with this district, has proved this conclusively. The rock series here unconformably underlying the Animikie are identical with the Vermilion lake iron-bearing series. Considering the foregoing evidence and the complete likeness of this lower series with that bearing iron at Vermilion lake, it can no longer be doubted that there is a great physical break between the Animikie and Lower Vermilion series in northeastern Minnesota, although the equivalence of the Animikie and Upper Vermilion may yet be maintained.

In the last few years the difference of opinion has been sharp as to the equivalence or nonequivalence of the Animikie with the Vermilion lake and equivalent iron-bearing series. Irving has maintained that the Animikie series in its lithological character is like the Penokee and Marquette, these like the Vermilion, and therefore the Animikie in all probability the equivalent of Penokee, Marquette, and Vermilion. Alex. Winchell, having visited the Lower Marquette series and seeing but little of the ground in which the Upper Marquette is found, and consequently not appreciating that in area and in volume this series probably surpasses the Lower Marquette, has maintained that the Marquette rocks are the equivalent of the Vermilion lake iron-bearing series, but that the Animikie series is separated from that at Vermilion lake by a great unconformity. He, however, appreciated that in the Marquette district are certain slates which in lithological character are like, and might be equivalent to, the Animikie. Both Irving's and Winchell's positions probably have an element of truth and an element of error. The Upper Marquette, Upper Vermilion, Upper Hunter's island (Ogishki), in their lithological characters and gentle folding, are closely analogous to the Animikie, and, as maintained by Irving, are its probable equivalent; while the Lower Marquette and Lower Vermilion lake, as maintained by Alex. Winchell, unconformably underlie the Animikie. The physical break within the clastic series in the Marquette, Vermilion, Hunters island, and Kaministiquia districts is, then, provisionally identified with the great physical break recognized by everyone at the base of the Animikie.

It is only fair to say that Lawson considers the unconformity at the base of the Animikie at a higher horizon than the physical break described in these various districts. He regards the Animikie series as separated by another great unconformity from the Upper Marquette, Upper Vermilion, Upper Kaministiquia, etc. To the writer there seem grave difficulties, based on general relations, in the way of accepting this conclusion. On the other hand, the Upper Kaministiquia conglomerates, not far distant from the ordinary phases of the Animikie rocks, have a decidedly different appearance. This may, however, be due to the fact that certain of these conglomerates are of volcanic origin, the chert and jasper of which appear to have been broken from their beds by volcanic action and mingled with lava and volcanic ash. This sudden change in the character of the beds of the same age is parallelized in the Penokee district, where the strata, within a distance of a few miles, rapidly change in character, become immensely thick, and are largely in the nature of agglomerates, greenstone conglomerates, etc. But it must be said that such detailed mapping has not been done adjacent to the National boundary of northeastern Minnesota and Ontario and in the Thunder bay district as will warrant any positive statement as to whether within the clastic series, between the base of the Keweenawan and the Basement Complex, there is another higher physical break, making two unconformities which separate the rocks into three series.

The ore, chert and jasper conglomerates used as evidence of physical breaks within the clastic series are not to be confounded with the purely volcanic conglomerates which may occur at any horizon. Also the occurrence of these conglomerates will have no such meaning as here assigned by those who believe that the ore, chert and jasper in their present condition are igneous rocks. To such they will be no more evidence of two series than that the Keweenawan conglomerates, the fragments of which are derived from contemporaneous traps, are evidence of many series. But to those who think the evidence is sufficient for the belief that the ore, chert and jasper are not only sedimentary rocks, but sedimentary rocks which have gone through a long and complex history, the evidence of a physical break furnished by these conglomerates will be satisfactory.

CORRELATION; GENERAL CONSIDERATIONS.

We pass now to the general correlation of the lake Superior formation lying between the two planes already defined, the base of the Keweenawan and the top of the Archean schist-gneiss-granite complex.

Before it can be decided whether series so far distant from each other as the Dakota quartzites and the Original Huronian (separated by 800 miles) can be parallelized, it ought to be more definitely settled to what extent correlation can be made by unconformities and lithological likenesses. Irving inclined to the belief that such structural breaks as that described in the Marquette district are of great extent, and this accords with the general trend of modern structural work. From what has gone before it appears exceedingly probable that the structural break between the Upper and Lower Marquette is identical with that which separates, even in a more pronounced manner, the Animikie and Kaministiquia series and the upper and lower Vermilion lake series on the other side of the lake Superior basin. The break, being thus so strongly marked at points so far separated, would argue that it extends over a very considerable area of the lake Superior region, not improbably from the most distant rock series before mentioned, the Dakota quartzites and the Original Huronian of the north shore of lake Huron. It would not be expected that a like succession is now recognizable in each of the areas parallelized, even if they all belong to the same geological series. In the first place, the rocks in some districts are not sufficiently tilted to make it certain that all of the layers are exposed. Further, nine-tenths or more of the surface of the country over large areas is heavily covered by the drift, so that it is all but certain that some of the formations which exist at the rock surface have not been discovered. Still further, no satisfactory explanation has yet been made of the subordinate succession of formations in the Marquette, Felch mountain, Menominee and Vermilion lake districts; so it is not yet known how far the order found in one of the districts is equivalent with that of another. From recent work it is probable that future investigations will show that this likeness is greater in the series below correlated than has been suspected. But even supposing the disagreements are as great as the present known facts might lead one to suppose, it would not be any very strong evidence against the correlations; for it is not to be expected that the same conditions of sedimentation have prevailed at all times in a geological basin 800 miles in diameter. While in one part of the basin fragmental sediments were accumulating, it would not be very strange if chemical sediments or organic sediments were accumulating elsewhere. Below, it is seen that the Penokee and Animikie series are the equivalents of each other in the broadest sense of the term. It is not necessarily true that sedimentation began or ended simultaneously in both districts, but only that in the main they stand as time equivalents. How far a correspondence can be made out among the subordinate members of the various districts can be determined only by a detailed investigation of each of the areas.

EQUIVALENTS OF THE ORIGINAL HURONIAN SERIES.

Passing now to the Original Huronian, shall this series be correlated with the Upper or Lower Marquette, or is it the equivalent of both?

Alex. Winchell lately announced that the Lower Slate conglomerate and the underlying formations of the Original Huronian are separated from the Upper Slate conglomerate and the overlying formations by an unconformity. No contacts are described, the conclusion being based upon general relations. No characteristic debris of the Lower Huronian is said to occur in the Upper Huronian. The locality at which the strongest evidence is brought forward is on the outskirts of the Original Huronian, and a part of the formation which Logan and Murray have mapped as Lower Slate conglomerate is placed by Winchell as Upper Slate conglomerate. The observations of Pumpelly and myself at a contact between the limestone formation and the Upper Slate conglomerate tend to confirm Winchell's conclusion, but since limestone fragments are plentiful in the Upper Slate conglomerate, we place the physical break just above this lower limestone, i. e., 300 feet higher than indicated by Winchell.

The term Original Huronian as here used is strictly confined to the areas first described by Logan and Murray on the north shore of lake Huron, and in 1863 mapped in detail. The Original Huronian only is here compared with the series about lake Superior because it is the area to which the term was first applied, and also because it has been more thoroughly described and mapped than any other area in Canada designated by the term Huronian. A careful field and laboratory study of the rocks of the Original Huronian has shown its upper series to consist in great part (1) of fragmental quartzites, the induration of which has been caused by deposition of interstitial silica; (2) of graywackes and graywacke slates (often conglomeratic—Logan's Upper Slate conglomerate), the induration of which is due to the deposition of interstitial silica and metasomatic changes in the feldspar; (3) of cherty limestones, and (4) of eruptives. The Lower Huronian series is more metamorphosed than the Upper.

In its readily recognized fragmental character and in its gentle folding the upper Original Huronian series, i. e., the upper 13,000 feet, is closely analogous to the Penokee, Upper Marquette, and Animikie, while the Lower Huronian may be compared with the Lower Marquette and Lower Vermilion iron-bearing series. In the order of succession of formations it can not be said that either series corresponds very closely with the series about lake Superior, to which they are compared.

It seems to us that in correlation the unmetamorphosed character of the Upper Huronian is a guide of some importance. As pointed out by McKellar, the intense folding to which the Vermilion lake and Kaministiquia series have been subjected must have preceded the much more gentle synclinal movement which formed the basin of lake Superior. That no violent dynamic movement has occurred since the beginning of Animikie time is known to be true of the lake Superior basin, and it seems exceedingly probable that the gently folded upper members of lake Huron belong with those of like character about lake Superior. If this is not the case, the intense dynamic movements which produced the closely folded rocks of northeastern Minnesota and Ontario lost their force before reaching the area about lake Huron, and this region must have escaped any serious folding for a longer time than any other closely studied part of the earth's crust.

Besides the reason already mentioned for placing the upper Original Huronian as the equivalent of the Animikie and Upper Marquette rather than below these series, as advocated by certain geologists, we have one characteristic feature already cited which is of some weight. One of the most peculiar rocks of the Upper Original Huronian is a conglomerate which carries numerous fragments of blood-red jasper. At present the source of these fragments is unknown unless they come from the iron-bearing formation of the Lower Huronian. From what has gone before it is apparent that a jasper conglomerate is the basal member of the Upper Marquette series, and also that similar conglomerates occur in a like position in Ontario and northeastern Minnesota. Considering the widespread character of this jaspery, cherty, and iron-ore conglomerate, its occurrence in the Upper Huronian of lake Huron suggests that this jasper may there be found in the future in the Lower Huronian in large quantity. This series would therefore, in position and in lithological character, be like the Lower Vermilion and Lower Marquette iron-bearing series. The existence of such a jasper-bearing series was inferred by Logan himself. Taking the Original Huronian north of lake Huron as a whole, if Winchell's general conclusion that it consists of two unconformable series be correct, the analogy between this district and the lake Superior region is complete. Above the fundamental complex and below the Keweenawan, as about lake Superior, are two discordant series.

EQUIVALENTS OF THE SIOUX QUARTZITES, ST. LOUIS SLATES, ETC.

Much of what has been said to show that the Upper Huronian series is the equivalent of the Animikie, Upper Vermilion, and Upper Marquette applies with equal force to such rock series as the Chippewa quartzites, the Baraboo quartzites, the Sioux quartzites and the St. Louis slates. None of these series are closely folded, although often dynamic movements have developed slaty cleavages. Also their original fragmental character is always seen under the microscope at a glance. Between these series and the Potsdam is a great unconformity. They present thick beds of fragmental rocks, the induration of which has been caused by the same process which vitrified the quartzites of the upper Original Huronian. The supposed absence of ferruginous rocks in these districts has been used in the past as an argument against the correlation of them with the Penokee and Animikie series below considered, but this absence has no particular weight because such beds, as compared with the mechanical sediments, are insignificant in amount; and further, it is quite possible that these formations may in the future be found in several or all of these districts. This probability is rendered greater by recently developed ferruginous beds between the two quartzite ranges of Baraboo and in the northward extension of the St. Louis slates. The rocks here found are the exact parallel of the iron-bearing beds of the Penokee and other iron-bearing districts. The percentage of iron is so great in certain localities that the material is being mined for an ore. For placing these rock series with the Keweenawan, as has sometimes been done, there is neither lithological nor structural grounds. In the character of the material of which they are composed, in the presence of iron formations in certain localities and in their induration, they differ profoundly from any of the rocks known to belong with the Keweenawan.

No one has placed these series lower in the geological column than Upper Huronian, so perhaps it is not necessary to give evidence that they are not Lower Huronian. The occurrence of chert and jasper fragments in the Chippewa quartzites, mentioned by Sweet, and the presence of abundant identical material in the quartzites of southern Minnesota and southeastern Dakota, at least show that before the formation of these series there was a prior series bearing chert and jasper. Such a series is the Lower Huronian. These series then in degree of induration, amount of folding and in lithological character are like the Upper Huronian.

SUCCESSION AND EQUIVALENTS OF THE PENOKEE AND ANIMIKIE DISTRICTS SERIES.

In the Penokee district of Michigan and Wisconsin is the following succession: At the base is a granite-gneiss-schist complex. The schists are always completely crystalline, although often finely laminated or foliated. The granites, with granite-gneisses, and the fine grained green hornblende-schists, mica-schists, and chlorite-schists occupy large separate areas, with a debatable ground along their borders. The contacts of the granites and granite-gneisses with the crystalline schists are eruptive ones, the former being clearly the intrusives. Above this complex, and separated from it by a great unconformity, is a Cherty Limestone member which in places is 300 feet thick. While it extends east and west many miles, it is not longitudinally continuous. Above this Cherty Limestone, separated by an unconformity, is the Penokee series proper, which consists of a Quartz-Slate member, the upper horizon of which is a vitreous quartzite, an Iron-bearing member, and an Upper Slate member. Above the Penokee series, separated by another very considerable unconformity, is the Keweenawan. The parallelism between this district and the Marquette already described is at once manifest. The Penokee series proper is the equivalent of the Upper Original Huronian, Upper Marquette and their equivalents; the Cherty Limestone member stands as the only known equivalent of the Lower Marquette; for in the Penokee district the upper members of the equivalent of the Lower Marquette have not been found or have been removed by erosion. That the latter is not improbable is indicated by the very considerable thickness in some places of the cherty limestone and its absence in others, while numerous fragments of it are found in the basal member of the Penokee series proper. These fragments are so abundant in places as to constitute a true basal conglomerate. They are well rolled and are mostly of chert, but are sometimes jasper. This chert and jasper, whatever their origin, were in their present condition before the deposition of the Penokee series proper.

Further, the relative geographical positions of the Penokee, the Upper Marquette, and the Chippewa quartzite districts are such as to strongly suggest that they were once connected. The Penokee series at the east is cut off by the unconformably overlying lake Superior sandstone; but east of the south end of Gogebic lake there are here and there outcrops of slate which are like the Upper Slate member of the Penokee district, and a short distance to the east the narrow belt spreads out into the broad area of upper fragmental rocks, of which the Marquette and Menominee districts are arms. At the west the Penokee series has been entirely swept away by erosion, the copper-bearing rocks coming in contact with the underlying gneisses and granites; but to the southwestward appear the fragmental quartzites of the Chippewa valley, which are believed to be its continuation.

The equivalency of the Penokee series with the Animikie is as plain as the equivalency of any two areas of detached rocks in a single geological basin can possibly be in which is lacking clear paleontological evidence. It has been seen that above the cherty limestone of the Penokee series is an erosion interval. In the Animikie series proper we know of no equivalent to this member, and in what follows it is excluded from the discussion. The Penokee and the Animikie rocks have a parallelism in lithological characters which is most remarkable. Not only is there a general likeness between the specimens from the two regions, but almost every phase of rock from the Animikie series can be matched by specimens from the Penokee series. In the Animikie district the formations underlying the iron-bearing belt are not extensively exposed, and consequently little is known of the Animikie equivalent of the Quartz-Slate of the Penokee series. But along the Lower Current river, near port Arthur, Ontario, quartz-slates underlying the iron-bearing member are found which resemble certain phases of the Penokee quartz-slate. Beginning with the iron formations, the parallelism between the two series is almost exact. The irony beds upon Gunflint lake, where are found the best known exposures of the formation, are in their lower parts jasper; magnetite-actinolite-schist, and cherty ferruginous rocks containing more or less iron carbonate. Higher up are thick layers of thinly bedded cherty iron carbonate. All these varieties of rock are found in the iron formation of the Penokee series, and at many places the order of succession is the same. Above the iron-bearing belt in both districts is a great thickness of fragmental clay-slates and graywacke-slates which are again practically identical in character in both districts. It is true that in the western part of the Penokee district mica-schists have developed from these slates, but the original condition of these rocks was essentially like that of the unaltered phases.

Underlying both the Animikie and Penokee series is a complex of granites and schists, the unconformity between which and these series is of the most pronounced character. That the Animikie series is thus separated from the underlying rocks has been seen by all who have studied it. Above both series follows the Keweenawan. In both districts, in passing at any place from the underlying rocks to the Keweenaw series in section, the two are in apparent conformity; but, when the lines of contacts between the iron-bearing and the Keweenaw series are followed for some distance, both with the Animikie and Penokee series, this apparent conformity is found to be illusory. That is, the Keweenaw series is found to come in contact with one member of the underlying series at one place and with another member at another place, until in both districts at one or more places the entire iron-bearing series is cut off, the basal Keweenaw rocks coming directly in contact with the fundamental complex. These relations mean that between the deposition of the Penokee and Animikie series and the outflows of Keweenaw time there intervened a period of erosion which was sufficient in places to remove the whole of the inferior series and to cut in some places quite deeply into the fundamental complex. There is then an immense time gap between these series and the Keweenawan, although this unconformity does not approach in the length of time involved to that separating the Animikie and Penokee series from the underlying schists and granites.

The Animikie series in its most typical development extends from Gunflint lake on the national boundary, between Minnesota and Ontario, to Thunder bay, lake Superior. The Penokee series lies upon the opposite side of lake Superior. The latter is a simple unfolded succession dipping to the northward under the lake; the Animikie is another such succession dipping to the southward under the same body of water. There is then little doubt, considering all the facts, that the two series represent a single period in the history of the synclinal trough which forms the basin of lake Superior. The relations and likeness of the Penokee and the Animikie series have been repeated at length as showing the breadth of the geological basin in which the deposition of like rocks was taking place simultaneously. The equivalency here shown is a long step in understanding the equivalency of other rocks in the lake Superior basin.

SUCCESSION AND EQUIVALENTS OF THE MARQUETTE DISTRICT SERIES.

In the Marquette district, as the succession has already been discussed, it need here be only briefly repeated. It is as follows: At the base is the Archean gneiss-granite-schist complex. In ascending order follow the Lower and Upper Marquette, having the lithological characters and relations above described.

Much work remains to be done in this district which has been studied so closely. From present knowledge it is not even definitely known whether certain of the iron ranges, as for instance that of Teal lake, are Upper or Lower Marquette, although it is very probable that the one mentioned belongs to the Upper. Also it is a serious question what part of the green schists and schist-conglomerates, some of which are cut by granite, belong in the Lower Marquette series. Recent work appears to indicate that much if not all of this surface volcanic material belongs here, although it can not be asserted that surface volcanic material does not occur with the green schists of the Archean.

SUCCESSIONS AND EQUIVALENTS OF THE MENOMINEE AND FELCH MOUNTAIN DISTRICTS SERIES.

Passing now to the Menominee and Felch mountain districts, information is less exact. It is, however, clear that in both of these areas the fundamental complex is found; that is, the granites and gneisses associated with crystalline schists having the usual eruptive contacts. Above this complex, Pumpelly, with whom this whole subject has been discussed and who has great familiarity with the entire lake Superior region, suggests as exceedingly probable that in the Felch mountain iron-bearing series only the equivalent of the Lower Marquette occurs, the upper series, if it once existed, having been removed by erosion; while in the Menominee district both representatives of the Lower and Upper Marquette are present. The Menominee proper—that is, that part of the area which includes the Chapin, Ludington, and Norway mines, those in which a cherty limestone is found—are Lower Marquette, while the western district, including such mines as the Commonwealth, Florence, and many others occurring in the upper black slate, are Upper Marquette. That between these two is a probable unconformity has already been shown.

EQUIVALENTS OF THE BLACK RIVER FALLS SERIES.

The Black river falls iron-bearing schists of Wisconsin have not such observable structural relations as to enable one certainly to determine their position. They are, however, thoroughly crystalline schists, and are in vertical attitude. On these grounds they are provisionally placed as the equivalent of the Lower Marquette.

SUCCESSION AND EQUIVALENTS OF WESTERN ONTARIO AND NORTHEASTERN MINNESOTA SERIES.

Combining the work of Dawson and Lawson about Rainy lake and the lake of the Woods, Smyth about Steep Rock lake, the Winchells and Irving in northeastern Minnesota, the succession appears to be granite-gneiss-schist (Coutchiching ?) complex, unconformity, Keewatin, unconformity, Animikie, unconformity, Keweenawan. There are also in this district great masses of granite-gneiss at least as late as the Keewatin. Included in the granite-gneiss-schist basal complex are only such granite-gneisses as are more ancient than the oldest sedimentaries. This vast area has been too little studied to say definitely what part of the areas referred to Irving's mica-schist group, Winchell's Vermilion series, and Lawson's Coutchiching belongs with the Basement Complex. It is equally difficult to say whether the Keewatin of Lawson and Winchell does not comprise more than one series. It is Lawson's opinion that it does and that the physical break described as occurring in the clastic series on the south shore exists between the Upper and Lower Keewatin. Our knowledge of this part of the lake Superior region is not sufficiently advanced to outline with any accuracy the areas which are to be referred to these main divisions. It is, however, tolerably clear that in this part of the region there are the same great subdivisions of the pre-Cambrian rocks as elsewhere; that a part of what has ordinarily been called Laurentian will be included in the Basement Complex; that a part of Irving's mica-schist group, Lawson's Coutchiching, and the Profs. Winchell's Vermilion also falls within this complex. It is further probable that a part of the Keewatin is the equivalent of the Lower Marquette, Lower Menominee, and equivalent series. It is possible that other parts of the series which have been designated Keewatin belong rather with the Animikie. If, however, the break at the base of the Animikie is higher than that above the Vermilion, Hunter's island, and Kaministiquia iron-bearing series, and the latter break belongs within the Keewatin, as now known, this group will need to be subdivided into two series, and the succession will thus be expanded at this point into Lower Keewatin, unconformity, and Upper Keewatin.

NOMENCLATURE.

There still remains the question of nomenclature. In Chapter VIII, the major taxonomy of the pre-Cambrian is discussed and reasons are given for including under the term Algonkian all the pre-Cambrian clastics, for confining the term Archean to the inferior crystalline complex, for restricting the term Laurentian to the coarser grained light colored granite-gneiss part of this complex, and for proposing for the dark colored fine grained schistose part of this complex the term Mareniscan. These reasons will not be repeated here, but the terms with these definitions will be applied to the rock successions of different districts of the lake Superior region. This will serve to illustrate the usage of these terms and at the same time will be a test of the propriety of the usages proposed, since the lake Superior region is the one in America about which most has been written and which furnishes the fullest pre-Cambrian column.

Belonging to the Archean on the south shore are the Southern Complex of the Penokee districts, the fundamental complex of the Marquette and Menominee districts, and a great expanse of rocks in northern Wisconsin. This complex is more largely of the Laurentian gneiss than of the Mareniscan schists. Between the two are often the peculiar gradations described which are taken to indicate the intrusive character of the granite-gneiss. Between the Archean and the Algonkian, as indicated by evidence fully given in another place, there is a great unconformity.

On the north shore Smyth finds decisive evidence of a thoroughly crystalline fundamental complex below the lowest clastics at Steep Rock lake. As has been seen, evidence pointing in this same direction is to be found in the reports of Logan, Dawson (Sir William), Selwyn, Bell, Macfarlane, Herrick, and Lawson, although several of these authors do not reach this conclusion. The difficult and uncertain point in this connection is in reference to the Coutchiching of Lawson or the Vermilion of Profs. Winchell. If, as believed by Lawson, there is a great time break between the Keewatin and Coutchiching and if the Coutchiching is found to be older than any of the clastics, it belongs to the fundamental complex and the term Coutchiching has priority over Mareniscan, proposed for the dark colored, fine grained schistose part of the Archean. This is the outcome which seems to the writer, according to present published evidence, to be most likely; but it must be stated that this impression does not accord with Lawson's opinion, who regards the Coutchiching as a sedimentary series more nearly connected with the Keewatin than with the Archean, nor with the Profs. Winchell, who regard the equivalent Vermilion as but a more metamorphosed downward extension of the Keewatin.

In restricting the word Laurentian to the granite-gneiss of the Archean, much of what has heretofore been denominated Laurentian will be excluded. This usage will throw out all of the granite-gneisses of an age later than the clastics, and therefore much of the granite-gneiss which Lawson has called Laurentian. It must be recognized that about the lake Superior region there are granite-gneisses of various ages. This is more evident in the main granite-gneiss areas than elsewhere, for not infrequently intruding them are other large bosses of granite or gneiss, which, with the earlier granite-gneiss, may have again been cut by still later material of the same kind. It is believed by some that there are in the lake Superior region granite-gneisses of at at least four different ages. It will not do to conclude that any certain granite-gneiss is Archean unless its structural relations to the Algonkian clastics are determined. However, the granite-gneisses which belong to the Archean on the south shore are pegmatized through and through and banded and contorted in the most intricate manner. Their constituent minerals show that they have undergone repeated dynamic movements. They are cut by eruptives of many kinds and of different ages. Many of the basic eruptives are so ancient that they themselves have become schistose and have passed over into hornblende-gneisses and similar rocks, which now are seen as dark colored intersecting or parallel layers in the pink granite-gneiss. This intricate complex of granite, gneiss, and schist, which has been subjected to repeated dynamic movements in various directions, is very different from the somewhat regular, little altered granite-gneiss which acts as a subsequent intrusive.

The early Canadian geologists used the term Huronian to cover all the fine grained schistose and clastic rocks between the Keweenawan or Upper Copper-bearing rocks and the Laurentian. The same is true of many of the American geologists. It is clear that the fine grained crystalline schists which constitute a part of the Archean can not here be included. Huronian can include only that part of the Algonkian between the Keweenawan and Archean, and, as has been seen, this Huronian is separable into two uncomformable series. On the part of the Canadian geologists of late there has been a tendency to restrict this term to the lower series, as shown by the exclusion of the Animikie from the Huronian, but if this is done the greater part of the Original Huronian must itself be excluded from the Huronian. Upon the other hand, Irving and the Profs. Winchell have advocated restricting Huronian to the upper series alone. The recognition of a general stratigraphical break in the rocks heretofore included by most authorities in the Huronian leads to the natural suggestion that for the superior division Upper Huronian shall be used, and for the inferior Lower Huronian. The fact that it has been recently maintained that in the Original Huronian area itself both of these series exist but renders this suggestion more appropriate. Further in favor of this position is its conservative character, although it is recognized that the rules of good nomenclature point rather to the restriction of Huronian to the upper or lower series. If restricted to one it should clearly be the upper, for it is certain that the greater part of sediments of the Original Huronian mapped in detail here belongs. Hence, as advocated by Alex. Winchell, is placed as an alternative to Lower Huronian in the following tabulation Lawson's term Keewatin. This term was first defined to cover a series of clastics with some crystalline schists about the lake of the Woods. It was later more clearly defined and restricted to the unmistakable clastics and altered volcanics about Rainy lake. By the Profs. Winchell it was applied to the Vermilion lake iron-bearing series, which was believed by them to be the equivalent of the Rainy lake Keewatin. In many respects the greater part of these series is like the Lower Marquette, Felch mountain, Lower Menominee, Hunters island, and Lower Kaministiquia series. If this supposed equivalence were demonstrated it would be preferable to adopt this term to cover all the series included under the Lower Huronian. It is, however, by no means clear that the Keewatin will not prove to be a complex series, just as have the Marquette and Vermilion lake rocks, consequently it is only tentatively placed in the general column. One other term has been proposed for this place, Marquettian; but this term is objectionable because as used it included both Upper and Lower Marquette.

Lawson has proposed the term Ontarian to cover the Keewatin and Coutchiching. It appears to us that the purposes of geology are better subserved by using the term Algonkian to cover all the clastic series between the Fundamental Complex and Cambrian, and to retain Archean as a term of coordinate value with this to cover the basal complex. If it shall turn out that the writer is correct as to the position of the Coutchiching, the base of the Lower Huronian, not the base of the Coutchiching, is the important horizon to mark. More evidence is desirable for the application of stratigraphical methods to the prominent structure of the Coutchiching, since, in many respects this structure has the characters of an induced one. Lawson recognizes a true physical break at the base of the Keewatin, not at the base of the Coutchiching. The break between the Coutchiching and the granite-gneiss is one which is also found between the granite-gneiss and Keewatin. It is not a structural horizon, but an eruptive contact. Upon the other hand, a great mass of evidence goes to show that there is at the base of the Keewatin a persistent structural plane which is recognizable throughout the lake Superior region.

Selwyn and N. H. Winchell maintain that the Keweenawan and Animikie are properly Cambrian. Whether the term Cambrian shall be so extended downward as to cover two great unconformities and two additional rock series of very great thickness is purely a matter of policy and of nomenclature, which is more fully discussed in another place. While it is of primary importance that an agreement shall be reached as to the actual rock successions in the lake Superior region, it is but a secondary matter as to the names which shall be applied to them. That fossils are found in the Huronian is not sufficient reason for extending the Cambrian downward indefinitely. That the evidences of abundant life are here found has been long known. Many of the thick beds of slates heretofore called Huronian, on the south shore of lake Superior, not only contain graphitic material, but a considerable percentage of hydrocarbons, not infrequently becoming graphitic or carbonaceous schists. In the Animikie, on the north shore of lake Superior, Ingall finds abundant carbon, and it is said that in certain mines and openings rock gas forms in considerable amount. Also small quantities of rock may even be obtained which will burn. These substances must result from the ordinary processes which produced rock gas and coal in the rocks of far later age. Also the great beds of iron carbonate are, to many, evidence of abundant life. In the Sioux quartzites one generally accepted fossil has been discovered by N. H. Winchell. A discovery of a fossil has been announced by Selwyn as occurring in the Animikie. It is a hope that in the future numerous other fossils will be found in this series, so that we may have the assistance of paleontology in lake Superior stratigraphy. Until, however, a fauna is known in these regions which is distinctly Cambrian, the discovery of life or of certain fossils in the Keweenawan and Huronian rocks is wholly insufficient evidence for placing them with the Cambrian.

We then have in the lake Superior region the following successions and correlations for the pre-Cambrian rocks:

Pre-Cambrian rocks of the lake Superior region.

		Western Ontario.	Northern Minnesota.	Michigan.			Michigan and Wisconsin.	Wisconsin.	Iowa, South Dakota, and southern Minnesota.
				Marquette.	Felch mountain.	Menominee.	Penokee.		
Algonkian.	Keweenawan.	Nipigon.	Keweenawan.				Keweenawan.	Keweenawan.	
	Unconformity.	Unconformity.	Unconformity.				Unconformity.	Unconformity.	
	Upper Huronian	Animikie and Upper Kaministiquia.	Animikie and Upper Vermilion.	Upper Marquette.		Western Menominee.	Penokee-Gogebic Proper.	Chippewa Quartzites. Baraboo Quartzites.	Minnesota and Dakota quartzites, surrounded by fossiliferous series.
	Unconformity.	Unconformity.	Unconformity.	Unconformity.		Inferred Unconformity.	Erosion interval.	Unconformity.	
	Lower Huronian.	Keewatin in part at least, and Lower Kaministiquia.	Lower Vermilion.	Lower Marquette.	Felch mountain Iron-Bearing series.	Menominee Proper.	Cherty limestone.	Black river falls Iron-Bearing schists(?)	
	Unconformity.	Unconformity?	Unconformity?	Unconformity.	Unconformity.	Unconformity.	Unconformity.	Unconformity(?)	
Archean.	Mareniscan.	(Coutchiching?)	(Coutchiching?)	Fundamental Complex. (Not yet separated in mapping.)	Fundamental Complex. (Not yet separated in mapping.)	Fundamental Complex. (Not yet separated in mapping.)	Southern Complex. (Separated in mapping into fine-grained schist, Mareniscan, and granites and granite-gneisses, Laurentian, showing characteristic eruptive contact.	Fundamental Complex. (Not yet separated in mapping.)	Minnesota river valley gneiss and granite.
	Eruptive Unconformity.	Eruptive Unconformity.	Eruptive Unconformity.						
	Laurentian.	Laurentian.	Laurentian.						

LAKE SUPERIOR BASIN.

The synclinal structure of the formations about lake Superior was noted as early as 1847 by Logan in his remarkably accurate general account of the lake Superior region. His five general formations were found to recur in reverse order on both sides of the lake, dipping to the center. Rogers and Agassiz, in 1848 and 1850, maintained that the shores of the lake are due to dikes. Owen, in 1851, in his studies north and south of the west part of the lake, saw that the formations occur in reverse order, and reached independently the same conclusion as did Logan. Bigsby and Whitney followed Logan and Owen in describing the lake Superior basin as synclinal. The next exact contributions to the structure of the lake Superior synclinal were by Sweet and Irving, who found it to continue to the southwestward in Wisconsin and Minnesota, the rocks adjacent to the shore on the south side of the west end of the lake being on the north side of the synclinal basin. Sweet, in 1876, spoke of the lake Superior synclinal as over 300 miles in length and 30 to 50 miles in width. That the lake Superior formations are not only a synclinal in an east and west direction, the rocks dipping respectively from the north shore south and the south shore north, but that it is a basin in the exact sense of the term, the rocks on the east shore dipping to the west, while the western termination of the synclinal in Minnesota plunges to the east or northeast, was shown by Irving. This author went further and also showed that the major bays of the lake are due either to faults or subordinate flexures within the Keweenawan. The basin is clearly a product of Keweenawan time. Chamberlin suggests that it began early in the Keweenawan. The Upper Huronian series partakes in several districts in large measure of the basin structure. This is apparent from the fact that the Huronian of the Penokee and Animikie series was so long regarded as conformable with the Keweenawan. It has been seen that there is between these series a great unconformity, although not one so vast as the other physical breaks about the lake. As a consequence of this the Upper Huronian series corresponds only locally with the synclinal structure, and chiefly about the west half of the lake. The structures of the Lower Huronian and Archean have no reference to that of the lake Superior basin.

CONCLUSION.

It appears that in the lake Superior region is a general succession which may be recognized, and that there is really a much greater degree of harmony than has been thought in the conclusions which the various writers have held most steadfastly as to the lake Superior stratigraphy. From the base upward it is as follows: Archean, including Laurentian granite and gneiss, the origin of which is largely unknown, but which were certainly in their present condition earlier than the formation of the Lower Huronian; unconformity; Lower Huronian (a closely folded semicrystalline series); unconformity; Upper Huronian (a gently folded and plainly clastic series, although indurated by cementation and metasomatic changes); unconformity; completely unaltered Keweenawan; unconformity; lake Superior sandstone. In addition to the above are great masses of eruptive rocks in all the series, both basic and acidic, including granite-gneiss, gabbro, porphyry, diabase, etc.

I can not close without comparing this succession of lake Superior formations with that given by Logan in his remarkable paper published in 1847. It is as follows: "(1) Granite and syenite; (2) gneiss; (3) chloritic and partially talcose and conglomeratic slates; (4) bluish slates or shales interstratified with trap; (5) sandstones, limestones, indurated marls, and conglomerates, interstratified with trap." Between 1, 2, 3, and 4, 5 there was said to be an unconformity. The granite, syenite, and gneiss are Archean; the chloritic and partly talcose and conglomeratic slates, Lower Huronian; the bluish slates or shales interstratified with trap, Upper Huronian; and the sandstones, limestones, indurated marls, and conglomerates interstratified with trap, Keweenawan. Of course, Logan at that time did not appreciate all the structural relations which obtain between these various series, although the greatest of the unconformities was discovered, nor did he suppose that they are all pre-Cambrian, and in his mapping in 1863, 1 and 2 are placed together as Lower Laurentian, and 4 and 5 together as a part of the Quebec group above the Potsdam; yet that he appreciated that in this region there are five fundamentally different kinds of rock, that he gave an accurate characterization of the Keweenaw series, comprehending that it is one of great thickness, not less than 10,000 or 12,000 feet, and that this series rests unconformably upon the granite and gneiss, can not be too highly spoken of. Not only was this paper the first announcement of all of the above great conclusions, but it gave the first mention, as has been seen, of the synclinal structure of lake Superior.

Looking toward the future as to the possible modifications of this arrangement by further work, the point of greatest doubt lies as to whether the unconformities here recognized as universal in the lake Superior region are really so. Is it not possible that the unconformity at the base of the Animikie is at a different position from that between the Penokee proper and the Cherty Limestone, and may not these be different horizons from that between the Upper and Lower Marquette? May not the break above the Lower Marquette be at a different position from that above the Lower Vermilion. These questions can not be positively answered in the negative, although all the evidence at hand bears strongly in this direction. It may be found in the lake Superior basin, so extensive in area, that while the folding and erosion producing an unconformity in one part was occurring, at some other distant part deposition was going on. In all probability this is to some extent true. That the rocks in the different districts referred to these periods have the same absolute duration would hardly be expected. Sedimentation in the series correlated probably continued longer in certain parts of the region than in others. A break even if as widespread as believed probably did not begin nor end everywhere at the same time; and certainly it would be true, after a certain movement and erosion had ended, as the sea began to encroach, that sedimentation would begin in one district before it reached another. So that if these correlations are correct and the breaks really general, as is believed, it does not follow that the periods opened or closed simultaneously, but that they stand in a general way as equivalent. The equivalency advocated may be much more strongly asserted of the districts immediately adjacent to lake Superior than of the more remote districts.

The further question arises, whether as work continues new breaks of considerable magnitude, not now recognized, will be found. This is not improbable. In fact, there is already some indication of such a break, although not now capable of being proved at any point. Does the series of great conglomerates which are placed at the base of the Upper Huronian, the debris being derived mostly from the Lower Huronian, grade conformably upward into the Animikie, or is there here a considerable additional break? It is by no means certain that the truth is not with the latter alternative, for the conglomerates certainly seem to have suffered more intense dynamic action than the adjacent Animikie. Their thickness is great, and it may well be that in the Thunder bay district will be found a considerable break which in a part at least of the lake Superior region will subdivide the Upper Huronian.

Also as a problem for the future is the real nature of the Archean schists. Are they clastic or igneous in origin? Are they, as has been supposed, a real fundamental complex, or will this be subdivided upon a structural basis? A few years ago all below the pre-Cambrian was a fundamental complex. Will not the future find our present fundamental complex further divisible and the real fundamental complex at a still lower horizon?

Accepting the general stratigraphy as given above, how far will it be possible to correlate the individual formations of the series? How far are the Quartz-Slate member, the Iron-bearing member, and the Upper Slate member of the Penokee series equivalent to those of the Animikie? When, as in this case, three like formations of great thickness are found in the same order, and the two series as wholes bear identical relations to underlying and overlying series, the correlation may perhaps be made with a considerable degree of probability, and later closer work rather leads to the conclusion that much will be accomplished in the direction of correlating formations; that is, several of the series may be divided into two or three or more members, which may with a considerable degree of probability be correlated with equivalent members in other districts, but that it will be possible to subdivide these various series into fifteen or twenty or more members, as was done by the early authors, and to correlate these small divisions with each other throughout the lake Superior region, there is not the least probability.

While perhaps more has been done in pre-Cambrian stratigraphy in the lake Superior region than in any other region in America, this very fact opens before us numerous and difficult problems.

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[208] Based on unpublished field notes made by W. N. Merriam in the summers of 1888 and 1889.

[209] Based on unpublished field notes made by C. R. Van Hise in the summer of 1890.

[210] Based on unpublished field notes made by Profs. Raphael Pumpelly and C. R. Van Hise in the summers of 1891 and 1892.

CHAPTER III.

THE GREAT NORTHERN AREA.

SECTION I. THE REGION ABOUT HUDSON BAY.

LITERATURE.

BELL,[1] in 1877, reports on explorations between James bay and lakes Superior and Huron. The rocks are described as Huronian on the course followed until the north side of Shatagami lake is reached, with the reservation that the gneiss just below Paul's lake may be Laurentian. In this distance the rocks are limestones, quartzite, diorite, chert-slate-conglomerate, hornblende-schist, pegmatite, syenite, clay-slates, and, at Paul's lake, gneiss. The diorites have a widespread occurrence, and an area of massive syenite continues for several miles in one local, ity. It is often mixed with crystalline diorite. Beyond Shatagami lake are several alternations of rocks which are referred to the Huronian and Laurentian before the fossiliferous series is reached. The conspicuous feature of the last Laurentian belts are large diorite dikes. The junction of the Laurentian and Huronian occurs at Davis's rapid, 51 miles north of the outlet of lake Kenohamissee.

On the return trip the course followed is by the west branch of Moose river, along toward its headwaters, thence to Michipicoten and lake Superior. The rocks are chiefly granite and syenite, gneiss, hornblende-schists and mica-schists and greenish schists. These are in part referred to the Huronian and in part to the Laurentian, several belts of the Huronian being found. At one place the Huronian is spoken of as passing into the Laurentian. As a result of the work it is shown that an immense area of Huronian rocks runs northward from lake Huron through the greater part of the distance lying between it and the area of unaltered rocks of the southwest side of James bay.

BELL,[2] in 1879, reports on explorations of the east coast of Hudson bay. In this region are large areas of gneisses which are referred to the Laurentian, and belts of schists referred to the Huronian. With the Huronian are schist-conglomerates and quartzites. At the contact of the Laurentian and Huronian, the former consists of a coarse quartz and mica rock, while the first rock which is considered Huronian is a dark green, highly crystalline hornblende-schist. The two formations appear as usual to be conformable. Along Manitounuck sound is an unaltered stratified series in which no fossils were found and which resemble the Nipigon rocks. These are called the Manitounuck group.

They consist mostly of siliceous and argillaceous limestones, sandstones, quartzites, shales, ironstones, amygdaloids, and basalts. At Little Whale river is a quartz-conglomerate of great thickness below these rocks. The limestones are found at many localities at the base of the series. They have a cherty concretionary and concentric structure. The quartzites and sandstones come in ascending order. Associated with the quartzites, and overlying them, is a series of cherts and shales. These are surmounted by a great thickness of amygdaloids of various kinds and of diorites of a basaltic character. At Richmond gulf the base of the section consists of sandstone and conglomerate, above which is limestone in a slightly unconformable position and all is capped by trap. In one place the trap rests with a slight unconformity upon ferruginous beds. Spathic iron ore, sometimes of considerable thickness, is sometimes interstratified with the sandstone.

BELL,[3] in 1879, reports on the country between lake Winnipeg and Hudson bay. The rocks along the route, with the exception of one Huronian trough, are described as Laurentian gneiss. The Huronian rocks belong in one basin or trough, conforming with the general trend of the Laurentian gneiss and mica-schist. Its breadth is about 14 miles and its length 143 miles, giving an area of about 2,000 square miles. A mica-schist at Pipestone lake contains different kinds of pebbles. At Seven-mile point the rock is a micaceous slate-conglomerate, the pebbles of which are chiefly of gray syenite. At the junction of the Laurentian and Huronian the two formations appear as usual to be conformable with each other. The last of the Laurentian series consists of gray coarse, rough-surfaced quartz and mica rock. The first rock on what is considered to be the Huronian side of the boundary consists of highly crystalline dark green hornblende-schist, ribboned with fine lines of white quartz grains. This schist is interstratified with bands of finely ribboned, slightly calcareous gray gneiss.

BELL,[4] in 1880, reports on explorations of the Churchill and Nelson river and around God's and Island lakes. The Laurentian gneiss is the prevailing rock throughout the whole district between Knee and Island lakes. The stratification, while moderately distinct, is often banded and contorted. Its average texture is of a medium variety, or rather tending to fine grain, but coarse forms are occasionally seen. There is no prevailing or general direction in the strike of the gneiss. The Huronian rocks occupy a series of troughs in several localities. The rocks are schist-conglomerate, sometimes garnetiferous, steatite-schists, green schists and felsite schists, most of them being more or less calcareous. The Laurentian gneiss occupies the area between the Huronian troughs. The strike of the Laurentian gneiss in the neighborhood of the Huronian rocks appears in most cases to correspond with that of the latter.

BELL,[5] in 1881, reports on Hudson bay and some of the lakes and rivers lying to the west of it. Various gneisses and schists are found at different points which are referred respectively to the Laurentian and

UNCLASSIFIED PRE-CAMB. | ALGONKIAN | POST-ALGONKIAN | ERUPTIVES: GRANITIC, BASIC

GEOLOGICAL MAP OF NORTHERN CANADA

SHOWING PRE-CAMBRIAN AND CRYSTALLINE ROCKS

Compiled from Official Maps of the Canadian Geol. Survey

Scale. 1/21,900,000.

Huronian. Hudson bay as a whole lies in the great Laurentian area of the Dominion. The long chain of islands which fringe the east coast are composed of bedded volcanic and almost unaltered sedimentary rocks, resembling the Nipigon series of lake Superior, which may be of Lower Cambrian age. On the western side of the bay, from the Churchill river northward, quartzites and other rocks are found which may also belong to the Cambrian system. Cambro-Silurian rocks rest almost horizontally upon the Laurentian along the southwestern side of the bay.

BELL,[6] in 1883, reports upon the geology of the basin of Moose river and adjacent country. The boundaries of the Laurentian and Huronian formations appear to be conformable to each other. Massive granites occur abundantly with the Laurentian gneisses and Huronian schists. The granites generally lie close to the junction of the Huronian and Laurentian, this being the usual position of these granite areas in the great region northward of lakes Huron and Superior.

BELL,[7] in 1885, describes granite and gneiss at North head, Button islands, Ungava bay, Nunaungok, Ashe's inlet, Nottingham and Digges islands, Stuparts bay, Eskimo inlet, port DeBoucherville, and port Laperriere. A portion of the west coast of Hudson bay is occupied with diorites, hornblende-schists and mica-schists, which may be referred to the Huronian series. Deadman's island consists of white and light-gray quartzites, and glossy mica-schists, striking north 75° west. The whole of the western part of Marble island consists of white and light colored quartzite bearing a strong resemblance to white and vein marble. The beds of quartzite are very massive, although their surfaces are often ripple-marked, being sometimes as fine and regular as the fluting on a washboard.

BELL,[8] in 1885, gives a general characterization of the geology of Hudson bay. The distribution of the Huronian series is intimately connected with that of the Laurentian, being found mostly within the limits of the latter. The rocks of the Huronian system appear to rest conformably upon the Laurentian in all cases observed. About the mouth of Churchill river, on the west side of the bay, and for some miles along the coast, are found massive and thinly bedded quartzites with conglomerate beds, the pebbles being mostly of white quartz, interstratified with occasional thin shaly layers. These strata may form a part of the Huronian series, but they also resemble the gold-bearing rocks of Nova Scotia. On the Little Whale river and in Richmond gulf on the east side of the bay another set of rocks is found following the Huronian and underlying unconformably the Nipigon series. This intermediate formation consists of beds of hard red siliceous conglomerate and red and gray sandstones, with some red shales, and appears to have a considerable volume. The Nipigon formation is largely developed along the east main coast of Hudson bay, between cape Jones and cape Dufferin, and consists of compact, nonfossiliferous, bluish gray limestones, coarse cherty limestone breccias, quartzites, shales, diorites, amygdaloids, and manganiferous clay ironstones. The limestones of lake Misstassini, in the interior of the Labrador peninsula, bear a strong resemblance to those of the east main coast.

BELL,[9] in 1886, gives additional observations on the geology of Hudson bay. From Eskimo point to the entrance of Chesterfield inlet, a distance of 180 miles, the rock specimens embrace hornblende-schists, greenstones, sandstone altered to quartzite and holding fragments of indurated shale, white quartz rock, quartzite like that of Marble island felsite, crystalline hornblende rock, diorite, chert, mica-schist, porphyry. granulite, red jasper, chloritic schists, etc. The majority of the lithological specimens correspond with the rocks of the Huronian series, Laurentian types are absent, and the probabilities are that Huronian rocks prevail all along the northwest coast of Hudson bay, from Eskimo point to Chesterfield inlet, and again at Repulse bay. The widely extended areas of massive granitoid character about Hudson bay are regarded as primitive gneiss, and there is little doubt are more ancient than the regularly stratified gneisses which prevail on the Ottawa valley. The Huronian rocks of the region are unlike those on the north shore of lake Huron, consisting of massive diorites, argillaceous and dioritic slate-conglomerates, granite-syenites, schistose and jaspery iron ores, limestones, dolomites, and imperfect gneisses, with a great variety of schists. The Manitounuck series is largely made up of rocks of volcanic origin.

BELL,[10] in 1887, reports on explorations of portions of the Attawapishkat and Albany rivers. Various granites, gneisses, and schists are found upon Pelican lake, lake St. Joseph, and the upper sections of Albany and Boulder rivers, and lake Lansdowne. Upon lake St. Joseph a conglomerate is found. The granites and gneisses are placed with the Laurentian and the schists and conglomerates with the Huronian.

SUMMARY OF RESULTS.

In all of the above works by Bell the rocks are classified as Laurentian or Huronian almost wholly upon lithological grounds, the coarse granites and granitoid gneisses being regarded as Laurentian and the clearly sedimentary rocks and fine grained calcareous gneisses and various green schists with associated rocks being placed as Huronian. Whenever the relations of the two series are spoken of they are said to be in conformity. The Huronian is, however, frequently spoken of as occurring in troughs, which probably implies that this series is taken to be the newer of the two; but in general this is an inference from its lithological character rather than a determination from an ascending succession. The dips are usually high and no structure is worked out, so that from the facts given it would be impossible to determine which is higher and which lower, except by the implication in the words Huronian and Laurentian. While certain of the rocks placed with the Huronian are lithologically like those of the Original Huronian, Bell distinctly states that in the main they are quite different. The likeness apparently goes no further than the fact that occasionally there are found unmistakable clastic rocks, and some of these clastics resemble more closely the fragmentals of the Ottawa series than they do those of the Original Huronian.

The Manitounuck group on Hudson bay, which is described as resembling very closely the Nipigon series, is, from the illustrations, a comparatively flat-lying one and is probably newer than either of the series referred to the Laurentian or Huronian. At least two unconformities are mentioned in it, one between two sedimentary rocks and another between a sedimentary rock and a trap. These unconformities are spoken of as slight, but the cuts illustrative of them represent the first of these unconformities as very considerable.

SECTION II. NORTHERN CANADA.*

LITERATURE.

STEINHAUER,[11] in 1814, gives localities for labradorite on the coast of Labrador.

MCCULLOCH,[12] in 1819, describes as coming from Baffin bay, 70° 37′, granite, gneiss, and graywacke-schist.

RICHARDSON,[13] in 1823, describes clay-slate as occurring in the northern arm of Great Slave lake. North of Great Slave lake the granite formation continues for a considerable distance toward Fort Enterprise, but contains more foreign beds in advancing to the northward. In this region in places mica-slate prevails and in other places the granite contains beds of mica-slate. Gneiss appears to exist throughout the great district to the eastward of Coppermine river. About Fort Enterprise are numerous hills capped by red granite, around which, on the acclivities, gneiss is wrapped in a mantle form. The rocks of this district include granite, micaceous and hornblendic gneiss, greenstone, mica-slate, and clay-slate. At Point lake are found graywacke-slate, clay-slate, and transition greenstone slate, as well as transition conglomerate, the fragments of which appear to consist of the same material with the bases. In the first part of the region of Coppermine river, between Point lake and the sea, are found granite, syenite, gneiss, clay-slates, and hills of trap. North of latitude 66° 45′ 11″ are found red and gray sandstones, compact feldspar rock, granular foliated limestone, trap rock, and greenstone which constitutes the Copper mountains. In these mountains are amygdaloids which contain amygdules of pistacite and calc-spar, scales of copper being generally disseminated through the

* This section is largely compiled from Geo. M. Dawson's account of this region accompanying his geological map of it. With a number of exceptions the original reports have not been seen. This unusual plan is here adopted because Dawson's summary of the geological material, widely scattered through the many volumes of Arctic travel, is so complete as to render unnecessary the labor of going through them a second time.

rock. In this region were also found masses of native copper and prehnite. The shores of Bathurst inlet are partly of granite and gneiss and partly of later rocks. On the road from Bathurst inlet to Point lake and Fort Enterprise, beyond Hood's river, the rocks are entirely gneissic or granitic.

PARRY,[14] in 1824, found granitic and gneissic rocks to occupy the whole southern part of the east shore of Melville peninsula and to continue northward behind a tract of limestone country, forming a range of mountains in the center of the peninsula to Hecla-and-Fury strait. They also form the south shore of this strait, most of the islands adjacent to it, and apparently the whole eastern shore of the adjacent south part of Cockburn "island."

KONING,[15] in 1824, describes the most characteristic rock collected by Capt. Parry on the west coast of Baffin bay as gneiss and micaceous quartz rock, with some ambiguous granitic compound in which hornblende seems to enter as a subordinate ingredient.

LYON,[16] in 1825, describes cape Fullerton on the main shore west of Southampton island to be composed of rugged red and gray granitic rocks with the strata running in a northwest direction.

JAMESON,[17] in 1826, states that the material collected by Capt. Parry shows that the west coast of Davis strait and Baffin bay, south of Lancaster sound, consists of primitive rocks, among which are gneiss, mica-slate, hornblende-slate, granite limestone, hornblende-rock, and greenstone. All these rocks are more or less distinctly stratified and numberless transitions from one into the other were observed.

RICHARDSON,[18] in 1828, describes the rocks of the Coppermine river series as extending westward to the Height of Land and consisting chiefly of sandstone and conglomerates with granite and porphyry. The southeast extremity of McTavish bay consists of red granites and gneisses. At the mouth of Dease river and the northeast extremity of the lake the prevailing formation is granitic and gneissic. On mount Fitton, along the Arctic coast west of the Mackenzie river, the mountain range consists of graywacke slates which are considered transition rocks.

LESLIE, JAMESON, and MURRAY (HUGH),[19] in 1830, mention in the region of Southampton island, Melville peninsula, and Hecla-and-Fury strait, as prominent varieties of rock, granite, gneiss, mica-slate, clay-slate, chlorite-slate, primitive trap, serpentine, limestone, and porphyry. The Primitive range bordering the east coast of Baffin land is a continuation of the Labrador coast; and on the west coast of Davis strait and Baffin bay, south of Lancaster strait, primitive rocks preponderate, including gneiss, mica-slate, and granite.

ROSS,[20] in 1835, finds granitoid and gneissic rocks to occupy exclusively the coast line and adjacent islands of the Boothian and Melville peninsula south of 70° 35′.

FITTON,[21] in 1836, describes the north side of Great Slave lake from the entrance of the north arm westward as consisting mainly of gneiss, porphyry, and granite. The large islands and promontory of the eastern part of the lake are of the trap formation. These are compared to the Coppermine series. Pebbles of jasper conglomerate were collected near the west end of the lake, but the rock was not seen in place. The rocks on the route from Great Slave lake northeastward by Clinton-Golden and Aylmer lakes and the Great Fish river to the Arctic coasts are different varieties of granite and gneiss.

BACK,[22] in 1838, describes granite as occurring in two places along the southeastern coast of Southampton island.

SIMPSON,[23] in 1843, applies the name Trap Point to the Kent peninsula. After an interval of low ground to the eastward granite forms the coast line.

RAE,[24] in 1850, finds north of latitude 61° on the west coast of Hudson bay, beyond Nevill's bay, the shore steep and rugged, being lined with bare primitive rocks. On the southern shores of the gulf of Boothia granite occurs in several places, and among the specimens found are gneiss, mica-slate, quartz-rock, hornblende-slate. Precipitous cliffs of trap were found on Simpson bay, in latitude 68° 27′.

RICHARDSON,[25] in 1851, states that the eastern side of the north arm of Great Slave lake is occupied by primitive rocks, which run across the outlet of Athabasca lake to the deep, northern arm of Great Slave lake, and onward by Marten lake, across the two eastern arms of Great Bear lake, to the Copper mountains. On Rae river, which flows into Coronation gulf near the mouth of the Coppermine, are limestone, quartz-rock, and high cliffs of basalt. From the similarity of the various rocks associated in this quarter to those occurring at Pigeon river and other parts of the north shore of lake Superior the author is inclined to consider that the two deposits belong to the same geological era, both being more ancient than the Silurian. At Rae river and Richardson river, to the northwest of the mouth of the Coppermine and on the west side of the Coppermine river, are series of basaltic cliffs.

SUTHERLAND,[26] in 1853, describes the rocks at cape York and cape Atholl, latitude 76°, as consisting of sandstones, interstratified with volcanic material. On the east coast of Baffin land, from Lancaster sound to Cumberland sound, are crystalline rocks which occupy the whole coast southward to Cumberland strait.

MURCHISON,[27] in 1857, states that cape Granite in the Arctic Archipelago is composed of quartz, feldspar, and chlorite, and is accompanied with gneiss of the same composition.

KANE,[28] in 1857, states that the rocks of the coast between Rensselaer harbor and the great Humboldt glacier (in Peabody bay), are stratified limestones, sandstones, feldspathic and porphyritic granite passing into gneiss, and in some places trap.

HAUGHTON,[29] in 1857, describes granitic rocks as composing a considerable part of North Greenland, on the north side of Baffin bay, and constituting the rock of the country at the east side of the island of North Devon. Between capes Osborne and Warrender the rocks are graphic granite, which passes into a laminated gneiss, and with the gneiss are interstratified beds of garnetiferous mica-slate. The whole series is overlain by red sandstones of banded structure. The granitoid rocks are again found on the north side of the island of North Somerset, where they form the eastern boundary of Peel sound. Cape Granite is the northern boundary of the granite. On Peel sound and Prince of Wales island is a dark syenite composed of feldspar and hornblende. This rock is massive and eruptive at cape M'Clure, and occasionally gneissic. The Silurian of the Arctic archipelago rests everywhere directly on the granite, with a sandstone, passing into a coarse grit, at its base.

HAUGHTON,[29] in 1859, states that granitoid rocks everywhere underlie the Arctic archipelago. At Montreal island is a gneiss which exhibits the phenomena of foliation in a marked degree. At Bellot's straits, in latitude 72° north, are found gneissoid granite, graphic granite, and syenite. At Pond's bay, at the northern extremity of Baffin land, quartziferous mica-schist underlies the Silurian limestone and is interstratified with gneiss and garnetiferous quartz rock inclining 38° WSW. Cape York, on the Greenland coast, is composed of fine grained granite. At Wolstenholme sound the granitoid rocks are converted into mica-slate and actinolite-slate, the two rocks passing into each other by almost insensible gradations. Carey's islands, west of Wolstenholme sound, are composed of a gneissose mica-schist, formed of successive layers of quartz granules, and layers of jet-black mica. The mica-schist passes into white gneiss. Yellow and white sandstones are also found in small quantity upon the islands, reposing upon the granitoid rocks.

LIEBER,[30] in 1860, describes on the coast of Labrador, gneisses, granites, labradorites, etc., at various localities.

DERANCE and FIELDEN,[31] in 1878, state that the Laurentian system is the fundamental one for the region visited by Sir George Nares. At cape Rawson is an important overlying series which occupies the coast of Grinnell land from Scoresby bay to cape Cresswell, in latitude 82° 40′ north. The rocks are in a series of sharp folds with a general west-southwest strike, the beds being often vertical and frequently cleaved. They consist of jet-black slates, of impure limestones, traversed by veins of quartz and cherts, and of a vast series of quartzites and grits. They are compared to the gold-bearing series of Nova Scotia and doubtfully referred to the Huronian system.

HIND,[32] in 1878, describes at Mullens cove, in the Laurentian series of Labrador, a succession of interbedded gneisses, micaceous schists, crystalline limestones, and a bed of calcareous conglomerate. The thickest layer of white crystalline limestone is 35 feet.

EMERSON,[33] in 1879, describes the rocks of Frobisher bay, collected by C. F. Hall, as consisting of granite, gneiss, magnetite-gneiss, hornblendic gneiss, mica-schist, etc.

BELL,[9] in 1885, describes on the Labrador coast gneiss and granite at Ford's harbor and Mission station, Nain, at Nachvak inlet, at Skynners cove, and other points. The granite sometimes becomes syenitic and the gneiss is sometimes well laminated.

BOAS,[34] in 1885, describes the nucleus of Baffin land as everywhere of gneiss and granite.

GREELY,[35] in 1886, finds toward the head of Chandler fiord high cliffs of schists and slate, and in Ruggles river, at the outlet of lake Hazen, large slabs of slate.

PACKARD,[36] in 1888, describes syenitic and gneissic rocks of the Laurentian formation at various points, among which are Sleupe harbor in Gore island near Shallop, the bay east of Anse-au-Loup, Caribou island, cape St. Francis, and Square island.

MCCONNELL,[37] in 1890, mentions granite-gneisses east of the Rocky mountains at the rapids of Slave river and fort Rae. These evidently belong to the Laurentian or the oldest division of the Archean. West of the Rocky mountains, crystalline schists are largely developed along the valley of the Pelly-Yukon, occurring in numerous exposures from the International boundary to fort Selkirk, and they continue up the Lewis about 30 miles. This belt of crystalline rocks has a width of somewhat over a hundred miles. The eastern edge of the area consists largely of quartzose schists, chlorite-schists, mica-schists, diabases, and serpentines, which are occasionally interbedded with bands of slate, limestone, and are broken in many places by igneous intrusions. The green schists, in ascending the river, are underlain by foliated mica-gneisses, alternating with hornblende-gneisses, which are distinctly Archean in appearance and lithological character.

SUMMARY OF RESULTS FROM DAWSON.

DAWSON,[38] in 1887, as a result of an exhaustive review of the literature of northern Canada, states that Archean or Eozoic rocks are dominant in the northern part of the continent. They also form the greater part of Greenland, and doubtless underlie at no great depth the entire Arctic archipelago. While the information available is sufficient to indicate the existence of the different subdivisions of the Archean which are met with in the southern portion of Canada, including the lowest Laurentian or granitoid gneiss series, the Middle Laurentian, possibly the peculiar rocks classed as the "Upper Laurentian" and certain of the more schistose and generally darker colored and more basic rocks classed as Huronian, it is far too imperfect to admit of the separation of these subdivisions on the map. It is evident that the Huronian is represented in parts of the west coast of Greenland, and it is probably also recognizable on the Labrador coast, and on the west coast of Hudson bay. The occurrence of well stratified gneisses with mica-schists and crystalline limestones, with associated graphite and magnetite, appears to indicate the presence of Middle Laurentian. These rocks occur on the southern part of Baffin land, Frobisher bay, Cumberland sound, and Melville peninsula. The term Cambrian is made to include all rocks above the Huronian to the base of the Cambro-Silurian. Extensive areas placed in the Cambrian on the Arctic coast and in the vicinity of Coppermine river are analogous in character to those of the Keweenaw or Animikie of the lake Superior region, and probably represent both groups of that great copper-bearing series. Throughout the northern part of the continent the characteristic Cambrian formation, composed largely of volcanic rocks, apparently occupies an unconformable position with regard to the underlying Laurentian and Huronian systems. The present remnants show that these rocks have undergone comparatively little subsequent disturbance. The cape Rawson beds of Grinnell land are provisionally referred to the Cambrian, on account of their lithological resemblance to the rocks of the Animikie, and also on account of their similarity to the Nova Scotia gold-bearing series.

In the above summary, as the terms are used in this volume, the Middle Laurentian, much of the Huronian, and the Coppermine and equivalent series, which are placed in the Cambrian, are to be included in the Algonkian; while the Lower Laurentian is largely or wholly Archean.

SECTION III. THE LOWER ST. LAWRENCE RIVER AND WESTWARD TO LAKES ST. JOHN AND MISSTASSINI.

LITERATURE.

BAYFIELD,[39] in 1840, describes granite rocks as occupying the following districts: Along the St. Lawrence from the Saguenay to pointe de Monts, a distance of 130 miles; from pointe de Monts to the Seven islands, a distance of 60 miles; the mainland to the eastward of Mingan islands and opposite Ste. Geneviève island, where the country for many miles inland is composed of low granite mounds; the coast from Ste. Geneviève east to cape Whittle, longitude 60° W., latitude 50° 10′ N. The granites are in part hornblendic and in part nonhornblendic. At Ste. Geneviève was observed hypersthene and Labrador feldspar. The granitic rocks are regarded as unstratified. They are traversed by trap veins, insignificant in size as compared with the immense size of the lake Superior granite masses. Reposing horizontally on the granites on the east side of Pillage bay and mount Ste. Geneviève are limestones. The islands of the south shore of the St. Lawrence and the south coast from Saguenay to cape Rozier are composed of alternating strata of graywacke and slate dipping to the southward at angles varying from 30° to 90°.

LOGAN,[40] in 1850, describes a metamorphic group of rocks in the vicinity of bay St. Paul, Murray bay, and White cape on the St. Lawrence river. The predominant rocks are mica-gneisses and hornblende-gneisses. No crystalline limestones were noted.

LOGAN,[41] in 1854, describes the district north of the St. Lawrence river, between Montreal and cape Tourment, below Quebec. To the metamorphic sediments the word Laurentian is applied. It is used to cover all of the prefossiliferous rocks. The name is founded on that given by Mr. Garneau to the chain of hills which the Laurentian series compose. At St. Maurice the Potsdam sandstone rests upon the gneiss.

DAWSON,[42] in 1861, describes the Laurentian rocks exposed on the coast cliffs of Murray bay. At one place the succession includes gneiss, white quartz rock, impure limestone, and hornblende slate, but the beds are so inverted that little reliance can be placed on apparent superposition. The crystalline limestone, dolomite, and serpentine are together 14 feet thick. The Silurian rocks rest unconformably upon the Laurentian beds.

RICHARDSON,[43] in 1870, describes the Laurentian and Labradorite rocks on the north shore of the lower St. Lawrence. The Laurentian gneiss has sometimes little appearance of stratification. The dips are high, approaching the vertical. The Labradorite, with moderate dips, rests unconformably upon the Laurentian. At one place there occurs in the gneiss a bed 12 feet thick of coarsely crystalline limestone. The Labradorite rocks have a wide extent. Both the Laurentian gneiss and labradorites are cut by granitic veins.

RICHARDSON,[44] in 1872, reports on the prefossiliferous rocks in the country north of lake St. John. They are classified under two heads: First, Laurentian gneiss, including a little crystalline limestone; second, crystalline schists, consisting of chloritic and epidotic rocks, with dolomites, serpentines, and conglomerates. The Laurentian occupies much the largest area of country and includes gneissic rocks cut by granite veins, limestones, quartzites, and hornblende rocks. The limestones and quartzites are comparatively unimportant, but the former is said to be in thickness not less than 500 or 600 feet. The rocks of the second class immediately succeed the Laurentian near the north end of lake Abatagomaw. Large expanses of the conglomerate of this series are composed entirely of rounded fragments of Laurentian gneiss of gray and red colors. In some places, without close examination, the conglomerate might be mistaken for the Laurentian gneiss. Sandstones and shales are met with which show lines of deposition. It is remarked that whatever the geological horizon of this series of rocks, it will be prudent for the present to withhold an opinion until further investigations are made. The only indication as to the geological age of this series is given by an obscure fossil occurring in a limestone which Billings thinks is a coral.

LAFLAMME,[45] in 1885, gives geological observations on the Saguenay region. The pre-Cambrian rocks are divided into two series, a gneissic and a labradorite series, which are together included in the Laurentian, although nothing is said as to their structural relations.

Low,[46] in 1886, reports on the Mistassini expedition. The Laurentian gneisses and associated rocks occupy the whole country from the gulf of St. Lawrence to James bay, along the route traversed, with the exception of some areas of Huronian and Cambrian in the vicinity of lake Mistassini. The Laurentian rocks include gneiss, hornblende-schists, mica-schists, crystalline limestones, and areas of triclinic feldspar rocks. The rocks described by Richardson, north of lake Abatagomaw, are similar to the epidotic and chloritic slates of the Shickshock mountains and the eastern townships and are referred to the Huronian.

SUMMARY OF RESULTS.

In the very brief and general studies of the area north of the lower St. Lawrence no attempt is made to map the region in detail nor to work out the structure of the rocks. The Labradorite rocks are separated by Richardson from the gneissoid rocks, to which he applies the term Laurentian. The reason for doing this is not given, so that we have no indication as to whether this is an eruptive or a sedimentary series, and if sedimentary, whether it underlies or overlies the gneisses. As in the Ottawa region, the great mass of gneiss is free from limestones. The limestones are local and are associated with other rocks which are presumably of clastic origin, such as quartzites.

The remarks which are made with reference to two series in the Ottawa area would apply equally well to this region. We have no indication as to the relations of the clastic series, described by Richardson, to the Laurentian gneiss which is referred by Low to the Huronian. Richardson, who did the work upon this series, was not able to give an opinion as to its position, and its reference to the Huronian by Low is made wholly upon lithological grounds. It is, however, probable that the great conglomerates in the neighborhood of Lake Abatagomaw, composed almost entirely of rounded fragments of Laurentian gneiss and which in some places closely resemble the gneiss, mark the structural boundary between the two series of rocks. The description of this conglomerate is that of a recomposed rock, the material being derived from the immediately underlying formation.

NOTES.

[1] Report on an Exploration in 1875 between James bay and lakes Superior and Huron, Robert Bell. Rept. of Prog. Geol. Survey of Canada for 1875–'76, pp. 294–342.

[2] Report on an Exploration of the East Coast of Hudson Bay, Robert Bell. Rept. of Prog. of Geol. Survey of Canada for 1877–'78, pp. 1–37 C. With a map.

[3] Report on the country between Lake Winnipeg and Hudson's Bay, Robert Bell. Ibid., pp. 1–31 CC. With 5 plates and 2 maps.

[4] Report on Explorations of the Churchill and Nelson Rivers, and around God's and Island Lakes, Robert Bell. Rept. of Prog. Geol. Survey of Canada for 1878–'79, pp. 1–44 C. With a map.

[5] Report on Hudson Bay and some of the Lakes and Rivers lying to the west of it, Robert Bell. Rept. of Prog. Geol. Survey of Canada for 1879–'80, pp. 1–56 C.

[6] Report on the Geology of the Basin of Moose River and adjacent country, Robert

Bell. Rept. of Prog. Geol. and Nat. Hist., Survey of Canada for 1880–'81–'82, pp. 1-9 C. Accompanied by a map.

[7] Observations on Labrador Coast, Hudson Strait and Bay, Robert Bell. Rept. of Prog. Geol. and Nat. Hist. Survey and Museum of Canada for 1882–'83–'84, pp. 3-37 DD.

[8] The Geology and Economic Minerals of Hudson Bay and Northern Canada, Robert Bell. Proc. and Trans. Royal Soc. Canada, vol. II, sec. 4, 1884, pp. 241-245.

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[12] Geological Appendix, Dr. McCulloch. A Voyage of Discovery, for the purpose of exploring Baffin's Bay, etc., by Sir John Ross, in 1818. London, 1819, vol. II, p. 141.

[13] Appendix I, J. Richardson. Narrative of a Journey to the Shores of the Polar Sea in the years 1819–'22, by Capt. J. Franklin. London, 1823, pp. 520-534.

[14] Journal of a Second Voyage for the Discovery of a Northwest Passage, etc., 1821–'23, Captain Parry. London, 1824.

[15] Notes on Rock Specimens, Charles Koning. Supplement to the Appendix to Capt. Parry's Voyage for the Discovery of a Northwest Passage in the years 1819–'20, (Natural History). London, 1824, p. CCXLVII.

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[17] Appendix on Geology of Countries discovered during Capt. Parry's Second and Third Expeditions, Prof. Jameson. Journal of a Third Voyage for the discovery of a Northwest Passage, etc., by Capt. W. E. Parry. London and Philadelphia, 1826.

[18] Appendix I, J. Richardson. Narrative of a Second Expedition to the shores of the Polar Sea in the years 1825–'27, by Capt. J. Franklin. London, 1828.

[19] Narrative of Discovery and Adventure in the Polar Seas and Regions, Sir John Leslie, Prof. Jameson, Hugh Murray. Edinburgh, 1830.

[20] Appendix on Geology. Narrative of a Second Voyage in Search of a Northwest Passage, etc., 1829–'33, Sir John Ross. London, 1835.

[21] Geological Notice on the New Country passed over in Capt. Back's Expedition, by W. H. Fitton. Narrative of the Arctic Land Expedition to the Mouth of the Great Fish River and along the shores of the Arctic Ocean, in the years 1833, 1834, 1835, Capt. Back, Appendix No. 4. London and Philadelphia, 1836.

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[24] Narrative of an Expedition to the Shores of the Arctic Sea in 1846–'47, Dr. John Rae. London, 1850.

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CHAPTER IV.

EASTERN CANADA AND NEWFOUNDLAND.

SECTION I. THE EASTERN TOWNSHIPS.

LITERATURE.

MURRAY,[1] in 1847, describes the metamorphic rocks of the Notre Dame mountains. The more important varieties are slate and trap. It is not certain that these rocks do not belong to the fossiliferous formation.

LOGAN,[2] in 1863, describes the Quebec group at length. Metamorphic rocks of various kinds are mentioned, but these are all regarded as belonging to the fossiliferous series. In the fossiliferous formations east of the Notre Dame mountains are veins and masses of intrusive granite.

SELWYN,[3] in 1879, gives observations on the stratigraphy of the Quebec group. This group is divided into three distinct groups of strata. First, the lower Silurian group; second, the volcanic group, probably lower Cambrian; and third, the Crystalline schist group (Huronian?). The rocks composing group three are chiefly slaty and schistose, embracing various schists, imperfect gneisses, micaceous dolomites, and magnesian limestones. The upper part of this series emerges from beneath the upper Silurian.

SELWYN,[4] in 1883, finds in the Stoke mountains an igneous belt unconformably overlapped and covered by the fossiliferous beds of the Levis formation and by the Siluro-Devonian rocks; but between these volcanics and the more schistose rocks of the central axis, by which they are underlain, no unconformity has been detected. These volcanics are provisionally classed with the lower series, that is, pre-Cambrian and probably Upper Huronian. In the Quebec series are found important masses of granite which are intrusive in the fossiliferous series. The stratified rocks in contact with them are disturbed and altered, the limestones converted into graphitic schists or crystalline marble, and the argillites into mica-slates, chiastolite and staurolite schists, which are traversed by streaks and veins (dikes?) of granite. These granites are regarded as of Silurian or Devonian age. The alteration of the fossiliferous beds has gone so far as to suggest a resemblance to the crystalline rocks which have been referred to the Laurentian or Huronian.

SELWYN,[5] in 1883, in further speaking of the Quebec group, asserts of the upper metamorphic or volcanic group that neither a schistose nor a bedded structure can be accepted as a proof of nonigneous origin, and that a massive lava flow is as likely, through pressure and metamorphism, to assume a schistose structure as are ordinary sedimentary strata. Much of the material of the upper part of the lower groups is of contemporaneous irruptive and eruptive origin, though for the most part, through cleavage and alteration, so changed in external and physical character as to cause these rocks to be classed as metamorphic, notwithstanding that they still closely correspond in chemical composition with recognized igneous and volcanic rocks, and differ essentially from any known ordinary unmixed sedimentary deposits. It is suggested that the upper volcanic group may represent the Keeweenian.

ELLS,[6] in 1887, reports on the geology of a portion of the Eastern Townships. Placed in the Cambrian are a set of slates of various colors, sandstones passing into quartzites, quartziferous schists and conglomerates in which are found no calcareous beds or fossils. The conglomerates are of two kinds; one is composed of pebbles of the ordinary kind, granitoid rocks, quartzites, slates, etc.; the other is composed largely of dioritic pebbles in a diorite paste with intercalated beds of sandstones and grits, and may be regarded as an agglomerate. This series in places is certainly unconformable to the Cambro-Silurian system on the one hand, and in a like manner is unconformable to the underlying ridges of crystalline rocks from the débris of which they are largely formed. These strata for the most part flank the ridges of crystalline schists and gneisses, but at other times are in intricately folded basins in them. These rocks resemble the gold-bearing series of Nova Scotia. When near to or cut by masses of granite the strata have developed in them crystals of chiastolite and staurolite.

The areas of crystalline schists, gneisses, and limestones, with serpentines and associated strata are referred to the pre-Cambrian. The age of these rocks is inferred from their lithological character, from their position of apparent unconformity below the overlying series referred to the Cambrian, and from the fact that their débris is found in the latter series. The areas of pre-Cambrian rocks are four in number. In position, and in the fact that they contain copper, they closely resemble the copper-bearing rocks of New Brunswick and the Huronian of Bruce mines. There is a similarity to the series in England and Scotland described by Hicks under the names of Dimetian, Arvonian, and Pebidian. Summing up it is said: Whatever may be the exact age of these altered rocks, their present aspect entitles them to be classed as very ancient sediments, although, in view of the great alterations which may result from intense regional metamorphism, there is no reason why many of the ordinary sedimentary rocks of Cambrian, Cambro-Silurian, or even Silurian age, should not assume much of the character of these just described. It is now tolerably clear that the series now considered

UNCLASSIFIED PRE-CAMB. ALGONKIAN ALGONKIAN? POST-ALGONKIAN ERUPTIVES: GRANITIC, BASIC

GEOLOGICAL MAP OF NEW BRUNSWICK, NOVA SCOTIA, AND PART OF QUEBEC

SHOWING PRECAMBRIAN ROCKS

Compiled from official maps of the Canadian Geol. Survey

Scale $\frac{1}{4000.000}$.

constitutes the lowest of all the geological formations encountered in this portion of the province.

Both plutonic and volcanic rocks occur in the Eastern Townships, including granites and diorites, some of which are at least as late in age as the Lower Silurian, although others are earlier, as is shown by the fact that fragments of them are included in the strata referred to the Cambrian. The sedimentary strata are altered at the contacts with these intrusives. These granites are, however, held by Selwyn to be metamorphic.

SELWYN,[7] in 1887, states that at the Bras stream, about 3 miles from the Chaudiere river, is well exposed a contact of the crystalline series with the black slates, showing the same unconformable relations between the Cambrian and pre-Cambrian as on the Quebec Central railway. The granites considered by Ells as intrusive are regarded as more probably formed in situ by the same metamorphic agencies that have altered the adjacent strata, and the so-called dikes are probably due to segregation; in fact, the latter are rather veins than dikes. The granites are then regarded as an effect of the metamorphosing agencies rather than the cause of the metamorphism.

ELLS,[8] in 1889, gives a second report on the geology of the Quebec group. Throughout the area of the rocks referred to the Lower Cambrian no fossils have yet been found, but they resemble the lower portion of the Cambrian of New Brunswick. The most that can be said of them stratigraphically is that they are intermediate between the chloritic and micaceous schists of the central anticlinal and the overlying rocks of the Sillery. These Cambrian rocks have certain beds which closely resemble those of the Potsdam age of the Sillery; on the other hand, it is not easy to separate them from the underlying pre-Cambrian schists, although at certain points there is a manifest unconformity between the two series, as is well shown between Broughton station and Harvey hill on the Quebec Central railway; the regular strike of the underlying chloritic rocks being nearly east and west, while the overlying black slate, with which are associated beds of grayish limestone, at times strike nearly north and south. The difference in the character of the Cambrian and pre-Cambrian strata, together with the fact of the occurrence of a line of fault between the crystalline schists of the Sutton mountain anticlinal and the slates and serpentines to the east, are the chief reasons for the separation of these two series into pre-Cambrian and Cambrian. The pre-Cambrian areas found are composed mostly of alternations of chloritic and micaceous schists. In certain localities, as at Les Saints Anges, are found micaceous black and gray slates, and quartzites with crystalline limestone, which may be Cambrian or pre-Cambrian. The areas of granite, diorite, and serpentine are described.

ADAMS,[9] in 1889, finds that the massive and stratified varieties of the anorthosite underlying the northwest part of the Eastern Townships are really only different portions of one and the same mass. It is concluded that most, if not all, of the areas are of eruptive origin, since they are frequently found cutting the gneisses. Bands of crystalline limestone are found in the region.

ELLS,[10] in 1890, states that the lowest beds of the Lower Cambrian frequently contain a very considerable thickness of conglomerates, the pebbles of which are without doubt derived from the underlying crystalline ridges which have been called pre-Cambrian. They are distinct in character from the pre-Cambrian of the anticlinals, the latter being in all cases highly crystalline, while there is a sharply defined line, either of unconformable overlap or of fault, between the crystalline series and the slates and quartzites of what has been styled Lower Cambrian. This line of fault is to be seen at certain points, and is heavy; at others the slates occupy basin-like areas infolded in the schists, where the rocks pass at once from the black, gray, and purple slates to the highly altered schists. There are certain areas of mica-schists and black slates which are apparently in the center of the anticlinal of Sutton or the Chaudiere. These probably represent a portion of the pre-Cambrian, but they are quite distinct from the ordinary black, purple, and gray slates and quartzites of the Chaudiere gold series.

SUMMARY OF RESULTS.

A large number of articles have been written in reference to the Quebec group which are not touched in the above, as their point of view is paleontological, and if the crystallines are referred to at all they are simply placed as the metamorphosed equivalents of the fossiliferous rocks.

While Ells places the middle series found in this region as Cambrian, he is very cautious to say that he has no paleontological evidence for this; so that it is yet to be considered an open question whether it is Algonkian or not. By Selwyn it is compared with the Keweenawan, and by Ells with the Nova Scotia gold-bearing slates. It is certain that the series is uncomformably below the Potsdam, and equally certain that it overlies crystalline schists. While the so-called Cambrian and pre-Cambrian are said to be unconformable, and several localities are cited in which these relations obtain, one wishes that they had been described in more detail. The only one mentioned in which the facts are given upon which the statement of uncomformity is based is the one on the Quebec railway, where it is said that the strike of the Cambrian slates is almost at right angles to that of the pre-Cambrian schists. When it is remembered that there probably are in this region great masses of intrusive granites which have metamorphosed the adjacent strata, and that as a result of such action a schistose structure oftentimes develops independent of the original bedding, the evidence cited at this particular locality is by no means sufficient to establish the conclusion. However, the basal conglomerates of the series referred to the Cambrian, the crystalline character of the pre-Cambrian as contrasted with the clastic character of the Cambrian, and the sharply defined line, either of uncomformable overlap or of fault, between the crystalline series and the slates and quartzites which are styled Lower Cambrian, indicates the probability that a structural break of great magnitude does occur between the two series. The supposed lower series of crystalline chloritic and micaceous schists and gneisses, with their associated quartzites and limestones, seems clearly to be of clastic origin. It is compared with the Huronian by Ells. From present imperfect knowledge it can only be safely placed as Algonkian. If it shall turn out that the nonfossiliferous rocks referred to the Cambrian by Ells are also Algonkian, this system is represented in the Eastern townships by two series which are probably uncomformable.

Selwyn's later position as to the nature of the granite is the opposite of that earlier held. In his reports published in 1879 and 1883 the granites are not only believed to be intrusive, but many of the crystalline schists are believed to be metamorphosed irruptives. In the footnotes accompanying Ells's reports these same granites are said to be metamorphic.

SECTION II. GASPÉ PENINSULA.

LITERATURE.

ELLS,[11] in 1885, describes the pre-Cambrian rocks of the Gaspé peninsula. These are confined to the Shickshock mountains. They are garnetiferous gneiss, hornblendic, chloritic and micaceous schists, epidosite, etc. These rocks are so like the pre-Cambrian as seen in New Brunswick and other parts of Canada that they are removed from the Quebec group and assigned to an older horizon. Serpentines, diorites, and granites are intrusives, a part of them later in age than Devonian.

LOW,[12] in 1885, also describes the pre-Cambrian rocks of the Gaspé peninsula. They are represented by the metamorphic schists and slates of the Shickshock mountains, among which are serpentine, and several beds of limestone, one of them being 90 feet thick. Great masses of granite and dikes of trap are found in these series. The granites are evidently of later date than the Silurian and Devonian rocks, as fragments of these are inclosed in them, and the adjacent stratified rocks show alteration.

SECTION III. CENTRAL NEW BRUNSWICK.

LITERATURE.

ROBB,[13] in 1870, gives a report on the geology of central New Brunswick. The crystalline rocks include (1) a band of metamorphic rocks immediately underlying the Carboniferous series and extending to the southeastern boundary of the great granite area, (2) the central granite area, (3) a band of noncalcareous metamorphic slate and quartzite lying immediately northwest of the granite area. The southern slate band extends from Magaguadavic lake to the southwest Miramichi, its breadth varying from 9½ miles on the St. John river to 17 miles on the Miramichi. The rocks consist of argillaceous and micaceous clay-slates, with interposed bands of crystalline, quartzose, micaceous and feldspathic rocks resembling sandstone. They are doubtless altered sediments. In one place apparently in this series are fossils, probably of Upper Silurian or Devonian age. The central granite occupies a considerable area to the northwest of the slates. The line between the slates and granite is somewhat arbitrary, for the slate and quartzite band includes three very considerable, with some smaller, bands of granite. The various feldspathic rocks of the region seem to merge into each other. This is true, not only of the granite and gneiss, but even of the foliated semicrystalline slates and quartzites. Occasionally fragments of gneiss of all shapes and sizes are found imbedded or incorporated in the granite, and vice versa; but no appearance of granite veins cutting the laminated rocks are noted. The slates, mica-schists, and quartzites of the northern slate belt locally assume a crystalline aspect. Bands of crystalline rocks resembling granite, syenite, and diorite are intercalated in the manner of conformable or interbedded masses. At one place is found a slate-conglomerate which is believed to occupy a depression in the older rocks.

ROBB,[14] in 1872, gives some additional facts in continuation of his studies. The central granite area is divided into two granitic bands. Much of the granite area is of a gneissoid character. Where the change from granite to slate occurs, the granite near the line of contact is often of a red variety and rather fine grained, gradually passing into the ordinary color and texture in receding from the line. All attempts to elucidate the structural relations of the granite have proved futile. In the slate band northwest of the granite are conformable dikes of diorite, syenite, and other feldspathic rocks. Immediately at the junction of the granite with this series is a band of pure crystalline limestone.

ELLS,[15] in 1881, reports on the geology of northern New Brunswick. The pre-Cambrian rocks are believed to underlie unconformably the Cambro-Silurian. The typical rock is a grayish feldspathic gneiss, frequently containing hornblende. The rocks referred to the pre-Cambrian include granites, felsites, gneisses, and schists. Granites, diorites, dolerites, and felsites are found. A portion of these are mingled with the pre-Cambrian, but others, and especially the basic eruptives, are found in the slates and other rocks belonging to the fossiliferous series. At the contact of the granites with the slates in places the latter become crystalline and contain crystals of staurolite.

ELLS,[16] in 1883, finds crystalline mica-schists, quartzites, etc., which are provisionally referred to the pre-Cambrian system. They are found at two places conformably to underlie the Cambro-Silurian series.

BAILEY,[17] in 1885, in a report on York and Carleton counties in central New Brunswick, finds no rocks which are regarded as pre-Cambrian; but granites, syenites, basalts, and diabases occur which are regarded as intrusive. Interstratified with the Lower Carboniferous are beds of volcanic or semi-volcanic origin. The granite is filled with imbedded fragments of other rocks, so that in places it has the appearance of a conglomerate. Beyond question they come from the schistose and micaceous rocks which border the granite, as is shown by their identity in character with these rocks. Also the lines of contact show the intrusive character of the granite.

BAILEY,[18] in 1886, in continuing his work in central New Brunswick, finds highly crystalline strata, including gneisses, syenites, and felsites, which are referred to the pre-Cambrian. They are thought to be a continuation of those described by Ells. In this pre-Cambrian are included without doubt very considerable masses of igneous rocks.

BAILEY and MCINNES,[19] in 1877, in continuing work on central New Brunswick find felsites, quartzites, and mica-schists, which are referred to the pre-Cambrian. Only the boundaries of the rocks are mapped, no attempt being made to work out the structure. These rocks are cut by granites which are found in two areas. These granites are the same character as those which have been previously described as of probable Devonian age.

SUMMARY OF RESULTS.

As a result of the above work in central New Brunswick it is clear that below the Cambro-Silurian rocks is a set of semicrystalline and crystalline schists containing among the former such rocks as slate, quartzite, and limestone. The character of these is such as to show that they are in part of clastic origin. Large masses of intrusive rocks, both basic and acid, cut both these rocks and the fossiliferous sedimentaries. The masses are sometimes so large as to cause important contact metamorphism.

There is little difficulty in separating the intrusives from the fossiliferous rocks, but upon account of the more crystalline character of the older series and its likeness in mineralogical composition to certain of the subsequent intrusives, and further, upon account of the intimate mingling which occurs between these two classes of rocks, it is difficult to make the separations with the same degree of sharpness. This difficulty is not improbably further increased by the presence of intrusives earlier than those which cut the Cambro-Silurian rocks.

The maps presented of the pre-Cambrian are purely areal, no attempt whatever being made to subdivide them or to work out their structure.

SECTION IV. SOUTHERN NEW BRUNSWICK.

LITERATURE.

GESNER,[20] in 1839, gives many details as to particular localities in southern New Brunswick. The succession of rocks below the Old Red sandstone is argillaceous slate and granite. The volcanic rocks of the bay of Fundy are of different ages.

GESNER,[21] in 1840, gives a continuation of his study of the previous year.

GESNER,[22] in 1841, describes the geology of the county of St. John more fully than in previous reports. The syenites occupy a large area, and against these lean the slates, graywackes, and limestones parallel to the coast of the bay of Fundy, but there is a group of more schistose rocks containing no organic remains which dip toward this ridge. These latter are evidently primary, while the graywackes and graywacke-slates are Cambrian or Silurian. It is certain that a part of the granitic and syenitic rocks which have been regarded as primary really belong to a later age.

GESNER,[23] in 1842, finds that the graywackes and slates provisionally correlated with the Cambrian were deposited prior to the elevation of the granitic, syenitic, and trappean masses upon which they rest, as they are fractured in all directions by dikes and extensive elevations of those rocks.

GESNER,[24] 1843, places the granite, syenite, trap, and serpentine in the unstratified rocks. To the Cambrian system are referred a series of graywackes and clay-slates which are sometimes conglomeratic. These rocks extend from the American boundary to near Bathurst, and in them organic remains occur.

JOHNSTON,[25] in 1850, in a report on the province of New Brunswick, gives a map by Robb in which the crystalline rocks are outlined as granite, gneiss and mica-slate, and trap rocks.

BAILEY, MATTHEW and HARTT,[26] in 1865, in observations on the geology of southern New Brunswick, give a résumé of the work previously done. Of the 15 different groups of rocks, the lowest consists principally of granite, gneiss, mica-schist, and thick beds of crystalline limestone. This is the Laurentian or Portland group. Resting upon the Portland group is the Coldbrook group, belonging to the Huronian division of the Azoic system, and thick deposits of altered slate of a volcanic character, surmounted by conglomerates. The Coldbrook group is succeeded by the St. John group, which contains no coarse material and is regarded as equivalent to the Potsdam or Primordial of New York. Above the St. John group is the Bloomsbury group of volcanic character, such as basalt, amygdaloid, and trap rock, which are associated with conglomerates and slates destitute of fossils. Geographically separated from the above groups are the rocks of Kingston, which are regarded as Upper Silurian, and the mica-schists of Queens county, which may be Cambrian. Scattered through all the above are igneous rocks such as granite, syenite, porphyry and trap, which may occur associated with rocks of any age. The Portland group is in almost entire conformity with the Coldbrook group. The lithological resemblance of the Coldbrook group (7,000 feet thick) with the Huronian is very close. The presence of graphite in the Portland and St. John groups is regarded as evidence of life.

The extreme metamorphism of the Portland group is evidence of its great antiquity. This age would never have been doubted were it not for the intimate association and conformability with the beds of the overlying groups, which are unquestionably Upper Devonian, and the Portland was supposed to represent either a portion of the Lower Devonian or possibly the upper part of the Silurian. During the deposition of the Azoic and Silurian ages a long period of repose prevailed, broken only by the volcanic activity of the Coldbrook group. The Bloomsbury rocks associated with rocks unquestionably of Upper Devonian age are referred to the same horizon. At one place the Coldbrook group overlies the St. John, its position being due to a reverse folding caused by a ridge of eruptive syenite. The Kingston group on its general lithological character and stratigraphical relations is provisionally referred to the Upper Silurian, although Lower Silurian and Lower Devonian beds may occur.

MATTHEW,[27] in 1865, correlates the Portland series, which includes limestone, syenite, gneiss, conglomerate, slate, and graphitic shale, with the Laurentian, first, because of its lithological characteristics, and second, because it is unconformably overlain by great thicknesses of deposits similar to the Huronian series of Canada. The Coldbrook Huronian group is conformable with the Lower Silurian St. John beds, although there is a marked contrast between the formations, the former containing conglomerates and volcanic products, but the latter none.

HIND,[28] in 1865, in a geological sketch of the province of New Brunswick, finds no rocks older than the Lower Silurian. The belts of granite are regarded as of Devonian age, being apparently thrust up through the Lower Silurian and Devonian strata before the beginning of the Carboniferous epoch. The Quebec group includes gneiss, anorthosite, mica-schist, hornblende rocks, diorite, various schists, and other crystalline rocks.

MATTHEW and BAILEY,[29] in 1870, divide the metamorphic rocks of New Brunswick and Maine into, first, a Laurentian series, which consists of gneiss, often granitoid in aspect, including (1) crystalline limestone and interstratified beds of quartzite and diorite, (2) a Labradorian or Upper Laurentian series, which consists of feldspar rock associated with hypersthene and magnetite; and, second, a Cambrian or Huronian series. The granites of St. Johns river are of Devonian age.

BAILEY and MATTHEW,[30] in 1872, find the Laurentian system to have a rather widespread distribution. The rocks are placed in the Laurentian because older than the Silurian rocks, which contain a Primordial zone, as well as on account of their general lithological resemblance to the ancient rocks of the Laurentian system. The Laurentian is separated from the Primordial beds by an accumulation of trappean and tufaceous strata which is supposed to be of Huronian age. The lower division of the Laurentian consists of diorites, syenite, granitoid gneiss, etc., while its upper division consists of crystalline limestone with diorite at intervals, greenish gray gneiss, quartzite, argillite, and slate conglomerate. The contact of the granite with the schistose rocks is peculiar. Contained in the granite are long irregular blocks of the schistose rock. Their occurrence suggests either a softening of the older series through metamorphism subsequent to the deposition of the upper series, or else the intrusive character of the granites. One section of gneiss and granite in the Lower Laurentian has a thickness of 12,600 feet. The maximum thickness of limestone and quartzite of the Upper Laurentian is not more than a thousand feet.

In the Huronian series are placed the Coldbrook, Coastal, and Kingston groups, which together occupy a wide area. The Coldbrook group at several points was observed to rest upon the gneissic and granitic rocks referred to the Laurentian system, and in turn to be conformably overlain by the slates of the St. John group containing Primordial fossils. The Coldbrook group consists of diorite, chlorite-schists, black slates, micaceous shales, argillites, gneissoid rocks, and other varieties. The rocks of the Coastal group consist of felsites and conglomerates, gray limestones, and gray clay slates, gray chloritic grits and schists, micaceous slate and gray dolomite, green and red clay slate, and diorite. The Kingston group consists of shales, felsites, diorites, and argillites. In Grand Manan are various crystalline rocks which are not definitely referred to any period, but are compared to the Huronian. The Devonian and Huronian rocks are folded together, but no evidence is seen of unconformity between the two series. The Mascarene series in general aspect resembles the Huronian series of St. John and King counties. Intrusive granites are found at many points. In general the contacts of these granites with the surrounding rocks are not found, and their age is thus unknown.

The diorites and schists of Bloomsbury mountain, formerly supposed on stratigraphical grounds to be more recent than the Huronian, resting upon the St. John group and overlain conformably by the Devonian sandstones, are now regarded as Huronian on lithological grounds, being probably brought up by a fault. At Musquash harbor and at Ratcliffe's mill stream green subcrystalline schists rest conformably upon the Primordial strata, but these are believed to be overturns and the former Huronian.

The rocks of the Coastal group at several points overlie Upper Silurian or Devonian strata. They were formerly described as Devonian; but as Hunt finds them similar to the Huronian in lithological character, they are here referred, and the apparent inferior position of the Devonian is supposed to be due to a dislocation. Accidental intercalations of Upper Silurian and Kingston strata are found.

BAILEY,[31] in 1872, describes the rocks of the greater part of Grand Manan as consisting of Triassic trap. Upon its east side are, however, found metamorphic rocks, which may belong to different series; but none are believed to be more recent than the earliest Primordial Silurian, while some of them may be Huronian.

MATTHEW and BAILEY,[32] in 1876, place the Mascarene and Kingston series, the latter of which was previously considered Upper Huronian, in the Upper Silurian upon account of fossils discovered in them.

BAILEY and MATTHEW,[33] assisted by Ells, in 1877, in observations on southern New Brunswick, provisionally refer the Coldbrook group, formerly considered as Laurentian, to the Huronian. The granites are separated from the stratified formations of the Coldbrook group.

MATTHEW,[34] in 1878, refers as doubtfully belonging to the Laurentian the slate formation of Charlotte county, formerly described as Coastal rocks and placed in the Huronian. In the Kingston series, more recent than the Coastal, are rather crystalline rocks which are believed in part to belong to the Upper Silurian, but, like the Coastal rocks, are of uncertain age. The crystalline mica-schists, hornblende-schists, gneisses, diorites, etc., of Grand Manan combine in characters the two belts of Kingston rocks and those of certain Upper Silurian strata.

BAILEY and ELLS,[35] in 1878, find in the Caledonia mountains of Albert and Westmoreland counties chloritic and talcose slates associated with beds of grit and conglomerate, which are regarded as probably of Huronian age.

ELLS,[36] in 1879, finds in Albert, eastern Kings, and St. Johns counties pre-Silurian rocks, which are placed in the Huronian and Laurentian. The older series is said to consist of syenite, felsites, feldspathic quartzites, and limestones. In many places are transitions from the slates through schists, felsites, and gneisses, to syenites. The newer series consists of felsitic, siliceous, brecciated, and ash rocks at the base, with talcose, chloritic, and older schists, ash rocks and purple grits, and conglomerates. The second group lies unconformably upon the rocks of the first.

BAILEY,[37] in 1879, divides the pre-Silurian rocks of southern New Brunswick into four divisions on lithological grounds. The first are syenitic, feldspathic, and gneissic rocks; the second, limestones and dolomites, with others. These two divisions are regarded as belonging to the Laurentian. The third is a felsite-petrosilex group which comprises sandstones and conglomerates, as well as amygdaloidal ash rocks and ash conglomerates. This is the Coldbrook group of the earlier reports and is regarded as a lower member of the Huronian system. The fourth division is a schistose, chloritic, and micaceous group, comprising among other rocks conglomerates, clay slates, quartzites, ash rocks, amygdaloids, etc., and is regarded as the upper member of the Huronian system. The passage from division 2 to division 3, that is, from the Laurentian to the Huronian, is a gradual one, as the two groups are intimately associated.

Placing the Upper Coldbrook group as pre-Silurian, the unconformability of this group with the Silurian is marked in general. The Primordial beds sometimes rest upon division 3 and sometimes upon division 4, they contain in places coarse basal conglomerates, and appear to have been originally deposited among the hollows of the Huronian series. South of Bloomsbury mountain, and on the main stream of Black river and the adjacent region, the Huronian rocks are associated with the Devonian, and the two formations accord almost exactly both in strike and dip, the Devonian being included among the Huronian rocks. But in addition to the fact that the conglomerates of the former are largely made up of the débris of the latter, there are points in which this accordance is clearly wanting. The discordance is pretty well seen at the east branch of Black river.

MATTHEW,[38] in 1879, finds the Kingston series to exhibit a strong resemblance to the Huronian formation of St. John county, but it is regarded as Silurian on paleontological grounds.

BAILEY, MATTHEW, and ELLS,[39] in 1880, give a general review of their work done upon southern New Brunswick, which covers an area of about 6,000 square miles. The rocks comprised under the pre-Cambrian include the Laurentian of 1871 and the three former divisions of the Huronian-Coastal, Coldbrook, and Kingston. Of the relations of the upper members of the Laurentian mica-schist, limestone, and fine gneiss, to the main body of coarse syenite and syenitic gneiss constituting the Lower Laurentian, nothing further is known than contained in the report of 1870–'71. The greatly broken and disturbed character of the supposed upper series, the obscure stratification of much of the underlying group, and the frequent occurrence of intrusive masses, combine to make the determination difficult. There can, however, be no question that the bulk of the calcareous and siliceous strata are more recent than the coarse granitoid rocks with which they are associated. With one possible exception, no instances of direct superposition of the Coldbrook rocks on the Laurentian have been observed; but the Coastal rocks are found upon the Coldbrook rocks as well as upon the Upper Laurentian, so there is no reasonable doubt as to the true succession. Contacts of the Coastal group with the Coldbrook group are found in the county of St. John, and especially along the line of the St. Martins and Upham railway, between Upham and Quaco, and on the lower Quaco road on either side of Bloomsbury mountain. In passing from one to the other there is often an abrupt change of dip, the beds of the higher series dipping at a lower angle than those upon which they rest, while along the same line of contact it is not uncommon to find masses of coarse breccia conglomerate, in which the fragments are largely the petrosilex derived from the inferior group. It is, however, questioned whether the unconformability is sufficient to prove the fact of any considerable lapse of time. The age and equivalency of the Kingston group, as well as that of the Mascarene peninsula, is somewhat uncertain, owing to the difficulty of obtaining stratigraphical evidence and from the close resemblance which many of them bear on the one hand to the rocks of the Huronian, and on the other to those of the Silurian.

BAILEY,[40] in 1881, in summarizing the work of the survey in New Brunswick, concludes that there is a Laurentian and Huronian, as in other parts of Canada. These are below the Primordial by a marked unconformity. These rocks east of St. John occupy irregular troughs in the pre-Silurian rocks, resting sometimes upon one and sometimes upon another of the subdivisions of the latter, crossing their strike obliquely and having coarse basal conglomerates. There is almost perfect lithological likeness between the great mass of rocks referred to the Laurentian, including coarse and fine grained gneisses, quartzites, graphitic, and serpentinous greenstones and dolomites, with the Laurentian of other parts of Canada, and particularly the Hastings series of Vennor. This series is capped by the great volcanic series of the Huronian. These pre-Silurian rocks are confined wholly to the region of the southern metamorphic hills, nothing of equivalent age having yet been identified in the central and northern portions of the province. In the rocks referred to the Huronian are two well marked divisions, the lower or Coldbrook group and the upper or Coastal group, between which there is not infrequently evidence of at least a partial unconformity. The pre-Silurian rocks are of vast thickness; their divisions were deposited under markedly different conditions; there are unconformities between these divisions. These facts show that these rocks are at least as old as the Huronian and portions of the Laurentian system. Above the Upper Silurian rocks are found felsite-porphyries and peculiar orthophyres at Passamaquoddy bay, and at Eastport and Pembroke, Maine. On the St. John river, associated with the fossiliferous rocks are amygdaloidal and ash rocks which are indistinguishable lithologically from the Huronian formation, and to which all of these rocks have previously been referred.

BAILEY,[41] in 1885, finds the granites of southern and central New Brunswick to be of intrusive character and to cut rocks as late in age as the Carboniferous. As evidence of this are cited the abrupt transitions from the massive granite to the associated schists; the widely different characters of the invaded beds; the fact that foliation and crystallization are most marked in the vicinity of the granite and decrease in receding from it; the outlines of the granite are irregular and sometimes parallel, at other times are oblique to, and at other times at right angles to the rocks cut; detached masses or bosses of granite border main granitic areas; granite veins like those of the main mass of granite penetrate the schists in all directions adjacent to the granite masses; large detached blocks of schists and gneiss, usually angular, are frequently contained in the granite, sometimes being so abundant as to produce the appearance of a coarse breccia. As to the age of these granites, no veins are found penetrating later strata than the Upper Silurian, but all conglomerates older than the Lower Carboniferous are destitute of granite pebbles, while the later formations abound in them, which appears to indicate that the granites are Devonian.

ELLS,[42] in 1886, finds in Albert county pre-Cambrian rocks which include quartzite, felsite, gneiss, syenite, and granite. The crystalline limestone rests generally upon the flanks of the schistose series. These rocks are an eastern extension of the pre-Cambrian of western New Brunswick.

BAILEY,[43] in 1890, says the evidences of unconformity between the Primordial and Archean are clear, varied, and widely distributed. It is equally evident that the Archean consists of two groups of sediments, which in many features resemble the Laurentian and Huronian systems of Canada; but there are equally striking differences between the supposed Laurentian rocks of St. John and those of Canada. This is especially marked by the greater proportional amount in the former of distinctly stratified rocks, such as slates and quartzites, and the absence of coarsely crystalline deposits. As regards the Huronian rocks, the greater part were referred to as felstones, clay-stones, porphyries, and petrosilex before the introduction of the present methods of petrographical research and their names in some instances are probably misapplied. The relations of the Laurentian and Huronian systems are not well understood. While the author does not doubt that the clastic and schistose rocks referred to the Huronian are more recent than the granitoid gneissic and crystalline limestones regarded as Laurentian, a contrary view has been taken by others.

MATTHEW,[44] in 1890, states that in the upper Laurentian of New Brunswick fossils occur at three horizons. The oldest of these is in a quartzite in the lower half of the system. This contains Hexactinellid sponges, allied to the genus *Cyathospongia*. The second horizon is in the upper limestone. It contains calcareous coral-like structures which bear a resemblance to *Stromatopora rugosa*. The third horizon is that of the graphite beds, in which occurs great numbers of sponge spicules, arranged in parallel sets, one set crossing the other at an acute angle. The type of sponge is apparently Monactinellid. Eozoon also occurs in the Laurentian. Between the upper Laurentian system and the basal Cambrian occurs a third system of rocks, the Coldbrook and Coastal, which has given conglomerates to the Cambrian and has a great thickness.

SUMMARY OF RESULTS.

While the mapping of the province of New Brunswick has been completed by the official survey, the statements of the later papers of those who have taken the most active part in this mapping make it certain that many of the supposed conclusions reached in the early reports are open to doubt. The most noticeable feature is the failure to subdivide the Huronian into two or three series on these maps when the divisions Coldbrook, Coastal, and Kingston have been found in the reports for many years. The reason assigned on the maps for this is that the three series are so intimately intermixed that their separation with any approach to accuracy is impossible.

The difficulty of the geology of this region is shown by the manner in which these groups have been shifted from one place to another. In the days of the earlier work none of them were regarded as pre-Cambrian, and a portion was given as high a place as the Devonian. The Kingston group in 1865 was called upper Silurian and was regarded as overlying the St. John; in 1872 was called upper Huronian; in 1876 was again placed as Silurian; and was not until 1879 finally placed with the upper Huronian. The Coastal group, first placed in the fossiliferous series, in 1872 was placed in the middle Huronian; in 1878 was doubtfully referred to the Laurentian, and in 1879 was again returned to its place as middle Huronian. The Coldbrook group has been reckoned as Huronian since 1865.

At the outset, in discussing the results attained as to the succession of crystalline rocks, the intrusive character of a very large part of the granite at a period later than pre-Cambrian time may be considered as demonstrated. To this conclusion all the official geologists have agreed with the exception of Hind, whose work was done at a time in which the metamorphic theory had extreme power. Announced by Gesner in 1841, the evidence cited by him for the intrusive character of the granite is in a measure the same as that so convincingly given by Bailey over forty years later, in 1884.

The plainly eruptive character of a part of the granite suggests the question as to whether the great mass of syenite, granite, and gneiss making up the lower Laurentian is not also of an igneous character. Even if this be so, it does not follow that it is not the most ancient rock in southern New Brunswick; but the possibility is suggested that it may be an intrusive of a much earlier age than those which cut the Silurian strata, and yet not be earlier than a portion of the crystalline rocks of clastic origin and pre-Cambrian age.

It is evident that among the rocks referred to the Laurentian of southern New Brunswick is a great series of completely crystalline rocks, and an apparently unimportant series composed of slates, quartzites, and limestones. This is shown by the estimated thicknesses given in the report published in 1872. The lower Laurentian is given a thickness of over 13,000 feet, while the upper Laurentian (clastics) have a thickness not to exceed 1,000 feet.

The suggested intrusive character of the lower Laurentian is made more probable by the fact that there is said to be transitions between these plainly clastic rocks and the thoroughly crystalline ones. Upon the other hand, it is also a possibility that there is a physical break between the clastics and crystallines of the Laurentian, but no fragments of the underlying series are found in the clastics nor is any structural unconformity mentioned. One is at once struck with the parallelism between the two parts of the Laurentian of southern New Brunswick and those of the Hastings series. In this latter case Vennor, in his later work, came to the conclusion that the clastic series is a newer unconformable one resting upon an older crystalline series.

The Laurentian and Huronian are in general said to be in conformity. While this is true, Matthew in 1865 states that the Portland series is unconformably overlain by the Huronian, and Ells repeats this statement in 1879. In 1880, however, this position is apparently abandoned; at least it is not alluded to in the general summary of conclusions. As the Huronian and Laurentian are regarded as conformable, the basis for separating the clastic series at the base of the Coldbrooks must be considered wholly lithological. It is somewhat difficult to determine the lithological criteria used in the distinction, but it seems that the appearance of abundant volcanic material is the most important of these. Also connected with this fact is a prevailingly darker color. When it is remembered that volcanic outbreaks are often of a local character, and that it is wholly possible that quartzites and slates are being deposited at the same time volcanic accumulations are occurring, it must be concluded that the criterion of volcanic activity is an uncertain one. It would seem that it would be more reasonable, without reference to other localities, to make the major break above the crystallines of the Lower Laurentian.

The only physical break finally maintained in the whole pre-Cambrian series is between the two divisions of the Huronian, the Coldbrook and Coastal. From the descriptions it seems that this break is a very considerable one; for detritus of the lower series is contained in the upper, and more important than this, the lower series has a steeper inclination. Such a break as this certainly implies not only an erosion interval, but an orographic movement, and this must mean a rather important time break.

Throwing aside all correlations with other regions and considering the pre-Cambrian succession in southern New Brunswick alone, it is as follows: (1) Wholly crystalline granites, gneisses, etc. (2) Quartzites, slates, slate conglomerates, gneisses, and crystalline limestones. (3) Volcanics and clastics of the Coldbrook. Unconformity. (4) Coastal and Kingston groups. While in the reports it is positively stated that the Coldbrook is lower than the Coastal and Kingston, even this conclusion apparently can not be taken without question, since the distinction is abandoned in the mapping. The dropping of the term Huronian for the post-Laurentian groups indicates that this correlation with Huronian, taken for granted for many years, is also considered an open question.

SECTION V. NOVA SCOTIA AND CAPE BRETON.

LITERATURE.

JACKSON and ALGER,[45] in 1832, in remarks on the mineralogy and geology of Nova Scotia, find the granites to protrude through the clay-slates. They are, however, regarded as older than the slates, the latter having been deposited on them in a horizontal position. This granite is the only Primitive rock of Nova Scotia. The line of junction between the slate and granite was not observed. The slates are cut by numerous dikes believed to be of igneous origin in age posterior to the slate.

BROWN,[46] in 1843, places the whole northern part of cape Breton in the Primary rocks. Cape North is composed of mica-slate, gneiss, and granitic rocks apparently interstratified, with an east and west strike, and upturned nearly on edge. Igneous rocks occupy a large part of the island. These protrude through the limestones and graywackes, which are associated with the coal measures.

DAWSON (SIR WILLIAM),[47] in 1850, divides the metamorphic rocks of eastern Nova Scotia into two groups; one along the Atlantic coast and vicinity, and another belt to the west, parallel to the first. The coast group consists of quartzites, mica-slates, and clay-slates, which are cut by granites, and it is therefore called the granitic group of metamorphics. The second group, the slates and quartzites, include micaceous and talcose schists, while the intrusive rocks are syenites and the group is therefore called the syenitic group. The syenitic group rests unconformably below the carboniferous rocks, the latter containing fragments from the former. These are seen at numerous points. Both of these groups of rocks are regarded as belonging to the fossiliferous series, the syenitic group being Silurian. The granitic group is probably older than the syenitic, and therefore also Silurian or pre-Silurian, but the actual superposition of the beds of the two groups were not observed.

DAWSON (SIR WILLIAM),[48] in 1855 and 1868, places in the Upper Silurian large areas in the northern and eastern parts of cape Breton as well as other smaller areas; large areas in northern Nova Scotia, and in southern Nova Scotia northwest of the gold-bearing series. The rocks have been subjected to great disturbances and are much complicated in structure. They include many varieties, syenite, porphyry, greenstone-slates, quartzites, conglomerates, and sandstones. Large areas of granitic rocks are also found associated with the metamorphic series referred to the Upper Silurian.

The Lower Silurian covers a very large area along the Atlantic coast of Nova Scotia known as the gold-bearing series. This area has afforded no fossils but appears to be a continuation of the older slate series of Jukes of Newfoundland which contain Paradoxides. Among the metamorphic rocks of this region are gneiss, mica-slate, quartz-rock or quartzite, and clay-slate. The gneiss is unquestionably the product of metamorphism due to the baking of sedimentary rocks by heat and water, while quartzite consists of grains of flinty sand fused together. The preponderant rocks are thick bands of slate and quartzite having a general northeast and southwest strike and highly inclined. Whether the mica schists and gneiss of cape Canso, and Queen's and Shelburne counties, and the chloritic beds of Yarmouth are to be regarded as more metamorphosed members of the Lower Silurian slates or are still older deposits remains uncertain. Granite is found in several places in the region in large masses projecting through the slates and quartzites, and adjacent to the granite these rocks are replaced by gneiss and mica-slate or other more highly metamorphosed rocks. The metamorphism of the rocks must have occurred prior to the Carboniferous period, and there is no doubt that the granite rocks have been the agent in effecting it, if they are not themselves portions of the stratified beds completely molten and forced up by pressure against and into the fissures of the neighboring unmelted rocks. Whatever view is taken as to the age of the granitic rocks, it is certain that they are strictly Hypogene, that is, they belong to deep-seated foci of subterranean heat and are not superficial products of volcanic action, but were probably at one time deeply buried.

CAMPBELL,[49] in 1863, divides the gold-bearing slates into a lower or quartzite group and an upper or clay slate group.

HIND,[50] in 1869, finds in the Waverly beds of the gold-bearing rocks obscure fossils, which are regarded as evidence that these rocks probably lie near the base of the Lower Silurian, perhaps being the equivalent of the Potsdam or lower part of the Calciferous.

HIND,[51] in 1870, describes the series of gneissic and granitic rocks which are said to extend as an interrupted axis from the Gut of Canso to the Tusket islands. These have heretofore been regarded as eruptives, because dikes of granite are frequently found in the quartzites which are supposed to be Silurian, and also fragments of quartzites and slates are imbedded in the granites near the contacts. It is, however, concluded that the granite is a sedimentary deposit resting unconformably below the slates and quartzites. The chief proof of the aqueous origin of the granitic rocks is the abundance of water-worn pebbles and bowlders, and this not only near the junction of the quartzites but remote from these rocks. These pebbles are symmetrically arranged, showing the dip of the gneiss. They are often smooth and rounded, but masses of schists are also contained which do not present rounded edges. The granites or gneisses are seen to break through the gold-bearing series in many places, but they are regarded as brought up by faulting; but in certain places on the line of the Halifax and Windsor railroad the gneisses were in a plastic state when the uplift took place, for veins are found squeezed into the cracks and interspaces of the thinly bedded gold-bearing rocks.

The sequence of formations is Upper Silurian, Lower Silurian, Cambrian or Huronian, and Laurentian. The Upper Silurian is a series of argillites estimated at 9,000 feet thick. The Lower Silurian consists of micaceous, schistose and corrugated black slates, and are estimated to have a thickness of from 12,000 to 15,000 feet. The gold-bearing Silurian rocks are seen to rest unconformably on a gneissoid series between Stillwater and Uniacke station on the Halifax and Windsor railway, and near the village of Sherbrooke, in Guysboro county. This series of Huronian rocks is composed of beds of gneiss, interstratified with micaceous schists, schist-conglomerate, beds of true quartzite, and grits. The gneiss is sometimes porphyritic, and the upper beds are almost always conglomeratic, holding pebbles and masses of schists, grits, and conglomerates, which are found in this series. This older series rests unconformably upon the Laurentian. The contacts are visible on the Windsor and Halifax railway, near New Stillwater and Mount Uniacke stations. The gold-bearing Silurian strata are also found to repose unconformably upon the Laurentian. This contact is also observed near Mount Uniacke station.

SILLIMAN,[52] (year unknown), finds that the gold-bearing rocks of Nova Scotia extend along the Atlantic coast for 250 miles, from cape Sable to cape Canso. These rocks are hard, slaty ones, which are sometimes micaceous schists, and occasionally granitic. When stratified they are always found standing at a high angle, sometimes almost vertical, and in the main with an east and west course. The zone of metamorphic rocks varies in width from 6 to 8 miles at its eastern extremity to 40 or 50 at its widest part, the area covered being about 6,000 square miles. While no fossil evidence has been found in any of these slates, opinion seems to favor the belief that they belong to the Silurian age, but as yet no place has been found where the rocks next higher in the geological column may be seen resting upon them. The most noticeable rock of the gold region is a dark gray massive rock, resembling a trap, but which is really a granular quartzite. It has three well defined planes of cleavage by which it breaks into very irregularly shaped masses. This rock is of enormous thickness, and is undoubtedly the fundamental or basement rock of the region.

LOGAN and HARTLEY,[53] in 1870, describe felsites, quartzites, conglomerates, and slates, adjacent to the Pictou coal fields, which are pre-Carboniferous, and are placed as probably of Devonian age.

SELWYN,[54] in 1872, in studying the gold-bearing slates, agrees with Dawson that they belong to the Primordial-Silurian epoch. As evidence of this is given the discovery in the slates of Oven's bluffs of numerous specimens of the genus *Eophyton.*

The granite impresses this author as of strictly indigenous character, and neither a granitoid gneissic series of Laurentian age nor an intrusive mass. The line of contact with the Silurian and Devonian leaves no doubt of its posterior origin, but whether intrusive or metamorphic in situ is perhaps uncertain.

ROBB,[55] in 1876, finds that a massive syenite and associated crystalline rocks have a quite widespread distribution in cape Breton. At some points the Carboniferous rocks are brought in contact with the syenite, but generally there are interposed metamorphic calcites, argillites, and quartzites associated with dolomites, and other magnesian rocks, which are in a vertical or highly inclined position, and evidently belong to a pre-Carboniferous altered sedimentary series. The junction of the pre-Carboniferous limestones with the syenite is approximately parallel to the mountain range, but is locally irregular, and in some instances the limestones seem to fill depressions in the syenite. The Lower Carboniferous rocks in places rest directly upon the syenite, filling the hollows in it, and have basal conglomerates, the debris of which is derived from the overlying syenite, limestone, and quartzite.

FLETCHER,[56] in 1877, finds in cape Breton, below the Silurian rocks, first, a set of syenitic, gneissoid, and felsitic rocks; and second, the George river limestone series, consisting of crystalline limestones and dolomites, interstratified with felsite, syenite, diorite, mica-schist, quartzite, and quartzose conglomerate, both of which are referred to the Laurentian, although the latter may be Huronian. The Lower Silurian shales lie nearly horizontally upon the syenites and felsites without any appearance of alteration and without being intruded by the felsites or syenites. The crystalline limestone series is in close affinity with the feldspathic group of rocks, but is distinct, as is shown by the occurrence of pebbles of syenite and felsite in the quartzose conglomerate of Murphy brook.

FLETCHER,[57] in 1878, continues his study of the pre-Cambrian of cape Breton and northern Nova Scotia. The George river limestone is bounded upon both sides by coarse syenitic and granitic rocks and is in apparent conformity with them.

DAWSON[58] (Sir William), in 1878, places the rocks of the Bloisdale hills in cape Breton as older than the Lower Silurian, and it is not impossible that rocks of the same age may occur in the vicinity of the Cambrian beds at Miré. Also the chloritic rocks of Yarmouth may conjecturally be placed with the Huronian. With the exception of the rocks of St. Anns mountain, of the island of St. Paul, and some parts of northern cape Breton, no rocks are found which are regarded as lithologically equivalent to the Laurentian of Canada.

FLETCHER,[59] in 1879, describes the pre-Primordial rocks as occupying two large areas, one constituting the Mira hills, while the other is a belt of variable width along the shore of the Atlantic. There are two basins of metamorphic rocks running parallel to the felsite series, one of which abounds in Primordial fossils and the second probably of Devonian age. The latter contains masses of granitoid and trappean rocks.

FLETCHER,[60] in 1881, in continuing his studies in northern Nova Scotia, again divides the pre-Cambrian rocks into two groups. In the first, or felsitic group quartzites are also found intimately intermingled. The George river limestone series is considered as an unconformable overlying group of pre-Cambrian age. The limestones in every case cap the felsites, with which, however, they often seem to blend near the contacts as if by a common metamorphism. As evidence of this unconformity are cited the occurrences of limestone in a higher position than the syenites and felsites; the irregular line of contact by which the syenite passes under the limestone; and the absence of veins and dikes of syenite in the limestone. The rocks are sometimes intricately mingled, as at Dallas brook, where layered felsite, limestone, and slate are met with, while on the top of the hill limestone occurs, and farther back syenite, displaying a coarse admixture of finely foliated gneiss. In some localities the syenite begins abruptly as if cutting vein-like across the strike of the gneiss; in others the change from syenite to gneiss is gradual. The gneiss is associated with large masses of white quartzite. Metamorphic rocks are described which are referred to the Devonian, but the evidence is so slight that it is concluded that all of these strata may belong to an older period. Between them and the pre-Cambrian series there is a marked unconformity, and also one of less importance between them and the Carboniferous.

FLETCHER,[61] in 1885, finds that in northern cape Breton the syenitic, gneissoid, and other feldspathic rocks of the Lower pre-Cambrian group are intimately mingled on the Margaree river with foliated rocks. At Coinneach brook, where the syenite comes in contact with the contorted mica-schist, the latter is seen to underlie the syenite. Higher up the syenite again appears and contains a layer 5 feet thick of mica-schist which is, as it were, intruded among the syenites. Red granite overlies unconformably the strata of the George river limestone group at Fionnar brook.

GILPIN,[62] in 1886, describes the pre-Cambrian rocks of cape Breton as including a felsite series and a crystalline limestone series, both of which are referred to the Laurentian, and the latter unconformably overlying the former. With the felsites and interstratified porphyries are also syenitic and gneissic rocks; while the crystalline George river limestone also contains interstratified with the limestones, syenites, diorites, mica-schists, quartzites, and quartzose conglomerates. The limestone area is limited in extent as compared with the felsite group.

FLETCHER,[63] in 1887, further describes the pre Cambrian rocks of a part of northern Nova Scotia. The crystalline rocks here found resemble none known as Cambrian in other parts of Nova Scotia, and are strikingly like those beneath the Upper Cambrian in cape Breton. Although they are certainly known to rest unconformably below the Cambro-Silurian strata, a part of all of these rocks may be Cambrian or even Cambro-Silurian. Similar gneisses and schists in southern New Brunswick have been included by Bailey in his Cambro-Silurian series. Volcanic rocks, both basic and acid and varying in age from pre-Cambrian to Devonian, or even Carboniferous, are abundantly found.

FARIBAULT,[64] in 1887, reports on the gold-bearing area of southern Nova Scotia. These rocks occupy 6,000 or 7,000 square miles. They are divided into a granitic division and a lower Cambrian division. The lower Cambrian rocks include quartzites, clay-slates, and conglomerates, and are estimated to have a thickness of 15,000 feet. These rocks, always greatly altered, are much more so when cut by masses of granite, and over considerable districts have been rendered thoroughly crystalline, the quartzites passing into fine gneissic rocks, and the mica-slates into mica-schists. Following Campbell, they are divided into a lower or quartzite group, 11,000 feet thick, and an upper or graphitic and ferruginous slate group, about 4,000 feet thick. The first of these, while in the main quartzite, is interstratified with numerous bands of slates and one or two of conglomerate. The Cambrian rocks are greatly disturbed from their original horizontality, being folded into a series of sharp parallel undulations. In the more altered portions the planes of bedding are not easily distinguished from those of slaty cleavage, the latter often being more distinct. The rocks are referred to the Cambrian upon the evidence of a single fossil, Eophyton. The group is analogous in some respects to Lawson's lake of the Woods series. The granites are found to cut the Cambrian rocks at many places, and at times are associated with gneisses. At the edge of large masses the granite frequently passes into a foliated schistose rock, losing its crystalline texture, and itself passing insensibly into the altered sedimentary rocks.

DAWSON (SIR WILLIAM)[65], in 1888, places the isolated rocks of St. Anns mountain in the lower Laurentian, and regards it as probable that rocks of this kind exist in the northern extremity of the island. In Nova Scotia proper no true Laurentian is recognized, the rocks here referred by other observers being intrusive granite masses of much later date associated with altered rocks.

SUMMARY OF RESULTS.

In Nova Scotia and Cape Breton, as in southern New Brunswick, is a great variety of eruptive and intrusive rocks, both basic and acid, and of varying age. It is also plain that there is to be here included considerable masses of rocks which were in early days referred to the Laurentian. The intrusive character of the granites was appreciated by Jackson as early as 1832. Since that time the only observer who has not agreed with this conclusion is Hind, who strongly maintains that they are metamorphosed sediments. His facts, however, clearly distinguishable from his theory, point to an eruptive origin of the granite. The chief fact cited in favor of their being water-deposited rocks is the presence of roundish fragments of slates, quartzites, and schists remote from the contacts with these rocks. All the other facts given by him—i. e., the irregular fashion in which the granite veins intrude the schists, the abundance of large angular fragments of these schists and slates adjacent to the sedimentary rocks—are better explained by regarding the granite as intrusive. The natural explanation of the rounded bowlders remote from the contacts is that they represent partially absorbed pieces of these rocks. The evidence given by Dawson as to the structural relations of the granite and the manner in which the granite fades off into the slates, mentioned by Faribault, is wholly conclusive as to the intrusive origin of a portion of the granites. The relations thus described by Faribault are precisely like those which obtain between the granites and intruded metamorphosed schists in the Black hills and about Rainy lake and lake of the Woods.

While it is thus certain that large areas of granite and felsite are intrusives of later age than the rocks which are certainly of clastic origin, it does not follow that a portion of the felsites, porphyritic gneisses and granites are not of earlier age than any of the plainly clastic rocks.

It is of interest to note that while Dawson insists that all of the granites of Nova Scotia proper are of truly Hypogene origin of later age than the sedimentaries, that he suggests that it is not improbable that they have themselves been produced by the actual fusing of these sedimentaries. This hypothesis is the same as that proposed by Lawson many years later to explain analogous phenomena between the granites and gneisses and the associated schists and clastics of Rainy lake and the lake of the Woods.

In considering the positions and successions of the plainly clastic rocks of cape Breton and Nova Scotia, we have two geological provinces: the first including northern Nova Scotia and cape Breton, which is analogous to southern New Brunswick; and, second, the main part of Nova Scotia, south of the line running from Minas basin to Chedabucto bay.

In the second of these regions, aside from the granites, the only area that is of interest in connection with our study is the gold-bearing Atlantic coast series. Dawson in 1850 places this as Lower Silurian or pre-Silurian. Later, in his Acadian Geology, it is classified as Lower Silurian, although it is stated that no fossils are found in them. Later it was placed by Faribault as Lower Cambrian. The only evidence cited by him for placing it in the fossiliferous series at all is the presence of the obscure fossil Eophyton, discovered by Selwyn. Dawson found no fossil evidence for his reference of this series to the Silurian; and it is remarked by Silliman that immediately overlying rocks containing fossils have never been found. Although Hind in 1870 says that the fossiliferous Upper Silurian conformably overlies the gold-bearing series, this statement has been found nowhere else and subsequent observers have not repeated it, so that it may be considered very doubtful.

It is then clear that the position of the gold-bearing slates in the Lower Silurian or Lower Cambrian is purely provisional. They can only be considered as certainly belonging here under the premise that we are to place in the Cambrian all rocks which contain well recognized fossils or show the evidence of life. Similar reasoning would place in the Cambrian a large part of the rocks which have heretofore been referred to the Animikie and the Huronian in the lake Superior region. This question is more fully discussed in another place. We know positively only that the gold-bearing series is pre-Carboniferous, as the Carboniferous rocks are the oldest found in contact with the former. Between these two is a great unconformity. How much time this break represents we have at present no means of judging.

Dawson is uncertain whether the more crystalline mica-schists and gneisses, which have a somewhat widespread occurrence in southern Nova Scotia, are to be regarded as older than the gold-bearing slates. Hind, in 1870, maintained that a set of older schists and gneisses lie unconformably below the slates on the Windsor and Halifax railway. Not only this, but that this set of schists and gneisses is unconformably above another series which he referred to the Laurentian. As no subsequent observer has mentioned the first of these unconformities, and as it occurs at so readily accessible a place, it may well be considered doubtful whether the facts were rightly interpreted. As suggested by Faribault, it does not appear at all improbable that the gneisses associated with the gold-bearing slates are due to dynamic and contact metamorphism of the intruding granite. The coarsely crystalline rocks which Hind referred to the Laurentian are certainly the series which Dawson and other observers regard as later granitic eruptions, and the unconformity mentioned is perhaps an eruptive unconformity.

In northern Nova Scotia and in cape Breton, among the rocks referred to the pre-Cambrian there is a great variety of rocks both eruptive and sedimentary. The sedimentaries are frequently much more metamorphosed than are the gold-bearing series of Nova Scotia. With commendable caution Robb, in 1876, only says of this older series that it is pre-Carboniferous. Later, Fletcher, on lithological grounds, correlated it with the Laurentian of Canada, and, like the original area of the Laurentian, the Ottawa rocks, he divided it into an Upper and Lower Laurentian, the lower consisting of various massive and laminated rocks all presumably of igneous origin whatever their age, and the upper series, including all limestones, sandstones, slates, conglomerates—that is, all which are certainly clastic in character. Associated with this upper series are eruptives of the same character as those found in the Lower Laurentian.

These two parts of the Laurentian were first described as in apparent conformity, but in 1881 Fletcher describes them as probably unconformable. The detailed evidence for this conclusion it has not been possible fully to give in the foregoing summary, but a close scrutiny of the evidence seems to point more strongly toward the later intrusive character of the so-called Lower Laurentian. The lines of contact between the Lower and Upper Laurentian are very irregular, and in general are found at a lower level than the Upper Laurentian, but both of these would be true if the Lower Laurentian were intrusive. The manner in which the syenite passed into the foliated gneiss, and the foliated gneiss into the ordinary schist associated with the clastics at Dallas brook, appear to indicate the intrusive character of the supposed Lower Laurentian at this place. It is very strange that basal conglomerates have not been found in the upper series which bear fragments of the underlying one, if the former is really newer and unconformable. The interstratified syenites, diorites, etc., placed with the limestone series are, without question, igneous rocks. So that there can be no doubt that many rocks of the same character as the so-called Lower Laurentian are igneous and later than the clastic series, which makes it probable that much of this so-called lower series is of the same age. While all of this is true, as before remarked, it is not certain that a portion of the so-called Lower Laurentian may not be of greater age than the clastic Upper Laurentian rocks.

The gold-bearing series referred to the Cambrian in southern Nova Scotia are nowhere found in contact with the pre-Cambrian of northern Nova Scotia and cape Breton. As has been said, we only know that the gold-bearing slates are unconformably below the Carboniferous. The supposed pre-Cambrian rocks of northern Nova Scotia and cape Breton are known only to be unconformably below the Cambro-Silurian. In this district not only are the igneous rocks apparently more abundant than in southern Nova Scotia, but the folding is of a more intricate character. So far as one can see, there is no evidence that the clastic series to the north is not of the same age as the Atlantic coast gold-bearing series, being, perhaps, more metamorphosed because of the folding and presence of eruptive rocks.

Summing up, it can only be said that all of the clastic rocks of Nova Scotia and cape Breton, so far as we have any positive evidence, may belong as high as Cambrian, as stated by Fletcher in his later work, or may be of pre-Cambrian age and the equivalent of certain one or more of the pre-Cambrian series.

SECTION VI. NEWFOUNDLAND.

LITERATURE.

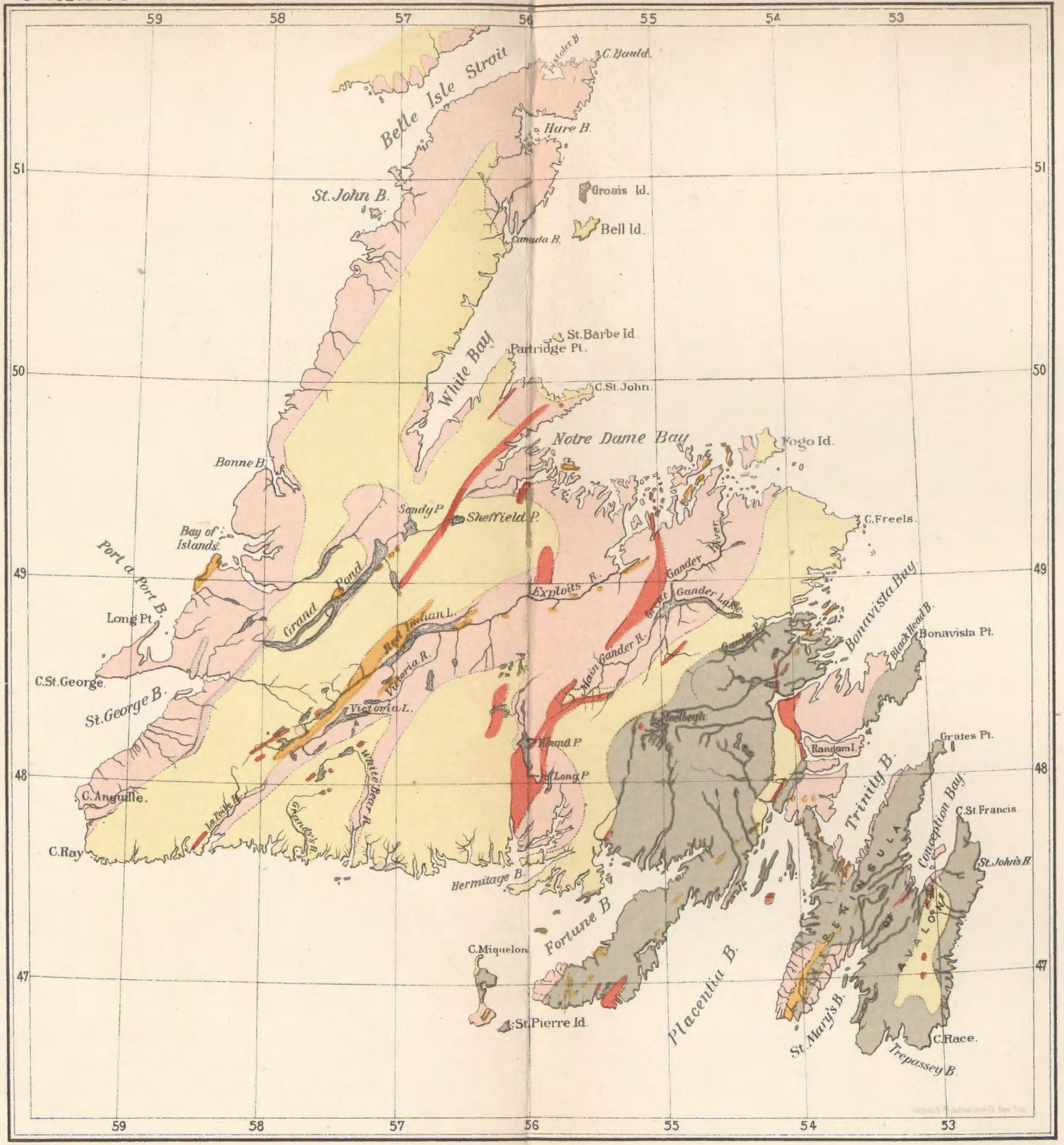
JUKES,[66] in 1843, divides the lower formations of Newfoundland in descending order into an upper slate formation, a lower slate formation, and a gneiss and mica-slate formation. The igneous rocks consist of various kinds of trap, greenstone, serpentine, hypersthene, porphyry, syenite, and granite. The upper slate formation is believed to be lower than the coal formation, although nowhere found in contact with it. The thickness of the upper slate must be many hundreds of feet. In one instance beds of upper slate rest unconformably upon those of the lower slate formation. The mica-slate and gneiss or quartz rock, chlorite slate, and primary limestone occur together. Nearly the whole of the province of Avalon is composed of the lower slate formation. On Conception bay at several places beds of variegated slate overlap and cover the edges of the lower slate in a perfectly unconformable position.

On Newell's island the junction of the gneiss and mica-slate with the granite is found. The mica-slate in approaching the granite becomes more crystalline and gneiss-like in certain layers. On continuing to approach the granite there appear thin beds of granite, which are not veins from the granite but an integral part of the beds. The granite becomes more abundant in getting toward the main mass of this rock, the alternations increasing in frequency, until after passing over the edges of many beds, the red and flesh-colored, perfectly crystalline granite, with no appearance of any lamination or bedding whatever, is imperceptibly reached. In the granite itself, for some distance from the junction, nodular masses of black rock, consisting of minute scales of mica were observed. In other places the mica-slate and gneisses alternate with each other and are cut by distinct granite veins.

The cleavage of the slate rocks is frequently parallel to the planes of stratification, but often cuts them at all angles. The strike of the cleavage is in a great majority of instances parallel to the strike of the beds, but not invariably so. The cleavage is much more constant as regards its strike and dip than is the strike and the dip of the beds. The dip of the cleavage is never at a less angle than 45°, while in the majority of instances it is nearly perpendicular. Its strike was not in any instance found to vary more than 10° or 15° from a NNE. and SSW. bearing. Certain of the granites are newer than the mica-slate and gneiss. Also some of the porphyritic granite is more modern than some of the shales. In other cases the red igneous rock, generally the syenite, is in all probability one of the oldest rocks in the country, as no veins were observed to proceed from it into the adjoining formations, and a rounded pebble of a precisely similar rock is found in a bed belonging to the older slate formation in Great Placentia.

MURRAY,[67] in 1865, describes the geology of the northeastern part of Newfoundland. Here is found a Laurentian group, which consists mostly of gneisses, but contains in places layers of mica-slate and whitish quartzite. These rocks are placed in the Laurentian because they have a lithological resemblance to the Laurentian of Canada, and because they are covered unconformably by the Lower Silurian strata. No crystalline limestones such as are associated with the Laurentian of Canada are found interstratified with the gneisses. The rocks of the overlying Potsdam and Quebec group are fossiliferous.

MURRAY,[68] in 1868, gives an account of a part of the coast of Notre Dame bay. A section of rocks in this locality consisting of slates, quartzites, dolomites, with various eruptives, is referred in part to the Quebec group. Among the intrusives are syenite and diorite. At



UNCLASSIFIED PRE-CAMB. | ALGONKIAN | ALGONKIAN? | POST-ALGONKIAN | ERUPTIVES: GRANITIC, BASIC

GEOLOGICAL MAP OF NEWFOUNDLAND

SHOWING PRE-CAMBRIAN AND CRYSTALLINE ROCKS

Compiled from map by Alex Murray

Scale $\frac{1}{3.500.000}$.

Lascie harbor the rocks are mainly gneiss, resting uncomformably upon which is a great mass of unstratified quartzite.

MURRAY,[69] in 1868, treats of the peninsula of Avalon. Here is found a gneiss which is referred to the Laurentian. Intermediate between this gneiss and the Lower Silurian strata is a great thickness of slates and quartzites, which are referred to the Huronian. Resting unconformably upon these rocks are others containing Potsdam fossils.

In the Laurentian are placed the gneisses of Conception bay, the masses of granite, syenite, and porphyries of St. Johns peninsula described by Jukes, and the granites of Placentia bay and Sound island. These rocks are like those referred to the Laurentian in the great northern peninsula. The intermediate system consists of diorites, quartzites, slate conglomerates, slate and sandstone, the whole series in Conception bay being over 11,000 feet thick. This series resembles lithologically the Huronian system of Canada in a high degree, although it may be admitted that lithological relations are of secondary importance in correlating rocks which are remote from each other. In one member of the group is a fossil, designated as Aspidella, of a low order of existence, which leads to the conclusion that the system is probably Cambrian. This series of rocks occupies by far the greater part of the peninsula of Avalon. The lower rocks in all cases pitch at a very high angle to the horizon, the prevailing inclination being to the eastward, while the upper formation, except where disturbed by eruptives, is either in a perfectly horizontal attitude or only slightly inclined. The lower series is also marked for its general absence of lime, while the upper formation is nearly all more or less calcareous. Further, the Potsdam rocks were found to overlie uncomformably the lower slates at Manuels brook and at Brigus South Head. The Nova Scotia gold-bearing rocks are lithologically like the system referred to the Huronian in Newfoundland, although they have been referred to the Lower Silurian.

MURRAY,[70] in 1870, finds the rocks of Bonavista bay to consist largely of slates, slate-conglomerates, quartzites, and diorites, intersected by intrusive granite or syenite, trap, and quartz veins. This series has such a close lithological resemblance to the intermediate system of Avalon that there is no doubt of their identity. These rocks also occur between the gneiss and the Paleozoic formations of Trinity bay.

HOWLEY,[71] in 1870, describes sundry parts of the coast. The rocks of cape Ray and the extreme head of Conception bay are of a gneissoid character. Granite, syenite and trap are interbanded with quartzite. Upon Great Miquelon island is found gneiss, supposed to be of Laurentian age. Greenstones and granite break at various places through the stratified rocks.

MURRAY,[72] in 1873, gives a further account of the Avalon peninsula. The line of contact between the Huronian and more recent rocks in Trinity bay is obscure and difficult to detect, and here *Aspidella* is very useful in deciding to which series the rocks belong. The rocks on the west coast of Trinity bay are correlated with the Huronian on lithological evidence. The rocks here are in some respects different from those on St. Johns peninsula, but this difference seems to be due to the intense volcanic activity which has affected the western part of Avalon. Dikes of various kind intersect the formation, and the strata are in places volcanic conglomerates, volcanic ashes, etc. The rocks of Brigue, described in the report for 1868, are found to contain several beds which are crowded with *Aspidella*.

MURRAY,[73] in 1873, finds gneissic rocks at several localities in St. Georges bay. Associated with these are labradorite and other anorthosite rocks which belong to the upper Laurentian system. Also, on the Great Codroy river is found white crystalline limestone with graphite, which is regarded as a further indication of the presence of this division of the Laurentian.

MURRAY,[74] in 1875, finds on Gander lake micaceous slate, fine grained granite, and gneiss, which are correlated with the Laurentian gneiss of Bonavista bay.

HOWLEY,[75] in 1877, further examines Gander lake and river and finds chlorite-slates, diorites, and mica-slates which contain no organic remains, and which on account of their lithological character and the serpentine they contain are provisionally placed with the Quebec group. Upon the upper Gambo pond and Riverhead brook are found sandstones and quartzites which at some places pass almost imperceptibly into gneiss, which rocks, with the associated micaceous slates, are provisionally placed with the Huronian.

HOWLEY,[76] in 1882, further describes the intermediate system of Huronian rocks. These metamorphic rocks occupy the greater part of the peninsula of Avalon. They rest upon a nucleus of Laurentian gneiss and are succeeded by fossiliferous beds of the Primordial age which skirt the shores of the bays and are found to rest unconformably on the basset edges of the upturned and altered Huronian, and occasionally in contact with the still older Laurentian. The intermediate rocks are found to be gently folded so that the same strata are repeated several times. Associated with these Huronian rocks are trappean beds and volcanic ash. Contained in them are found two fossils, *Aspidella terranovica* and *Arenicolites spirales*. This latter fossil is said to occur in the Primordial rocks of Sweden. These fossils give important assistance in the ready recognition of the Huronian. The gneissic rocks which have been described as being members of the Laurentian system protrude through the Huronian strata by which they are surrounded. Cutting the Huronian rocks is found a series of granitoid and other plutonic rocks which obliquely intersect the eastern part of the peninsula, including the Laurentian gneiss. A second great igneous intrusion cuts all of the rocks of the western part of the peninsula, including the Potsdam sandstone. The intrusions of the eastern peninsula are taken to be of older date than the trap of the western peninsula, although probably later than Huronian, as the former is never found to cut the Potsdam sandstone.

WALCOTT,[77] in 1889, corroborates the unconformity between the series referred by Murray to the Huronian and the overlying series called Potsdam. This latter is found to contain the *Olenellus* fauna below the Paradoxides and is placed as lower Cambrian.

SUMMARY OF RESULTS.

The reports of Jukes and Murray are far more complete as to the geology of the peninsula of Avalon and the district immediately to the west than they are of the great northern peninsula. The map of this latter area is greatly generalized.

The unconformity described between the Upper and Lower slate of Jukes is evidently the same as that found by Murray between his Potsdam and Huronian. The Potsdam was later determined by Walcott to be basal Cambrian.

It is perfectly clear that in Newfoundland, and particularly in Avalon and southeastern Newfoundland proper, is a great series of fragmental rocks unconformably below a series bearing the *Olenellus* fauna. This series is of great thickness, probably more than 10,000 feet. In certain layers it carries obscure fossils which, according to Walcott, are of an earlier form than those of the Cambrian. It then follows that in this region we have a pre-Cambrian series of rocks bearing a small fauna of a rudimentary type. This result is very important as giving a start toward a fauna which, whatever the series in which it is found shall be called, is greatly older than that now recognized as basal Cambrian. Whether the series shall be called Huronian, as is done by Murray, depends upon the definition of that term. If all pre-Cambrian clastic series are to be placed in the Huronian, this series can be said to belong to that age, but if only those rocks are to be here placed which are the equivalent of those referred to that term on the north shore of lake Huron, we have as yet no means of determining whether the Newfoundland series is Huronian or not.

The relations of the series referred to the Huronian with the granites, gneisses and schists which are placed with the Laurentian are far less satisfactorily known. Nowhere is anything said as to any structural breaks between these two series, and evidently the lines between the so-called Laurentian and Huronian are based upon a very general study. Jukes, Murray and Howley agree that in Avalon and in other parts of Newfoundland are large areas of eruptive rocks, including both basic and acid kinds, which cut the various sedimentaries. Murray does not find that the Cambrian of Avalon is cut by granites and porphyries, but, according to Jukes, in other parts of Newfoundland this is the case. However, both basic and acid eruptives, including granites, syenites and porphyries, are found to cut in the most intricate manner the pre-Cambrian sedimentaries, and as a result of this, this series is found to be more than usually metamorphosed in the area between Trinity and Bonavista bays. The peculiar manner in which the granitic rocks vary into the slates by gradual interlaminations, combined with the occurrence of fragments of the schists within the granite, so well described by Jukes and corroborated by Howley, indicate that a large part of the rocks referred to the Laurentian are certainly intrusive, and that the more crystalline character of the clastic formations adjacent to them are due to metamorphism. It is then by no means clear that within Avalon are any rocks of sedimentary origin older than the series referred to the Huronian, although the fact mentioned by Jukes of a single bowlder of syenite in the older slate series indicates the probability of a pre-Huronian syenitic or gneissic series. At present we have, however, no means of judging what part of the rocks referred to the Laurentian are later intrusives and what part, if any, are older than the pre-Cambrian clastic series.

As to the rocks referred to the Upper Laurentian because of the presence of anorthosite rocks and limestones, the question arises as to whether the crystalline limestones associated with the gneisses are not of later age than supposed, being perhaps more metamorphosed. The associated anorthosite—that is, a probably eruptive rock—may be an explanation of this metamorphism. If the presence in Newfoundland of a Lower Laurentian is doubtful, it is much more doubtful whether here an upper series of fragmental rocks has been shown to exist which are older than the pre-Cambrian series referred to the Huronian.

The observations made by Jukes as to the relations of slaty cleavage and bedding are of the greatest interest and importance. The strike of the cleavage is in a great majority of instances parallel to the strike of the beds, but not invariably so. The cleavage is much more constant as regards its strike and dip than is the strike and the dip of the beds. The dip of cleavage is never at a less angle than 45°, while in the majority of instances it is nearly perpendicular.

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CHAPTER V.

ISOLATED AREAS OF THE MISSISSIPPI VALLEY.

SECTION I. THE BLACK HILLS.

LITERATURE.

HAYDEN,[1] in 1862, states that the nucleus of the Black hills consists of red feldspathic granites, with stratified metamorphic Azoic slates and schists, upon which rests unconformably, forming a zone around the ellipsoidal nucleus, a series of reddish ferruginous sandstones, which by their organic remains are shown to belong to the Potsdam. In the Potsdam are found as pebbles the different varieties of the changed rocks beneath.

HAYDEN,[2] in 1863, describes the Black hills as an outlier of the Rocky mountains. They are formed of a granite nucleus surrounded by a series of Azoic highly metamorphosed strata standing vertical, and comprise slates, gneiss, syenite, quartzose and calcareous rocks.

HAYDEN,[3] in 1872, describes the Black hills as being the most complete illustration of an anticline not complicated by any other influences that he has found in the west. The nucleus is a massive feldspathic granite with a series of gneissic beds outside of it, which incline in every direction from this nucleus in a sort of narrow oval quaquaversal, and include all the unchanged beds known in this portion of the West from the Potsdam sandstones to the top of the Tertiary lignites.

WINCHELL,[4] in 1875, describes in the Black hills, below the Primordial sandstones and quartzites, a series of mica-slates and mica-schists which contain intercalated beds of quartz. These rocks often stand nearly vertical. In the neighborhood of the granite areas they are interstratified with beds of true granite, and with this granite is found tourmaline. The granite area is near the southern part of the hills and of this Harney peak may be taken as a center.

NEWTON,[5] in 1880, gives a systematic account of the Black hills of Dakota. The Black hills is a geological area which is admirably circumscribed. They consist of a nucleal area of metamorphic slates and schists containing masses of granite, about which is an inward facing unconformable escarpment of Potsdam sandstone and Carboniferous limestone which dip away on all sides from the axis of the hills. The Archean rocks as a whole occupy an area of about 850 square miles, being about 60 miles long and 25 miles wide at its maximum. At numerous points within the hills are centers of volcanic eruption of an age probably coincident with the elevation of the mountains. It is impossible to estimate with any degree of accuracy the thickness of the Archean schists, as they are highly inclined and distorted, and in their present metamorphosed and denuded condition it can not be determined whether they are the remnants of several great folds or whether they are the broken strata of one vast fold, though the latter seems to be the more probable structure; in which case the total thickness of the Archean strata must be more than 100,000 feet, about 25 miles. The examination showed no evidence of the duplication of any parts of the Archean strata, and it is presumed, if a repeated folding has taken place, that it did not occur within the area exposed in the hills.

The Archean sedimentaries are divided into two groups, schists and slates. The schists include quartzose, garnetiferous, ferruginous and micaceous varieties, together with some gneiss, chloritic, talcose, and hornblendic schists, and quartzite. The schists are occasionally staurolitic. The whole series is coarse in texture, highly crystalline, and contains seams or veins of quartz conformable with the stratification and having a lenticular form. The slates are distinguished from the schists mainly by their fine and compact texture, although, as shown by Caswell, their ultimate mineral composition is similar. They are mainly micaceous clay-slate, siliceous slate and quartzite, which are sometimes associated with specular oxide of iron. On Box Elder creek is a ridge 400 feet in height, which is a vast deposit of siliceous hematite and resembles the siliceous hematites of the lake Superior region. The quartzites of the two classes are similar. The mica-schist passes into chlorite-schist, siliceous schist and quartzite. The schists of the southern part of the hills are associated with an area of highly feldspathic granite which culminates in the region of Harney peak. On the outskirts of this district are many smaller masses of granite. So far as the structure was made out, each of the bodies has a lenticular shape and is intercalated among the strata of the schists. No granite is found associated with the slate. The general strike of the rocks is northwest and southeast. The topography shows that there is a series of ridges in this direction which mark the position of the particularly hard layers such as quartzites. The schists are found in the western and southwestern parts of the area and the slates in the east and northeast.

Between these two groups Jenney noted a distinct discordance of dip on Castle creek, but in the absence of corroborative observations the unconformity of the two series can not be insisted upon. The division of the system into two series is then based on lithological differences purely and is warranted on this ground. The lithological difference is, however, more a mineralogical one than chemical, being probably due to a difference in metamorphism. The apparent discordance discovered by Jenney, and this lithological difference, gives strong support to the view that the slate and schist periods were separated by an interval of

UNCLASSIFIED PRE-CAMB

ALGONKIAN

SLATES & SCHISTS — GRANITE

POST-ALGONKIAN

GEOLOGICAL MAP OF PORTIONS OF MONTANA, IDAHO, WYOMING AND DAKOTA

SHOWING PRE-CAMBRIAN ROCKS

Compiled from the King, Hayden, & Powell Reports.

Scale $\frac{1}{4752.000}$.

time between which there was erosion and metamorphism of the lower series. The granite is coarsely crystalline. It is concluded that, because of the great amount of feldspar in the granite, because pieces of schist are inclosed in it without any transition, because the granite masses in the schist have a long lenticular shape, because of the coarseness and evenly granular character of the granite, and because there is never any transition between the schist and granite, the latter is an eruptive rock in the schists. That the Archean rocks were upturned and metamorphosed before Potsdam time is shown by the fact that the basement conglomerate of the Cambrian contains fragments of slate, schist, and granite precisely like the underlying rocks.

Since the lithological character of the Black hills Archean is the only means of judging their affinities it should have some weight. The eastern slate division bearing the lean ores are very similar to the Huronian rocks of the south shore of lake Superior and Canada. The western schist series containing granite masses differs from the Huronian and from the Laurentian in that gneiss, the most characteristic rock of the latter, is nearly lacking, so that no correlations are made further than to call the slate series newer Archean and the schist series older Archean.

BLAKE,[6] in 1885, on account of the presence of staurolite in the Black hills schists, places these formations as the probable equivalent of the Coos group of Hitchcock in New Hampshire, and it is said that there is sufficient breadth of formation to include all the rocks from the Huronian to the Coos.

CROSBY,[7] in 1888, finds that the two groups of Archean as mapped by Newton are quite sharply defined from each other. It is said that in the eastern series of slates are pebbles which have been quite certainly derived from the harder rocks of the western series. The strike of the schists is found to curve around the granitic and gneissic area and the normal dip of the strata is away from this nucleal granitic mass. A conglomerate is associated with the quartzite of the eastern slate area, the pebbles of which have suffered extensive deformation by compression. The granitic rocks of the schist area do not penetrate the slates of the newer series, although this is not devoid of eruptive rocks. The newer series of slates is correlated with the Taconian of western New England. The conclusion is reached that the granite, instead of being of eruptive origin, is pegmatitic.

CARPENTER,[8] in 1888, states that the unconformity supposed to exist by Newton between the eastern slate and western schist series is supported by an observation upon Spring creek east of Hill city. A huge dike of igneous rock a thousand feet broad in places is described as passing through the entire length of the eastern series.

VAN HISE,[9] in 1890, finds that the prominent structures of the Black hills, which have heretofore been taken as bedding, are secondary structures. As evidence of this is the fact that alternating bands of sediments of different characters are seen to cut across the prominent lamination. Sometimes these belts are conglomeratic and the pebbles are deformed by pressure. The longer axes of the pebbles are parallel to the slaty or schistose structure, but the belts as a whole cut across this structure. The fact cited by Newton that there are persistent belts of quartzite parallel with each other also indicates duplication by folding. The thickness of the Archean is then unknown, instead of being more than 100,000, as supposed by Newton. The crystalline schists are in a broad zone about the granite area, striking parallel to it and dipping away from it, and in the northern hills there are great quantities of later eruptives. Granite is found in the slate area as mapped by Newton.

A study of the boundary between the slate and schist series leads to the conclusion that there is a gradation from the slates to the schists rather than an abrupt change. The foliation of the schists about the granite is secondary and is caused by the contact and dynamic metamorphism due to the intrusion of the granitic rock. The effect has extended for several miles from the main granite area. The normal foliation of the slates and schists is north and south, and this was produced by folding earlier than the intrusion of the granite. About the granite area both sedimentation and this earlier foliation were destroyed and a more prominent newer foliation produced. Also, in the northern part of the slates is a considerable area about Deadwood which is now as crystalline as the schist area of the south. This is taken to be due to the abundant later intrusives here found. We thus have in this region evidence of an original bedding which is nearly obliterated by a prominent slaty cleavage, and both of these have been wholly destroyed for considerable areas by a newer and more prominent schistose structure. The slates and schists can not then be divided into two series with the surface distribution and upon the lithological differences given by Newton.

The mica-slates, mica-schists, and mica-gneisses are found to be clastic rocks, the processes of change from their original clastic condition to their present crystalline one being traced out. Associated with the clastic rocks are other green crystalline schists which are metamorphosed basic eruptives which were probably intruded before the earlier folding of the slates. Corroborating Newton's conclusion, it is said that the Black hills rocks exhibit a remarkable lithological analogy to certain of the iron-bearing series of the lake Superior region, which in the past have been included under the term Huronian. While this correlation is not beyond doubt, there is no question that these series in common belong to the Algonkian.

SUMMARY OF RESULTS.

The summary of Newton's work is altogether unsatisfactory because of the very large amount of material contained in this report. The descriptions in the original are condensed, and to include all which bears upon structural relations would greatly extend the digest given. In the light of the present facts it would seem that we have in the Black hills a set of slates and schists as yet of unknown thickness and undivided into series, although perhaps capable of subdivision by closer work. These slates and schists have a prominent cleavage which is independent of the structure. The different parts of the area vary in degree of crystallization, and this crystalline character is due to the intrusion of igneous rocks; but, unlike ordinary contact metamorphism, has extended from the granitic areas for a distance of several miles. For the present we are obliged to consider the whole as a single series. In the alternating slaty and quartzose characters of the rocks, in the presence of siliceous hematite and a much folded condition, the present structures being in a vertical attitude, they more nearly resemble the Lower Huronian of the lake Superior region than any other rock series, but this is not sufficient warrant for the positive conclusion that the two are time equivalents. The correlation of the Black hills rocks with the Taconic on slight lithological evidence as is done by Crosby, or a part of them with the Coos group on account of the presence of staurolite, can be considered as no more than guesses.

SECTION II. MISSOURI.

LITERATURE.

KING, (H.),[10] in 1851, states that the Primitive formation is met with near a point about 70 miles south of St. Louis and 30 miles west of the Mississippi. It consists chiefly of granite, syenite and porphyry, and rises in cone-like elevations or detached ridges to the height often of 1,000 or 1,200 feet above the level of the Mississippi river. Its sides and valleys are frequently covered with sandstone and limestone in such quiet relationship as to show that their deposition has taken place since the Primitive rocks assumed the form they now have. It is not at all unusual to find portions or fragments of the older rocks imbedded in those that are stratified. This occurs both in the lowest magnesian limestone and in the overlying sandstone. The Primitive rock is broken through by greenstone dikes which reach the surface of this rock, yet never penetrate the overlying sandstone. At Iron mountain is a layer of specular oxide of iron, below which at one place is a stratified rock which may have been a modified granite. The iron-ore deposit is often in the form of pebbles of various sizes up to a foot in diameter. In the interstices of these pebbles is a reddish brown clay. The bed of iron in the thickest point opened is 20 feet. At the summit of Pilot knob is an immense mass of solid ore which is associated with porphyry and appears to pass by insensible gradations into that rock.

WHITNEY,[11] in 1854, describes Iron mountain and Pilot knob as localities in which are found eruptive ores of Azoic age. Iron mountain is a flattened dome-shaped elevation, composed of feldspathic porphyry. The surface of the mound is covered with loose pieces of ore, which is in some places in a layer at least 15 feet thick. Pilot knob is mainly composed of dark siliceous rock, distinctly bedded, dipping to the south at an angle of 25° or 30°. For about two-thirds of its height of 650 feet quartz rocks predominate. Above that, iron is found in heavy beds alternating with siliceous matter.

SWALLOW,[12] in 1855, describes the granite, greenstone, and porphyry of Missouri as igneous rocks. Red feldspathic granite, sparingly micaceous, occurs in Sec. 15, T. 34 N., R. 3 E. Nearly all of the hills and ridges in the neighborhood of Iron mountain and Pilot knob are wholly or in part formed of compact reddish-purple feldspathic porphyry. The porphyry is one of the oldest rocks of the state, but no opportunity occurred for determining whether it is older than the granite, although there is no doubt that it is older than the greenstone, as the latter rock is said to occur in dikes in the porphyry. The porphyry is older than the stratified rocks of the region because they are found resting upon knobs and ridges of porphyry in a position so nearly horizontal as to preclude the idea that they were deposited before the upheaval of the principal masses which form the hills. Whether the slates interstratified with the iron near the top of Pilot knob are older is not easily determined.

SWALLOW,[13] in 1859, states that in one locality in Laclede and in one or two in Crawford county are granite dikes or ridges which rise above the stratified rocks.

HARRISON,[14] in 1868, describes two localities in Washington county, where between the horizontal limestone and the solid porphyry are conglomerates consisting of water-worn pebbles and bowlders all of porphyry, cemented together by a calcareous matrix. Interstratified with the limestone are also thin layers containing water-worn porphyry pebbles. It is therefore concluded that the porphyry hills existed as such before the Silurian hills were deposited.

PUMPELLY,[15] in 1873, states that the Archean (Azoic) rocks of southeastern Missouri form an archipelago of islands in the Lower Silurian strata which surrounds them as a whole and separates them from each other. They appear as knobs 1,400 to 1,800 feet above the sea, and rising 300 to 700 feet or more above the valleys. The rocks consist chiefly of granites and felsitic porphyries. They reach their most extensive surface development in the region forming the northern part of Madison, Iron, and Reynolds, and the southern part of St. Francis and Washington counties. This series is the near equivalent in point of age to the iron-bearing rocks of lake Superior, New Jersey, and Sweden. The rocks overlying them belong to the oldest known members of the Silurian, but they may be the deep-seated equivalents of the Potsdam sandstone or even older. Before the deposition of the Silurian the porphyries and granite had undergone an enormous amount of erosion, an amount at least several times as great as they have suffered since that remote time.

The surface of Iron mountain has disintegrated and decomposed in mass, the entire porphyry-hill being changed to a clay. Disintegration has often taken place to a depth of certainly more than 50 feet in the granites of Madison county. The iron ore of Iron mountain is a residuary deposit, having its origin in the gradual removal of the existing crystalline rocks and leaving behind the iron ore.

Pilot knob is composed of more or less massively bedded porphyries, porphyry-conglomerates, and beds of hard specular ore. These strata strike N. 50° W., and dip on an average 13° southwest by south. The top of the knob consists of stratified porphyry conglomerate with a thickness of 140 feet. This rock is made up of small and large, more or less angular, pebbles of porphyry cemented together by iron ore and containing frequent layers and bodies of ore. At the base of this series is a great bed of ore divided into two parts by a thin slate seam. Immediately below the ore is porphyry, which continues to the base of the hill.

The rocks forming the southwestern flank of Cedar hill are the extension of the conglomerates and ore beds of Pilot knob. Manganese ores are found associated with the porphyritic rocks, and in Sec. 16, T. 33 N., R. 2 E., in Reynolds county, the manganese ore is one of the members of a series of bedded porphyries. At this locality metamorphic limestone is one member of the porphyry series, but it is now by physical and chemical agents greatly changed from its original condition, and is very manganiferous. Another member of this same succession is a porphyry-conglomerate or breccia, consisting of pebbles of red and compact porphyry containing grains of quartz and crystals of feldspar, and cemented by porphyry of a similar character. This rock resembles the Calumet-Hekla conglomerate of lake Superior.

SCHMIDT,[16] in 1873, also describes the iron-ore deposits of Iron mountain, Pilot knob, Shepherd mountain, Cedar hill, Buford hill, Big Bogg mountain, Lewis mountain, Cuthbertson bank, and Hogan mountain. The succession at Cedar hill includes slates of red-banded porphyry, stratified quartz-porphyry, slates of red porphyry, green porphyry, banded jasper, and jasper with specular ore.

SHUMARD,[17] in 1873, states that granite is found in Laclede, Crawford, and Ste. Genevieve counties.

BROADHEAD and NORWOOD,[18] in 1874, describe granite and porphyry at numerous points in Madison county. On the west side of St. François river in the NW. ¼ of NE. ¼ Sec. 33, T. 34 N., R. 5 E., there is an exposure of sandstone and conglomerate resting directly on the granite.

HAWORTH,[19] in 1888, states that the Archean area of Missouri covers an irregularly outlined portion of no less than ten different counties and extends to the west as far as Texas county, to the north and northeast as far as Washington, St. François and Ste. Genevieve; to the east it passes through Madison county, and to the south nearly through Wayne county, but only a small portion of this territory is covered by Archean rocks. The rocks are the different kinds of porphyry, which predominate, granite, and dikes of diabase and diabase-porphyry. Numerous instances were observed where the stratified rocks overlie the massive ones and are nonconformable with them. Nowhere at the contact zone was metamorphosed limestone or sandstone observed. The granites, so far as observed, occur on low ground, while the hills are almost invariably composed of porphyry. At numerous places dikes of various sizes occur, sometimes in the granite and sometimes in the porphyry, and, as stated by Broadhead, sometimes in the sandstone. Detailed descriptions are given of the granites, porphyries, and dike rocks.

HAWORTH,[20] in 1891, describes the crystalline rocks in the vicinity of Pilot knob, Missouri. These are chiefly porphyries, felsites, and breccias. These rocks are regarded as Archean in age, because there is no contact metamorphism between them and the surrounding Paleozoic rocks, and because in the Paleozoic sandstones and limestones are numerous fragments of the crystalline rocks. The crystalline rocks are regarded as of eruptive origin, as shown in the field by the absence of bedding, by flow structure, by banded structure, by lithophysæ, by breccia, by scoria, by amygdaloids, by tuffs, and by absence of gradations into noncrystalline rocks, and as shown by the microscope, by the texture of the groundmass in the porphyries and breccias, by flow structure in them, by magmatic corrosion of porphyritic crystals and fragments of the breccias, and by other phenomena. The laminated ferruginous rocks of Pilot knob and of other localities are regarded as volcanic breccias. As evidence of this it is said that this material passes into the porphyry, that the fragments are all of porphyry or felsite, and that the groundmasses of the breccias or conglomerates are always felsitic or porphyritic, the apparent detrital fragments being merely set in a lava of a similar character.

PUMPELLY and VAN HISE,[21] in 1890, find that at Iron mountain the ore (specular hematite), in its original position, occurs in the form of veins in the porphyry. These veins are sometimes of very considerable thickness, running as high as 30 feet. They vary from this size to those much smaller, ramifying through and cutting the porphyry in various directions. In some places on the mound between the stratified sandstone and the porphyry is a pre-Silurian mantle of detrital material, which is largely composed of fragments of the vein ore. The chief mining at the present time is from a mass of bowlders of the iron ore in a pre-Silurian ravine. In the process of disintegration the more resistant and heavier masses of iron ore have been concentrated in the upper slopes of the ravine, forming a deposit analogous to a placer. The vast amount of this iron ore in these ravines, as well as that which occurs as a residuary deposit upon the mound, indicates that in pre-Silurian time there was here an enormous erosion in order that this quantity should accumulate from the relatively sparse and small veins of iron ore in the mountain. The Pilot knob iron-ore bed was found to grade upward into a conglomerate, the matrix of which is largely composed of ore and the most of the pebbles of which are porphyry. The whole appearance of the deposit is that of a detrital one, and the question arises whether this bed has been produced from the erosion of earlier vein deposits in the porphyries, such as are found in Iron mountain. Pilot knob itself bears the same relations to the Silurian as does Iron mountain, and if this suggestion as to the origin of the Pilot knob ore is correct, it implies that the pre-Silurian history has not only been very long, but complex.

SUMMARY OF RESULTS.

As the crystalline rocks of central Missouri are islands surrounded by Cambrian sediments, we have no definite means of determining their age except that they were in their present condition and deeply eroded before the overlying rocks were deposited. With a considerable degree of probability they may therefore be referred to the pre-Cambrian. The series is mainly an eruptive, porphyritic one, but the lavas are oftentimes bedded. The clastics are sometimes porphyry-conglomerates, the materials of which have evidently been derived from the underlying porphyry flows. At Pilot knob the iron ores are associated with the conglomerates.

There is, then, in central Missouri a pre-Cambrian clastic series, and therefore a member of the Algonkian system. Whether any of the crystalline rocks are older than the Algonkian there is no certain means of judging. There are also no certain data upon which to parallelize this Algonkian series with the Algonkian series of the nearest pre-Cambrian region, that of lake Superior. Upon the whole, the lithological character of the series more nearly resembles that of the Keweenawan than any other, although it has a very considerable likeness to the Upper Huronian. This is indicated by the porphyries and porphyry-conglomerates, while the analogy with the Upper Huronian is indicated by the beds of iron ore. This comparison is rather strengthened by the fact that the Upper Huronian quartzite outcrops of southern Wisconsin are associated with and cut by porphyries. But a reference of the Missouri rocks either to the Keweenawan or Upper Huronian has a very uncertain value, and it is not impossible that it rather represents the period of erosion which separates the Keweenawan and Upper Huronian, since in lithological characters it combines to a considerable extent those of these two series.

SECTION III. TEXAS.

LITERATURE.

ROEMER,[22] in 1848, mentions granitic rocks at several points, 15 miles north of Fredericksburg, on the banks of the Llano, in the country between the Llano and San Saba, and between the Piedernales and San Saba rivers. These granitic rocks are surrounded by Paleozoic strata.

SHUMARD,[23] in 1860, describes in Burnet county rocks upon which rest directly the fossiliferous Potsdam.

SHUMARD,[24] in 1861, describes the Primordial rocks of Texas as resting upon reddish feldspathic granite very similar in character and composition to the granites of Iron mountain, Missouri.

BUCKLEY,[25] in 1866, states that the known Azoic rocks of the state are mostly in Llano and adjoining counties. There are here granites with steatite or soapstone, immense beds of iron ore, and metamorphic rocks, consisting chiefly of slates, mica-schist and gneiss with quartz veins. The granites of Burnet county probably belong to a later period of elevation than the Azoic. Here the metamorphic rocks are on the outskirts of the granite, in nearly vertical, more or less broken or contorted strata. In Mason county are highly inclined micaceous shales. At Packsaddle mountain are dark shales which, near Honey creek, extend unconformably beneath the nearly horizontal layers of Potsdam sandstones and limestones. In Mason county is a very large deposit of iron ore, which is believed to be a true vein. Another bed of iron ore lies between two granite ridges and is traversed by veins of quartz. House mountain, consisting of granite, is capped by massive beds of nearly horizontal sandstone. The Azoic rocks trend in a northeast and southwest direction, being on the same line of upheaval as the Ozark mountains of Arkansas and the Iron mountains of Missouri.

BUCKLEY,[26] in 1874, describes as resting unconformably beneath the Potsdam, in Llano county, shales and argillites which lithologically resemble the old slates of Vermont and New Hampshire. They are barren of fossils. Locally a slaty cleavage is developed. Sometimes the slate is changed into a gneissoid rock, all gradations of the change being seen. Friable mica-slates containing garnet sometimes underlie the granite. These rocks are referred to the Laurentian. Most, and probably all, of the granites of this region are of a later period than the metamorphic rocks associated with them. Associated with the granite in Burnet and Llano counties are immense beds of magnetic iron ore.

BUCKLEY,[27] in 1876, describes Azoic granitic rocks in many of the mountain ranges west of the Pecos river. At a number of places basaltic rocks occur. All the igneous rocks north of the Pecos are either of upper Cretaceous or Tertiary age, as is shown by the uptilted strata of these rocks.

WALCOTT,[28] in 1884, finds that the Potsdam sandstone rests unconformably on a great formation to which the term Llano group is applied.

These rocks are alternating beds of sandy shales, sandstones, limestones, and schists that have a dip from 15° to 40°. They are little metamorphosed. The overlying sandstone in its fossils is like the Tonto group of the Grand canyon, and the Llano group is correlated with the Grand canyon and Chuar series of the Grand canyon on the basis of position and lithological character. The best exposures are at Packsaddle mountain, in Llano county, where the horizontal Potsdam rests on the uptilted and eroded Llano beds. Across the valley of Honey creek, 4 miles west of Packsaddle mountain, the strata of the Llano group have been more metamorphosed, plicated, and broken by intrusive dikes of granite. The intrusive rocks are of pre-Potsdam age, but largely the result of extrusion of granite at or near the close of the erosion of the Llano. They are the chief cause of the metamorphism of the Llano rocks. No rocks of undoubted Archean age were observed.

SHUMARD,[29] in 1886, describes as eruptive rocks the granites, porphyries and basic rocks which compose the whole of Wichita, Limpea, Hueco, and Mimbres mountains. In the Organ mountains are partly sedimentary and partly eruptive rocks; while the Guadalupe, Sacramento, and Horse mountains are wholly sedimentary. None of these crystalline rocks are regarded as pre-Cambrian.

GLENN[30], in 1890, describes the Azoic rocks as consisting principally of red granite, occasionally gneissoid, intersected by numerous nearly vertical dikes of quartz rock. West of the granite in Llano county is an extensive field of schist, sandstone, and limestone of uncertain age. At Spring creek, in Burnet county, is also a small schist formation succeeding the granite. Were it not for the interposition of sandstone between the granite and the schists they would be assigned to the Azoic.

COMSTOCK[31], in 1890, divides the Archean rocks of central Texas into a Burnetan (Laurentian?) system and Fernandan (Ontarian?) system.

The fundamental gneisses of the Burnetan occupy a lens-shaped area striking N. 75° W., and they are well exposed in Burnet county. Within the group there are no unconformities. The rocks of the system are largely gneisses, but they graduate upon the one hand into quartzose mica-schists, and upon the other into friable sandy gneisses and fine-grained binary granites and graphic granite. Stratigraphically the group is divided into three series from above downward, (1) Bodeville, consisting of mica-schist and chlorite-schists (chiefly acidic); (2) Long mountain, consisting of hornblendic and pyroxenic rocks (basic); (3) Lone grove, consisting of gneiss, granite, etc. These rocks are compared with Lawson's lake of the Woods Archean. The igneous eruptions of the Burnetan are of different ages, some of them earlier and some later than the Potsdam.

The Fernandan or Ontarian system is well exposed along the valley of San Fernando creek. Its exposures are more extensive than those of any other pre-Cambrian system. While in the main there is little difficulty in distinguishing between the Fernandan and Burnetan strata, metamorphism has caused a close resemblance in many exposures. The general succession from above downward is calcareous rock, chloritic slates and shales, carbonaceous schists, ferruginous rocks, quartzites, acidic schists, and basic schists. In this system are various eruptives, including granites, quartz dikes, and basic rocks. Whenever the Fernandan beds are visible in connection with the Burnetan strata, through their own excessive erosion or by reason of the persistence of prior elevations of the earlier system, there is always abundant evidence of unconformity; and if any fractures occur the joints of the northwest (Fernandan) trend invariably cross and cut the strike of the Burnetan rocks. Additional support for the unconformity of the two systems is gained from the fact that contortions occur in the lower system only where this or later trends affect its continuity. Moreover, the composition and texture of the Fernandan beds are to a large extent that of derivatives of the Burnetan lithologic series.

Above the Fernandan system is an Eparchean group of rocks, the stratigraphical affinities of which are nearer the Archean than the Cambrian. There is no doubt that they rest unconformably below the Paleozoic. To this group, including Walcott's Llano group, is given the term Texan (Algonkian?) system. The rocks of the Texan system are chiefly siliceous, but shales and limestones are not wanting. The succession includes from the base upward a set of micaceous sandstones, with thinly laminated shales and chloritic detrital material; hard, white laminated quartz rock or quartzite, associated with ferruginous and schists layers; ferruginous shale beds, in part somewhat graphitic, and limestones or marbles. It is often difficult in the field to distinguish the graphitic shale and marble, as a belt, from the similar lithologic set of the earlier Fernandan system. In hand specimens, however, the distinction is obvious. The Texan beds are much less altered, as a rule. The graphitic strata are plainly derivatives of the preexisting graphite schists, and the marbles are white or brown, instead of blue. The Packsaddle marbles and shaly beds are compared with the Chuar; the Llano quartzites and sandstones, with eruptives, to the Grand canyon, and the Mason sandy shales and schists to the Vishnu series.

There must have been a vast amount of erosion after the folding of the Texan strata and prior to the deposition of the Cambrian sediments upon the upturned edges. The outcrops of the Texan strata are almost invariably accompanied by some of the Fernandan beds, or by members very closely resembling these, often in such relations as to make it difficult to determine the boundary between the two groups upon structural grounds alone; but the rocks here included as of the Texan system are never involved in an earlier uplift than the north-south trend.

COMSTOCK,[32] in 1891, further describes the relations of the pre-Cambrian rock series of central Texas. The Fernandian system is held to rest unconformably upon the Burnetian, because no other terrane within the Burnetian has structural planes or breaks following a course N. 75° W., while every other axis of uplift is traceable through the rocks of the Burnetian system, and because the basal members of the Fernandian system are made up in part of material apparently derived from the Burnetian rocks. That the Texian (Algonkian?) system rests unconformably upon the Fernandian is concluded from facts of the same character as those which show the discordance between the Burnetian and Fernandian. The nearly due north-south strikes of these rocks are commonly peculiar to them, the earlier fractures and lines of uplift being invariably absent, but the later ones can be more or less distinctly traced through the members of this system. There are localities exhibiting the juxtaposition of the Texian with the underlying Fernandian, in which the nonconformability between the two is seen. These relations are seen south and southeast of Packsaddle mountain, southwest of Sharp mountain, in portions of the country north of Lockhart mountain, north and northeast of Mason, in the Beaver creek valley, and elsewhere in Mason county. Further, the derivative character of the Texian beds is a marked feature. In the Fernandian is a great development of magnetites. While these deposits appear to be in discontinuous lenses or bosses across the region, there is almost always an indication of continuity in the shape of a line of ferruginous soil or other landmark. The iron deposits have above them carbonaceous and calcareous beds and below them quartzose beds.

SUMMARY OF RESULTS.

It appears that in central Texas there are two thick series, of clastic origin which are of pre-Cambrian age. The upper is Walcott's Llano or Comstock's Texian, and the lower Comstock's Fernandian. The first of these is but little altered, the second is considerably metamorphosed and has associated with it a greater quantity of eruptive rocks. Between these series it is asserted by Comstock that there is a great unconformity, as shown by numerous contacts, by Fernandian debris in the Texian, and by the fact that the Texian rocks are never involved in the earlier uplifts which have affected the Fernandian.

The Archean is represented by the Burnetian. Between the Burnetian and the Fernandian an unconformity is maintained by Comstock upon essentially the same grounds as between the Texian and Fernandian; that is, there are unconformable contacts between the series; the Fernandian bears debris from the Burnetian, and the Burnetian has been affected by orographic movements which are earlier than the Fernandian.

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CHAPTER VI.

THE CORDILLERAS.

SECTION I. LARAMIE, MEDICINE BOW, AND PARK RANGES IN SOUTHERN WYOMING.

LITERATURE.

STANSBURY,[1] in 1853, states that in the Black hills (Laramie) is an extensive formation of massive red feldspathic granite with occasional outcrops of ferruginous quartz.

HAYDEN,[2] in 1863, describes the Laramie hills as consisting of numerous centers of uplifted granite upon the sides of which the Carboniferous limestones are scattered or unconformably overlie. There is every gradation from unchanged fossiliferous limestone to completely metamorphosed rock, melted material sometimes being found thrust into the seams of the unchanged mass. The core of Laramie peak is of granite, while, as if thrown off by this nucleus, is a series of Azoic stratified rocks consisting of gneiss, hornblendic, micaceous, and talcose slates, syenite, and quartz, which are cut here and there by dikes of trap or basalt.

HAYDEN,[3] in 1868, mentions granites and syenites as occurring in the Laramie and Medicine bow ranges. On the east side of Laramie range, especially near fort Laramie, are seen the distinctly discordant relations between the crystalline rocks of the mountain range and the unmetamorphosed strata.

HAYDEN,[4] in 1872, describes on one of the branches of the Chugwater, in the Laramie mountains, as occurring interstratified with red feldspathic granite, beds of magnetic ore which resemble the lake Superior iron ores. The rocks between the headwaters of the Chugwater and Laramie consist of beds of quartz, black gneiss, seams of feldspar, with now and then beds of massive granite. On approaching the mountains the red feldspathic granite is found in great ridges, the gneissic strata diminishing and the massive granite increasing in approaching the mountain range.

ENGELMANN,[5] in 1876, finds that the Laramie peak system consists of the igneous rocks, granite and granitic syenite.. Among the igneous rocks are also greenstones, which are of later date than the granite in which they frequently are dikes.

HAGUE,[6] in 1877, gives detailed descriptions of the Laramie, Medicine bow, and Park ranges. The Archean rocks of the Laramie hills are classed under granites, gneiss, mica schist, and hornblende schist, the first covering much the largest area. The central body consists of coarse grained granite. Above this, and forming the outer edges, dipping east and west away from the main mass, occur heavily bedded granitoid rocks. At the north and south ends of the range the granites gradually pass into well defined gneisses and schists, there being the most gradual transitions from the massive granites to the thinly laminated schists. Among the crystalline rocks is a variety of gabbro in the region of Iron mountain, Chugwater, and Horse creeks, where it forms knobs and knolls protruding through the granitoid rocks. At Iron mountain, north of Chugwater creek, are masses of titaniferous iron ores incased in the granite. No large bodies of eruptive granites were seen nor eruptive rocks younger than the Archean. In structure the Laramie hills are regarded as a broad anticline, accompanied by many secondary folds. There is no case of decided nonconformity in the entire series of beds, and their uniform character indicates that they all belong to one division of the Archean, which without doubt is the Laurentian. The sedimentary rocks of the eastern foothills everywhere rest unconformably upon the Archean crystallines. East of Table mountain is the only outlying mass of Archean granite occurring eastward of the sedimentary foothills.

The second great range of the Rocky mountains—the Medicine bow—like the Laramie range, is made up almost exclusively of Archean crystalline rocks. In their general habit they resemble the formation of the eastern range, but additional varieties are found. The rocks include granite, gneiss, hornblende-schist, mica-schist, dioritic schist, slate, argillite, quartzite, chert, hornstone, conglomerate, and limestone. The larger bodies of true granite are confined to the southern end of the range, where it is closely connected with the Front range of Colorado. Even this granite shows more or less tendency to bedding, the constituent minerals being arranged in parallel layers. From Brush creek northward 15 or 20 miles are light colored mica-gneisses and dark hornblende-schists, with occasional beds of vitreous quartzite. Medicine peak is a mass of pure white quartzite rising 2,000 feet above the surrounding country. The main ridge has a trend approximately north 20° east, which appears to be the strike of the rocks. The dip is to the eastward at a high angle. While no accurate measurements could be made, the thickness of the formation is certainly not under 2,000 feet. The quartzite is white, compact, and brittle, with a uniform texture, and is traversed by thin iron seams. Near the base of the formation the quartzite is interstratified with beds of conglomerate, the pebbles being of quartz and many of them having been pressed and elongated in the direction of the strata. The formation is cut by dikes of dark intrusive rocks which are probably diorites. At the head of the northern branches of French creek, conformably under a quartzite, is a series of thinly laminated dark argillaceous slates and schists, which dip eastward into the mountain. Below these are quartzose argillites, which are again underlain by crystalline schists. Mill peak, north of east from Medicine peak, has at its base a white quartzite, which is overlain by a body of red conglomerate resembling the red jasper conglomerate of the Huronian series of lake Huron. Above this is amorphous quartzite, and the peak is capped by white and gray siliceous limestone. The prevailing dips at Mill peak are to the west, while those at Medicine peak are to the east, indicating that there is a broad synclinal fold between the two. A striking characteristic of the entire series is the banded and laminated appearance of the constituent minerals. The Archean series of the Medicine bow range present many marked features analogous to the Huronian formation on the shores of lake Huron and Canada, as well as to various localities throughout the Appalachian chain; and they are—with considerable hesitation, however—recognized as of Huronian age, because they are so widely separated from any beds distinctly recognized as such, and the reference is based entirely upon lithological evidence. The rocks also present many features in contrast with Laurentian rocks of the Colorado Front range.

The Park range, the third of the great Archean uplifts of the Rocky mountains, is a system of highly crystalline rocks of Archean age. The later rocks form a very subordinate part of the uplift, rising not more than a few hundred feet above the plain, where they rest unconformably on the older series. The rocks of the Park range resemble more closely those of the Colorado Front range than they do the Medicine bow, and are referred to the Laurentian. The range contains much structureless granite overlain by gneisses and schists similar to the series of the Colorado range, but carrying more hornblende-bearing beds in the upper members. On the other hand, there are not wanting rocks which are characteristic of the Medicine bow series and which were referred to the Huronian formation. The range has a monoclinal structure with the prevailing dips to the west, while an outlying spur to the east indicates the existence of the eastern side of the fold.

EMMONS,[6] in 1877, describes Rawlings peak as an outlying area of Archean granite-gneiss which shows distinct lines of bedding, having an inclination of 45° to the west, while the overlying quartzites and sandstones dip 10° to the east.

KING,[7] in 1878, describes the rocks which unconformably overlie the Archean of the Colorado range as varying from the lowest Paleozoic up to the post-Pliocene. The Archean core of the range is a broad central anticline, the arch having a flat summit and the dip increasing rapidly as the axis becomes distant. In this range complex faulting, metamorphism and crystallization, combined with widespread erosion, took place before the beginning of Cambrian time. The rocks comprise granites and granite-gneisses, above which, with no apparent unconformity, are red granites showing distinct bedding, and above these a great thickness of mica-gneisses, the estimated thickness of which is

12,000 to 18,000 feet. From the lowest exposure to the highest there is a gradual passing from the structureless granite to the dark mica-gneisses. Among eruptive rocks are granites, gabbros, and felsite-porphyries. The Clark's peak ridge is thought to be another and later series of rocks than those of the Colorado range.

In the Medicine bow range, above the hornblendic and dioritic, gneisses and schists are quartzitic schists, argillites, and limestones. The gneisses and hornblende-schist are older and underlie, in apparent conformity, the quartzites.

In the Park range the crystalline rocks all dip to the west, being but half of an anticline, the other half having suffered a deep downthrow which has only left traces of the easterly dips. The rocks are granite, gneiss, hornblende-schists, and dioritoid rocks, with a limited quantity of quartzites, there being no eruptive rocks, unless some obscure dioritic bodies are intrusive. At Jacks creek is a bed of pure white quartzite 50 feet thick. The upper members of the Medicine bow and Park ranges, somewhat less than 12,000 or 14,000 feet thick, are referred to the Huronian and the remaining formations to the Laurentian.

ENDLICH,[8] in 1879, describes Rawlings peak as consisting of a metamorphic granite nucleus about which the sedimentary strata are quaquaversally arranged.

VAN HISE,[9] in 1889, made observations upon the Laramie and Medicine bow ranges.

The Laramie hills at Sherman, where most structureless, are found to have alternate bands of coarse and fine material. The latter are more resistant to weathering and stand out as ridges. This stratification or flowage or foliation structure is at a flat angle—15° or 20°. The country granite is cut by very numerous dikes of granite, which project above the ground in intersecting ridges.

The course of travel in the Medicine bow range was up one of the branches of the Laramie river to Medicine peak, and over this range in a course, north of west across the strike of the rocks down Brush creek. Mill peak was visited.

The pre-Cambrian rocks first found are banded and contorted gneisses, varying from fine grained to granitoid varieties, which are cut by hornblendic and granitic veins or dikes, with here and there considerable areas of massive granite. In passing toward the interior of the range the granite becomes less plentiful and the gneiss more laminated, passing into regularly banded gneiss, which appears to grade by imperceptible stages, into fine grained green schist, and finally into black slate. In continuing to pass from east to west quartzites are found, then a broad belt of yellowish white, finely granular chert, with layers of cherty limestone sometimes ferruginous. About a mile before Medicine peak is reached the quartzites appear. These continue (often conglomeratic) to beyond Medicine peak. West of Medicine peak are again found slates, slate-conglomerates carrying abundant pebbles of white quartz and granites and interstratified with quartzite. Schistose and massive basic rocks, much altered, in dike-like forms, are found in the clastic series precisely as in the gneissic series. They oftentimes strike approximately parallel to the inclosing rocks. East of Medicine peak the rocks, including the gneissoid and clastic series, have a dip of about 60° to 80° to the southeast. Therefore the Medicine peak series appears to underlie the gneissoid series. The dip of the Medicine peak series in going north of west beyond the mountain becomes flatter, until 2 or 3 miles beyond the crest the dips are not higher than 30°, which observations agree with Hague's statement that west of Medicine peak is the crown of an anticline. As the strike of the Medicine peak series is nearly toward Mill peak, and as on the top of that peak there are cherts (Hague's amorphous quartzite) and cherty limestones very like those found east of Medicine peak, it seems probable that the Mill peak series represents these cherty limestones. Though the original sedimentary character of the Medicine and Mill peak series is evident, the pressure to which the rocks have been subjected is so great in places that the slate-conglomerates bearing granite pebbles take on an appearance closely resembling gneisses. The grains of quartz in the fragmental quartzites in thin section also show profound evidence of dynamic action. However, as the layers of pebbles in the quartzites and the fine laminations in the cherts and cherty limestones correspond with the schistose structure, there can be no doubt that the strikes and dips are those of bedding.

The foregoing facts seem to imply that in passing up from the gneissic series to west of Medicine peak we have passed a syncline overturned to the west, and 2 or 3 miles west of Medicine peak have nearly reached the crown of the next anticline. This structure makes the slates and slate-conglomerates bearing granite pebbles the base of the clastic series, above which are the quartzites, and occupying the highest position in the center of the syncline are the cherts and cherty limestones of Mill peak and those east of Medicine peak. The clastics thus rest upon the granite-gneiss series. No contacts or evidence of discordance in strike or dip were found between them, but the conglomerates bearing granitic detritus show the presence of a granite earlier than the formation of these beds, and presumably the present apparent accordance and transition are due to dynamic action, combined, perhaps, with the disintegration of the earlier series before the clastics were deposited.

SUMMARY OF RESULTS.

It is plain that in the Medicine bow range are two classes of rocks: those which are thoroughly crystalline and are mostly of the acid type, and those which are unmistakable clastics, such as quartzites, conglomerates, marbles, cherts, etc., while in the Laramie and Park ranges is only the first class, if the white quartzite, which seems to be in the nature of a vein in the latter, is excluded. The granites and gneisses were regarded by Hayden as eruptive, and they were believed to have intruded and metamorphosed the overlying Paleozoic limestones. King and Hague, on the other hand, regard all of the material of the three ranges as metamorphic, with the exception of the basic dikes and possibly some small areas and dikes of a later granite. That the horizontal sedimentary rocks were deposited unconformably upon and against these ranges is now admitted by all; so that the truth of the observations of Hayden must be considered doubtful, unless he found some place where there is actually present later important masses of intrusive granite.

At the present time many would doubt the conclusions of King and Hague, that because the structureless granite of the center of the ridges vary gradually in passing outward into well laminated gneisses and schists, therefore the whole is of sedimentary origin, the interior parts being more completely metamorphosed than the exteriors. These relations might equally well be produced by the increasing effects of dynamic action upon the outer borders of once massive ranges. The variation of massive or nearly massive core rocks into laminated gneisses and crystalline schists on the outer borders, which occur in many other mountain regions, are thus explained by numerous later observers, the whole being regarded as igneous. The lamination is explained equally as well by one theory as by the other; for in either case the central axes are the parts which are most deeply buried, and which, even if composed of material originally sedimentary, have become recrystallized. On either hypothesis it is probable that in the region under discussion are two fundamentally different series, the very ancient crystallines and the pre-Cambrian clastics. The presence of abundant granite débris in the lower members of the Medicine peak series certainly shows the existence of a granite earlier than this time. That the clastics are later than the crystallines is perhaps further indicated by the numerous dikes of granite which are found in the main granite area, but have not been noted as cutting the clastics. It can not be said whether many of the mica-schists and other intermediate kinds of rocks such as occur in the Medicine bow and Park ranges belong with the Archean or the Algonkian. It is wholly among the possibilities that schist series exist which are older than the granite; these together forming a basement complex upon which the readily recognizable clastics were deposited.

SECTION II. CENTRAL AND WESTERN WYOMING.

LITERATURE OF THE BIG HORN MOUNTAINS.

HAYDEN,[10] in 1861, states that red feldspathic granites, with metamorphic slates and schists, constitute the nucleus of the Big Horn mountains. As these are surrounded by strata as recent as the Cretaceous, this uplift is subsequent to this time.

HAYDEN,[11] in 1868, states that the unconformity between the crystalline and unmetamorphosed strata at the Big Horn mountains is very apparent.

CARPENTER,[12] in 1878, describes the Big Horn range as composed at the base of thick masses of Primordial sandstone resembling the Potsdam sandstone of the Black hills, although the heat coeval with the upheaval of the mountains has probably obliterated the fossils which are so abundant in that region. The sandstone rests unconformably against the Archean, is inclined from the flanks, is folded, and in many places is upturned as in the Black hills and Colorado mountains. Above the sandstone is a limestone containing numerous casts of *Spirifer cameratus*. The crystalline rocks appear at an elevation of about 9,000 feet and compose the higher parts of the range. Near the summit fine grained, grayish granite predominates, occasionally varied by various patches of mica-schist. The Owl creek mountains are composed of porphyritic granite rich in feldspar, which give place at higher elevations to a gneissoid granite. They connect the southern end of the Big Horn mountains with the northern part of the Wind river range.

LITERATURE OF THE RATTLESNAKE MOUNTAINS.

ENGELMANN,[5] in 1876, states that granites and granitic syenites which are regarded as igneous rocks form a large part of the Rattlesnake mountains.

LITERATURE OF THE SWEETWATER AND ADJACENT MOUNTAINS.

BALL,[13] in 1835, notes granitic rocks along the Sweetwater.

HAYDEN,[11] in 1868, mentions granites and syenites as occurring in the Sweetwater mountains.

ENGELMANN,[5] in 1876, places the crystalline schists between the three crossings of the Sweetwater and South pass, and those on the eastern slope of South pass as metamorphics. They include gneiss, mica-schist, argillaceous and siliceous schist, and hornblendic rocks.

ENDLICH,[8] in 1879, describes in the Sweetwater valley and in adjacent regions Prozoic and metamorphic rocks. In the Sweetwater hills are Prozoic rocks, coarse grained, structureless granite, like those west of the Wind river mountains which are cut by basaltic dikes, but which never penetrate the overlying younger rocks. The metamorphic granite of the Sweetwater and Seminole hills is regarded as a continuation of the youngest granite of the eastern slope of the Wind river range. East of Elkhorn gap is found a series of folded sedimentary beds, upon both sides of which is granite apparently of the same character. The northern and northwestern portions of the granite hills, instead of being composed of Prozoic granite, are formed of stratified granites with hornblende-schists. Toward the eastern termination the stratification is so apparent that from a short distance the rocks were supposed to be unchanged sedimentary ones, and the suspicion presented itself that a portion of these are metamorphosed Silurian beds. The Potsdam quartzite with an easterly dip is found to rest upon the schists, and at the western end of the Sweetwater hills sub-Carboniferous dolomites rest directly upon the Prozoic granites. In the Sweetwater region the younger metamorphics occupy a more conspicuous position than the older metalliferous schists. That the older schists and Prozoic granites do not appear is due to the thickness of the youngest metamorphic series, erosion not having succeeded in cutting through them. The metamorphics are all referred to the Huronian system.

LITERATURE OF THE WIND RIVER MOUNTAINS.

HAYDEN,[10] in 1861, states that the Wind river mountains have a nucleus of red and gray feldspathic granite.

HAYDEN,[11] in 1868, states that the stratified rocks rest unconformably upon the granites and syenites of the Wind river mountains along the eastern slope.

HAYDEN,[4] in 1872, describes the Wind river range as forming a complete anticline. It has a nucleus of granitic or gneissic rocks rising on either side step by step toward the central axis, and on each side of the nucleus are the various unchanged rocks inclining at a variety of angles. From fort Stambaugh northwest toward the granites of Wind river is found for a distance of 10 miles metamorphic slates.

COMSTOCK,[14] in 1875, describes the Wind river mountains as having a nucleal area of gray and reddish granites, gneissoid granites, gneisses, metamorphic slates and schists, and pre-Potsdam metamorphics, this being the order of succession from the center to either flank. It is doubtful whether any igneous rocks here occur, and there appears to be a gradation from the structureless granites to the pre-Potsdam metamorphics.

ENDLICH,[8] in 1879, describes the geology of the Wind river mountains and country eastward. The crystalline rocks are divided into Prozoic and Metamorphic. Placed as belonging to the Prozoic is the coarse grained, structureless red granite forming the subsidiary range along the western base of the mountains. Going eastward the granites disappear and in the Wind river range schists take their place. These granites and those of the Sweetwater and Granite hills are believed to have a subterranean connection and are regarded as the oldest rocks of the Wind river mountains because of the absence of all structure, their position relative to the range and their relations to the undoubted metamorphics to the east. Against them were deposited the old metalliferous schists. Granite composing the main chain followed, and this was succeeded by a narrow band of schist, and the fourth or lowest group is represented by the younger granites. The metamorphic rocks of the Wind river mountains are mainly granites but are associated with schists; but the layers of different mineralogical constitution do not appear to remain constant in certain zones. Passing to the eastward the granites disappear and are replaced by schistose granites or typical schists. The granites are flexed and contorted in every possible direction and contain simple bands of micaceous and chloritic schists, which denote the original planes of stratification. It is believed that by a careful examination evidence will be found bearing upon the former condition of this metamorphic area. The Wind river range is regarded as a steep anticlinal fold. The rocks constituting it are regarded as representing siliceous shales (schists) and are more or less argillaceous sandstones (granites). On the eastern side of the Wind river range is found hard red quartzitic sandstones directly overlying the youngest metamorphic granites. It extends up the gently sloping ridges in a scalloped line. In direct contact with the granites it is difficult to determine where the granite ends and the quartzite begins, so that it may be said that the quartzites and granites blend into each other. It appears that the lowest Silurian strata were deposited before the thorough metamorphosis of the entire mass took place, unless the change in the sandstone is caused by a generation of heat during the period of mountain elevation. The Archean rocks of the Wind river, Sweetwater, and adjacent ranges are classified into the Huronian, Laurentian, and Prozoic systems. The first includes micaceous, hornblendic, and chloritic granite, 30,000 feet thick. The Laurentian includes metalliferous schists composed of quartz, feldspar, hornblende, and mica, 18,000 feet thick. The Prozoic includes massive structureless muscovite granite of indefinite thickness.

PEALE,[15] in 1879, states that the western foothills of the Wind river mountains and a few isolated buttes are composed of muscovite granite, the most prominent of the latter being Fremont's butte.

ST. JOHN,[16] in 1883, describes the Archean rocks of the Wind river range and gives a number of sections showing the unconformable relations of these rocks to the overlying Potsdam and higher sedimentaries. The Archean area is composed of granitic, gneissic, and various schistose rocks, including hornblendic, micaceous, talcose, and garnetiferous varieties.

LITERATURE OF THE GROS VENTRE AND WYOMING RANGES.

ST. JOHN,[17] in 1879, states that the Gros Ventre range has an Archean nucleus, consisting chiefly of distorted gneissic and schistose layers, and forms a sort of transverse bar or truss connecting the Wind river and Teton ranges. The Primordial quartzite was seen lying in immediate contact unconformably above the Archean schists, from which it is separated by a rose-colored finely laminated gneissoid layer, which may be the metamorphosed basal member of the quartzite.

ST. JOHN,[16] in 1883, further describes the Gros Ventre range and gives various sections through it. The Primordial quartzite rests directly upon the Archean rocks. In the Wyoming, as in the Gros Ventre range, the Archean is unconformably below the stratified rocks.

LITERATURE OF THE TETON RANGE.

BRADLEY,[18] in 1873, describes the central nucleus of the Teton mountains as consisting of granites, gneisses, and schists which vary greatly in character. No rock succession was ascertained. The granite is in thick solid beds and the other rocks are much broken and tilted in various ways, and are crossed in every direction by innumerable large and small veins, mostly of quartz, but a few of granite. There is a general strike in an east and west direction. Trap-like rocks are interlaminated with the gneiss and granite, which suggest that they may be dikes, but they are evidently conformable with the layers and were either contemporaneous sheets or else subsequent intrusives.

ST. JOHN,[17] in 1879, describes Archean rocks as constituting the nucleal ridge of the Teton mountains. The major portion of them are metamorphics of a gneissic or schistose variety. The Archean strata of the Teton, Wyoming and Gros Ventre ranges are divided into Huronian and Laurentian. With the former are placed the quartzites, micaceous and chloritic slates forming heavy deposits several thousand feet in thickness and developed only in the southwest, while with the Laurentian are the gneisses, various schistose rocks, and granite. In the southwest part of the Teton district is a narrow tongue of quartzites which are placed with the Primordial, but may be Huronian.

SUMMARY OF RESULTS.

The rocks referred to the Archean by the various authors can, with considerable certainty, be considered pre-Cambrian, as the region is one in which no folding has taken place since the beginning of Paleozoic time, and the various members of the Paleozoic are found in unconformable contact with the underlying crystallines at many points. It is not necessary to assume, as was done by Endlich, that a portion of the metamorphism of the Archean took place subsequent to Paleozoic time, for the indurated quartzites so often found in direct contact with the crystalline strata have probably been thus hardened by the now well known process of cementation. The quartzites which so closely resemble the unaltered granite are doubtless recomposed rocks which have been cemented in the same manner.

Whether among the pre-Cambrian rocks in these various ranges of mountains there are any which are now of a distinctly clastic character is uncertain. Those between fort Stambaugh and the central Wind river mass spoken of as metamorphic slates, and the rocks described by St. John in the southwestern part of the Teton district as consisting of quartzites, micaceous and chloritic slates, may very likely be of this character, but it is not certain that the latter do not belong to the Cambrian, for nothing is said of their relations to the recognizable Paleozoics.

The separation of the rocks into Laurentian and Huronian, or into Prozoic, Laurentian and Huronian, as is done by Endlich, is purely lithological. They are all thoroughly crystalline, and have been assumed by the various authors to be metamorphic because having a lamination or foliation, and the more massive rocks are regarded as being older because more metamorphic, and also because they are usually core rocks. As has been seen in the case of the Laramie hills and other regions, these facts may be equally well explained by regarding the rocks as all ancient igneous rocks, parts of which have been given a laminated structure by dynamic action.

Nowhere is anything said as to any unconformable relations between any parts of the various series referred respectively to the Huronian, Laurentian, or Prozoic, as the case may be. Consequently the only sure structural conclusion reached is that there is in these mountain ranges a great complex of granites, gneisses, and schists, thoroughly crystalline, and as yet undivided, which are of pre-Cambrian age.

SECTION III. CENTRAL AND SOUTHWESTERN MONTANA, WITH ADJACENT PARTS OF WYOMING AND IDAHO.

LITERATURE.

HAYDEN,[10] in 1861, describes along the Madison, one of the forks of the Missouri, beds of feldspathic rocks, and mica-slates and clay-slates above the eruptive granites of the region.

HAYDEN,[19] in 1872, describes Archean rocks at many points in southwestern Montana. Among the localities mentioned, the following are worthy of note: Upon Black-Tailed Deer creek in southwestern Montana is an immense thickness of alternating beds of quartzites, true gneiss and mica-schist, the first predominating, and inclining to the west from 30° to 45°. Old granite ridges are also found. On the north side of this creek are gneissic beds, which incline to the northwest at angles varying from 30° to 60°. On the Stinking water are immense thicknesses of micaceous gneiss underlying massive layers of quartzite. Along the Madison canyon is found granite. The rocks adjacent to Virginia City are clearly stratified, wholly metamorphic, and are regarded as below the Paleozoic. Upon the Upper Gallatin are granitic nuclei, with the unchanged sedimentary beds upon the sides and summits inclining at various angles. In the first canyon of the Yellowstone is true gneissoid granite and micaceous gneiss of different shades of color, giving its sides a peculiarly stratified appearance. At Cinnabar mountain is a plainly metamorphic reddish feldspathic quartzite, upon which rests unconformably the Carboniferous limestone. Hell-Roaring mountain consists of stratified gneiss and massive red or gray feldspathic granite. At Horse plain valley are quartzites and micaceous schists, which rise beneath the limestones and quartzites of Carboniferous age.

PEALE,[20] in 1872, gives many details with reference to the lithological and mineralogical character of the rocks, the locations of which are given by Hayden.

HAYDEN,[21] in 1873, gives many additional facts with reference to the occurrence of Archean rocks in southwestern Montana and adjacent regions. The mountain range east of the Yellowstone, supposed to be mostly of igneous origin, has the characteristic granitic nucleus common to the mountain ranges of the region. In ascending the lower canyon of the Yellowstone the first ridge is composed mostly of metamorphic quartzite, the second of mica-schists and granitoid gneiss. The ribboning and banding of the gneiss is quite remarkable for its perfection and regularity. Granitic rocks constitute the nucleus of the Yellowstone range and make up a rugged granite range east of Clarks fork. At Henrys lake and Tahgee pass the quartzites and gneissic rocks appear beneath the limestones. The lower portion of the unchanged rocks are pebbly arenaceous sandstones and limestones containing pebbles which are much worn and are either quartz or micaceous gneiss, showing that the sediments were derived directly from the metamorphic rocks. The lowest strata of unchanged rocks are here regarded as Silurian, and probably Potsdam, although no organic remains were found. The Carboniferous limestones higher up are filled with characteristic fossils. In the Middle canyon of the Madison the stratified rocks are also believed to belong to the Potsdam epoch, although no fossils were found lower than the Carboniferous, and here the unconformable relations of the limestones to the metamorphic rocks are clearly shown. On both sides of the Madison there is, in restricted localities, an enormous development of very hard gray quartzitic sandstone, apparently partially metamorphosed, which evidently forms the underlying rocks of the sedimentary strata resting on the strictly metamorphic gneiss. No organic life has been found, yet it undoubtedly belongs to the oldest Silurian. Along the valley of the Madison, below the mouth of Cherry creek, for several miles there are successions of gneissic beds thousands of feet in thickness, which show great variety of composition and flexures in the bedding. In this gneiss are layers of black hornblende gneiss 4 to 6 feet thick, which appear as though they were intrusions of trap. Near Helena the sedimentary beds overlying the granite are tilted from 20° to 45° past a vertical. The work of reducing the metamorphic strata which underlie the entire country to a system and connecting them over extended areas has not been attempted, and it seems to the author an almost hopeless as well as a fruitless task.

PEALE,[22] in 1873, describes at many localities crystalline rocks in southwestern Montana and adjacent regions. Gneissic and granitic rocks are mentioned in the Cinnabar mountains, in the rocks of the Third canyon of the Yellowstone, at Elk creek, at the junction of the two forks of the Yellowstone, at West Gallatin canyon, Bozeman creek, and other localities. Upon one of the head waters of the Madison are found quartz-schists and chlorite-schists, below which in apparent conformity are layers of limestone. Still below these are Carboniferous limestones. The whole is believed to be an overturn. Between Red Rock lake and Henry lake is an exposure of quartz-schist dipping to the southwest at an angle of 20°, estimated to be 2,000 feet in thickness, which is believed to rest directly upon the granite. On Cherry creek the gneissic rocks are succeeded by beds of massive quartzite, shale, limestones, etc., resting unconformably upon them, the latter being probably Lower Silurian.

HAYDEN,[23] in 1876, describes some geological sections about the headwaters of the Missouri and Yellowstone rivers. There is an anticlinal axis between the Madison and Jefferson which has a granitic nucleus, and on the east side of the Gallatin the Silurian rocks rest upon granitic hills.

HOLMES,[24] in 1883, describes the Silurian strata as resting upon the metamorphic rocks at Cinnabar mountains. The butte at Bear gulch is composed of vertical shales, and these are underlain by metamorphic quartzites. Between the butte and Junction valley are hard metamorphic quartzites and quartzitic schists which not improbably consist chiefly of altered and distorted Paleozoic or Mesozoic strata, but there is but slight resemblance to these formations. The ridge near the canyon of Bear creek is composed of schists that have a decided quartzitic character. The East Gallatin range is largely of granite. At different places the Archean granites are unconformably overlain by the Silurian.

DAVIS,[25] in 1886, describes Archean rocks as occurring in the neighborhood of Neihart, about the headwaters of Belt creek in the Little Belt mountains. They are dark reddish and gray gneisses with the folia generally at steep angles, cut by granitic eruptions that were not found to extend into the overlying bedded rocks. The Paleozoic series begins with a vast series of Lower Cambrian barren slates, at least 10,000 or 15,000 feet thick at many places. The slates are capped by hard sandstone or quartzite, 100 or 150 feet thick, persistent throughout the area examined, which is overlain by an equally persistent trilobitic limestone 100 to 300 feet thick clearly of Potsdam date. With the upper members of these slates are found diabasic eruptions. These lower Cambrian slates are found in the main range at Cadottes pass, in the Big Belt mountains, and in the Little Belt range. In the sections the Archean rocks at Little belt are represented as resting unconformably below the Lower Cambrian slates, while on the Bridger range they are placed in conformity with the slates.

PEALE,[26] since 1884, has been working on the "Three Forks Sheet" of Montana (the square degree included between 111° and 112° of longitude and 45° and 46° of latitude). In the northern part, in the Bridger range, of this area is found Archean gneisses.

Other Archean areas are the one extending north of Virginia city some 28 miles, in which a body of eruptive granite occurs, and the one bordering the canyon of the Madison. The gneiss of the Madison canyon extends across to the Gallatin canyon, a distance of 24 miles. This latter belt is about 12 miles in width. There are also two smaller gneissic areas bordering the southern edge of the Gallatin valley. The beds of Lower Cambrian age at a number of localities in the range include angular fragments and masses of gray and red gneiss, evidently derived from these Archean beds.

In the vicinity of the Three forks and in the northern portion of the Bridger range, lying between the basal quartzite of Lower Cambrian age and the Archean gneisses referred to above, is another series of beds that are considered pre-Cambrian. This group, referred to the Algonkian, has a thickness of 5,000 or 6,000 feet in the Bridger range and is correlated with the Lower Cambrian barren slates of much greater thickness found by Davis farther to the north. The beds are made up of alternations of coarse micaceous sandstones and fine conglomerates with beds of hard argillaceous slates and bands of very hard thin-bedded dark blue limestones. These are the beds seen by Hayden in 1861 which were mistaken for eruptives, and which were described by Peale in 1873. Where the lowest exposures were noted, pebbles and angular masses of the Archean gneisses are numerous in these sandstones, indicating that Archean land masses existed not far to the southward. In fact the ancient shore line crossed the area from 12 to 15 miles south of the northern limit of the Three forks sheet. As to age, this series is probably pre-Cambrian as it lies below beds containing Lower Cambrian fossils, being nonfossiliferous themselves so far as examined. So far as observed no evident unconformity exists between the series and the overlying Cambrian beds, but there is certainly an unconformity by subsidence, for after the series was deposited there was an orographic movement by which the Archean area of nearly the entire district of the sheet south of the Three forks was submerged just prior to the beginning of the Cambrian, as is shown by the great southward extent of the lower or basal quartzite over this area which was not before submerged and which therefore shows no rocks of this Algonkian series. Whether the movement occurred immediately after the laying down of the Algonkian beds just described or after an interval can not be decided with the meager data now at hand.

South of the old shore line the Algonkian group is absent, the lower quartzite of the undoubted Cambrian everywhere lying unconformably upon the Archean gneisses, with the exception of two localities, where it rests upon a series of beds considered to be a lower division of the Algonkian. The main area is on the west side of the Madison river, about 20 miles south of Meadow creek, and is about 8 miles in length by about 4 in width. A limited area of these beds occur on the east side of the Madison valley at the west edge of the Madison range between Bear and Indian creeks. The series consists of crystalline limestones, mica-schists, quartzites, and gneisses, very highly inclined and conformable so far as seen with the stratification or bedding of the gneisses. Without more detailed examination and search for obscure folds it is impossible to estimate the total thickness, but it is certainly very great.

SUMMARY OF RESULTS.

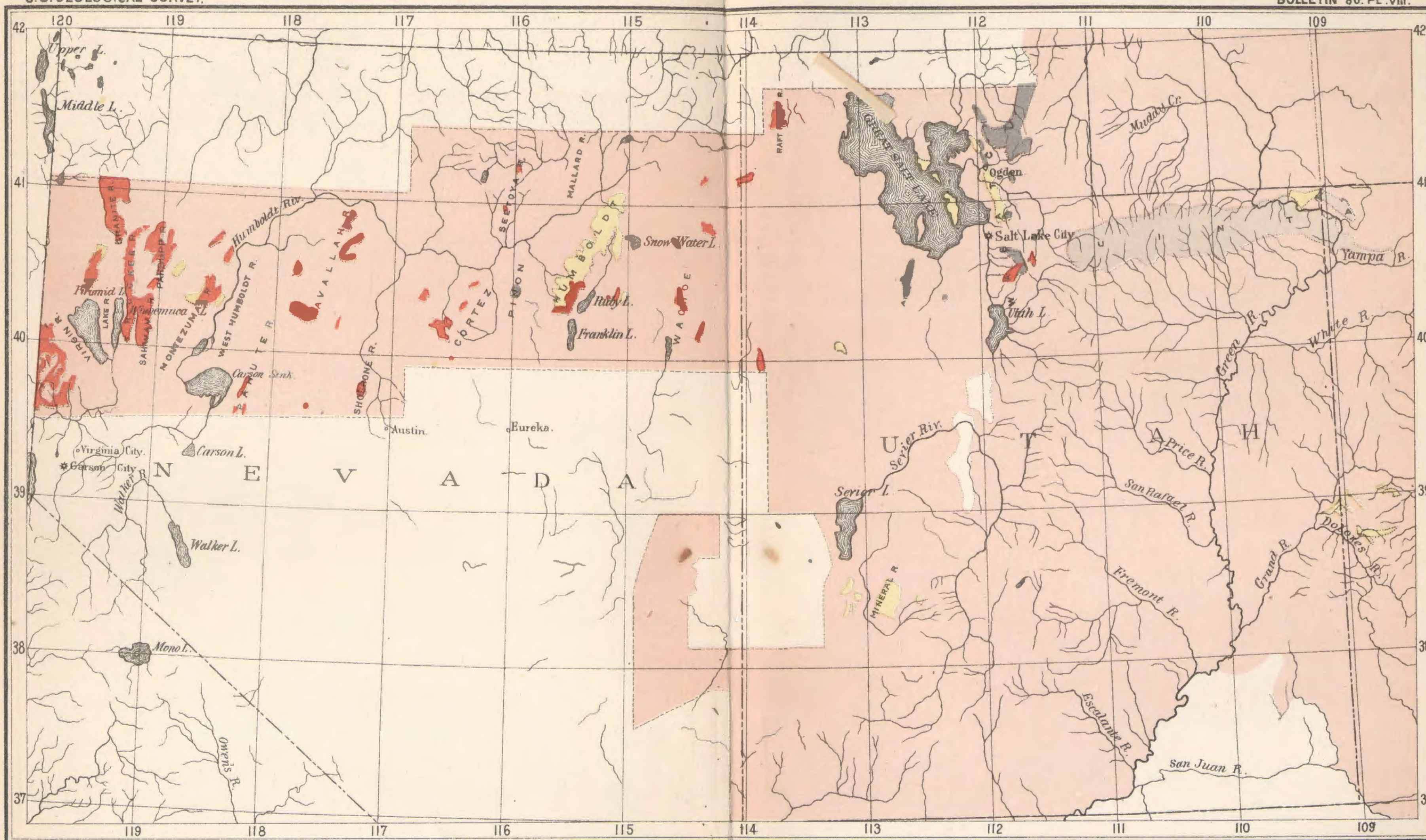
It is evident from the literature, as well as from Hayden's own statement, that no systematic work has been done among the pre-Cambrian rocks, with the exception of that by Peale on the Three forks sheet. The information at hand makes it clear that this region will yield results of extreme interest when considerable areas are mapped. In the region are great areas of intricately mingled granitic and gneissic rocks which certainly belong to the Archean. Associated with this class of rocks are immense thicknesses of regularly bedded gneisses, mica-schists, chlorite-schists, quartz-schists, quartzites, and limestones. Whether the regular lamination of the gneiss is due to sedimentation or to other forces is uncertain, but the great belts of interstratified crystalline limestone, quartz-schists, and quartzites are evidence that here is a series of clastic origin, although at the present time it has become thoroughly crystalline. The relations of this series to the granites and gneisses doubtfully referred to the Archean have not been worked out.

There is also in this region, as shown by the work of Davis and Peale, a great series of unaltered strata which are probably Algonkian. This series is a downward succession of barren slates below the fossiliferous Cambrian, and if Algonkian, is the uppermost division and equivalent to the upper Algonkian of the Wasatch. Peale's results indicate that while there is no actual unconformity, there is a change of physical conditions, a subsidence, and perhaps a real time break between the Cambrian and Algonkian. Nowhere yet have the unaltered barren slates and the more crystalline series of clastic origin been found in contact. Between the slates and the Archean gneisses is a great unconformity, and there is little doubt, when the unaltered series is carried over to the vertical limestones, quartzites, and quartz-schists, that it will be found to rest upon them unconformably. There is, then, in this region probably two series of Algonkian rocks, one almost completely unaltered, the other thoroughly crystalline, and both of great thickness.

SECTION IV. UTAH AND SOUTHEASTERN NEVADA.

LITERATURE OF THE UINTA MOUNTAINS.

MARSH,[27] in 1871, states that in the Uinta mountains is an extensive series consisting of reddish sandstones and quartzites, sometimes metamorphosed and apparently without fossils. The series is referred provisionally to the Silurian on the ground that resting conformably upon them are limestones bearing Carboniferous fossils.



Sackett & Wilhelms Litho Co. New York

UNCLASSIFIED PRE-CAMB. ALGONKIAN ALGONKIAN? POST-ALGONKIAN Granite.

GEOLOGICAL MAP OF UTAH AND NEVADA

SHOWING PRE-CAMBRIAN ROCKS

Compiled from the Powell, King and Wheeler Reports

Scale $\frac{1}{4308000}$.

HAYDEN,[4] in 1872, states that in the Uintas, from the red beds of the Triassic to the oldest quartzites no unconformity was detected. The whole series has a thickness of 10,000 feet or more; of this the lower 8,000 consists of sandstones and quartzites. Although no fossils were found, the upper part of these 8,000 feet is believed to be Silurian and to pass down without a break to the rocks of the Huronian age. The quartzites are like the Sioux falls, Dakota, quartzites which are associated with the pipestone referred by Hall to the Huronian. In the Uinta series is an excellent illustration of a gradual transition from unchanged to metamorphic rocks.

Passing upward to the crest of the mountains, but downward in a geological sense, we find a series of purplish sandstones and slates, conformable with the limestones and apparently unchanged, which gradually pass into thick beds of gray and purple quartzite, which are exceedingly brittle and plainly metamorphosed by heat. The later formations once passed over the older ones in the Uintas, and therefore there has been in this region tremendous erosive forces. On Red creek, the only place where such a rock is found, is the largest display of white quartz that the author has seen in the West. This is associated with outbursts of old trap and some beds of true gneiss and mica-schist. The igneous matter has protruded itself in every opening or fissure in every possible direction, sometimes between the strata and sometimes across them, in thin layers or in huge branching masses. It is believed that this igneous material was protruded among the quartz beds prior to their upheaval. It is difficult to account for this development of quartz with gneiss, which rises abruptly above the quartzite, occupying a belt 5 to 9 miles in width and ending as abruptly as it commences. The upper quartzites and white quartz beds seem to conform. It is remarked that the geology of the eastern portion of the Uinta range is very complicated and interesting, but to have solved the problem to entire satisfaction would have required a week or two.

POWELL,[28] in 1874, describes in the Uinta mountains crystalline schists upon which rest unconformable Carboniferous rocks.

POWELL,[29] in 1876, describes the Uinta sandstones, shales, and quartzites 12,500 feet thick, as resting unconformably below the Lodore group. Again, unconformably below the Uinta sandstone is the Red creek quartzite associated with hornblendic and micaceous schists, 10,000 feet thick. It is evident that the metamorphism of the Red creek quartzite is anterior to the deposition of the Uinta group, for the beds of the latter, especially near the junction, are chiefly made up of fragments of the former; hence the unconformity is very great, and the quartzite was a lofty headland in the old Uinta sea—perhaps 20,000 feet high—when the lowest member of the Uinta sandstone was formed. The period of erosion separating the Uinta sandstones from the Carboniferous beds was sufficient to carry away at least 3,000 feet of the former, and how much more can not be said. This unconformity is seen at Whirlpool canyon and the canyon of Lodore, the difference of dip between the two groups being from 4° to 6°, and the members of the Lodore group steadily overlapping the upper members of the Uinta and cutting off more than 2,000 feet of the latter. At the canyon of Lodore the Uinta sandstone also protrudes into the Lodore shales. On the northeast side of O-wi-yu-kuts plateau the Uinta sandstones are seen to disappear, having been cut off by erosion before the deposition of the limestone, and there is from 1,000 to 2,000 feet more of the Uinta sandstone at one end of the ridge than at the other. The unconformity can also be seen in the canyon of Junction mountain, and has been observed on the south side of the Uinta mountains in a canyon cut by the tributaries of the Uinta river. It is suggested that the Uinta sandstones may be considered as Devonian, an opinion which would be yielded upon the slightest paleontological evidence to the contrary.

The Red creek quartzite is believed to be Eozoic. This Eozoic is in large part a pure white quartz, but is intimately associated with irregular aggregations of hornblendic and micaceous schists. These schists were, perhaps, argillaceous strata between the thicker strata of pure siliceous sandstone. The whole group has been greatly metamorphosed so as almost to obliterate the original granular or sedimentary structure so far as is apparent to the naked eye. Besides the recrystallization, they have been profoundly plicated or implicated, so that it is only in a general way that any original stratification can be observed.

The great mass of the Uinta range is of the Uinta sandstone. Intercalated with these are shales, argillaceous material, and semicrystalline quartzite; the whole group is exceedingly ferruginous and contains seams of clay ironstone. While weeks and months were spent in the search, no fossils were found in the Uinta group. The Uinta mountains as a whole have been produced by the degradation of a great upheaved block, having its axis in a general east and west direction. The upheaval is partly a flexed, partly a faulted one, the major part of the faulting and the steeper inclinations being on the north side.

EMMONS (S. F.),[6] in 1877, describes the Uinta mountains as a remarkably simple and regular uplift of an immense thickness of conformable strata, the regularity being disturbed only about a small area of Archean rocks at the eastern end. These old rocks, occurring along Red creek and covering a comparatively small area, are quartzites, white mica-schists, and hornblende-schists, with a local development of paragonite beds, and they correspond most nearly to those classed as Huronian in the Rocky mountains. The beds are steeply inclined and have suffered intense compression and distortion. The general section is that of a double anticline.

On these older rocks are seen the conformably gently dipping Weber quartzites, and the succeeding beds were then deposited around the shores of an Archean island. Above the Archean is a thickness of 10,000 or 12,000 feet of unconformable beds, part of which consists very largely of quartzite and is regarded as before the Carboniferous, while the upper part is placed in the Upper Coal Measures and Permo-Carboniferous. The Upper Coal Measures are limestones and sandstones and bear fossils; but in the great thickness of lower beds referred to the Weber no fossils are found.

KING,[7] in 1878, describes the Archean rocks of the Uinta range as a group of pure white quartzites, hornblende schists, hydromica- (paragonite) schist, richly charged with garnet, staurolite, and minute crystals of cyanite. They are referred to the Huronian.

The Paleozoic rocks of the Uintas rest unconformably upon the Archean. They comprise an immense body of quartzites and indurated sandstones intercalated with shales, 12,000 feet in thickness, referred—not, however, without some questioning—to the Weber quartzite or Middle Coal-measures. Directly overlying these is a series of sandstones and limestones having a thickness of 2,000 or 2,500 feet in which Coal-measure fossils are obtained.

PEALE,[15] in 1879, describes in the Green river district, at Station 77, a Cambrian section consisting largely of quartzite and amounting to 7,000 feet. At Station 130 is another red quartzite which has a limestone below it, and below them a series of green chloritic rocks unlike those of any other section in the district. The author inclines to place these below the Cambrian quartzites and considers them of probably Huronian age. None of these sections expose the underlying crystalline schists.

VAN HISE,[9] in 1889, examined the Archean core of the Uintas. The so-called white quartzite is found to be largely composed of white feldspar. It is thoroughly crystalline and its lithological affinities are rather with the granites than the quartzites. The black bands contained in it, supposed by some to represent original layers of a different constitution, and by others to represent dikes, were found to be much altered eruptives. The unconformable contact between the Uinta series and the Archean was seen at many points.

LITERATURE OF THE WASATCH MOUNTAINS.

HAYDEN,[19] in 1872, describes in the Wasatch mountains and on the canyon of the Weber a nucleus of granite. In Box Elder canyon are gneisses, quartzites, and slates. In the Port Neuf canyon there are exposed at least 10,000 feet of quartzite, the age of which is obscure, the only thing indicating its position being that Carboniferous fossils are found in the upper horizon.

SILLIMAN,[30] in 1872, regards the granite of Big and Little Cottonwood canyons as probably metamorphic from conglomerates, because of the conspicuous patches of dark colored material which they have in a light gray matrix, and because with a glass there can be detected a sort of pebble-like roundness in the quartz of the granite.

HAYDEN,[21] in 1873, describes syenite in the Little Cottonwood canyon of the Wasatch at the base of the series, upon which rest feldspathic gneissic strata, and unconformably upon these the lower quartzites. The Wasatch is probably a complete anticlinal fold.

PEALE,[22] in 1873, states that the base of the mountains near Ogden is for the most part a red syenite which passes into granite and gneiss, and contains in places veins of hornblende, quartz, and specular iron. The granites of Cottonwood creek are conspicuously bedded, the dip being about 50° or 70° to the east, and they contain rounded pebble-like masses of a dark color inclosed within the gray matrix. These granites are cut by veins of feldspar. The pebble-like masses suggest that the formation is metamorphic.

BRADLEY,[18] in 1873, regards the core of the Wasatch as metamorphic. The occurrence ot angular and rounded patches of dark material in the granite of the Little Cottonwood canyon is taken as evidence that these were pebbles of a conglomerate before its metamorphism. The rocks are chiefly hornblendic gneiss and syenite, with quartz veins.

HOWELL [31], in 1875, states that in Rock canyon, near Provo, pebbly chlorite-schist is unconformably below hard quartzite.

EMMONS, (S. F.)[6], in 1877, describes the Wasatch range as a sharp north and south anticlinal fold over preexisting ridges of granite and unconformable Archean beds, the axis being bent and contorted by longitudinal compression so that at times it assumes a direction approximately east and west. In connection with the folding is a widely-spread system of faulting and dislocation, in a direction generally parallel to the main line of elevation, which has cut off and thrown down the western members of the longitudinal folds and the western ends of the transverse folds, and they are now buried beneath the valley plains. In the northern region is a second broad anticlinal fold to the east of the main line of elevation. This mountain range occupies the line of former Archean uplift, around which were deposited a thickness of 30,000 or 40,000 feet of practically conformable beds extending upward from the Cambrian to the Jurassic. At the base of the Paleozoic is the Cambrian formation, which has a small thickness of calcareous slates bearing Primordial fossils and a great thickness of white quartzite, including a few micaceous beds and argillites, the whole being 12,000 feet. The granite mass constituting the center of the Wasatch was not protruded through the sedimentary rocks, but the latter were deposited around them, and their present conditions are due to subsequent elevation, flexure, dislocation, and erosion.

In the Cottonwood canyons is a large mass of granite which shows a conoidal structure, and, while massive, has distinct planes of cleavage which dip 50° to the westward. It is a white, rather coarse grained granite, dotted here and there with round black spots where there has been a concentration of the dark green hornblende, which is a prominent constituent of the mass. On the western flanks of the Cottonwood granites are some remnants of Archean quartzites and schists, which have a general strike northeast, and dip from 45° to 60° to the westward. At the mouth of the Little Cottonwood canyon they consist of a body of quartzites about 1,000 feet in thickness. These quartzites are different from the Cambrian quartzites of the Big Cottonwood canyon; they contain mica in varying quantity, and where this is abundant approach a true mica-schist. Toward the mouth of the canyon the mica is replaced by hornblende. Between the Cottonwood canyons is about 2,000 feet of Archean slates, quartzites, hornblende-schists, and mica-schists. The Cambrian slates above the granites of the Cottonwood stand at an angle of 45° dipping to the northeast. It is difficult to tell whether the granite should be considered as a part of the main granite body, which it does not resemble very closely, or with the later outbursts of granite-porphyries and diorites which intersect the sedimentary beds of this region. These dikes are very frequent, especially around the Clayton peak mass, and in the region where the mineralization of the beds has been most developed. One of these in the Wasatch limestones is a dike 20 feet wide of syenitic granite-porphyry. The Paleozoic beds of the Cottonwood canyons, which fold around and partly cover the granite bodies, have been subjected to intense compression and local metamorphism, and cut by intrusive dikes and mineral veins.

The Farmington Archean body is composed of a conformable series of gneisses, mica-gneisses, and quartzites, 12,000 or 15,000 feet thick, which dip westerly at about 15° or 20°. The lowest part of the series is coarse and structureless, but it grades up into an evenly bedded rock.

HAGUE,[6] in 1877, describes the northern Wasatch region and the region north of Salt lake. The geological structure of the Front range remains of the same type as to the southward, but the Archean rocks are less abundant. In the lower canyon of the Weber river are rocks like the Farmington Archean body, which have, however, a westerly dip of 40°. The Cambrian quartzite of Ogden peak lies unconformably on the edge of the Archean beds. In the Ogden canyon the quartzite is occasionally conglomeratic, containing pebbles of quartzite and jasper. These pebbles are sometimes flattened and elongated in almond-shaped bodies, and are frequently distorted and banded into curious forms. Sometimes two or more pebbles are pressed together so as to form apparently one mass. The flattened pebbles appear with their longer axes in parallel planes.

KING,[7] in 1878, states that on the west side of the Wasatch is a fault which has thrown the layers downward from 3,000 to 40,000 feet. The Archean rocks occupy the core of the range. Above these is unconformably exposed in the Cottonwood canyons a conformable series of Paleozoic strata 30,000 feet thick. The nucleus of the Archean rocks in the Cottonwood area is a mass of granite and granite-gneiss. This rock at Clayton's peak possesses the physical habit of a truly eruptive granite and has been the center of local metamorphism, but the evidence points to the belief that it is of Archean age. In the Cottonwood canyon there is no sharp division between the structureless granite and the bedded gneissoid form. In the neighborhood of Clayton's peak are bodies of granite-porphyry which are probably a dependent of the granite. West of the granite body of Little Cottonwood canyon is a belt of Archean schists and quartzites having a thickness of 2,000 or 3,000 feet and dipping at a high angle to the northeast. In the Little Cottonwood canyon the quartzites are in junction with the granite, while at the mouth of Big Cottonwood canyon, in direct contact with the granite is mica-schist. Between the Archean granite and the crystalline schists there are no transitions such as to lead to the belief that the granite is a more highly metamorphic form of the schist. The contact is clearly defined, the rocks mineralogically dissimilar, and the granite is either an intrusive mass, or else an original boss over which the Archean sedimentary materials were deposited. The absence of granite dikes in the schists strengthens the belief that the granite is older. The Cambrian rocks are in such a position as to indicate that the granites and schists alike antedate them, although in some instances intrusive dikes do cut the marbleized limestone, but they are middle-age porphyries, not to be confounded with the Archean crystalline rocks.

In the next Archean mass to the north—the Farmington area—in Sawmill canyon, there seems to be two distinct series. The later series consists of conformable beds of gneiss, quartzite, and hornblende-schist, which dip west at angles from 15° to 40°, and rest unconformably upon an intensely metamorphosed material composed of quartz, orthoclase, and muscovite. In reference to the Farmington gneisses it is said: A mica-schist passing into a hornblende-schist, or a hornblende-schist into a granite, or a gneiss rock into an argillite, along the line of their longitudinal extensions, are phenomena which fail to appear on the fortieth parallel. The small granitoid body in Sawmill canyon is referred to the Laurentian, while the second series of metamorphic rocks, comprising the gneisses and schists, 12,000 or 14,000 feet thick, are referred to the Huronian, as are also the argillites of Salt lake islands.

The Paleozoic series of the Wasatch, although 30,000 feet in thickness, show in their lowest portions only a very slight tendency to become crystalline schists. The pre-Cambrian topography of the northern part of the Wasatch was that of dome-like peaks with gently inclined sides. The Cottonwood canyons, however, presented an almost precipitous face of 30,000 feet to the westward. The height of the range was then, therefore, from 17,000+ feet to 30,000+ feet.

Passing upward from the Archean, at the base of the Paleozoic slates are Lower Cambrian slates and dark argillites and intercalated siliceous schists 800 feet thick; above this Cambrian quartzite, an immense series of siliceous and arkose rocks 12,000 feet; and above this Cambrian calcareous shales of variable thickness, and containing Primordial fossils, 75 to 600 feet. This great thickness is found in the Cottonwood area, on the lower half of Big Cottonwood canyon, and from Big Cottonwood canyon in a northeasterly direction across the spur which divides the waters of Cottonwood creek from Mill creek. In other localities the Cambrian is far thinner or wholly absent. The section in the Big Cottonwood canyon, in passing upward, comprises black slates and thinly laminated argillites 800 or 900 feet in thickness; above these, 8,000 or 9,000 feet of mixed siliceous schists and argillaceous schists; above these, 3,000 feet of true quartzite capped by 200 feet of schistose rock, quite micaceous toward the bottom, and at Twin peak approaching a true mica-schist. At the second section the series consists of four members: the bottom slates, 800 feet thick; varying siliceous and argillaceous schists, containing some mica-bearing zones, 8,000 or 9,000 feet thick; salmon colored and white quartzites, intercalated with dark schists, 2,500 to 3,000 feet; and the capping schists of 200 feet, which are partly argillaceous and calcareous rocks and partly mica-bearing argillites. Passing up the Little Cottonwood, the successively higher members of the Cambrian rest against the granite until the latter rises into contact with the Silurian limestone, which conformably overlies the Cambrian. Although a careful search was made in these schists no fossils were found.

GEIKIE,[32] in 1880, discusses the nature of the pre-Cambrian mountains of the Wasatch and the eruptive or metamorphic origin of the Cottonwood granite. That this granite is eruptive is maintained on the grounds of the enormous height of the cliff which would be required in case it was an Archean island; that if it were an old shore line, somewhere granite pebbles would be found to-day; that the granite is said by King to be a source of local metamorphism; that there are porphyries cutting the limestones, probably dependent on the granite; and that it is exceedingly improbable that there was a cliff 12 miles high which has been turned over on its back as required by the descriptions and sections by King. All these difficulties are overcome by regarding the granite as a subsequent intrusive of post-Carboniferous age.

WALCOTT,[33] in 1886, describes the Big Cottonwood canyon section of Cambrian rocks, which is found to be 12,000 feet thick. It consists of shales, quartzites, sandstones, and slates. The upper 250 feet of shale bears the Olenellus fauna, while other layers, although in a most excellent condition for finding fossils, did not reveal any. The Olenellus horizon is placed at the base of the Middle Cambrian and the great remaining part as Lower Cambrian.

EMMONS, (S. F.),[34] in 1886, discusses the possibility of the post-Cambrian eruptive character of the Cottonwood granite. This body occupies an area of about 7 by 15 miles, and a thickness of some 5 miles of sedimentary rocks abuts against its northern side, the principal members sweeping around and in part covering its eastern portion and continuing southward in an almost horizontal position. There is no especial disturbance of these beds in contact with the granite so far as observed. Neither are any masses or fragments of sedimentary rock included in the granite. Regional metamorphism exists in changing the sandstone to quartzite and limestone to marble, and porphyry dikes cross the sedimentary strata, but these have no necessary connection with the granite. If the granite is an intrusive mass cutting the Carboniferous strata, it is necessary to believe that it has assimilated or eaten up over 500 cubic miles of sedimentary rocks. If it has done this it has left no trace of fusion in the adjoining rock, and without showing in its own structure and position any marked variation from that of a normal rock. It is further difficult to understand where the great supply of heat is to be obtained to do this work.

WALCOTT,[35] in 1889, places the Olenellus horizon at the base of the Cambrian and the great series of conformable siliceous rocks, 11,000 feet thick, below this zone as pre-Cambrian or Algonkian rocks.

VAN HISE,[9] in 1889, made an examination of several canyons of the Wasatch. While the Cottonwood granite mass has a regular structure which is seen in the great cliffs, it is apparently completely massive, even in huge blocks. The apparent lamination is due to the parallel arrangement of the minerals, which have crystallized with their longer axis in the same direction. The lamination of the granite is not more marked than is the case with some of the unmistakable gabbros of the Keweenaw series. An examination of the granite in thin section shows that the feldspars have universally a well marked and beautiful zonal structure, such as is known only in eruptive rocks. Sections of some of the black bowlder-like areas so common in the granite differ from the mass of granite only in that hornblende is more plentiful. The main Cottonwood mass and Clayton peak granite are identical in character. In places the sedimentary rocks, and especially the limestones, are exceedingly metamorphosed. In one place, near the head of Little Cottonwood canyon, at a contact with the granite it was exceedingly difficult in the field to tell where the white granite ended and the crystalline marble began. In thin section there is no difficulty in separating the marble and granite, so that there is no transition here. However, the granite became a true porphyry in places, a fact difficult of explanation unless it is regarded as a later intrusive.

In the Cambrian of the Little Cottonwood was found a conglomerate which carries unmistakable granite pebbles and black fragments which were thought in the field to resemble the black hornblendic areas so often mentioned in the granite. These, however, when examined in thin section were found to be entirely unlike those contained in the granite. The granite fragments are small and sparse and do not appear to be lithologically like the massive granite of the Cottonwood.

An examination of the Weber canyon of the Farmington area showed that the rocks, instead of always having a western dip as described, are most intricately and minutely folded and dip both east and west, although having a general sameness of dip for considerable areas. In this canyon and in Sawmill canyon a search failed to find evidence of unconformity between two series of Archean rocks. The schists and gneisses are cut by pegmatitic granite veins in the most irregular and intricate fashion. The main mass of the lower part of the Sawmill canyon Archean is a series of schists. In going up the canyon, granite begins to appear cutting the schists, and becomes more and more prominent until it is the most abundant material. It is here exceedingly coarse, and the whole appearance is that of an intrusive which has cut the schists and gneisses by numerous apophyses. It is probable that the small area referred to by King as being the older unconformable Archean was not found.

LITERATURE OF THE PROMONTORY RIDGE, FREMONT ISLAND AND ANTELOPE ISLAND RANGES.

STANSBURY,[1] in 1853, states that granite, gneiss, mica-schist, slate, and hornblende-rock occur at Antelope and Fremont islands. On the west side of Fremont island is a bold escarpment 100 feet high of talcose slate, overlain by granite and gneiss. On Promontory point mica-slate and limestone were seen.

HAGUE,[6] in 1877, finds the promontory of Great Salt lake to consist of quartzites and mica-bearing schists in a conformable series, dipping to the west about 38°, and estimated to be 3,800 feet thick. In the middle of the series is a zone of calcareous sandstone, within which are several beds of limestone. In the vicinity of Promontory station the Archean schists are overlain by limestones. On Fremont and Antelope islands are outcrops of Archean rocks. That of Fremont island consists of hornblendic and micaceous gneisses, dipping to the west, while that of Antelope island is mostly gneisses with some quartzites and mica-slates, one of these beds becoming calcareous and approaching a limestone.

LITERATURE OF THE OQUIRRH MOUNTAINS.

HAYDEN,[21] in 1873, describes regularly stratified quartzites as resting upon a series of granitoid strata in the Oquirrh mountains at the south end of Salt lake. The quartzites pass up into micaceous clays or shales, then into limestones. The lower beds of quartzite and limestone are probably of Silurian age, and it is known that the second limestone is of Carboniferous age.

EMMONS, (S. F.),[6] in 1877, finds granite-porphyry in the foot-hills of the Oquirrh mountains, and in the same range, at the head of Bingham canyon, are diorite dikes which resemble those of the main Wasatch range.

LITERATURE OF THE AQUI MOUNTAINS.

EMMONS, (S. F.),[6] in 1877, describes at Bonneville peak a body of white quartzite not less than 6,000 feet in thickness dipping to the westward. In this quartzite are beds of conglomerate strata, the pebbles of which are flattened and of argillaceous rock, containing mica and becoming imperfect mica-schists like those east of Farmington. This series is regarded as equivalent to the Cambrian of the Wasatch on lithological grounds, because it rests below a great limestone formation and because it is thicker than any of the higher quartzite series of the Wasatch. On Grantville peak a similar series is found.

KING,[7] in 1878, describes in the ridge east of Egan canyon as occurring directly over the granite several thousand feet of quartzitic schists, capped by about 50 feet of highly laminated fissile argillites, which are quite similar to the quartzitic schists of the Wasatch

LITERATURE OF THE RAFT RIVER RANGE.

HAGUE,[6] in 1877, describes in the Raft river range a considerable body of structureless medium grained granite, forming the central mass.

LITERATURE OF SOUTHERN UTAH AND SOUTHEASTERN NEVADA.

GILBERT,[36] in 1875, states that the ridges of the Basin range system are in part composed of granitic and cognate rocks. The granite occupies various positions. Often it is the nucleus of the range against which inclined strata rest. Elsewhere it appears in dikes, traversing either the sedimentary rocks or other granites. In a few instances it was observed to overlie the sedimentary rocks, while in a number of localities the evidence of its eruptive character is unequivocal; in others it is plainly metamorphic, and in by far the majority of cases it appears to have assumed its relation to the undoubted sedimentary rocks before the upheaval of the combination. In the Granite mining district the section shows a white crystalline marble overlain by granite, which appears to extend from the summit of the range to the opposite base. The axis of the Snake river range consists of quartzite and limestone, with a limited amount of crystalline schists and granite. Metamorphic sedimentary rocks of undetermined age were seen at a number of points and have been regarded provisionally in mapping as Archean, with which have been grouped the granitoid rocks.

MARVINE,[37] in 1875, states that crystalline rocks are found on the Salt lake road in the Virgin mountains.

HOWELL,[31] in 1875, states that Granite rock is an island of granite in the desert, which shows traces of bedding, with a high dip to the west. The nucleus of Snake range is granite, exposed at many places, and overlain by quartzite, shale, and limestone.

SUMMARY OF RESULTS.

In the Uinta mountains the much folded, banded, and contorted granitic rock (so-called quartzite) of Red creek canyon, in its crystalline character, in the intricate way in which it is folded and is cut by ancient metamorphosed basic eruptives, is more nearly analogous to the fundamental complex of other areas in the West than to the Huronian, as has been before suggested.

The lithological analogy between the overlying Uinta series and the Huronian Sioux quartzites, mentioned by Hayden, is very close indeed, but can be considered as a guide of no great importance. This great series of sandstones, quartzites, and shales, unconformably below the Carboniferous and separated by a great unconformity from the fundamental complex, may, so far as present certain knowledge goes, belong anywhere from the Devonian to the Algonkian.

That it is the equivalent of the Weber conglomerate of the Wasatch and belongs to the Carboniferous, as tentatively placed by the Fortieth Parallel survey, is not likely. Its great thickness, its separation by a very considerable unconformity from the fossiliferous Carboniferous, and its lithological character, combined with the fact that a careful search by different observers has revealed no fossils, make it probable that it belongs as low in the geological column as the great basal quartzite series of the Wasatch, in which case it is Upper Algonkian. It is not certain that the series does not occupy a still lower position, perhaps being equivalent to the Huronian, as already suggested.

The general structure of the Wasatch, as explained by the Fortieth Parallel surveyors, stands untouched by later work; that is to say, there is here a great series of pre-Cambrian rocks, against which was deposited unconformably an immense thickness of clastic deposits, and the abrupt western face of the Wasatch is due to a great fault.

Passing to details, it is plain that Geikie's objections to the pre-Cambrian character of the Cottonwood granite mass have great weight. However, it is to be said that while the difficulties involved in the explanation of the Fortieth Parallel surveyors is considerable enough, they do not appear to the writer to be so great as indicated by Geikie. The pre-Cambrian mountain represented in the sections, instead of being 12 miles high, is but half of that height, since its height is not ascertained by measuring its horizontal base, but by the perpendicular distance between the extension of the Cambrian basal beds and the topmost granite. Also, if the stratified beds are supposed to be deposited about the mountain with a slope away from it, as is common along a steep shore line, the altitude of the mountain would be even less than this. This estimate does not provide for the increased altitude which the mountains must have had before being buried. If the section is turned back so as to represent the stratified rocks as horizontal, the average steepness of the granite to its culminating point is found to be in the neighborhood of 45°, the lower reaches being less than this, but the steepness increasing to more than this amount in the upper slopes of the mountains. If the strata are considered as originally deposited with a dip of 10° away from the mountains, this would reduce the average slope of the mountain to 35°. Even with these allowances it is to be said that a buried slope of this degree of steepness, which is covered by the debris of an advancing shore line with the additional altitude of the mountains required in order to furnish the surrounding debris, seems highly improbable.

So far as facts were observed by the writer bearing upon the question of the character of the Cottonwood granite, they tend in the same direction as Geikie's conclusion. If this granite is supposed to be a later intrusive, the metamorphism of the sedimentary beds noted by the Fortieth Parallel surveyors, the presence in them of the granite-porphyry dikes, the sharp contacts and manner in which this eruptive mass cuts across the Archean crystalline schists at the foot of Little Cottonwood canyon, are all explained. In this connection it is to be said that so far as known the zonal character of the feldspars so well displayed by this rock is nowhere found in such perfection in such, ancient rocks as the pre-Cambrian, although this point may not be one of much weight. If the granite is an eruptive, the contained round black areas described by nearly all observers, and early taken as evidence that the granite is metamorphic, must either be partially absorbed fragments caught by the eruptive mass, or else segregations of hornblende which formed at the time of the crystallization of the rocks. If the post-Cambrian eruptive origin of the granite be accepted, there is no necessity for considering the Wasatch fault of such great magnitude and the pre-Cambrian mountains of almost incredible steepness and height.

Upon the other side, it must be said that if the estimate given by Emmons of the amount of sedimentary material of necessity absorbed by the eruptive theory—500 cubic miles—be correct, it is almost an equal strain upon belief. In this connection the question arises whether a closer study of the region will not show that the Cambrian strata have a quaquaversal arrangement about the Cottonwood granite as do the Silurian, Devonian, and Carboniferous strata, the edges of the Cambrian being uptilted, and, like them, the structure as a whole being batholitic. While it may be found that the entering granite has absorbed a portion of the Cambrian quartzite, the amount thus assimilated would be comparatively small. On this hypothesis the present distribution of the rocks would be explained by intrusion and erosion.

The relations of the clastics to the much larger Farmington and northern Archean areas, unquestionably older than the sedimentaries, are such as to require comparatively low and relatively gentle slopes and pre-Cambrian mountains not higher than from 12,000 to 18,000 feet; that is, mountains not higher than those at present existing adjacent to the ocean.

In the Wasatch, among the rocks which the Fortieth Parallel survey placed as pre-Cambrian, the writer was able to find no rocks which are not completely crystalline. An examination of the specimens collected by that survey showed no clastic rocks. In the Farmington area the crystalline schists and gneisses are cut by coarse, intrusive granites; hence, so far as at present known, aside from the usual fundamental crystalline complex, there is no evidence of any rocks below the conformable succession placed in the Paleozoic, excepting the small area of quartzites and quartzose mica-schists at the foot of the Cottonwood canyons. The reference of the basement complex of the Wasatch to the Huronian on lithological grounds by the Fortieth Parallel survey could have been made only by a mistaken conception of the real character of that series. This complex is lithologically much more nearly like the crystalline complex of rocks usually referred to the Laurentian.

The calcareous argillites, limestone, and the quartzites occurring on Antelope island and Promontory ridge are of a different lithological character from the main area of Wasatch Archean and may represent a later series of rocks. To this series the Lower Cottonwood schists may also belong. There is no decisive structural evidence in the nature of known contacts showing that these rocks are older than the lower part of the succession which was referred to the Paleozoic, but the latter series is nowhere so crystalline, and the fact that these rocks were placed in the Archean rather than the Paleozoic by the Fortieth Parallel survey shows that the affinities of these rocks were thought to be with the former. Since part of the rocks here included are certainly of clastic origin, it appears that there is in this region representatives of the Algonkian system.

Below the Olenellus fauna in the great succession of rocks referred to the Paleozoic by the Fortieth Parallel survey is a conformable inferior series of quartzites and schists about 12,000 feet in thickness. There is no evidence that these are not pre-Olenellus, and they are therefore doubtfully mapped as pre-Cambrian or Algonkian. The descriptions of this series show that it is a considerably altered one. The sandstones have been indurated to quartzites, and the mica-schist of Twin peak is quite crystalline. If this reference of the Wasatch lower quartzite to the Algonkian proves correct, it stands as the uppermost series of this system, in a position equivalent to the great series of barren slates of Montana, described by Davis and Peale as conformably below the Cambrian.

SECTION V. NEVADA, NORTH OF PARALLEL 39° 30′.

LITERATURE.

SCHIEL,[38] in 1855, states that in the Humboldt and other island mountains of the desert west of Salt lake are granites, syenites, quartzose rocks, and clay-slates.

EMMONS, (S. F.), and HAGUE,[6] in 1877, describe the mountain ranges of the Nevada plateau and the Nevada basin.

Granites constitute the entire cores, or a large part of the cores, in the following ranges: Ibenpah, Wachoe, Antelope, Schell creek, Egan, Franklin buttes, Ombe, Gosi-ute, Peoquob, East Humboldt, White Pine or Pogonip, Wah-weah, Cortez, Seetoya, Shoshone, Toyabe, Augusta, Fish creek, Havallah, Pah-ute, West Humboldt, Montezuma, Pah-tson, Granite, Pah-supp, Sah-wave, Truckee, and Lake.

In the hills between Antelope and Schell creek mountains, in the Goose creek hills, and in Franklin buttes, granite-porphyry is also found. In the Franklin buttes there is a gradation from syenitic granite, through granite-porphyry, into genuine felsite-porphyry. The hills between the Antelope and Schell creek ranges contain cores of granite, east of which are interstratified beds of dolomite, marble, and dikes of granitic porphyry. These are considered to represent the development of an Archean body.

The granite of the Wachoe range is different in its lithological character from the Raft, Ombe, Gosi-ute, and Peoquob ranges, and is therefore regarded as eruptive. No decisive evidence shows its age, but it is regarded, because of the nature of its occurrence, structure, and mineralogical habit, as probably Jurassic. The granite of the Fish creek mountains is structureless and would seem to be an intrusive body. The entire mass of the Pah-supp range consists of granites which resemble the later granite of the Pah-tson range.

The Cluro hills of the Cortez range are composed of syenite-granite, which is the only true syenite found in the region.

The Peoquob, East Humboldt, Shoshone, West Humboldt, Montezuma, Pah-tson, Truckee, Lake, and Pea Vine mountains contain, besides the granitic rocks, various crystalline slates and schists which are regarded as Archean. On Spruce mountain of the Peoquob range are mica-schists and mica-slates which probably belong to the older series, but the relations are obscure. They are distinctly bedded, finely laminated, and similar to the crystalline schist series of the Humboldt range. The East Humboldt range, the main range of central Nevada, is a mass of Archean rocks, which acts as the axis of an anticlinal fold and upon which rest unconformably the Devonian and Carboniferous strata. The southern part of the range is composed of granite in two large areas, which possesses, at White Cloud peak, the characteristics of an eruptive granite, there being no distinct lines of bedding, although divisional planes are noticeable. The northern granite mass is unconformably overlain by a series of quartzites, hornblende-schists, and gneisses which contains beds of dolomitic limestone from 1 to 6 feet in thickness, separated by micaceous quartzites and mica-schists. This series, estimated in the northern part of the range to be from 5,500 to 6,000 feet in thickness, is best seen on Clover canyon and Boulder creek. There is every gradation between the coarse gneissoid phases and the fine grained mica-schists. The granite of the Humboldt is similar to the Laurentian of the Appalachian, while the unconformably overlying series closely resembles the eastern Huronian. In the Southern Shoshone range an original Archean island is wrapped around by fine grained micaceous slate. The Archean granite of Ravenswood peak has remarkably regular bedding planes apparently conformable to those of the overlying slates, which give it the appearance of being a stratified granite, although it at the same time traverses the slates in dikes. The Ravenswood peak granite to the east is essentially different from the Archean granite and is evidently of later origin. In the West Humboldt range the granite shows structural planes. Along its northern and western edge it is overlain by a series of metamorphic schists and gneisses, which are in turn overlain by fine, white, knotted schists. The strike of these beds is N. 38° E., and they stand nearly vertical. The contact of the granite and schist shows in a horizontal plane irregular angular intrusions of the former into the latter, masses of schists lying in the granite and extending as promontories from the main mass for 400 or 500 feet. The line of demarcation between the two bodies is easily observed, and there seems to be no tendency for the schists to pass by gradation into the granite. Dikes penetrate both the granite and schists. The range is regarded as an anticlinal fold. In the Montezuma range are slates and schists which rest unconformably upon the granite. The Pah-tson mountains consist almost entirely of granite and crystalline schists, which are cut by numerous dikes, the whole being regarded as Archean, because the dikes do not cut later eruptive granites, which are found in considerable quantity, and differ markedly from those which are regarded as Archean. In the Truckee range are found quartzitic schists and hornblendic rocks with both older and later types of granite. The metamorphic schists cut by intrusive granites referred to the Archean occupy but a small area, the later granites making up the greater part of the range. In the Lake range are granite and Archean gneissic rocks, which are quite unlike any other observed rocks in western Nevada. The Pea Vine mountains consist of quartzites and fine grained feldspathic rocks, which are referred to the Archean, but their relation to the other crystalline rock masses has not been made out.

In Schell creek, Egan, Pogonip or White Pine, and Piñon ranges the granite is overlain by Cambrian strata. In the Schell creek mountains are limestones bearing Primordial fossils overlying heavy bodies of Cambrian quartzite. In the Egan range, overlying the granite, is a series several thousand feet thick of quartzites and quartzitic schists with a 50-foot bed of roofing slate. The main mass of quartzite is thoroughly vitrified, showing little trace of granular structure. A portion of the quartzites show evidence of having been submitted to great pressure, and the slate at times gets to be micaceous, and even becomes a normal mica-schist. This series doubtless represents the Cambrian, but the direct contact of the overlying limestones was not observed. Overlying the granite of the Pogonip mountains, apparently unconformable with the granite, are outcrops of mica-slate and black arenaceous and argillaceous slates and shales, in turn overlain by an undetermined thickness of compact vitreous quartzite. Above this quartzite (regarded as Cambrian because resembling the Cambrian quartzites of the other Nevada localities) occurs the Pogonip fossiliferous limestone the higher beds of which are referred to the Quebec group. In the Piñon range, below the heavy Silurian limestone there occurs a heavy bed of red and brown quartzite underlain by mica-schists and quartzitic schists 5,000 feet in thickness, which from their position inferior to the Silurian and their similarity to the Wasatch Cambrian are referred to the Cambrian age.

In the East Humboldt range overlying the granite is quartzite, which is referred to the Ogden, but without any overlying rock. In the Wah-weah range, surrounding the granite, occurs a heavy bed of quartzite, which is referred to the Ogden Devonian, although but little examined.

In the Ombe, Gosi-Ute, Peoquob, Little Cedar, Toyano, Fountain Head, Cortez, River, Northern Cortez, and Battle ranges the rock overlying the granite is a nonfossiliferous quartzite referred to the Weber. These quartzites are generally of a bluish gray color, contain flint and chert fragments, often angular, and jasper pebbles, sometimes have thin seams of carbonaceous material, are often ferruginous, and not infrequently conglomeratic. At these ranges the Weber is overlaid by heavy bodies of limestone referred to the Upper Coal-measures, generally carrying fossils to the contact with the quartzite. At most of these ranges the quartzite is several thousand feet thick, sometimes as much as 6,000 or 7,000. At Pilot peak of the Ombe range, interstratified with the quartzites, are mica-schists, and the series resembles the Cambrian of Bonneville peak, Aqui mountains. In the Seetoya and Shoshone ranges the quartzites referred to the Weber are between heavy beds of limestones, and in Two Cubits it conformably overlies an enormous development of Wasatch limestone.

The stratified rocks overlying the Havallah, Pah-Ute, West Humboldt, and Truckee granites are referred to the Triassic; that overlying the granites of the Pah-supp range is referred to the Jurassic; while the gray slates resting unconformably above the Sah-wave are referred to the Miocene. These references are mostly made on lithological grounds, because no Paleozoic strata have been recognized west of the Battle mountains, although in certain cases paleontological evidence is found.

It is remarked that throughout Nevada are large bodies of quartzites without any clue to their stratigraphical relations with an underlying or overlying limestone, the adjacent rocks being either granites or Tertiary volcanic outflows. It is then exceeding difficult, if not impossible, definitely to determine their true geological horizons. In many cases lithological and structural resemblances furnish a strong aid, which, when followed up, not infrequently throw the evidence in favor of one or the other of the great zones of quartzites; but in many cases such resemblances are meager, and the references are made upon theoretical grounds, being upon slight evidence, or even personal impressions received in the field.

KING,[7] in 1878, describes many of the Nevada ranges.

In the Gosi-Ute range the Archean rocks are granite, granite-porphyries, and crystalline dolomites, all of which are interlaminated and are chemically allied to those of the Humboldt range. That the granite-porphyries are interstratified with the marbles confirms the probability of their being metamorphic.

The Archean of the Humboldt range, with the exception of a small body of granite, is composed of a conformable series of gneisses, gneissoid schists which are sometimes hornblendic, dolomitic limestones, and quartzites, all of which dip to the west. It is evident by the entire absence of easterly dipping Archean and Paleozoic rocks that a fault similar to that at the Wasatch has cut down the core of the range from north to south, and that the eastern half is depressed below the level of the Quaternary plain. The White Cloud peak granite bears a singular resemblance to some of the Huronian granitoid rocks, also conceived to be metamorphic. The granite appears to underlie conformably the series of schists. The gneisses of Clover peak can not be distinguished in hand-specimen from a granite, except that there is an indistinct parallelism of its dark constituents. Between this stage and the truly schistose gneisses there is every possible transition. The limestone series is not over 50 or 60 feet thick, in beds from half an inch to 6 feet. Intercalated with the limestones are gneiss and porphyries very like those in the Gosi-Ute range. The upper beds pass through a transition into the pure quartzites. The Humboldt Archean schists have a family likeness with those of the Farmington region of the Wasatch and those of the Medicine Bow.

In the Cortez range a central body of granite is invaded by syenites, is overlain on the west by a quartzite, which is, for the sake of convenience, referred to the Weber.

In the Shoshone range the stratified series dip away from the central mass, which has rather the appearance of an intrusive core. From their likeness to other known Archean rocks, and for want of reasons to the contrary, these schists, together with the granite, are referred to the Archean. Regular parallel divisional planes are seen in the granite, so as to give it an appearance of stratification, but as it penetrates the schists in the form of a dike, there is no doubt of its eruptive origin.

In the Havallah range, associated with the older granites, are intrusive granite bodies, but such occurrences are exceptional along the area of the fortieth parallel.

In the West Humboldt range a variety of crystalline schists are found unconformably upon the granite, there being no tendency for a passage to occur between the two rocks and dikes of granitic material invading the schists. In the schists are roundish areas of quartz, which might be explained on the supposition that they are the pebbles of conglomerates, but they are more probably an aggregation formed during metamorphism.

In the Montezuma range the granite of Trinity peak is undoubtedly of eruptive origin, as may be determined from its general habitus and from its penetrating the Archean schists in well defined dikes.

In the Pah-tson range the Archean nucleus consists of crystalline schists, a limited amount of granite, and a subsequent granite which has cut through the older granites and schists. These are all cut by dikes of later age, but supposed to be Archean.

The Truckee range is composed of schists and granite representing two periods of formation.

The Pea Vine mountains consist of a series of conformable, highly altered beds, striking from north 50° to 65° east, made up for the most part of fine grained quartzite strata, riven in every direction with minute fissures, which are filled with ferruginous material.

It is remarked that in the absence of any granitic dikes penetrating the stratified series, or of peculiar local metamorphism, or general evidence of intrusion, the bodies are usually referred to the Archean. Only in cases where the granite is actually seen to penetrate the openings in the strata is it safe to refer it to a later age than the sedimentary series.

In the analytical map the rocks are divided into two classes, the intention being to discriminate those formations which are sedimentary from the class of eruptive rocks; but this line can not be drawn with precision, because the series of gneisses pass into the massive layers and because limited bodies of granite which are massive might if more largely exposed pass into crystalline schists or other Archean sedimentary rocks.

It is not easy to analyze those subtle appearances which lead the observer to incline to one or the other of the two possible modes of origin of a granite outcrop. Parallelism of bedding, and even parallelism of the arrangement of minerals, are consistent with the theory of an eruptive origin. Certain masses of gneissoid granite appearing in the great eruptive granite body of the Sierra Nevada show quite as much parallelism of bedding and internal arrangement of minerals as the Rocky mountain granites to which we have assigned a metamorphic origin; yet the Sierra field, as a whole, is clearly eruptive. But at the same time, in the intimate arrangement of the mineral particles and in the mode of contact between the various mineral ingredients, there is a certain broad uniformity in all the eruptive granites which produces a characteristic impression upon the eye. On the contrary, the granites which we conceive to have been of metamorphic origin, no matter how simple the mineralogical composition, have always a peculiar variability of arrangement; and even in the absence of any pronounced parallelism, they show the effect of interior compression and irregular mechanical influences. On the one hand, in the eruptive granites there seems to have been a steady expansive force, doubtless due to the heat and elastic fluids, which gave to all the particles a certain independent polarity, while in the metamorphic granites they seem to have been crowded into constantly conflicting positions. As the result of this, the crystalline particles of the metamorphic granites are much less apt to have completed their crystallization, or, if it was completed, they have been crushed and torn asunder and their particles scattered, while in the case of the eruptive granites crystallization seems to have been more perfected. The result of this is to give to the eruptive granites something of the uniformity of texture of a volcanic rock, while all the metamorphic granitoid rocks, when once the gneissoid parallelism of minerals is broken up, have a crushed, irregular, and confused mode of arrangement.

The metamorphic rocks of the Humboldt mountains, Franklin buttes and the Kinsley district are provisionally correlated with the Huronian of Canada.

The foregoing ranges are referred to the Archean simply on petrological evidence. This mode of correlation is dangerous, but a general study of the whole region has strengthened the belief that in the Paleozoic series as a whole there are none of those results of extreme metamorphism which in the Appalachian system are described by some geologists as closely approximating to Archean forms.

Besides mentioning localities given by Hague in which Cambrian is found, it is said that an excellent exposure of Cambrian schists and quartzites is found underlying the Pogonip limestone, in the range of hills including the Eureka Mining district and connecting the Diamond and Piñon ranges.

HAGUE,[39] in 1883, describes the Eureka district as a mountain block standing between the Piñon and Diamond ranges. At the base of the series is the Prospect mountain quartzite, 1,500 feet thick, over which is a shale 100 feet in thickness bearing the Olenellus fauna. One small area of granite is found. The Prospect mountain quartzite lies in contact with and dips away from it in irregular broken masses.

WALCOTT,[33] in 1886, describes the Eureka series of Nevada as middle Cambrian and finds at the top of the Prospect mountain quartzite the Olenellus fauna. In the adjacent Highland range a more abundant fauna is found in the lower 1,500 feet of quartzite.

WALCOTT,[35] in 1889, places the lower quartzite of the Eureka and Highland sections as basal Cambrian.

SUMMARY OF RESULTS.

It is evident that west of the Wasatch no such detailed and careful work was done by the Fortieth Parallel Survey as in that range and in the ranges to the east. In the Nevada ranges, which contain granite only, the reference of the rocks to the Archean or to a later period is based upon too little evidence, and it can only certainly be said that in each case the granites are older than the oldest sedimentary rocks with which they are in contact and do not cut. Some of the granite areas are said to be as late as the Jurassic, as for instance that of the Washoe range, which is in eastern Nevada. That this is an intrusive could be determined, because it cuts the pre-Jurassic rocks; but in the numerous cases in western Nevada the undisturbed sedimentary rocks adjacent to the granite ranges are Triassic or Jurassic; so that granites earlier than these periods, but far later than the Archean, would show no structural evidence of their late age.

It is now well settled that granitic-textured rocks vary into porphyritic forms, but to the Fortieth Parallel Survey belongs the credit of an early recognition of this. In the Gosi-Ute and Franklin butte ranges, in which the rocks are referred to the Archean, the granites are said to grade into granite-porphyries, and at Franklin butte into a genuine felsite-porphyry.

In the Gosi-Ute the granite-porphyry is so associated with crystalline limestone, referred to the Archean, as to lead to the conclusion that both the granite and granite-porphyry are metamorphosed sedimentary rocks. It seems far more probable that they are eruptives later than the crystalline limestone and have been the cause of its metamorphism. This explanation was applied by the Fortieth Parallel surveyors to the case of the interstratification of marbles and granitic porphyry in the hills between the Antelope and Schell creek ranges. In the western half of Nevada, especially, are abundantly found late rhyolites, trachytes, porphyries, etc., so that it may be said that this has been a region of great volcanic activity until late time, the chemical composition of many of the rocks being the same as granite. While probably mistakes have been made as to the age of the granites in individual cases, the general point which King makes that the ancient granites have a crushed, irregular, and confused mode of arrangement of the minerals is one of considerable weight, although it would have no bearing upon their origin; for this condition of the minerals would by many geologists be taken as merely evidence of powerful dynamic action which has produced the present confused condition in an eruptive granite, rather than the result of metamorphic processes upon a sedimentary rock. The exhibition of these characters by one mass of granite and their lack in an adjacent one, indicates that the former is of greater age because the other has escaped the effects of dynamic action.

In the cases of the Schell creek, Egan, Pogonip, and Piñon ranges, where below the Olenellus Cambrian there is a great thickness of in ferior conformable nonfossiliferous quartzite and then an unconformity before the rocks are reached referred to the Archean, the conclusion can not be questioned. Also it is probable that where there is a complex of granite, gneiss, and schists (as in many of the mountain ranges), precisely like that found elsewhere in the West, and known to be pre-Cambrian, the lithological evidence for reference to the Archean is sufficient. Among such ranges are the Cortez, Shoshone, Havallah, East and West Humboldt, Montezuma, Pah-tson, Truckee, Pea Vine, and others.

The question as to the separability of the rocks referred to the Archean into two series is hardly touched. In the East Humboldt it is evidently thought that the White Cloud peak granite is older than the schistose series, the former being regarded as Huronian and the latter apparently as post-Huronian. One wishes that more evidence were given that the granite mass in this case does not cut the schists and gneisses as in most of the other ranges. This is especially true because Hague says the White Cloud mass has the characteristics of an eruptive rock. More often the granites cut the overlying schists, as in the Shoshone, Havallah, West Humboldt, Montezuma and Pah-tson ranges, so that all of the rocks referred to the Archean are in these ranges basement complexes.

Whether there is in any of the northern Nevada ranges genuine clastics which are placed among the Archean is not positively determined. The quartz-schists, limestones, and mica-schists of the Humboldt range seem to be such a series, although they have now become very crystalline by dynamic action. In the West Humboldt range in the schists are mentioned fragment-like areas of quartz, which are explained to be aggregations formed by metamorphism. In the Pea Vine range there are quartzites. While from the descriptions there is no definite indication that truly clastic series exist elsewhere, such may hopefully be searched for in the Peoquob, Shoshone, West Humboldt, Montezuma, Pah-tson, Truckee, with perhaps a greater probability of success in the Shoshone, Peoquob, and Truckee.

If the lower 10,000 or 12,000 feet of quartzite in the Wasatch below the lowest fossiliferous horizon belong with the pre-Cambrian rocks, as suggested in the previous section, it is probable that parts of the quartzites below the Primordial fauna in Schell creek, Egan, Pogonip, and Piñon ranges belong in the same series—that is, the Upper Algonkian.

It is possible that several of the quartzites referred to the Ogden and Weber belong much lower in the geological column than supposed, for it is stated that in some cases these are referred to the Weber or Ogden for the sake of convenience, upon the slightest lithological evidence, or the mere personal impression of the observer. Some of these may be as low as Upper Algonkian. The series referred to the Weber, which in its lithological character is most similar to the Algonkian, is that in the Ombe range, where interstratified with the quartzite are seams of mica-schists.

Upon general principles it appears improbable that an equivalent to the Weber quartzite of the Wasatch should so widely be a basal formation. That a quartzite should be the lowest formation adjacent to an earlier mountain range is what one would expect, but that in so large a proportion of the ranges should now be found exposed as the basal series the same division of a single period is contrary to probability.

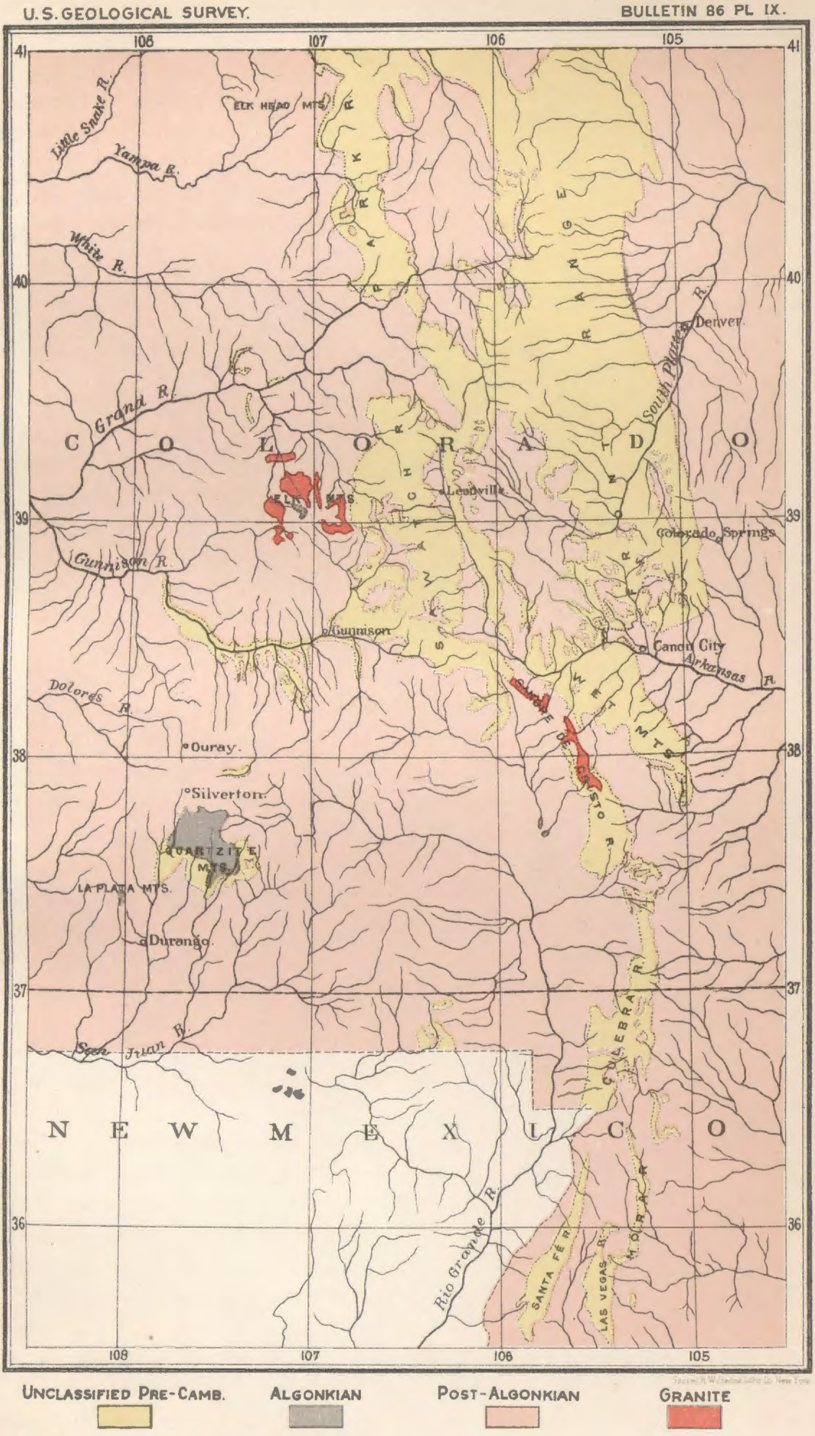
SECTION VI. COLORADO AND NORTHERN NEW MEXICO.

LITERATURE OF THE FRONT RANGE, NORTH AND EAST OF THE ARKANSAS.

LONG,[40] in 1823, describes granite as succeeding pudding-stone or conglomerate on Defile creek. The granite is coarse grained and rapidly disintegrates. A high peak was ascended and was found to consist of an indestructible aggregate of quartz and feldspar, with a little hornblende in small particles.

HAYDEN,[3] in 1869, states that all the mountains east of the South park have a gneissic and granitic nucleus. Each of the great ranges of the park are anticlinal axes with massive granite cores and gneissic granites inclining from each side in the form of ridges. The trend of the ranges is in most cases northwest and southeast or nearly so. The Azoic rocks have two planes of cleavage, one of them with a strike northeast and southwest, and the other at right angles. Besides these cleavage planes there are in most cases distinct lines of bedding. At Golden city the sandstones lie close to the metamorphic rocks, inclining 30° to 54°.

MARVINE,[41] in 1874, describes fully the metamorphic crystalline rocks of the Front range. The rocks of this great area are mostly composed of schists, gneisses and granites. Disregarding unimportant occurrences of undoubted ancient eruptives, as well as some minor granite areas of uncertain nature, the series as a whole must be regarded as a system of ancient sedimentary rocks which have undergone the most profound metamorphism, the result of which over large areas has reached the last term, structureless granite. Considering the extent and antiquity, the formation as a whole is remarkably simple and uniform, running from quartzite through siliceous and mica-schists to very simple varieties of gneisses and granites in which the mica is wholly subordinate. The least metamorphosed rocks observed were excessively hard and compact quartzites found in the lower canyons of Coal and Ralston creeks. They here pass into a series of highly siliceous schists, in places ferruginous, in which may possibly be found workable deposits of iron ore. These are associated with fine siliceous mica schists, above which are very irregular schists, intercalated together. Gneissic and granitic strata are frequent, while below is a great granite mass with but few remnants of bedding left, but which is apparently conformable with



GEOLOGICAL MAP OF PORTIONS OF COLORADO AND NEW MEXICO

SHOWING PRE-CAMBRIAN ROCKS

Compiled from the King, Hayden & Wheeler Reports

Scale $\frac{1}{3.450.000}$

the series above. A similar succession was observed near the Little Thompson, quartzites being found at the top and granites at the base. On South Saint Vrain's, and at the mouth of South Boulder canyon are found quartzite resting upon zoned but structureless granite. The Triassic shales rest unconformably upon the mica-schists on Little Thompson. The dominant rocks are granitic and gneissic, although schists are found over large areas, and of these the tendency is toward a binary granite to which the name Aplite might apply.

That the characters noted above are evidence of a structure that once existed throughout the whole mass; that the inclosed schistose patches and areas are neither remnants of foreign schists inclosed in an eruptive granite mass, nor accidental lamination developed by crystallization or motion in a plastic rock, is abundantly proved by the fact that whenever over a continuous area a great many of the strikes and dips of such remnants are carefully noted and platted on the map, they are invariably consistent among themselves in indicating a definite structure of the whole, and accord with the structure that may be indicated by neighboring schists and other masses of undoubted bedded rocks.

As in the derived sedimentaries is found the débris from the crystalline rocks, it is concluded that the folding which affected the metamorphism is older than that which has upturned the sedimentary strata. It is not supposed that sufficient heat was necessary to cause dry fusion, but aqueo-igneous fusion.

While metamorphism alone has often left sharp lines of demarkation between differently affected rocks, there are also points where movements of the plastic rock seem to have occurred; while, in tracing a line of schist into a granite area, points may occur where the normal granitoid strata regularly belonging to the series may gradually increase in number and thickness, monopolizing the series and producing a normal metamorphism; or tongues of granite may invade the schists, as if an active metamorphism had proceeded outward from the granites, eating, as it were, into the schists, and absorbing first those beds by nature most readily succumbing to the change, and leaving the intercalated masses less changed. Yet the remnants of structure left in the granites still show that no important movement has taken place in the mass, but that the rocks remain in situ, and are an indigenous granite. But, besides these confusing appearances, lines of the granite sometime appear as if actually injected or intruded among the schists, sometimes on their bedding, and perhaps across them as eruptive veins. Indeed, there seemed cases where, in approaching the same mass of granite from different points, at once all the appearances of a truly exotic and eruptive origin might be found—abrupt lines of demarkation and veins, while at another point nearly all the steps of a gradual metamorphism and transition from the schists beyond might be traced, while the remnants of structure through the mass itself would, in greater part, conform to the surrounding system of folds, showing it as a whole to be an indigenous mass. Two observers thus approaching such a mass would justly render different verdicts as to its nature, one ascribing to it a wholly eruptive origin, the other a clearly metamorphic character. A few minor masses of granite did not show well marked transitions from schists, though in part the ends of the latter gradually, yet abruptly, merged into the granite, as if absorbed by it, the mass as a whole presenting an intrusive character. There is, however, no evidence whatever to show that such masses have traveled far or that they might not have come from a short distance only and have been derived from rocks similar to those in which they are inclosed or others of the same series, for their likeness may be found at other points as true metamorphics. Penetrating various portions of the series are granitic, usually mostly feldspathic, veins, many of which probably extend long distances and appear to be of true eruptive character, while other granitic veins, usually of very coarse bluish quartz and white cleavable feldspar, with sheets and large crystals of white mica, seem to be more naturally referred to infiltration or to be endogenous in character, like many metalliferous veins, some of each kind showing layers of deposition or structure.

While it is exceedingly difficult to obtain structural results, a map of the eastern slope of the Front range is presented. The portion in which the structure is most clearly made out is that south of South Clear creek and having mount Evans as its culminating point. The granite of mount Evans occupies as low a geological position as any rocks in the range. No special facts bearing on the equivalency of the metamorphic series to any of the divisions of the Archean of the east were observed.

PEALE,[42] in 1874, describes several sections in the Front range at Pleasant park, glen Eyrie, Bergen park, and Trout creek, in all of which the granite underlies the fossiliferous series. On the South Platte, at the change from the sandstone to the granite the former contains fragments of unchanged granite. In other places the sandstone appears to pass by gradations into the granite. Pikes peak is composed of fine grained, reddish granite, the origin of which, whether eruptive or metamorphic, is a question. On the road from Colorado springs to South park is a granitic ridge which seems to be thrown up through the coarse beds which lie about it. In the range of the South park several sections of the fossiliferous series are described which rest upon granite or gneiss. At Georgia pass eruptive granite forms the peak, while black micaceous gneiss is at the base of the series, there being between the two slates and quartzites. At several of the sections given the basal layer of the series is a quartzite.

ENDLICH,[43] in 1874, describes granite as forming the heaviest mass of rock north and east of the Arkansas and south of the line running east and west 6 miles south of Pikes peak. Upon Cottonwood creek the rock resembles a gneiss. Resting immediately upon the granite is the Silurian, characterized by but a few fossils, and the well known quartzitic formations. The granite of this area is the oldest found in the region.

STEVENSON,[44] in 1875, states that metamorphic rocks occur in the Front range. On the North fork of the South Platte the schists are much contorted. The schists near Baileys ranch contain rudely oval nodules of quartz and feldspathic granite which in several localities are observed in layers. In many instances the large masses of gneissoid granite string out like veins on all sides from the center, and these veinlike projections break up into these nodules and thus finally disappear. It is sufficiently evident, then, that these are not metamorphosed pebbles, but concretions, the result of segregation, which marks the formation of the separate layers of quartz, feldspar, and mica in gneiss, and of the great masses of coarse granite, which occur so frequently in the gneisses and schists. Gneissoid granite is exceedingly common. It often occurs in the gneiss as great included masses of irregular shape or in elongate-vein form, spreading from a center and throwing out seams which become exceedingly thin before they disappear. In each instance the deposit seems to bear no relation to the bedding of the including rock. For the most part, however, it is found entirely displacing the gneiss and forming the prevailing rock for miles. In every such instance, however, it occasionally changes into gneiss for short distances. Not unfrequently seams of granite are found along the planes of cleavage. This granite, which may be termed segregated granite to distinguish it from the granite which many regard as eruptive, is coarsely crystalline, with the feldspar in great quantity, while the proportion of mica is very small. The feldspar varies in color from white to red, and the rock as a whole yields readily under the influence of the weather. The gneissoid granite of Taylor river exhibits granite of both the eruptive and metamorphic varieties, one passing into the other with no line of separation. There is then no room to doubt that they are of common origin and that the whole is metamorphic.

The gneiss of Ten-Mile creek is compact and might be mistaken for a quartzite. Below the junction is an immense segregation of granite, thoroughly veinlike, interlacing and running across the bedding in every conceivable way, but not persistent, as each of the veins tapers off until it disappears. In the canyon of the Arkansas, above the junction with Tennessee creek, is a gneiss which has very close affinities to the granites usually called eruptives. It passes gradually into a micaceous schist. On Trout creek is syenite and granite, which gradually assumes a gneissoid structure and contains fragments of gneiss from 6 to 20 inches in diameter which are fragmental in shape. Their presence is difficult to account for. If the granite is eruptive these might be included fragments, but there is no reason to assign any such origin to it, for its gradual passage into the gneiss is easily traced. On

Currant creek, at the west side of South park, near mount Lincoln, at Idaho springs, on the east side of South park, massive granite or syenite is seen grading into gneiss and mica-schist. At Chicago creek coarsely crystalline granite is sharply separated from the adjacent gneiss, the junction being as sharp as between a trap dike and adjoining rock. Some of the porphyritic rocks, granites and syenites are placed among the eruptives. This is done in deference to commonly received opinion; but as there is no locality in which these rocks do not pass imperceptibly into gneiss, the conclusion is reached that the preponderance of evidence is in favor of their metamorphic origin.

In speaking of Colorado metamorphic rocks in general it is said the prevailing rock is a micaceous schist passing into gneiss, and containing much granite, which in some localities entirely replaces the others. Not unfrequently the mica-schist is displaced gradually by hornblende-schist, which becomes a hornblende-gneiss, containing masses or strings of syenite, as the other form contains ordinary granite. Slates are almost wanting, and thick strata of quartzite belonging to this series were observed at only two or three localities. Serpentine and limestone seem to be absent altogether. It is impossible in the present state of our knowledge to come to any definite conclusion respecting the relations of these rocks. Hayden, in one of his reports, has referred them with doubt to the Laurentian. To determine this matter careful investigation at the north is still needed.

KING,[7] in 1878, states that in the Colorado range are two series which are probably unconformable. The upper group is distinctly bedded, has a variable amount of mica, and is correlated with the upper horizons of the Medicine bow and the higher members of the Park range, Red creek in the Uinta, the Wasatch and Salt lake islands, and the exposures in the Humboldt mountains, Franklin buttes, and Kinsley district. In the Clear creek region the series is not less than 25,000 feet thick.

EMMONS, (S. F.),[45] in 1890, states that Cross has discovered in the hills east of the Arkansas river, at Salida, a thickness of about 10,000 feet of slates and schists entirely distinct from the Archean and probably unconformable with it. These are referred to the Algonkian.

LAKES,[46] in 1890, made observations upon the district of South Boulder, Coal and Ralston creeks. In the South Boulder and Coal creek area were found between the Trias and the heavily bedded gneisses a series of quartzites, schists and conglomerates the clastic character of which is unmistakable. The series has been subjected to intense dynamic action, so that the pebbles of the conglomerate are elongated, and if it were not for the bands of this material it would be difficult to show that the series was an original clastic one, as the finer grained rocks are completely crystalline quartz-schists and mica-schists. The dip of the series is at a high angle away from the main mass of the mountains. Its higher members are quartzite, and pass down into mica-schists and quartz-schists, which are interstratified with beds of conglomerate. In passing downward the mica-schists become interlaminated with gneiss, which becomes more and more abundant, and upon Coal creek cutting the schists are also pegmatitic granite veins. Nowhere between the clastic and gneissoid series was any discordance discovered, there appearing to be between them a gradation, although a somewhat rapid one. The clastic series at South Boulder creek is at least 1,000 feet thick. The lower gneissoid series at times is in part quite regularly laminated, at other times becomes a heavily bedded granite-gneiss, but for several miles toward the core of the mountains, as far as investigated, does not become structureless granite.

On Coal creek, at one place within the clastic series, is a wedge of granite of considerable thickness, and this does not grade into the clastic rocks as does the main granitoid gneiss area. The relations of the Trias both to the granite-gneiss and to the clastic series are such as to show that it is clearly a later formation separated from them by a very great unconformity.

At Ralston creek the heavily bedded gneisses were found to vary into hornblende-gneiss interlaminated with granite veins, and these into rather fine grained schistose rock, but there was discovered here no clear evidence of a clastic series, although the more schistose phases immediately under the Trias may represent the more altered clastic schists of Coal and South Boulder creeks.

LITERATURE OF THE WET AND SANGRE DE CRISTO MOUNTAINS.

SCHIEL,[38] in 1885, describes the predominating rock of the Sangre de Cristo valley as a feldspathic granite, passing gradually into a gneiss on the right bank of the creek, the gneiss supporting a hard, shaly sandstone and a bluish brittle limestone.

ENDLICH,[43] in 1874, describes the region south of the Arkansas as consisting chiefly of granite. That forming the Sangre de Cristo mountains is of different character and appearance from that of the Front range. The Wet mountains are regarded as eruptive. Gneiss occurs in this range at Hunts peak and from there 6 or 7 miles to the northwest, and is regarded as metamorphic, although it weathers more like granite than a stratified rock. From the granite axis of the Sangre de Cristo the sedimentary rocks dip away both to the east and west. The eruptive granite of the Sangre de Cristo is the youngest of the region. Although the Sangre de Cristo range is spoken of as eruptive, this is not considered to be so in the same sense that basalt is eruptive, but to imply that the granite by some vertically acting force has been thrown upward and may now be in contact with strata which were once above it.

COPE,[47] in 1875, states that in the Sangre de Cristo mountains is stratified granite, which is either heavily bedded feldspathic porphyry or finely bedded hornblende-gneiss.

ENDLICH,[48] in 1877, states that metamorphics compose the main bulk of the interior portion of the lower Sangre de Cristo range, though at many places sedimentary beds and volcanic flows have obscured the relations. The highest peaks of the range are as a rule metamorphics among which granites and gneisses are predominant. These are associated with granites and gneissoid-schists, associated with which are hornblendic, chloritic, and micaceous schists. Near Trinchera the sedimentary strata stand nearly on end and lie tipped up against the granite. At other places the granite protrudes through the Carboniferous. It is concluded that the metamorphics of the lower Sangre de Cristo are altered Silurian rocks. North of the Arkansas river the Silurian formation occurs. From here it crosses the river toward the south and is last seen as such near the northern end of the Sangre de Cristo range. In its stratigraphical relations it is conformable with the overlying younger formations wherever it has been there seen.

ENDLICH,[49] in 1878, states that while in the Sangre de Cristo the eruptive granite is the cause of the upthrow of the Carboniferous strata, nowhere in the sedimentary beds is found any case of intrusion. These granites are regarded as post-Carboniferous.

EMMONS,[45] (S. F.), in 1890, states that quartzites have been noticed connected with the Archean of the southern end of the Sangre de Cristo range which may be assumed to be the remnants of some Algonkian beds.

LITERATURE OF THE FRONT RANGE OF SOUTHERN COLORADO AND NORTHERN NEW MEXICO.

WISLIZENUS,[50] in 1848, states that granitic rocks prevail in the mountains about Santa Fe, and for some distance to the south. These are associated with porphyry and trap.

BLAKE,[51] in 1856, describes ridges of metamorphic slate in the Santa Fe mountains, upon the edges of which rest horizontal Carboniferous strata.

LOEW,[52] in 1875, states that the mountains between Santa Fe and Las Vegas contain Azoic rocks which are chiefly granite and syenite. At Santa Fe creek gneiss is accompanied by primitive clay-slate and syenite. Veins of fine grained gneisses occur in a coarse aplite or granulite also intersected by syenite seams.

ST. JOHN,[53] in 1876, describes the Black mountains as a lofty granite barrier. The upper canyon of the Cimarron is composed of granitic rocks, with which are associated micaceous schists and hard quartzose rocks. In the Raton hills are granitic igneous rocks, the relations of which to the Tertiary are not easy to make out. The Vermejo mountains have a nucleus of massive metamorphic rocks.

NEWBERRY,[54] in 1876, states that in the Santa Fe mountains is found coarse red granite, characteristic of the central portion of the Rocky mountain system. It differs from the granite of the Appalachian as well as those of the Sierra and Cascade. The Carboniferous strata rest directly upon the granites. The central axis of the Nacimiento mountain is composed of a similar massive red granite, upon the slopes of which rests the Carboniferous formation, for the most part limestone, in many places nearly vertical yet but slightly metamorphosed.

STEVENSON,[55] in 1879, describes a continuous Archean area on the western side of the district running from Spanish peaks south. It forms the axis of the Culebra range, continues through the Taos and the Mora ranges, and passes into the Cimarron range. The Santa Fe and United States anticlines show Archean rocks which are separated from the main area. The rocks show great uniformity in character, including gneissoid granite, gneiss, and mica-schist as the predominant types.

STEVENSON,[56] in 1881, gives a systematic account of the Archean rocks of southern Colorado and northern New Mexico. Four areas are seen within the district. The most western marks the course of the Santa Fe axis; the second, that of the Culebra-Mora axis, and the third and fourth that of the Cimarron axis. The rocks in the Santa Fe axis are gneiss, mica-schist, which resembles sandstones, and granite. South of the Santa Fe road are frequent exposures of an exceedingly coarse granite, which resembles a metamorphosed conglomerate, the pebbles being thoroughly distinct. With this are many beds of almost black gneiss, holding beds of snow-white quartz. The Culebra-Mora axis varies in width from 5 to 25 miles. It includes granite, gneissoid granite, micaceous and hornblendic schists, and quartzites. Compact gneiss, quartzite-like in character, is found in the main canyon of Costilla creek. Bands of quartzites are found on Comanche creek, the north fork of Moreno creek, in Costilla creek range on Coyote creek, and in the vicinity of Santo Niño on the Cebolla creek. These are sometimes found in gneissoid-granite and sometimes in mica-schist. The granite below the junction of the forks of Moreno creek is very coarse and resembles conglomerate. The rocks of the Cimarron axis include mica-schist, coarse granite, and gneiss sometimes resembling quartzite. The dips of the Archean rocks are much confused and the distortion at most localities is so great that neither the succession of the strata nor the general structure could be made out during the brief examinations. Positive proof of nonconformability to the overlying Carboniferous is not easily obtained, the main obstacle in the way of making the determination being the character of the rock. Usually the disturbance near the junction of the two series is very violent and the rate of dip changes greatly within a short distance, sometimes becoming even reversed. But distinct nonconformability may be asserted as existing in the vicinity of Costilla peak, where the enormously thick Carboniferous series terminates abruptly against the Archean core of the Cimarron axis. No absolute evidence exists to settle the age of these rocks. Lithologically, they bear a close resemblance to the Laurentian series of the east, and at more northern exposures within the Rocky mountain region they have been referred by all observers to that age. The coarse gneissoid and often conglomerate granite immediately underlying the Carboniferous at many localities may possibly be of somewhat later origin.

LITERATURE OF THE PARK RANGE.

MARVINE,[41] in 1874, describes the northern part of the Park range as composed of a very distinctively and evenly bedded series of schists, gneisses and granites, which have a strike nearly with the ridge, and a dip of 40° or 50° to the southward.

LITERATURE OF THE SAWATCH MOUNTAINS.

HAYDEN,[57] in 1874, describes the Sawatch range as a solid mass of granite, 80 miles in length by 40 in width, which has acted as a single wedge thrust upward, and thus causing the sedimentaries to incline from either side.

PEALE,[42] in 1874, states that on Massive mountain the rocks are mainly gneissic, with alternations of porphyritic granite or granite-porphyry, with seams of quartzite and hornblendic volcanic rock. On Eagle river, at the base of the section is gneiss, and above this is white quartzite.

ENDLICH,[43] in 1874, states that the granite of the Sawatch on the west side of the Arkansas is probably post-Silurian. This range has two kinds of granite that are peculiar to it and an older predominating one. Both of these are newer than the red, middle, and coarse grained rock found in the Wet mountains. The first of these varieties composes the main part of the range and constitutes its most prominent peak, mount Princeton. Besides this, there is protogine and eruptive granite. Mount Ouray is composed in large part of hornblende rock. On one side the hornblende and granite are interstratified, the granite being regarded as intruded between the strata. The change from the granite to the hornblende rock is always abrupt.

ENDLICH,[48] in 1877, states that at the southern end of the Sawatch range trachyte is the principal rock.

EMMONS, (S. F.),[58] in 1882, states that in the Mosquito range are found granites, gneisses and amphibolites. The granites are in most cases stratified and are of undoubted sedimentary origin. In other cases the evidence is less clear and they have the characteristics of eruptive granites. Within the masses of the normal granite occur large irregular vein-like masses of secondary origin, corresponding to pegmatite. The gneiss is mostly mica-gneiss. The amphibolite is less abundant than the gneiss and granite and occurs interstratified with them. Unconformably above these are quartzites which bear Primordial fossils belonging to the Potsdam.

LAKES,[59] in 1886, describes the Sawatch range as consisting of gneiss and granite penetrated by volcanic dikes, with patches of Silurian, Carboniferous and more recent strata resting on or uptilted against each flank. In the Aspen region are two granites, one the metamorphic granite of the Sawatch and the other a diorite and eruptive lava of the Elk mountain system. On the granites are unconformably located the Cambrian strata, the base of which is quartzite.

LITERATURE OF THE ELK MOUNTAINS.

HAYDEN,[57] in 1874, describes the Elk mountains as composed of an upthrust of igneous granite, which carries portions of the sedimentary beds on its summits or tilting away from the sides at various angles. The lowest group of sedimentary rocks is Lower Silurian. In some cases there is complete overturn of immense groups of beds, so that for several miles there is a double series from the Silurian up to the Cretaceous, inclusive, as at the head of East river and near Snow Mass peak. Northeast of Snow Mass the sedimentary beds may be seen resting on the granite, on these a great thickness of red beds, and on the top of the latter masses of irregular thickness of eruptive granite from 100 to 400 feet thick, and at both ends the red beds again resting upon the eruptive mass, so that the granite now appears like an interstratified rock. Gothic mountain and Crested butte are regarded as immense dikes, the melted matter being pushed up through the superincumbent matter so as not to disturb to any great extent the thickness of yielding Cretaceous shales and clays. On Eagle river are beds of sandstones and quartzites, the fragments of which indicate that they have been derived from gneissic and granitic rocks.

PEALE,[42] in 1874, describes the entire mass of granite of the Elk mountains as having been either in a plastic or melted condition. The elevation of the range was post-Cretaceous. The mountains are cut by numerous dikes, which are in part trachytic, but which are, however, believed to be connected with the eruptive granite. On the southeast side of Elk mountains are chloritic schists, quartzites, and sandstones, all very much metamorphosed.

HOLMES,[60] in 1876, gives the geology of the northwestern portion of the Elk range and describes in detail the character of the folding, faulting and relations of the crystallines to the sedimentary rocks. On the east side the sedimentary strata lie up against the granite of the Sawatch range, and on the west they have been carried high up on the arch of the Elk mountains, leaving the synclinal depression between the ranges. The axes of the two ranges are not parallel, but approach each other toward the south and separate toward the north, giving an included angle of some 30°. In the vicinity of Italian peak the granites of the two ranges are in contact, or nearly so, being totally distinct in appearance and in reality. The sedimentary beds of Sopris and Rock creeks show a considerable amount of metamorphism and lateral crushing, the Dakota sandstones of the latter being changed to hard, flinty quartzites. A great fault, combined with a fold, runs from the north part of the Elk group, i. e., Snow Mass mountains, to its south part, White Rock mountains. In the sections the granitic rocks are represented in places as being above the sedimentary and in other places as intruding themselves among the layers.

LAKES,[61] in 1885, describes the stratified rocks adjacent to the Elk mountains as riddled with dikes and baked and metamorphosed in places almost past recognition. The huge volcanic masses are some of them dikes, while others may be laccolites.

LAKES,[59] in 1886, describes the Elk mountain eruptions as having occurred under an enormous pressure of superincumbent strata not less than 10,000 feet thick. The Elk mountains are diorite instead of being eruptive granite as called in Hayden's reports.

LITERATURE OF THE GRAND AND GUNNISON RIVERS.

SCHIEL,[38] in 1855, states that along Coochetopa creek and Grand river valleys are granite, gneiss, shale and mica-slate.

PEALE,[42] in 1874, states that adjacent to the Gunnison a section has at its base rust-colored granite, above which is mica-shist, and over this quartzite and sandstone.

STEVENSON,[44] in 1875, states that at several localities along the Grand and Gunnison is a peculiar, regularly laminated gneiss which resembles a micaceous sandstone. It always occurs directly under the sedimentary rocks and no similar formation occurs lower down. It is clearly unconformable to the great mass of schist and gneiss, though precisely like them in its changes. In consideration of all the circumstances, one can not resist the temptation of regarding it as belonging to a later series.

PEALE,[62] in 1876, describes Archean rocks as occurring along and near the gorges of Eagle and Gunnison rivers. The rocks of the Eagle river are known to be pre-Potsdam, because at the head of the stream such rocks rest upon them. On the Gunnison river the Archean rocks are gneisses and schists. The presence of Dakota beds here resting upon the Archean is supposed to prove that in pre-Cretaceous times this area was above sea level.

PEALE,[63] in 1877, describes the Archean rocks of the Grand river. These occur in limited areas throughout the district between parallels 37° 52′ and 39° 15′ and meridians 107° and 109° 30′. They are generally confined to the courses of streams flowing in canyons. In many places the schistose character is very distinct and the bedding clearly seen, but in most cases no traces of bedding were seen, the rocks being granitoid. From the number of exposures noticed it is evident that the rocks underlie the entire district, although from the limited and isolated exposures it was not possible to trace connections from one place to another. The oldest sedimentary beds resting upon these rocks are Carboniferous or pre-Carboniferous, showing that they are at least pre-Carboniferous, but it is believed that they are pre-Silurian. Along the Gunnison outcrops of quartzitic layers occur with softer red and gray gneissic layers. On the Little Dolores are mica-schists and quartzites dipping northeast at angles of 60° to 70°. As to the origin of these rocks it is said: They were once deposited as sediments. Whence were their materials derived? We have no data from which we are able even to guess what was the extent of the Archean continent, or what its character was. From the fact that in the Grand Canyon of the Colorado similar rocks are found below the Potsdam, and from the profundity of their metamorphism it is believed that these crystalline rocks are Archean.

LITERATURE OF THE QUARTZITE MOUNTAINS.

ENDLICH,[64] in 1876, describes the Quartzite mountains. Near the northern border and toward the middle, quartzites and schists predominate, while granite appears toward the east and south. The quartzites are mostly of a white or gray color, gradually becoming filled with mica or chlorite, thus turning into schists. The relations of the quartzites are extremely varied and complicated. Granites change into quartzites between stations 21 and 22. The schists have a less horizontal extent but are just as distinct as the quartzites. They also show great variations in strike and dip. As a rule they seem to be older than the granite, but it was not possible to establish this point beyond doubt. The schists were nowhere found except in the quartzite group. All the granite shows a remarkable regular stratification, not an apparent one only, produced by the main cleavage plane of the feldspar or mica lying in one direction. The dip of the strata is conformable with those of the quartzites and schists and away from the anticlinal axis toward the south. Generally the dip is not very marked but still reaching from 7° to 10°. All along the Animas the junction of the sedimentaries with the granite was not observed. The latter was exposed in the valley, while the former appeared in steep bluffs on both sides. From the dips observed it became evident that the two were conformable.

As to the origin of the metamorphic group of rocks it is said that the Devonian strata were deposited on the granitic strata conformably. Also that from the quartzite into granite the transition is perfect, although often small specimens can be found showing on the one side granite and on the other granular red quartzite. Near the top of a bluff the latter is white or yellowish, becoming red and brown lower down. Finally some mica is observed in it, and the feldspar appears as such, until the coarse grained granite is reached. The metamorphosis is very thorough, and can be admirably studied at this point. So far as could be decided, the granite was formed out of a partly argillaceous sandstone, containing some iron in an oxidized state, while the purer sandstones were turned into quartzites. Probably the process of metamorphosis was a very slow one, and lasted a long time. Throughout the stratification is well preserved in all the rocks of that group, but particularly so in the granite of the locality just described. Even the thicknesses of the various strata which have been altered into granite correspond approximately to those at present exhibited by the superincumbent beds. At a short distance north of station 48, the granite overlies the dark schists, which in turn seem to be younger than the true quartzites forming the main bulk of the mountains still farther north. Taking into consideration, therefore, the observed conformity of the underlying metamorphics with the overlying sedimentaries; taking into consideration, furthermore, the analogous character of stratigraphical relations, the conclusion must be reached that those sedimentary beds, which existed below the Devonian, furnished the material for the metamorphic masses.

COMSTOCK,[65] in 1883, states that in San Juan county there are no rocks which are of Archean age. The granitic and quartzitic series of the Animas river are regarded as metamorphic and said to be of Upper Silurian or Devonian age.

COMSTOCK,[66] in 1887, describes the metamorphic series in southwestern Colorado as probably Silurian or Devonian. This series is susceptible of division into an upper or granitic division and an underlying quartzitic formation. The quartzitic group is exposed in the Animas canyon below Silverton, forming a line of jagged peaks to the eastward, the Needle mountains. Whenever the quartzite is well uncovered the more recent granites are usually traceable along the flanks of the belt. The geological map brings out no apparent system in the metamorphic rocks.

LAKES,[67] in 1889, describes on the Mears road, south of Ouray, as succeeding the Carboniferous limestone, a thickness of 13,000 feet of distinctly stratified and hard vitreous quartzites, slates and schists. Part of these may belong to the Silurian and Cambrian, but as these combined rarely attain in Colorado a thickness of 1,000 feet, so great a body is extraordinary and suggests that the lower part of it may, as in Canada, belong to the Huronian or Laurentian, upper divisions of the Archean not elsewhere represented in Colorado. The dip of the quartzite is about 75° to the north. The uplifted crests have been deeply eroded and in the hollows so formed rest the massive volcanic breccias.

EMMONS, (S. F.),[45] in 1890, states that on the north slope of the San Juan mountains, near Ouray, is over 10,000 feet of closely folded quartzites, conglomerates, and slates of the pre-Cambrian age, and it is believed that the quartzite peaks in the southern portion of this region are probably composed of the same series of rocks. These are referred to the Algonkian.

VAN HISE,[9] in 1889, made observations along the Animas, the railroad being followed from below Needleton to Silverton, a distance of about 17 or 18 miles. As mapped by Endlich on Sheet XV of the atlas of Colorado, this course is situated, with the exception of 5 or 6 miles, in the quartzite area. Quartzites occur for a little more than 2 miles in the vicinity of Elk park in the middle of the area mapped as quartzite. The granitic area was found to be a most intricate complex of massive granite, coarse and fine, white and black banded gneiss, and black hornblende-schist or gneiss in dike-like forms. The strikes and dips vary greatly, although for the most part they are high, running from 75° to 85°. At one place the dip of the schistose structure was observed to be as flat as 10° or 15°.

The quartzitic area is in places conglomeratic. The rock is for the most part a rather pure white or gray vitreous quartzite, although occasionally it shows more or less of a slaty appearance. Nowhere in the quartzite was found any hornblende-schist in dike-like forms such as occur in the granite, or any layers which could possibly be mistaken for the black or white gneissoid phases of rock which occur so abundantly in the granite area and have such intricate relations with the granite. The dips of the quartzites are also for the most part high, being from 60° to 70°. In the quartzites, as in the granites, there are great local variations in the strike and dip of the rock. Upon both sides of the quartzite area where the change to granite occurs no evidence whatever was seen of a transition between the two classes of rocks. In neither were the quartzites and granites in contact; they were found however, a few paces apart. At the southern boundary, while the two rocks were not actually found in contact, there is a marked discordance in the strike and dip of the schistose structure of the granite and of a series of sharply folded anticlines and synclines of quartzites which are adjacent to the granite.

What is said by Endlich as to the sharp contrast between the sedimentaries and granite may mean the contrast between the black hornblende-schists and gneisses with the coarse granitoid gneisses and granites. If this is the case, the statement is true, for these materials are seen in sharp contact at very numerous places along the Animas. If these hornblende-schists and gneisses are altered eruptives, as they appear to be, the sharp contacts would have no bearing upon the metamorphic origin of the granite.

Some of the quartzites have a color similar to the coarse reddish or grayish gneisses, and also show to some extent a banded appearance. It may be that this fact has led to the statement that there is a transition between them and the granitic rocks.

A study of numerous thin sections of the material collected shows that the rocks composing the area here called granitic are always completely crystalline, giving in the thin section no evidence whatever of clastic characters; on the other hand, all the rocks belonging in the quartzite area, while locally considerably altered by dynamic action, show very clearly their clastic character. However, the evidence of the microscope is not necessary to show the clastic origin of these quartzites, as the conglomeratic phases seen in the field are sufficient to demonstrate this.

As to the conformability described by Endlich between the flat-lying Devonian and these crystalline rocks, no observations were made. It is, however, to be remarked that Endlich states that the crystallines are flat-lying, having a dip of not more than 10° to 15°. This was observed to be the case in one locality, but as before said, the great number of observations along the Animas show the dips to be for the most part very high, i. e., from 60° to verticality, and in various directions. All of the evidence as to the strike and dip show that the area of quartzites and granites is one in which the folding is very complicated.

Bearing upon the question of the position of the quartzitic series with reference to the fossiliferous rocks is the occurrence south of Ouray, along Red mountain creek and one of the branches of the Uncompahgre, of a great series of slates, quartzites and conglomerates, with high dips and repeated by folding, which are in lithological character identical with the quartzites south of Silverton. Just south of Ouray the red beds of the Jura-Trias are found in almost horizontal position upon the upturned edges of the slates and quartzites. This unconformity, in the distance at which it may be observed and in the masses of rocks exposed, is remarkably handsome. Conformable below the red beds of the Jura-Trias, at Ouray, the Carboniferous rocks appear, but they were not seen in contact with the slates and quartzites. That the quartzite series was an old shore against which the Carboniferous and Jura-Trias were deposited can not be doubted. In the distance of about 5 miles in which this quartzite series is exposed a slate band is found five times. In going north the dips are first south and then change to the north, in which position they continue until the Carboniferous appears. All this suggests that we have here to deal with a folded series and not one necessarily of very great thickness, although probably several thousand feet thick. As Ouray is only a few miles from Silverton, the argument of analogy makes it probable that the similar plainly fragmental slates and quartzites south of Ouray are the equivalent of the quartzites of Elk park. The facts bear against the probability of a transition from the Devonian into the quartzitic series of the latter place. The one occurrence in which this transition is definitely asserted is perhaps a case of a recomposed rock resting upon a crystalline one. Similar occurrences have often been described.

As to the relations of the granitic area to the quartzites along the Animas, there is no clear evidence. The fact that the granitic area is an intricate complex of regularly banded gneisses, of granitoid gneiss, and of granites cut by hornblende-schists in dike-like forms, combined with the fact that no such dike-like areas are found near the quartzites, seems to indicate that the quartzite is of later age than this complex. This probability is still further strengthened by the completely crystalline character of one series and the plainly fragmental character of the other. This point would have little weight if the granitic area was a simple massive rock which might be the result of a single eruption. But the varieties of rock of which it is composed and the intricate way in which these lithological phases are mingled indicate that the history of the granite area is a most complex and long-continued one, and was far advanced before the deposition of the fragmental rocks. If it should be held that this granitic area is eruptive as a whole and later than the quartzite, the question arises, Why is it that nowhere do any of the rocks which belong in it cut the quartzites? If, on the other hand, it is maintained that it is metamorphic in origin, the question arises, Why is it that all parts of it have become so completely crystalline while the quartzite is still so near its original condition?

LITERATURE OF THE LA PLATA MOUNTAINS.

HOLMES,[68] in 1877, places the La Plata mountains in the metamorphic belt because the central portion, as exposed in the deep-cut valley of the La Plata river, is composed of uplifted and altered sedimentary rocks; but there are associated with these a very considerable area of eruptive rocks with a resulting great complication of structure. This metamorphic group seems to be a prolongation to that to the northeastward about the Animas. Against attributing any great amount of change in the sedimentary rocks to the presence of the trachyte is the fact that in the neighboring groups of mountains of trachytic origin there is little or no metamorphism apparent. In the central part of the altered area the metamorphic mass proper extends up to and includes the red beds. As one of the best examples of the metamorphism may be mentioned that on the west face of the first mountain south of Hesperus. Here a mass of metamorphic shales abuts or is welded to the trachyte face of the mountain. The exact point of contact can not be determined, as the metamorphism has been so complete that the shales seem to change gradually into trachyte. Away from the trachyte they gradually assume the appearance of a massive grayish yellow quartzite, and in a mile or more from the place of contact assume a shaly character and dark color.

ENDLICH,[49] in 1878, gives a general discussion of the formations of Colorado. In preference to the word Azoic the word Prozoic is used. Belonging to this group, in southern Colorado, is an extensive series comprising gneisses, granites, various schists and diorites. Of these the first named appear to be the oldest, as may be inferred from the relations to the granites more particularly. The schists are in subordinate quantity. It often is a matter of difficulty to discriminate between the Prozoic and the next group of metamorphic rocks. This latter is the most varied and enormous in its development. Large areas are covered by rocks of this group, which occur in almost endless variety. In several instances localities may be observed where the transition from undoubted sedimentary into metamorphic beds is evident. This, however, must be considered as an exception rather than the rule. The gneiss is the oldest of the metamorphic rocks in the district examined. Micaceous, hornblendic and chloritic schists occur as such associated with other metamorphic rocks. Frequently they are due to the substitution of minerals within the gneiss, but they are also found totally independent thereof. If a suggestion may be offered which, however, can not at present be proved, the author would say that argillaceous sandstones form granite. With the decrease or increase of argillaceous matter in the sandstone the quantity of feldspar in the granite stands in direct proportion. Siliceous sandstones form quartzites. Shales, arenaceous in part, are changed into gneisses, and if the quartz in them is predominant they turn into schists. Quartzites can not be generally classed with the metamorphic rocks, but in the Quartzite mountains a complete alteration of the original sandstone has taken place, although stratification has been retained in a measure. Granite is the most representative species of the metamorphic group. It is younger generally than the schistose rocks occurring with or near it. In the Quartzite mountains there is a direct transition from sedimentary beds into typical granite. A large part of the granites in southern Colorado is regarded as metamorphosed Silurian, Devonian, and in rare instances even Carboniferous strata.

SUMMARY OF RESULTS.

The greater parts of the Front, Wet, Sawatch, Park, and Quartzite ranges and the crystalline rocks of the Gunnison and Grand are a completely crystalline complex of rocks which are certainly pre-Cambrian; for, resting upon these ranges unconformably and bearing débris from the older series are the fossiliferous Cambrian. These contacts are found both on the east side of the Front range and in the parks along the Sawatch, as well as at Eagle river in the Gunnison and Grand region. The granite-gneiss-schist complex of the Quartzite mountains also without much question belongs in the same position.

The relations, so excellently described by Marvine and Stevenson, between the nearly structureless granites constituting the core of the ranges and the well laminated schists and gneisses are those between the granites and associated crystallines described in Massachusetts by the elder Hitchcock in 1860, by King along the fortieth parallel, by Lawson about the Rainy lake and the lake of the Woods, and by Winchell in northeastern Minnesota. That is, in passing from a schistose to a granitic area the finely laminated schists become coarser and coarser; then appear thin belts of gneiss, which become more and more prominent until the rock has changed to a gneiss, and this by imperceptible stages passes into a granitoid gneiss, then into a granite. A whole or a part only of the laminated rocks may be cut by granite veins, while oftentimes there are considerable masses of granite in the schists of the same character as the main granite mass, the contacts being exceedingly sharp. In a few cases in the massive granites are found fragment-like areas of the schists. These imperfectly summarized relations are regarded by Stevenson, Marvine, and the other writers to be evidences of the metamorphic character of the whole series, while the intrusives are regarded simply as parts of the main mass which have become perfectly fluid and therefore locally take on eruptive forms. Lawson declines to carry the term metamorphic over to the plastic material and speaks of it as a subcrustal magma. As the real character of such granite-gneiss-schist complexes is a question which concerns not only the Colorado ranges, but almost every other pre-Cambrian region of North America, the discussion of this question is deferred for the general chapter. It is, however, plain that in the mountain ranges of Colorado is a thoroughly crystalline, intricate, fundamental complex like that found in most of the pre-Cambrian areas already considered.

Besides these crystallines there are at least two areas in which unmistakable pre-Cambrian clastics are present. These are the districts of Big and Little Thompson, South Boulder, Coal and Ralston creeks in the Front range, and the district of the Quartzite mountains in the San Juan region. It is also probable that the quartzites and mica-schists of northern New Mexico, described by Stevenson, is a third series, although the relations of these beds to the other rocks are not indicated. The great beds of white quartzite and the granite-conglomerate in the neighborhood of Santa Fe strongly suggests that here is a clastic series, the granite-conglomerate probably being a recomposed rock. A fourth great series which possibly falls among the pre-Cambrian clastics is that seen by Cross in the neighborhood of Salida.

In the Front range the descriptions of Marvine and Lakes agree that there is an apparent gradation from the clastic quartzite and mica-schist series to the gneisses and gneissoid granites, although Lakes states that the transition is somewhat abrupt. Two explanations may be applied here: First, there may be a real physical break which has not been detected between the clastics and the crystallines. In favor of this hypothesis is the fact that quartzites are found nowhere else in the vast area of the Front range, and that nowhere else are there any rocks which are even described as having any evidence of fragmental character, unless foliation be taken as such evidence. If this clastic series and the great complex of granite, gneiss and schist are of the same origin and age, it is certainly strange that nowhere except in this very restricted area do beds of quartzite or quartz-schist occur. Also the presence of genuine granitic pebbles in the conglomerates at least shows that there existed an earlier granite from which débris was derived. Second, those who believe that the fine-grained gneisses, completely crystalline schists and granites are all really of eruptive origin, the foliation being but evidence of powerful dynamic action, will probably maintain that this clastic series is the more ancient one and has been cut and metamorphosed by the intrusion of the igneous rocks.

In the Quartzite mountains the evidence that the fragmental slate and quartzite series is more recent than the granite-gneiss-schist complex is far more weighty. Here an intricate complex of irregularly banded gneisses, granitoid gneisses and granites are cut by foliated dikes of hornblende-schist, which never penetrate the fragmental series. At one of the places along the Animas at which the quartzite is separated by a very short interval from the granite complex there is a sharp discordance in its foliation and a series of sharply folded anticlines and synclines of quartzite, which with considerable certainty indicate the bedding of the latter group. Also, while the quartzite series inclines at a steep angle and is in places sharply folded, it upon the whole has not suffered any such profound and repeated dynamic movements as are exhibited by the granite-gneiss complex. If the latter series be taken as sedimentary its complete metamorphism argues its greater age; and if it be taken as wholly eruptive its present implicated character, with strongly developed schistose structures, denoting profound metamorphism, indicates a history much longer than the one revealed by the quartzites. This great quartzite and slate series can then with a considerable degree of certainty be regarded as much later in age than the granite-gneiss-schist complex. Also it is far more ancient than the Carboniferous, because near Ouray the Trias conformably above the Carboniferous rests in a nearly horizontal position upon the upturned, nearly vertical, truncated edges of the quartzite. On general structural and lithological grounds it may with great probability be referred to the Algonkian. Of the two other areas of clastic rocks too little is known to offer any suggestions as to their age or relations.

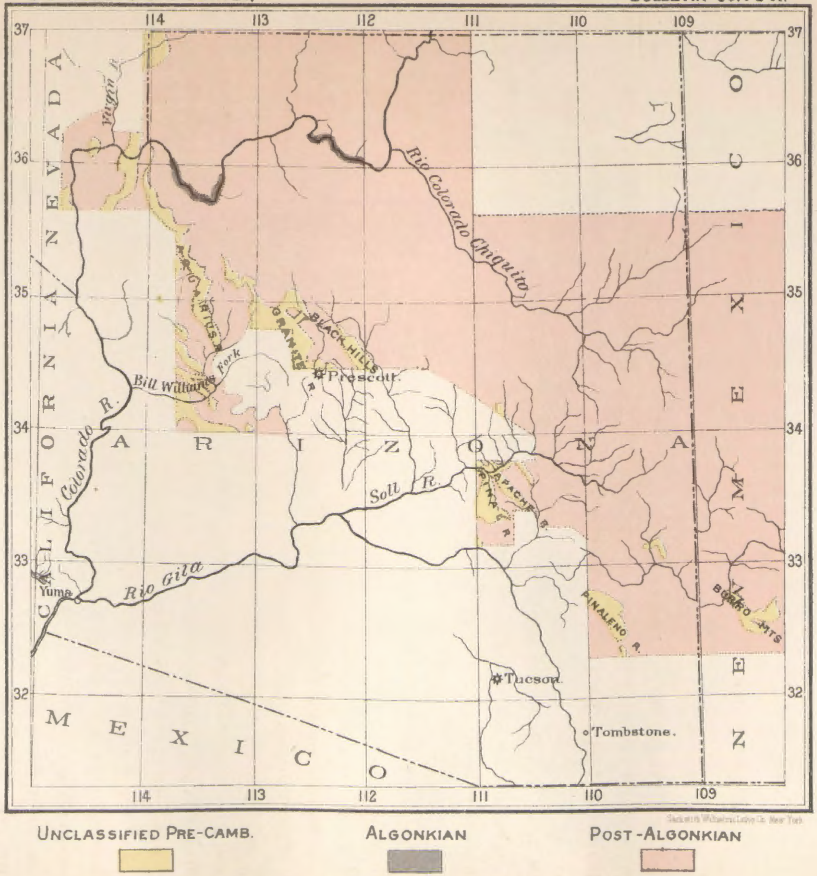
A part of the so-called granite (diorite?) of the Elk mountains and a part of that of the Sangre de Cristo range is plainly an eruptive of later age than the Cambrian, and therefore it does not properly fall within the province of this review.

Whether there are any pre-Cambrian rocks in the La Plata mountains is uncertain. The small area of metamorphosed rock bears such relations to the eruptives as to suggest that their present condition may be due to contact metamorphism.

SECTION VII. ARIZONA AND WESTERN NEW MEXICO.

LITERATURE.

POWELL,[28] in 1874, states that below the Carboniferous is a succession of nonconformable shales, sandstones and limestones, the greatest thickness of the beds being a little more than 10,000 feet. The beds are traversed by dikes of trap or greenstone and irregular layers of the same eruptive material are found in places between these nonconformable rocks and the overlying beds of Carboniferous age. Provisionally these sedimentary rocks are called Devonian and Silurian. Still underlying these is an extensive series of metamorphic crystalline schists, in some places yet showing faint traces of the original stratification, but usually these are so degraded that the total thickness of the



GEOLOGICAL MAP OF ARIZONA AND PART OF NEW MEXICO

SHOWING PRE-CAMBRIAN ROCKS

Compiled from the Wheeler and Dutton Reports

Scale $\frac{1}{6.336.000}$

beds was not determined. In places they constitute about a thousand feet of the altitude of the walls. These beds are traversed by dikes of granite, and beds of granite are found which are believed to be intrusive, hence of igneous origin. In some places the evidence is complete. An extensive period of erosion separates these schists and granite from the overlying Silurian and Devonian rocks.

In the Grand canyon are the records of an extensive period of deposition in the schists, followed by plication, erosion, fissuring and eruption. Again we have an invasion of the sea, which remains until 10,000 feet of shales, sandstones and limestones are deposited; and this is followed by a dry-land period, marked in some places by at least 10,000 feet of erosion and accompanied by plication, fissuring and eruption.

POWELL,[69] in 1875, further describes the Grand canyon group. Unconformably below the Carboniferous of the Kaibab plateau is a middle series of slates, sandstones and limestones 500 feet thick, so inclined that the total thickness of its beds is 10,000 feet. Below these are unconformably a thousand feet of crystalline schists with dikes of greenstone and beds of granite. This lower series is composed chiefly of metamorphosed sandstones and shales, which have been folded so many times, squeezed and heated, that their original structure as sandstones and shales is greatly obscured or entirely destroyed, so that they are metamorphic crystalline schists. After these beds were deposited, folded and deeply eroded they were fractured, and through the fissures came floods of molten granite, which now stands in dikes or lies in beds, and the metamorphosed sandstones and shales, with the beds of granite, present evidence of erosion subsequent to the periods just mentioned, yet antedating the deposition of the nonconformable sandstones. Here, then, we have evidences of another and more ancient period of erosion or dry land. Three times has this great region been left high and dry by the ever-shifting sea; three times have the rocks been fractured and faulted; three times have floods of lava been poured up through the crevices, and three times have the clouds gathered over the rocks and carved out valleys with their storms. The first time was after the deposition of the schists; the second was after the deposition of the red sandstones; the third time is the present time.

GILBERT,[36] in 1875, describes the axis of the Black and Colorado mountains in northwestern Arizona as consisting of granitoid rocks and highly crystalline schists. In Bowlder canyon of this range upon a nucleus of syenite are plicated crystalline schists. In Virgin canyon the nucleus is gneissic, with a general anticlinal structure. In Black canyon the nucleus is a homogeneous rock resembling pegmatite, but is probably metamorphic.

In the Grand canyon of the Colorado the Tonto sandstone rests directly on plicated and eroded schists and associated granites, and demonstrates them to be pre-Silurian. Following down the river the same relation is seen in the Virgin range, and in the next ridge to the west, through which the river has cut Bowlder canyon, are gneisses so similar to those of the Virgin range that they may safely be classed with them. In Music mountain, in the Black hills near Prescott, and on Canyon creek, or, more generally, all along the soutwestern border of the Plateau region in Arizona, the Archean schists and granites are seen beneath nonconforming members of the fossiliferous rocks, usually the Tonto sandstone. To the south and west of this line stretches a great ocean of metamorphic ridges in which no one has found fossils. Whether a portion of the rocks are altered Paleozoic or whether the Paleozoic has been completely removed in the progress of erosion, or whether the Archean rocks have been covered by no later ocean sediments has not been decided. The purity and great thickness of the Carboniferous limestones up to the very margin of the region would appear to negative the idea of a permanent continent from Archean time, if, indeed, it is not negatived by the survival of acute mountain ridges.

GILBERT,[70] in 1875, describes the range region of western New Mexico and eastern Arizona. Northwest of the Burro mountains for 50 miles are islands of Archean and Paleozoic rocks. The most conspicuous of the former is a deep-red granite. In the Santa Rita mountains the axial rocks are Archean schists. On the eastern border of the Plateau region is a chain of ranges which coalesces with the Rocky mountains of Colorado and consists mainly of Archean and Carboniferous rocks. The whole front of the Sandia mountains except the crest is Archean. The Zuñi range of the Plateau region has a crystalline nucleus which Howell suspects to be due to the metamorphism of lower Paleozoic strata, as they are conformable with unaltered upper Paleozoic beds. The specimens show a gradation from compact sandstones to gneissic quartzite and quartzose granite. Between the Archean and the Silurian there is, first, a wide unconformity, demonstrating the tilting and erosion of the Archean beds anterior to the deposition of the Silurian; and, second, there is always at the contact a contrast of conditions as regards metamorphism, the Silurian rocks being usually merely indurated and the Archean invariably highly metamorphic. The two characters of the break serve to show that it represents a vast chasm of time, a chasm the duration of which may have been greater than that of the ages which have since elapsed. A third character of the break, one that is supported by less evidence but is negatived by none, is that the lowest of the superposed rocks are conglomerates and coarse sandstones. The conclusion to be drawn from the coarse, fragmental nature of the lower deposits is that the water which spread them was an encroaching ocean, rising to possess land that had long been dry. The recognized interpretation of a widespread sandstone is continental submergence, or, what is the same thing, an advancing coast line.

MARVINE,[37] in 1875, states that granite is found below the Tonto sandstone at the mouth of Grand canyon, at Music mountain, and in the canyon of New river. At Truxton and on the road to the southwestward granite occurs in the hills, often lava-capped; is found at Cross mountain, near fort Rock; at Aztec pass; at Juniper mountains; between Prescott and Agua Fria valley, and in the Black hills. In the Juniper mountains there are also found highly metamorphic rocks, as schists, slates, etc., often covering considerable areas and with which many of the silver and gold bearing lodes of the country are associated. At camp Verde on the river Verde sedimentary rocks rest upon syenites. The Tonto sandstone rests upon the granite in the Sierra Ancha, in the San Carlos valley, and in the Apache mountains. The main mass of the Pinal mountains is granite, but upon their northeast flanks is a long area of highly metamorphic rocks, consisting mostly of crystalline schists, micaceous, chloritic and talcose, their erosion forming an intricate maze of small valleys, separated by sharp ridges, which present a strong contrast with the more massive features of the mountains. The granites and schists of Pinal mountains extend along Pinal creek to camp Pinal.

POWELL,[29] in 1876, further describes as unconformably below the Tonto sandstone the Grand canyon sandstones, shales and limestones, 10,000 feet in thickness; and below this the Grand canyon schists, of undetermined thickness, composed of hornblendic and micaceous schists and slates, associated with beds and dikes of granite. The Grand canyon group rests unconformably upon the crystalline schists. The evidence of this is complete, for the lower sandstones and conglomerates first filled the valleys and then buried the hills of schistic rocks, and these conglomerates at the base of the group are composed of materials derived from the metamorphic hills about; and hence metamorphism was antecedent to the deposition of the conglomerates. The plane of demarkation separating this group from the Tonto group is very great. At least 10,000 feet of beds were flexed and eroded in such a manner as to leave but fragments in the synclinals. Then followed a period of erosion, during which beds of extravasated material were poured over the fragments, and these igneous beds also were eroded into valleys prior to the deposition of the Tonto group. Fossils have been found at the base of the Grand canyon series, but they are not well preserved and little can be made of them. Still, on geological evidence, these beds are considered Silurian.

WALCOTT,[71] in 1883, describes below the Tonto a great series of unconformable sediments which are divided into two groups, the Chuar and Grand canyon, between which there is an unconformity by erosion. The lower or Grand canyon group is made up of an immense mass of sandstones and interbedded greenstones, and the Chuar group is a series of sandy and clay shales. The Archean at the base of the Grand canyon group consists of thin-bedded quartzites broken by intrusive veins of a flesh-colored granite, the layers of quartzite standing nearly vertical. The Grand canyon and Chuar groups unconformably deposited over the underlying Archean are referred to the Lower Cambrian and placed as the stratigraphical equivalent of the Keweenawan group of lake Superior. In the Grand canyon series are found a few obscure fossils. The Chuar and Grand canyon series are both wholly unmetamorphosed and but slightly disturbed.

WALCOTT,[33] in 1886, states that the Tonto sandstone of the Grand canyon district is Upper Cambrian or Potsdam. Then below a great unconformity occurs by the erosion of an entire cross section of 13,000 feet of strata of the Chuar and Grand canyon series; below the unconformable series rest unconformably on underlying highly inclined strata, which where the section terminates belong to a system of strata between the Grand canyon series and the Archean. On account of this great unconformity below the Tonto it is thought better to classify all the pre-Tonto strata as pre-Cambrian, the middle and lower Cambrian times being in the Grand canyon district a period of erosion. The Chuar formation or upper 6,000 feet of limestones and argillaceous shales lithologically resemble the Trenton limestone and Utica shales of the New York section. There is no evidence of the great age of these strata in their physical aspect. The lower 6,000 feet of Grand canyon formation are sandstones with interbedded lava flows toward the upper portions. Ripple marks and mud cracks abound in many of the layers, but not a trace of a fossil was seen. Midway in the lower portion of the overlying Chuar strata the presence of a fauna is shown by a minute Discinoid or Patelloid shell, a small Lingula-like shell, a species of Hyolithes, and a fragment of what appears to have been the pleural lobe of the segment of a trilobite belonging to a genus allied to the genera Olenellus, Olenoides, or Paradoxides. There is also an obscure Stromatopora-like form that may or may not be organic. The fauna as given above is very unsatisfactory, but it shows the presence of a fauna that is Cambrian in character, as far as we know, although it may be a trace of a fauna preceding that of the Lower Cambrian of the Atlantic border; and as the stratigraphic evidence favors this view it is thought that it cannot be considered of Cambrian age.

WALCOTT,[35] in 1889, refers the section laid bare in the Grand canyon of the Colorado to the Keweenaw group. This section presents one of the best opportunities known to the author for the discovery of a pre-Olenellus fauna.

WALCOTT,[72] in 1890, gives the Algonkian section of the Grand canyon as follows: Chuar (shales and limestones), 5,120 feet; Grand canyon (sandstones with lava flows in upper part), 6,830 feet; Vishnu (bedded quartzites and schists), 1,000+feet.

SUMMARY OF RESULTS.

It is evident from the literature that in western New Mexico and in the major part of Arizona is a fundamental, thoroughly crystalline complex, consisting of most intricately mingled and folded granites, gneisses, micaceous and hornblendic schists, etc., precisely as in the previous sections concerned with the Rocky mountain system. This complex occurs at many points, constitutes the axes of many ranges, and its structure is of so intricate a character that no attempt has been made to estimate its thickness or to work out its structure, although in general the laminated rocks have been referred to as metamorphic. The granite in this complex plays the same part with reference to the crystalline schists as in the other areas referred to. Besides this ancient granite, which existed before the next newer series of rocks was formed, there is apparently in certain areas granites of later age, and these are more plentiful as the western part of Arizona is reached.

In eastern New Mexico and western Arizona, so far as the descriptions guide us, there is no certainty that any clastic rocks exist older than the fossiliferous series. In the central part of Arizona, however, in the Colorado canyon district, is the most complete section of rocks older than the Cambrian and newer than the fundamental complex in any known part of the world, with the exception of the lake Superior region.

The Tonto sandstone of the Grand canyon region, called by Powell and Gilbert Silurian in accordance with the nomenclature of the time, by present classification is to be placed as Upper Cambrian. The great unconformity which separates this sandstone from the earlier series makes it very probable that the latter are pre-Cambrian. These inferior series in descending order are the Chuar, Grand canyon, Vishnu series (together the equivalents of Powell's Grand canyon group), and the basal complex. The upper series consists of shales and limestones. Below this, with an erosion interval, is the second, consisting of sandstones, with interbedded and cutting basic eruptives. Inferior to this series, and separated by a great unconformity, is a set of thinly bedded and nearly vertical quartzites of undetermined thickness, broken by intrusive masses of granite. These three are clearly clastic series. The basal complex as described by Powell and Gilbert consists of thoroughly crystalline hornblendic and micaceous schists, gneisses, and granites, like the fundamental complex of the remainder of New Mexico and Arizona. Between this basal complex and the Vishnu series, as shown by Powell, is a vast unconformity. We have then in this region passing from the base upward, a fundamental complex; great unconformity; quartzite series of unknown thickness (Vishnu); great unconformity; Grand canyon series; minor unconformity; Chuar series; great unconformity; Cambrian.

The fundamental complex of Arizona has all the characteristics of the fundamental complex of lake Superior. The next overlying series is a quartzitic one, and quartzite is one of the most abundant and characteristic formations of the Upper Huronian of the Northwest. The next great succession is the Grand canyon and Chuar series, which in their unmetamorphosed condition, and in the character of the sediments are almost identical with the great thickness of sediments of the Keweenawan. Also the eruptives, which are interbedded with the Grand canyon series and cut it, are practically identical with the basic eruptives of the Keweenawan. These interbedded and cutting greenstones are characteristic of the lower, but are not found in the higher series, a still further analogy with the Keweenawan, for the lower Keweenawan contains eruptives and the upper Keweenawan is wholly detrital. The Grand canyon succession is then remarkably like that in the lake Superior region, and the respective series are lithologically alike.

It is exceedingly unsafe to correlate a single series with another series in a different geological basin upon lithological grounds; but when two great series of rocks are found, each of which has respectively similar lithological characteristics in two regions, and they are both separated by a physical break, and both sets of series are in exactly similar positions with reference to the overlying Cambrian and to the basement complex, the likeness suggests that they stand respectively as the time equivalents of each other. Between the two regions is the difference that in the Grand canyon area, a possible equivalent of the Lower Huronian of the lake Superior is not known. The correlation suggested can be considered no more than a conjecture since the parallelism in the two regions may be no more than a remarkable coincidence. It is remarked by Walcott that in the pre-Tonto series are a few obscure fossils, and that this locality is perhaps one of the best in the world in which to search for a pre-Cambrian fauna. Since in the lake Superior region the beginning of a pre-Cambrian fauna is also known, it may not be too much to hope that within a few years we shall have the assistance of fauna of sufficient fullness in these distant regions upon which the correlation above suggested may be tested.

SECTION VIII. CALIFORNIA, WASHINGTON AND BRITISH COLUMBIA.

LITERATURE OF CALIFORNIA, WITH ADJACENT PARTS OF NEVADA AND ARIZONA.

DANA,[73] in 1849, describes various crystalline rocks in the Umpqua and Shasty ranges. These include granite, syenite, porphyry, talcose rocks, serpentine. The hornblendic and talcose rocks are rarely schistose. Associated with the former rocks are conglomerates and sandstones.

TYSON,[74] in 1850, describes sections in the Sierra Nevada and the Coast range. The rocks are, first, metamorphic, consisting of those of sedimentary origin, such as slate, but subsequently altered by the effects of heat, and second, of hypogene rocks, which include granite, trap rocks, and others. At the summit of the Sierra, granite is the prevailing rock, and upon its flanks slates. The cleavage of the slates have a uniform course, about north of west. These lines of cleavage are usually taken for those of stratification, but it is frequently difficult to determine the stratification even where extensive excavations have been made. However much the slates have been disturbed during their period of upheaval, they assume the slaty structure in continuous or parallel lines extending over considerable distances—in the present instance for more than 70 miles—the inclination being nearly vertical.

BLAKE,[51] in 1856, states that the contorted gneisses of the Aquarius mountains are metamorphic. In the Aztec mountains the horizontal Carboniferous strata show that it was an ancient granitic uplift. The specimens of granite are of a red or rose color, few or none being white or light gray, in this respect contrasting strongly with the collection made from the Sierra Nevada and the Bernardino Sierra, as well as from those of the Great basin and along the Mojave river. The metamorphic rocks are in all probability not older than the Silurian or Carboniferous. This is certainly the case in the Aquarius mountains. In the rapid reconnaissance of these disturbed and metamorphic rocks it was not possible to bestow the attention upon them which their obscured condition demands, and it is therefore not possible to assign a dividing line between the truly erupted granitic rocks and those which simulate them but in reality are of sedimentary origin.

NEWBERRY,[75] in 1856, states that in the coast mountains are found occasional protrusions of granite and serpentine. The great mass of the Sierra Nevada is composed of plutonic or volcanic rock, granite, gneiss, mica schists and porphyries, traps, trachyte, etc., with auriferous talcose slates and veins of quartz. The western slope of the Cascade mountains in one place where crossed is composed of trappean and metamorphic rocks.

ANTISELL,[76] in 1856, states that in the Coast range the igneous rocks that form the axis are of two kinds, granitic and trachytic. While altogether distinct in their extreme types, when they approach each other in position and age they merge these separate differences. The granites of the Sierra Nevada are anterior to the Eocene and posterior to the later Paleozoic. All of the observed sedimentary rocks were post-Cretaceous. Granitic and primary metamorphic rocks are mentioned as occurring at several places in the Coast range, and in the Cordilleras in many localities. At one locality hornblende-gneiss is found.

BLAKE,[77] in 1857, states that granite is found at points along the coast from Monterey to near the Golden Gate. At the Tejon, in the Sierra Nevada, the rocks now generally classed as metamorphic, such as gneiss, mica-schists, hornblende-slate and chlorite-slate, are predominant. While these rocks are probably a metamorphosed sediment, the linear arrangement of the minerals is not regarded as satisfactory evidence of it. This structure also appears when the rocks are so far fused as to obliterate the original planes of stratification, and therefore the words strata or stratification in relation to these rocks are avoided, but to designate the lines or layers of minerals are used planes of structure or lamination. At one section was found granite, upon both sides of which is white limestone; next to the latter, on one side is quartz rock, which is followed by chlorite-slates. If the structural relations were regarded as conclusive evidence, the whole series would necessarily be considered metamorphic; but there is little reason to doubt that the granite is eruptive. The metamorphism in the limestone is complete and resembles the coarsely crystalline white limestones of Sussex county, New Jersey. There is no indication as to the age of the limestone or quartz rock, but there is some reason to regard them as Carboniferous, for these are the nearest known formations of limestone which are recognizable by fossils. On the section of the Cañada de las Uvas the rocks are similar to those of the western slopes of the Tejon. Along the Mojave river the rocks consist of metamorphic slates, very compact and so much changed as to resemble granite. In the Colorado desert the most of the metamorphic rocks are highly laminated and contain lenticular beds of limestone. In the gold region talcose and clay-slates are the prevailing rocks, and in general present a low degree of metamorphism. Next to the slate in importance is white crystalline limestone.

EMORY,[78] in 1857, states that in southern California there is a great preponderance of crystalline metamorphic granite pertaining to the older Paleozoic series of rocks and an entire absence of any member of the lower Paleozoic or secondary rocks in their regular stratified character. The central axes are represented by somewhat variable granite, assuming in some places a close syenitic texture and at other times there is a preponderance of mica. Belonging with the granitic series, particularly on the eastern side of the range, are mica and talcose slates.

NEWBERRY,[79] in 1861, describes the great mass of the Peninsular mountains east of San Diego as composed of granitic and gneissoid rocks, which are similar to most of the granites of the other systems of the Colorado; that is, a predominance of the feldspathic over the hornblendic ingredients. Where the Colorado cuts through the Chocolate mountains they are composed of gneisses traversed by veins of granite and quartz. The gneissoid rocks are frequently foliated and much convoluted. Their aspect is such as to lead an observer more readily to refer them to a metamorphic origin than any other rocks seen on the route. The great mass of Monument mountains is a coarse, massive feldspathic granite. On both sides of the granitic axis are highly metamorphosed conglomerate and sandstone. The principal mass of the Mojave mountains is composed of white granite, traversed by numerous veins of quartz. The Black mountains as a whole are characterized by the prominence of eruptive rocks, such as massive granite, trap, porphyry and trachyte, and the rarity of gneiss, mica slate, clay-slate, etc., which are probably metamorphic. In the lower Colorado canyon, unconformably below the Potsdam sandstone, is granite, which is cut by veins of quartz and red syenite. This sandstone is somewhat metamorphosed, but its consolidation is not due to volcanic heat, but rather to molecular changes induced by long-continued pressure of the immense mass of superincumbent rocks. The Cerbat mountains have a core of granite.

WHITNEY,[80] in 1865, describes the Coast range, the region between the Cañada de las Uvas and Soledad pass, and the Sierra Nevada, in all of which regions are found granitic and metamorphic rocks.

Granite occurs at many points in the Coast range and is described and figured as breaking through the Cretaceous and Tertiary strata and metamorphosing them.

In the Cañada de las Uvas region, at San Emidio canyon, occur granite, mica-slate, syenite, hornblende-slate and limestone, turned on end and unconformably overlain by unaltered Cretaceous and Tertiary strata. In the Tejon pass are found mica-slate, granite, gneiss, and syenite. Near the fort occurs crystalline limestone associated with mica-slate and gneiss, together with magnetic iron ore.

At many localities in the Sierra Nevada are described areas of granite, many of them of great magnitude. With them are associated metamorphic slates, a portion of these being mica-slates. In places granite dikes and veins are seen to intrude the slates. At Dome mountains, near the head of Kern and Kings rivers, a granite has a peculiar concentric dome structure which is not regarded as due to sedimentation, but results from the cooling of igneous material. The few fossils described in the slates of the Sierra are such as to cause them to be referred to the Jurassic.

GILBERT,[36] in 1875, states that in the Inyo range are found syenite, granite and gneissoid rocks. On its east face quartzites, siliceous schists, green schists and limestones make the section over 1,100 feet thick. In the Amargosa range the Whites peak series is 11,500 feet thick, and is composed of quartzites, green garnetiferous schists and siliceous and argillaceous schists. At the base of the section in the Amargosa range is 900 feet of quartzite resting conformably upon 600 feet of mica-schist and chlorite-schist. A section at Boundary canyon 2,500 feet thick is made up of limestones, micaceous and other schists and quartzites. None of these rocks are regarded as pre-Silurian. Although no fossils are found, the Whites peak section is presumptively Silurian.

MARCOU,[81] in 1876, states that granitic rocks occur in the Sierra Madre in southern California at a number of points. This mountain chain is described as the most ancient of the modern chains of southern California; that is to say the granite, pegmatite, gneiss and metamorphic rocks which form its principal mass date from times anterior to the Paleozoic.

LOEW,[82] in 1876, states that nearly all the mountain ranges of southern California belong to the Primitive formation. In the San Bernardino mountains the main mass is granite, accompanying gneiss, mica-schist, talcose schist and primitive clay-slate. The River-Side and Half-Way mountains consist of granite and gneiss. At the Mojave range is a series of Azoic rocks consisting of fine grained granite, syenite, hornblende-schist and quartzite. At the Panamint range are primitive limestone and clay-slate as accompaniments of the granite. Eruptive gneiss is found in the Coahuila valley which has metamorphosed the limestone on either side. The gneiss shows by the position of its mica plates a stratification parallel to the limestone layers, indicating the effect of pressure during the consolidation of the injected rock mass. Eruptive syenite occurs in the Buena Vista and Inyo ranges and eruptive granite at Dead mountains and in the Opal ranges. Occasionally in the San Bernardino mountains the granite gives rise to the formation of beds of arkose, a rock in which granitic débris has been recemented, forming a sort of granitic sandstone resembling to some extent granite, but the uniform grain, friability, and rusty surface of the fragments elucidate its true nature.

NEWBERRY,[54] in 1876, states that in the Aquarius range the Carboniferous strata rest directly upon the granite. In the Cerbat mountains gray granitic rocks are found upon which rest unchanged Carboniferous strata. In the mountains of the lower Colorado metamorphic rocks are abundant, consisting of gneiss, mica-slate and clay-slate, talcose slate and limestone, the latter highly metamorphosed and crystalline, forming marble, so far as observed, wholly destitute of fossils. This metamorphic limestone of the Sierra is suspected to be Carboniferous.

CONKLING,[83] in 1877, states that the ridge-like line of the eastern summit of the Sierra consists entirely of granite, flanked in several places by igneous rocks. In the Western Summit range are also found granitic rocks.

CONKLING,[84] in 1878, describes portions of western Nevada and eastern California, including a part of the Sierra range, and finds little aside from metamorphic and igneous rocks. Granite is found at many localities.

BECKER,[85] in 1888, states that granite underlies the Coast ranges and the Sierra Nevada. The evidence in California is in favor of the hypothesis that the main mass of the underlying granite is primeval. While it is not absolutely certain that Archean rocks occur in California, the unquestionable occurrence of the Archean in Arizona, together with the similarity of the rocks of southeastern California to those of the adjacent territory, make it probable that San Bernardino county is largely Archean. In the Gavilan range the lowest sedimentary formation is a crystalline limestone, associated with which are rocks of the Archean gneiss type. It is possible that it is a member of the Knoxville series more metamorphosed than usual, but it appears more probable that it is a remnant of some older formation which has perhaps undergone repeated metamorphism. Aside from these the earliest metamorphic rocks of the coast are probably Cretaceous.

BECKER,[86] in 1891, describes the sierra between the Stanislaus and Truckee rivers as being chiefly granite and diorite overlain in part by andesite and basalt. The granite and other granular rocks are intersected by fissures at short intervals which are believed to be early Cretaceous.

LITERATURE OF WASHINGTON.

GIBBS,[87] in 1855, states that in central Washington, in the valley of the Methow, is found granite, syenite and gneiss, well characterized and blended with each other. The syenite is often divided by joints so as almost to appear stratified and to give its perpendicular walls the semblance of artificial construction. The gneiss is found both horizontal and displaced by the intrusion of trap. Along the Columbia river was found syenite, granite, gneiss, quartzose rocks, talcose slate and greenstone.

LITERATURE OF BRITISH COLUMBIA.

RICHARDSON,[88] in 1872, mentions crystalline rocks on the east coast of Vancouver which are pre-Carboniferous and may be of Laurentian age.

RICHARDSON,[89] in 1873, finds below the coal-bearing series of Vancouver and Queen Charlotte islands crystalline limestones, diorites, red and green slates, the age of which is uncertain, but are probably Silurian or later.

RICHARDSON,[90] in 1876, finds crystalline rocks throughout a widespread area in British Columbia, extending through 7 degrees of latitude, from New Westminster on the Fraser river to Wrangel on the Stickeen river, and through 6 degrees of longitude, from Vancouver to Cariboo and Tête Jaune cache. While not able to speak authoritatively on the age of this great series of crystalline rocks or to say whether different portions of them will be proved to belong to distinct epochs, they present such a wonderful uniformity in character as to favor the idea that they constitute one great and widespread series. They are doubtless the gold-bearing rocks of British Columbia.

SELWYN,[91] in 1877, in a report on exploration in British Columbia, divides the rocks into five divisions from above downward. Division four consists of semicrystalline rocks, among which are limestones, shales, mica-schists and quartzites, which appear to have obscure fossils. The age of these rocks is not clearly determined. Division five consists of granitic rocks.

MACOUN,[92] in 1877, finds granite-gneiss and gneiss a few miles up the Quatre Fourches river, which are referred to the Laurentian.

DAWSON, (G. M.)[93] in 1877, states that a crystalline series occurs in the Cascade mountains about Eagle and Tatla lakes. These are chiefly highly crystalline gneisses, granites and diorites.

DAWSON (G. M.),[94] in 1878, states that the crystalline series of Vancouver, described by Richardson in 1872, are found to contain fossils. They have, however, become metamorphosed, and in lithological character resemble the Huronian and altered Quebec groups of eastern Canada.

DAWSON (G. M.),[95] in 1879, describes in some detail the Cascade crystalline series, which are referred to the Carboniferous period. The only rocks tentatively referred to the Laurentian are crystalline rocks of Shuswap lake and the gold range, which comprises gneisses, greenstones, schists, limestones and granites.

BAUERMAN,[96] in 1885, describes, near the forty-ninth parallel, west of the Rocky mountains, large areas of crystalline rocks, among which are granites, gneisses, basalt, étc. The gneiss of Spokane resembles the typical Laurentian gneiss of Canada. The metamorphic slates and greenstones perhaps belong to the Huronian.

DAWSON (G. M.),[97] in 1886, in that portion of the Rocky mountains between latitudes 49° and 50° 30′, places the lowest rocks found in the Cambrian. These comprise quartzite, quartzitic shales, argillites, limestones, and conglomerates. One section, between South Kootanie pass and Flathead river, has a maximum thickness or more than 11,000 feet. These rocks are apparently destitute of fossils and are compared in their lithological character with the Cambrian of the Wasatch, but they have a still closer resemblance to the Chuar and Grand canyon groups of the Colorado river.

DAWSON (G. M.),[98] in 1887, describes Vancouver island and the adjacent coasts. All the stratified rocks are Cretaceous or Triassic, although they are often metamorphic and crystalline. To all the volcanic material underlying the Cretaceous, including the limestones, argillites and quartzites, the term Vancouver series is applied. These rocks, the oldest in the district, were not deposited upon a granitic floor, as the granites are evidently later in date, and nothing is known of the character of the surface upon which the Vancouver beds were deposited. Granitic rocks are very widespread. The granites near the line of junction with the Vancouver series are charged with innumerable darker fragments from that series. In the immediate vicinity of the parent rock they are angular and clearly marked, but at a greater distance are rounded and blurred in outline. The width of the belt in which these fragments occur may exceed half a mile; in other cases it is only a few hundred feet. It was in several instances found impossible to draw a distinct line between the granites and the Vancouver rocks. The Vancouver series for some distance from the contact is very generally shattered and penetrated by granitic spurs or by felsite dikes. If the granite were in limited intrusive masses these would be regarded as ordinary intrusive rocks, but it appears everywhere to be the material upon which the Vancouver series rests, and is nevertheless evidently of later date than these rocks. The only explana tion which appears satisfactorily to account for the appearances met with is that in consequence of upheaval and denudation we now have at the surface a plane which was at one time so deeply buried in the earth's crust that the rocks beneath it had become subject to granitic fusion. It is clear that the granitic rocks beneath were in a plastic condition, not alone from the fact that they are found to penetrate the older series, but also from the evidence everywhere met with of the scattering out of fragments of the stratified rocks into the granites. Both the granites and the rocks of the Vancouver series have been subjected to great pressure in a horizontal direction, causing the fragments in the agglomerates to assume lenticular forms and impressing a more or less distinctly schistose character upon them, while the dark included fragments in the granites have been squeezed out into sheets, giving the portions of these rocks which are characterized by an abundance of such fragments an almost gneissic lamination. At the time at which this effect was produced the granites must still have been in a plastic state. On the inner side of Vancouver island it may further be remarked that for a long stretch the flaggy argillites and quartzites are frequently directly in contact with the granitic rocks, rendering it probable that the refractory character of their materials has proved a sufficient barrier to the progress of the granitic change, which may, locally, have nearly reached its possible limit. Particular occurrences of granite at many localities are described in detail.

McConnell,[99] in 1887, describes the Bow river series in the eastern part of the Rocky mountains. It consists of dark-colored argillites, associated with sandstones, quartzites and conglomerates. The base is not seen, but the part exposed has an estimated thickness of 11,000 feet. The argillites are occasionally cleaved and have scales of mica often developed along the divisional planes. The only fossils obtained from this formation are a couple of trilobitic impressions, one of which was identified by Walcott as *Olenellus gilberti.*

Bowman,[100] in 1889, states that certain schists are found in the Cariboo gold belt of British Columbia, which are referred to the lower Paleozoic. These consist in the main of slates and sandstones, the total thickness being placed in the neighborhood of from 5,000 to 8,000 feet. No fossils are found, and their position as lower Paleozoic is tentative. In the Alpine region of Cariboo are found gneisses, granites and quartzites, which resemble the characteristic rocks of the Archean. Associated with these are lower granitic rocks. The entire crystalline series of the gold region of Cariboo is lithologically identical, as near as can be described in general terms, with the rocks of the pre-Cambrian and Cambrian gold regions of eastern Canada. The gneissic and schistose type of rocks of the mount Stevenson group especially (supposed to represent the lowest horizon, on account of their association with granite in a central and massive mountain group) finds lithological representatives in the pre-Cambrian rocks of the eastern provinces of the Dominion and in the Appalachian axis.

DAWSON, (G. M.)[101], in1891, describes a section in the Selkirk range and compares it with a section of the interior plateau region at Kootanie and Adams lakes and on the west side of the Rocky mountains. The sections are given and correlated as follows:

Provisional comparative table of formations met with (1) in the eastern border of the interior plateau of British Columbia, (2) in the Selkirk range, and (3) on the western side of the adjacent portion of the Rocky mountain ranges.

	1. Section on Kootanie and Adams lakes.		2. Section in the Selkirk range on line of Canadian Pacific Railway.		3. Section in the Rocky mountains (west side of range, McConnell).	
	Feet. 6. Greenish and gray schists, with limestone .... 2,000 5. Limestone or marble with black, glossy argillites and some gray schists 2,500		*Feet.* Quartzites, with gray schists and some limestone. Black shaly argillites, limestone, and gray schists.		*Feet.* Halysites beds, dolomites, and quartzites 1,300 or more. Graptolite-bearing shales. Black fissile argillites, with some limestone 1,500	Cambro-Silurian and Silurian.
Adams lake series.	4. Chiefly greenish, with some gray schists. 4,050 3. Chiefly gray, with some greenish schists 8,550	Selkirk series.	Gray schists and gray quartzites, with some quartzose conglomerate and interbedded blackish argillites, the last chiefly toward the base 25,000	Castle mountain group.	Greenish and gray calc-schists and greenish and reddish shales and slates, with some dolomitic limestone...... 10,000 (probably).	Cambrian.
Nisconlith series.	2. Black, shaly or schistose argillite, with some limestone .... 1,000 or more.	Nisconlith series.	Blackish argillite-schists and phyllites, generally calcareous, with some beds of limestone and quartzite 15,000	Bow river series.	Dark argillites, with some quartzites and conglomerates, the latter particularly toward the summit. Base not seen .... 10,000 or more.	
Shuswap series.	1. Mica-schists, gneisses, and marbles ..... 5,000 or more.	Shuswap series.	Gray gneissic rocks and coarse mica-schists ... 5,000 or more.			Archean.

Associated with the Archean schists are certain granitoid rocks which may represent either portions of the schists in which the bedding has been obliterated or very ancient intrusives. Besides these there is at least one later series of intrusive granites which are probably later than most of the Paleozoic rocks. The Shuswap series of the Adams lake section appears to be traceable on their line of strike into diabases and diabase rocks, which are often agglomerates and pass into volcanic ash rocks. In the Shuswap series of the Selkirk nearly half of the entire mass of the rocks exposed consist of intrusive or vein granite with pegmatitic tendencies. In the Nisconlith series the lamination is often true bedding, but in some cases a slaty cleavage is developed. In the

Castle mountain group and the upper 3,000 feet of the Bow river series of the Rocky mountain section the Olenellus fauna is found. Nowhere in any of the sections were unconformities seen. In sections 1 and 2 no fossils have been discovered. The correlations are made upon relative positions and lithological grounds. Between the Shuswap and overlying series there is believed to be a great time break, for this lower series is of a markedly more crystalline character, and the numerous granite veins which everywhere cut it at no point enter the overlying Cambrian strata. The rocks placed in the Cambrian are then 40,000 feet thick. The use of the term Algonkian to designate the rocks conformably below the Olenellus fauna is objected to, it being more philosophical to include, for the present at least, the whole of this great conformable mass of rocks to its base under the name Cambrian.

SUMMARY OF RESULTS.

The literature of the vast region covered by the western coast ranges and British Columbia is too meager to make possible any systematic comparisons between the rocks of different districts. No attempt has been made accurately to map any considerable areas in the region. The crystalline series have been referred to the pre-Cambrian, Cambrian, Huronian, or Laurentian, as the particular author thought advisable.

In California, Whitney evidently regarded all of the granites and metamorphic rocks as of very late age, but Becker, on the contrary, regards the main mass of them as the equivalent of the most ancient complex of Arizona and other western Territories. The earlier observers, such as Antisell, speak of the granites and metamorphic rocks which occur in the different ranges as Primary, but this reference was clearly made upon lithological grounds. While nothing definite can be said, the descriptions of some of the areas in southern and southeastern California and in the district along the Cañada de las Uvas certainly suggest that in these districts are thoroughly crystalline complexes which are lithologically like the fundamental complex of the Rocky mountain region, but it can not be positively asserted that anywhere in this region, except in British Columbia, such an ancient rock system has been found. Here the recent work of Dawson has shown the existence of a fundamental complex in all respects like that found in the Rocky mountains of the United States.

Nothing definite can be said as to the existence in California of pre-Cambrian clastic series later than such a possible fundamental complex. It is not at all impossible that such great series of crystalline schists as that described by Gilbert at Whites peak, in the Amargosa range, is the equivalent of the clastics of the Grand canyon group. This series was by this author referred to the Silurian; but the Grand canyon series at that time, when the lowest fossiliferous rocks were so called, was also called Silurian.

In British Columbia the lower 7,000 feet of the Bow river series of rocks may be pre-Olenellus, and not improbably belong to the Algonkian under our usage of the term, although placed by Dawson under his usage as a part of the Cambrian. If a part of this Bow river series is Algonkian, it would carry with it also, in all probability, the Nisconlith series, with possibly a portion of the Selkirk series, and doubtless also a portion at least of the section at Kootanie and Adams lakes; hence it is not improbable that in British Columbia is a great area in which Algonkian rocks occur.

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CHAPTER VII.

EASTERN UNITED STATES.

SECTION I. THE NEW ENGLAND STATES.

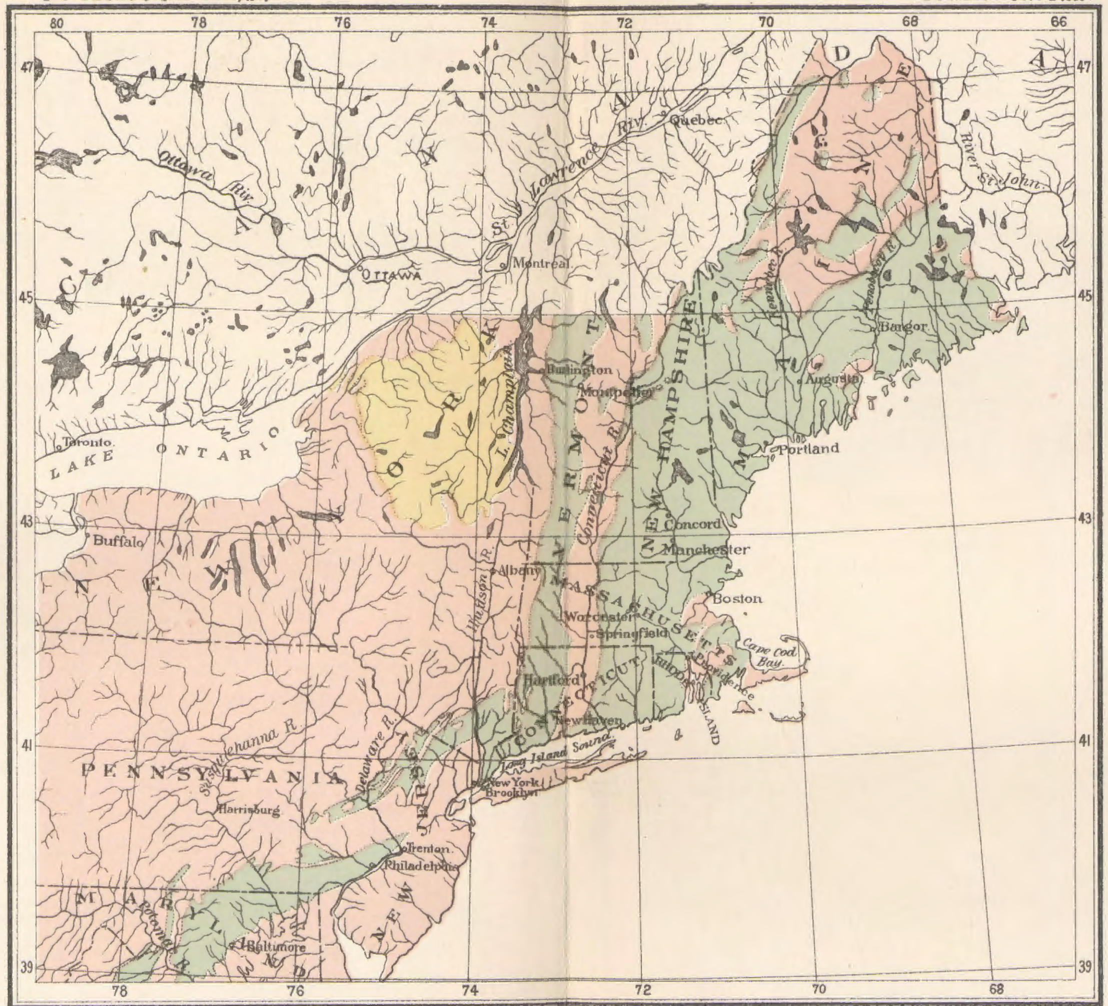
LITERATURE OF MAINE.

JACKSON,[1] in 1837, observed granite, gneiss, and mica-schist at many localities. At one place schistose fragments occur in syenite, which indicates that the syenite has been thrown up in a melted state since the deposition and induration of the argillaceous and talcose slates included. Dikes very frequently cut the fossiliferous horizon.

HITCHCOCK[2] (EDWARD) in 1837, describes a rock succession at Portland as consisting from the base upward of (1) granite; (2) gneiss; (3) talcose and mica-slates, with quartz-rock; (4) hornblende-slate; (5) limestone; (6) plumbaceous mica-slate; (7) pyritiferous mica-slate. The latter has the aspect of a graywacke-conglomerate, being filled with distinct rounded masses of quartz rock. It is really a mica-slate conglomerate. The series are in a vertical position and the whole are cut by greenstone dikes.

JACKSON,[3] in 1839, includes in the Primary rocks of Maine the granites, gneiss, talcose slate, and argillaceous slate. The transition rocks are a great formation, which includes slates, limestones, fine graywackes, and coarse conglomerates. It is also fossiliferous. At one place mica-slate is thrown aside by intrusive granite.

HITCHCOCK [4] (CHAS. H.), in 1861, divides the unfossiliferous rocks into Stratified or Azoic and Laurentian. With the latter are placed granitic, trappean, and Archean rocks. The Azoic rocks, which may be in age Laurentian to Carboniferous, include gneiss, mica-schist, quartz-rock and conglomerate, jasper, siliceous slate, and hornstone. The quartz-rocks and conglomerates are associated. At one place a conglomerate has elongated pebbles which indent each other, which is evidence that they must have been in a plastic condition. Metamorphism may even produce granite and gneiss by aqueo-igneous fusion. The syenites containing fragments of schist and trap, described by Jackson, are believed to be metamorphosed conglomerates, the included pebbles of which have preserved their original shapes. The foliation of the metamorphic rocks generally correspond with the planes of stratification, but may cross the strata like cleavage planes. The trap dikes are believed to be eruptive.



Unclassified Partly or Wholly Crystalline Rocks

Unclassified Pre-Cambrian

Post-Algonkian

GEOLOGICAL MAP OF THE NORTHEASTERN STATES.

SHOWING PRE-CAMBRIAN AND CRYSTALLINE ROCKS.

After McGee and Hitchcock

Scale $\frac{1}{7.600.000}$.

HITCHCOCK (CHAS. H.),[5] in 1862, describes the rocks of the southern part of the state as granite and syenite, gneiss and mica-schist, saccharoidal Azoic limestone, quartz-rock, (Taconic), Eolian limestone, etc. Presumably the granite and syenite, the gneiss and mica-schist, and Azoic limestone are Primitive. In the Kennebec valley are found interstratified limestones and slates, the cleavage of which is almost transverse to the bedding, so that it is only possible to get at the true direction of lamination by following the limestone belts. At one place is an abrupt change from mica-schist to granite. A red conglomerate rests uncomformably upon a slate at Woodstock.

HITCHCOCK (CHAS. H.),[6] in 1874, describes at Portland three groups of rocks, the oldest of which is the Huronian. In this system are green talcose schists, hornblendic schist, micaceous and plumbaceous schist, and other varieties. They are referred to the Huronian on the ground that such rocks are typical of this period, and continuity of mineral character indicates similarity of age till otherwise proved.

HUNTINGTON,[7] in 1878, describes the region about the headwaters of the Androscoggin river. The rocks are classified as Laurentian, Huronian, and Paleozoic. In the Laurentian is gneiss, containing limestone. In the Huronian are White mountain gneisses and schists, mica-schists, with staurolite, chloritic and whitish argillitic mica-schists, sandstone-schists, diabase, diorite with serpentine, argillitic mica-schists with staurolite, and Rangely conglomerates. In the Rangely conglomerate, when freshly broken, every portion of it except the pebbles resembles in all respects the staurolitic schist. Going across the stratification are places where the pebbles are wanting, or have been so changed that they are not apparent, although locally the fragments of the conglomerate are a foot in diameter. Granite, diorite, and felsite are placed among the eruptive rocks.

SHALER,[8] in 1889, describes the rocks of mount Desert. The island consists of a central mass of hornblende-granite and a succession of sedimentaries on the north and south sides. About the massive core are the following series: The Sutton island series of highly metamorphosed clay-slates, quartzites, bedded felsites, and associated traps; the Cranberry island series, essentially the same as the Sutton island series, with many beds of volcanic ash; the Schooner head series of contorted argillaceous schists, shales, and the associated injected rocks; the Bar harbor series of thick-bedded flaggy slates and associated bedded felsites and quartzites, with numerous injections of igneous rocks; and the Bartletts island series of contorted schists, with frequent beds of quartzites, which often assume a gneissic aspect with the associated injections of igneous rocks. The great central mass of granite is said to be essentially a dike. In approaching the central granite the amount of granitic dike injections in the sedimentary series greatly increases, and in the sedimentary rocks are found numerous dikes of granite. No two of the various sedimentary series are found superimposed upon each other, although there are at least a half dozen series which are regarded as representing different parts of the geological section. The aggregate thickness of the various sections is not less than 6,000 feet and may be one half more than this. The great part of mount Desert rocks are referred to the lower part of the Cambrian section, although the volcanic rocks of Cranberry island resemble deposits of similar nature at Eastport, Maine, which seem to be of Silurian age.

LITERATURE OF NEW HAMPSHIRE.

JACKSON,[9] in 1841, in a general consideration of the geology of the state, states that granite is an igneous rock and is the foundation on which all the more recent formations rest. When it is found cutting other rocks, the intense heat has often metamorphosed the adjacent rocks for considerable distances. Reposing directly on the granite is found gneiss, the origin of which is undetermined. By some geologists gneiss is considered a metamorphic rock; others suppose that its stratified structure is due to the crystallization in laminæ and that it is merely the upper crust of granite. Above the gneiss are found mica-slate, chlorite-slate, and argillaceous slate, which are regarded as metamorphic rocks. Slates and granite alternate with each other, and this is due to the subsequent intrusion of granite. There have been several periods of eruptions of trap dikes, as is shown by the manner in which they cut each other.

JACKSON,[10] in 1844, gives many facts as to the distribution of the rocks, with numerous sectional profiles. Granite, syenite, porphyry, trap, basalt, and lava are regarded as eruptive rocks. As a result of outbursts and elevations the strata have been broken up, altered in position, and included between masses of molten gneiss and granite. In this way is explained the intercalation of masses of argillaceous slates in the primary series and the metamorphosis of the sedimentary deposits by igneous action.

ROGERS, (HENRY D. and WM. B.),[11] in 1846, states that the assumption that the White mountains belong to the Primary series involves two errors: first, in assigning all the rocks to the gneissoid class; and, second, in supposing that none of the strata contain organic remains. The gorge of the Saco was closely examined. The rocks were found to have a stratified structure throughout, although in many cases approaching very close to granite. They are regarded as very highly metamorphic sandstones and slates. Associated with the crystalline rocks are semicrystalline sandstones which contain distinct fragments. In a shale are found fossils, which lead to the conclusion that the series represents the Levant or Matinal. The metamorphic beds are cut by beds and veins of syenitic granite, and the extremely crystalline character of the slates and sandstones is regarded as due to the igneous material.

JACKSON,[12] in 1848, maintains that in the White mountains are numerous localities where fragments of slate are included in the granite which are not altered by heat beyond mere induration. In New Hampshire numerous masses of older Silurian strata occur intercalated with the Primary rocks.

HITCHCOCK (C. H.) and HUNTINGTON,[13] in 1877, give a full account of the geology of New Hampshire. Hitchcock divides the pre-Paleozoic rocks of the northeastern United States into two divisions: first, the more ancient gneisses and granites; second, the area of hydromicaceous and micaceous schists, which are termed Huronian. In the Paleozoic are placed great expanses of clay-slates. The first division is divided into four parts: first and oldest, the Laurentian; second, the porphyritic gneiss and the various undetermined granites; third, the Atlantic; and fourth, the Labradorian. Among the Huronian is placed the Quebec group of Logan.

Huntington gives the geology of the Coos and Essex district. The Coos rocks, consisting of argillaceous schists, clay-slates, and micaceous sandstones, are supposed to belong to the fossiliferous series. The Huronian rocks are found east of the line limiting the Coos group. They consist of green chloritic rocks, in which the lines of stratification are obscure. Contained are greenish feldspathic sandstones, with intercalated bands of siliceous limestones. There are also here contained stratified diorites, diabases, and hornblende-rocks. The porphyry which occurs connected with the Coos and Huronian penetrates the rocks with which it comes in contact, and the intrusive character can not be doubted. Outcrops of granites and granitoid gneisses have a wide extent, a part of them being regarded as genuine eruptive granites since they intersect the schists in numerous veins and beds. The basic dikes are the latest of all, cutting the granites and intersecting the schists at many places.

Hitchcock gives the formations of the White mountain district in ascending order, as follows: (1) Porphyritic gneiss; (2) Bethlehem gneiss; (3) Berlin or Lake gneiss; (4) Montalban group; (5) Franconia breccia; (6) Labrador system or Pemigewasset series of granites, ossipytes, compact feldspars, etc.; (7) syenite; (8) andalusite slates; (9) Pequawket or mount Mote granite. The three first are regarded as metamorphic, although the stratification is destroyed. The Montalban group includes granitic gneiss, mica-schist, and quartzite. The granitic gneiss sometimes shows no visible mark of stratification, as in the Concord granite, although the whole is regarded as metamorphic. An unconformity is inferred between the Montalban schists and the porphyritic gneiss on account of the divergence in the strike of the two groups. Eruptive granite is found in the Montalban schists. The Franconia breccia is placed later in the chronological scale than the Montalban group, because it is the impression of the author that he has seen Montalban fragments in this rock. The Labrador system is considered as the probable equivalent of the Labrador system of Logan and Hunt. It includes the Conway granite, Albany granite, Chocorua granite, Ossipyte or Labradorite rocks, and various compact and crystalline feldspars or porphyries. The relations of the Albany granite and the Andalusite slate do not show that the underlying granites are certainly not sediments, although they have been so thoroughly metamorphosed as to have lost their lines of original bedding; but the evidence in favor of their eruption since the deposition of the andalusite slates is increasing. The slates are twisted and broken in many places, the fragments being cemented together by a granitic paste; also, fragments of slate occur imbedded in the underlying granite. The Labrador group is found in seven areas. The Labrador rocks lie unconformably upon the upturned edges of the Montalban gneisses, the discordance varying from 45° to 70°. Porphyry occurs in this system, which is regarded as intrusive. Syenite has quite a widespread occurrence. The andalusite slates are regarded as the equivalent of the Coos series, but they are similar to the Huronian system. The Pequawket series is regarded as late eruptives. The stratigraphic order in the White mountains is finally concluded upon as follows: (1) the Laurentian, represented by the Porphyritic gneiss and the Bethlehem group; (2) the Atlantic, consisting of the Lake or Berlin and Montalban gneisses, and the Franconia breccia; (3) the Labradorite; (4) the Huronian; (5), the Merrimac schists; (6) the Andalusite schist group; (7) eruptions of porphyry; (8) eruptions of the Conway, Albany and Chocorua granites and syenites; (9) the formation of the mount Pequawket or mount Mote porphyritic breccia. This order is somewhat different from that stated at the beginning of the chapter. The Huronian barely touches the White mountain area. With it are placed certain quartzites which are lithologically like those of Canada. The Green and White mountain gneisses are regarded as Eozoic because they are a continuation of the Eozoic rocks of New Jersey and New York, because they are bordered by quartzites which are of Cambrian age, which dip away from them both to the east and west, because the Labrador series is present, and because fossiliferous Helderberg strata are found on both the east and west sides of the White mountains side by side with the metamorphic schists, the former containing fossils.

In the Ammonoosuc gold field of the Connecticut valley the following succession is found: (1) Laurentian, consisting of the Porphyritic and Bethlehem gneisses; (2) Atlantic gneiss, represented by the Lake division; (3) Huronian, embracing the Lisbon and Lyman groups and the auriferous conglomerate; (4) Cambrian clay-slate; (5) Coos group; (6) Swift water series; (7) Helderberg quartzites, slates and limestones. The Huronian formations embrace schists, conglomerates, the pebbles being sometimes flattened, quartzites, dolomites and jaspers.

In the area between Haverhill and Claremont the subdivisions are as follows: (1) Bethlehem gneiss; (2) Huronian, with three or four subdivisions; (3) Cambrian clay slate; (4) Coos quartzites; (5) Coos slates and schists; (6) calciferous mica-schist; (7) eruptive granites, including the mount Ascutney area, which is partly composed of rocks older than Huronian.

In the Connecticut valley district, between Claremont and Hinsdale, the succession is as follows, beginning with the lowest: (1) Bethlehem gneiss; (2) gneisses of the Montalban series; (3) Huronian; (4) Coos quartzites; (5) Coos slates and schists; (6) calciferous mica-schist; (7) eruptive granite. The Coos quartzites and calciferous mica-schists are only semicrystalline rocks, all the thoroughly crystalline schists being placed with the pre-Cambrian. The thickness of the Huronian rocks in New Hampshire is placed in the neighborhood of 10,000 feet.

Huntington gives the order of superposition of the rocks in the west part of the Merrimac district, as follows: (1) Porphyritic gneiss; (2) Bethlehem or Protogene gneiss; (3) common or Lake gneiss; (4) ferruginous concretionary schist; (5) fibrolite schist, sometimes gneissic and passing into common mica-schist; (6) quartzites and quartz conglomerates; (7) intrusive rocks and veinstones. Hitchcock gives the order in the east part of the district thus: (1) Porphyritic gneiss; (2) Lake gneiss; (3) Montalban series, including the Concord granite; (4) ferruginous schist; (5) Andalusite mica-schists, with coarse granite veins; (6) Rockingham mica-schist; (7) Kearsarge andalusite group; (8) Merrimac group, including a little clay slate. There are no eruptive rocks in this area of sufficient importance to find a place upon the map.

Hitchcock gives the succession in the Lake district, embracing the Winnipiseogee lake and the flat country to the north, as follows: (1) Porphyritic gneiss; (2) Lake gneiss; (3) Montalban. The eruptive rocks are more plentiful and varied, consisting of (1) Conway; (2) Albany; (3) Chocorua granites; (4) porphyry; (5) Pequawket breccia; (6) Labradorite diorite; (7) syenite; (8) granite, not allied to any of the foregoing.

The succession in the Coast district, including the southeast corner of the State, is as follows: (1) Porphyritic gneiss; (2) Lake gneiss (including the Laurentian of Massachusetts); (3) Montalban; (4) Rockingham group; (5) Merrimac group; (6) Kearsarge group; (7) Huronian and Cambrian of Massachusetts. The unstratified rocks are the syenites of Exeter and Pawruckaway, inferior granites, and the well developed granites and porphyries of York county, besides a great many trap dikes along the coast.

In considering the principles of classification, as guiding principles it is premised that in this field are inverted flexures and dislocations of the strata. Also that formations of the same mineral composition in one part of the field may be identified with those of like composition in another part of the field, as, for instance, the porphyritic gneiss in thirty areas has feldspar crystals very conspicuous for their size. All these areas are assumed to be identical in age, and in placing the relative positions of the intervening groups this is relied upon for a starting point. The general order of succession for New Hampshire, from the base upward, is, Porphyritic gneiss; Bethlehem gneiss; Lake and Montalban series; argillaceous, talcose, hydromicaceous and calcareous series; Labrador series (present in New Hampshire, limited in amount); various types of mica-schists. Andalusite slate in this mica-schist formation lies unconformably upon the Montalban at mounts Monadnock and Kearsarge. The principal eruptive masses are the Conway, Albany, Chocorua granites, syenites, other granites, and labradorite, diorites and dolerites. The granites cut rocks as high as the Coos group. The Porphyritic gneiss and the Bethlehem group are referred to the Laurentian. The Lake gneiss can not easily be assigned. The Montalban certainly is not characteristic of the Laurentian, but all of the preceding are regarded as underlying the Huronian. It is thus concluded to place the Porphyritic, Bethlehem, and Lake gneisses with the Laurentian, leaving the position of the Huronian and Montalban to be settled by other considerations.

The Huronian is divided into two divisions, the upper chloritic, and the lower quartzose and feldspathic. The greenstones seem to be closely allied to the upper Huronian and the porphyries to the lower division, and to this may belong the supposed eruptive porphyries of the White mountains. The Merrimack, Rockingham, and Kearsarge mica-schists are somewhat related to the Huronian, as well as to the Cambrian. They are all referred doubtfully to the Paleozoic system. The doubtful Paleozoic is placed at 11,600 feet thick; the Upper Huronian, 12,129 feet; Lower Huronian, not estimated; Montalban, 13,700; Laurentian, 34,900. The Labrador system if present in New Hampshire is in very limited amount. Certain of the labradorites are surely injected dikes, and hence it is doubtful whether the Waterville area really represents the Labrador system of Canada.

HAWES,[14] in 1878, regards the diabases, diorites, gabbros, felsites, granites, and syenites of New Hampshire as eruptive rocks. Some of them may have been produced by the fusion of sediments, but however this may be, they have all been in a molten condition and been free to crystallize. There are beds of granite which are unconformable with the associated stratified rocks; there are granites filling well defined dikes; there are granites which so far as can be seen are entirely devoid of structural relations; there are granites which are mixed with other rocks, or which hold huge fragments of other rocks inclosed in their masses. All these features are often repeated. Among the crystalline schists are placed gneiss, mica-schist, argillitic mica-schist, and quartz-schist. The gneisses, like the granites, are believed to be of eruptive origin, or at least to have acted like an eruptive rock, the lamination being an induced structure which may or may not correspond with original bedding in case they are completely metamorphosed material. The gneisses in their minerals, inclusions, and microscopic characters are like granites, and pressure may have been as effective in producing lateral movements and forming foliation in a plastic mass as sedimentation. If the stratification of the gneiss is then regarded as an induced structure it would not follow that the stratification should correspond with the original bedding, and even if the lamination does correspond with the plane of the strata, the lamination can not be referred to stratification of sediments, for the cleavage of the adjacent rocks may also be due to pressure and be different from the plane of bedding. The greenstones, including metamorphic diorite, quartz-diorite, and amphibolite, are regarded as metamorphosed sedimentary rocks. These have marked lithological distinctions from the fresh basic rocks recognized as eruptives. The clay-slates and quartz-schists are semicrystalline rocks. The slaty cleavage and bedding are sometimes discordant.

HAWES,[15] in 1881, describes the Albany granite as penetrating and metamorphosing the schists, and as having a porphyritic structure near its contact with them, and it is therefore concluded to be intrusive.

HITCHCOCK, (CHAS. H.)[16] in 1890, regards the oval granitoid areas occurring in the White mountains, about which occur foliated rocks with an anticlinal quaquaversal arrangement, as the oldest known or fundamental rocks of the region which are remains of an ancient archipelago.

WILLIAMS,[16] in 1890, with the same facts before him gives an exactly opposite interpretation to Hitchcock, that is, that the central granites are younger intrusive masses.

LITERATURE OF VERMONT.

ADAMS,[17] in 1845, divides the older rocks of Vermont into Primary strata and Paleozoic rocks. The Primary system is highly crystalline and destitute of fossils. It is divided into argillaceous slate, calcareo-mica-slate, mica-slate, talcose slate, Green mountain gneiss, gneiss proper, which however does not represent the order of superposition as the strata are involved in great confusion. The marbles of the state are divided into three systems, Primary, Taconic and New York. There are few Primary marbles in the state. The Taconic marbles occur throughout the range of limestone from Massachusetts to the north part of Madison county. The Taconic system includes roofing slate, Taconic slate, Sparry limestone, magnesian slates, Stockbridge limestone, and granular quartz-rock.

ADAMS,[18] in 1846, includes the Taconic and Primary systems of his previous reports under the general term Azoic stratified rocks, as simply expressing the fact of the absence of organic remains, for it is not to be assumed that the Azoic Taconic rocks are more ancient than the Paleozoic, and the same remarks may be said of the so-called Primary rocks, not a small portion of which may be as metamorphic and recent as the Champlain rocks. In the Green mountains are quartz-rock, gneiss, talciferous limestone, quartz-gneiss and limestone which are supposed to be Taconic. Dikes of greenstone cut through all the divisions of the stratified rocks and are therefore more recent than any of them.

ADAMS,[19] in 1847, gives additional details as to the rock occurrences in particular localities.

THOMPSON,[20] in 1856, states that the Green mountains form the center of an anticlinal axis, the dips increasing both east and west from the principal summits. Slates, schists and quartzites are found which contain a few obscure fossils, and are referred to the Taconic system.

HITCHCOCK (EDWARD),[21] in 1861, divides the rocks in general into Stratified or Aqueous and Unstratified or Igneous. With the latter are placed granitic, trappean and volcanic rocks. The former are subdivided into Fossiliferous and Unfossiliferous, or Azoic. In this latter division are placed clay-slate, quartz-rock, mica-schist, talcose schist, and chlorite-schist, steatite or soapstone, serpentine, hornblende-schist, gneiss, and crystalline limestone. The important practical question with respect to the metamorphic rocks is, what was the original rock from which the metamorphosed deposit was derived? In not a few instances so complete has been the metamorphism that it can not be told whether the rock belongs to the oldest of the crystalline rocks or is earlier than the Silurian or Cambrian. While the degree of metamorphism gives no clue as to the age of the rocks, from other evidence it is probable that most of the highly metamorphosed rocks of Vermont are altered Devonian and Silurian. In the western part of the state, and especially that part of New York that lies southwesterly, are found these fossiliferous rocks but little altered, and these form a starting point for the Green mountain rocks and those farther east.

Metamorphism is made to apply to any transformation of any kind of rock into another. At Newport, Rhode Island, East Wallingford and Plymouth, Vermont, are found schist-conglomerates in which the pebbles are elongated very much in the direction of their strike. They are flattened, but not so strikingly as elongated; they are indented deeply into each other; they are sometimes a good deal bent; they are cut across by parallel joints and fissures. At times the process has gone so far as to merge the pebbles together, and as to scarcely present the appearance of ordinary pebbles. If the talcose conglomerate schist is looked at on the edge corresponding to the dip, nothing is seen but alternate folia of quartz and talc and mica, and the rock would be pronounced a good example of a talcose-schist. But a fracture at right angles reveals the flattened pebbles, and shows that their edges are what have been regarded as folia. If the process of flattening was carried a little farther no evidence would remain that they were ever pebbles. How extensively the process has been carried through, thus producing schists and gneisses from conglomerates in the Green mountains, is unknown. No examples have been found of decided pebbles in a gneiss.

At Whately, Massachusetts, on Ascutney, and at Barnet and Granby, Vermont, are conglomerates which have as a matrix granite and porphyry. The granite sometimes passes into syenite. At Ascutney the syenite abounds in black rounded masses which are for the most part crystalline hornblende and feldspar, and are probably transmuted pebbles. At Granby the pebbles, manifestly rounded, are either mica-schist or white almost hyaline quartz, just such as form the pebbles in the conglomerates at Wallingford and Plymouth, and the base is a fine-grained syenite, passing sometimes almost into mica-schist. A pebble of hornblende-schist is also sometimes seen. In bowlders of this conglomerate found at Northampton, Massachusetts, and probably derived from Whately, the most abundant pebbles are those of the brown sandstone, considerably metamorphosed and flattened. Those of hornblende-schist are common. Sometimes they are merely crystalline hornblende, not foliated generally, however, but mixed with some feldspar, and they may become syenite, and are frequently porphyritic by distinct crystals of feldspar. The cement is syenite, often more hornblendic than usual. When the pebbles are highly crystallized they become so incorporated with the matrix that it is difficult to separate them with a smooth surface, and if we are not mistaken they pass insensibly into those rounded nodules, chiefly hornblendic, so common in syenite, especially that of Ascutney. These occurrences are regarded as proof that the completely crystalline granular matrix is a metamorphic rock.

The pre-Potsdam rocks of Vermont are called Laurentian or Hypozoic, although it does not follow that they are not equivalent with the fossiliferous series elsewhere. It is only believed that if fossils once existed in them they have been obliterated. Of the Hypozoic rocks, Vermont contains, so far as known, only a small belt, which is the eastern edge of an immense development of the same in New York. These are referred here because there seems to be a discordance in the stratification between these rocks and the Lower Silurian, to which they are adjacent. The oldest of the Paleozoic series lies directly upon the Hypozoic at least at one point. As we approach the Green mountains, metamorphism has so nearly destroyed the fossils that the identification of the strata becomes extremely problematical, until at length the clue is lost entirely and the age of the formations can only be conjectured; hence they are distinguished mainly by lithological grounds and are grouped into a third class, Azoic rocks. Probably most of the Azoic rocks of Vermont will be found to be more recent than the Laurentian of Logan. The fossiliferous rocks are sometimes found under those that are more crystalline and nonfossiliferous, and these cases are thought to be the result of inversions. Certain great thicknesses of schists of uniform character are regarded as folded several times so as to be vertical, because otherwise the thickness of the series would be enormous. The talcose conglomerates, talcoid schists, Georgia group, etc., are referred to the Potsdam and later formations. The Georgia group and sand-rock may be possibly Primordial. The talcose conglomerate is placed as a continuation of the Quebec group and Sillery sandstones of Canada. The Taconic system is regarded as having an extension into Vermont, and to it are referred the black Taconian roofing slates, Sparry limestone, magnesian slate, Stockbridge limestone and granular quartz rock, with associated talcose beds, the thickness of the whole being 25,200 feet.

It is supposed that the chief action of metamorphism was in the Laurentian system and the cases of subsequent thorough alteration exceptional. The theory of the Laurentian age of the Azoic rocks of New England and that of the Cambrian age of the Taconic system stand or fall together. The Taconic system is regarded as older than the Lower Silurian and newer than the Laurentian, because it underlies the Silurian, because it is immensely thicker, and because the fossils which it contains are different from those of the Silurian.

HITCHCOCK, (CHAS. H.),[22] in 1861, gives a lithological treatment of the Azoic rocks of Vermont. They are divided into the following groups which are described in detail: Gneiss, hornblende-schist, mica-schist, clay-slate, quartz-rock, talcose schist, serpentine and steatite, and saccharoid limestone. Cleavage has a widespread occurrence, although it is believed that the strike and dip of lamination and stratification generally correspond. The granite-gneiss approaches so near to granite that in hand specimens the two rocks can not be distinguished from each other. The granite of the two Ascutneys seems to have cut across the strata of the calciferous mica-schist quite a distance into the gneiss, although the granite is regarded as of metamorphic origin. Clay-slate often passes by insensible gradations into mica-schist, which is regarded as a modified fragmental rock. Associated with the talcose schists and constituting an integral part of the formation are clay-slate, gneiss, quartz-rock, sandstones, and conglomerates. Igneous rocks, both trap and granite, are also associated with this formation.

HITCHCOCK, (EDWARD),[23] in 1861, considers in detail the relations of the granitic to the other rocks and considers the origin of the granite. This rock is found interstratified with slate, limestones and mica-schists in many localities. At the "Narrows," in the northern part of Coventry, the number of alternations is very large, the thickness of the different layers of granite varying from 1 to 7 feet.

The conglomeratic syenites of Whately, Massachusetts, and Ascutney, Granby and Barnet, Vermont, which contain fragments, are described in detail. These may be described as conglomerates whose cement is syenite, or a syenite through which is scattered pebbles mechanically rounded. Generally the pebbles are more or less metamorphosed and sometimes almost converted into syenite subsequent to their introduction. In their present state white quartz, mica-schist, hornblende-schist, and hornblende have been noticed. At Ascutney all traces of stratification in the conglomerate are lost and it passes first into an imperfect porphyry and then into a granite without hornblende in the same continuous mass. Where the conglomerate is least altered it is made up almost entirely of quartz pebbles and a larger amount of laminated grits and shales, the fragments rounded somewhat, and the cement in small quantity. The fragments are sometimes metamorphosed to mica-schist. The conviction can not be resisted that the granitic rocks of this mountain are nothing more than conglomerate melted down and crystallized. At Granby the bowlders are of all sizes, from a few hundred pounds to 50 to 60 tons. They cover many acres, are associated with those of contorted mica-slate, quartzose granite, and many other varieties common in the region.

At several localities in Vermont, Craftsbury, Northfield, New Fane, Proctorsville, and Stanstead, just beyond the Canada line, is a remarkable variety of white, fine grained, highly feldspathic granite which contains scattered through its face numerous spherical or elongated and somewhat flattened nodules of black mica from half an inch to 2 inches in diameter. They are usually more or less flattened and have a shriveled appearance like dried fruit. In some cases the concretions occupy more than half the mass. These concretions have sometimes been called petrified butternuts. The rock is regarded as produced by the metamorphism of a stratified rock.

Veins of granite are found to cut syenite, schist, gneiss, and limestone, in a most intricate manner at many localities. Sometimes there are several generations of granite veins. The foregoing facts lead to the conviction that the granite acts essentially like a liquid mass, but it is regarded as the product of aqueo-igneous fusion rather than dry fusion. Also it is believed that for the most part the granites have formed in situ, their material being furnished by the sedimentary rocks, hence they are called metamorphic. As evidence that they are metamorphic is the fact that it is often difficult to tell where a gneiss ceases and a granite begins. It is sometimes found, where granite masses come in contact with stratified rocks, that the latter have been more or less disturbed and broken, but only to a limited extent and often not at all. In many cases also the adjoining strata have suffered mechanical displacement, such as the forcible injection of melted matter would produce. For a considerable distance around the granitic masses also, the strata are frequently indurated and metamorphosed as if by heat, a fact that seems to decide the question of the emanation of much heat from granitic foci. The granites are more abundant in the crystalline than in the fossiliferous series, in fact it is uncertain whether any occur in rocks which bear fossils, although they are found in those which are regarded as the equivalent of the Devonian. The granite is most common in gneiss and mica-schist, less so, especially in the form of veins, in clay-slates, and least of all in talcose schist. In the stratified rocks cleavage and foliation occur, while joints are found both in the stratified and unstratified rocks.

THOMPSON,[24] in 1861, describes the greenstone or trap dikes of parts of Vermont. These are found to cut all the other rocks at many localities. Besides these there occur calcareous dikes, veins and dikes of quartz, and metallic veins.

HITCHCOCK, (CHARLES H.),[25] in 1861, gives detailed descriptions of sections in Vermont. The relations of the Ascutney syenite to the stratified rocks is again described. Upon examining the ledges immediately contiguous to the granite, most powerful marks of alteration by heat are found. Everywhere in approaching the syenite it is surrounded from a quarter to half a mile with indurated schists that ring like pot metal when touched with a hammer, and the lime-rock that is usually arranged in separate strata, seems to have become a constituent part of each stratum, the whole rock resembling the compact vitrified quartz west of the Green mountains. Often crystals of staurotide, and perhaps scapolite, are formed in the schist by the heat. In the west part of the larger mountain there are enormous veins crawling round in all conceivable directions in former crevices among the schists. This syenite is full of nodules of hornblendic masses, which look in some cases much like pebbles. They are probably concretionary, and are all allied to the concretions of black mica in granite at Craftsbury and elsewhere.

HALL (S. R.),[26] in 1861, gives many details as to the geology of northern Vermont. The granites are here particularly abundant. The occurrences are such as to lead to the conclusion that they are eruptive and that in their eruptions the fragments which are there contained have been caught from the strata cut. As evidence that the granite has been thrown up since the mica-schists were formed are cited the facts that the slates on the borders of the granite furnish unmistakable signs of contortion, and in some instances of change both in the direction of the strata and dip. In more than one instance, granite is found overlying the calcareous mica-slates, and in one instance, at Derby, encrinite limestone occurs below granite. In many places jointed granite is found between the strata of slates, conformable to them, and in other instances, in dike form, crossing the strata at a large angle. Fragments of the older slates are, in many places, found imbedded in masses of granite, and retain the characteristics of the slates, without any essential change. Nodular granite, containing masses imbedded like plums in a pudding, run from Memphremagog lake through Derby, Brownington, Irasburg, Craftsbury, and Calais.

HITCHCOCK (CHARLES H.),[27] in 1868, gives the following succession for the rocks of Vermont: Unstratified rocks, including granites, syenite, protogine, with the traps and porphyries; Eozoic system, including Laurentian gneiss of West Haven and the Green mountain gneiss; Paleozoic system, in which are placed the Georgia slates, the talcose conglomerate and schists, the mica-schists and other formations.

HUNT,[28] in 1868, states that there is no evidence of the existence in Vermont of any strata, except a small spur of Laurentian, lower than the Potsdam formation. The so-called middle and lower Taconic is in part Potsdam and in part Utica, Hudson river, and Quebec.

MCCORMICK,[29] in 1887, describes the inclusions in the granite of Craftsbury. The inclusions are spheroidal or elongated nodules of biotite 1½ to 2 inches in diameter, and sometimes 4 inches long, cemented with quartz, which by Hitchcock were compared to butternuts. The line of contact between the inclusion and the rock is usually rather distinct, it being possible to extract the former, leaving a lining of biotite. It is concluded that these nodules indicate the igneous origin of the granite because not capable of being formed from aqueous solution or by metamorphic action.

LITERATURE OF MASSACHUSETTS.

HITCHCOCK (EDWARD),[30] in 1818, divides the Primitive rocks of a section of Massachusetts on the Connecticut river into syenite, granite, argillite, alternating with mica-slate, siliceous slate, and chlorite-slate.

DEWEY,[31] in 1818, states that the country of the Taconic range and Saddle mountain is principally Primitive. Granite is found on both sides of Hoosac and Pownal mountains. Gneiss and mica-slate are found on the Hoosac and Saddle mountains. The Taconic range is composed principally of a talcose or soapstone slate, but quartz, granular limestone, and argillaceous slate are found. Quartz occurs on Stone hill, above which is argillaceous slate. Granular limestone occurs on both sides of the Hoosac. Argillaceous slate occurs in the valleys connected with the limestone.

DEWEY,[32] in 1820, finds the section from the Taconic range at Williamstown to the city of Troy to consist of chlorite-slate, graywacke, and argillaceous slate, this being the order of succession. The strata all incline to the east from 10° to 40°, the general inclination being 20° or 25°.

HITCHCOCK (EDWARD),[33] in 1823, describes granite as occurring at many localities in the region contiguous to the Connecticut river. It sometimes shows a tendency to stratification, which at Southampton is in beds in the mica-slates, at Bellows falls grades into mica-slate, and frequently veins of it cut the strata. These veins divide and subdivide like the top of a tree. In this region are also found gneisses, hornblende-slate, mica-slate, talcose slate, chlorite-slate, syenite, primitive greenstone, argillite, and limestone, all of which are referred to the Primitive. The gneiss is the most abundant rock, and often alternates with mica-slate and passes into it. The dips of the layers are from 20° to 90° to the east. At Hatfield, by following up the syenitic ridge, a rock is found which contains numerous imbedded masses of other primitive rocks, and these imbedded fragments are almost uniformly rounded and are often so numerous as to make the rock appear like a real secondary conglomerate. Thus we have a really conglomeratic syenite. The primitive greenstones are distinguished from the secondary because the latter are more coarse and crystalline.

DEWEY,[34] in 1824, in a sketch of the geology of western Massachusetts, divides the principal rocks into granite, gneiss, mica-slate, granular limestone, argillaceous slate, quartz-rock, transition limestone, and graywacke, mica-slate being the more abundant rock. The granite is not stratified, and must be considered as beds or veins rather than a continuous rock like the mica-slate. In the town of Windsor is a conglomeratic mica-slate.

NASH,[35] in 1827, finds the rocks of Hampshire county to include granite, mica-slate, micaceous limestone, hornblende-rock, talcose slate, Old Red sandstone, etc. The limestone often alternates with mica-slate, and frequently passes into it by insensible gradations. It is oftentimes garnetiferous. The granite veins are of all sizes up to 3 or 4 feet, cut the rocks in every possible direction, and intrude granite as well as the mica-slate.

HITCHCOCK (EDWARD),[36] in 1833, divides the rocks of Massachusetts into stratified and unstratified. Below the New Red sandstone in the former are graywacke, argillaceous slate, limestone, scapolite-rock, quartz-rock, mica-slate, talcose slate, serpentine, hornblende-slate, and gneiss. The unstratified are greenstone, porphyry, syenite, and trap, each of which is discussed. Among the agents which have consolidated the rocks heat is the predominant one, although chemical action has played an important part. The mica-slates have been mechanically deposited in water, and subsequently subjected to such a degree of heat as to enable their materials to enter into a crystalline arrangement without destroying their structure. The granite is supposed to have resulted from the melting down of other rocks. Where it is completely melted, granite results; where partially fused, granite-gneiss is found; while another portion might be converted into porphyritic gneiss and another into schistose rock. This theory explains the gradation of gneiss into granite and the crystalline and porphyritic structure of the gneiss. The unstratified rocks are all igneous. They occur in irregular protruding masses in the forms of veins of various sizes and as overlying masses. In cases in which they exist interstratified with other rocks, an examination shows that such interlaminated masses are always connected with an unstratified mass, and are merely veins which for a time coincide in direction with the strata. The syenite quarries of Sandy bay, cape Ann, have a parallel lamination, but as these grade into an unstratified syenite they are considered as examples of concretionary structure on a large scale rather than as a result of real stratification.

HITCHCOCK (EDWARD),[37] in 1841, in a systematic account of the Geology of Massachusetts, divides the rocks below the New Red sandstone into the following classes: Graywacke, metamorphic slates, argillaceous slate, limestone, quartz-rock, mica-slate, talcose slate, serpentine, hornblende-slate, gneiss, greenstone, porphyry, syenite, and granite. From the graywacke to the gneiss, this is the order of occurrence. The greenstone, porphyry, syenite, and granite are regarded as eruptive. At Bellingham is a remarkable metamorphic rock, which is a distinct mica-slate and a no less distinct conglomerate. In this formation is also placed aggregates of porphyry, which is a coarse breccia or conglomerate, chiefly made up of fragments of porphyry reunited by a cement of the same material, and sometimes almost reconverted into a compact porphyry. Flinty slate, chert, and jasper are simply the ordinary slate which have been changed to their unusual condition by the proximity of granite, porphyry, or trap. The clay-slate is entirely destitute of organic remains, as is also the graywacke. The limestones are water-deposited stratified rocks metamorphosed by heat. The mica-slate is generally associated with gneiss, but also occurs associated with all other rocks at least as high as the argillaceous slate. Hornblende-schist and greenstone-slate, a single formation, are tentatively regarded as metamorphosed from ordinary argillaceous rock by the action of heat. Gneiss is often much folded and curved, is cut by veins of other rocks, but is regarded as generally regularly stratified.

At Whately occurs a peculiar conglomeratic syenite. The syenite is generally found between the granite and metamorphic rocks and may be due to the conversion of the granite into syenite or else to the eruption of the syenite at a different epoch. The pseudo-stratification of granite is regarded as due to concretionary action on a gigantic scale. The granite cuts and is interstratified with all the stratified rocks and certain of the other eruptives in the most intricate fashion.

In Massachusetts are six systems which are unconformable and succeed each other in age. These are as follows: The Oldest Meridional system, the Northeast and Southwest system, the East and West system, Hoosac mountain system, the Red Sandstone system, the Northwest and Southeast system. In western Massachusetts, from Hoosac mountain to the Taconic range, a powerful force has folded the strata so that in many cases they have actually been reversed.

LYELL,[38] in 1844, describes the plumbago and anthracite in the mica-schist near Worcester. This is in the immediate neighborhood of masses of granite and syenite, the character of the plumbago and anthracite being due to this local metamorphosing effect and to more general chemical or plutonic action. The difference in dip of these rocks from the nearest Carboniferous of Rhode Island and Massachusetts is no evidence that they are not equivalent and the graphite metamorphosed organic material.

ROGERS,[39] in 1857, describes Trilobites belonging to the Paradoxides as occuring in the metamorphic beds of eastern Massachusetts at Braintree, which shows that these ancient and highly altered sediments are the base of the Paleozoic column.

HITCHCOCK, (C. H.),[40] in 1859, describes the rocks from Greenfield to Claremont, Massachusetts, as having the following order: Micaceous slates and schists interstratified with siliceous limestone, mica-slate, hornblende-slate, mica-slate interstratified with limestone, and, lastly, calcareo-mica-slate. The dips as far as the West Shelburne falls gneiss are to the east; at this latter point it is to the west. The whole is regarded as an anticline.

GREGORY,[41] in 1862, describes Marblehead as consisting mainly of the Primitive formation. The northern part of the peninsula is greenstone, intersected by dikes of the same rock. In the southern section syenite contends with the greenstone for supremacy, for here the two rocks are thoroughly intermingled. The deposits of greenstone, syenite, and porphyry are for the most part distinct, although occasionally the greenstone grades into the syenite.

JACKSON,[42] in 1866, gives the following section at the base of South mountain, at Chester, Massachusetts, from the base upward: Hornblende rock, magnetic iron ore, emery bed, granular quartzite, chlorite-slate and talc-slate, crystallized talc, talcose slate rock, soapstone or talcose rock, mica-slate. At North mountain, separated from South mountain by a branch of the Westville river, the section is as follows: hornblende rock, magnetic iron ore, emery 7 feet, hornblende rock, chlorite-slate, magnetic iron ore 6 feet, talcose slate, magnetic iron ore 6 feet, mica-slate.

SHALER,[43] in 1871, in a consideration of the rocks in the vicinity of Boston, states that there can be no doubt that the syenites of eastern Massachusetts are the oldest rocks found in the region. The quarries at Quincy show planes of separation in the syenite which can be only referred to stratification, despite the opinion generally entertained that the rocks are of igneous origin. This is evidenced by the fact that in the deeper portions of the syenite the bedding is imperfect and gradually passes toward the exterior of the rock into a more laminated phase. The first rocks of unquestionably sedimentary origin lie north of Quincy and consist of bedded sandstones approaching quartzite. This series is fossiliferous. The alteration of the bedded quartzite at Hayward landing is so great that the rock has assumed something of the appearance of a gneiss. In addition to these rocks, in the vicinity of Boston are the Roxbury conglomerate and the Cambridge slates. In the latter are found evidences of organic life in the presence of numerous indistinct impressions of fucoids. It is believed that the Cambridge slates and the Roxbury conglomerate belong to the same great series of beds. As there is a coincidence in the direction of dip it is thought they all may eventually be found to be a part of the same series of beds as the Braintree. The slates have a perfect cleavage in the plane of stratification in some places. Over both the slates and conglomerates are outflows of amygdaloid.

JACKSON,[44] in 1871, states that there is an insensible passage from the syenite into the greenstone porphyry. The obscurely stratified rocks on the border of the great syenite mass at Quincy prove the igneous influence of the eruptive syenite upon the upturned strata which it had elevated by its protrusion.

DANA,[45] in 1872, maintains from the descriptions of full sections that at Great Barrington is a conformable succession of quartzites, limestones, mica-schists and gneisses. The layers of quartzite are found along the strike to change to mica-schist and gneiss. This series, many of them later in age than the Stockbridge limestone, is similar to the Green mountain series, which has been regarded on lithological evidence to be pre-Silurian. The Stockbridge limestone, on fossiliferous evidence, is found to be either Silurian or younger. It appears that lithological evidence is a very uncertain test as to geological age, as crystalline rocks are found later than the Stockbridge limestone; as quartzite changes into mica-slate, schist or gneiss, these into hydromica-slates, and these into chloritic mica-slate.

HUNT,[46] in 1872, states that the rocks seen in the vicinity of Boston consist of three classes, crystalline stratified rocks, eruptive granites, and unaltered slates, sandstones, and conglomerates. The crystalline stratified rocks include the felsite-porphyries, nonporphyritic and jasper-like varieties, and porphyritic syenite; while the second division includes dioritic and chloritic rocks, sometimes schistose, and frequently amygdaloidal. These rocks are penetrated by intrusive granites, generally more or less hornblendic, the syenites of Hitchcock, and others. At several places the phenomena of disruption and inclosure of broken fragments of rock in the granite are well seen, the lines of contact being always sharp and well defined. The third class, consisting of the unaltered argillites of Braintree, containing the Primordial fauna, were found to rest directly upon the hard porphyritic felsite of the ancient series, the line of demarcation being very distinct. At other places reddish granulites directly underlie the black argillites, and in several places quartzites with conglomerates are observed in contact with the old dioritic and epidotic rocks. The Roxbury conglomerate contains pebbles of the felsite-porphyries, diorites, and intrusive granites of the older series, besides fragments of argillaceous slate.

BURBANK,[47] in 1872, states that the bands of crystalline limestone that occur in the granitic gneiss which extends in a southwesterly direction from near the mouth of the Merrimac river, supposed to contain Eozoon, are not true stratified rocks, but are subsequent deposits of a vein-like character. As evidence of this are cited the facts that the principal deposits occur along the line of an anticline, filling cavities produced by the folding and falling down of portions of the included strata of the gneiss. The deposits are all of very limited extent, the largest appearing at the surface not more than 220 feet in length, the widest part being about 60 feet. The aggregate length of all the limestone deposits occurring in a line some 25 miles in length is probably less than 1,000 feet. The principal masses are coarsely crystalline magnesian limestones, homogeneous in texture, and showing no traces of stratification. The various silicates occur attached to or near the inclosing walls of the cavities.

DODGE,[48] in 1875, divides the rocks of eastern Massachusetts into two groups, the crystallines and the more clearly stratified rocks among them. In the crystallines are placed the syenite and greenstone. These rocks have a dip to the west or northwest, and they unconformably underlie strata holding Paradoxides. For the most part metamorphism has been so complete that the rocks have entirely lost their original character. While eruptive rocks have often an appearance of schistose structure, in metamorphic syenites and diorites, on the other hand the original stratification is often completely lost. Throughout the crystalline area there are immense masses of hornblende rock, diabase, and diorite, usually crypto-crystalline, in which no indication of sedimentary origin can be traced. The syenites consist of quartz, feldspar, with little or no hornblende. The porphyry probably belongs with the crystalline group, and pebbles of it are abundant in the Brighton conglomerates. Perhaps some of the slates are so altered in this region as to resemble real porphyry.

Among the second division are siliceous slates and breccias. The siliceous slates are often much contorted. At Arlington they pass through fine grits and coarse syenites by various stages. The crystallines occupy distinct bands, separated by more recent rocks collected in the area between them. These more recent rocks are shown to be such by their position in relation to the underlying crystallines, as well as by the fact that they are composed of detritus of the latter. In places they are fossiliferous, and at Braintree contain the Paradoxides fauna. These stratified rocks are in part slates and in part conglomerates, the former appearing to occupy the inferior position. The conglomerates are well developed in the vicinity of Newport and Newberry. Cutting the slates and conglomerates are rocks which have been called eruptives, but so close is the resemblance in chemical and mineral composition and in appearance to the more fusible portions of the crystallines that it seems almost unreasonable to doubt that the former were derived from many deep lying masses of the latter.

CROSBY,[49] in 1876, describes and maps the Eozoic rocks of Massachusetts. They are divided into Norian, Huronian, and Montalban on lithological and chronological grounds. The lithological characters of the divisions are as unlike as the fauna of any two successive geological formations. The Norian is found in two areas in Massachusetts; that including the city of Salem and adjacent region, and that which includes the seaward end of large Nahant. The Norian rocks, composed chiefly of feldspar, hornblende, and pyroxene, are sometimes stratified and in other places massive. The Huronian rocks occur over a wide area, having an extreme length of 65 miles and an extreme breadth of about 40 miles. The Huronian comprises areas marked on the geological map of Hitchcock as syenite, porphyry, and hornblende-slate. The rocks here included are treated under hornblendic granite, felsite, diorite, stratified rocks, and limestones, all of which are regarded as metamorphosed sedimentary beds. The Montalban includes granite, which comprises exotic, indigenous and endogenous forms, gneiss, mica-slate, argillite, and limestone. Most of the slates in the vicinity of Boston are regarded as of Primordial age, although fossils have only been found at Braintree. The argillite of Kents island and the metamorphic slate of Newport are also regarded as Paleozoic.

BURBANK,[50] in 1876, lithologically divides the formations of the Nashua valley into (1) argillite; (2) mica-slate and quartzite; (3) granite and granitoid gneiss. With the argillite and mica-slate are small beds of conglomerate, and inclosed in the gneiss are nodular masses of crystalline magnesian limestone. In the slates at Harvard and Bolton occurs conglomerate in which the pebbles in many cases are flattened, bent, and even drawn out into layers, giving an agate-like structure to the rock. The principal conglomerate beds lie between hills of granite on the west and north and mica slate and gneiss on the south, yet not a pebble of granite or gneiss has been discovered. As to the age of the Nashua rocks no positive opinion is offered, but the author is inclined to regard them as belonging to a distinct system older than the Wachusett gneiss. The mica-slate appears to be interstratified with and overlie the gneiss, and the argillite beds appear to be for the most part conformable with the mica-slate.

DANA,[51] in 1877, maintains that the garnetiferous mica-slate, staurolitic slate, mica-schist, gneiss, and quartzite of Bernardston are Helderberg, on the ground that in these rocks are found fossils indicating this.

WADSWORTH,[52] in 1879, describes the felsites of Marblehead neck as altered rhyolites, which show characteristic fluidal structure. These felsites are not stratified, and are younger than the granite on the neck, as dikes of felsite are seen cutting it. There is no passage of the conglomerate into the felsite in this locality.

CROSBY,[53] in 1880, divides the Azoic formations of eastern Massachusetts into Naugus head, Huronian, and Montalban, these terms being used on account of a lithological and stratigraphical resemblance which they bear to the Azoic divisions of other regions. The Naugus head is provisionally regarded as equivalent to Hunt's Norian (although it contains no labradorite), as older than the Huronian, and the Huronian older than the Montalban. The entire Naugus head formation seems to have been plastic, and the extravasation has been so extensive that the character of the rocks changes at nearly every rod to varieties regarded as composed of metamorphosed stratified rocks. The Naugus head series has been extensively extravasated through the superjacent Huronian formation, but is penetrated by nothing foreign to itself, the Huronian granite being never found to cut the Naugus head series, from which the conclusion is formed that the Naugus head is older than the Huronian. In fact, the Huronian granite pierces every rock in the region save the Naugus head series and the newer uncrystallines, so that it can not be doubted that it overlies this ancient terrane. The latter must be regarded as the lowest, and hence the oldest member of the succession.

The Huronian is principally composed of granite, petrosilex, diorite, hornblendic gneiss, and limestone, this being the order of age from the base upward. The petrosilex is the most characteristic rock. In the Huronian distinctly bedded rocks are the exception. Although many apparently structureless rocks are probably really stratified, it is undoubtedly true that a large part, perhaps the greater part, of the formation has been more or less fluid, and extravasation may be set down as a characteristic structural feature. Besides cutting various rocks, in the granite at many points at the contact with the mica-slates are found angular fragments of the latter. The induration of the slate and conglomerate at points where they adjoin the granite, with the frequent development of amygdaloid characters, are facts which tell strongly in favor of the igneous character of the granite. The petrosilex is frequently cut by the granite, but the reverse is never the case. There is an apparent transition between the granite and the petrosilex or porphyry. The two are regarded as conformable, both having been metamorphosed from the same set of sediments, the more crystalline character of the granite being due to its greater depth. With the diorite is included all the basic rocks which have been fluid. These blend with and grade into the stratified hornblende-gneisses.

The Montalban series in the area covered is the most important of the three systems. It comprises the ascending conformable succession, granite, gneiss, mica-slate, argillite, and limestone, although subordinate breaks of no great importance occur. The granite acts as an exotic to a large degree, although it is believed to belong with and come from the endogenous metamorphic granite at the base of the series. The exotic granite has sometimes cut rocks as new as the Carboniferous. Granite grades into gneiss, the gneiss into mica-slate, and the mica-slate into argillite, in which are found the conglomerate bands. In these conglomerates in many cases the pebbles have been flattened, bent, and even drawn out into lenticular layers, developing a schistose structure. One of the best localities is that at Bellingham.

The Shawmut group is a fragmental series resting unconformably upon the Huronian terranes. The chief constituents of the Shawmut group are breccia and amygdaloids, the relations of which are somewhat uncertain. The petrosilex breccia of the Shawmut group are oftentimes very like the petrosilex of the Huronian. This group is perhaps equivalent to the copper-bearing rocks of lake Superior which they resemble lithologically. The Paleozoic formations form different troughs which rest unconformably upon the older series.

DILLER,[54] in 1881, describes the felsites and their associated rocks north of Boston. The granite is found to contain fragments of distinctly stratified rocks, and is regarded as an eruptive rock. The felsites are found to have all the microscopical characteristics of eruptive rocks; to cut both the stratified rocks and the granites; to show no transitions into the clastic rocks, and are regarded as eruptives. The diorites contain distinct fragments of the granites and felsites, cut across the bedding of the stratified quartzites and schists, and are eruptives of later age than the granite and felsite. The framgental rocks are in part older and in part younger than the felsites, as a portion of them is cut by the felsites while certain conglomerates contain fragments derived from the felsites.

WADSWORTH,[55] in 1882, states that the Quincy granite is eruptive, as is shown by the fact that its junction with the slate is irregular. Along the contact the latter rock is greatly indurated and changed in color, and the granite has lost its distinctive characters, being transformed into a spherulitic quartz-porphyry.

WADSWORTH,[56] in 1882, describes as a trachyte at Marblehead neck and having all the characteristics of this eruptive rock, a rock which Crosby has described as a sandstone or arenaceous slate.

WADSWORTH,[57] in 1884, describes the relations of the argillite and conglomerate of the Boston basin. At the junction of the two the argillite is found to be irregularly eroded and the conglomerate laid down unconformably over it; in places the argillite is cut off and the conglomerate abuts unconformably against it, and pebbles of the argillite are found in the conglomerate at the junction. There are at least two distinct argillites. One, underlying the conglomerate at Beacon street, resembles that of the Paradoxides argillite at Braintree; the other, of a coarser grain, oftentimes a true sandstone as far as its relations have been ascertained, is a component part of the Roxbury conglomerate. So far as any evidence is at hand, the oldest surface rocks in the basin are the argillites and schists. Of these the age of only a small area at Braintree carrying Paradoxides is known. Through the schists and argillites have been protruded immense quantities of eruptive rocks in the forms of lava flows, ashes, dikes, and bosses.

PERRY,[58] in 1885, states that the mica-schist at Worcester contains a coal seam, and bears fossils of Carboniferous age. The mica-schist is cut by granite.

JULIEN,[59] in 1887, describes the succession of rocks in the Great Barrington, from the base upward, as consisting of Stockbridge limestone, schist or gneiss, quartzite, and dolomite. The proof that the dolomite occupies a distinct bed at a higher horizon from the main sheet is clear.

EMERSON,[60] in 1887, describes the succession of crystalline rocks in Hampshire county, in order of their age from the base up, as gneiss, feldspathic mica-schist, hornblende-schist, hydromica-schist, and calciferous mica-schist. Granite and syenite are placed as eruptive rocks of the older series.

CROSBY,[61] in 1888, maintains that there are no Carboniferous beds in the Boston basin; that it contains essentially one formation of conglomerate and one formation of slate; that these sediments include the Paradoxides bed at Braintree, are conformable, and therefore are Primordial or at least of Cambrian age; that the conglomerate underlies the slate. The pebbles of the conglomerates are made up of crystalline rocks of the regions adjacent. The contacts of the conglomerate and felsite are always well defined, and fragments of the latter are always contained abundantly in the former. The same relations hold between the granites and conglomerates. The conglomerates and slates have often a well developed cleavage, which frequently cuts across the bedding, although in places where the folding has been intense the two correspond. The discordance is shown by bands of the conglomerate cutting across the cleavage.

SHALER,[62] in 1889, describes cape Ann as consisting mainly of granite, which is cut by very numerous dikes of diabase and quite abundant ones of quartz-porphyry. Squam river is an area of diorite. The relative age of the granite and diorite has not been determined.

EMERSON,[63] in 1890, describes the Bernardston series of rocks. The succession is here found to consist of fourteen members. From above downward the upper seven consist of alternations of mica-schist and hornblende-schist, after which follow quartzite, hornblende-schist and magnetite, limestone, hornblende-schist, quartzite-conglomerate, argillite, and calciferous mica-schist. The whole series is very crystalline, some parts so thoroughly so as to have been compared by Hitchcock with the Bethlehem gneiss, his basement Laurentian. In the limestones fossils are found of such a character as to prove that the whole series is Upper Devonian.

EMERSON,[64] in 1890, describes the rocks of central Massachusetts, between the Berkshire limestone and the Boston basin, as consisting of a series of mica-schists, quartz-schists, and hornblende-schists, presumably Paleozoic, and eight bands of granite and granitoid gneiss, in small part Archean, in larger part Cambrian, and in largest part intrusive. In the western part is a small row of Archean ovals, about which are the Cambrian conglomerates and conglomerate-gneisses, the latter rocks having a quaquaversal arrangement. Here are included the Princeton and Athol granites, often well foliated, which have a great extent north and south. To the great intrusive masses of granite is applied Suess's name batholites. These have melted their way through a great thickness of folded strata and absorbed much of the latter in their own mass. At times the central masses of granite are cut by dikes of coarse muscovite-granité which seem to be later intrusions. About the batholites are broad areas in which contact metamorphism has altered the rocks, changing the argillites to mica-schists, etc. The contact metamorphism has a zonal character. The Barre and Orange bands of biotite-granite so combine the peculiarities of the Cambrian conglomerate-gneisses and the batholitic gneisses that no opinion is expressed as to their origin.

PUMPELLY,[65] in 1891, describes Cambrian quartzite as resting unconformably upon granitoid gneiss at Clarksburg mountain. In the granitoid gneiss is found a dike which has been decayed and washed out before the quartzite was deposited, leaving a fissure which caused the beds of quartzite to thicken and sag, and which contain at the bottom material derived from the dike. On Hoosac mountain there is a core of granitoid gneiss, upon which rests unconformably at the axis coarse basal conglomerate with a sharp contact. In other places there is an apparent gradation between the metamorphosed conglomerate and the granitoid gneiss. This Cambrian quartzite-conglomerate is found to vary laterally in the legs of the fold into completely crystalline white gneiss. The Cambrian formation, containing Olenellus fauna, mantles around the pre-Cambrian granitoid gneiss, and the whole mountain is an overturned fold.

PUMPELLY,[66] in 1889, gives a systematic general account of the Green mountains in Massachusetts. These include three principal elements, Hoosac mountain, the Taconic range, and the great valley between these. The mountain rocks are composed of crystalline schists, which are found to be of Cambrian and Lower Silurian age, resting on pre-Cambrian rocks. The valley has a floor of crystalline limestone or saccharoidal marble, on which are ridges of schists, both being of Lower Silurian age. The Taconic range is a synclinal in the Lower Silurian schists, the limestone foundation appearing only at its base. At Hoosac mountain the succession is (1) granitoid gneiss; (2) quartzite-conglomerate and white gneiss; (3) Hoosac phyllite, and (4) Rowe schist. On Greylock the succession is (1) Stockbridge limestone; (2) Berkshire phyllite; (3) Bellowspipe limestone, and (4) Greylock phyllite. At Hoosac mountain the quartzite-conglomerate and white gneiss appear to grade down into the granitoid gneiss in perfect conformity. At Stamford a basic dike was discovered which cuts the granitoid gneiss, but stops abruptly at the quartzite. Indeed, the quartzite sags down at this place, its layers thickening and filling the hollow. These relations are considered definite proof of an unconformity between the granitoid gneiss and the quartzite. The general transition between the two is explained by considering the granitoid gneiss as disintegrated at the time of the transgression which formed the quartzite. The quartzite-conglomerate and white gneiss are traced into each other laterally, and are therefore but different forms of a sediment of the same age, and unequally metamorphosed. Across the valley the Hoosac phyllite was traced by gradual transitions into the limestone; and the Stockbridge limestone, Berkshire phyllite, Bellowspipe limestone and Greylock phyllite are all correlated with the Hoosac phyllite. In the quartzite is found the Olenellus fauna, hence the only pre-Cambrian rock is the granitoid gneiss. In structure Greylock is a complex synclinal, while Hoosac mountain is an anticlinal overturned toward the west. At the ends of the Hoosac ridge the anticlinal bends nearly to an east and west direction. This is explained by regarding the granite-gneiss as a rigid mass which resisted the lateral thrust, and the abnormal overfoldings as the result of compensatory movements.

WOLFF,[67] in 1889, gives a systematic account of the geology of Hoosac mountain. The rocks of the region are thoroughly crystalline, but little trace remains of their original elements, whether of detrital or of eruptive origin; but the bedding corresponding to their original planes of deposit is well marked, and under proper conditions the order of succession can be determined. The basement rock is a coarse granitoid banded gneiss, which forms the base of the Hoosac mountain proper. Crushing and development of new minerals makes it perhaps impossible to say certainly what is the origin of this rock. It could perfectly well be an eruptive granite modified by metamorphism, while on the other hand its field relations show its close association with and frequent transition into coarse gneisses which seem to form a part of the detrital series.

Overlying the granitoid gneiss is a series of rocks called the Vermont formation. At one place, where perhaps folded, it is 600 or 700 feet thick. This formation contains numerous gradations between coarse gneisses similar to the basement gneiss; finer grained banded gneisses; gneisses with but a small amount of mica; metamorphic gneiss-conglomerate; ordinary quartzite-conglomerate and quartzites. These phases pass into each other along the strike. In the metamorphic conglomerate it is difficult or impossible to separate the old quartz and feldspar from that formed in situ. The rock is considered metamorphic because of the shape and distribution of the pebbles in alternations of coarse and fine materials, because of the diverse nature of the pebbles, including blue quartz, white quartz, granulite rock, and granite, and because of frequent transitions into quartzite and quartzite-conglomerate.

The next member of the series is the Hoosac schist, which conformably overlies the Vermont formation. In this schist no recognizable clastic element is found. The minerals appear to have formed contemporaneously. This schist is often coarsely crystalline, yet it is very similar to the albite phyllites of Germany.

The next rock found is the stratified limestone, which occurs in the Hoosac valley, where it is in contact with the Vermont formation and the Hoosac and Berkshire schists. The rock is generally an impure, coarsely crystalline white marble. Layers of quartzite are frequent in the limestone and the change from one to the other is gradual. Also, there is in some sense a transition between the Stockbridge limestone and Vermont gneiss, and also a transition between the limestone and Hoosac schist. There also occur certain dark colored rocks interstratified with and in one case cutting the others, amphibolites. Detailed descriptions are given of the occurrences at the various districts.

At the Hoosac tunnel the main facts brought out are that there is a large central mass of coarse granitoid gneiss (Stamford gneiss) forming the core of Hoosac mountain; that this is flanked on both sides by the white gneiss-conglomerate (Vermont conglomerate), the eastern band having a steady dip east and overlain by the albite-schist series; the western band broader, with varying dips, passing by gradual transitions into the coarse gneiss, and bounded on the west by a narrow band of the albite schist (Hoosac schist), the contact being conformable and transitional. This schist is succeeded on the west by another band of fine grained white gneiss (Vermont), and this in turn by the limestone (Stockbridge), no contacts being observed. The structure is anticlinal.

This succession and these relations are found to correspond with the distribution in the central district of Hoosac mountain. It is also found that the anticlinal of Hoosac, consisting of the Stamford gneiss, Vermont formation and Hoosac schist, has a pitch to the northward of from 10° to 15°, while the western side has been overturned, which makes the beds in inverted order on the west side. The whole northern third of the region and a broad strip along the east is occupied with albite-phyllite. In the district south of Cheshire and that of Hoosac valley the Stockbridge limestone and Vermont quartzite are found to be conformable, and the latter lower in horizon, as shown by contacts, lithological passages and the corrugations of the two together; the quartzite-conglomerate of the Vermont formation is identical with the fine grained white gneisses of the Dalton-Windsor area and to those of Hoosac mountain; and the schist area of Hoosac mountain is conformable with the quartzite and white gneiss series of Hoosac valley. The Hoosac valley schist and limestone appear to be conformable, although contacts are wanting.

At Clarksburg mountain the granitoid gneiss (Stamford gneiss) is overlain by Clarksburg quartzite (Vermont formation), in which Walcott has found remains of trilobites, showing it to be Lower Cambrian. The two in a general way appear to be conformable, but in one place an undoubted dike runs in a straight line through the granitoid gneiss, but abuts against the quartzite without passing into it; and the quartzite has a curious thickening of its layers where the dike joins it, as though there had been a hollow owing to erosion of the dike before the deposition of the quartzite. It seems, therefore, to show the most perfect unconformity between the granitoid gneiss and the overlying quartzite, although the structure of both rocks is parallel. Excepting the granitoid gneiss and the amphibolite, if the rocks are simply the Cambrian and Silurian limestones, sandstones and shales, altered by metamorphism, as they appear to be, the transition ought to be traced to the unaltered forms toward the Hudson. An examination of the rocks of Greylock suggests that the metamorphism is in general in accordance with this idea eastward, and also perhaps downward.

As a result of the work it is concluded that the gneisses of the Green mountains are just as capable of stratigraphical investigation as the unaltered sediments of the Appalachians, only the problem is much more difficult, owing to the secondary structures produced by metamorphism.

DALE,[68] in 1889, gives a systematic treatment of the structural and areal geology of Greylock. The rocks are all metamorphic and of few kinds, crystalline limestone and various schists. The key to the structure is in the distinction between cleavage foliation and stratification foliation. The phenomena of cleavage and stratification as studied on Greylock lead to the adoption of the following structural principles: I. Lamination in schist or limestone may be either stratification foliation or cleavage foliation, or both, or sometimes, in limestone at least, "false bedding." To establish conformability the conformability of the stratification foliations must be shown. II. Stratification foliation is indicated by: (*a*) The course of minute but visible plications; (*b*) the course of the microscopic plications; (*c*) the general course of the quartz laminæ whenever they can be clearly distinguished from those which lie in the cleavage planes. III. Cleavage foliation may consist of: (*a*) Planes produced by or coincident with the faulted limbs of the minute plications; (*b*) planes of fracture, resembling joints on a very minute scale, with or without faulting of the plications; (*c*) a cleavage approaching slaty cleavage, in which the axes of all the particles have assumed either the direction of the cleavage or one forming a very acute angle to it, and where stratification foliation is no longer visible. IV. A secondary cleavage, resembling a minute jointing, occurs in scattered localities. V. As ascertained by Pumpelly, the degree and direction of the pitch of a fold are indicated by those of the axes of the minor plications. VI. The strike of the stratification foliation and cleavage foliation often differ in the same rock, and, as suggested by Pumpelly, are then regarded as indicating a pitching fold. When the fold is horizontal the two are parallel. VII. Such a correspondence exists between the stratification foliations and cleavage foliations of the great folds and those of the minute plications that a very small specimen properly oriented gives, in many cases, the key to the structure over a large portion of the side of a fold.

There are large areas, sometimes half a mile square, where the only foliation presented by the outcrops is of secondary character and where no trace of stratification can be detected. As the cleavage foliation in some places coincides with the stratification foliation both in strike and dip, in others agrees in strike while differing in angle of dip, and in still others differs both in strike and dip, and, furthermore, as the marks of stratification are not infrequently subject to purely local changes, the whole matter is attended with much difficulty. As a rule the most reliable structural data on Greylock have been obtained from outcrops where two different beds were in visible contact, or from a series of related outcrops in all of which both cleavage foliation and stratification foliation were equally manifest and discordant, or else from large surfaces of rock at right angles to the strike where the general trend of the minor folds could be distinctly seen. As a result of a large number of observations the difference in angle of dip between the cleavage foliation and stratification foliation was found to be from 10° to 120°. When the difference is over 90° the direction of the two dips is opposite. The absolute dip of cleavage in a large number of cases is almost universally to the east. Also, there is lack of conformity in the strikes of the cleavage foliation and stratification foliation.

Early in the work attention was directed by Pumpelly to methods of detecting the pitch in the axes of folds. It is usually determined by observing the pitch of the axis of any part of the fold. The correctness of the method seems to be verified by the general parallelism which exists between the minute and general structure of the rock masses, and also by the opposite direction of the pitch as determined at the extreme ends of the mountains. An application of these principles to Greylock shows that the range consists of a series of more or less open or compressed synclines and anticlines which, beginning near North Adams, increase southerly in number and altitude with the increasing width and altitude of the schist area, and then, from a point about a mile and a half south of the summit, begin to widen out, and to diminish in number and height until they finally pass into a few broad and low undulations west of Cheshire. Between that point and the villages of Berkshire and Lanesboro the folds become sharper and more compressed and the schist area rapidly narrows, terminating within a short distance of Pittsfield.

Mount Greylock, with its subordinate ridges, is then a synclinorium, consisting at the surface of eleven synclines alternating with as many anticlines, but in carrying the sections downward they are resolved into two great synclines with several lateral and minor ones. There are five more or less distinct lithological horizons in the Greylock mass.

Beginning above, the succession and correlations, with the classifications of E. Emmons, James Hall, Dana and Walcott, are as follows:

Horizons, natural order.	Lithological character.	Thickness.	Age.			
			Emmons, 1855.	Hall, 1839–1844.	Dana, 1882–1887.	Walcott, 1888.
		Feet.				
V................. (Upper schists.)	Muscovite (sericite), chlorite and quartz-schist, with or without biotite, albite, magnetite, tabular crystals or lenticular plates of interleaved magnetite and chlorite; ottrelite, microscopic rutile and tourmaline. These schists are rarely calcareous or graphitic.	1,500–2,200	Pre-Potsdam. Lower Taconic No. 3, "talcose or magnesian slate."	Trenton (Hudson river).	Lower Silurian.	Trenton (Hudson river).
IV................. (Upper limestone.)	Limestone, more or less crystalline, generally micaceous or pyritiferous, passing into a calcareous mica-schist or a feldspathic quartzite or a fine-grained gneiss with zircon and microcline or a schist like V and III. The more common minerals are: graphite, pyrite, albite and microscopic rutile and tourmaline. More rare: galena and zinc-blende.	600–700	Pre-Potsdam. Lower Taconic No. 3, included in "talcose or magnesian slate."	Trenton (Hudson river).	Lower Silurian.	Trenton (Hudson river).
III .... (Lower schists.)	Muscovite (sericite) chlorite and quartz-schist, with or without biotite, albite, graphite, magnetite; frequently with tabular crystals or lenticular plates of interleaved magnetite and chlorite; garnet; (ottrelite?); microscopic rutile and tourmaline. These schists are in places calcareous, especially toward the underlying limestone.	1,000–2,000	Pre-Potsdam. Lower Taconic No. 3, "talcose or magnesian slate."	Trenton (Hudson river).	Lower Silurian.	Trenton (Hudson river).
II .... (Lower limestone.)	Limestone, crystalline, coarse or fine; in places a dolomite, sometimes quartzose or micaceous, more rarely feldspathic, very rarely fossiliferous. Galena and zincblende rare. Irregular masses of iron ore (limonite), associated sometimes with manganese ore (pyrolusite). Some quartzite.	1,200–1,400	Pre-Potsdam. Lower Taconic No. 2, "Stockbridge limestone."	Lower Silurian. (Trenton and lower.)	Lower Silurian.	Trenton (Trenton, Canadian, Chazy, calciferous).
I .... (Quartzite.)	Quartzite, fine grained, alternating with a thin-bedded, micaceous and feldspathic quartzite. (The latter with calcite, pyrite, tourmaline.) Associated with these quartzites, and probably at the base of this horizon, is a coarse grained micaceous quartzite (tourmaline) passing, in places, into a conglomerate, and containing blue quartz, feldspar (plagioclase, microcline) and zircon, all of clastic origin.	800–900	Pre-Potsdam. Lower Taconic No. 1, "granular quartz."	....	Cambrian (Potsdam).	In part Lower Cambrian (Olenellus).
	Total thickness: Minimum.. Maximum..	5,000 7,200				

LITERATURE OF RHODE ISLAND.

JACKSON,[69] in 1840, describes the older rocks of Rhode Island as Primary and Metamorphic. The Primary rocks are generally said to be rocks produced in the state of igneous fusion. Among these are placed granite, gniess and mica-slate, although it is doubtful as to the manner in which these two latter rocks were formed. At Woonsocket a conglomerate passes into a mica-slate. In general the contact between the gneiss, mica-slate and graywacke are perfectly sharp.

COZZENS,[70] in 1843, finds that the section on the island of Rhode Island, from the base up, includes granite, serpentine, black slate, graywacke, black slate, Rhode Island coal and diluvium.

JACKSON,[71] in 1859, maintains that the pebbles of the Newport conglomerates in their present condition were mechanically formed by being rolled upon beaches, often the distortions and indentations being accounted for in this way.

HITCHCOCK (CHAS. H.),[72] in 1861, describes the lower rocks of the island of Aquidneck, in ascending order, as (1) talcoid schists, and conglomerates with red jasper pebbles; (2) the Purgatory conglomerate, the pebbles of which are distorted; (3) mica-schists, mica-slates, conglomerates, sandstones, and grits west of Purgatory; (4) second conglomerate, and (5) coal measures.

DALE,[73] in 1883, gives detailed sections of many localities and descriptions of various places. The conglomerates are found in some cases to be highly metamorphic, the pebbles being uumistakably elongated and cut with scales of mica. The cleavage of the pebbles is regarded as partly due to their adhesion to the cement. The fractures with which they are cut is possibly due to wave motion or to the contraction of the conglomerate in cooling from a heated state. The chronological order and thickness of the series is in ascending order as follows:

	Feet.
1. Hornblende-schist alternating with mica-schist	950
2. Chloritic schists and associated argillaceous and micaceous schists	500–750
3. Greenish, slaty conglomerate, with argillaceous and siliceous serpentine. (Conglomerate I.)	500
4. Quartz and clay, aggregate	750
5. Argillaceous schists and associated slates, etc	600
6. Quartzite conglomerate, with grits and some argillaceous schist. (Conglomerate II.)	750
7. Carbonaceous schists and shales with argillaceous schists	500
8. Fine argillaceous conglomerate and grit	500
Total	5050–5300

LITERATURE OF CONNECTICUT.

SILLIMAN,[74] in 1820, states that Primitive rocks occur in many places in the counties of New Haven and Litchfield. These rocks succeed each other with almost precisely the arrangement and succession laid down by Werner—clay-slate, including beds of trap; mica-slate; gneiss. Granite crowns the whole, although it occupies but a small extent compared with the gneiss and slaty rocks. As a whole the slates occupy the lowest and the granites and gneiss the highest situations.

MATHER,[75] in 1832, describes the succession from Killingly to Haddam as consisting of gneiss, granite, syenite, mica-slate, hornblende-slate, granular quartz rock, the latter underlying thick strata of gneiss. Powerful veins of granite traverse the gneiss, while in other places the granite is found both in veins and beds.

MATHER,[76] in 1834, divides the rocks of Connecticut into gneiss, hornblende-slate, mica-slate, granular feldspar, granular quartz, syenite, granite, limestone. The strata generally show themselves in long belts extending unbroken to a considerable distance. The thickness of the gneiss at one locality is not less than 10,000 feet. At Lebanon the gneiss surrounding a great part of the syenite dips so as apparently to pass under the latter rock. The syenite is not stratified, but the granite is partly so. The limestone occurs in beds from 1 to 20 feet thick, embraced in the contorted gneiss in the northwest part of Stonington.

PERCIVAL,[77] in 1842, divides the consolidated rocks of Connecticut into Primary, Secondary, and Trap rocks. The Primary rocks occupy the greater portion of the surface of the state and are divided into the western and eastern sections. These primary rocks are formed entirely of original materials, exhibiting no appearance of any fragment or remains of any anterior formation. The trap rocks are chiefly connected with the secondary rocks, although they also cut the Primary. These are regarded as intrusive and igneous. In describing the Primary rocks the term parallel is preferred to stratified, as simply expressing the fact as to the arrangement of the minerals without implying any opinion as to the mode of formation. The western primary system, which extends on the west and southwest into the state of New York and on the north into Massachusetts, is divided into a large number of local formations, including the classes, mica-slate, argillite, granite, calciferous schist, limestone. The formations as a whole present a series of parallel ridges which have a general curvature with a convexity toward the east. The central portion exhibits a series of granitic and micaceous alternations, which appear partly as elongated bands and partly as isolated nuclei, generally granitic, around which the more micaceous formations are concentrically arranged. The eastern primary system is divided into several main groups, the rocks here including gneiss, micaceous and chloritic rocks. In one of the granitic formations the arrangement consists of a central nucleus of granite-gneiss surrounded by narrow concentric ranges of various characters. The zone immediately adjoining the granitic nucleus is characterized by the almost constant presence of anthophyllite. From the coarsest granites to the finest and most uniform schist the structure is characterized by a parallel arrangement of the mineral constituents. Continual alternations were observed of series of granitic, micaceous, hornblendic and various other formations. The trap rocks occurring in the primary and secondary formations are so near alike that they can not be separated, but in the primary rocks there is no conformity between the traps and the adjacent formations, such as prevails in the secondary.

DANA,[78] in 1872, states that the quartzite of Canaan outcrops in six exposures, is unconformably below the limestone, and its jointing, uplifting and consolidation took place before the latter was deposited.

GENERAL LITERATURE.

DANA,[79] in 1877, maintains that the conformable succession in Berkshire county, Massachusetts, and in Vermont are the same, being (1) limestones and schists; (2) quartzites and schists; (3) quartzites and limestones; all conformable. The Taconic range of Berkshire is probably Upper Trenton or Hudson river or Cincinnati. There are frequent abrupt transitions between the quartzite and gneiss which are believed to represent transitions from sand deposits to mud deposits in the old seas.

HITCHCOCK, (C. H.),[80] in 1879, describes the Atlantic system as including the highlands of the Atlantic ocean between Newfoundland and the Carolinas, comprising the Terranovan, confined to Newfoundland and Nova Scotia; the Montalban, with Green mountain branch, in which is the White mountains; and the Carolina or Southern, which culminates in the Black mountains. The rocks of the system were deposited in a Laurentian basin with the Adirondacks on the west and the ancient gneisses of eastern Massachusetts on the east.

DANA,[81] in 1880, finds that the western and eastern halves of the Green mountain area are one orological system, the rocks being similar, and all are of Lower Silurian age. With these belong part of the central mountain section. In view of these various considerations the evidence, although not yet beyond question, is manifestly strong for embracing the whole region between the Connecticut and the Hudson (and to an unascertained distance beyond) within the limits of the Green mountain synclinorium.

DANA,[82] in 1884, finds that the schistose rocks constituting the Taconic range grade from north to south from feebly crystalline argillite and hydromica-schist to coarse grained mica-schist, garnetiferous and staurolitic. The eastern and western limestone belts blend with one another through the low regions, cross the Taconic line, and prove the two to be one formation. The limestone passes underneath the schist of the Taconic range and outcrops on its east and west sides on opposite sides of the synclinal. The limestones which constitute the lower part of the Taconic system contain fossils, which designate it as Lower Silurian; hence the schists of the Taconic are later than Silurian age and probably belong to the Hudson river. The structure of the range is a compound synclinal. Mount Washington is a synclinal of the same kind, which dies out to the south with a multiplication of small subordinate flexures.

HITCHCOCK (C. H.),[83] in 1884, describes a number of geological sections across New Hampshire and Vermont, and correlates the rocks. The order and thickness of the crystalline formations from above downward are as follows:

	Feet.
Calciferous mica-schist and Coös group	12,000
Kearsarge group	1,300
Rockingham mica-schist	6,000
Merrimac group	4,300
Huronian	12,000
Hornblende-schist	1,500
Montalban	10,000
Lake Winnipiseogee (Green mountain) gneiss	18,600
Bethlehem gneiss	6,300
Porphyritic gneiss	5,000
Total thickness	77,000

The various groups are classified according to stratigraphical and not lithological reasons. Unlike rocks are never assumed to be identical. If a hornblende-schist and clay-slate dip toward each other they are assumed to be of different age and separated by a fault. If a granitic rock shows foliation it is classed among the gneisses. The igneous rocks are devoid of marks of stratification. The Montalban is used to cover pre-Huronian and post or upper Laurentian rocks. Huronian is used for convenience to designate the various schists of chloritic and argillitic aspect overlying the gneisses and inferior to the Cambrian so far as known. The Ascutney granite seems to have been erupted from below through one or more vents and spread over the rock adjacent, as is shown by the fact that in the valleys where erosion has cut into the base of the granite it is discovered that schists run under the igneous rock certainly for 300 feet. The mica-schists show the presence of heat for a distance of 500 feet or more from the granite. The slates have been indurated so that they ring like iron when struck with a hammer. The limestones are sometimes calcined and even glazed. Veins enter both of the rocks from several yards distant. The gneiss is not altered by the contact line. It would seem, therefore, as if we had here examples of contact phenomena, and only the later strata are affected, because the gneiss had been already made crystalline before the eruption of the granite.

HITCHCOCK, (C. H.),[84] in 1886, divides the older rocks of Vermont into (1) granite (Devonian); (2) Eozoic gneiss; (3) Potsdam and later formations. In (3) are included the Georgia slates, the calciferous mica-schist, etc. The Eozoic gneiss occurs in five areas and is believed to underlie the Potsdam or Quebec group. At Wallingford the quartzite is superimposed upon a gneiss, as shown by peculiar erosion. At Sunderland, East Wallingford, Ripton, Bristol and Clarksburg, Massachusetts, the fossiliferous rocks contain pebbles of a peculiar blue quartz which is derived from the gneiss. The gneiss is a northward continuation of the Eozoic rocks of New Jersey, the Highlands of New York and of southern New England. In Maine the Cambrian, Huronian and Taconic rocks are placed together and also the Montalban and Laurentian. The granite and trap and altered slates are not placed in the strati. graphical column. The gneisses are regarded as older than either the Cambrian or Huronian. The pre-Silurian rocks of New Hampshire are classified as follows:

Eozoic	Laurentian	Porphyritic gneiss.
	Atlantic	Bethlehem group.
		Lake Winnipiseogee gneiss.
		Montalban or White mountain series.
		Franconia breccia.
	Labrador or Pemigewasset	Conway granite.
		Albany granite.
		Chocorua granite.
		Ossipyte.
		Compact feldspar.
		Exeter syenites.
	Huronian	Lisbon group.
		Lyman group.
		Auriferous conglomerate.
Paleozoic	Cambrian	Rockingham schists.
		Calciferous mica-schist.
		Coös group.
		Clay slates.
		Mount Mote conglomerate.

The Atlantic system is proposed to cover all the rocks along the Atlantic coast from Maine to Alabama, being regarded posterior in time to the Laurentian but anterior to the Cambrian and later formations.

WALCOTT,[85] in 1886, places the Georgia formation, which is found to contain the Olenellus, in the middle Cambrian, and the Braintree series of Massachusett bearing the Paradoxides fauna is placed in the Lower Cambrian.

WALCOTT,[86] in 1888, in a consideration of the Taconic, places the western core of the Green mountains as pre-Cambrian, the bounding line being at a considerable, but a varying distance east of Rutland, Middlebury, Burlington and St. Albans. All of the rocks of western Massachusetts are regarded as Cambrian or post-Cambrian, including the Stockbridge limestone, the granular quartz rock, the magnesian slate, Sparry limestone, and Taconic slate. In northwestern Connecticut is an area of pre-Cambrian rocks which is surrounded by quartzite referred to the Georgia formation.

WALCOTT,[87] in 1889, after a consideration of the Cambrian fauna reverses the position of the Georgia and Braintree horizons, placing the latter as Middle and the former as Lower Cambrian.

SUMMARY OF RESULTS.

In this discussion no attempt will be made to consider in detail the structures worked out by the various authors in individual districts, but rather to indicate the general character of the results which have been reached.

It is plain that the knowledge of the pre-Cambrian structure of the New England states is in a very unsatisfactory condition. Even in such a district as that of eastern Massachusetts, including the Boston basin, there is the greatest diversity of opinion, a district which one would naturally expect would have been systematically studied and certain results reached. In western Massachusetts, where the most elaborate of the older surveys has been made, the rock successions given from time to time and the correlations with other series have varied greatly. These areas are particularly mentioned because most studied. What is here true is still more emphatically the case with the remainder of the region.

While, then, systematic work in the New England states is but fairly begun, one great structural fact is clearly apparent, that large areas of rocks which have commonly been regarded as pre-Cambrian are proving to be Cambrian or post-Cambrian. This is most marked in western Massachusetts, where the recent work of Dana, Pumpelly, Dale, Wolff, Emerson and Walcott has established the conclusion that the pre-Cambrian rocks are confined to small areas. The results reached in this district show that it will not do to call the crystalline rocks pre-Cambrian and the uncrystalline ones post-Cambrian, a principle clearly recognized by Adams and the elder Hitchcock many years ago. Over large areas mica-slates, mica-schists and evenly granular gneisses have been demonstrated beyond all question to belong to the Cambrian or post-Cambrian. If in the remainder of New England the pre-Cambrian rocks shrink in proportion as they have done in the districts closely studied, they will not occupy more than a fraction of the area usually assigned to them.

If it be true that a very large proportion of the New England rocks which have been supposed to be pre-Cambrian are really Cambrian or post-Cambrian, it is evident that the reference of them to the Montalban, Norian, Huronian, Laurentian, etc., is wholly unwarranted. In the districts already referred to where definite knowledge is available many of the rocks before referred to these various series are being divided into two classes, sedimentary and igneous, and are being distributed from the Cambrian to the Carboniferous.

As yet it can not be positively said of any district that the pre-Cambrian rocks can be subdivided upon a structural basis, although recent unpublished results by Pumpelly and his assistants in the Green mountains indicate that it may be possible to do this in the future.

This New England region is one of great interest as being the first in which it was clearly shown by structural work that fragmental rocks pass over into crystalline schists. The descriptions by the elder Hitchcock of the way in which the schist-conglomerates at various points pass over into mica-schist in which no trace of the pebbles remain are remarkably like those given many years later by Reusch, the chief difference being that in the latter case partly destroyed fossils were found in the semicrystalline rocks. Hitchcock's summary of the evidence for the production of completely crystalline schists from fragmental rocks over extensive areas, published in 1860 in the Vermont reports, is demonstrative in its nature. The case could hardly be put more forcibly at the present time, except by the additional evidence derived from microscopical structures.

One of the most interesting differences of opinion has been as to the origin of the granite and its relation to other rocks. The elder Hitchcock believed that the granites and syenites are produced by the aqueo-igneous fusion of the sedimentary beds, that they have usually not moved far, and thus represent older stratified rocks. Locally it was recognized that they have become fluid and have intruded the adjacent rocks, showing all the characteristics of an ordinary eruptive. The term metamorphic was made to cover this once fluid material. Along the contacts of the granite with the slates and schists, at various localities were found many rounded fragments which were taken as evidence of the metamorphic origin of the whole, the matrix being regarded as completely fused and the fragments as residuary bowlders which had resisted the process of metamorphism. Stevenson and Marvine interpreted like facts in the Rocky mountains in the same manner. These relations are precisely the same as those described by Lawson between his Laurentian granite-gneiss and the clastic series northwest of lake Superior. The latter writer, however, declines to carry the term metamorphism over to the final product and regards the granite-gneisses along the contact zone containing fragments of the adjacent rocks as irruptive ones, the fragments being caught in the fluid material rather than being a residual unfused substance. The emphasis is then thrown upon the intrusive character of the granite-gneiss, a position less consonant with the theory of subcrustal fusion than that of Hitchcock, Stevenson, Marvine, and Winchell. An objection to the acceptance of this theory of the origin of granite and granite-gneiss is that it is one that is not easily verifiable. As soon as a rock becomes liquid it does not longer reveal the source of the material, and the conclusions that it has not moved far and has been produced by the fusion of the adjacent rocks is an unproved and perhaps unprovable assumption.

By Crosby the granites which cut other rocks are placed as the older; this conclusion follows from the hypothesis that the granites are metamorphic. If they intrude overlying rocks they must have been produced from a more deeply buried series and are hence older. Most geologists interpret these relations to mean that the granite is a later intrusive rock. By Shaler the lamination of the minerals in the syenites and granites, and particularly the more distinct lamination of the exterior parts of the exposures, is regarded as unquestionable evidence of sedimentary origin. Jackson, among the older geologists, has steadily maintained the essentially igneous origin of the granites and syenites. Hawes was the first, however, to clearly study from the modern point of view the granites and granite-gneisses and to show that the lamination of the latter is not necessarily an evidence of original bedding, and that such a structure may appear in an igneous rock as well as in a sedimentary one. It is only since the recent work of Pumpelly and Emerson that it has been generally appreciated that there are two classes of granites in New England. These geologists have shown that in western Massachusetts is a granitoid gneiss, which beyond all question antedates the Cambrian rocks and has yielded débris to them. While this is the case, the greater mass of the granites are far later in age, some of them ranking in time as late as the Carboniferous. Frequently the masses are so large as to metamorphose the sedimentary beds about them by contact or dynamic action, or more probably by both, producing the concentric schistose structure so early mentioned by Percival and so fully described by Emerson.

By the early advocates of metamorphic granite a massive form was regarded as evidence of the completed process and of the great age of the granite. In any given granite the age of which is not known, from the modern point of view, its perfectly fresh granular form, or an even lamination of mineral constituents which results from crystallization under ordinary circumstances in great beds or masses, bears rather toward its late formation; while the contorted and foliated granitoid gneisses, because of their structures, show that they have undergone repeated powerful dynamic actions, and consequently are more likely to be ancient rocks.

The "diorite-schists," "amphibolites," "metamorphic diorites," and similar schistose rocks described even by Hawes as metamorphic, probably belong for the most part with the other greenstones, which have almost universally in late years been placed with the eruptives. These schistose phases are more ancient than the massive forms or have been subjected to more intense metamorphism.

While it was early recognized by most geologists that slaty cleavage and foliation may cut across the bedding, it was generally assumed that cleavage and stratification foliation correspond. As early as 1842 Percival so clearly saw the danger of this course that he states that he prefers to use the term parallel instead of stratified in describing the structures of the crystalline rocks as expressing the fact of the arrangement of the minerals without implying any opinion as to the mode of formation. Hawes, in 1878, states that the granite-gneisses in their affinities are like the eruptive granites, the lamination being an induced structure which may or may not correspond with bedding in case they are completely metamorphosed material. He, however, includes among the metamorphic rocks diorite, quartz-diorite, and amphibolite, since they have marked distinctions from the fresh basic rocks recognized as eruptives. From the assumption that cleavage foliation and stratification generally correspond have probably resulted more mistakes than from any other cause.

The cautious work of Adams, the elder Hitchcock and Percival in correlation is noticeable. Adams preferred to call the rocks of Vermont Azoic, referring to their present state, and specifically saying that many of them might prove quite late in the fossiliferous series. The same course is followed by the elder Hitchcock, who says that probably most of the Vermont rocks will prove to be later than the Laurentian of Logan. Percival, in Connecticut, carefully described the rocks as they occurred without attempting to give any succession or to correlate them with other rocks. The building up of successions upon insufficient data and crude correlations is mainly the work of later men.

The work of Dana, Pumpelly, Emerson, Dale, Wolff, and Walcott in the past decade marks a new epoch in the study of the crystalline rocks of New England. The complexity of the problem has been for the first time appreciated. It has been seen that the old method of making a few sections wide apart across a district, and bringing the discrepancies into harmony by assumptions, wherever necessary, of inversions and faults, and making correlations of formations with those of distant regions because of lithological likenesses, can lead only to conclusions worse than valueless.

In applying the new method of work, as exemplified in western Massachusetts, it has not been assumed that a rock stratum is the equivalent of another stratum in a different locality. In order to establish equivalence it is necessary that the two be actually traced together, or else that unquestionable fossil evidence be found. Instead of assuming that stratification and cleavage foliation correspond, the assumption has been rather that they usually do not correspond and that nothing can be taken as bedding which can not be demonstrated to be this, as, for instance, the contact planes of two formations, such as quartzite and limestone or one of these with schist. Instead of building up a structure from a few sections wide apart, all sources of information have been sought; every outcrop was visited; the information furnished by artificial excavations was utilized; full suites of specimens were collected, and all the light which can be furnished by the modern petrographical methods has been brought to bear upon the problems. Finally, a more careful search for fossils has revealed their presence in rocks so crystalline that former search has resulted in failure. In this study Pumpelly, besides using these and other well known principles, has formulated new ones. These are:

(1) The degree and direction of the pitch of a fold are indicated by those of the axes of the minor plications on its sides. (2) When the strike of the stratification foliation and cleavage foliation differ in the same rock, this is regarded as indi-

cating a pitching fold. (3) Such a correspondence exists between the stratification foliations and cleavage foliations of the great folds and those of the minute plications that a very small specimen properly oriented gives, in many cases, the key to the structure over a large portion of the side of a fold.

This author has further ascertained that apparent conformity, which sometimes exists between strata really unconformable, may be due to the disintegration of the earlier series.

Notwithstanding that advantage has thus been taken of all sources of information, the problems of the structure of western Massachusettts have been found so difficult that it has taken years of labor of a number of men to build up correctly the stratigraphical succession. The labor involved in this work and the relatively small size of the area covered show that before any accurate map of the whole of New England can be presented many years must elapse, although it may be reasonably hoped that, as experience accumulates, the application of the new method will proceed more rapidly than in the decade of its inauguration.

That the structural mapping of the crystalline rocks in New England is less extensive than in some other parts of America has not been due to a lack of ability or industry upon the part of the workers in this region as compared with those of others, but rather to the greater difficulty of the problem. This region is one in which repeated dynamic movements, accompanied by great outbursts of igneous material, have occurred until late in Paleozoic time.

SECTION II. THE MIDDLE ATLANTIC STATES.

LITERATURE OF NEW YORK.

PIERCE,[88] in 1818, describes the nucleus of Staten island as consisting of steatite, which stamps the formation as Primitive.

AKERLY,[89] in 1820, describes a section running from Long Branch, in New Jersey, northward to New Marlboro, Ulster county, New York. The rocks included are divided into principal rocks, metalliferous rocks, basaltic rocks, and alluvial formations, which correspond to the German terms Primitive, Transition, Floetz, and Alluvial. Staten island has a rocky base composed of the magnesian order of rocks, consisting of serpentine, steatites or soapstones. Hoboken is of the same nature as Staten island. The Highlands of New York consist of granitic rocks belonging to the primitive class. Gneiss and micaceous schist are the most prominent; but granite, properly speaking, also enters into the composition. The commencement or termination of any of these rocks has not been found, and as they graduate into one another they are considered the same formation. At Hell Gate the rocks are gneiss and micaceous schist. The northern part of New York island is of the primitive formation and includes granite, gneiss and limestone. Crystalline limestone is also found at other points. All these rocks are placed in the primitive formation and they contain no organic remains.

JESSUP,[90] in 1821, describes in Essex county, in the vicinity of lakes George and Champlain, rocks of the primitive class, including trap, syenite and carbonate of lime.

EATON,[91] in 1822, describes as occurring in the Highlands of the Hudson, without reference to order of time, gneiss, hornblende rocks and argillite. The gneiss appears to be the center or oldest formation.

EATON,[92] in 1824, describes the rocks adjoining the Erie canal. Among the primitive rocks are placed granite, gneiss, hornblende rock, mica-slate, talcose rock, granular quartz, granular limerock, sparry lime rock and primitive argillite, which are described as occurring at numerous localities. There are two primitive districts, that in southeastern New York and that west of lake Champlain, called Macomb mountains.

EMMONS (E.),[93] in 1837, describes granite and gneiss as having a widespread occurrence in the northeastern part of the state. The granitic nucleus of Essex county is traversed by dikes of greenstone of igneous origin, and the granite is considered to have the same genesis. Gneiss, hornblende and granular limestone are classed together as primitive rocks and regarded as absolutely of the same age. Above the primitive rocks is a transition sandstone, superimposed upon which is a transition limestone.

CONRAD,[94] in 1837, describes at the base of the Mohawk valley ridges of gneiss which are regarded as a prolongation of the northern primary chain. Upon the gneiss is found calcareous sandstone.

MATHER,[95] in 1838, mentions gneiss on Long island; granite and serpentine on Staten island; and granite, gneiss and granular quartz in the southeast part of Dutchess county. In the serpentine was observed a trap rock.

EMMONS (E.),[96] in 1838, states that in St. Lawrence and Essex counties are found Primitive rocks. The stratification of the gneiss is often obscure and its texture confusedly crystalline. Subordinate to it and mingled with it is granite, which occurs in beds and protruded masses in the forms of veins and in overlying masses analogous to lava currents and greenstones. In St. Lawrence county is a widespread granite composed of labradorite, feldspar and hypersthene, which is traversed by dikes of greenstone, amphibolite, syenite, and porphyry. Associated with the gneiss and limestone are numerous beds of magnetite and hematite. The transition rocks of Essex county, such as limestones and shales, are cut by dikes and veins. The primitive limestone is always coarse, crystalline and friable. It occurs in most intricate and curious relations to the granite and hypersthene rock, many of its areas being in vein-like form. This fact, combined with the presence of foliated plumbago and the induration of sandstone when in contact with the limestone, leads to the conclusion that it is of igneous origin.

VANUXEM,[97] in 1838, finds Primitive rocks in Montgomery, Herkimer and Oneida counties.

MATHER,[98] in 1839, describes the rocks of New York, Westchester and Putnam counties as comprising granite, gneiss, mica-slate, quartz rock, talcose slate, limestone, syenite, serpentine, steatite, augite rock, greenstone, the latter traversing the other rocks like veins or being interstratified with them. The gneiss and granitoid rocks are distinctly stratified, as is also the limestone.

HORTON,[99] in 1839, describes the Primitive rocks of Orange county as less regular in stratification and dip along the banks of the Hudson and at their western margin than in their center. The strike of the primitive gneiss is about northeast and southwest, with a dip to the southeast from 45° to nearly vertical. Interstratified among the primitive rocks are hornblende rock and white limestone. Argillite is placed with the transition formations.

GALE,[100] in 1839, finds that the rocks of New York county are chiefly a gneiss, associated with which as subordinate rocks are serpentine, hornblende, primary limestone and anthophyllite rock. On the western side of the island the gneiss so abounds, with the veins of granite parallel with the strata, that in many places they constitute the chief material. At Kings bridge the limestone at its junction with the gneiss retains the structure of that rock with the mineral matter of limestone, but the pure limestone is in beds without stratification.

EMMONS (E.),[101] in 1839, describes Primitive rocks in Hamilton, Clinton and Warren counties. The primitive rocks are gneiss, hornblende, limestone and serpentine. The limestone and serpentine occur in irregular veins or beds, which are sometimes analogous to greenstone dikes so prevalent in the hypersthene rocks.

EMMONS (E.),[102] in 1840, states that the magnetic iron ore occurs associated with granite, gneiss and hypersthene rock in veins which are regarded as of igneous origin. The specular oxide occurs in two horizons, the first associated with the primary limestone, the second with gneiss or some other primary rock beneath it.

VANUXEM,[103] in 1840, states that the primary rocks which are defined as earlier than any which bear organic bodies in Lewis county consist mostly of granite and gneiss, but are associated with amphibolite or hornblende, forming syenite and hornblende rock. The Potsdam sandstone rests unconformably upon the primary rocks. There is a great contrast between the two classes, the latter presenting a disturbed appearance, exhibiting high grades of inclination, while those of the transition are like the deposits of tranquil waters.

MATHER,[104] in 1841, states that the primitive rocks occupy two-fifths of Saratoga and one-fifth of Washington county, being mostly gneiss and granite, although coarsely crystalline white limestone containing plumbago, augite and hornblende is a common rock.

EMMONS (E),[105] in 1841, mentions primary limestone at lake Janet, gneiss at Long lake, and on Racket river hypersthene rock.

EMMONS (E.),[106] in 1842, gives a report on the entire Adirondack region. The older rocks are classified under primary and transition. There are few transitions from the primary into the sedimentary rocks. There are, however, many transitions among the primary masses themselves, and often intermediate series are found which are with difficulty placed under appropriate names. The primary rocks are divided into unstratified, stratified and subordinate. Among the unstratified rocks are included granite, hypersthene rock, primitive limestone, serpentine and rensselaerite. The stratified rocks include gneiss, hornblende, syenite, talc or steatite; the subordinate rocks include porphyry, trap, magnetic and specular oxides of iron.

The granites occupy a comparatively small extent in the region, being in limited patches of irregular appearance. One of the largest beds of granite is about 6 miles long. In one place granite and limestone are somewhat intermingled. The hypersthene rock occupies a triangular area to which it is almost wholly confined, but it constitutes almost the entire county of Essex, with the exception of a belt a few miles in width along the shore of the lake. Under primitive limestone is included a coarse, crystalline mass, readily recognized as a mineralogical species, but as a rock not holding a definite place in the primary series. This rock is believed to be unstratified and of igneous origin, as is shown by its occurrence in dike-like forms and its association with eruptive rocks, the imbedded minerals being of such a character as would be produced by metamorphism. Also limestone produces a metamorphosing effect upon the minerals imbedded in it, is always without stratification, often underlies granite, and is so intimately associated with it as to make it probable that the two have a common origin. Serpentine intimately associated with the limestone has an origin common with it.

The stratified rocks have a much wider occurrence than the massive ones. Of these gneiss is by far the most important. Syenite is applied to a stratified rock composed of feldspar and hornblende. It often occurs injected in the form of dikes and associated with beds of iron ore and is in part an igneous rock. Trap includes dark-colored igneous rocks, which cut the various other primitive formations. These are compared with mineral veins, and because the former is eruptive the latter is concluded to have a probably similar origin. Porphyry is also found in igneous forms. Magnetic and specular oxides of iron occur as masses and as veins. They are sometimes apparently interstratified with rocks with which they are associated, but often also break across the strata. In their mode of occurrence they resemble trap, greenstone, and porphyry, and are therefore regarded as of igneous origin. Between the primary and transition systems is the Taconic system.

VANUXEM,[107] in 1842, describes the primary system as occurring in the northern parts of Montgomery and Herkimer counties, the northeast corner of Oneida, and the whole of Lewis county east of Black river. This system consists wholly of granite and gneiss, with which is associated a small quantity of limestone and iron ore. Primary rocks occur isolated in the New York system; the first at the Noses on the Mohawk; the second at the little falls of the Mohawk; the third at Middleville. With the Taconic system are placed a lamellar white crystalline limestone, with specular iron ore and compact red iron ore and plumbaceous rocks in Lewis county.

MATHER,[108] in 1843, gives a systematic account of the geology of the first district, comprising the southern part of the state. The Potsdam sandstone is at the base of the unmodified series. In places it is metamorphic and has more or less the aspect of gneiss; at other times it is in an intermediate state, showing rounded gravel and sand. The dips are usually eastward at from 5° to 20°, but in the Hudson valley it is upturned with other rocks at a high angle toward the east. The Taconic system consists of slates, limestones, and granular quartz rocks, which form a belt of mountainous country from Vermont to Peekskill on the Hudson and a narrow belt across the Highlands to the mouth of Peekskill creek. They are again found on the right bank of the Hudson, between Stony point and Caldwells landing, and range south-southwest until they disappear beneath the red sandstone formation. The strike and dip of the rocks of this system are the same as those of the Champlain division and apparently underlie them. The dip is in a general easterly course, varying from 15° to 90°. As to the superposition of the formations the granular quartz either rests upon or pitches under the gneiss or granitic rocks. The limestones lie next in order from the gneiss or granite, either in super or sub position, and the slates next follow. This may be found difficult of verification, as the rocks are almost universally much deranged from their original position. Many local details are described, and it is concluded that the Taconic system represents the Champlain division metamorphosed. In favor of this position are the facts that the succession is the same; that both of these systems are superimposed upon the primary without any intervening strata; the unmodified beds are traced into those that are metamorphic; and the places where the rocks are most metamorphic are those where there are intrusives and have been upheavals.

Under the head metamorphic rocks are described such rocks as are not included in the foregoing, and which, while there is no demonstrative evidence of it, are regarded as originally sedimentary rocks, which have since been altered in their character so as to change them into such rocks as have usually been called primary. The metamorphic rocks are divided into two divisions, those east of the Highlands of the Hudson, and those of the Highlands of Saratoga and Washington counties. In the first district the limestones are granular, dolomitized and stratified. The slates are talco-argillaceous, talcose, chloritic or micaceous, the last predominating; and the sandstones are changed into granular quartz rock, eurite, and gneiss. In the second district the limestones are changed to white or red, coarse grained, crystalline limestone, containing various crystallized minerals, with scales of plumbago, and rarely show any traces of stratification. The slate is changed to mica-slate, micaceous gneiss or hornblende-slate, and the quartz-rock is changed so as to be scarcely recognized as such. In the first class, also, the intrusive rocks bear but a small proportion to the altered rocks and are mostly quartz and granite, but in the second class the undoubted plutonic rocks abound and consist of granite, syenite, greenstone, augite, serpentine, diallage, and intrusive metalliferous veins.

The metamorphic rocks east of the Hudson and Highlands are in a continuous range from Bennington in Vermont to the west part of Massachusetts and Connecticut and the eastern part of New York. Between the Taconic rocks and the metamorphic rocks to the east no well marked line of distinction can be drawn, as they blend into each other by insensible shades of difference. In considering the metamorphic rocks as a whole the descriptions necessarily include certain of the Taconic rocks. The strata of metamorphic rocks are very much broken, so that no stratum has been traced continuously more than a few miles. The only beds which can be traced with any degree of success are the limestones, which are described in detail. The limestones of Westchester county have the same dip and line of bearing as the contiguous gneiss, and like that, are distinctly stratified. They form several nearly parallel ranges at intervals of 2, 3, or 4 miles. They all dip east-southeast, with local exceptions, at a high angle, varying from 45° to 90°. The metamorphic slates of Dutchess, Putnam, Westchester, and New York counties have been traced in different localities through different modifications and texture from the gray and semicrystalline limestones associated with talcose slate and the sandstone of the Taconic system, to the perfect dolomites and white and gray crystalline marbles associated with mica-slate and granular quartz-rock, north of the Highlands; and to still more crystalline limestones associated with mica-slate, micaceous gneiss, hornblende-slate, hornblendic gneiss, hornblende-rock, syenite and granite, south of the Highlands. In these latter limestones are frequently found some mineral substances, such as serpentine, brown tourmaline, copper and iron pyrites, magnetic sulphuret of iron, mica and magnesian minerals, particularly where near to undoubted plutonic rocks. It is believed that all the crystalline limestones of Vermont, Massachusetts and Connecticut and the eastern part of New York, are metamorphic rocks; that they were originally the Mohawk limestone and Calciferous limestone, and that the associated rocks were originally the Potsdam sandstone and the slate rocks of the Hudson valley; that they were, in fact, the rocks of the Champlain division, but much more altered and modified by metamorphic agency than the Taconic rocks.

In the study of the metamorphic rocks of the Highlands and Saratoga county, as in the other district, most attention is given to the limestones. At Warwick the white limestone is rarely stratified or shows any distinct traces of stratification, but in some places it exhibits a regular gradation into the gray and blue limestone, which is fossiliferous in some places and oolitic in others, and stratified in nearly horizontal strata. The limestones of the Highlands of Orange, Rockland, and Putnam counties are in long narrow belts associated with the granite, syenite, hornblende and augite rocks and some anomalous aggregates. The limestones of Washington county are coarse, white and crystalline. They contain various imbedded crystalline and amorphous minerals, the most common of which are plumbago, augite, and hornblende. Hornblende, coccolite, and plumbago are the most constant associates. Scapolite is not uncommon. In some places the limestone is so much intermixed with other materials found in the gneissoid and granitic rocks, that without close examination it would not be suspected as a limestone. Quartz is frequently found in it, transparent or translucent, with irregular, rounded forms, as if it had been partially melted. Many localities that I have visited show that it has been softened, if not melted. The similarity of the crystalline limestones of the northern counties to the crystalline phases of those at Warwick which grade unmistakably into fossiliferous forms leads to the conclusion that they are all really the same rock. The limonitic and hematitic ores are confined to the valleys of the Taconic and metamorphic rocks and are usually associated with talcy slate on one side and limestone on the other.

Under Primary rocks are included those usually called by that name and those not yet described as Taconic or metamorphic, though some of them are probably of the same age as the metamorphic rocks. This is particularly the case with the plutonic rocks, as granites, syenites, hornblende rocks, some of the trappean rocks, and the metalliferous beds and veins which have intruded themselves among and altered the adjacent rocks. The hornblendic gneiss, micaceous gneiss, and mica-slate may perhaps be referred to the same period. The primary rocks in the different districts are very similar. They include granite, syenite, gneiss, mica-slate, augite-rock, greenstone, hornblende rocks, quartz rock, talcose slate, limestone, serpentine, and steatite, although the last five have been already included among the metamorphic rocks. In Rockland and Orange counties the strata dip to the southeast at angles from 50° to 90°, but there are localities where the strike and dip are transverse to the general directions. Granite veins are very numerous in the granitic gneiss; the greenstones include basaltic greenstone or trap, granular greenstone, and primitive greenstone. Associated with the primary rocks is magnetic oxide of iron, confined to the southern counties of the Highlands and forming masses in gneiss and hornblendic gneiss rocks which might be called beds, but which are thought to be veins. Their course is parallel to the layers of rock, but in several instances after continuing with this parallelism for a certain distance the ore crosses a stratum of rocks and then resumes its parallelism, and then obliquely crosses another, and so on. Also in other places where there are great beds of ore, a few small strips of ore penetrate the surrounding rocks as if they have been cracked asunder and these seams forced up from the main mass below.

The rocks that are most metamorphosed are usually near granite, syenite, trap, quartzose and metalliferous protrusions, dikes and veins. It is believed that trappean injections took place as late as the time of the red sandstone of New Jersey. The granitic, syenitic and augitic rocks appear to belong to the epoch immediately preceding the slates and grits of the Champlain division, since they have altered the preexisting rocks where they come in contact up to that time, but no traces of such changes are found in the more recent rocks. Another intrusion of granite is believed to have preceded the red sandstone of Rockland and New Jersey, being probably more recent than the rocks of the Catskill division.

COZZENS, Jr.,[109] in 1843, divides the rocks of Long island into granite, syenite, serpentine, mica-gneiss, hornblende slate, quartz rock, primitive limestone and diluvium. The distribution of all is given. At the Palisades, on the west side of the Hudson river, the section from the base up is granite, serpentine (different from that at Long island), sandstone, greenstone-slate and trap. The section of Staten island from the base upward is granite, serpentine, sandstone, trap or greenstone, beds of iron ore and diluvium. At Donderberg the section is granite, gneiss, talcose slate, limestone (called transition limestone) and brick clay.

EMMONS (E.),[110] in 1846, gives a systematic treatment of the character and relations of the Taconic system. The Taconic system is held to be below the New York system, because the base of the latter is perfectly schistose, like that of the former, and because the material of the New York system is derived from the Taconic. Again, contacts between the Taconic system and the calciferous sandstone and Hudson river shales show that the former are unconformably below the rocks of the New York system. As evidence that the Taconic system is newer than the primary rocks is the occurrence of porphyritic quartz of the Taconic upon gneiss. It is, then, not to be doubted that there is a system of rocks lying between the Hoosac mountain range and the Hudson river of an age posterior to the gneiss and mica-slate and anterior to the New York system. It consists throughout of beds of sedimentary matter in a state of fine division conformable to each other and arranged in uninterrupted succession, although their lithological characters are very diverse. The Taconic system comprises the Taconic slate-bearing fossils, the Sparry limestone, the Stockbridge limestone and the brown sandstone or granular quartz. The primary limestone carries graphite, and on this account can always be distinguished from Stockbridge limestone; also other minerals, such as spinel, sapphire, idocrase, hornblende, pyroxene, chondrodite, and mica, are found plentifully in the primary, but do not occur in the Stockbridge. The rocks of the Taconic system are inverted, greatly disturbed, and their relations with the underlying and overlying rocks are obscure, so that the true structure can only be ascertained by most careful examination.

CREDNER,[111] in 1865, states that the island of New York and the east part of Long island consist of gneiss, which, toward the north, contains hornblende-gneiss, hornblende-schist, syenite, and hypersthenite, and in the last two are magnetite. The northern hilly part of Staten island consists of dioritic rocks, of serpentine, with layers of soapstone.

MACFARLANE,[112] in 1865, describes the rocks in the neighborhood of Rossie as belonging almost exclusively to the Laurentian formation, which is here and there unconformably overlain by patches of Potsdam sandstone. The rocks here found comprise micaceous and hornblendic gneiss, mica-schist, gneiss-granite, granite, tourmaline rock, coarsely granular saccharoidal crystalline limestone, and diorite. The strata are in an almost vertical position.

STEVENS,[113] in 1867, describes New York island as consisting in the main of gneiss, in which lie veins and beds of granite, anthophyllite, and hornblende. The granite occurs in veins generally coincident with the gneiss, but also in massive beds which lie across the strata. At times it is distinctly separated and in others insensibly blends into the gneiss. The hornblende and anthophyllite occur like the granite. Limestone occurs at several points and is interlaminated and folded with the gneiss. This New York group of rocks is like and regarded as equivalent to Emmons's Taconic. For it is proposed the name Manhattan group.

DANA,[78] in 1872, describes the mica-schist of Poughquag as underlying conformably the Stockbridge limestone. The mica-schist is underlain conformably by the gneiss of the Taconic series. Besides the limestones and Taconic schists and gneiss, there is near Poughquag, in still more intimate connection with the quartzite rocks of Azoic age, a continuation of the highlands of New Jersey, which are probably Laurentian. But as this point is not definitely settled, and since the term Azoic has been ruled out by facts proving that the era was not throughout destitute of life, it is proposed to use for the Azoic era and its rocks the general term *Archæan* (or Archean). These Archean rocks, coarsely crystalline gneisses, are exposed in a deep cut on the Hartford and Fishkill railroad. The quartzite formation of this region shows no conformability to the Archean gneiss, and none to the gneiss, mica-schist, or limestone of the Taconic series. The nearly horizontal beds of quartzite lie on the nearly vertical Archean, and both occur within a few hundred yards of the steeply inclined Taconic beds.

LEEDS,[114] in 1878, describes the rocks of the Adirondacks. They are found to be stratified rocks which belong in the Norian system, are composed of hypersthene and diallage, and labradorite with menaccanite.

DANA,[115] in 1880 and 1881, considers the geological relations of the limestone belts of Westchester county. The rocks here found are divided into metamorphic rocks, not calcareous; calcareous rocks or limestones; serpentines and other hydrous minerals; augitic and hornblendic rocks not above included. Of metamorphic rocks the prevalent kinds are micaceous gneiss, mica-schist, ordinary gneiss, and granitoid gneiss. The calcareous rocks are white and coarsely crystalline, although locally they are feebly crystalline. The hornblendic and augitic rocks constituting the Cortlandt series include soda granite, norite, augite-norite, diorite, hornblendite, pyroxenite, and chrysolitic kinds. These rocks are held to be conformable with a part of the adjoining schists and limestone, which are of metamorphic origin, although they may have been in a former state of fusion or plasticity. The limestones and adjoining schists are found to be one in series and system of disturbance, are considered a part of the Green mountain system, younger than the Highland Archean, and probably Lower Silurian. At Annsville there is evidence of unconformity between the Archean and this series. The limestone here lies unconformably against the hornblendic contorted Archean gneiss. A similar unconformity exists half a mile northeast, although the upturning of the limestone and its associated schist has usually placed them in near conformity to the strike of the Archean rocks.

DANA,[116] in 1882, ascertained that a large part of the rocks referred to the Taconic range are shown by their fossiliferous contents to be Silurian and the equivalent of the Hudson river group, although it is not asserted that all of the hydromica-schists do belong here. A part are Primordial.

NEWBERRY,[117] in 1882, states that the mottled serpentine of New York island is like the Moriah marble of the Adirondack region, which affords strong indication of a Laurentian age of the New York and Staten Island rocks.

HUNT,[118] in 1883, describes near port Henry coarsely crystalline limestones in the highly inclined Laurentian gneisses, in which are inclosed irregular masses and layers of the adjacent gneiss. Although regarded by Emmons and Mather as eruptive and by another eminent geologist as evidence that the crystalline limestone unconformably overlies the gneiss, it is believed to be a great calcareous vein stone. The Norian, massive, bedded, labradoritic rocks are well displayed between Westport and port Kent.

DANA,[119] in 1884, finds that the hornblendic and augitic rocks of the Cortlandt series have such relations to the schists as to show that they are of igneous origin, the eruptions taking place subsequent to the era of the limestone, mica-schist, and soda-granite.

HALL (CHAS. E.),[120] in 1885, states that between the limestones and the magnetic ore series or lower members of the Laurentian there is an undoubted unconformity; but the relations of the Labrador series to the limestone are not clear. In ascending order are the Lower Laurentian or Magnetic Iron Ore series; the Laurentian Sulphur Ore series; the limestones and the Labrador series, or Upper Laurentian with its Titanic Iron Ores. The relations of the sulphur ores and limestone series are still undetermined. Between fort Ann and South bay, along the east side of the valley, the Silurian limestones lie against and apparently dip under the crystalline rocks of the Laurentian. The Potsdam sandstone, resting on the crystalline rocks of the valley, dips to the eastward under the Silurian limestones.

BRITTON,[121] in 1886, states that a schistose series of crystalline rocks occurs in the Adirondacks. It consists of schistose gneiss, mica-schist, and hornblende-schist, and occurs north of Harrietstown and near the northern end of the Lower Saranac lake. Norite occurs at Miller's hotel, about a mile distant.

JULIEN,[122] in 1886, states that the borders of the Adirondack region consist very largely of thinly bedded gneisses, especially to the eastward.

SMOCK,[123] in 1886, describes the crystalline rocks of Dutchess, Putnam, and Westchester counties. This district is divided into four belts, Stissing mountain, East or Dover mountain, Highlands of the Hudson, and Westchester county. The prevailing rocks of Stissing mountain are gneisses, granites, granulite, and syenite, which resemble closely those of the Highlands of the Hudson. The rocks of the East mountain comprise gneiss, granite, granulite, quartz-syenite, syenite-gneiss, and mica-schist chiefly. Between the quartzite and the gneiss, when they are seen close to one another, is a want of conformability. The more common of the rocks of the Highlands of the Hudson are gneiss, syenite-gneiss, granite, quartz-syenite, granulite, and hornblende-schist. The Poughquag-Fishkill quartzite is found to rest unconformably upon the Highland gneisses, the discordance being best seen on the New York and New England Railroad, 1 mile west of West Pawling railroad station. Here the quartzite has a dip of 15° or 20°, while the gneiss, but 300 feet distant, has an almost vertical inclination. Belonging with the Archean gneisses are limestones, among which is that at Sprout brook. On the eastern side of the Highlands the Archean border has the micaceous, schistose rocks and the quartzites resting upon it. These relations are particularly well shown at Towner's station. Near here the limestones and schists in a syncline rest unconformably upon the granulitic gneiss. Provisionally the rocks of the Highlands are referred to the Archean. They may be all Laurentian also, but the Huronian has not been identified. In Westchester county is a great variety of crystalline rocks. To these is applied the name Manhattan gneiss, proposed by Hall. These rocks are less massive than those of the

Highlands, include micaceous gneiss and schist, as well as crystalline limestones, and to the ordinary observer are more like the common fragmental rocks than the massive gray granitoid gneisses.

HALL (JAMES),[124] in 1886, in describing the building stones, includes in the Laurentian rocks the granitic, syenitic, and gneissoid rocks, as well as the crystalline marbles which are everywhere interstratified with the gneiss rocks, but usually form a small proportion of the entire mass.

WILLIAMS,[125] in 1886, 1887, and 1888, describes the peridotites, norites, gabbros, and diorites of the Cortlandt series and their relations to the mica-schists and limestones. They are regarded as eruptive rocks because they have the structure and mineralogical composition of eruptive types; because their schistose phases have nothing which suggests an original sedimentary structure; because they occur in well defined dikes in other massive rocks, in mica-schists, and limestones; because fragments of crystalline schist and limestone are found inclosed within the massive rocks; and because contact phenomena are found in the crystalline schists and limestones adjoining them.

BRITTON,[126] in 1887, describes the serpentine of Staten island as a stratified rock probably derived by the extensive alterations of limestones. This serpentine appears to overlie the crystalline limestones. These metamorphic rocks with the gneisses are regarded as Archean.

KEMP,[127] in 1887, describes Manhattan island as consisting of a long ridge of gneiss, with Triassic trap and sandstone on the west and connected with the gneiss of the mainland on the north and south.

MERRILL,[128] in 1890, agrees with Britton that the basal member of the pre-Cambrian of southeastern New York and New Jersey is a granitoid hornblende-gneiss, which is followed by a second member, the iron-bearing group, and this in turn by the schistose group. The thickness of the pre-Cambrian rocks in the Hudson river valley is between 2,300 and 2,800 feet. They are unconformably below the Cambrian quartzite and nothing more definite can be predicted as to their age. These rocks display a number of anticlines, two of which are those at Fishkill and the Storm King. In the synclinal trough between are the rocks of the iron-bearing group. The metamorphic strata of New York and Westchester counties, called the Manhattan group, are divided into several divisions from the base upward, as follows: (1) Yonkers gneiss, which is an arkose-gneiss; (2) Fordham gneiss, a quartzite-gneiss; (3) Inwood limestone; and (4) Manhattan mica-schists. The age of the Manhattan group has not been determined, but it is thought to be pre-Cambrian. This group and the Lower Cambrian sandstone are both found to lie on the second or iron-bearing member of the pre-Cambrian formation, and no unconformity has been found between the Manhattan group and the underlying pre-Cambrian beds. Of equal significance is the lack of unconformability between the Lower Silurian strata of Peekskill hollow, Tompkins cove, and Verplanks point with the partially metamorphic beds of the Manhattan group.

PUMPELLY, WALCOTT, and VAN HISE,[129] in 1890, under the guidance of Walcott, who had seen most of the localities before, examined various districts on the eastern side of the Adirondacks from fort Ann, south of Whitehall, to Westport. The peripheral area of this part of the Adirondacks was found to be a great series of laminated rocks, consisting for the most part of white and red, regularly laminated gneisses, very frequently garnetiferous, and in lesser quantity of garnetiferous quartz-schist, crystalline limestone, graphitic gneiss, and beds of magnetic iron ore, dipping as a whole at rather a flat angle toward the east and southeast. The garnetiferous quartz-schists were found in rather persistent beds. A graphite mine in the neighborhood of Hague is a layer of very graphitic gneiss, comparable, as said by Walcott, to a coal seam in an ordinary bedded succession. Scales of graphite are uniformly disseminated through the coarsely crystalline limestone, the amount often being very considerable. Below the crystalline limestone is a coarse black hornblendic gneiss, the contacts between it and the limestone being of a most extraordinary character. The plane between them is one of great irregularity. In the limestone are contained numerous fragments, and even great bowlders of the gneiss, and also for a distance of some feet away from the contact are numerous crystals of feldspar. The appearance is such as to suggest very strongly that here is an unconformable contact, the limestone being deposited along an encroaching shore line. The phenomena are, however, probably due to the breaking up of layers of gneiss and veins of pigmatite by powerful dynamic movements. In passing from Westport within a short distance appeared coarse gabbro, which continued as far as the region was penetrated, near to mount Marcy. This rock in the interior is generally massive, but on its outer border grades into a regularly laminated rock, resembling in exposure very closely the laminated gneisses. The whole is, however, clearly an eruptive rock. Granite was seen locally associated with the gneisses.

WILLIAMS and VAN HISE,[130] in 1890, examined the western side of the Adirondacks. Just as on its eastern side, there was found a peripheral succession of regularly laminated gneisses and crystalline limestones of great thickness. The latter is particularly well seen in the neighborhood of Gouverneur. The contacts between the limestones and lower gneiss were found to be almost identical with those on the eastern side of the mountains, but the appearance here strongly suggests that the relations have been produced by interior movements of the rocks, the irregular contact surface being a contorted one as a result of folding, and the contained fragments broken off and included in the limestone by means of dynamic action. The interior of the Adirondacks was here found to consist of gabbro, in every respect like that on the east side of the mountains.

In passing inward from the gneissic series this is first found in small quantity, then appears more and more abundant, until finally it becomes predominant. At Bonaparte lake a contact of the gabbro with the limestone was found which showed all the characteristics of an intrusive rock, the limestone giving evidence of contact action. There were found, both in the limestone and in the gabbro areas, smaller areas of coarse red granite.

As a result of the reconnaissance it was concluded as probable that the Adirondacks core is an eruptive basic rock, which has upthrust and intruded itself within the gneissic series. Because of the character of the gneissic series, containing quartz-schist, graphitic schist, and crystalline limestone, including graphite, it is regarded as having been originally clastic. Its present crystalline character and quaquaversal arrangement is doubtless due to the intrusion of the gabbro. It thus appears that there is in this region a great bedded succession which belongs to the Algonkian system. The lowest coarse grained gneiss inferior to the limestone perhaps belongs to a still earlier series, but this is a point upon which closer studies are needed.

LITERATURE OF NEW JERSEY.

VANUXEM and KEATING,[131] in 1821, state that the country around Franklin is composed of syenite which is found in beds or layers of variable thickness, running in a direction parallel to that of the ridge. A white limestone forms a bed with eminently crystalline structure, the inclination, direction, and dip of which are the same as those of the syenite. This limestone has been traced for a distance of 8 miles, and, although the limestone is subordinate to the syenite, masses of the latter are found in it. At Franklin, next to the syenite, are found masses of graywacke, which, on the road from Franklins to Dr. Fowler's, is seen to be superimposed upon the syenite and is evidently a later formation. About a quarter of a mile below the furnace it is covered with a violet limestone which rests upon it in parallel superposition. This limestone and that associated with the syenite are not of contemporaneous origin, but the blue limestone is a real mantle-formed superposition.

PIERCE,[132] in 1822, describes the Highland ranges as primitive, with the exception of an isolated transition region. The rocks here included are granite, gneiss, and syenite, while in the transition are found graywacke, graywacke-slate, chlorite-slate, and limestone.

ROGERS (H. D.),[133] in 1840, gives a systematic account of the Primary rocks of New Jersey. These are almost exclusively of the stratified class, consisting of gneiss under all its forms, the granitoid variety predominating. Innumerable small veins of feldspathic granite, syenite, greenstone, etc., penetrate the gneiss. The gneiss is comparatively seldom of the schistose kind. Mica is deficient, the usual mixture being either feldspar or quartz with a little mica, or these minerals with an excess of hornblende, and hornblende and magnetic oxide of iron, the latter being so abundant as to be a characteristic constituent. It occurs not only as an occasional ingredient of the gneiss, but in great dikes or veins penetrating the strata. The massive granitoid gneisses of the Highlands are in striking contrast with the gneiss belt of New York and Staten island, which reappears at Trenton and ranges through Pennsylvania and Maryland, which is distinguished by the prevalence of mica and other thinly laminated minerals, imparting to the rock a schistose structure or the thinly bedded character of ordinary gneiss. The massive strata are, upon the whole, decidedly less than in the Philadelphia belt. They are usually highly inclined, the average dip exceeding 45°. In many of the principal ridges an anticlinal arrangement is plainly visible.

There are three main axes of elevation in the granitic area rising above the secondary sandstones and limestones. The metalliferous veins generally coincide with the direction of the strata in strike and dip, but they exhibit many minor irregularities, such as frequent change in thickness and deviation from the direction of the strata, and are regarded as unchanged matter. The gneiss formation of Trenton has a steep inclination, about 70° to the southeast, and rests unconformably under the more recent formations, and is regarded as the equivalent of the gneiss of Manhattan island.

The blue limestone belonging to the older secondary strata has often a secondary cleavage corresponding with the slate to which it is adjacent. Associated with these limestones are various igneous rocks which have locally caused it to become crystalline and have developed within it plumbago and various silicates. Often these crystalline forms of limestones are associated with the metalliferous veins, which are regarded as the cause of its crystalline character.

JACKSON,[134] in 1854, maintains that the New Jersey crystalline limestones are of igneous origin.

KITCHELL,[135] in 1856, places the formations of the Highlands in the Azoic system. These include gneiss, hornblendic, micaceous, feldspathic, and quartzose schists, and white crystalline limestone interstratified with seams or layers of magnetic iron ore. These rocks are traversed by numerous intrusive dikes of granite and syenite; the strata are highly metamorphic; exhibit violent dislocations; their general strike is northeast and southwest, the same as the intrusive dikes, and their dips southeast. In addition to their distinct stratification they exhibit planes of cleavage frequently at right angles to the former and generally inclining toward the northeast at an angle varying from the horizontal to 45°. At one place limestone rests unconformably upon the gneiss.

COOK,[136] in 1868, places under the Azoic rocks the gneisses, crystalline limestone, and beds of magnetic iron ore. The crystalline limestone in every case is conformable to the gneiss and interstratified with it. It is not, as supposed by Rogers, the metamorphosed blue limestone. The iron ores, instead of being igneous, are believed to be true *beds which were deposited as sediments in the same way as the material* of the gneiss rocks. The gneiss is divided into four principal belts. The Azoic formations, with trifling exceptions, are stratified. Usually they are inclined a good deal, but the dip varies from zero to 90°. The axes of the folds are generally in a northeast and southwest direction. Some of the rocks are so thin bedded as to be schistose, while other portions are so thick bedded that for long distances it is almost impossible to tell which way the rock dips. The gneiss is cut by veins and dikes of trap and granite. The Azoic rocks of Trenton are much more like a true gneiss than those of the Highlands. The Potsdam sandstone, the base of the Paleozoic, is found resting unconformably upon the Azoic gneiss at Franklin furnace and at Green pond mountain. The relations of the two rocks are such as to make it certain that the sandstone is later than and unconformably upon the gneiss. The Franklin furnace sandstone is capped by the blue magnesian limestone, which is equivalent to the calciferous sandstone of the New York reports.

COOK,[137] in 1873, gives the four Azoic belts of New Jersey the names Ramapo, Passaic, Musconetcong, and Pequest. In the first and last are found numerous bands of interlaminated limestones, but in the others these are not known to occur. Lithologically the greater portion of the Azoic rock is syenite-gneiss. There is no way of identifying it with the Laurentian or Huronian of Canada. As to origin all are agreed that these Azoic syenitic gneisses are sedimentary. The crystalline limestone of the Ramapo belt is associated with the serpentine, sometimes in large quantity.

COOK,[138] in 1883, states that the rocks of the Highland include granite, syenite, several varieties of gneiss, crystalline limestone, and magnetite, with rare species of various schists and some serpentine. The strata dip to the southeast at an angle of from 45° to 80°, although it is often difficult to determine the directions of strike and dip positively because of the massive character of the rock. The ranges are regarded as anticlinal folds in general, although this is not probably true in every case, and the valleys are synclinal. The massive syenites, granites, and traps are very limited in quantity, and they are perhaps a part of the stratified beds in which stratification has been obliterated, although granite and syenite dikes are found traversing the bedded gneisses.

DARTON,[139] in 1883, states that at Sparta granite cuts across the limestone beds and may be in true veins.

COOK,[140] in 1884, finds that besides the southeastern dips northwest dips occur. There is difficulty in separating the stratified from the unstratified rocks, as nearly all the glaciated ledges look like massive rocks. The relations of the syenite rocks and gneisses are not made out and it can not be asserted which are the older, but these granitoid and syenitic rocks are surrounded by stratified gneisses and other crystalline rocks. To the Highlands the term Archean is applied because it does not necessitate any correlation or theory, as would the use of Laurentian or Azoic.

BRITTON,[141] in 1885, states that few, if any, of the ridges are simple anticlinal folds, the southeast dips being generally as prevalent on one side of the mountain as on the other, though often differing perceptibly in degree. The crystalline limestones do not represent the blue magnesian limestone metamorphosed by granite and syenite. The supposed dikes of granite are strata conformable to the white limestone, as are the iron and zinc ore beds contained in it, all geologically older than the blue limestone with the quartzites and slates composing the Lower Silurian system. The conclusion is now reached that the unstratified rock masses underlie the bedded crystalline rocks, although the line of separation is but poorly defined, as the stratified rocks of the same mineral composition commonly occur on the sides of the massive area with an apparent gradual passage between the two, and at no point was any actual unconformability found, although at some places abrupt changes in the lamination have been observed within short distances. This leads to the conclusion that the massive beds are only so because stratification has been wholly destroyed through greater metamorphism. The schistose series commonly have a steeper dip along their southern margins than along their opposite sides; thus the axial planes of the folds are often inclined toward the southeast.

While the Potsdam and Paleozoic rocks are unconformable upon the Archean, the newer rocks are tilted in such a way as to show that folding has occurred since they were deposited. At only a few places are actual junctions found, the two more important being in Owens island, in Sussex county, and at Franklin furnace. At several localities the relations are perplexing, for the quartzites and conglomerates are so heavily feldspathic that near the junction they appear to grade gradually into the older rocks, fragments and masses of which are included in them. Along the southeastern margin of the Highlands the Silurian is crystalline, including crystalline limestones and hydromica-slates, and here the unconformity is much less pronounced, no satisfactory contacts being known in New Jersey. At Pompton the slate ledges have nearly the same dip and strike as the nearest Archean outcrops. At Peekskill hollow and Annsville cove, in New York, the slates and quartzites and crystalline rocks appear to be directly conformable, the strata having been subjected to an overturn and causing the quartzite to dip under the older rocks, and it is difficult to say where the line of separation is.

BRITTON,[142] in 1887, divides the Archean rocks into a massive group an iron-bearing group, and a gneissic and schistose group, which is also believed to be the order of superposition, although there is a gradual change from one sedimentary rock into the other. While the massive rocks are but faintly laminated, there is no evidence adducible in favor of an igneous origin for them, but all indications point to their deposition as sediments of one kind or another, and to the more or less complete obliteration of the bedding planes by excessive metamorphism. The beds of magnetic ore occur in different horizons of the middle group, but never occur in the highest or lowest. In this same group the beds of crystalline limestone appear generally to be at a slightly higher horizon than the magnetite beds. The highest gneissic and schistose group corresponds very well in character with the Montalban system of Hunt. These rocks are like those of Trenton and Westchester counties in New York. Among the eruptive rocks are placed those which occur in dikes, such as diorite, diabase, kersantite, and porphyry.

BRITTON,[143] in 1888, describes as occurring in the Archean of New Jersey an organic form, apparently algæ, to which he applies the name *Archæophyton newberryanum.*

NASON,[144] in 1890, describes the Archean of New Jersey. Here are found four types of rock: The mount Hope type, a foliated magnetitic gneiss, the magnetite sometimes largely replaced by hornblende, with little mica; the Oxford type, foliated hornblende-gneiss, magnetite and biotite in places almost wholly replacing the hornblende; the Franklin type, a less foliated biotite-gneiss; the Montville type, white or crystalline limestone. The Franklin type differs from the mount Hope and Oxford types in that the quartz and feldspar are usually in sharply angular grains, which contrast with the roundish grains of these minerals in the first two types. The crystalline limestone is placed under the Archean only provisionally. As there are apparently many reasons why it should be considered of more recent origin, there is greater reason for supposing that if a part of it proves to be Archean all will not. This rock is found at Montville, Wanaque, Pequest furnace, Jenny Jump mountain, Oxford church, and Mendham. No actual contacts between the different groups have been found. The distribution of the various types is described in detail. Whether the gneisses are sedimentary or eruptive has not been ascertained, but there are many localities in which true eruptive granitic rocks inclose within their masses fragments of the adjacent schistose and gneissic rocks. Also in the Archean is frequently found gabbro which is almost certainly of igneous origin. Graphite is found to be widely separated in the Archean rocks. At one place, commencing at the old graphite mine near South bridge, it is found continuously for 35 miles. A similar rock has been found at Iona island in the Hudson river, 35 miles northeast. Another line is found on Bald hill, and a third graphite gneiss is found on a hill east of Pompton station and in part of the range of Ramapo mountains. Also, graphite occurs at other places.

NASON,[145] in 1891, describes the relations of the white and blue limestones of Sussex county, New Jersey. They are found to grade into each other at many points. The white limestone is always associated with later granitic eruptions. In passing away from a boss or dike the limestone is white, but changes steadily with rapid gradations into the blue limestone. Sandstones and quartzites of identical character underlie both the white and blue limestone and bind them together. The one distinguishing fact which separates the white from the blue limestone is the presence of eruptive rocks. It is therefore concluded that the two are identical. As the blue limestone belongs to the Cambrian, it is concluded that in this region there are no Archean limestones, as has been supposed.

LITERATURE OF PENNSYLVANIA.

FINCH,[146] in 1824, finds, near Easton, syenite, serpentine, and transition limestone, transition granite, transition clay-slate, and transition sandstone.

FINCH,[147] in 1828, finds a section from Chads fork to Westchester to include gneiss, mica-slate, hornblende-slate, primitive sandstone, and transition quartz rock.

ROGERS (H. D.),[148] in 1858, gives a systematic account of the metamorphic rocks of Pennsylvania. These are divided into three main divisions: the gneissic series proper, or Hypozoic; Azoic, or those destitute of relics of life, and Paleozoic. The Hypozoic rocks only are placed with the primary. The Azoic schists are regarded as newer than the Hypozoic, because of differences in the position of the two sets of strata, in condition of metamorphism, and in manner of plication. The former dip almost invariably to the southeast, while the gneiss in many localities has no symmetrical folding. These dissimilarities imply essential differences in the directions and dates of the crust movements. The Azoic rocks, however, when they show the maximum amount of metamorphism, simulate in mineral aspect and structure those of the gneissic series. The old strata are then separated into three systems by two main horizons, the lower, a physical break between the Hypozoic and Azoic; the upper, a life limit denoting the first advent, so far as discovered, of organic beings.

The gneissic rocks are separated structurally into three districts: First, the area running southwestward from Trenton, through Philadelphia; second, the area between the Schuylkill and the Susquehanna, north of the first area; and, third, the South mountain region, a continuation of the Highlands of New Jersey. The Philadelphia belt is intersected very extensively by eruptive rocks, such as granite, greenstone, syenite, and trap. The second or middle belt is sometimes called the mica-schist belt, because of the amount of this mineral which it contains. The upper or northern belt of gneiss is regarded as a part of the lower Primal rocks and as resting unconformably upon the upper gneissic group, the belief being based upon the manner of the flexure of the two formations rather than upon actual unconformable contacts.

In the Philadelphia belt there is a general prevalence of the northward dip of the strata, varying generally from 30° to 50°. At Fair-mount the true dip of the rocks is very steep, although there is a deceptive appearance of a nearly horizontal stratification in thick and almost parallel beds; but this is not to be confounded with the genuine stratification or grain of the rock as marked by the general distribution of its mica and other minerals. In this belt there are really two groups of rocks, which, viewed broadly, constitute one synclinal wave. The lower is a harder feldspathic and hornblendic gneiss at the south side, dipping northward, and reappearing in steep and multitudinous contortions on the other side of the trough; and the upper is a more micaceous group filling the synclinal center of the trough and compressed into lesser folds.

In the middle division the rocks are mostly of the granite-like varieties of feldspathic gneiss, with hard hornblendic gneiss, such as constitute the central ridges of the South mountain. These are believed to be in a series of anticlinal and synclinal waves, and in addition to the folds there is a series of folds along which the iron-ore deposits are found in V-shaped masses.

The northern or South mountain zone is composed of massive or thick-bedded gneisses, with which is no talcose slate, or else the Primal white sandstone, the lowest member of the Paleozoic. The limestone associated with the gneisses is generally found in the synclinal valley. The gneisses are regarded as stratified, dip to the southeast, and, as the breadth of the chain is so great, the structure is believed to be due to overturn flexures.

On the Delaware section is found the best evidence of unconformity discovered between the semicrystalline rocks called Primal and the gneiss. In one case here the Primal siliceous slates and quartzites are a porphyritic and crystalline quartzose conglomerate. Below this is an arch or wave of granitoid gneiss containing injections of syenite; and the dip of the gneiss seems also to be steeper than that of the Primal conglomerate. The relations are, however, best seen at Durham creek. Here at one place the sandstone, slates, and conglomerates rest with their beds almost perpendicular to the lamination of the gneiss.

The lower part of the Paleozoic rocks are Primal crystalline schists, or the Azoic group; Primal conglomerate; Primal older slate; Primal white sandstone, Potsdam of New York. The Primal series contains but few eruptive rocks, even trap dikes being uncommon, which is regarded as proving that the metamorphism is due to heated gases through fissures rather than to the contact of igneous material.

The Primal southern belt is first considered. At Attleboro there is no marked discordance between this and the gneissic series which is supposed to be older. East of the Schuylkill and in Montgomery county, the observer is very liable to confound the lowest Primal beds with the uppermost hornblendic feldspathic layers of the adjacent genuine gneiss. West of the Schuylkill the Primal slates are of so crystalline a character that it is sometimes difficult to distinguish the strata from certain forms of the more micaceous beds of the true gneissic or Hypozoic. It is impossible to subdivide the members of the Lower Primal group in southern Pennsylvania, because of a prevailing transverse cleavage, which extensively effaces all clear traces of the original bedding, and because of the presence of innumerable plications, often so closely compressed as to appear as only one uniform dip, the anticlinal and synclinal foldings in many cases escaping detection through the obscuring influence of cleavage, and because of mutations in the composition of the beds. The rocks between the Primal white sandstone and the genuine gneiss then include talcoid siliceous slate, talco-micaceous slate, and schistose and quartzose micaceous rock. On the Brandywine the massive gneisses and finely laminated material are interlaminated in such a way as to lead to the conclusion that the latter are closely infolded in the older metamorphic series. In the Primal of Susquehanna and York counties, the true bedding is very obscure, being almost obliterated.

In passing southward on the Susquehanna the rocks become steadily more crystalline, until they are so altered as to have been hitherto mistaken for the true Hypozoic. The precise line of contact of the limestones with the slates is not clearly visible at times; indeed, there seems to be no line of sudden transition. The cleavage planes are in general parallel with those of the original bedding. The dips on this river are steadily in a southeast direction for a distance of 7 or 7½ miles, and it is believed that the rocks consist of many compressed folds which repeat the same strata many times over. Southwest of the Susquehanna, in the South mountains, in Adams, Cumberland, and Franklin counties, is an extensive area which is placed with the Primal series. It is a continuation of the Blue ridge of Maryland and Virginia. There are a few intrusive rocks, mostly of greenstone and trap. Some of the rocks are very crystalline, but none are regarded as belonging to the gneissic series. In this series are found limestones associated with iron ore.

LEEDS,[149] in 1870, states that on the Germantown railroad, 3 miles from Philadelphia, in the micaceous schists are imbedded huge bowlders of hard, compact hornblende rock. They are supposed to be a primitive surface formation which was broken up before the deposition of the metamorphic rocks of undetermined age.

FRAZER,[150] in 1876, describes several sections in York and Adams counties. Here are included hydromica-slates and hydromica-schists, chloritic rocks, quartzite, quartz-slate, gneissoid mica-schist, limestone, and chert. Several sections show an unconformable contact between the York limestone and the crystalline schists. The latter usually dip at a high angle.

FRAZER,[151] in 1877, describes cross-sections in the counties of York, Adams, Cumberland, and Franklin. In South mountain the structure is found to be essentially the same as that given by Rogers, except that it also contains limestone. In one section is a thickness of over

17,000 feet of quartzite and sandy shale and about 2,000 feet of chloritic slates. In another section the rocks observed are quartz-conglomerate-schist, jaspery quartzites, crystalline schists, and orthofelsites. The relations seem to show an unconformability between the older (Huronian?) orthofelsites and schists and the more recent (Cambrian?) sandstone, but it would seem additionally to imply that the alignment of the one system was the result of causes entirely different from and anterior to those that formed the other. In another section the rocks increase in felsitic character to the southeast and in conglomeratic schistose character to the northwest. It is concluded that the South mountain chain is composed of two groups of rocks, the lower consisting of quartz-conglomerates in which quartzite occurs; the upper felsitic in character, containing hydro-mica schists and chlorite-schists. The felsite itself ranges from a sandy slate to a coarsely porphyritic rock.

HUNT,[152] in 1877, states that near Conshohocken is a belt of Laurentian gneiss identical with that of the South and Welsh mountains, that separates the Philadelphia gneisses and mica-schists, which are Montalban, from the Auroral limestone. The Laurentian gneiss is succeeded on the northeast by serpentines, chloritic schists, micaceous schists, and argillites, which are typical Huronian rocks. The intermediate position of the Huronian seems to show that it is below the Montalban. The Primal and Auroral are the Lower Taconic of Emmons. South of the Susquehanna, South mountain rocks again appear and stretch southward to the Potomac. They here consist of Montalban and Huronian rocks. In the southern part of Pennsylvania are bedded petrosilex rocks, often jasper-like, which are associated with characteristic rocks of the Huronian series, to which they are all referred.

PRIME,[153] in 1878, describes gneiss and mica-schist in Lehigh county as Laurentian. A little west of Seller's quarry the Potsdam sandstone and Laurentian rocks are seen in contact. The dips of the two seem to be conformable, but this may be wrong, as the exposure is small and the gneiss apparently has a slight roll. The gneissic rock is here distinctly bedded.

FRAZER,[154] in 1880, includes in the post-Eozoic series of Lancaster county calcareous argillites, nacreous slates, hydro-mica-schists, chikis quartzite, and chloritic series. In the Eozoic series is placed the mica-schist and gneiss belt. Between this series and the previous one there is no certain evidence of nonconformability, the transition from one rock to the other being gradual and the line between them difficult to define.

FRAZER,[155] in 1880, states that the chloritic series pass into the Peach bottom slates within a breadth of a few hundred yards, and equally abruptly into chlorites again, and finally into greenish chloritic quartzite, in all respects like those of the South mountain. If the Peach bottom slates are Hudson river age as supposed, a difficulty is here presented.

HALL (CHAS. E.),[156] in 1881, describes Philadelphia county and the southern parts of Montgomery and Bucks. The schistose rocks are placed in the three belts as divided by Rogers, but there is an intermediate belt between the first and second belts of Rogers. The first belt is made up of gray schistose gneiss, composed of quartz, feldspar, and brown or black mica, with occasional garnets, interlaminated with occasional beds of black hornblendic slate and fine grained sandy gneiss. The second belt is characterized by serpentine, soapstone, silvery micaceous garnetiferous schists, light colored thin bedded sandy gneisses, with disseminated light colored mica in minute flakes. The third belt is composed chiefly of quartz, feldspar, and hornblende. The beds are often massive, but usually have thin bands of mica or hornblende through them. They are syenitic and gneissic granites or granitic gneisses in which is found a peculiar variety of blue quartz. The prevailing northward dips of the schists and gneisses of the first and second belts do not hold for the third. The Primal sandstone (Potsdam), wherever it occurs, invariably rests upon the rocks of the third belt, and its sandstones and conglomerates are invariably composed of débris from this belt, and in it is found not a single flake of mica, quartz, or other material which can belong to the first or second belts. For considerable distances the Primal rocks are found between the third belt and the schists of the second belt. At the Schuylkill the rocks of the first and second belt rest upon and against the rocks forming the third belt. The third belt is regarded as Laurentian and the first and second belt are assigned a position above the Primal Potsdam sandstone and the Auroral limestone. In the midst of the roofing-slates of the Susquehanna river occur Hudson river fossils, and the first and second belts are referred to or above the Hudson river group, while the third belt is referred to the Laurentian.

LESLEY,[157] in 1883, describes in the southern part of Northampton county the continuation of the Highlands of New Jersey. There are in this region four ranges. In the valleys are limestones, the stratification of which is visible everywhere but is much broken and crumpled. The stratification of the gneiss or syenite beds of the mountains is, on the contrary, rarely to be seen and can only be judged from topographical features. Dips are hard to find, owing to the general decomposition of the rock surfaces of the country, to the amount of débris on the surface, to the vegetation, and to the massive and homogeneous character of the beds where the true bedding plane has sometimes been made out by observing the parallel arrangement of the minerals. The South mountain gneisses evidently belong to a different system from the Philadelphia belt and they are comparable with the Laurentian system. Why they are not covered by Huronian or Cambrian rocks is not known. If the views of Hall are accepted that the Philadelphia belt underlies the Potsdam and overlies the Philadelphia syenites, it is hard to see why they do not appear between the Potsdam and gneisses at South mountain. The ridges, instead of being simple anticlines, are a series of anticlines and synclines. At Morgan hill there is discordance between the dips of the Potsdam and the gneiss, showing apparent nonconformity. The syenite rocks underlie the limestones, which may represent residual material which has not been removed by erosion. The crystalline character of these outlying ridges of limestone may be explained by the fact that the material has been buried 30,000 or 40,000 feet below the surface. At Chestnut hill gap on the Delaware, the Potsdam sandstone is sometimes vitreous and over it are limestones changed into crystalline dolomites holding serpentines. In contact with a dike of coarse granite near the south side of the gap the slates are changed into chlorite, mica-slate, and hornblende-slates, but in the coarser grits the original pebbles are seen.

HALL, (CHARLES E.) [158] in 1883, describes many localities of slates, gneisses, and granites in the South mountain area.

D'INVILLIERS,[159] in 1883, states that the existence of anticlinal and synclinal folds in the South mountain belt of Berks county is suggested by the alternate anticlinal and synclinal belts of limestone and slate, but it is not conclusively proved, for these formations belong to different systems of rocks, and no doubt lie unconformably upon the older mountain rocks. The South mountain rocks are gneisses and granites, which are of two kinds, a distinctly stratified, thick bedded, massive gneiss, and a stratified syenite where hornblende is predominant. The eroded edges of the Potsdam sandstone run along the northern slope of the belt overlying the gneissoid rocks.

HALL (C. E.),[160] in 1885, places the syenites of Delaware county with the Laurentian. Overlying these are the micaceous and garnetiferous schists, these relations being well exposed at Chester creek. The cleavage dip varies from 75° to 90°, but the true dips are nearly horizontal and undulating, which fact tends to reduce the hypothetical thickness of the crystalline rocks of southeastern Pennsylvania to a minimum. The serpentines occupy shallow synclinal basins and are the most recent of the metamorphosed rocks. East of the Schuylkill river, outside of Delaware county, the schists rest upon the upturned edges of the Potsdam and limestones, proving the relative age conclusively. The serpentines, mica-schists, and gneisses are regarded as more recent than the Hudson river group. In this schistose series one kind of rock gradually fades into the next succeeding kind, which renders a delineation almost impossible.

FRAZER,[161] in 1885, states that at Hendersons station, in the Philadelphia region, there is an unconformable contact of the limestone with the sandstone; and that in the section here there is a series of gentle folds rather than a monoclinal structure, as made out by Hall.

FRAZER,[162] in 1886, describes the Archean rocks of York county. The lowest members of the Archean series here found are the Huronian schists, which have a thickness of 14,400 feet. A somewhat arbitrary division is made between the Huronian and the next following age, the rocks of which are denominated Azoic schists or phyllites, as they can not be certainly assigned either to the Archean or to the Paleozoic. A belt of them is found on either side of the broad Huronian area of the crystalline schists.

RAND,[163] in 1889, describes a section of the crystalline rocks from the Triassic of Chester county, Pennsylvania, to the Cretaceous of New Jersey, passing through Philadelphia. The rocks are doubtfully referred to various horizons, running from the Laurentian to the Hudson river.

LITERATURE OF MARYLAND.

DUCATEL and ALEXANDER,[164] in 1834, describe the Primary rocks as one of the chief divisions. These include the following formations: Granite, gneiss, limestone, and serpentine.

AIKIN,[165] in 1834, states that granite and primitive schists are intermingled in every possible manner in the region west of Baltimore, the dips being with a good deal of regularity toward the southeast. Succeeding the primitive rocks are transition slates, sandstones, limestones, and greywackes interstratified with transition limestones.

DUCATEL,[166] in 1839, states that the limestones of Harford and Baltimore counties occur in the valleys. In the northwest part of these counties the rocks are argillites, which pass into talcose slates, and these are succeeded by granitic aggregates in which hornblende is the prevailing rock.

TYSON,[167] in 1860, classifies the rocks of Maryland into those of igneous and aqueous origin. In the former are granite, syenite, massive quartzite, porphyry, amygdaloid, trap (including hornblende rock or amphibolite), and serpentine. The rocks of aqueous origin include chemical deposits, among which are limestone and dolomite; mechanical deposits, among which are sandstone, conglomerate, breccia, clay-slate, shale, and clay; and metamorphic rocks, among which are gneiss, mica-slate, hornblende-slate, talc-slate, quartzite, granular limestone, and dolomite. The rocks of igneous origin are defined as those which give no evidence of stratification. These are found in the area about Baltimore, mingled with the sedimentary rocks. In the limestones in many cases the stratification has been obliterated. Gneiss is the most largely developed of the rocks in the central part of the state. While there is usually ample evidence of stratification in gneiss, in some localities it has been so much altered by the joint action of heat and intrusive forces as to have nearly obliterated its stratification planes and cause it to resemble granite. The four lowest formations of Maryland are eruptive; the fifth formation is composed of gneiss, mica-slate, and hornblende-slate, which includes the intrusive rocks of the first four formations and a portion of the limestone. These rocks occur as a belt in Cecil, Harford, Baltimore, Howard, and Montgomery counties, and are bounded on the northwest—or, more correctly speaking, pass by insensible shades of difference into the talcose slates. Near the southwestern limit the prevailing rock is gneiss, which is interlaminated with hornblende-slate. In proceeding northwest mica-slate increases in quantity, and in passing still farther this mica-slate passes into talc-slate. The metamorphic limestones are found in two ranges; the first, the gneisses and mica-slates; and second, the talcose slates.

WILLIAMS,[168] in 1886, describes the gabbros and associated hornblendic rocks of Maryland. These are all found to be of igneous origin and the schistose hornblendic rocks the result of metamorphism.

WILLIAMS,[169] in 1891, describes the structure of the Piedmont plateau in Maryland. The western part is a semicrystalline area consisting of phyllites, sandstones, marbles, and but few eruptive rocks. The eastern area is completely crystalline. The sedimentary rocks include biotite-gneiss, biotite-muscovite-gneiss, muscovite-gneiss, mica-schist, quartz-schist, conglomeratic quartz-schist and dolomitic marble. Within this area are very numerous eruptive rocks, including granites, gneisses, gabbros, diorites, and basic rocks, such as pyroxenite, lherzolite, etc. Two sections are described in detail. In the semicrystalline rocks a cleavage is developed which much obscures the bedding, and the succession may be repeated many times by folds and faults. Between the semicrystalline and completely crystalline rocks there is a somewhat abrupt passage. The structure of the western area can be accounted for by a single period of folding, while the eastern area, as shown by its implicated structure, must have been wrenched, folded, and faulted at different times. It is concluded that the eastern area is composed of rocks far more ancient than the western, which extend under the latter, forming the floor upon which they were deposited. This hypothesis accounts for the difference in crystalline character between the rocks of the two areas, for the abruptness of their contact, and, since both series have been subjected to a folding together, for their apparent conformity along their contact. As to the age of the rocks, it is probable that the Paleozoic should include all the semicrystalline schists, while the holocrystalline rocks east of them would be assigned to the Algonkian or Archean.

KEYES,[169] in 1891, gives as a supplement to the preceding a section across the Piedmont plateau of Maryland. In the Frederick limestone of the western semicrystalline rocks are fossils of several types characteristic of the Trenton, and the entire series of limestones and shales probably represent the Chazy, Trenton, and Hudson river formations. East of the western semicrystalline rocks are contorted gneisses, with general westerly dips, which are cut by basic and acid rocks and which are believed to have been originally granitic, but through the agency of enormous orographic pressure have been squeezed into their present gneissic condition, as shown by the mechanical deformations through which the grains have gone.

LITERATURE OF DELAWARE.

BOOTH,[170] in 1841, includes among the primary rocks gneiss, feldspathic rocks, limestones, serpentine, and granite, the first comprising about three-quarters of the area. This region is, without question, stratified. The average bearing of the rocks is north 47° east, and the dip 70° northwest, but occasional bearings are found which differ widely from this, and the dip is vertical. The trap rocks have a dip and strike conformable with the gneiss and grade into them. The limestone is a coarse to fine grained crystalline marble, interstratified with the gneiss. The serpentine and surrounding rocks are cut by numerous veins of granite. The greater part of the trappean formation possesses a clearly stratified structure and grades by transition into the gneiss, but the hornblendic and coarse feldspathic veins do not. The variation in the strike and dip of the gneiss is regarded as due to the granitic veins or to the serpentine.

CHESTER,[171] in 1885, places in the Laurentian the hornblendic rocks along the line of the Pennsylvania railroad and the area to the east of West Chester. The rock is a dark hornblendic gneiss or amphibolitic schist, with which is associated a dioritic or syenitic granite of the Pennsylvania survey. The two rocks grade into each other, and probably form varieties of the same eruptive series. North of the Laurentian gneisses, and resting upon them, is a series of mica-schists and granitic gneisses, with which are associated bedded granites, serpentines, and hornblende rocks which have been referred to the Montalban, or, with the Laurentian, have been called Azoic. These do not form two successive formations, for, while the former is either Laurentian or Huronian, the latter must be placed above the Trenton, and possibly above the Hudson river slates. The granite of the State is in intrusive beds and in beds which are no more than highly metamorphosed granitic gneiss or mica-schist, the two latter grading into each other. Crystalline limestones are found at Pleasant hill, Hockessin, and near Centreville. Serpentine is found northeast of Wilmington as a dike, running with the micaceous schist. Vitreous quartz and quartzite occur as thin or massive seams interstratified with the micaceous rocks. The quartzite of the northeast corner of the State, underlying limestone, is probably of Potsdam age. The strikes and dips of the crystalline rocks are very variable, and this variation is often due to the disturbing action of granitic intrusions. The Laurentian is an extension of the third belt of Rogers. The limestones are younger than the Potsdam quartzites, and are regarded as calciferous; the mica-schists and gneisses certainly overlie the limestones, and the latter therefore begin somewhere in the Silurian, and possibly mount as high as the Devonian.

CHESTER,[172] in 1890, describes the gabbros, gabbro-diorites, and hornblende-schists of Delaware and their relations to the surrounding rocks.

The gabbro, gabbro-diorites, and hornblende-schists are found to grade into each other by imperceptible stages, and the two latter are regarded as a metamorphosed product of the former and all of igneous origin. These rocks are found at various points in contact with the mica-schists and gneisses. Where the eruptive rocks have a schistose structure this is in apparent conformity with the foliation of the mica-schists. Sometimes the mica-schists appear to dip beneath the eruptive rocks, and at other times to overlie them. No evidence was found of any bedding not coincident with the cleavage. The unconformity discovered by Hall between the trappean rocks and mica-schists in Delaware county, Pennsylvania, was not found on the Delaware side of the line. If the horizontal bedding described exists, it is so obscured as to be unrecognizable; if the mica-schists are considered to lie horizontally the eruptive character of the gabbros, gabro-diorites, and hornblende rocks is but the more evident.

GENERAL LITERATURE.

MARTIN,[173] in 1886, states that the Tide-water gneiss has mineralogical characters which distinguishes it strongly from the gneisses of the northern Laurentian and from the Highlands. In particular the abundance of subsilicates and of hydrous silicates is to be noted.

SUMMARY OF RESULTS.

The literature summarized clearly shows that in the central Appalachian area, as in the northern, only general certain results have been reached. While there are numerous areas of crystalline rocks, it is not clear that many are of pre-Cambrian age. The exceptions are the Adirondacks; the Highlands of New Jersey, with its northern extension the Highlands of New York, and its southern extension South mountain of Pennsylvania; and the eastern area of Maryland. A part of the northern extension of the Blue ridge is probably also to be here included.

The most widespread rock in the Adirondacks is a gabbro, which has all of the characteristics of this eruptive rock. The outer border of the mass has a well laminated structure, due either to original crystallization or to subsequent metamorphism. This rock is in all respects like the Labradorian or Norian of the Canadian survey, to which indeed it has been referred by the advocates of the Norian system. The bedded succession of gneisses, limestones, and quartzites is in nearly all respects like the original Laurentian described by Logan. While now it nowhere has indubitable clastic characters, its beds are such as to show that it was originally a sedimentary series. Since the series is not closely folded, probably the principal cause of its metamorphism is the great batholitic mass of gabbro occupying the core of the mountains, which seems to have thrust itself up among the clastics. Whether the coarse gneisses which underlie the limestones belong with the latter series or represent an earlier one, we have no knowledge. There is, then, in this district a possible pre-clastic series, which in its character, so far as seen and described, is like the fundamental complex, the true Archean; and a clastic series of great but unknown thickness which belongs with the Algonkian. That the Adirondack rocks as a whole are unconformably below the Potsdam has been unquestioned from the first.

The relations of the Highland area of New Jersey with the Potsdam sandstone are such as to make it certain that between them there is a great structural break. The rocks comprising this area consist largely of granite-gneiss, in general very nearly massive, but having a somewhat laminated arrangement of the mineral constituents. The strike of the lamination conforms closely with the trend of the area as a whole, being east of north and south of west. The gneisses over large areas are graphitic. Interlaminated with them are beds of iron ore, and apparently of crystalline limestone. They are cut by various basic and acidic eruptives.

The weight of opinion in former years has been in favor of the sedimentary origin of this gneissic series. Mather, who gave by far the best early descriptions of the district, and Nason, who has recently been closely studying the limestones of New Jersey, find that the white crystalline limestones which have been regarded as Archean grade into the blue limestones which are fossiliferous. These writers regard all of the white limestone as parts of a newer series which have been metamorphosed either as a result of extreme folding or by intrusive masses of granite of later date, with which they are frequently associated. If all of these limestones are excluded from the pre-Cambrian and this is a very doubtful assumption, the evidence in favor of the detrital origin of the Highland area is restricted to the widely disseminated graphite and to the magnetite beds of iron ore. Magnetite is widely associated with certain belts of the granite-gneisses of New Jersey, but this and its concentration in lenticular masses within the gneisses in the form of magnetite can hardly be considered as decisive evidence of their sedimentary character. The magnetites associated with the basal gabbros of the lake Superior Keweenawan are in purely igneous rocks. The graphite of the graphitic gneiss is a point of more weight. The absence of graphite as an important constituent over large areas in any definitely determined igneous granite-gneiss, bears in favor of the sedimentary origin of the gneissic series. If this theory proves true, the Highland gneissic series more nearly approaches the characters of a massive eruptive than any other metamorphic sedimentary rock known to the writer. Upon the whole, in the regularity of its lamination, in its lack of extreme contortion and foliation, and in the presence of graphite, the Highland gneiss is not like the fundamental complex, the genuine Archean of Canada and the West. However, there are no certain criteria upon which it can be referred either to the Algonkian or Archean. It must be simply classified, so far as present knowledge goes, as pre-Cambrian.

If it can not yet be decided whether the Highland gneisses are sedimentary the supposed structural divisions of Britton and Nason can be regarded as only lithological. Britton's arrangement of a massive group in the cores and schistose groups on the outer parts of the ranges can be as well explained, as has been repeatedly seen, by the eruptive theory of the origin of the series as by the sedimentary. From Nason's work it appears that certain varieties of rock have a continuous wide-spread distribution; but the descriptions show that his various types grade into each other instead of being sharply differentiated as supposed. Magnetite is the distinguishing characteristic of one type, and yet, in order to make out the continuity of this belt, rocks have to be classed with this type, in which hornblende and biotite are the chief basic constituents. The same thing is true of the second type, in which the hornblende, the distinguishing characteristic, is locally almost wholly replaced by magnetite or biotite.

Of the eastern Crystalline area of Maryland nothing can be said as to age, except that it is pre-Cambrian.

The work of Mather and Dana in eastern New York and on Manhattan island, the work of Emerson, Dale, Wolff, and Pumpelly in the adjacent district in Massachusetts, combined with the paleontological work of Walcott, show beyond all reasonable doubt that a considerable part of the crystalline area of southeastern New York, including in all probability Manhattan island itself and the so-called Taconics, belong with the Cambrian and post-Cambrian formations. The detailed evidence for this is rather for another to consider.

Various other crystalline areas in southeastern Pennsylvania, in Maryland and in Delaware, are in large measure metamorphosed Cambrian and post-Cambrian rocks, as shown by the work of Rogers, Hall, Williams, and Chester. There are also probably in these areas pre-Cambrian rocks, although often the gradations described between the gneissic series, supposed to be pre-Cambrian and the crystalline schists supposed to be Cambrian or post-Cambrian, are so complete as to leave the reader quite in doubt as to the reality of the break supposed to exist between them.

Among all the earlier writers on the crystalline rocks of the Middle Atlantic states, Mather is distinguished for the fidelity of his descriptions and for the keenness of his insight. While in his great New York report of 1843 there are some crude notions, the comprehensive general results announced accord to a remarkable degree with the views held by the best informed of the geologists who are working in this field to-day.

SECTION III. THE SOUTHERN ATLANTIC STATES.

LITERATURE OF THE VIRGINIAS.

CORNELIUS,[174] in 1818, finds west of the Secondary formations ranges of granites, schists, and other primitive rocks. The Blue ridge is the dividing line between the granite and the limestone country to the westward.

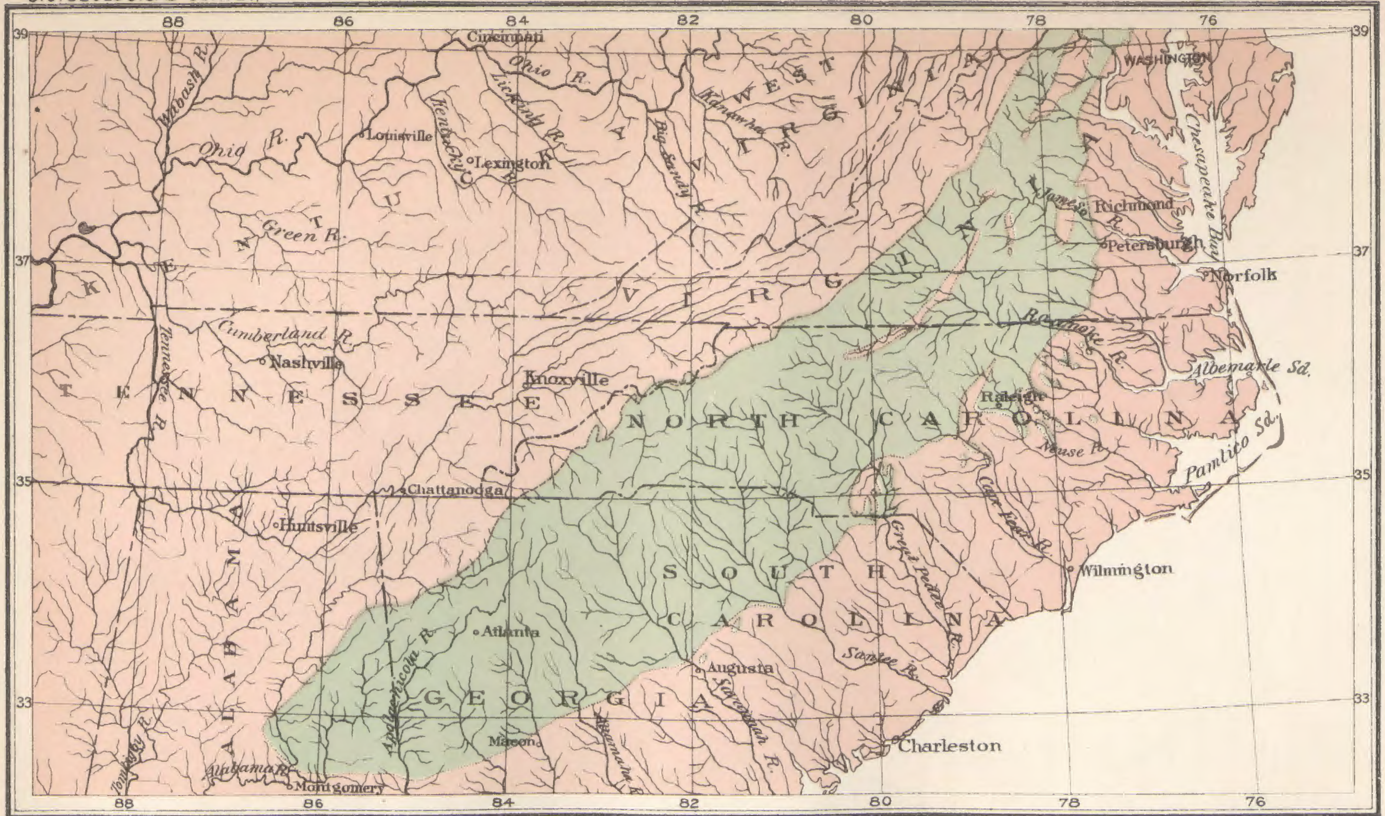
ROGERS (W. B.),[175] in 1840, describes the southern district east of the Blue ridge as occupied mostly by rocks of very ancient date, most of them believed to be primary. A part of them are in irregular masses, and others have regular stratification, but all are alike considered of metamorphic origin. Aside from these there occur igneous rocks. The more important metamorphic rocks are granite, syenite, gneiss, mica-slate, talc-slate, argillaceous slate, pseudo-gneiss or gneissic sandstone, soapstone rocks, micaceous and talcose limestones, and marbles. By pseudo-gneiss or gneissoid sandstone is meant rocks which resemble the truly crystalline rocks, but which plainly betray their sedimentary origin by the rounded character of the quartz and other constituents which compose them. The igneous rocks cut the shales and sandstones of the Middle Secondary.

ROGERS (W. B.),[176] in 1841, gives the geological occurrences of the primary and metamorphic rocks. In these, beds of limestone are included at various points. Quartz-slate and quartzite are found in the Bull Run mountains and other localities.

FONTAINE,[177] in 1875, describes several sections of crystalline rocks which are regarded as pre-Silurian. Among them are argillite, greenstone, and syenite. At a tunnel the contact of the Silurian with the argillite is beautifully exposed and the great contrast of the two systems is well shown.

FONTAINE,[178] in 1875, describes the central part of the Blue ridge as consisting of coarse granites and gneisses of Laurentian age. Along the eastern slope of the syenite is a formation of argillites which is covered by a series of mica-slates, schists, and gneisses. The axis is occupied by talcose limestones, quartzites, mica-slates, and hydromica-slates which closely resemble those in Berkshire county, Massachusetts. In this belt are probably two systems, one older than the Primordial, and the other metamorphosed Silurian. The unconformity which exists between the syenite and argillite apparently shows the latter to be Huronian, although its age is not positively determined.

CAMPBELL (J. L.),[179] in 1879, states that the Archean rocks of the Blue ridge are granite and syenite. They underlie the stratified rocks of the region, but are probably more recent than they, being thrown upward through them. The bedded rocks resting upon the syenite are much metamorphosed and gneissoid in character. These are followed by a bed of conglomeratic quartzite and slates, upon which lie unconformably the Primordial rocks.



Sackett & Wilhelms Litho Co. New York

UNCLASSIFIED PARTLY OR WHOLLY CRYSTALLINE ROCKS

POST-ALGONKIAN

GEOLOGICAL MAP OF THE SOUTHEASTERN STATES

SHOWING PRE-CAMBRIAN AND CRYSTALLINE ROCKS

After McGee and Hitchcock

Scale $\frac{1}{7,600,000}$

CAMPBELL (J. L.),[180] in 1880, describes the metamorphic Archean rocks along the James river and Kanawha canal as including limestones, schists, and quartzites.

CAMPBELL (J. L.),[181] in 1880, describes the Archean rocks at James river gap as consisting of granulite and syenite, upon which rest much metamorphosed beds of conglomeratic quartzite, and over these slates. These Archean rocks are unconformably below the Primordial rocks, which contain fragments of slate, crystals of feldspar, epidote, etc., more or less waterworn and cemented together. The slates were metamorphosed before they were deposited in the Primordial strata. The syenite and granulite are eruptive rocks which have been thrown up since the deposition of the Primordial, as is indicated by the fact that the stratified rocks dip at a high angle away from the igneous masses, and also from the influence of heat exerted upon the overlying slates and sandstones. Higher in the series traces are found of metamorphic changes. The syenite and granulite are supposed to be the result of aqueo-igneous fusion and to represent material which is really older than the stratified rocks.

FONTAINE,[182] in 1883, describes the Blue ridge between Turks gap and Balcony falls as consisting of Laurentian, Huronian, and Primordial rocks. The first is mostly gneiss; the second mostly hornblendic, micaceous, and argillaceous schists; and in the Primordial is found Scolithus.

ROGERS (W.B.),[183] in 1884, states that the Blue ridge is a continuation of the Green mountains of Vermont, the Highlands of New York and New Jersey, and the South mountain of Pennsylvania, and, continued southward, becomes the Smoky or Unaka mountains of Tennessee. The rocks consist for the most part of the older metamorphic strata, including gneiss, and micaceous, chloritic, talcose, and argillaceous schists, together with masses referable to the earliest Appalachian formations, sometimes in a highly altered condition. Innumerable dikes and veins of all dimensions, and consisting of a vast variety of igneous materials, penetrate this belt, disturbing and altering its strata in a remarkable degree. Southern dips are prevalent throughout the whole of the region. This is particularly the case in the southeastern or most disturbed side of the belt, but on the northwest side the reverse dips are more common. In many cases the ordinary anticlinal and synclinal structures are regarded as overturned in a northwest direction, which makes the two sides of the fold approximately parallel, and when this is not the case gives the northwest sides a deeper dip than the southeastern. In many of the sections the unconformity between the Cambrian and the crystalline metamorphic rocks is unmistakable, the lower members of the former being seen to rest on the slope of the ridge, with northwest undulating dips on the edges of the southeastward-dipping older rocks. In other cases the primal beds, thrown into southeast dips in the hills which flank the Blue ridge, are made to underlie, with more or less approximation to conformity, the older rocks forming the central part of the mountain. But even in those instances it is not difficult to discern the true relations of the strata. As examples of the phenomena are the sections exposed at Vestals, Gregorys, Snickers, and Manassas gaps, and Jeremies run, in the northern part of the Blue ridge; and at Dry run, Turks, Tye river, Whites, James river, point Lookout, Fox creek, and White-top mountain gaps, in the middle and southwestern prolongation of the chain.

CAMPBELL (J. L. and H. D.),[184] in 1884, conclude from an examination of the Snowdon quarries that the core of the Blue ridge is an igneous mass belonging to the Archean, and that upon its northwestern slope are unconformable beds of slates, sandstones, and conglomerates which are Potsdam or Cambrian. They are in a highly metamorphosed condition, and were regarded by Rogers as Huronian, and by the authors as pre-Cambrian, but the discovery of fossils in them has definitely determined their age. The slaty cleavage of the quarries sometimes corresponds with the planes of original bedding or stratification, but more frequently is more or less oblique to the strata.

GEIGER and KEITH,[185] in 1891, in discussing the structure of the district about Harpers ferry, state that between the Cambro-Silurian shale and the granite-schist there is an unconformity of the ordinary type of deposition.

LITERATURE OF NORTH CAROLINA.

OLMSTED,[186] in 1824, describes as parallel with the freestone and coal formations a great slate formation which extends across the state from northeast to southwest, being about 20 miles wide, running through Person, Orange, Chatham, Randolph, Montgomery, Cabarrus, Anson, and Mecklenburg counties. Within this district are found numerous beds of porphyry, soapstone, serpentine, greenstone, and whetstone. From Halifax to Person courthouse hardly any kind of rock but granite is met.

OLMSTED,[187] in 1825, more fully describes the great slate formation, which includes argillite, greenstone, porphyry, novaculite, petrosilex, hornstone, black steatite, syenite, etc. Between the great slate formation and the Blue ridge is a granitic district, various limestone beds, and a transition formation. The granitic district occupies the whole country, with subordinate exceptions, from the slate formation to the Blue ridge. The term granitic as here used embraces gneiss and mica-slate as well as granite. Among the subordinate beds non eare so numerous as greenstone. In Stokes and Surrey, in connection with the iron ores, are numerous isolated beds of limestone which lie in mica-slate rocks.

MITCHELL,[188] in 1829, states that of the primitive rocks of North Carolina, the more ancient lie farther west and the more recent in the midland counties. Those of the eastern division are highly crystalline in their structure, consisting of gneiss, slate, and schist, with some granite, while those of the western division are almost exclusively granite. The transition argillite is widespread, and in it occurs most of the gold mines.

MITCHELL,[189] in 1842, describes as primitive formations the granites, gneiss, mica-slate, chlorite-slate, hornblende-slate, and talcose-slate, quartz-rock, serpentine, and limestone. A vast body of granite traverses the state in a northeast and southwest direction, comprising a large part of Person, Caswell, Orange, Guilford, Randolph, Davidson, Rowan, Cabarrus, and Mecklenburg counties; also some of Lincoln, Iredell, Davie, Stokes, and Rockingham counties. Within this belt is no well defined gneiss, micaceous primitive slate, serpentine, or limestone. West of this formation are the most ancient primitive rocks, on the upper waters of the Dan, Yadkin, Catawba, and French Broad. Here are a great variety of granites. Gneiss and slate also occur. All of these are interstratified. Limestones are found at three points in Stokes county. In Anson and Richmond counties is a beautiful porphyritic granite. East of the red sandstone in the counties of Cumberland, Wake, Granville, Warren, Franklin, Nash, Johnston, Halifax, and Northampton, is another body of ancient primitive rock in which granite prevails.

EMMONS (E.),[190] in 1856, gives a systematic account of the crystalline rocks of North Carolina. Rocks of igneous origin are often massive, but also frequently are laminated, and laminated rocks are frequently called stratified, but this latter term should be restricted to the sedimentary rocks. The metamorphic rocks are excluded from the sedimentary classification because all rocks may become metamorphic, and a stratum metamorphic in one locality may not be metamorphic in another. The highest proof of the age of rocks is the order of superposition. When this method can be applied it is paramount, but paleontology may be used subject to proper principles. At the base of the Paleozoic, under the Silurian, is placed the Taconic.

The granitic formations are regarded as eruptive or pyrocrystalline. They form two continuous belts, which cross the state in a northeast and southwest direction. The eastern one is the Raleigh belt, and the western one the Salisbury and Greensboro belt. Granite is generally the underlying rock, but there are cases on record in which it is shown that it is an overlying one. At Warrenton, in Warren county, of the Raleigh belt, it is found to overlie gneiss, mica-slate, and hornblende, where it is considered to have been projected through fissures in these rocks. This eastern belt contains no metallic veins, nor is it cut by trap or other instrusive rocks. Its breadth is from 20 to 25 miles.

The Salisbury granite is frequently syenitic, that is, hornblende takes the place of mica. This belt is cut by numerous peculiar dike rocks in which, when they decompose, the hornblende trap appears in dark-green stripes, and many, when carefully examined, have assumed the structure of a sediment or a laminated rock, and which often appears like the dark-green slates of the Taconic system. This singular structure of an eruptive rock is interesting and important, as it proves that it may be produced in rocks which have been regarded as sediments, but which, in these cases, are the farthest removed from rocks of this description, and with which water has had nothing to do. The lamina are sometimes as thin as paper, and from their appearance can not be distinguished from the slates referred to. These dikes are bounded by walls of granite, and are frequently only from 6 to 10 inches wide. The mineral veins are generally found on the borders of the granite areas, usually within 1 or 2 miles of the slate. This western belt is 10 to 14 miles wide.

Among laminated pyrocrystalline rocks are placed gneiss, mica-schist, talcose slates, hornblende, and certain limestones. It is difficult to determine the line of demarkation between gneiss and granite, as frequently there are passage beds connecting one with the other. As to the pyrocrystalline limestones, they certainly occur among the gneiss and mica-slate and hornblende-rocks with laminæ parallel with them, but still they have many characters which belong only to the eruptive rocks.

Resting upon the laminated pyrocrystallines, with the granite as a substratum, are rocks of sedimentary origin which are supposed to be Azoic. Above these are other rocks which have been in the past regarded as Azoic but are now found to be fossiliferous. The older deep seated sediments are sometimes distinguished with difficulty from the true primary series, their lithological characters very often belonging to the same order. It might be doubted whether they were sediments at all were it not that they are associated with conformable pebbly beds, which is the only proof that these rocks are really sedimentary.

The Taconic rocks are divided into lower and upper parts. The lower series contains talcose slates with white and brown sandstones and quartz, with granular limestones and associated slates, and with these occur hornblende, which makes it difficult to determine where the primary rocks end and the Taconic begins, especially when the pebbly beds are absent. Vitrified quartz can not be regarded as always an igneous product, but rather as a deposit of silica from chemical solution. The materials composing the belts of detritus are apparently derived from the granites, as shown by the fact that the quartz and feldspar of these rocks are distinguishable in the brecciated conglomerates.

KERR, [191] in 1867, finds that the slates of western North Carolina have an average strike of N. 50° E., the dips being high to the southeast, for the most part about 65°. The greatest variations in strike and dip are in the central area, where the strata are contorted and folded to an unusual degree. This region extends from the Black mountains to the southeastern corner of Clay county. This central area is the axis of the state and is composed for the most part of granitic and gneisses rocks which are extremely metamorphosed. These rocks, as well as the slates and schists, belong to the most ancient of the Azoic series, and the Black mountains are the oldest part of this Azoic.

KERR,[192] in 1875, gives a systematic account of the geology of North Carolina. The Azoic rocks are divided into Huronian, Laurentian, and Igneous. With the Huronian are placed the siliceous and argillaceous slates and conglomerates, micaceous and hornblendic slates and schists, chlorites, quartzites and diorites, with cherty, jaspery and epidotic beds, and much specular iron ore. The Laurentian includes gneiss, granite, hornblende slates, etc., while the Igneous includes granite, syenite, porphyry, etc.

The Laurentian occurs in four areas. The Raleigh area is a belt 20 or 25 miles wide, running northeast from this place to the state line, and consisting of light colored and gray gneisses which occasionally pass into granite. These are cut by coarse syenite and diorite dikes. The second, the Salisbury granite area, is from 10 to 30 miles wide, and has an area of about 3,000 square miles. The prevalent rocks are syenite, dolerite, greenstone, amphibolite, granite, porphyry, and trachyte. In it there is no well defined gneiss, mica-slate, serpentine, or limestone. The large area of Mecklenburg syenite is regarded as the oldest rock of North Carolina, the bottom of the Laurentian. West of the Salisbury area is the largest connected area of Laurentian in the state, covering not less than 16,000 square miles. It closely resembles the Raleigh area, especially in the southeastern part, where it consists of a succession of schists, gneisses, and slates, for the most part thin bedded, and only occasionally showing granite-like masses and syenites which are generally in the forms of dikes. Belonging with this series are probably the interstratified crystalline limestones of Forsyth, Yadkin, and Stokes. The outcrops are generally limited to two or three rods in thickness, a few hundred yards in length, and seem to graduate into the neighboring gneisses. The fourth considerable area of Laurentian rocks, occupying an area of 3,000 or 4,000 square miles, is west of the Blue ridge, between this range and the Smoky mountains. This is probably a continuation of the preceding belt, being separated from it by a narrow belt of Huronian slates, and like it containing crystalline limestones.

The Huronian follows the Laurentian without a break of geological continuity. These rocks are found in five principal lines of outcrops. These are that east of the Raleigh Laurentian, that between the Raleigh and Salisbury granite, that west of the Salisbury granite or King's mountain belt, that of the Blue ridge mountains, and that of the great Smoky mountains, called the Cherokee slates. These belts are placed with the Huronian because they succeed the Laurentian, and because they differ from them in degree of metamorphism and lithological character, so that the change from one to the other is obvious along the whole line of contact. The slates included are often highly plumbaceous, sometimes containing as high as 50 per cent of graphite, and also contain beds of coarse granular limestone, in which is tremolite as well as magnetic iron in bedded veins sometimes 20 feet in thickness. Conglomerate belts are common. The second Huronian area is the largest, is from 20 to 40 miles wide, frequently contains quartzite, which often passes into conglomerate, and in it are most of the mineral veins. The western dips prevail, but in the western part of the tract the dip is east for several miles. This belt is bounded on both sides by the Laurentian, on which it lies unconformably and from it its materials were derived. This is the principal area of Emmons's Taconic. The western Huronian area by Safford and Bradley has been concluded to be Potsdam and sub-Potsdam. If this turns out to be Silurian it is probable that the Cherokee, Blue ridge, and King mountain belts are of the same age and therefore post-Huronian.

FURMAN,[193] in 1889, describes a section through King's mountain, running from 5 miles northwest, and another from the old gold mine to the granite. The rocks have a high inclination and consist of interstratified quartzite, limestone, mica-slate, etc., cut by dikes of trap and greisen veins.

LITERATURE OF TENNESSEE.

TROOST,[194] in 1840, describes the Primordial rocks of Tennessee as occurring in detached areas along the eastern side of the state. These are granitic and are associated with greywackes, which are fossiliferous. The state line is approximately the dividing line between the crystallines and the fossiliferous rocks.

OWEN,[195] in 1842, states that the metamorphic rocks in the Unaka mountains dip at a high angle toward the granitic rocks. These relations are supposed to be due to dislocations.

CURREY,[196] in 1857, states that the Great Smoky mountains are of granite, gneiss, mica-slate, talcose slate and quartz rock. The sandstones, shales, and slates on the western descent of the mountains are regarded as primitive or metamorphic. They are in an inclined position, dipping inwardly toward the center of the mountain, the Primordial rocks appearing to overlie them. No anticlinal or synclinal axes are found, and the tilting is explained by faults.

SAFFORD,[197] in 1869, places the lowest formations of Tennessee as Potsdam and metamorphic. The Ocoee group is at the base of the Potsdam and is, so far as known, Eozoic. The metamorphic formations are altered rocks, Azoic or Eozoic in part, mountain-making, and many thousand feet thick. They include the talcose slate, in part, of Beech mountain and Slate face, in Johnson county; gneissoid rocks of Stone mountain; the syenitic gneiss of Roan mountain; the gneiss and mica-schist of the Great Bald; the talcose slates and hornblendic beds of Ducktown.

The Ocoee or basal division of the Potsdam is semimetamorphic, Eozoic, mountain-making, and has a thickness of 10,000 feet. Equivalent with this are the slates and conglomerates of Monroe county, the Little Tennessee river, the west fork of Little Pigeon, of Sevier county, of the French Broad in Cocke county, of Big Butt, and of Laurel gap of Iron mountain. The metamorphic rocks occur in stratified beds, are mostly of the variety called gneiss or stratified granite, and all are metamorphic. The line of separation between the metamorphic rocks and those to the west is sometimes well defined, but often poorly, the rocks gradually losing their crystalline characters and running insensibly into the adjacent conglomerates and slates. The general line of separation conforms to the Appalachian ridges. The metamorphic beds and the other groups all appear to follow the same law of dip and strike. The dip is in the main at a high angle to the southeast. The author has not been able to satisfy himself as to want of conformableness in the beds, although in Johnson county the metamorphic gneiss comes abruptly against the limestone; and other similar cases occur, but these unconformable junctions are naturally referable to local fractures and displacements, and this unconformableness is local and not the rule. There is no reason for believing that the metamorphosed beds include formations of any more recent date than the Ocoee conglomerates and slates, and a portion of them are certainly referable to this group. The remainder, although conformable, may be and most likely are older. The transitions from the slates and conglomerates to the gneiss and mica-schists are well seen at Ducktown and at the Ocoee. There is no sufficient reason for referring any of these rocks to the Huronian or Laurentian.

BRADLEY,[198] in 1875, describes sections in east Tennessee from Athens to Murphy, and from Knoxville to Murphy. The rocks include semimetamorphosed slates, like those of Ocoee, quartzites, crystalline limestones, and gneisses, all being regarded as probably of Silurian age, with the possible exception of the massive granite at Marietta, Cobb county, Georgia. The Silurian rocks thus include the Taconic and pyroclastic rocks of Emmons.

ELLIOTT,[199] in 1883, states that the mica-schist and gneiss at Jasper dips beneath the marble and is therefore metamorphosed Knox sandstone. The porphyritic gneiss of the West Atlantic railway is identical with that at Talking rock, and is a metamorphosed form of the Ocoee sandstone.

LITERATURE OF SOUTH CAROLINA.

RUFFIN,[200] in 1843, describes as primitive the limestones which enter South Carolina at York, west of Kings mountain, and run to Spartanburg. Embracing nearly all the country above the lower falls of the river is a granitic region.

TUOMEY,[201] in 1848, gives a report on the geology of South Carolina.

The unstratified or igneous rocks underlie the stratified rocks, or are pushed up through them, and include granitic and basaltic rocks, being generally found in the form of dikes. Discordances between slaty cleavage and bedding are found. The crystalline structure of the Primary stratified rocks is supposed to be due to heat which comes from the contact of the underlying intensely heated granite. These formations have no invariable order of superposition, although they generally overlie each other in the following manner: Clay slate, talcose slate, mica-slate, hornblende-slate, gneiss; and associated with these are also beds of limestone, quartz, chlorite, slate, and soapstone.

A very massive gneiss, known as "table rock," on the west side of Saluda, rests unconformably upon the slates, and is regarded as evidence of the prior deposition of the slates, and also as evidence of a time break between the two. The mica-slates pass by insensible gradations into the talcose slates. The lime rock is interlaminated both with gneiss and with mica-slates, the latter occurring at Kings mountain. The quartz rocks are regarded as residual material left by the disappearance of the micaceous and talcose portion of the rock. It sometimes passes into a conglomerate-like phase, but this is a step on the way toward complete crystallization. The quartz rock at times passes into itacolumite. The magnetic and hematitic ores are associated mostly with the slates and limestones, and appear as beds interlaminated with and grading into them.

LIEBER,[202] in 1858, describes the rocks of Chester and York districts. They are divided into clay-slate, which includes limestone, itacolumite, and specular schist; and hornblende-slate, which includes talcose slate and mica-slate. The first class, which may possibly be Paleozoic, appears wherever the Tertiary deposits have been removed by erosion. It has a dip unconformable to the talcose slate. Itacolumite is described, and below it at times are found specular schist and above it limestone. The igneous rocks are divided into trachytic, trappean, and granitic rocks. The trachytic rocks include eurite, quartz-porphyry, coarse trachyte, domite, and phonolith; the trappean rocks include diorite, diorite-slate, soapstone (?), talcose trap (?), melaphyre, and aphanitic porphyry; the granites include coarse grained granite, syenite, and other granite and gneiss.

LIEBER,[203] in 1858, divides the rocks of Union and Spartanburg into a Super-itacolumite, Itacolumite, and Sub-itacolumite groups. The first includes limestone. The second includes itacolumite with talcose slate, limestone, specular schists, and itacolumite conglomerate. The third includes clay-slate, talcose-slate, mica-slate, and gneiss. There is no definite proof that the gneiss occupying the lowest position is of sedimentary origin. Indeed there is greater probability that it is, strictly speaking, a granite having a parallel distribution of the scales of mica. It passes into the ordinary granite, with no distinct boundary between the two. The mica-slate overlying the gneiss is of insignificant thickness, as shown by the fact that mining shafts and streams frequently cut through it to the gneiss. The dip of the slate is almost always constant to the southeast. It is the predominant position in the country for the metalliferous veins. The itacolumite is described in detail. The conglomerate-like itacolumites, mentioned by Tuomey, are regarded as real conglomerates, with a micaceous and arenaceous cement. The pebbles are obscured and elongated, the longest diameters being parallel to the bedding, and they also partake of the schistose structure of the matrix in which they are contained. Every stage in the passage from the fine grained rock to the conglomerate with pebbles is seen, and there is no question that the itacolumite is a sandstone. The eruptive rocks include granites, eurite, and trappean rocks, among which are schistose aphanite, aphanitic porphyry, minette, diorite, diorite-slate, and saponite. That the schistose rocks here included are really eruptive is shown by the manner in which they intrude the granitic rocks.

LIEBER,[204] in 1859, gives a general account of the rocks of South Carolina. The peculiar structure of the schistose aphanites is regarded as due to weathering. In the Greenville and Pickens districts the succession includes gneisses, limestones, and mica-schists, the ruling dips being southeasterly. Toumey's representation of these rocks as 60 to 70 miles thick is believed on theoretical grounds to be incorrect. The ruling southeasterly dip of the slates are probably due to faults which have repeated the stratified rocks many times. It is concluded that the isolated bodies of stratified rocks overlying the gneiss are actually islands occupying, with much regularity, the apical lines of certain parallel ridges. It can not be asserted that any of the mica-slate beds exceed 100 feet in thickness and the horizontal slates 25. The talcose slate below the itacolumite is frequently highly graphitic. Above the talcose slate is limestone, and above this the itacolumite, the outlines of the latter being extremely tortuous. The dike rocks are aphanite, porphyritic hornblende rock, eurite, and garnet. A detailed account of itacolumite is given.

LIEBER,[205] in 1859, definitely states that itacolumite is regarded as occupying a constant position, and is taken as a starting point upon which to determine the chronology of the Azoic rocks of the southern Alleghanies.

LITERATURE OF GEORGIA.

PECK,[206] in 1833, divides the mountain-region rocks into Primitive and Transition, the first being on the west, and the boundary between the two being the Smoky mountains.

COTTING,[207] in 1836, divides the primary formation into granite, syenite, porphyritic granite, gneiss, mica-slate, talcose slate, granular limestone or marble, serpentine, greenstone, epidotic gneiss, quartz rock, hornblende, and clay-slates. The granite passes by imperceptible gradations into the gneiss, beds of the two sometimes alternating, and the latter also passing into the stratified mica-slates. Gneiss also passes into the stratified mica-slate, and the mica-slate into talcose slate. The graywacke is the beginning of the transition.

LITTLE,[208] in 1875, mentions crystalline rock, presumably primary, at various points.

CAMPBELL (J. L.) and RUFFNER,[209] in 1883, divide the Archean upon chemical, lithological, and structural grounds into Laurentian and Huronian. In the metamorphosed rocks the prevailing dips are toward the southeast. It is believed that while they were somewhat plastic they were folded and overturned, although sometimes left in a vertical position, and not infrequently found in a nearly horizontal position, or sometimes resting in arches and depressions. In the Choccolocco valley the railroad passes abruptly to the Lower Silurian rocks. This relation between the Silurian and Archean is attributed to a fault, with a downthrow of the former.

LITERATURE OF ALABAMA.

TUOMEY,[210] in 1850, places the granites, gneisses, and associated crystalline rocks as primary and metamorphic. The slates sometimes carry plumbago, and true granite is found only at Talladega.

TUOMEY,[211] in 1858, finds in various sections granite, syenitic gneiss, ordinary gneiss, hornblende-slate, mica-slate, talcose slate, and soapstone. In certain localities are found limestones, and also occasionally interstratified quartz-rocks occur. Granite is found about Rockford in large masses.

SMITH,[212] in 1875, states that the counties of Chilton, Talladega, Calhoun, Cleburne, Lee, Tallapoosa, and Elmore lie partly, and Coosa, Clay, Randolph, and Chambers wholly, within the Archean region of the state. On account of the absence of fossils, it is difficult to determine the relative ages of the subdivisions of the crystalline rocks. Lithologically they are classified into Laurentian, Huronian, and White mountain series, following Hunt's characterization of these terms. The rocks here included are granite, gneiss, mica-schist, mica-slate, hydromica-slate, clay-slate or argillite, syenite, syenitic gneiss, hornblende-schist, diorite, norite, talcose slate, soapstone or steatite, chlorite-schist, quartzite, siliceous slate, itacolumite, itabarite, jasper, crystalline limestone, dolomite, and igneous rocks. Crystalline limestone occurs in Chilton county. It is succeeded in apparent conformity by semicrystallines 15,000 to 20,000 feet in thickness.

SCHMITZ,[213] in 1884, describes a metamorphic region in Alabama as covering the whole or parts of counties Chilton, Coosa, Talladega, Calhoun, Cleburne, Lee, Tallapoosa, Elmore, Clay, Randolph, and Chambers, with about 5,000 square miles of area. The rocks of this region are partly metamorphosed Lower Silurian rocks (Calciferous, Potsdam, and Acadian), partly Upper Azoic rocks (Huronian), and perhaps partly Lower Azoic rocks (Laurentian).

Going at a right angle with the strike, from northwest to southeast, is found the following zones, which, however, cannot be sharply separated. (1) *Silurian.*—Crystalline limestones, conglomerates, heavy quartzites, and slates (often gold-bearing), semi-metamorphosed. (2) *Huronian.*—Mica-slates and schists (with garnets), limestones, coarse grained granites, diorites, quartzites, and clay-slates (sometimes gold-bearing); the mica-schists often alternating with gneisses; associated with graphite and graphitic slates, itacolumite, specular ore, brown hematite, etc. (3) *Huronian or Upper Laurentian.*—Gneisses (micaceous and hornblendic), granite, diorite, mica-schists, quartzites, slates (sometimes gold-bearing), associated with chloritic schists and steatites, mica with tourmaline crystals, etc. Some of the granites have the characteristics of eruptive rocks.

GENERAL LITERATURE.

BRITTON,[214] in 1886, describes at Natural bridge the contact between sandstones which appear to be under the Potsdam and over the Archean. The two are widely unconformable; the sandstone dips 45° to the northwest and strikes N. 40° E., while the Archean dips 65° E. and strikes N. 5° E. The Archean rocks consist of quartz-bearing syenite and granulite, fragments of which are found in the overlying series.

On the Doe river, in eastern Tennessee, the Archean and basal Silurian quartzite are in contact. The Archean is a pegmatite, with no bedding or lamination. Five hundred feet east of the contact it is a much contorted hornblendic gneiss and syenite. These rocks are intersected by a trap dike. The quartzite is thickly bedded and contains many pebbles of quartz and much feldspar, so as to make the rock in places an arkose.

On the French Broad river are found quartzites like those of the Doe river, which are succeeded by basal crystalline rocks, and near Mare shall station begins a stratified micaceous schistose series. The character of the transition between this and the basal Archean rocks was not apparent. About Asheville are well bedded gneisses and mica-schists which bear the same relation to the heavily bedded basal Archean as do the Westchester county, New York, and Philadelphia gneisses to the basal rocks to the westward. These rocks extend to the top of mount Mitchell.

SUMMARY OF RESULTS.

The state of knowledge of the crystalline rocks of the southern Appalachians is in a still less advanced condition than that of the middle and northern Appalachians.

It is reasonably certain that from northern Virginia to Alabama there are large areas which are pre-Cambrian, including much of the granite and granitoid gneiss region. Not only this, but, if lithological characters are sufficient evidence, parts are Archean; that is, belong with the fundamental rocks of Canada and the West; for areas are found which consist of an intricate complex of foliated and contorted granite and gneiss cut by or containing masses of basic eruptives of various kinds. In their intensely implicated structure and lack of thoroughly massive characters they give evidence of vast antiquity.

How far the rocks which have been denominated Huronian belong with the pre-Cambrian there is no means even of guessing. It is very certain that large parts of the rocks called Taconic and Huronian are Cambrian, Silurian, or later. When the Cambrian and Silurian have been definitely outlined, whether any of the unmistakable clastics will remain to be correlated with the Huronian, or, more accurately, to be placed in the Algonkian, is uncertain.

The disturbances in the southern Appalachians are of a different type, and, upon the whole, have been less intense than in the central and northern regions, as a consequence of which it will be easier to reach definite results here than it has been farther north.

The only really systematic work which has been done is that in Virginia by Rogers; that of Emmons in North Carolina; that of Safford in Tennessee, whose work barely reaches the pre-Cambrian rocks; and that of Lieber. The last in his earlier reports carefully refrained from generalizations based upon insufficient evidence, but patiently mapped the rocks lithologically in several counties, and thus gives serviceable information unmingled with theories of no value.

In the south, as in New England, occur formations which by contained belts of conglomerates are definitely proved to be of clastic origin, and these gradually pass into unmistakable crystalline schists. These transitions were clearly described and their meaning definitely pointed out by Emmons and Lieber respectively in 1856 and 1858.

More remarkable than this is the discovery of Emmons and Lieber that hornblende-schists and other schists are metamorphosed eruptives. These rocks are said sometimes to be as thinly laminated as paper, and are compared with slates; but their occurrence in dikes within the granites, and their gradations into the ordinary massive forms, demonstrate them to be later igneous rocks. These conclusions were not based upon petrographical work, but upon careful field study. The microscope in recent years has shown accurately the method of change; but that the change does occur from a massive eruptive rock to a thoroughly schistose one was proved beyond doubt by these men before 1860.

Emmons and Lieber further appreciated that the granite-gneisses in their lithological affinities as well as by actual transitions belong with igneous granitic rocks rather than with the sedimentaries. Emmons also reached the same conclusion for the South which Emerson demonstrated many years later for the New England states, that there are two granites, one of which is more ancient than the clastics and the other intrusives within these. According to Emmons the ancient form is predominant, but occasionally granite has been projected through fissures like other intrusive rocks.

The great discovery that regularly laminated rocks are produced by the metamorphism of eruptive rocks as well as from sedimentary rocks naturally carried the discoverer too far in the application of the principle. Emmons included in the metamorphic igneous rocks many mica-schists, talcose slates, and limestones for which he gave no evidence whatever. Lieber's discrimination between the metamorphic-igneous and metamorphic-sedimentary rocks was much more satisfactory. But Emmons's general statements as to the small value of lamination alone in rocks as an evidence of origin and the method of stratigraphical work in the crystalline rocks can hardly be improved upon at the present day. Says this writer: Rocks of igneous origin are often massive, but also are frequently laminated, and laminated rocks are frequently called stratified, but this latter term should be restricted to the sedimentary rocks. The metamorphic rocks are excluded from the sedimentary classification because all rocks may become metamorphic, and a stratum metamorphic in one locality may not be metamorphic in another. The highest proof of the age of rocks is the order of superposition. When this method can be applied it is paramount, but paleontology may be used subject to proper principles.

The Primitive rocks from Emmons's point of view are all igneous; with aqueous rocks begins the Azoic, the oldest sedimentaries, and above the Azoic are rocks which in the past have been regarded as Azoic, but are found to be fossiliferous; that is, they constitute the Taconic system. We have here a definite theory as to the order of development of the earth, the primitive rocks being wholly pyrocrystalline, the Azoic stratified rocks being earlier than the dawn of life, and the Taconic rocks being the fossiliferous rocks earlier than the Potsdam.

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CHAPTER VIII.

GENERAL SUCCESSIONS AND DISCUSSIONS OF PRINCIPLES.

SECTION I. LITERATURE.

MACLURE,[1] in 1809, places in the primitive rocks granite, gneiss, mica-slate, clay-slate, primitive limestone, primitive trap, serpentine, porphyry, syenite, topaz rock, quartz rock, primitive flinty slate, primitive gypsum, white stone; and in the Transition, transition limestone, transition trap, graywacke, transition flinty-slate, transition gypsum. The rocks of the Primitive prevail to the east of the Hudson river. Throughout the greater part of the eastern and northern states the sea washes the primitive rock, but to the southwestward the Primitive runs in a broad belt as far as Alabama, and between it and the ocean is a wide belt of alluvial rocks. The Transition rocks occur in one main belt, running in a northeast and southwest direction from New York to Alabama, and in several minor belts.

EATON,[2] in 1832, places as Primitive rocks granite, mica-slate, hornblende rock, talcose rock, granular quartz, granular lime rock. These primitive rocks are all contemporaneous, excepting the granular quartz and lime rocks, since they alternate continually. These rocks are destitute of organized remains. Numerous localities are given for each class.

EMMONS, (E.),[3] in 1855, divides rocks into Pyrocrystalline, Pyroplastic, and Hydroplastic.

The Pyrocrystalline comprises massive rocks, including granite, syenite, hypersthene, pyrocrystalline limestone, serpentine, rensselaerite, octahedral iron ore, and laminated rocks, including gneiss, mica-slate, hornblende, talcose-slate, etc., laminated limestone, laminated serpentine. The Pyroplastic rocks comprise Subaerial, including lavas, tufa, or volcanic products, and Submarine, including greenstone, porphyry, basalt, trap. The Hydroplastic rocks comprise Paleozoic, Mesozoic, and Cenozoic. The Paleozoic is divided from the base upward into Taconic, Silurian, Devonian, Carboniferous, and Permian. Metamorphic or Azoic rocks are not recognized as classes, as they may occur in all series from the earliest to the latest sediments. That gneiss, mica-slate, hornblende, and talcose slate, etc., are metamorphic altered sediments there is no evidence. Azoic is objectionable because it presupposes that our observations have made certain that which must ever remain doubtful.

The Pyrocrystalline rocks are due to the consolidation of the earth's crust. These rocks increase in thickness by additions below. On the contractions of these rocks fissures are formed, through which flow fluid material which are hydroplastic and later. The age of rocks may be deduced from the perfection of their crystalline state. The pre-eminently crystalline granites are the product arising from the first cooling of the first crust. Granite may or may not be connected with the oldest masses of the globe. The granites of the United States are of two classes; one more ancient than the Taconic rocks, and others, which are later eruptions, certainly as new as the Carboniferous. In New England the ancient granites are widespread, but there are also found granitic areas which have been erupted from fissures and which have overflowed wide areas and whose structure is more or less sheeted. It is impossible to draw lines of distinction between the two kinds of granite, except when the earlier granite is traversed by the later. The lamination of the laminated Pyrocrystalline rocks is probably due to crystallization. Gneiss, mica-slate, hornblende, and talcose slate are so blended that it is difficult or impossible to define their boundaries, and they are all regarded as contemporaneous formations.

The oldest Hydroplastic rocks constitute the Taconic system, which has a clear and well defined base, rarely obscured by passages into the primary schists or the Pyroplastic syenites or granites. This system is limited above by the Silurian system, at the base of which is the Potsdam sandstone. The thickness of this system is from 25,000 to 30,000 feet. Sediments of all systems must necessarily consist of the same materials. Sandstones, limestones, slates, conglomerates, and breccias must make up the matter which composes them; but a comparison of the lower members of the Taconic and the Silurian show a decided difference in mineral constitution. The first partakes of the primary character of the granite, gneiss, mica, and talcose slates of the Pyrocrystalline rocks, from the last two of which it is often difficult to distinguish them, while the materials of the Silurian are derived from the Taconic rocks. The Taconic system, from the base upward, comprises (1) conglomerates and breccias; (2) limestones; (3) slate of enormous thickness; (4) dark-colored Taconic slates; (5) sparry limestones. The absence of fossils in the Taconic rocks is thought to be due to the probable absence of animals and plants at the time the Berkshire limestone and earlier Taconic rocks were deposited. In the Upper Taconic rocks are found remains of both plants and animals. The rocks of the Taconic system form a belt on both sides of the Blue ridge. On the west it is continuous from Canada East to Georgia. On the east it is wider in certain places than on the west side, but its continuity is broken. The Taconic system rests then on the following points: The formations of the series are physically unlike the Lower Silurian; it supports the Lower Silurian unconformably at numerous places; it is a system in which life existed, and the remains of organisms are left which are unlike those of the Lower Silurian; it carries back many stages farther the time when life appeared, and represents a period vastly longer than the Silurian, although it may occupy a less superficial area.

LOGAN and HUNT,[4] in 1855, gave a geological sketch of Canada. The ancient rocks are divided into the Laurentian system and the Cambrian and Huronian system.

The rocks of the Laurentian system are almost without exception old sedimentary beds that have become highly crystalline; they have been greatly disturbed, and form mountain ranges running about northeast and southwest, and sometimes rising to heights of 800 or 1,000 meters, and even beyond. The rocks of this formation are the oldest known on the American continent, and probably correspond to the oldest gneisses of Finland and Scandinavia, and to similar rocks in the north of Scotland. The rocks of the Laurentain formation are in large part crystalline schists, mostly gneissoid or hornblendic. Associated with these schists are seen heavy stratified masses of a crystalline rock, which is almost entirely composed of feldspar with a base of lime and soda. With these schists and these feldspars are found strata of quartzite, associated with crystalline limestones which have a rather important place in this formation. The limestones form beds from 1 meter to more than 100 meters thick, and often present a succession of thin beds, intercalated in beds of gneiss or quartzite. The quartzites sometimes present themselves under the form of conglomerates, and in certain cases have a paste of dolomite. Beds of dolomite or of more or less magnesian limestone are often intercalated with pure limestones. These schists, feldspars, quartzites, and limestones, such as we have described them, constitute the stratified part of the Laurentian system; but there are, furthermore, intrusive granites, syenites, and diorites which form quite important masses; the granites are sometimes albitic and often contain tourmaline, mica in large flakes, sphene, and sulphate of molybdenum. Associated with the limestones are important beds of hematite and limonite. Graphite is very frequently disseminated in little flakes in the crystalline limestones, and forms also veins having sometimes a considerable thickness. Two of these are found near Grenville, on the Ottawa. The graphite exists in three detached bands, each having a thickness of about 12 centimeters.

In the Cambrian and Huronian system are found the rocks on the north shores of lakes Huron and Superior where are present a series of schists, sandstones, limestones, and conglomerates, interspersed with heavy layers of diorite, and resting unconformably on the Laurentian system. As these rocks are lower than the Silurian terrane, and as they have thus far not yielded a single fossil, they may well be referred to the Cambrian system (the Lower Cambrian of Sedgwick). The schists of this system, on lake Superior, are bluish, and inclose layers of horn flint, having calcareous bands, and whose cracks are often filled with anthracite. These rocks are covered with a considerable thickness of trap, on which are superposed heavy beds of white and red sandstone, which sometimes pass into a state of conglomerate, inclosing globes of quartz and jasper. Beds of a reddish argillaceous limestone are found interspersed with these sandstones, which are cut through and covered by a second formation of diorite of great thickness, offering a columnar structure. This formation, which has a total thickness of nearly 4,000 meters, is traversed by a great number of trap dikes. In the corresponding formation of the north shore of lake Huron are found sandstones having a more vitreous aspect, and conglomerates more abundant than on lake Superior, associated, however, with schists and schistose conglomerates, resembling those which we have just described, the whole presenting great masses intercalated with diorite. A layer of limestone having a thickness of 16 meters forms part of this series. After the eruption of the interstratified diorites have appeared two systems of dikes of diorite, and a third of granite, of an epoch intermediate between the two latter. The formation of the metalliferous veins belongs to an epoch still more recent.

This Huronian formation is observed over a distance of nearly 150 leagues on lakes Huron and Superior.

DANA,[5] in 1863, gives an account of the Azoic age. This age is defined as the age in the earth's history preceding the appearance of animal life. Among the Azoic rocks are included all the rocks that are older than the Potsdam sandstone of New York, between which and the Azoic general unconformable relations obtain. The Azoic rocks constitute the only universal formation. They cover the whole globe, and were the floor of the oceans and the rocks of all emerged land when animal life was first created. But subsequent operations over the sphere have buried the larger part of the ancient surface, and to a great extent worn away and worked up anew its material, so that the area of the old floor now exposed to view is small. The Azoic regions include Canada north of the St. Lawrence, reaching northeast from lakes Huron and Superior to Labrador, and continuing northwest to the Arctic ocean, the Adirondacks of northern New York, a similar area south of lake Superior, west of the Mississippi a small area in Missouri, the Black hills in Dakota, the Laramie range in Nebraska, part of the Ozark mountains in Arkansas; and in northern New Jersey Azoic gneiss, limestone, and other crystalline rocks containing beds of iron ore. The rocks of the Azoic are mostly of the metamorphic series, related to granite, gneiss, syenite, and the like, but they embrace only the most ancient of these rocks. The Azoic rocks are nearly all crystalline, a few sandstones, slates, and conglomerates being the only exceptions. They are remarkable for the small amount of silica they contain, as shown in the diorites and labradorite rocks. Prevalence of iron ore is another characteristic, and none of the minerals are simple silicates of aluminum. While the Azoic rocks are crystalline they follow one another in variations and alternations like sedimentary beds of later date. Granite or gneiss may lie between layers of slate or schist, and quartz-rock may have any place in the series. The Azoic rocks are the results of alteration of sedimentary strata, as is shown by the fact that schists graduate into true slates, and quartzites into sandstones, and conglomerates and gneiss into gneissoid granite, and thence to true granite and syenite. As evidence of life in the Azoic age are cited the formations of limestone strata, the occurrence of graphite in the limestone, the occurrence of anthracite in small pieces in the iron-bearing rocks of Arendal, Norway. Crystalline rocks have been formed in various ages, those in New England, for instance, long after the Azoic; hence it is possible that some of the Azoic rocks have undergone a second or third alteration subsequent to the original one in the Azoic age.

LOGAN,[6] in 1864, gives a general account of the ancient rocks of Canada. He states that the rocks composing the Laurentide mountains in Canada and the Adirondacks in the State of New York are the oldest in North America. They have been shown to be a great series of strata which, though profoundly altered, consist chiefly of quartzose, aluminous and argillaceous rocks, like the sedimentary deposits of less ancient times. This great mass of crystalline rocks is divided into two groups and it appears that the Upper (Labradorian) rests unconformably upon the Lower (Laurentian) series. The united thickness of these two groups in Canada can not be less than 30,000 feet, and probably much exceeds it. A third Canadian group, the Huronian, has been shown by Murray to be about 18,000 feet thick, and to consist chiefly of quartzites, slate conglomerates, diorites, and limestones. The horizontal strata, which form the base of the Lower Silurian in western Canada, rest upon the upturned edges of the Huronian series, which, in its turn, unconformably overlies the Lower Laurentian. The Huronian is believed to be more recent than the Upper Laurentian series, although the two formations have never yet been seen in contact.

The united thickness of these three great series may possibly far surpass that of all the succeeding rocks, from the base of the Paleozoic series to the present time. We are thus carried back to a period so remote that the appearance of the so-called Primordial fauna may be considered a comparatively modern event. We, however, find that, even during the Laurentian period, the same chemical and mechanical processes which have ever since been at work disintegrating and reconstructing the earth's crust were in operation as now. In the conglomerates of the Huronian series there are inclosed bowlders derived from the Laurentian, which seem to show that the parent rock was altered to its present crystalline condition before the deposition of the newer formation, while interstratified with the Laurentian limestones there are beds of conglomerate, the pebbles of which are themselves rolled fragments of still older laminated sand-rock, and the formation of these beds leads us still further into the past.

In both the Upper and Lower Laurentian series there are several zones of limestone, each of sufficient volume to constitute an independent formation. Of these calcareous masses it has been ascertained that three, at least, belong to the Lower Laurentian. But as we do not as yet know with certainty either the base or the summit of this series, these three may be conformably followed by many more. Although the Lower and Upper Laurentian rocks spread over more than 200,000 square miles in Canada, only about 1,500 square miles have yet been fully and connectedly examined in any one district, and it is still impossible to say whether the numerous exposures of Laurentian limestone met with in other parts of the province are equivalent to any of the three zones, or whether they overlie or underlie them all. As evidence of life in the Laurentian limestone, are graphite, great beds of iron ore, and the presence of recognizable organic forms resembling Stromatopora.

HUNT,[7] in 1867, again characterizes the Laurentian and Huronian rocks.

Under the name of Laurentian terrain, the Geologic Commission of Canada at first comprehended two distinct series of rocks, one resting unconformably on the other, which it afterward distinguished as Lower Laurentian and Upper Laurentian or Labradorian. The first of these two series corresponds to the primitive gneiss (Urgneiss) of Scandinavia and of the west coast of Scotland. After carefully studying this ancient gneissic system of North America, the Geologic Commission of Canada gave it the name of Laurentian system, taken from the Laurentide mountains. As early as 1855 the conviction was expressed that it is identical with the primitive gneiss of European countries, an identity which afterwards was established by Murchison for Scotland. More recently, Gumbel and von Hochstetter, after an exhaustive study of the old gneiss of Bavaria and Bohemia, enunciated its identity with the Laurentian terrain of Canada, a conclusion which the former of these scientists, moreover, supported by a comparison of the organic remains of the two regions.

The Lower Laurentian is composed of crystalline schists, a large part of which are gneiss, at times granitoid, with quartzites often conglomerates, amphibolic and micaceous schists, pyroxenic rocks, ophiolites and limestones sometimes magnesian. These limestones, ordinarily very crystalline, are found united in three great distinct formations, each having a mean volume of 1,000 to 1,500 feet, and separated by still more considerable masses of gneiss and quartzite. The measured thickness of this series on the Ottawa exceeds 20,000 feet, which is probably far from representing the total volume of the system, which, in Bavaria, is supposed to attain not less than 90,000 feet. In Hastings county, to the north of lake Ontario, there is found resting conformably on Laurentian gneiss a series of at least 20,000 feet of crystalline schists, comprising a great thickness of impure limestones and calcareous schists, and terminating in a heavy mass of dioritic rocks. It seems established that this series, which differs sensibly by the succession of the beds and by its lithological characters from that described above, belongs also to the Lower Laurentian, of which it would form a higher member; and thus the known thickness of this system in Canada would rise to at least 40,000 feet.

The Upper Laurentian or Labradorian terrain is found resting, in the form of patches, unconformably on the Lower Laurentian, both on the Hastings series and on the Ottawa series, where it often occupies a width of several miles. It is found at intervals from lake Huron to the coasts of Labrador, and is everywhere recognized by its lithological characters. This Labradorian terrain inclosed gneiss with orthose, with quartzites and crystalline limestones, but its predominating element is an anorthosite, or rock composed essentially of a feldspar of the sixth system, with a mixture of pyroxene, often assuming the form of hypersthene. This anorthosite is sometimes gneissoid, and even fine grained; but it assumes rather often a granitoid structure, with great cleavable forms in the feldspar. The latter is ordinarily andesite or labradorite, of which it sometimes presents fine opalescent varieties resembling those brought from Labrador. The thickness attained by the Upper Laurentian terrain is not certain, but it probably exceeds 10,000 feet. The Lower Laurentian presents nothing that resembles the anorthosites of the Upper Laurentian, which form the highest summits of the Adirondacks, and seems to be identical with the hypersthenites of the Hebrides of Scotland, described by MacCulloch. The limestones of the Lower Laurentian of Canada inclose organic remains, principally belonging to an organism studied and described by Dawson, who has given it the name of *Eozoon canadense.*

The Lower Laurentian terrain is affected by many undulations that have upraised the beds, rendering them at times almost vertical. The mean direction of these foldings is about north and south, but secondary undulations from east to west appear in the region north of the Ottawa, the only one where thus far it has been possible to study the intimate structure of this terrain. The beds of the Upper Laurentian also are upraised at high angles, but the structure of this terrain, which has evidently undergone part of the movements that affected the lower, has not yet been studied. The lower terrain is traversed in several localities by igneous rocks, and there have been ascertained at least four epochs of effusion, three of which are anterior to the Silurian period. These eruptive rocks are syenites, quartziferous porphyries, and dolerites.

Under the name of Huronian terrain is designated a series of rocks, more or less altered, resting unconformably on the Lower Laurentian terrain, and probably also on the Labradorian terrain. This series is composed of quartzites, of more or less chloritic or epidotic schists, sometimes with impure serpentines, and with diorites, which constitute very important masses in the series. The quartzites, as well as the chloritic schists, often inclose rolled pebbles, many of which are derived from the Laurentian gneiss. This Huronian terrain comprises, moreover, a band of about 300 feet of granular limestone, which is impure and often very siliceous. The Huronian terrain on lake Huron has a thickness of about 18,000 feet. It is also found on the Ottawa, and from there it extends to the west of the Mississippi, though covered in large part by Paleozoic terrains. It does not seem to exist in the eastern region of Canada, but recent observations made on the island of Newfoundland and in Nova Scotia have demonstrated there the existence of rocks that have been referred to this old terrain, which for the rest seems to correspond to the primitive schists (Urschiefer) of Scandinavia. No fossils have yet been found in this terrain. Considerable masses of schistose hematitic iron ore are inclosed in this Huronian terrain on the northeast shore of lake Superior, and in still greater abundance at the south, where the famous iron mines of Marquette are found. This terrain is more or less affected by undulations anterior to the Silurian epoch.

DANA,[8] in 1872, states that lithological evidence for the chronological arrangement of the crystalline rocks of New England means nothing until tested by thorough stratigraphical investigation. This evidence means something, or probably so, with respect to Laurentian rocks, but it did not until the age of the rocks, in their relations to others, was first stratigraphically ascertained. It may turn out to be worth something as regards later rocks when the facts have been carefully tested by stratigraphy. A *fossil* is proved, by careful observation, to be restricted to the rocks of a certain period before it is used—and then cautiously—for identifying equivalent beds. Has any one *proved* by careful observation that crystals of staurolite, kyanite, or andalusite, are restricted to rocks of a certain geological period?

DANA,[9] in 1876, gives an account of Archean time. The Archean time includes an Azoic and an Eozoic era, though not yet distinguished in the rock. The Azoic age is the era in which the physical conditions were incompatible with the existence of life. But this era, so far as now known, is without recognizable records; for no rocks have yet been shown to be earlier in date than those which are now supposed to have been formed since the first life began to exist. The Archean rocks of North America are mostly crystalline or metamorphic rocks, and their beds stand at all angles, owing to the uplifting and flexing which they have undergone. Where the Silurian strata overlie them, the two are *unconformable*, the latter being often spread out in horizontal beds over the upturned edges of the Archean rocks.

The areas of the Archean include those which have always remained uncovered; those which have been covered by later strata, but from which the superimposed beds have been removed by erosion, and those like the last, which in the course of mountain-making have been pushed upward among the displaced strata. The principal areas are the great northern, to which belong the lake Superior region and properly the Adirondack area; the area along the Appalachian line, including the Highlands of New York and New Jersey, and the Blue ridge of Pennsylvania and Virginia; the Atlantic coast range, including areas in Newfoundland, Nova Scotia, and eastern New England; isolated areas of the Mississippi basin, in Missouri, Arkansas, Texas, and the Black hills; the Rocky mountains series, embracing Wind river, Laramie, and other summit ranges, and the Pacific coast range of Mexico.

The Archean era is divided into two periods, the Laurentian and the Huronian. The estimated thickness of the former is 30,000 feet, and of the latter from 10,000 to 20,000 feet. The Laurentian rocks are metamorphic or crystalline, with few exceptions, and include granite, gneiss, mica-schist, hornblende, and pyroxenic rocks, beds of crystalline limestone, quartzite, conglomerate, and labradorite. The Laurentian beds are altered sedimentary rocks of the ordinary character, as the schists grade into true slates, the quartzites into sandstones, and conglomerates and gneisses into gneissoid granites. No distinct remains of plants have been observed. Graphite is very abundant. Only the lowest division of animal life, such as the Rhizopods and Protozoans, occur. This is shown by the occurrence of the fossil *Eozoon canadense.* The Huronian includes the series on the north shore of lake Huron composed of slates, conglomerates, quartzites, layers of jasper and chert, with quartz and jasper conglomerates, limestones, beds of diorite which graduate into syenite or epidote, and also other areas which have been placed as the equivalent of this series on lithological grounds.

KING,[10] in 1878, states that in the Archean outcrops of the fortieth parallel one can not fail to notice the widespread simplicity of petrological forms, the prevalence of granites, granitoid gneisses, and dioritic metamorphic rocks, the paucity of argillites, quartzites, limestones, and zirconiferous and staurolitic schists, the infrequence of large bodies of magnetic, specular, or spathic iron, and the complete absence of corundum, chrysolite, serpentine, steatite, pyroxene rocks, the true nacreous schists, and other minor forms observed in the Appalachian system.

Without doubt, the most interesting laws which come out of the comparison of these exposures are, that, when considered in depth, from the uppermost limits of our so-called Huronian to the lowest Laurentian exposure, there is, first, a regular, steady increase of the intensity of metamorphism, and, secondly, a pretty regular increase in the thickness of individual members of the series. The lowest Laurentian aplitic granitoid bodies of the Laramie hills are the heaviest beds and the most changed from their original sedimentary condition. The higher Huronian group of gneisses, quartzites, conglomerates, dolomites, and argillites are at once the most thinly bedded and least metamorphosed. Individual beds remain as specialized as the day they were deposited. At the lower exposures of the whole Archean formation well defined crystals are of great rarity; even microscopic apatite, the best presented species, is generally crushed and dislocated; micas are distorted, and all feldspars are more or less fragmentary. A marked contrast is observable at the upper extreme. Here many micas, hornblendes, garnets, and even feldspars are nearly, if not quite, completed crystals. The exceptions to this are those places already described, where local compression has broken up the original arrangement of the crystalline ingredients.

Nearly every considerable mountain body between the Wasatch and the California line shows in the lowest horizons exposures of one or more bodies of granite. These are classified into four groups upon petrological grounds. The first type consists of quartz, orthoclase, an unimportant amount of plagioclase, and muscovite, with a small quantity of microscopical apatite. These are all west of Reese river, longitude 117°. These are all associated with the Nevada type of Archean crystalline schists composed of quartz, biotite, muscovite, and magnetite, or quartz, hornblende, and magnetite. As to the age of the granites of this type there are practically no data available. At one place it is intimately involved with the crystalline schists and is overlain unconformably by the Carboniferous. There is little doubt that it is Archean but its reference to that period is on general lithological grounds. The second type is of the same composition as the first, except that biotite is substituted for muscovite. It has a range from the Ombe mountains west of Salt lake desert to the California line. The third type is like the second except that biotite and hornblende are found together. This distribution is coextensive with that of the second type. The fourth type is the most complex in its petrological features of any of the families of granite, and consists of quartz, orthoclase, plagioclase, often equal in quantity to the orthoclase and sometimes exceeding it, usually a high percentage of biotite and hornblende, titanite, and a high proportion of microscopic apatite. Between this class and the diorites that are unusually rich in orthoclase there is but little difference, although there is little danger of ever confounding the granitoid diorite with the dioritic members of the fourth type. These granites are the most prominent as regards geographical distribution of the truly eruptive varieties observed in the Cordilleras. When the different types of granite are seen in apposition so as to give a clew as to their relative ages it is found that they occur in the order given. In denominating these groups of granite as eruptive it is only intended to indicate that in their relations to the contiguous Archean schists they have the appearance of intrusive bodies, and that in their interior structure and general mode of occurrence there are none of those evidences of alliances to the crystalline schists which are observed in the granitoid gneisses of so many localities, especially in the Rocky mountain region. In so-called eruptive granites there is neither parallelism of general bedding nor of interior arrangement of the minerals, and the most ordinary phenomenon of structure is the development of conoidal shapes formed of concentric layers varying in thickness from a few inches to 100 feet. This structure, so far as observed, is strictly confined to the hornblende-bearing granites, and never makes its appearance in those of the first and second types. Although instances of each type of granitic rock are found unconformably underlying the low members of the Paleozoic series, this is not the case with each outcrop; many granitic masses are found unconformably underlying Mesozoic or even Tertiary volcanic rocks. But there is absolutely no evidence whatever in favor of the belief of granitic extrusions later than the Archean age. Although Whitney has found intrusions of granite in sedimentary strata other than the Archean crystalline schists, any attempt to correlate age by petrological features alone is dangerous, as may be shown by the fact that the Jurassic granite of California and the granite of the Cottonwood region on the Wasatch, which is unmistakably Archean, are positively identical down to the minutest microscopical peculiarity.

In the crystalline schists and gneisses are found identically the same minerals which characterize the granites. In the schists the characteristic feature is the parallel bedded arrangement. Granite possesses the same minerals; the sole difference seems to be that granite is often demonstrably a plastic intrusion and possesses no parallel arrangement of minerals. The geognostic position of the schists is exactly like the other strata which were deposited horizontally and afterwards disturbed. On the other hand, granite in an immense majority of cases is found exposed in the hearts of the mountain ranges. It is only when we can observe granite in direct connection with the strata into which it has intruded or out of which it has been made that the true relations can be seen; and it is safe to say that wherever these intimate relations are observable, the granite occupies a region which has been subjected to horizontal or circumferential pressure. The frequent phenomena of the under-dip of the strata flanking a granite mass, as in the great granite body of the Sierra Nevada, are prominent instances of the intimate relation spoken of. If in such cases an unconformable overlying and unaltered series were to cover all but the summits of the granite hills, the granite would appear simply as an unconformable underlying body whose genetic relations are absolutely unknown. Into this category a vast number of granite exposures of the Cordilleras have to be placed.

It is an invariable law, then, that where the genetic relations are clearly perceived, eruptive granite is always found in connection with very great horizontal pressure and consequent disturbance. Suppose, now, a deep-lying series of varied sedimentary beds, covered by a sufficient superimposed mass to exert a pressure powerful enough to sink them to the necessary thermal horizon for the induction of crystallization in the material of the beds. As long as the attitude of these beds was undisturbed by horizontal compression, the result would be a series of crystalline schists and gneisses. But the moment horizontal or tangential pressure either overcame or disturbed the action of the downward pressure, the horizontal arrangement of these crystallizing materials would be broken up, and their resulting arrangement would depend upon the interaction of the two forces.

SELWYN,[11] in 1879, proposes the following general stratigraphy for the older rocks: I. Laurentian: To be confined to all those clearly lower unconformable granitoid or syenitic gneisses in which we never find interstratified bands of calcareous, argillaceous, arenaceous, and conglomeratic rocks. II. Huronian: To include (1) the typical or original Huronian of lake Superior and the conformably—or unconformably, as the case may be—overlying upper copper-bearing rocks; (2) the Hastings, Templeton, Buckingham, Grenville, and Rawdon crystalline limestone series; (3) the supposed Upper Laurentian or Norian; (4) the altered Quebec group and certain areas not yet defined between lake Matapedia and cape Maquereau, in Gaspé; (5) the cape Breton, Nova Scotia, and New Brunswick pre-Primordial subcrystalline and gneissoid groups. III. Cambrian: In many of the areas, especially the western ones, the base of this is well defined by unconformity, but in the Eastern Townships and in some parts of Nova Scotia it has yet to be determined. The limit between it and Lower Silurian is debatable ground. One point is particularly insisted on, that great local unconformities and lithological differences may exist without indicating any important difference in age, especially in regions of mixed volcanic and sedimentary strata, and that the fact of crystalline rocks (greenstones, diorites, dolerites, felsites, norites, etc.) appearing as stratified masses and passing into schistose rocks is no proof of their not being of eruptive or volcanic origin; their present metamorphic or altered character is, as the name implies, a secondary phase of their existence, and is unconnected with their origin or original formation at the surface, but is due partly to original differences of composition and partly to the varying physical accidents to which they have since their formations respectively been subjected.

SELWYN,[12] in 1881, states that the anorthosite rocks are in general conformity with the crystalline limestones, but are occasionally interfered with and disturbed by intrusions (?) of the more massive and granitoid variety of labradorite. This is proof that the labradorite or Norian rocks of Hunt do not constitute an unconformable Upper Laurentian formation, but occur in part as unstratified intrusive masses, and in part as interstratifications with the orthoclase-gneisses, quartzites, and limestones of the Laurentian system, as developed in the Grenville region, and mapped by Logan.

As to the granites which have been regarded as intrusive by Logan, both in the crystalline and fossiliferous rock, there is no doubt they are of later origin than the Silurian rocks which surround them, and which are everywhere, on approaching the granite, considerably altered; chiastolite, andalusite, garnet, mica, and other minerals appearing in the slates, which are also occasionally changed to quartzose or feldspathic mica-schists, and the associated fossiliferous limestone to crystalline and micaceous dolomites with the fossils still perfectly distinct. It has been customary and orthodox to regard these granites as "intrusive," and they are so designated by Logan. The author holds that there is absolutely no proof of their being so, either in the Eastern Townships, in Nova Scotia or in Australia, and that all the phenomena connected with them may be more readily explained and understood if we regard them as completely metamorphosed portions of the strata which now surround them; while the mere displacement of strata involved in the intrusive theory appears, in view of the enormous area now occupied by the granite, wholly inexplicable, as does also the manner in which the surrounding strata often dip down against and on to the granite and show no signs of having been deflected or otherwise affected as regards strike and dip by the supposed intrusions.

There is, however, often seen along the contact lines of the granite and the slates a considerable breaking up and crushing of the latter, and this has been held to indicate and be the result of the intrusion of the granite. It appears to be mainly due to the unequal resistance that the two rock masses have offered to the disturbing forces of upheaval, depression, and consequent pressure which have repeatedly affected them long after the formation of the granite. The effect thus produced is analogous to that which occurs where the forces producing slaty cleavage encounter interstratified hard layers of sandstone, when the elsewhere perfectly regular and parallel cleavage planes are immediately crushed, crumpled, and deflected.

In regions where the granite or other hard crystalline rock is older than the adjacent or alternating softer strata, perfectly similar contact lines may be seen, but unaccompanied by any change in the mineralogical character of the adjacent strata, such as occurs when the crystalline rock is the youngest; and therefore this phenomenon can not be taken as conclusive evidence of the intrusive origin of granite or other crystalline rock.

SELWYN,[13] in 1883, remarks that the Devonian granite-forming epoch has had immense influence in the pre-Carboniferous rocks of the region to the southeast of the great St. Lawrence, Champlain, and Hudson river break. This is certainly deserving of more careful consideration and study than it has yet received, and more especially so in connection with the alteration and metamorphism it has produced in large areas of Paleozoic, and perhaps pre-Paleozoic rocks. When these altered Paleozoic strata come in contact, as they often do in eastern Canada and in New England, with the more ancient Huronian and Laurentian gneiss, granite, mica-schist and other crystalline rocks, it is only possible to distinguish them or to define their respective limits by the most careful and minute stratigraphical work, such as the nature of the regions in

New England and in the adjacent provinces of Canada, where these rocks are chiefly developed, renders almost impossible, or at any rate has never yet been attempted. Hence the maps hitherto published, representing the geological structure of these regions, have necessarily been based almost entirely, so far as the crystalline groups are concerned, on lithological and mineralogical comparisons and considerations, producing petrological rather than geological maps, and as a consequence, though important and valuable aids to future investigation, they afford a very incorrect and imperfect idea of the true geological structure and the sequence and distribution of the several formations. Unfortunately, while careful, patient, and minute observation in the field has been unavoidably limited and local, study in the laboratory and theoretical deductions therefrom have been unlimited and widespread, but, as might have been expected, have not only afforded no satisfactory solution of the intricacies of Appalachian geological structure, but have on the contrary involved it in deeper mystery and complication. It is now evident that an entirely different system of procedure must be adopted before there will be any hope of definitely and satisfactorily solving the problems which have been presenting themselves to successive observers in this difficult field.

SELWYN,[14] in 1884, states that recent investigation has greatly enlarged the area over which the Archean rocks are known to extend, though it has not yet afforded any more satisfactory evidence of the relations of the Huronian rocks to the Laurentian. In all cases the supposed junction of the strata of the two systems either shows them vertically side by side or the Huronian strata apparently dipping under the Laurentian, while both present a very constant northeasterly strike. Notwithstanding these facts, their exceedingly different mineralogical characters and general appearance, broadly viewed, render it almost impossible to suppose that the superposition, as indicated by these dips, is the true one, or that the Huronian is not newer than the Laurentian. If so, then we must admit that both systems are presented in a constant succession of enormously thick overturned folds, with perhaps many dislocations and slips on the lines of the anticlinal axes.

As regards the so-called Norian or Upper Laurentian formation, the writer has no hesitation in asserting that it has, as such, no existence in Canada, its theoretical birthplace. Wherever these Norian rocks have been observed they are either intimately and conformably associated with the ordinary orthoclase or pyroxenic gneisses, or they occur as intrusive masses when they present no gneissic or bedded structure. They clearly cut the surrounding gneiss, and are probably due to volcanic or other igneous agency in the Laurentian age. Such masses may not unreasonably be supposed to mark the sites of the Laurentian volcanoes, while the bedded labradoritic gneisses and other associated strata may with equal probability represent the eruptive rocks—lava-flows, etc.—which emanated from them, and were locally interbedded with the ordinary sediments of the period, as rocks of similar origin and composition certainly were in the Huronian and in all later geological ages, a fact which has been singularly overlooked or ignored by most writers on American geology.

At present we have in Canada no evidence which would warrant us in making more than two great divisions in the Archean crystalline rocks. In many parts, especially in the eastern provinces, it has been found impossible to define even these clearly. Rocks of typical Laurentian character are there so intimately associated with others of equally typical Huronian characters, and in such constant alternations, that in mapping them they could not be separated, and are therefore all classed as Archean or pre-Cambrian.

WHITNEY and WADSWORTH,[15] in 1884, after a very wide but disproportionate review of the literature of the pre-Potsdam rocks, conclude that it is impossible for any unprejudiced worker in this department of science to peruse with care the pages given and not be obliged to admit that the geology of a large portion of this country, and especially that of Canada and New England, is in an almost hopeless state of confusion. The belief is justified that our chances of having at some future time a clear understanding of the geological structure of northeastern North America would be decidedly improved if all that were written about it were at once struck out of existence. While not desiring to conceal the fact that some of the problems presented in the course of the study of the older rocks are extremely difficult, it is clearly proved that want of knowledge, want of experience, and a desire to produce sensational theories, have brought about this condition of confusion.

In reference to Azoic rocks, there are several classes to which this term may be applied. First, it may be applied to strata once fossiliferous in which the evidences of life have disappeared. Second, rocks may be Azoic even if laid down when life was existing on the globe, provided the local conditions were not favorable to its development at the particular locality under consideration. Third, rocks must necessarily be Azoic when formed or originating under such a condition as were incompatible with the existence of life. Such was the original crust of the earth and the volcanic eruptive rocks. Fourth, we may have rocks formed under such conditions as were not inimical to life, but yet Azoic, because life had not begun to exist on the globe at the time of their deposition. These, according to our view, would be the rocks properly designated by the term "Azoic," and the body of rocks having this character might properly be called the "Azoic System." And we think that, in view of what has here been set forth, no one will deny that it is important that, if there are such rocks, they should have a special designation, and that the term "Azoic" would be a proper one to apply to them.

This, however, is exactly what was done by Foster and Whitney in 1850, when they gave the name of the "Azoic System" to a body of strata, originally—in part, at least—of sedimentary origin, which did not show by their character that life could not have existed at the time of their deposition, but which proved, on examinaion, to be entirely destitute of fossils, and which, moreover, were found everywhere to underlie unconformably other stratified formations which were recognized as containing the lowest known forms of organic life. It is denied that Eozoon, beds of limestone, the presence of graphite in crystalline limestone, or any other discovered material in the pre-Potsdam rocks, are sufficient evidence for the presence of life.

It is considered that we are fully justified in saying that the results of geological investigation during the last thirty-five years have given no encouragement to the idea that below the well known Primordial zone—the Potsdam sandstone of American geologists—there is another series of fossiliferous rocks.

If the Azoic rocks are really azoic, as is believed, then it follows, as a matter of course, that the series thus designated can only be separated into subsystems on purely lithological grounds; if they are fossiliferous, as held by the Canada survey, then it is equally clear that any subdivisions proposed for them should have a paleontological basis. It is denied that *Aspidella* and *Arenicolites spiralis* are of organic origin.

If we examine the often repeated statement that the Huronian unconformably reposes on the worn edges of the Laurentian, and contains the debris of the latter, it will be found that in the seven cases in which the rocks referred to these two formations were found in contact in the Canadian district, the Huronian, with but two exceptions, is said to be conformable with and to generally pass imperceptibly into the Laurentian. In one of the these two exceptions the rocks show mutually intrusive relations, and in the other the Huronian abuts against and runs under the Laurentian.

In all cases in which pebbles and fragments of the Laurentian have been found in the Huronian, they were seen occurring high up in the latter series, and not forming basement conglomerates. All the other so-called proof of unconformity has been made out of the fact that the strike of the foliation in the two formations, when not in contact, has been found to be discordant—worthless evidence unless the rocks observed in both formations be proved to be sedimentary and the foliation be shown to be coincident with the stratification. Now, if the Laurentian was an old metamorphosed sedimentary formation which had been upheaved and contorted, and on whose worn edges the Huronian has been laid down, the evidence of the fact ought to be overwhelming in amount after the country has been studied for so many years.

It is well known that any eruptive rock so soon as it comes in contact with erosive agencies will yield fragmental material even before it is cold, and that much eruptive matter is ejected in a fragmental state, so that in a mixed series of eruptive and detrital rocks nothing is more common than to have the debris of one inclosed in another, without that inclosure proving that the rocks differ in geological age. This is well known to be the case with the copper-bearing rocks of Keweenaw point, and it has been shown that the iron ores of the Marquette district, which form a constituent part of the so-called Huronian, are overlain by a conglomerate containing the debris of the former; yet both are by every geologist placed in the same series.

The basis of fact which forms the main support of the twofold division of the Archean—including under that designation all rocks lying below the lowest fossiliferous series—is this: the axial or eruptive portions of disturbed and mountain regions are largely granitic and gneissoid in character. These granitic, granitoid, and gneissic masses are brought to light in the cores of great mountain chains, where long-continued uplift of the original crust of the earth has through a succession of geological ages been furnishing the material from which the sedimentary formations were built up. That the gneissic or gneissoid rocks are closely allied to the distinctly granitic and not necessarily metamorphosed stratified deposits is clear, as the result of long continued investigations in regions where rocks of this kind occur. Not that all gneisses are of this character; but those are ordinarily so which with granite make up the axial masses of disturbed regions. That the parallel structure of the materials forming gneiss is not necessarily the result of sedimentation seems clearly to result from that which has been done both in experimental and field geology within the last few years. It can not be denied that a foliated arrangement or a parallel disposition of the mineral elements of various sedimentary rocks can be, and often has been, induced in them after their deposition, and that this parallel arrangement is not by any means neecssarily coincident with the planes of stratification. This fact alone is absolutely conclusive in favor of the idea that parallel arrangement of the mineral constituents of a rock—in other words, a gneissic structure, in rocks of the granite family—is not proof of sedimentation.

Overlying the granitic and gneissic axial rocks we are likely to find, and in many cases do find, the stratified masses which were formed from the preexisting crust themselves usually highly metamorphosed, because formed at a period of great chemical and mechanical activity. With these stratified and highly altered masses are associated eruptive materials—both interbedded and injected in dike form—these also often greatly metamorphosed, and to such an extent that their original character is only with difficulty, and with the aid of the microscope, to be recognized. This protrusion or forcing out of eruptive materials seems to have followed the preceding uplift of the original crust, if not as a necessity at least as something extremely likely to occur, as is shown by the fact that in so many great mountain chains we find volcanic activity more and more predominating with the progress of geological time. Since these eruptive materials come from a gradually increasing depth below the surface of the original crust they are more basic than this, and, since as a rule they contain more iron than that crust, are darker colored than the masses by which they are directly underlain. Hence the detrital beds formed from the debris of these more basic materials are themselves of a dark color, and as a result of their metamorphism we have the various slates, argillaceous, talcose, and chloritic, which so commonly rest upon the granitic and gneissoid rocks which form the core or axis of the disturbed region. With these slaty rocks are also associated limestone masses, which, so far as our observations go, are not ordinarily interstratified with the slates, but are of the nature of segregated deposits, having been formed posterior to the formation of the sedimentary beds with which they are associated, while the metamorphosing agencies were at work making over the beds into the crystalline form in which we now see them.

In the division of the rocks into Laurentian, Huronian, Norian, Montalban, Taconian, Arvonian, only lithological principles are now used, and every fact pertaining to the origin and relations of these rocks is ignored; and since, while it is assumed that all these rocks are sedimentary, they are found to occur in dikes and other eruptive forms, it becomes necessary to hold that all eruptive (including volcanic) rocks were the products of a metamorphic (aqueo-igneous) action. Hence it is claimed that all these rocks had been deeply buried and then denuded, and most extravagant views have become current regarding denudation.

It thus came about that the coarser grained granitoid and gneissic rocks were set apart as Laurentian; the gabbros and some of the more coarsely crystalline diabases and diorites were erected into the Norian; the felsites and quartz-porphyries were placed as the Arvonian; the finer grained diorites, diabases, melaphyres, and chlorite-schists were formed into the Huronian; the more friable granitic and gneissic rocks with the mica-schists were classed as Montalban, and the quartzites, limestones, and argillites were united into the Taconian. Of course, in each case the metamorphic fragmental forms of each rock were placed with the rocks they resembled, while the other forms of crystalline rocks were distributed through the groups.

ADAMS,[16] in 1887, gives a general consideration of the Upper Laurentian or Norian, which has been separated from the Lower Laurentian by the predominance of plagioclase feldspar. These rocks occur in detached areas in the Laurentian districts and are similar to the gabbro and gabbro-diorites of Scandinavia. At least nine areas are known to exist in Canada, and one in the state of New York. Besides pyroxene and plagioclase, many other minerals are found.

The rocks show much variation in structure. They are rarely quite massive, frequently well foliated, but usually consist of a rather coarsely crystalline groundmass through which are scattered irregular strings and masses composed of iron ore, bisilicates, and mica, as well as larger porphyritic crystals of plagioclase. Even when tolerably constant in composition there is generally a great variation in size of grain, coarse and fine layers alternating in rude bands or rounded masses. In the case of some of the areas there can be but little doubt that the anorthosite is eruptive; in others, however, it seems to be interstratified with the Laurentian gneiss, and in one of them to merge imperceptibly into it. The original relations of the rocks are, of course, much obscured by the effects of subsequent heat and pressure. The evidence at present, however, seems to indicate that the anorthosites are the result of some kind of extravasation which in early times corresponded to what in modern times we call volcanic eruption.

DAWSON, (SIR WILLIAM),[17] in 1888, describes the Eozoic rocks of the Atlantic coast and compares them with those of western Europe and the interior of America.

The Laurentian system consists in all parts of the world largely of orthoclase-gneiss associated with crystalline schists, and locally quartzites and limestone.

No one who has studied the typical districts of the Ottawa river can doubt for a moment that they are regularly bedded deposits, and that in the Middle Laurentian those conditions which in later periods have produced beds of limestone, sandstone, iron ore, and even of coal, were already in operation on a gigantic scale. At the same time it may be admitted that some areas of the lower gneiss may be cooled portions of an original igneous mass, and that many of the schistose rocks may be really bedded igneous materials.

Laurentian rocks compose the nucleus of the island of Newfoundland, occur in cape Breton, and in southern New Brunswick.

In the typical area of lake Huron, as originally described by Logan and Murray, the Huronian rests unconformably on the Lower and Middle Laurentian, and presents a great contrast in point of mineral character to these formations. It is comparatively little disturbed, and is clastic rather than crystalline in character. This point has been well insisted upon by Bonney and by Irving in recent papers. Further, its conglomerates contain pebbles of Laurentian rock in the same crystalline state in which these rocks are found at present. It consists chiefly of quartzites, conglomerates of different kinds, limestone, and slates, sometimes chloritic, with interbedded diorite.

In Newfoundland the older slate series of Jukes is lithologically very like the Huronian, and this likeness is increased by the fact that red sandstones and conglomerates like the Keweenian of the West overlie these lower slates.

On the coast of southern New Brunswick are the Coldbrook and Coastal series, essentially like those of Newfoundland. The Coastal group may perhaps be of later age than the Huronian proper, although pre-Cambrian.

As in Newfoundland, the typical Huronian of New Brunswick is overlain by conglomerates, sandstones, and shales. The Huronian rocks of Huron, Newfoundland, and New Brunswick are also compared with the Pebidian of Wales. The Huronian marks a period of igneous disturbance and coarse mechanical deposition succeeding to the Laurentian foldings.

IRVING,[18] in 1888, after a detailed consideration of the principles applicable to the classification of the early Cambrian and pre-Cambrian formations, reaches the following general conclusions as to the use of lithological characters and structural breaks in correlation.

Lithological characters are properly used in classification:

(1) To place adjacent formations in different groups, on account of their lithological dissimilarities, when such dissimilarities are plainly the result of great alteration in the lower one of the two formations and are not contradicted by structural evidence, or if used as confirmatory evidence only, when such dissimilarities are the result of original depositional conditions.

(2) To collect in a single group adjacent formations because of lithological similarities when such similarities are used as confirmatory evidence only.

(3) To correlate groups and formations of different parts of a single geological basin when such correlations are checked by stratigraphy, and particularly by observations made at numerous points between the successions correlated.

They are improperly used:

(1) To place adjacent formations in different groups, on account of lithological dissimilarities, when such dissimilarities are merely the result of differences in original depositional conditions, and when such evidence of distinction is not confirmed by or is contradicted by structural and paleontological evidence.

(2) To collect in a single group adjacent formations because of lithological similarities when such similarities are not confirmed by or are contradicted by other evidence.

(3) To establish general correlations between the clastic groups of different geological basins, except possibly when the gneissic and true crystalline schist basement formation of one region is compared with the similar basement formation of another.

(4) To establish and determine any world-wide subdivisions of the noneruptive basement crystallines, i. e., those which underlie the clastic groups here called Huronian—at least until very much more definite evidence of the existence of such subdivisions be gathered than has hitherto been done.

The structural breaks called unconformities are properly used in classification—

(1) To mark the boundaries of the rock groups of a given region.

(2) To aid in establishing correlations between the formations of different parts of a single geological basin.

(3) To aid in the establishment of correlations between the groups of regions distantly removed from one another; but caution is needed in attempting such correlations in proportion as the distances between the regions compared grow greater.

They are improperly ignored—

(1) When the evidence they offer as to separateness is allowed to be overborne by anything but the most complete and weighty of paleontological evidence.

As here used the terms system, group, and formation are the three orders of magnitude in stratigraphical subdivisions. Cenozoic, Mesozoic, and Paleozoic are systems; Carboniferous, Devonian, etc., groups; and the subordinate members of these groups are formations.

Applying these principles, it is concluded that such series as the Keweenawan and Huronian are entitled to the rank of groups (1) because, notwithstanding they include a considerable content of volcanic crystallines, they are nevertheless in the main made up of genuine sedimentary strata, whose formation by the same processes which have been at work in the accumulation of later sedimentaries is easily demonstrable; (2) because they have accumulated during the existence of life on the globe, as hereafter maintained; (3) because of their great volumes, which are not only comparable with, but very considerably exceed those of the ordinary rock groups; (4) because they are divisible into subordinate members which are in turn fully entitled to the rank of formations; (5) because of their entire structural separateness from the oldest of the groups above them, from each other and from the crystalline basement rocks below them; and, finally, (6) because of their presumptively wide extent.

Conditions similar to those of the lake Superior region recur in the Grand Canyon of the Colorado and probably also in central Texas. In Newfoundland, again, we have unconformably placed beneath the Cambrian, here developed with an enormous thickness, two mutually discordant series, the upper one of which is entitled on the principles advocated in this paper to full recognition as a clastic group, while the lower one is crystalline and gneissic. In numerous other regions similar conditions have been more or less distinctly made out; but the geological column, as it is now ordinarily presented, provides beneath the Cambrian for one great division only—the Archean. By some authors this Archean is recognized as divisible into Huronian and Laurentian; but very few writers, even when they have recognized the independent existence of pre-Cambrian and post-Laurentian groups seem to have accorded to such groups the taxonomical rank to which they are entitled. Certainly there has been no general recognition of these groups, such as would lead to the provision for them of a proper place in the general geological column.

If it is agreed that all clastic formations which unconformably underlie the Cambrian are to be thrown out of the Cambrian group, it is necessary to inquire whether the new groups are to be regarded as Paleozoic. All may be regarded as Archean; Paleozoic may be carried down to the break between the Keweenawan series and the Huronian; Archean may be restricted to the gneissic basic series; and, finally, some entirely new term of equal rank with Paleozoic and Archean may be introduced to cover the formations between the gneissic series and the Cambrian. The apparent relative extent of the time intervals between these several groups and the indications presented by them of the existence of life during their deposition lead to the conclusion that there should be introduced a system term equivalent to Paleozoic and Archean. In favor of restricting Archean to the gneissic basement terrane are the facts that this is essentially a crystalline schist series, having rarely any traces of fragmental constitution, because it shows an amount of disturbance prior to the deposition of the Huronian, which entirely outweighs that received by the Huronian, while the amount of denudation of the pre-Huronian land surface, as compared with that which followed the Huronian, was immensely greater; and because many believe that the exact conditions which gave rise to the pre-Huronian basement formation has never been repeated in later geological times.

There is no satisfactory evidence of the existence of life previous to the deposition of the Huronian. That it existed plentifully in the Huronian is indicated by the high development of life at the beginning of the Cambrian and its consequent necessary existence for great periods prior to that time; by the occasional discovery of obscure fossil remains; by the abundant occurrence of shales and slates filled with organic matter; by extended ferruginous strata whose original accumulation in the form of carbonate was certainly dependent upon the existence of organic matter. That the carbon of the shales is matter of genuine organic origin is shown by residual traces of hydrocarbons and by the fact that the carbonaceous substance in character and occurrence is entirely similar to that contained in the carbonaceous shales of later formations. If the term Paleozoic is to be used to cover all formations accumulated after the beginning of the existence of life, it should extend downward over the groups in question; but such is not its ordinary use, and to extend it downward over the Keweenawan and Huronian strata and the intervals indicated by the unconformities between the groups already discovered, and over such groups as shall be discovered in the vast area of the earth's surface not yet geologically known, does not seem warranted. It is therefore desirable that a new term shall be introduced of equal classificatory value, indicating that the great pre-Cambrian and post-Archean series are zoic in character and are equal to or greater in volume than the Paleozoic. For this place is suggested the term Agnotozoic, but some of the writer's colleagues prefer the more noncommittal term of Eparchean, signifying simply the position of these formations upon the Archean.

The following table shows alternative arrangement suggested by the above:

Systems.	Groups.	Systems.
Paleozoic	Carboniferous	Paleozoic.
	Devonian	
	Silurian	
	Cambrian	
Agnotozoic or Eparchean	Keweenawan	
	Huronian	
	(Other groups?)	
Archean	Laurentian (including Upper Laurentian)	Archean.

HUNT,[19] in 1888, summarizes the results of his work on the arrangement, subdivision, and nomenclature of the pre-Cambrian terranes, as follows:

(1) Laurentian. Under this name, proposed and adopted by the author in 1854, is comprised the old gneissic terrane found especially in the Laurentide and Adirondack mountains, as well as in the great Atlantic chain and in the Rocky mountains of the center of North America. To this same series the author has also annexed the similar gneisses of Great Britain and Scandinavia, as well as the old or central gneiss of the Alps. From the time of our first studies in Canada, in 1847, we had pointed out the existence, in this gneissic terrane, of two subdivisions, one lower, of granitoid gneiss which blends with the fundamental granite, to which succeeds with unconformable stratification a series of gneisses also granitoid, frequently amphibolic, interspersed with quartzites and crystalline limestones, with serpentine. These two subdivisions, which we may provisionally name Lower and Upper Laurentian, have been called respectively the Ottawa gneiss and the Grenville series. In order to avoid all error it is necessary to note that the title of Upper Laurentian was for some time given by Logan to the terrane designated afterward as Labradorian and Norian. It is therefore through misunderstanding that some have wished to retain as a designation of the upper division of the Laurentian terrane the term Middle Laurentian.

(2) Norian. The terrane thus designated by the author in 1870 is in large part composed of those stratified rocks with an anorthic feldspar base, to which the name norite has been given. This terrane, however, includes intercalated beds of gneiss, quartzite, and crystalline limestone, all being rather similar to those of the Upper Laurentian terrane. These norites, which have sometimes been designated by the name gabbro, must not be confounded with the very distinct gabbros of the Huronian terrane, nor with certain plutonic rocks, to which they bear mineralogic resemblances. The facies of the norites serves to distinguish them.

(3) Arvonian. This terrane is composed in large part of petrosiliceous

rocks which pass into the state of quartziferous porphyry, with which, however, certain amphibolic rocks are intercalated, as well as sericitic schists, quartzites, oxides of iron, and more rarely crystalline limestone. This terrane, indicated for the first time by Hicks, in 1878, in Wales, is regarded by Charles Hitchcock as forming in North America the lower part of the Huronian terrane.

(4) Huronian. This name was given by the author in 1855 to a terrane already recognized in North America, where it rests unconformably either on Laurentian gneisses or on Arvonian hornstones. It comprises, besides quartzose, epidotic, chloritic, and calcareous schists, also masses of serpentine and lherzolite, as well as euphotides, which represent in this terrane the norites of the Norian terrane, with which they are sometimes confounded under the common name of gabbro.

This terrane predominates in the Alps, where it forms the series of red stones (pietre verdi).

(5) Montalban. The studies of von Hauer, published in 1868, on the eastern Alps, and those of Gerlach on the western Alps, published the year following, agree in recognizing in these regions two gneissic terranes, that is to say, an old or central gneiss and a young or recent gneiss; the latter, which is very distinct from the old gneiss from a petrographic point of view, being accompanied by micaceous and amphibolic schists. The studies of Gastaldi, published in 1871, and those of Neri, published in 1874, while confirming Hauer and Gerlach's results, have furnished more details on these terranes and their lithologic characters. It is proper to remark here that all these observers seem to be agreed in placing the horizon of the greenstones (Huronian) between the old gneiss (Laurentian) and the young gneiss.

Before he had knowledge of the first observations of these scientists, the author, in accordance with his own studies in North America, was led to identical conclusions, and in 1870 he announced the existence of a series of young gneisses, quite distinct from the old gneisses, and accompanied by crystalline limestones and by micaceous and amphibolic schists. To this terrane, in view of its great development in the White mountains of New Hampshire, he gave in 1871 the name of Montalban. This series, for the rest, appears identical with the young gneiss of the Alps, with gneisses and mica-schists called Hercynian in Bavaria, with the granulites with dichroite rocks, mica-schists, and lherzolite of the Erzgebirge in Saxony, and similar rocks in the mountains of Scotland. This Montalban terrane in North America includes not only crystalline limestones, but beds of lherzolite and serpentine, quite like the Huronian and the Laurentian. It is also in this series that are found most of the "filonian" or endogenous masses of pegmatite, often inclosing emerald, tourmaline, and tin, uranium, tantalum, and niobium ores.

Gastaldi, in a memoir published in 1874, declares that the greenstones, properly so called, lie between the old porphyroid and fundamental gneiss and the recent more finely grained gneiss, more quartzose than the other, which he also designates as gneissic mica-schist or as very micaceous gneiss passing into mica-schist and often amphibolitic; the two gneissic series being according to him easy to distinguish. To these two divisions above the old gneiss Gastaldi added a third division still more recent. This division contains considerable thicknesses of beds designated by him under the titles of argillaceous schists, or, rather, lustrous, talcose, micaceous, and sericitic (silk-like) schists. Associated with these schists are also found quartzites, statuary and Cipolino marbles, with dolomite, karstenite, and sometimes amphibolic rocks and serpentines, the presence of which in this division, and even in the recent gneisses, as well as in the greenstones, properly so called, seemed to him to justify the name of "zone of greenstones," often given by Gastaldi to the whole of this triple group of crystalline schists which he recognized as being less old than the central gneiss.

(6) Taconian. This third division, to which Gastaldi gave no distinctive name, has, as is known, a very interesting history in Italian geology. A terrane having at the same time the same horizon and the same mineralogical characters is found greatly developed in North America, where it comprises quartzites (often schistose and sometimes flexible and elastic) and crystalline limestones, yielding statuary and Cipolino marbles. There are also found there deposits of magnetitic and of hematitic iron, as well as important beds of limonite, the latter being epigenic either from pyrites or from carbonate of iron, two species which by themselves form considerable masses. This terrane furthermore contains roofing slates, as well as lustrous and unctuous schists, ordinarily with damourite, sericite or pyrophyllite, but inclosing sometimes chlorite, steatite, and amphibolic rocks with serpentine and ophicalcite. There are also found among these schists, which are found at diverse horizons in this terrane, beds visibly feldspathic, with others of ill defined nature, which are transformed into kaolin by aerial decomposition. These same schists also yield remarkable crystals of rutile, as well as tourmaline, disthene, staurolite, garnet, and pyroxene. This terrane, which for the rest appears diamond-bearing, was described in 1859 by Lieber under the name of itacolumitic group. Eaton, as far back as 1832, had placed the quartzites and limestones forming the lower members of the group in the primitive terrane; while the argillites, found toward the summit of the same group, were regarded as constituting the lower division of the transition terrane, covered, according to him, unconformably by the fossiliferous graywacke (first graywacke) which formed the upper division of the same transition terrane. Emmons, on his part, in 1842, comprised in what he called the Taconic system all this crystalline series, as well as the graywacke; but in 1844 he separated the latter, in which he had recognized the existence of a trilobitic fauna, giving it the name of Upper Taconic. Long studies have convinced the author that this upper division is entirely in-

dependent of the Lower Taconic, with which this fossiliferous graywacke is in contact only in relatively restricted regions, while in other localities it rests directly on older crystalline terranes. Seeing, moreover, that the Lower Taconic is found alone in a great number of localities from the gulf of St. Lawrence to Alabama on the south and to lake Superior on the west, and recognizing also the fact that the Upper Taconic really forms part of the Cambrian terrane (as for that matter was recognized by Emmons in 1860), the author proposed as far back as 1878 to restrict the employment of the term Taconic to this crystalline and infra-Cambrian series which forms the lower Taconic of Emmons and the itacolumitic group of Lieber, and to give it the name of Taconian terrane.

The mineralogical resemblances existing among the various crystalline terranes mentioned above are easy to recognize. The type of rocks with orthose base that appears in the fundamental granite and the Laurentian gneisses is also found in the quartziferous porphyries of the Arvonian and the gneiss of the Montalban, and less distinctly in the feldspathic rocks of the Taconian. The nonmagnesian micas, rare in the fundamental granite and the Laurentian gneisses, are found abundantly represented in the gneisses and mica-schists of the Montalban, as well as in the lustrous schists found in the Huronian and Taconian terranes, and even predominate in the latter. It is still to be remarked that the simple silicates of alumina, such as andalusite, disthene, fibrolite, and pyrophyllite, which seem foreign to the oldest terranes, abound in the Montalban and also appear in the Taconian. At the same time the crystalline limestones, the oxides of iron, and the calcareous and magnesian silicates are found represented in each terrane beginning from the fundamental granite. The chemical and mineralogical differences between these various terranes are greater than the resemblances, which has not prevented certain observers from confounding the recent gneiss with the old gneiss. In fact, the resemblances between the Huronian and Taconian terranes have led the late Prof. Kerr, in North Carolina, to refer the latter terrane to the Huronian terrane. In the vicinity of lakes Superior and Huron, too, where the Laurentian, Norian, Arvonian, Montalban, and Taconian terranes are found all at once, the outcrops of the latter have been confounded with those of the Huronian terrane by Murray and other observers. In 1873, however, the author, distinguishing between the two, gave to the Taconian terrane in this region the provisional name of Animikie series. Only later did he recognize the fact that this series, which in certain localities rests unconformably on the Huronian terrane, is only the Taconian. Emmons, on the contrary, who knew the existence in this region of what he called the Lower Taconic, thought that the terrane to which in 1855 the author had given the name Huronian was identical with this same Lower Taconic or Taconian. The differences between the two terranes in the basin of lake Superior, indicated first by Logan and afterward by the author, appear very clearly from the recent studies of Rominger. On the various crystalline terranes, including the Taconian, there rests in this region unconformably an enormous series of sandstones and conglomerates, with contemporary plutonic rocks, the whole being remarkable for its content of metallic copper. This series, which had been alternately confounded with the Huronian and Taconian terranes on the one hand and with the trilobitic sandstones of the Cambrian on the other, was for the first time separated by the author in 1873 under the name of Keweenaw group, a term which he in 1876 converted into that of Keweenian terrane. It still remains to be determined whether this series, on which these same trilobitic sandstones rest unconformably, should form part of the Cambrian terrane or whether it should form a distinct terrane between the Taconian and the Cambrian.

BELL,[20] in 1889, characterizes the Huronian as the great metalliferous series of Canada. While rocks of igneous origin constitute a marked feature in the Huronian system, a large proportion of it is made up of those of an undoubted sedimentary character. On the other hand, it is questionable if the great bulk of the Laurentian rocks can be proved to have been deposited from water. It is supposed by many that the foliation of much of the gneiss may have been produced by pressure and some kind of flowing movement in an igneous mass. Whatever view we may take of the origin of the common Laurentian gneiss, which forms the surface of the country over such a vast extent of the Canadian half of North America, the commencement of the Huronian period marks a great change which then came over the earth—a change characterized by widespread volcanic outbursts and by evidence of the existence of water (perhaps the first) on the surface of the globe, and of certain progress in the building up of the aqueous deposits which has been going on ever since.

BELL,[21] in 1890, gives a general account of the Archean. The Azoic or Archean period is divided into the Laurentian and Huronian systems, into which the primitive rocks of all countries may be classified, and which everywhere are essentially the same and retain the same relative positions. In some instances newer rocks have been so altered locally or over considerable tracts as to resemble the Azoic, but there is generally found some means of distinguishing between them. In Canada and the United States the Laurentian and Huronian are usually intimately associated, but their lithological features and internal characters are sufficiently distinct to separate them. The Huronian rocks are less contorted or corrugated on the small scale than the Laurentian, but on the large scale they partake of the same foldings which have affected the latter. The Huronian rocks seem to be interwoven with the Laurentian as basins or troughs more or less elongated, and as tracts of angular and other forms filling spaces between great nuclei or rounded areas of Laurentian rocks.

The Laurentian system is divided into two formations, the lower of which is sometimes called the primitive gneiss series. It consists essentially of obscurely foliated or stratiform granitic or syenitic gneiss. The prevailing colors of the Lower Laurentian gneiss are grayish and reddish. In some districts the Laurentian rocks are cut by dikes of greenstone or trap. In the Upper Laurentian are placed both the anorthosite rocks and the limestone-bearing series of eastern Ontario. The anorthosites, which are considered by some as eruptives and others as bedded rocks interlaminated with the limestones, may be in part of both origins. Anorthosites, after spreading out upon the surface of the earth or the bottom of the sea, may have become incorporated in a conformable manner with the contemporaneous deposits, while others may have flowed over preexisting rocks which were not disturbed. Between the Upper and Lower Laurentian there may be a general want of conformity. The Upper Laurentian contains metallic ores and very numerous minerals, which are not found in the Lower Laurentian. The gneisses of the Upper and Lower Laurentian often have a close resemblance. As the evidence is so strongly in favor of the aqueous origin of a part of the Upper Laurentian at least, this lends support to the view that even the primitive gneisses may have been formed by the action of water during some early condition of the earth, of which we can form but little conception judging by the later stages of its history. Eozoon is regarded as a myth, and the limestones, iron ores, graphite, and apatite are not considered as evidence of the existence of animals or plants in Laurentian times. The limestones may be chemical sediments; the graphite and apatite occur principally as vein matter; the iron ores occur in greater masses than in deposits of organic origin, and their mode of occurrence is opposed to any theory of this kind. The Upper Laurentian rocks seem to be much more limited in geographical extent than the Lower Laurentian.

The Huronian system in Canada has a great thickness and variety of strata, for the most part crystalline, but in a less degree than the Laurentian, together with many unstratified igneous masses. Like the Laurentian it is Azoic, or devoid of any trace of organic life, so that the distinction between the two systems is based entirely on lithological grounds. The difference in this respect is great, and is easily recognized by those who have paid any attention to geology. The prevailing dark green and gray colors of the Huronian offer a marked contrast to the lighter grays and reddish grays of the Laurentian. The latter are massive and coarsely crystalline, while the former are usually fine grained and schistose or fissile, this cleavage structure constituting a striking difference from the solid Laurentian. There are some exceptions to this rule, such as the light-colored quartzites and the granites and syenites of the Huronian, to be noticed further on. The change in passing from one to the other is often sudden and complete, but sometimes beds of passage are met with. The Huronian is the great metalliferous system of Canada. Although the Huronian strata have generally been thrown into sharp folds, or stand at high angles, they are, as a rule, less bent about or contorted than the Laurentian. The total volume of the system is very great, probably not far from 40,000 or 50,000 feet, or perhaps even more.

In Canada, as far as our investigations have gone, the two systems appear to be everywhere conformable to each other, but in rocks of such ancient date and which have undergone such profound structural changes, owing to pressure, etc., affecting alike the stratified and unstratified portions, this appearance may not everywhere indicate a truly conformable sequence. Both sets of rocks having been thrown by lateral pressure into sharp folds, standing at high angles to the horizon, the Huronian often appears to dip under the older Laurentian, but this is merely the effect of overturning, and does not show that a part of the Laurentian is newer than the locally underlying Huronian. Notwithstanding the geographical relations of the two sets of rocks, their general difference in character and composition would indicate that some great change in terrestrial conditions had occurred when the formation of the one system ended and that of the other began. In the Laurentian an "acid" or siliceous composition prevails, whereas the Huronian rocks as a whole are more basic, chemically speaking. The latter can be shown to be very largely of volcanic origin, although this may not always be obvious at first sight.

The term Huronian is made to include all the rocks lying between the Laurentian below it and the Cambrian or earliest fossiliferous rocks above. Among the areas placed with the Huronian are the Keewatin and similar rocks. In the Huronian are numerous areas of northern Canada, and perhaps certain of the rocks of Hastings and Lanark counties, some of the crystalline rocks of the Eastern Townships and the provinces of New Brunswick, Nova Scotia, cape Breton, and Newfoundland. In the Cambrian system are placed in ascending order the Animikie, Nipigon, and Potsdam formations. Between the Huronian and Cambrian is a great unconformity. Between the Animikie and Nipigon and the Nipigon and Potsdam are probable unconformities.

WALCOTT,[22] in 1890, gives a full account of the Lower Cambrian or Olenellus zone.

The base of the Olenellus zone is considered to be where the genus Olenellus, or the fauna usually accompanying it, first appears; beneath that horizon the strata are referred to some of the pre-Cambrian groups of rocks. In some cases the underlying rocks are in layers, conformably beneath the Cambrian, and no physical separation of the two groups is possible. In other instances the subjacent rocks are the remains of the old Archean continent, near the shores of which much of the life of this portion of the Cambrian period existed.

The line of demarcation between the Cambrian and pre-Cambrian may be considered (1), at the base of the Olenellus zone, in continuous sections; (2) at the line of an unconformable contact between any member of the Cambrian group and the subjacent Algonkian or Archean; (3) at the line of unconformable contact, which is the base of the Olenellus zone.

Placed in the Algonkian under this definition are 11,000 feet of quartzites, conformably below the Olenellus, in the Wasatch; 10,000 feet of argillites, sandstones, quartzites, and conglomerates, conformably beneath the Olenellus, in British Columbia; 12,000 feet of sandstones, shales, and limestones unconformably beneath the lowest known Cambrian, in the Grand canyon of Colorado; a similar series of rocks unconformably beneath the Cambrian in Llano county, Texas; a series unconformably below the Upper Cambrian in the Adirondacks; and the rocks of St. Marys and Placentia bay, Newfoundland, which are unconformably below Lower Cambrian strata. In the Grand canyon, in a bed of dark argillaceous shale, 3,550 feet from the summit of the section, was found a small Patelloid or Discinoid shell, a fragment of what appears to be the pleural lobe of a segment of a trilobite, and an obscure, small Hyolithes, in a layer of bituminous limestone. In layers of limestone, still lower in the section, an obscure Stromatoporoid form occurs in abundance. These fossils indicate a fauna, but do not tell what it is.

The Olenellus fauna includes Spongiæ, Hydrozoa, Actinozoa, Echinodermata, Annelida, Brachiopoda, Lamellibranchiata, Gasteropoda, Pteropoda, Crustacea, and Trilobita. The abundance of the Olenellus fauna shows that the life in the pre-Olenellus seas was large and varied. The few traces known of it prove little of its character, but they prove that life existed in a period far preceding Lower Cambrian time; and they foster the hope that it is only a question of search and favorable conditions to discover it.

DANA,[23] in 1892, gives the following as the philosophical divisions of pre-Cambrian times, although the early physical and biological conditions of the globe are not within the range of observation:

I. The Astral æon, as it has been called, or that of liquidity.

II. The Azoic æon, or that without life.

1. The *Lithic era*, commencing with completed consolidation; the time when lateral pressure for crust disturbance and mountain-making was initiated, and when metamorphic work began.
2. The *Oceanic era*, commencing with the ocean in its place; oceanic waves and currents and embryo rivers beginning their work about emerged and emerging lands, and the tides, the retarding of the earth's rotation.

III. The Archæozic æon, or that of the first life.

1. The *era of the first Plants;* the Algæ and later the aquatic Fungi (Bacteria); commencing possibly with the mean surface temperature of the ocean about 180° F.

2. The *era of the first Animal life;* the Protozoans, and forms related to the embryos of higher invertebrate species, commencing possibly with the mean surface temperature of the waters about 120° F., and ending with 90° F. or below.

While these divisions mark off great steps in the progress of the developing earth, the rocks bear no marks of them that can be distinguished.

The Huronian period covered probably much of Archæozoic time, and this is all in the way of correlation that can be said. It is well to note here that if the Eozoon is really animal in origin, the "Laurentian" rocks of Canada in which it occurs must be Huronian or the later of Archæan terranes.

SECTION II. GENERAL DISCUSSION.

NAMES APPLIED TO PRE-CAMBRIAN ROCKS.

In the early days of American geology the name Primary or Primitive was more widely applied to the ancient rocks than any other. Among the older geologists this name, including under it in a general way the pre-fossiliferous or metamorphic rocks, was used by Akerly, Alexander, Booth, Dewey, Ducatel, Eaton, Emmons, Hitchcock (Edward), Jackson, Mather, Mitchell, Percival, Rogers (H. D.), Rogers (W. B.), Silliman, Tuomey, Vanuxem, and others. It was nearly universal in 1820 and was applied as late as in the forties.

The term Primitive in the United States was gradually superseded by Azoic. Used by Adams as early as in 1846, in the literature of the fifties and sixties it very widely occurs, and has not yet disappeared. Among more prominent geologists in whose writings it may be found are Adams, Cook, Crosby, Emmons (E.), Frazer, Hitchcock (C. H.), Hitchcock (E.), Kerr, Rogers, (H. D.), Safford, Whitney, Wadsworth, and others. In its earlier use Azoic was often made to cover all rocks which were apparently destitute of life, without reference to whether they are older than the fossiliferous rocks or not. It was thus applied by Adams, Emmons (E.) and the elder Hitchcock. With Rogers the Azoic included nonfossiliferous rocks which are younger than the Hypozoic or gneissic series proper. Ordinarily, however, the term was used to cover all pre-Silurian sedimentary rocks, the Silurian being then regarded as the base of the fossiliferous systems. It was thus definitely defined by Foster and Whitney in their application of it to the lake Superior rocks and the Azoic was held by them to be strucurally indivisible. While the rocks of the Primitive and Azoic were early subdivided into lithological divisions there was little or no attempt to apply stratigraphical methods to them. Later the Azoic was subdivided by certain geologists into Laurentian, Huronian, etc.

The work of Logan and Murray marks in America the beginning of a truly structural study of the ancient rocks. They found in different places in Canada pre-Cambrain rocks which they mapped in detail. The two areas in which this work was begun were the north shore of lake Huron and the Laurentide mountains. With scientific spirit they applied to the rocks of these areas no terms which involved any theory of origin or equivalence, but gave the rocks the names of the localities, in this following one of the fundamental principles of good structural work. Having no fossils for guides, they built up a succession on the north shore of lake Huron by following formations in continuous exposure, by lithological likenesses of exposures separated by short intervals, by a like order of formations in different localities, and by the use of an unconformity, which was held to occur between the Huronian sediments and the underlying crystalline rocks.

In Logan's work upon the Laurentian, the same methods were used as far as practicable, but on account of the complicated structure of the region his success was here much less conspicuous. The difficulty of the district drove Logan to take the one characteristic formation, the limestones as horizons to follow and to serve as planes of reference in working out the structure. But even this guide was not a certain one, as Logan never became quite sure as to the number of limestones present. As the study of the Laurentides continued the rocks were divided into two divisions, a Lower Laurentian free from limestone and an Upper Laurentian containing the limestones. The two were held by Vennor, and by Selwyn for a time, to be unconformable. As the area studied in the Laurentide mountains widened, a new formation was found, a laminated gabbro. It was recognized as being largely composed of labradorite or anorthite and so was first called Anorthosite or Labradorian, and afterwards Norian. The contacts of this formation with the other formations of the Laurentian were recognized as not those of conformity. In these early days it was naturally supposed that all laminated rocks, whatever their character, were sedimentary, and as in certain places the Labıadorian appeared to cut across or overlap the old Laurentian it was designated as Upper Laurentian, and what had before been called Upper Laurentian was designated Middle Laurentian. When the eruptive character of the Labradorian was shown, the Canadian Survey returned to the first uses of the terms Upper Laurentian and Lower Laurentian.

In comparing the Huronian and Laurentian, it appears that the principle used in reaching the conclusion that the original Upper Laurentian, separated by a great distance from the original Huronian and nowhere in contact with it, is the older, was the metamorphic character of the former as compared with the latter which in the early work of Logan and Murray was called a nonmetamorphic series. The lithological likeness of the gneisses and granites of the original Lower Laurentian to the granites and gneisses called Lower Laurentian unconformably underlying the Huronian doubtless was the reason for placing these as equivalents.

In the later work of Logan and Murray the names Huronian and Laurentian were applied to regions far distant from the original areas, the guiding principles for so doing being wholly lithological likeness and degree of metamorphism. Working under these principles, as granites and granite-gneisses are so abundant in the original Laurentian, and are nearly absent in the original Huronian, it became customary with these authors to refer to granitoid areas as Laurentian, while sedimentary series containing quartzites, limestones, or dark, fine grained schists were referred to the Huronian, and this reference was frequently made when the series as a whole was very much more crystalline than the original Huronian. The only exception to a reference of all pre-Cambrian rocks to the Huronian and Laurentian were the series now known as Keweenawan and Animikie. These were recognized as resting unconformably upon the so-called Huronian of lake Superior, while the Keweenawan was seen to be of a wholly different lithological character from the lake Huron rocks. These series were called the Upper Copper-Bearing series, the original Huronian often being called the Lower Copper-Bearing series.

We find these two geologists, Logan and Murray, starting with scientific principles, laboriously studying year after year the detailed occurrences of the rocks in the midst of a forest-covered wilderness, until their inductions built up the original Huronian and Laurentian series. In their later work of a very much less detailed character over vast areas the terms were applied somewhat indiscriminately, and in such a way as to imply that below the Upper Copper-Bearing rocks there are only two systems, one of which is equivalent to the original Huronian, and the other of which is equivalent to the original Laurentian.

These terms, Huronian and Laurentian, were gradually adopted by geologists working on the United States side of the boundary, so that in recent years, with the exception of Archean, they have been the most widely used of any names for designating the ancient rocks.

If Logan and Murray departed in their later work from strict scientific methods in their use, this departure was as nothing compared with the extremes to which later geologists of America have gone. By many geologists, coarse grained granites and granite-gneisses were designated as Laurentian without reference to evidence as to whether they were intrusive rocks of far later age. In applying the term Huronian the methods followed were even worse. Sometimes authors took a green color to be a characteristic feature of the Huronian and here referred all the green schists; others took a laminated structure to be characteristic of the series and here referred all the laminated rock, including even coarse grained laminated gneisses; others took the volcanics associated with the Huronian to be its characteristic feature and so called various pre-Cambrian volcanic series Huronian; others regarded metalliferous rocks as the important feature of the Huronian.

Lying at the root of all this work is the assumption that rocks of a certain kind are characteristic of a definite period of the world's history, and that if rocks are found which are really like the Huronian and Laurentian in lithological character they should be referred respectively to these series.

As to the relations between the Laurentian and Huronian, it was plainly believed by Logan, Murray, and the other early geologists that where the two come in contact they are unconformable, although oftentimes the structural relations which obtain are admittedly obscure. That was the position of the present director of the Canadian survey as late as 1879, who used the term Huronian not only to include rocks that had been theretofore placed, but to cover all of the Upper Laurentian and the Upper Copper-Bearing series, thus greatly expanding the system. In recent years he has held that the Huronian and Laurentian are always conformable, and that often the former grades downward into the latter, and this is the position which has been taken by many geologists of the United States, both in the East and in the West.

The lake Superior region furnishes a rather marked exception, as do certain others, to the indiscriminate and unwarranted use of the term Huronian. This region is so near to and is connected in such a way with the original Huronian of lake Huron that it was possible to make a strong case of probability in favor of the equivalence of the clastic rocks of the two regions. The lake Superior Huronian was divided into formations upon the same principles used in mapping the original Huronian. While the term Laurentian was applied to the pre-Huronian rocks on the north shore of lake Huron and about lake Superior, it was recognized by a number of geologists that this was a variation from its application in the original Laurentian area.

As geological knowledge increased and as the theories involved in the terms Primitive and Azoic were more and more attacked, in order to avoid a theory of origin, the term Archean was proposed for the ancient rocks by Dana in 1872. This term rapidly grew in favor. By its use not only the advantage of a theory of origin was avoided, but in common with Primitive and Azoic it was not necessary to subdivide the ancient rocks into Laurentian and Huronian, and thus imply a correlation with the rocks of other regions. In the early rapid work of the Far West, detailed observations usually stopped at the base of the fossiliferous series, and it was convenient to regard all the remaining rocks as a unit, and to cover this unit the term Archean was adopted. After a more detailed study of certain regions the terms Laurentian and Huronian were applied to subdivisions of the Archean. This term Archean also found early favor with the Canadian survey to include these two divisions of pre-Cambrian rocks.

Eozoic was another term suggested to replace Azoic, when it was thought by many that the rocks once supposed to be destitute of life are not really so. This was used to a considerable extent in the sixties and seventies, and retains a place in literature to the present time. This term implies a theory just the opposite of Azoic.

As already said, the theory involved in referring all pre-Cambrian rocks to the Laurentian and Huronian is that there was in pre-Cambrian time an invariable succession. This theory was carried to the extreme by Hunt and his school, who held that before Cambrian time there are six rock systems, which are universal and are separated by unconformities. These are, from the base upward: Laurentian, Norian, Arvonian, Huronian, Montalban, Taconian. Of these terms Norian was devised to include the laminated gabbros, the so-called Upper Laurentian of Logan. Arvonian was imported from Wales, where it was applied by Hicks to a series of acid volcanics. Montalban came from the White mountain region in New Hampshire, where a series of gneisses was thought to be of different lithological character from the Laurentian and Huronian and to overlie them. Taconian was introduced by Ebenezer Emmons to cover a series of fossiliferous rocks which was supposed to be earlier than the base of the Silurian.

Besides the terms given, others have been used to some extent, but they are of little importance. Among these may be mentioned Hypozoic, Prozoic, and Pyrocrystalline.

As the metamorphic theory gained force it became the habit of many geologists to refer to old crystalline or semicrystalline rocks as metamorphic, assuming that they are all produced by the alteration of sediments of some kind. This went so far as to include perfectly massive rocks, such as diabases, gabbros, granites, etc., among the metamorphics. Recently the term has also been applied to rocks recognized as laminated eruptives, but this is not the use referred to. This term metamorphic had the advantage of saying nothing as to age or correlation, but in escaping this difficulty another theory was accepted which, so far as its assumption is concerned, was quite as bad.

In many cases local names have been applied to formations or series in order to avoid any theory of age or correlation. The most conspicuous example of this kind is that of the Keweenaw series of lake Superior. More recently Lawson has proposed the terms Keewatin and Coutchiching for certain series northwest of lake Superior, and to include these two he proposes the Ontarian system. In the Grand canyon the local names Chuar, Grand canyon, and Vishnu have been applied to pre-Cambrian series which there occur. Comstock has proposed the terms Burnetian, Fernandian, and Texian for series which are found in Texas.

This tendency to return to the use of local names in recent years is plainly a reversion to scientific methods which were never departed from by certain geologists. This class has declined to use any term for the ancient rocks which involves a theory of origin or succession, but have divided the rocks which they found in their respective districts into lithological divisions or into local formations. Conspicuous among early geologists of this class are Jukes, Percival, and Lieber.

Recently Irving has proposed that there be placed below the Paleozoic group another group of coordinate value, for which the term Agnotozoic or Eparchean is suggested. This term cuts out of the Archean a large class of rocks which have before been here included. Finally, the name Algonkian has been brought forward by the United States Geological Survey for a systematic place opposite Agnotozoic or Eparchean.

In the following discussion, as stated in the introduction, Cambrian is defined as extending downward to the base of the Olenellus fauna. The pre-Olenellus clastics and their equivalent crystallines are called Algonkian, and the completely crystalline rocks below the Algonkian are denominated Archean. The reasons for these usages will appear in the following pages. The stratigraphical terms, group, system, and series correspond with the usage proposed by the International Geological Congress. The same is true of the chronological divisions, era and period. Formation is a lithological subdivision of a series.

THE CHARACTER OF THE ARCHEAN.

From the review of the literature it is plain that there is an essential unity in the character of the complex of rocks which is the oldest known in America. This statement covers all the areas in which the rocks are demonstrated to be exceedingly ancient. It includes the basal complex of Arizona, between which and the Tonto sandstone is a clastic system 15,000 feet thick, separated into three series by unconformities, and these again separated from the Tonto above and the basal complex below by great unconformities; it includes the basal complex of the Wasatch and certain of the ranges of Nevada, between which and the Olenellus Cambrian is a great unconformity and a thick series of quartzites; it includes the basal complex of southwestern Montana, between which and the Olenellus Cambrian is 12,000 feet of unaltered slates and a thick series of crystalline rocks of clastic origin, the two being probably separated by a great unconformity; it includes the basal complex of Texas, between which and the Cambrian is an unconformity, at least one and perhaps two thick series of clastic rocks; it includes the basal complex of the lake Superior region, between which and the Cambrian is an enormous system of clastics many thousands of feet thick, separated by unconformities into three series, and the whole bounded above and below by unconformities; it includes the basal complex of the north shore of lake Huron, between which and the Cambrian is a clastic series 18,000 feet thick, bounded above and below by unconformities; it includes the basal complex of the original Laurentian area, between which and the Cambrian is a clastic series estimated to be many thousands of feet thick; it includes the basal complex of Hudson bay, between which and the Cambrian are almost certainly two, and perhaps three series of clastics separated by unconformities; it probably includes the basal complex of Newfoundland, between which and the Olenellus Cambrian is a series of clastics 12,000 feet thick, and above this a great unconformity; it includes much of the great area of northern Canada known as Laurentian, between which and the Cambrian in various districts are clastic series.

In all of these regions in which the basal complex is vastly older than the Cambrian, it consists of a most intricate mixture of nearly massive rocks, among which granite and granite-gneiss are predominant; of gneissic and schistose rocks, all of which are completely crystalline, and so folded and contorted that nowhere has any certain structure ever been made out over considerable areas. The granites and basic eruptives may occupy considerable areas; the gneisses may be regularly laminated and grade into the granites; the crystalline schists may occupy the outer zones of an area; they may all be confusedly intermingled, schists, gneisses, and granites alternately predominating; sometimes the schistose rocks appear in dike-like forms in the granites; at other times the massives are in dike-like forms in the schists; at still other times the alternations of granite, gneiss, and schists are quite uniform and persistent for considerable areas. The granites usually show a rough lamination, which may not appear in hand specimens, but which is evident in large masses.

The minerals in the rocks generally show evidence of dynamic action; they do not have the clear cut, definite relations characteristic of the later plutonic rocks. In the chief mineral constituents of the rocks there is essential uniformity in all of the areas, although certain less common minerals may be found in one area which have not been discovered in another. Orthoclase and acid plagioclase feldspar, quartz, hornblende, muscovite, and biotite are the standard minerals. To describe accurately the appearance of the rocks of the basal complex is exceedingly difficult, but any one who examines a series of specimens from the various areas will perceive the truth of the statement made as to the essential likeness of the rocks from different regions. A suite from any one of the regions which has been personally examined by me, if unlabeled, could by no possibility be asserted not to come from any other.

The unparalleled intricacy of the structure of this complex, the general laminated arrangement of its parts, and the broken and distorted forms of the constituent minerals are evidence of repeated dynamic movements of the most powerful character. Further, the basal complex is not only recognized by its positive but by its negative characters. Nowhere in it is a persistent thick formation of quartz-schist (although vein-quartz is abundant), of limestone or marble, of a graphitic schist, or of a conglomerate. If sandstones and limestones or other sedimentary materials have been a part of this system the profound and varied mutations through vast lapses of time have wholly obliterated all evidence of their presence.

Besides the areas mentioned in which these most ancient rocks occur, there are many other areas in which there are between the Cambrian and the basal complex great series of clastic rocks, although the evidence at hand in favor of vast age for the basement complex is less than in cases before cited. Here are included the Front range of Colorado, which has between the basal complex and the fossiliferous rocks on its eastern slope the clastic series of Boulder, Coal, and Thompson creeks; and the Quartzite mountains of Colorado, where between the basal complex and the Carboniferous is a great series of quartzites. There is definite structural evidence for placing these and other areas with the group first considered. In a third class of areas no definite evidence in the nature of intervening series shows that between the Cambrian and the basal complex has intervened an era or even a period.

Because of the unique lithological character of this fundamental complex in all these regions, and because of the essential likeness in structure prevailing, we have ground for grouping these rocks together, whether exactly of the same age or not. Lithological arguments for correlation may be well distrusted; but the exceedingly strange, varied, and complex lithological and structural characters of this system, the like of which we have no evidence has been duplicated anywhere in later times, is an argument of great weight. In the complexity of its parts and the implications of its structure it gives evidence of vast antiquity.

In Algonkian, Cambrian, Silurian, Devonian, and even later times, completely crystalline schists have been produced over large areas; but, while often in these systems no evidence now remains of clastic characters, they rarely if ever closely resemble this fundamental complex. A clastic series was in the beginning of its history of necessity a shale, a sandstone, a limestone, a chert, or some other form of sediment and often containing carbonaceous material. Cementation, metasomatism, dynamic action may have profoundly changed any of these deposits. A limestone may have been transformed into a crystalline marble, or if impure into a hornblende schist containing scarcely a remnant of original carbonate. A cherty carbonate of iron may have become an actinolite-magnetite-schist. Carbonaceous shaly material may have become a graphite-schist, but if such a rock is represented in the fundamental complex what has become of the carbon? A sandstone may have become a granular quartzite or a foliated micaceous quartz-schist. But that a great quartzite formation like those of the Huronian of lake Superior or the pre-Olenellus of the Wasatch can have become wholly obliterated by any process short of fusion is almost inconceivable. As has been said, none of these rocks are found in this fundamental complex throughout its whole vast area. In its positive as well as its negative qualities it is a unit. While it can not be considered demonstrated that all of its area are of the same age, it may then be accepted that in North America is a system of granites, gneisses, and crystalline schists which are the oldest rocks of North America, and which have representatives in many areas throughout the United States, although most widespread and abundant in Canada. That such a basal system exists is no new idea; but it has not generally been recognized that between it and the Cambrian there elapsed an era in which were alternating cycles of the deposition of systems of rocks and of vast erosion intervals.

As here used the term Archean is restricted to this fundamental complex. It is no longer possible to regard as a unit or treat together all the pre-Cambrian rocks. The rocks included in the fundamental complex are everywhere called Azoic or Archean. The crystallines and semicrystallines above this complex, often called Archean, must be distributed from the Devonian or later to the pre-Cambrian. It is clear that if Archean is to remain a serviceable term it must be restricted to some unit. Such a unit is the fundamental complex, and to it this term is most appropriate.

ORIGIN OF THE ARCHEAN.

As has been shown, whatever the origin of the Archean, it is of vast age. It will be remembered that south of the lake Superior region, where is known the greatest volume of pre-Cambrian clastics, there is abundant evidence showing that the lowest of the clastic series has derived its débris from and rests upon the foliated edges of the Archean. In the Arizona region, in which the time of the pre-Cambrian clastics is only inferior to that of the lake Superior region, the evidence of a great hiatus below these clastics is of the most decisive character. The same may be said of several of the other areas of Archean. Consequently in many regions the Archean complex, in essentially its present condition, may be asserted upon definite structural evidence, to be vastly older than the Cambrian.

As to the origin of the Archean rocks, three different views are prominent: (1) The Archean has been considered as metamorphosed detrital rocks; (2) it has been considered as igneous, but later in origin than certain of the pre-Cambrian clastics with which it is in contact; (3) it has been considered as igneous and representing a part of the original crust of the earth, and therefore earlier than any sedimentaries. A modification of this theory is suggested under the topic Delimitation of the Archean.

(1) Those who believe in the detrital origin of the Archean, as above defined, will not question the conclusion reached as to the age of the fundamental complex; for to produce results so different from any known metamorphic clastic series must not only imply great age, but probably sediments which were originally deposited under different conditions from those of later times. This school, while believing in the detrital origin of the Archean as a whole, is conscious that it has been cut again and again by eruptives of all kinds; that the supposed clastics have thereby been profoundly metamorphosed by contact and dynamic action, and often have been so changed that the place can not be pointed out where the intrusives end and the clastics begin.

If this sedimentary view of the origin of the Archean be correct, as no universal break in geological continuity can be accepted, it should be found that between the Archean and the clastics there are somewhere gradations. It has been seen in the summary of the literature that Hitchcock, Marvine, Stevenson, King, Winchell, and others, accepting such a sedimentary origin, believe gradations have been found in the Rocky mountain system, in the lake Superior region, and in the Appalachians, between the basal complex and the recognizable clastics. These authors have regarded the fact that as a whole these rocks show lamination as evidence that they were originally sedimentary. A few years ago it was a matter of course that distinct lamination in a rock, however faint, is evidence of sedimentation. Lamination being found in the granite-gneisses, combined with the fact that these rocks graded into the clastics, was taken as conclusive evidence of the original sedimentary origin of the whole.

It is now everywhere recognized, as early shown by E. Emmons and Lieber, that schistose structure is often produced in eruptive rocks; also like structures are produced in sedimentary rocks which have no relation to the original lamination, as early noted by Tyson, E. Emmons, Blake, Adams, E. Hitchcock, Jackson, Jukes, Rogers, and Lieber. E. Hitchcock, E. Emmons, and Lieber traced the actual gradations between schist-conglomerates and crystalline schists, while Mather traced the blue fossiliferous limestones into completely crystalline granular marbles. Laminated or schistose structure in crystalline schists then bears neither for not against a clastic origin.

The manner in which the finely laminated schists and gneisses vary into the coarsely granitoid phases has been admirably described by Jukes in the rocks of Newfoundland, by Lieber and E. Emmons in the rocks of the southern Appalachians, by Hitchcock in the rocks of Massachusetts and Vermont, by Marvine and Stevenson in the rocks of Colorado, by King, Hague, and S. F. Emmons in the rocks of the fortieth parallel, and by Lawson in the rocks about lake Superior. Most of these writers and many others, including Selwyn, approaching the problem from the side of the clastic rocks, have regarded the coarsely crystallized rocks as produced by metamorphism, although in the more granular rocks the process has gone so far as to produce aqueo-igneous fusion. Those who have maintained this origin for these rocks have recognized the fact that they have locally acted as eruptives, although in general the material is thought not to have moved far. Marvine so clearly saw that the facts could be explained in two ways that he says that, while he regards the whole as metamorphosed sedimentary rocks, another observer approaching the field from a different direction, where the evidences of intrusive nature are most manifest, would reach the conclusion that the whole is eruptive. Hitchcock and Stevenson and most of the others are in practically the same position.

The school of geologists that regards massive rocks as metamorphic without any intervening time of fluidity, the granitic and gneissic layers interlaminated with the schistose being selectively metamorphosed, and the fragments of schist and gneiss within the massive rocks as residual unmetamorphosed material, while nearly gone, still has representatives. That the matrix of a fragmental rock could become slowly heated to such a temperature or be subject to such other conditions as are necessary in order that it should crystallize as a coarsely granular granitoid gneiss or granite, and not at the same time destroy the bowlders and pebbles which it contains, seems incredible. The explanation of these rocks and of the interlaminations of granite with slate and schist by metamorphism implies not only that the fragments and the bands of slate and schist have been able to resist the forces of change during the slow processes which have been sufficient to produce coarsely crystalline material adjacent, but that in situ they have continued to resist these forces during all the time required by the matrices to pass once more into ordinary conditions. The processes embodied in such "selective metamorphism" certainly need explanation.

The need of an exact definition of metamorphism is evident. It appears to the writer that it should not be applied to a rock which has actually suffered igneous fusion. Shall it apply to sedimentary material which has been free to recrystallize under aqueo-igneous fusion? May not rocks under pressure beyond the crushing strength of rocks and saturated with hot water recrystallize at a much lower temperature than is required for ordinary fusion? If so, where is the boundary between aqueo-igneous and ordinary fusion? Is there not a transition between the two and does not aqueo-igneous fusion pass by imperceptible steps into ordinary metamorphism? Is there not here a transition between the extremes just as there is between different rock species, between basic and acidic rocks, between organic and inorganic sediments, between fragmental and crystalline rocks, between aqueous and surface igneous rocks.

(2) All or a part of the Archean is considered as of igneous origin, but later in age than the pre-Cambrian clastics. The facts of those who have described downward gradations from unmistakable clastics into a crystalline complex by this school have not been interpreted as above. It has declined to apply the term metamorphism to a product which has become fluent, and has insisted upon its essentially igneous character. Lawson is conspicuous as having recently strongly put this side of the case; but it is noteworthy that Winchell, belonging to the first school, and Lawson, to the second, have had essentially the same facts before them, both having done their work in the same region. The difference is one of definition and emphasis rather than ideas. Both schools regard the granite-gneiss as material which has resulted from a change in the condition of original sediments and has not moved far.

This theory that the Archean or a part of it is the liquefied floor of the clastic rocks has the objection that it is an unverified hypothesis. When once a sedimentary rock has become fluent and is wholly free to crystallize anew how shall the material be identified? To state that such material has not moved far is pure assumption. If the fusion theory is true the average composition of the unfused part of the clastic series and the subjacent material should agree. To obtain average analyses of rocks which vary widely in mineral character within short distances is not easy, but is a thing which must apparently be attempted if this theory is to be maintained, for the writer sees no other way in which an attempt can be made to verify the hypothesis.

Another class of geologists, noting these contact relations between the granitic rocks and the clastics, hold that the former, called by others Lower Laurentian or Archean, are eruptives of later age than the clastics with which they are in contact, without attempting to give any theory as to the source of the material. Here are included Hawes, Hall, Mather, Foster, Whitney, Wadsworth, Rominger, Herrick, and others. Rominger distinctly recognized the granites and granite-gneisses of this kind on the south shore of lake Superior as the subjacent rocks upon which the schists rest. Herrick saw the same relations with reference to his granitic and schistose groups on the north shore. In the last two cases the facts before the writers are precisely the same as those of the geologists of the second school; but, by giving no explanation of the source of the material for the granite-gneisses, they have escaped the difficulty of the unverified assumption that these eruptives represent fused sediments. They fail to explain what has become of the floor upon which the clastics are deposited. Some floor they must have had. Where these eruptive contacts are found the floor has disappeared, and if so the eruptives, if extraneous, must be considered to have eaten up or absorbed it.

The three positions, that the granite-gneiss is selectively metamorphosed material, is due to subcrustal fusion, or is an extraneous intrusive, may be considered to grade into each other. Those who insist on the first have selective metamorphism and contact phenomena to explain. Those who insist on subcrustal fusion may be called upon to identify their material. They can only show the former fused condition by contact phenomena, and contact phenomena are not evidence of progressive fusion, but intrusion. Those who regard the granite-gneiss as intrusives may be asked what has become of the floor upon which the clastics were deposited.

(3) That the Archean is an igneous system earlier than any of the sedimentaries is apparently the conclusion of Emmons, Lieber, and others. These careful observers not only maintained the igneous origin of the granite-gneiss of the southern Appalachians, but traced the gradations between basic schistose rocks and massive eruptives, including hornblende-schist and unmistakable dikes, and drew the correct conclusion, lately regarded as a new discovery, that such rocks are sometimes

metamorphosed eruptives. While the major portion of granite-gneiss and associated rocks were considered older than the oldest clastics, later intrusives of a similar character were recognized. This theory that the fundamental complex is igneous is that of Geikie as to the major part of the Archean of Great Britain and that of many German geologists as to the basal complex of Germany, among whom Lehmann and Roth are conspicuous. Indeed, these last two maintain the igneous origin of all the pre-Cambrian rocks, and Geikie says of the true Archean of Great Britain that with certain possible exceptions it not only contains no material which gives any evidence of ever having been sedimentary material of any kind, but it further contains no material which can be considered a surface volcanic, while in it there are many rocks which are certainly plutonic eruptives.

The geologists of this third school, with the second school, recognize the igneous character of the granite-gneisses having irruptive contacts with the clastic series, but they decline to recognize these rocks as Archean. Such rocks are eruptives. Their age is to be designated precisely as are eruptive rocks which cut Cambrian, Silurian, or Devonian strata.

As bearing in favor of the really igneous character of the Archean is the fact that no case has been demonstrated, except possibly that of the marbles, of the production of a perfectly massive crystalline rock from a clastic without intervening fluidity. Metamorphism, whether the original rock is a massive eruptive or a stratified sedimentary, produces a laminated or schistose rock. If a granitic structure can be taken as evidence of eruptive origin, and we know many eruptive rocks do have such a texture, a very strong case can be made for the eruptive origin of the larger part of the fundamental complex. The line of argument is precisely analogous to that by which the whole has been held to be sedimentary. There are complete gradations from the most completely schistose and laminated phases to the most massive phase. Also bearing in favor of a truly igneous character for the basal complex is the fact that the rocks referred in the first part of this section to the Archean are more nearly simulated by igneous rocks which have irruptive contacts with ancient clastics than by any recognizable metamorphosed sedimentaries. In this connection may be mentioned the occurrences in the Appalachians and in British Columbia of relations between granitic rocks and strata as late as the Carboniferous or Triassic, analogous to those which often prevail between the granite and granite-gneiss and the pre-Cambrian crystalline schists. Here the one class of rock is known to be sedimentary, the other intrusive. It may be said that the actual gradations between the Algonkian and Archean in certain places are evidence that the latter are not igneous rocks earlier than the former; that gradations can be explained between subsequent intrusives and clastics, but not between igneous rocks and sedimentaries of later age. It has, however, been shown that as a consequence of powerful dynamic action two unconformable series, the one of which is composed of material from the other and therefore resembles it in composition, may have developed conformable secondary structures and gradations, the latter consequent upon the induced crystalline character of the clastic series, the original structures being simultaneously obliterated. Also recently Pumpelly has ascertained that subaerial disintegration of the earlier series is an important assistance in the production of such gradations. In certain areas it has been demonstrated that perfect conformity and complete gradation exist between series separated originally by wide unconformities, the earlier of which was probably of igneous origin while the later was certainly sedimentary.

Whatever the origin of the fundamental complex, it is plain that the parts of any given area of it are not all of the same age. The dikes which everywhere cut it are the pipes through which have passed the later eruptives. At the time of the intrusion of these eruptives, large lakes of liquid material may have formed which crystallized as bosses, causing the Archean to contain considerable masses of rocks of really later age. Where these rocks are predominant the material must be classified as a later eruptive; where they are subordinate to the Archean material they are often difficult to separate from it although really later in age. Between the areas which rank as eruptives of later age and the genuine Archean, there are doubtless gradations. Along the zone of contact, if the mass of later eruptive be great, there might be an area which could equally well be placed with the fundamental complex or with the later eruptive. Between the Archean and later eruptives, as between the Archean and undoubted sedimentaries, there are gradations.

The problem of the relations of the Archean as a whole to the overlying clastics is the same as that within the Archean itself. The finely laminated crystalline schists and gneisses, and the granite-gneisses and granites with which they are associated, have contacts in every respect analogous to those occasionally found between the Archean complex and the clastic series. For example, it has been seen that the rocks heretofore called Archean on the north shore of lake Huron comprise two parts. One part is older than and lies unconformably below, yielding fragments to the original Huronian. The other part has relations with the clastics of the character just considered with transition phenomena. If this material is an extraneous intrusive it is a post-Archean eruptive. If in situ it represents a portion of the pre-Huronian floor completely metamorphosed by selective metamorphism, or by aqueo-igneous fusion, it can fairly, according to the first and second school, be called a part of the Archean.

It is plain from the great diversity of opinion as to the origin of the Archean rocks, and from the fact that many of the opinions are beliefs rather than verified conclusions, that we have no definite knowledge upon parts of the subject. That there are comparatively few or no wholly massive rocks in this complex is precisely what would be expected under any theory. Its history is too long. Whether originally igneous or aqueous, it could not be hoped that there would be found the characteristic lithological forms of igneous or aqueous agencies. Many or all of these rocks, not only subject to the movements which have taken place since Paleozoic time, but to the movements which have occurred in the far greater length of previous time—if not too deeply buried to be beyond the influence of the outer foldings, in which case they were buried beyond the crushing strength of rocks—were latently plastic, and were probably at a high temperature. If originally massive and igneous in the ordinary sense, dynamic action has obliterated the regularity of the arrangement of the constituent particles and has given them a more or less laminated or schistose structure. If sedimentary, all trace of that original sedimentary structure has been obliterated by the repeated foldings, contortions, and perhaps high degree of heat to which they have at various times been subjected. Of a necessity, through this complex have passed all subsequent eruptives. Doubtless at various places and times in its history, parts of it have become practically fluid and from this condition it has again crystallized in the forms characteristic of eruptives.

DELIMITATIONS OF ARCHEAN.

It is generally accepted that the Archean has no limit downward. It is the oldest system, and surely includes, if such rocks exist, all of the original crust of the earth. But as denudation progresses, material far within the earth approaches its surface, not by intrusion but by gradually rising as a whole. Before reaching the surface the material has become crystallized. This original crystallization may have taken place in or even later than Algonkian time; hence, if these rocks are to be considered as belonging to the age in which they crystallized, the Archean grades below into the Algonkian, even as it is believed in places to grade above into the Algonkian. The truth of this position is not lessened by the fact, if fact it be, that the earth as a whole, subject to sudden strain, acts as a rigid body. Even if true, it is equally certain that the crust of the earth, under continued strain, adapts itself to it, thus showing real plasticity. But in any case it can not be assumed that the rock material deep within the earth, under pressure far beyond the crushing strength of any known material, and at a high temperature, exists as crystallized minerals. We only know that it has these forms when the material rising by erosion nears the surface.

The upper limit of the Archean is not easy to define, and the task is rendered more difficult because geologists are not agreed upon the origin of the Archean. If either the sedimentary or the subcrustal fusion theory of its origin be accepted, there will be found gradations from rocks constituting the ancient complex described to rocks having like relations with clastics of Algonkian and post-Algonkian time. Upon either of these theories, if sedimentary rocks are only buried deep enough, they will pass into crystallines by progressive metamorphism or by subcrustal fusion, just as do rocks of Cambrian and post-Cambrian age. This the elder Hitchcock so clearly saw that he distinctly said that the so-called Laurentian granites and gneisses of Vermont are probably, in part at least, not older than the fossiliferous series. If the Archean be made to include all the thoroughly crystalline rocks below pre-Cambrian clastics, it includes rocks the age of which varies from Algonkian to pre-Algonkian. This anomaly is perhaps best met by making a more or less arbitrary division between Archean and post-Archean crystallines. The natural theoretical plane to choose is the beginning of life; that is, to include in the Archean all truly azoic rocks. While this suggestion has a plausible sound, we must believe that the dawn of life was very gradual and that its traces in its early stages are exceedingly sparse, so that there would be great, if not insuperable difficulties in its practical application.

If the third theory, that the Archean includes only pre-sedimentary rocks, be correct, its upward limit is easy to define; the Algonkian begins for each region at the time of the deposition of the first sedimentaries. But there are those who deny the existence at the present time of any such ancient rocks, although they concede their existence at one time, and they believe that the Archean as thus defined represents a vast lapse of time in the history of the earth. This denial of the present existence of any rocks of greater age than the oldest sedimentaries is of course a pure unverified assumption defended on the ground of probability. If the original crust of the earth be defined as including more than the first outer skin, it is a question whether the converse proposition is not equally probable. Even if the position be true, the school that believes in the igneous origin of the Archean would still have a large mass of rocks for the Archean by shifting their ground so as to include in it all the material which in the slow process of inward crystallization has now reached the surface of the earth, not by intrusion in the rocks above, but by erosion. This position would, however, be controverted by those who regard such rocks as plutonic and belonging to the age of their equivalent sedimentaries. But in the nature of the case it is not possible to designate the particular age to which these rocks belong. That there exists upon the surface of the earth a part of the original crust of the earth, or its downward continuation by later cooling, can hardly be doubted; and since these can never be assigned to any definite period of sedimentaton they might well be considered as Archean. At any rate they are a class by themselves which, if not here placed, can not be referred to any of the geological periods. Further, this class of rocks when in contact with detritals of whatever age, by the very hypothesis of their origin must rest unconformably below them. The coincidence that so frequently: if not always, there is really a great hiatus between the ancient sedimentaries and the basal complex might be urged as evidence of the truthfulness of this hypothesis. It is interesting here to remember that Emmons defined pyrocrystalline rocks as those due to the consolidation of the earth's crust, which rocks were said to increase in thickness by additions below.

Sedimentation must have begun in the earliest seas, while upon parts of possible continental areas volcanic materials alone were still accumulating. These latter, in accordance with the definition, would belong to the Archean. There would be in this case no positive equating one with the other. When later, upon these Archean rocks contemporaneous with the earlier Algonkian rocks, sedimentaries began to form, this would be for this region the opening of the Algonkian. However, it is not impossible that all such supposed contemporaneous Archean materials may have been carried away by erosion. Certainly this would have been the case with a large portion of them, and it follows that this difficulty may be rather theoretical than practical.

The banded and contorted granite-gneiss which serves as a background for the Archean may not improbably be the part which has the origin above suggested, while the other parts of the complex may be due to subsequent intrusives; the whole being kneaded into their present extraordinary complex relations by repeated dynamic movements and other metamorphic influences. This igneous theory of the origin of the Archean, modified so as to include the pre-sedimentary original crust, if any remains, and the deeper crust which has reached the surface by denudation, perhaps more nearly covers the facts than any other as to the relations of the Archean to subsequent rocks, its complex lithological character, the relations of the rock phases to each other, and the long history written in the strained, altered, and broken mineral constituents. It accords with the idea held by Irving, Bonney, and others, that this earliest crystalline complex was produced under conditions differing from those of the rocks of any subsequent period.

But the difficulties in the theoretical delimitation of the top of the Archean are so great that I prefer to confine myself to a statement of some possible solutions rather than to commit myself to any theory, although now inclining toward the third theory modified as suggested. Although the obstacles are not nearly so great in delimiting later periods, the difficulties of making an exact definition for the Silurian, Devonian, or Carboniferous are so considerable that almost any of those given have been found to controvert the facts of some locality. If this is the case with reference to these later periods in which so much more is known, it should not be surprising that the obstacles to an accurate delimitation of the Archean are at present apparently insuperable.

But while it is impossible to make a wholly satisfactory theoretical definition of the Archean, it is frequently easy in the field to say with a great degree of probability what rocks are Archean and what post-

Archean. For instance, in the Arizona region, as has been seen, above the typical Archean complex there is the most profound unconformity, upon the upper side of which the rocks are readily recognized clastics. From the writer's point of view the same thing is true for a large part of the lake Superior region. In the Uinta and Wasatch mountains, again, below the quartzites of probable Algonkian age, is a great unconformity, and then appears the implicated Archean. In certain other regions the separation of the Algonkian and the Archean is a matter of exceeding difficulty. As representative of this class of cases may be taken the Front range of Colorado, along the east side of which are unmistakable clastics, with an apparent gradation between them and the crystalline complex. In the Appalachians, again, where for the most part the oldest clastic rocks recognizable are Cambrian, it can not be said whether the crystalline complex below is Algonkian or Archean. Here the separation of the Cambrian from the pre-Cambrian has been accomplished only by a minute and laborious study. The two appeared to be in conformity and to grade into each other. It is only recently that this gradation has been shown by Pumpelly to be consistent with a great unconformity between the two. The causes producing this gradation between the Cambrian and pre-Cambrian in Massachusetts (post-Cambrian dynamic action and pre-Cambrian disintegration) may also be found to explain the conformities and gradations between the Algonkian and Archean.

While it is then not easy to define the Archean, it is plain that the discrimination in the field between Archean and Algonkian is a real one and should continue to be applied even if its exact theoretical meaning can not be said to be certainly known. It has been the custom in the past to refer to the Archean practically all crystalline rocks, with many semicrystalline rocks which seem to be old, or the age of which was not determined. Under this practice vast areas in the Appalachians have been referred to the Archean, which are now being placed in the Cambrian, Devonian, and Carboniferous. Doubtless in the same way many other areas which have been placed in the Archean upon closer study will be removed from it and the rocks distributed from the Algonkian upward. At this point a reform in geology is needed. If, for instance, the oldest rocks of clearly recognizable age are Triassic, and these Triassic rocks rest upon a complex, the structural relations of which are not studied in detail, this complex should be denominated pre-Triassic rather than Archean. A large part of the difficulty in getting to understand from the literature the actual facts as to the occurrences and relations of the crystalline rocks has arisen from this practice of using the Archean as the dumping ground for everything of unknown age.

STRATIGRAPHY OF ARCHEAN.

In characterizing the Archean the methods applicable to its subdivision are clearly pointed out. If no part of it is demonstrably sedimentary, structural methods can not apply. Its subdivisions must be made upon purely lithological grounds. If a part of it is demonstrably eruptive the relative ages of these parts may often be ascertained and all are necessarily newer than the part not recognized as eruptive, else these could not be shown to have this origin. Many attempts to apply stratigraphical methods to parts of the Archean have been made, but they have not thus far been successful. Such attempts have been based upon the belief that foliation represents sedimentation, but even working upon this erroneous basis it has been stated that the structures are so complicated that little progress has been made. So far as attempts to apply stratigraphical methods to this fundamental complex are concerned the conclusions of Whitney and Wadsworth are very largely true. If their review of the "Azoic rocks" had been confined to this basement system, which is perhaps truly Azoic, the conclusion as to its indivisibility on a structural basis would have plausibility.

The only division generally applicable to the Archean warranted by present knowledge is its separation into (1) fine grained mica-schists, feldspathic mica-schists (technically gneisses), hornblende-schists, horn blende-gneisses, etc; and (2) the granites and granitoid gneisses with their associates. The first class is generally dark colored, the second light colored. The lithological affinities of the second are with the igneous rocks. As already indicated, the change from a granite-gneiss area to a schistose area is not infrequently a transition. In passing from the schists to the granites often veins or dikes of granite are first found, or interlaminations of granite-gneiss with the schist. After a time the schistose rocks and granite-gneiss are about equally important. Proceeding onward the granite-gneisses become predominant. These relations are precisely those already described and interpreted by one school to mean that the granite-gneisses are extraneous intrusives, by another that they are the aqueo-igneous fused sedimentary beds in situ, and by a third that they are selectively metamorphosed beds. To designate the gneissoid granite part of the Archean the term Laurentian has always been employed and is now generally restricted, the finely laminated crystalline schists being commonly referred to the Huronian. Laurentian under this usage is made to include the implicated granite-gneiss of the basal complex, somewhat regularly laminated granite-gneiss, and also many areas of nearly massive granite, a part of which latter may be and probably is of later age than the former. The first is clearly Laurentian. It is equally clear that the granite-gneisses known to be of later age than Algonkian clastics, like those described by Lawson northwest of lake Superior, should be excluded from the Laurentian. To place these rocks here is to introduce a new principle in geology; i. e., it is giving rocks of recognized eruptive origin a separate term when they should be given the name of their contemporaneous clastics. The eruptives which are contemporaneous with the Tertiary rocks are so named. Rocks which cut Tertiary rocks and can not be more accurately located are called post-Tertiary. In like manner the granite-gneisses which are recognized as eruptives of later age than sedimentaries should be assigned if possible to the age to which they belong, and if not, their limitations expressed. This restriction of the term Laurentian will undoubtedly eliminate from it large areas of rocks which have heretofore been recognized as Laurentian, but to include both the original granite-gneiss and later granite-gneisses under a single time term is but to deliberately continue a confused classification after facts have been discovered which render it unnecessary. All were first referred to the Laurentian only because a discrimination as to age had not been made between them.

It appears to me that the best use which can now be made of the old term Laurentian is to restrict it to the Archean granite-gneisses, including in it no rocks which traverse Algonkian sedimentaries. This use of the term Laurentian is different from the original proposal of Logan. The original Laurentian is largely and, with the exception of the great lower "orthoclase" gneiss, perhaps wholly a series of detrital origin, being composed of limestones, quartzites, and regularly laminated gneisses which almost certainly are altered clastic rocks. Dawson (Sir William) in a late paper insists that the bedded sedimentary character of this and adjacent series can not be doubted. It was natural in the days in which lamination of any kind was by most geologists regarded as proof of sedimentation, that the term Laurentian should be carried over to the underlying thoroughly crystalline granitoid gneisses. The known area of this latter class has now become so great that the clastics of the type series and other clastics here placed are insignificant in comparison. The Hastings series, afterwards connected by Vennor with the original Laurentian, was first referred by him to the Huronian, and there is little doubt that this series would, if newly found in the great expanse of northern Canada, be thus placed. This is still more emphatically true of the so-called Laurentian clastics of lake Nipissing, which were referred to the Huronian by Selwyn. That two groups of rocks were included in the Laurentian of Logan, that author early recognized by his subdivisions: Lower Laurentian, including the basal granitoid formation; and Upper Laurentian, including all the limestones, etc. The later work of the Canadian survey has emphasized the reality of this division. In recent years the practice of the Canadian Survey has been to include all or nearly all of the more regularly laminated rocks which may be positively asserted to be of clastic origin, as well as many of which this assertion can not be made to the Huronian. The difference between the Laurentian of lake Superior and that of Logan's original area was early noted by Macfarlane, Brooks, and Rominger. The last two went so far as to suggest that about the lake Superior region it is probable that the Laurentian of eastern Canada is not represented. That possibly the fragmental rocks of the Laurentian of the East may be equivalent to the more crystalline of the fragmental rocks about lake Superior, here called Lower Huronian, was early suggested by Chamberlin. Excluding from the Laurentian the small areas of clastics here referred, and applying the term to the vast areas of rock referred to this system during the last forty years would seem now to be the preferable course. This usage accords with the principles of good nomenclature in that it makes the Laurentian a definite unit and avoids the anomaly of including under one term two radically different groups of rocks.

The fine grained, dark colored schists belonging to the basal complex and antedating the Algonkian should have a name assigned to them coordinate with Laurentian as the other main lithological division of the Archean. If Lawson's Coutchiching series belongs here this term has priority for this place. Lawson, however, regards this series as probably sedimentary, although upon this point additional evidence is needed. If it turns out that the Coutchiching is sedimentary under the classification proposed in this paper the series belongs with the Algonkian. As a provisional name for this second division of the Archean is proposed the term Mareniscan. This term, like Laurentian, is a geographical one derived from Marenisco township, Michigan, south of the Gogebic range, where these rocks have a typical development.

The Archean as a whole naturally occupies a group place in the classification, and its Laurentian and Mareniscan would be systematic in their value if they were structural terms. But until the Archean can be separated on a structural basis, if it ever can be, it will be necessary for the purposes of atlas sheet mapping to treat the group as a unit, except that lithological divisions may be made. With reference to Archean, we are in the same difficulty as with Agnotozoic or Proterozoic, considered below. This group can at present have but a single system division, the Algonkian, because we are not yet able to subdivide the group into systems which can be shown to be general for the whole of America.

The anticlinal structure described as generally characteristic of the Archean ranges of the west has been based upon the belief that foliation represents bedding, and also on the obsevations that the overlying sedimentary rocks often dip away from the axes. The anticlinal structures of the sedimentary rocks and that of the Archean are independent questions. If the Archean as a whole be regarded as of igneous origin, it would be expected that a gradation from massive rocks in the cores to schistose rocks upon the flanks would be found, for these outer zones are the places where the most powerful effects of dynamic action are felt, and also the parts where greater interior accommodations of the constituent particles are necessary. In dynamo-metamorphic eruptives of post-Archean age precisely these relations prevail. The determination of the structure of the Archean cores must wait until the origin of the Archean has been determined; in short, until it is known whether structural methods are applicable at all.

NECESSITY FOR A GROUP BETWEEN CAMBRIAN AND ARCHEAN.

The Olenellus fauna is taken as the base of the Cambrian. The reasons for thus delimiting the Cambrian below are fully considered by Walcott in one of this series of correlation papers and will be summarized on a subsequent page. His results are accepted. The Cambrian fauna in development is far, some biologists say nine-tenths of the way, up the life column. This statement, if accepted, implies a prior life of vast duration.

Just as another period of life has succeeded the Cambrian, another has preceded it. The progress of paleontologic knowledge has of late been downward. Before there was a recognized Cambrian there was a well known Silurian, and it is probable that when all parts of the world become geologically known other faunas will be discovered below the Cambrian as distinctive in character as the Cambrian is from the Silurian. If this be done, definite information will be available to correlate rock series of different parts of the world in the time place between the Cambrian and Archean.

If the condition of the globe was such that life existed in pre-Cambrian time, it also was such that stratified rocks could be deposited not unlike those of later times, so that the only question which arises is whether any of these stratified rocks now remain in such a condition as to be recognizable. The foregoing pages and the literature summarized give a mass of evidence upon this point which is overwhelming. Such intervening clastic series do exist below the Olenellus fauna in many regions in North America, and in some cases the volumes of rock and great intervening erosions represent a lapse of time which may be not inaptly compared with all subsequent time. If geological history were to be divided into three approximately equal divisions, these divisions would not improbably be the time of the Archean, the time of the clastic series between the Archean and the Cambrian, and the time of the Cambrian and post-Cambrian. In this connection it is well to recall that many years ago Logan suggested that the thickness of the Laurentian and Huronian may surpass that of all succeeding formations, and the appearance of the so-called Primordial fauna may be considered a comparatively modern event.

It is imperative that some term shall be available to cover the great mass of rocks between the Cambrian and Archean. Irving was the first to realize and urge the necessity for such a term and proposed for it Agnotozoic. This term implies the existence of life in this system, and the evidence upon this point is conclusive. Life is indicated by the presence of thick beds of graphitic limestones, beds of iron carbonate, and by great thicknesses of carbonaceous shales, which are represented by graphitic schists in the more metamorphosed phases of the rocks. It has been urged by Whitney, Wadsworth, and others that the limestone and graphitic schists may have an origin other than organic. Whitney and Wadsworth have gone so far as to say that there is no valid evidence of life in any pre-Potsdam rocks. This was, however, before it was generally recognized that the Potsdam is Upper Cambrian and that an abundant Cambrian life extends far below. If it were true that these limestones and ore beds are no evidence of life (and it may be admitted that another origin is possible without implying that it is probable), it will hardly be maintained that the hydrocarbons which occur so abundantly in the little metamorphosed shales of the Huronian about lake Superior are other than of organic origin, and, if so, the graphitic schists which stand in the same great system in the geological column are in all probability only these hydrocarbonaceous shales in a more altered condition. However, we are not obliged to depend upon the presence of these varieties of rocks as the only evidence of life. Whether the *Eozoon canadense* found in the original Laurentian of Canada is of organic origin will not be discussed here. Its literature is voluminous and it is a question which concerns the paleontologists. It is doubtless true that many of the specimens which have been called Eozoon are results of the forces of crystallization; but, admitting this, it does not follow that all of the material called Eozoon is of this character. Passing by this question, the pre-Cambrian fossils described by Walcott in the Grand canyon of the Colorado include: "A minute Discinoid or Patelloid shell, a small Lingula-like shell, a species of Hyolithes, and a fragment of what appears to have been the pleural lobe of the segment of a trilobite belonging to a genus allied to the genera Olenellus, Olenoides, or Paradoxides. There is also an obscure Stromatopora-like form that may or may not be organic."

A Lingula-like shell has been found by Winchell in the pipestones of Minnesota. Selwyn has described tracks of organic origin in the Animikie (Upper Huronian) series of lake Superior. Murray, Howley, and Walcott found several low types of fossils in the pre-Olenellus clastics of Newfoundland.

That these fossils are of organic origin can not be doubted. But while many will admit the clastic character of the great groups of rocks considered and the organic origin of the forms mentioned as well as the carbon of the carbonaceous shales and schists, they will say that these are merely evidences that the rocks in which they lie are Cambrian. The reply to this is that it is a question of nomenclature. If it be premised that all clastic and fossiliferous rocks more ancient than the Olenellus horizon are Cambrian it is useless to try to prove that there are pre-Cambrian clastic rocks which bear life. It is, however, necessary to recognize that the carrying downward of the term Cambrian to cover not only the great thicknesses of rocks which are now included within it, but all pre-Olenellus clastics, will probably make the Cambrian as great as or greater than all the subsequent periods put together. That this is inadvisable is plain, and the clastic rock masses below the Olenellus fauna are so enormous that the proposal to introduce a general term like Agnotozoic as the equivalent of Paleozoic, Mesozoic, Cenozoic, to cover this great group is a conservative one. Irving foresaw that the term would be objected to because sooner or later the life will become to a greater or less degree known, and he suggested as an alternative for Agnotozoic, Eparchean in contradistinction to Archean, which was reserved by him to cover the fundamental complex. As the character of the life of this group is already beginning to be known, it seems to me that the term Proterozoic, considered for the place by Irving, but rejected, is preferable to either Agnotozoic or Eparchean.

In a conference of the members of the U. S. Geological Survey, called by the Director at Washington, these terms were discussed with reference to atlas-sheet-mapping, although there was no question on the part of any one as to the necessity for some such term. Recognizing the impracticability of the certain correlation with one another of the one or more pre-Cambrian clastic series which occur in the various regions, and recognizing the fact that for use in mapping a uniform plan must be adopted, it was suggested that a term of the same class as Cambrian, Silurian, and Devonian should be selected for rocks here included, and to occupy this place the term Algonkian was proposed and accepted. The proposed general scheme of classification for the lower part of the geological column is then as follows:

Paleozoic	Carboniferous. Devonian. Silurian. Cambrian.
Agnotozoic, or Proterozoic	Algonkian.
Archean	Archean.

The introduction of the term Algonkian has been objected to on the ground that it will supersede the older term Huronian. In answer to this it may be said that Huronian has not been generally used as Algonkian is defined, and it therefore does not supersede this term. Huronian will be retained for certain of the clastic series of Lake Superior and Canada, as well as for rocks in an equivalent position in other parts of North America and Europe, if such equivalence can be determined, just as before Algonkian was introduced. The Huronian will stand as one of the great series of rocks which together make up the Algonkian.

DELIMITATIONS OF THE ALGONKIAN.

The further back we go in the history of the world for any given region the more frequent have been the changes through which a rock stratum has passed, and therefore there is increasing difficulty in determining bounding planes with sharpness, although in different regions rocks of the same degree of metamorphism may differ vastly in age.

The truth of this is well illustrated by comparing the eastern and western regions of the United States. In the former powerful dynamic movements have occurred until late in Paleozoic time, as a result of which the Cambrian, Silurian, and Devonian rocks over large areas have not been separated from the pre-Cambrian. In certain areas this separation has been accomplished, but only by the most accurate and painstaking application of modern methods. In parts of Massachusetts and Vermont the areas covered and the results reached have involved an enormous amount of labor, although of late paleontology has been an important help in unraveling the problem. Under these circumstances how much more difficult would one expect it to be to separate the pre-Cambrian clastic series from the Archean!

In parts of the West, where no close folding has occurred since Cambrian time, it is easy to separate the Cambrian from the pre-Cambrian, and in regions in which metamorphosing influences have not been at work for a still longer time it is easy to separate the pre-Cambrian clastics from the Archean. But in other regions this separation is made with the greatest difficulty, and doubtless over large areas this will never be satisfactorily done. Just as in the Appalachians, in parts of which it may be impracticable to separate the Cambrian rocks from the pre-Cambrian clastic series, if such exists, so it will be for a long time impossible to decide in some regions upon sharp boundary lines between the pre-Cambrian clastics and the Archean. Giving full force to this position, it is no reason why the discrimination should not be made where it can be.

Recent work in petrography has demonstrated that dynamic movements and environment, not time, are the important elements in the obliteration of clastic characteristics. Dynamic movements also destroy the evidences of discordances between series where there have been real unconformities. This destruction of the evidence of structural breaks comes about largely as the result of an approaching parallelism of bedding, caused by the close folding, but far more important than this is the production of a common cleavage and foliation with the simultaneous development of crystalline schists from the newer series. As a consequence basal conglomerates are often almost the only means of discriminating between the newer and the older series, and if the metamorphosing influences are powerful enough to destroy the pebbled character of such beds, changing them into schists or gneisses, as has occurred in many places in the Cambrian of the Appalachians, this means of detecting a break between series is also lost. The problem is rendered still more difficult because of the fact that often when there is a real unconformity there has been originally no basal conglomerate. At many localities in the far West the basement fossiliferous series are built up of the constituent minerals of the underlying rocks rather than of large fragments of them, and even when not folded have sometimes so closely simulated the original rocks that geologists have been at a loss to determine at what plane the clastics end and the crystallines begin. If it has proved difficult to separate the unfolded clastics from underlying crystallines how much more difficult must it of necessity be to separate series that have together been subjected to intense and perhaps repeated dynamic actions.

The Algonkian has been defined as including all recognizable pre-Cambrian clastics and their equivalent crystallines. In the consideration of the character, origin, and delimitation of the Archean the lower limit of the Algonkian has been given. Its basal plane is the lowest of the recognizable clastic rocks. It has been seen that there are great differences in the ease of recognition of the basal Algonkian plane in different regions. In the Uinta mountains, in the Grand canyon region of Arizona, in portions of the lake Superior region, in the original Huronian region, and elsewhere, between the Algonkian and the Archean, there are great unconformities, above which are the readily recognizable clastic rocks, and below which are the thoroughly crystalline basal complexes. Even in many regions in which there have been repeated foldings since Archean time, and in regions obscured by eruptive activity, it is perfectly clear that a large part of the rocks are clastic and belong with the Algonkian, while other parts have all the characteristics of the fundamental complex. Occupying an intermediate position are occasionally found areas of rocks which can not certainly be placed with the Algonkian or Archean, but this difficulty is not peculiar to this separation any more than to other general recognized planes, such as that separating the Cambrian and Silurian in folded districts. Many of the members of the Canadian Geological Survey have described the Huronian and the Laurentian as conformable, with gradations between the two. This apparent accordance and gradation is in many cases due to the fact that placed with the Huronian are many rocks which would under the use of the terms here proposed be regarded as Archean. In other cases there are apparent conformities and gradations between undoubted clastics and the underlying rocks having all the characteristics of the fundamental complex. The significance of these gradations is discussed in another place, where it was seen that they are not inconsistent with genuine structural breaks.

It has been stated that the reasons for placing the base of the Cambrian at the Olenellus fauna are considered by Walcott in this series of correlation papers, and that his results are here accepted. It is, however, to the point to consider whether this horizon answers equally well for the upper limit of the Algonkian. Evidently all the arguments brought forward by Walcott for placing this fauna as the base of the Cambrian apply as well for considering the horizon below this as uppermost Algonkian; for the widespread character, both European and American, of the Olenellus fauna makes it a particularly easy one to identify and therefore valuable for the purposes of discrimination. In the lake Superior region and in many other localities above the upper Algonkian are unconformities, the first of the Cambrian being middle or upper. In other regions, as in Newfoundland, the upper Algonkian is marked by an unconformity, and the formation immediately above bears the Olenellus fauna. This is the most favorable and clear case. In the Wasatch and several other ranges of Utah and Nevada, in British Columbia, and probably in the southern Appalachians, below the Olenellus fossiliferous Cambrian are conformable series of quartzites and slates of great thicknesses. Are these lowest Cambrian or uppermost Algonkian? May not the Olenellus fauna in the future be found to extend downward through a greater or less thickness of these apparently barren rocks? If in any region the fauna be found to extend downward for a long way, it is probable that species and genera characteristic of the Olenellus horizon as now known will drop out and others appear which are different. The Olenellus would thus grade into a pre-Olenellus fauna. Such a gradation will doubtless somewhere be found, while in other regions the change from an Olenellus fauna to one of a pre-Olenellus type may occur abruptly. In either case there will finally appear a fauna which is not the present known Olenellus fauna, but which is as different from it as is the Cambrian from the Silurian (Ordovician). As the term is here used, such a fauna is pre-Cambrian, and the rocks containing it are Algonkian. In the following paragraphs great barren inferior series conformably below the known Cambrian are placed with the Algonkian on the ground of probability. The presence of an abundant lower Cambrian life at a certain horizon within the conformable succession, with apparent complete absence of life in immense thicknesses of rocks conformably below, which, so far as lithological character is concerned, are equally likely to bear fossils, throws the weight of evidence in favor of the Algonkian age of these rocks. It is, however, more than probable that some part of the conformable downward extensions of the Cambrian which are here provisionally referred to the Algonkian will in the future be found to belong with the post-Algonkian.

The newest Proterozoic or Algonkian rocks of different regions may stand in different positions, just as the superior rocks of the Paleozoic may in any given region be Cambrian, Silurian, Devonian, or Carboniferous.

DIFFICULTIES IN ALGONKIAN STRATIGRAPHY.

Since among the pre-Cambrian clastics, paleontology is not yet available in correlation, it is exceedingly difficult to make widespread subdivisions of the Algonkian, such as are made in later time. The difficulty is further increased by the unequal metamorphism in different regions of series of the same age. The Algonkian is in just such a position as regards wide correlation of its constituent series as would be the Paleozoic and Mesozoic if their known fossil contents were so small as to be useless for the purposes of correlation. The structure of individual districts and regions could be worked out and the formations correlated, but the attempt to equate the Cambrian, Silurian, Devonian, or Carboniferous of one region with rocks of the same age in a far distant one would be an almost hopeless undertaking. In the Carboniferous the beds of coal would serve as an important guide, but if implicitly followed and no fossils were available the Triassic of Virginia, the Carboniferous of the central United States, and the Cretaceous of the west would be placed together. If the iron carbonate formations of the Algonkian in the lake Superior region, which appear to be the most characteristic of any one kind of rock, were followed as a guide, the results would probably be as far from the truth.

We may, perhaps, go so far in some cases as to correlate series which occur in different districts of the same region when a set of characteristic formations forming the series occur in like order and the series as a whole is in the same relative position to overlying and subjacent series, one or both of which are known to be identical in both districts. It is probable, when several pre-Cambrian series occur of the same general character, with like relations to each other and to the Archean and Cambrian, and not so far apart as to be outside of the same geological basin, that a provisional correlation is warranted. While, then, it is not practicable to subdivide the Algonkian into general systems which shall cover the whole of North America, it is often possible so to do in a single geological basin, or in adjacent basins in which the relations of the separate formations and series can be worked out.

Before considering the principles applicable to the subdivision and correlation of the Algonkian series, it will perhaps be well to review briefly the regions in which pre-Cambrian rocks occur, and indicate their character and relations, as well as their relations to the Archean. The order followed is that of the review of literature. No attempt is made to give detailed evidence for the conclusions stated. For this it will be necessary to refer to the fuller accounts of the several regions in the previous chapters.

THE ORIGINAL LAURENTIAN AND ASSOCIATED AREAS.

In this region are Algonkian rocks at the following localities: Hastings district, lake Nipissing, Ottawa river, and Upper St. Lawrence river. The Grenville area of the Ottawa is the original Laurentian type district and the one mapped in most detail. While the maps do not connect these areas, the similarity of their clastic rocks is such as to indicate a present or former continuity, with the exception, perhaps, of those of lake Nipissing. The clastics consist of interstratified limestones, quartzites, conglomerates, green slates and schists, mica-schists, hornblende-schists, and regularly bedded gneisses, together estimated to be thousands of feet thick. Associated with these are diabasic and chloritic rocks, both massive and schistose.

In the Hastings series there are found considerable areas of peculiar volcanic clastics. Below these rocks is a great complex in every respect like the Laurentian Archean as above defined. This latter system, called usually Lower Laurentian, occupies the main area of the region, and the clastics are in a series of troughs within it. What the relations are between the clastics and the fundamental complex has not been definitely made out, although Vennor believes that between the two is an unconformity, and that the clastics are infolded patches. The evidence given for this is, however, rather meager, and doubtless almost as good a case could be made out with present facts for the theory of an irruptive contact between the crystallines and the clastics. The Labradoritic rocks (gabbros) found in this region need not be considered in the stratigraphical succession, as they are eruptives of later age than the clastic series. Besides this eruptive, other acid and basic eruptives cut the bedded succession.

To the clastics, Logan, Murray, Vennor, and all who have worked in this region recognized that ordinary stratigraphical methods could be applied. The persistence of the bands of limestones is such as to enable them to be traced for long distances. Although the problem was a difficult one, a detailed mapping, with sections, has been submitted for a small part of the area. The structural relations and correlations which Vennor first gave differ greatly from his final ones, and it may be that even in the areas in which detailed mapping was attempted that serious mistakes had been made; but if this be true, the region is in no respect different from any other in which the structure is difficult.

All of the pre-Cambrian rocks here found were supposed by the Canadian geologists to be lower in the geological column than the Huronian of lake Huron. Upon the last point no positive evidence is at hand. The two rock series do not come together. In the most western Hastings district of the Laurentian, the clastics, in lithological character, degree of crystallization, and amount of folding are intermediate between the Laurentian and Huronian of the type areas. At first the Hastings clastics were correlated by Vennor with the Huronian, and with this correlation certain of the official Canadian geologists now agree, but afterwards they were traced with breaks of not very great distances to the original Laurentian area and have always been thus mapped.

THE ORIGINAL HURONIAN.

The Original Huronian of the north channel of lake Huron consists of comparatively little-altered quartzites, slates, slate-conglomerates, graywackes, cherts, and limestones having a total thickness of 18,000 feet, counting considerable masses of interstratified greenstone which are recognized as eruptives. Recent observations render it probable that these rocks are to be divided into two unconformable series, the lower of which is 5,000 feet and the upper 13,000 feet thick. The first would thus be properly designated as Lower Huronian and the second as Upper Huronian. Although cut locally by later granites, the lowest member of the inferior series is separated from the basement complex by a great unconformity. The upper members rest unconformably below the Potsdam sandstone. The upper series is so gently folded that the careful work of Logan and Murray enabled them to map these rocks in detail and to work out their structure. This has been done for a considerable district with as much certainty and accuracy as in many areas among the fossiliferous rocks. The rocks were divided into a number of formations, which were found to be persistent throughout the district. They were traced as a broad belt for several hundred miles in a general direction northeast. Along the Canadian Pacific railway as far as Sudbury and in the vicinity of Sudbury more than a general study of this great area has been made. The clastic rocks of this part of the region have the same general character as the type district, but in the Sudbury district there are peculiar contemporaneous volcanic clastics. In the little studied remainder of the region, as mapped, numerous granitic and gneissic areas are included, some of which may be subsequent intrusives, but many of which probably represent the underlying Archean.

LAKE SUPERIOR REGION.

In the lake Superior region, between the Archean and the Potsdam sandstone, the great Algonkian system is subdivided into three series, which are separated by very considerable unconformities. The lowest series is closely folded, semicrystalline, and consists of limestones, quartzites, mica-slates, mica-schists, schist-conglomerates, and ferruginous and jaspery beds, intersected by basic dikes, and in certain areas also by acid eruptives. It includes volcanic clastics, often agglomeratic, and a green chloritic, finely laminated schist. The thickness of this series has not been worked out with accuracy, but at its maximum it is probably more than 5,000 feet. As the term Huronian has been for many years applied not only to the Upper Huronian series, but to this inferior series about lake Superior, it is called Lower Huronian.

Above this series is a more gently folded one of conglomerates, quartzites, shales, slates, mica-schists, ferruginous beds, interbedded and cut by greenstones, the whole having a maximum thickness of at least 12,000 feet. In the Animikie district a fossil track has been found, and in the Minnesota quartzites lingula-like forms as well as an obscure trilobitic-looking impression. Carbonaceous shales are abundant. In its volume, degree of folding, and little altered character the Upper Huronian is in all respects like the upper series of the original Huronian, and can be correlated with it with a considerable degree of certainty. Above the Upper Huronian is the great Keweenawan series, estimated at its maximum to be 50,000 feet thick, although its average thickness is much less. Its lower division consists largely of basic and acid volcanic flows, but contains thick beds of interstratified sandstones and conglomerates, especially in its upper part. The upper division, 15,000 feet thick, is wholly of detrital material which is largely derived from the volcanics of the same series.

The unconformity which separates the Lower Huronian from the Upper Huronian and that which separates the latter from the Keweenawan each represents an interval of time sufficiently long to raise the land above the sea, to fold the rocks, to carry away thousands of feet of sediments, and to depress the land again below the sea. That is, each represents an amount of time which perhaps is as long as any of the periods of deposition themselves. In parts of the region the lowest clastic series rest unconformably upon the fundamental complex, but in certain areas the relations have not been ascertained. The upper of the three clastic series, the Keweenawan, rests unconformably below the Cambrian.

In the lake Superior region it has been possible with a considerable degree of certainty to refer the detached areas of pre-Cambrian clastic rocks to one or another of the three series mentioned, although there have been sharp differences of opinion with reference to certain of the areas. It has been possible further to subdivide the series into formations, some of which have a widespread extent within the region. The best results in correlating the subdivisions within the series have been reached in the Penokee and Animikie districts.

Correlations of series in this region have been based upon unconformity, upon lithological similarity, upon the belief that the greater dynamic movements which have affected the region have been widespread, and upon degree of crystallization of the rocks. The correlation of the formations within a given series has been based upon lithological characters and upon a similar succession of like beds.

THE REGION ABOUT HUDSON BAY.

Within the main Canadian area of pre-Cambrian in the region about Hudson bay exist several troughs in which there certainly occur fragmental rocks such as slate-conglomerate, limestone, and dolomite. These are associated with "imperfect" gneisses, a great variety of schists, and schistose and jaspery iron ores. The Marble island series, with that of the adjacent shore, is closely analogous in lithological character to the Upper Huronian, while the more crystalline phases resemble the Lower Huronian. The chief indication available as to the relations of these rocks to the basal complex is the presence in the slate-conglomerates of syenite pebbles, like the rocks of the underlying crystallines. Resting unconformably upon the foregoing clastics and upon the basal complex is the Manitounuck series, which consists of siliceous and argillaceous limestones, sandstones, quartzites, shales, ironstones, with interbedded amygdaloids and basalts, all the members of the series being in a practically unmetamorphosed condition. This series, in its structural and lithological characteristics is remarkably like the Keweenawan of lake Superior, and its distance from the nearest area of this series, the Nipigon, is not very great, so that its correlation with the Keweenawan can be made with a fair degree of probability. There are then about Hudson bay, between the Cambrian and the Archean, at least two, and perhaps three, series of rocks, the uppermost of which rests upon the lower series unconformably.

OTHER REGIONS OF NORTHERN CANADA.

Too little is known of the vast expanse of pre-Cambrian rocks which constitute the northern parts of Canada to make any definite statements. It is, however, evident that rocks lithologically like the Archean of the previous regions discussed constitute the great area. It is equally plain that within this area, at various districts, are rocks which show undoubted evidences of clastic characters as shown by the presence of limestones, schistose conglomerates, volcanic clastics, etc., which have a lithological likeness to the Keweenawan, Upper or Lower Huronian of lake Superior, but which can not yet be closely located. The Huronian area of the north channel of lake Huron extends to an unknown distance in a north and northeast direction. Also, it is by no means certain that many of the rocks referred by Dawson to the Cambrian are not really pre-Cambrian, as used in this essay. The Coppermine series, for instance, in its lithological character and position, is such as to lead to a comparison of it with the Keweenawan or Animikie of the lake Superior, or both. But the structural work in this vast area can be considered but as barely begun.

THE EASTERN TOWNSHIPS.

In the Eastern Townships there is unconformably below the fossiliferous Cambro-Silurian a series of little altered slates which rests unconformably upon crystalline or semicrystalline schists. These have been regarded by the Canadian geologists as Lower Cambrian, although in them no fossils have been found. In position and lithological character they are compared with the gold-bearing slates of Nova Scotia. As the Canadian Geological Survey uses the term Cambrian, including the Animikie and Keweenawan, this series is probably Cambrian, but, making the basal Cambrian as is done in this essay the series bearing the Olenellus fauna, it is probable, although not certain, that this series of slates is pre-Cambrian and Upper Algonkian. Of the series of schists unconformably below this series there are no very full descriptions. It, however, includes mica-slates, staurolitic schists, crystalline limestones, argillites, and graphitic schists, and with these volcanic clastics. This is certainly a clastic series in part at least. The whole is associated with granites which are regarded by Ells as intrusives in the schists, and one of the causes of their metamorphism, but by Selwyn are supposed to be the clastic series in a more metamorphosed condition. In this region it is probable that the fundamental complex does not appear, the lowest series found being a clastic one which is to be placed in the Algonkian. The lithological character of the Lower Algonkian crystalline series more nearly resembles the Upper Laurentian of the original Laurentian area than any other. The unmetamorphosed slate and quartzite series unconformably above it can not now safely be correlated with any of the clastic series to the west. It may be that it is Upper Huronian or later.

SOUTHERN NEW BRUNSWICK.

In southern New Brunswick, while the geology is exceedingly complicated, and the later conclusions of the official geologists differ fundamentally from those earlier held, it is plain that there exists here a pre-Cambrian clastic series of great thickness. The wholly crystalline granites, gneisses, etc., at the base, in their general lithological description, resemble the Archean of the West, but from present evidence it is impossible to decide whether these are subsequent intrusives, the product of complete metamorphism of the clastic series, or are a basement complex. The geologists who have described the region clearly maintain that this series is more ancient than the oldest associated clastics, although the relations strongly suggest the possibility of an eruptive contact between the latter and the granites and gneisses. The older series of clastics, called the Upper Laurentian, does not have a great thickness, consists of quartzites, slates, and crystalline limestone interstratified with argillites, slate-conglomerates, and gneisses. This series in its lithological character is like the original Upper Laurentian. Above it, conforming with this series and the granites and gneisses, is the Coldbrook series, which is very largely composed of surface volcanic flows and clastics. Above this are the Coastal and Kingston series, which are wholly unmetamorphosed clastic rocks, associated with contemporaneous eruptives. Between the two is something of an unconformity, but it is not thought by the New Brunswick geologists to have marked a considerable epoch of time. The two upper series can not certainly be correlated with series in other parts of Canada and about lake Superior, but not improbably they belong above the horizon of the Lower Huronian, being perhaps equivalent to the Upper Huronian or Keweenawan, or with the erosion intervals which separate these series.

NOVA SCOTIA AND CAPE BRETON.

In Cape Breton the relations between the basal complex and the George river limestone series are identical with those between the basal complex and the so-called Upper Laurentian of southern New Brunswick; i. e., there is here a clastic series and a granitoid gneiss series in which it is impossible to say definitely whether the relations are those caused by an eruptive contact or whether the crystalline complex is older than the clastic series, the latter being deposited upon it.

In Nova Scotia the great gold-bearing series of the Atlantic coast, of unknown thickness, mapped by the Canadian Survey as Cambrian, may be pre-Cambrian as terms are here used. It contains the evidence of life in Eophyton, but this does not forbid regarding it as Algonkian in our sense of the term. The series may be as high as the Cambrian, or it may be the equivalent of one or more of the pre-Cambrian series. In this region the relations of the granites and gneisses to the gold-bearing slates are such as to demonstrate with a reasonable degree of probability that the granites are intrusive, although they have been regarded by certain writers as metamorphic. This fact suggests that a part of the granite of the fundamental complex of southern New Brunswick and Cape Breton may also be a later eruptive, but even if this were the case it would not demonstrate the absence of an earlier granite-gneiss series.

NEWFOUNDLAND.

In Newfoundland is a clear case of a great series of rocks of perhaps 10,000 feet thick, referred to the Huronian by Murray, which is a part of the Algonkian. Here is found the Olenellus fauna in the basal Cambrian rocks, and these are separated by an unconformity from the underlying clastic series, in which, however, has been discovered two or three fossils of a low type. What the relations of this lower slate series are to the crystalline granite-gneiss which has been referred to the Laurentian is uncertain. No evidence is available showing that lower than this slate series are any clastics. Certain of the granites of the island of Newfoundland are intrusives of later age than the slates, some of them being as recent as Carboniferous; so that it is not impossible that many of the granites, syenites, and porphyries referred to the Laurentian may be of far later age.

THE BLACK HILLS.

In the Black hills is a great series of slates, quartzites, quartzose conglomerates, mica-schists, and mica-gneisses of unknown, although probably of great, thickness. These are cut both by intrusive granites and basic rocks of Algonkian age and by eruptives of later time. All of the clastic rocks are more or less metamorphosed by the contact and dynamic action to which they have been subjected, and adjacent to the great batholites of granite they have become thoroughly crystalline. In degree of folding, crystalline character, and mineral composition they resemble the Lower Huronian of the lake Superior region nearer than any other series. They are separated from the Potsdam sandstone by a very great unconformity, that formation resting upon them in a wholly unfolded condition, while the prominent secondary structures of the underlying series are nearly vertical and the bedding is in a series of sharp folds. No pre-Algonkian rocks are here known.

MISSOURI.

The Algonkian clastics of Missouri are a group of isles surrounded by Paleozoics. They consist of limestones, slates, iron ores, and conglomerates, the most of the débris of which is from porphyries and are interbedded with surface quartz-porphyry flows, which make up the greater part of the volume of the series. There are here also granites, which are probably of the same age. If this is the case no rocks older than the Algonkian are here known. The series shows conclusive evidence of vast denudation before the horizontal Cambrian was deposited upon it. The lithological character of the series is intermediate between the Upper Huronian and Keweenawan of the lake Superior region, and it may stand as the equivalent of one or the other of these, or in an intermediate position.

TEXAS.

In Texas the Algonkian is represented by the Llano series of Walcott or the Texian series of Comstock and by the Fernandian of Comstock. The first series consists of gently folded shales, sandstones, limestones, and schists with ferruginous beds, and is cut by both basic and acid eruptives. It is for the most part very little metamorphosed, and is said to repose unconformably upon the Fernandian. The Fernandian series consists of quartzites, ferruginous rocks, carbonaceous schists, chloritic slates and shales, calcareous rocks, and other acidic and basic schists. It is now a rather crystalline series, but it is clearly, in part at least, of clastic origin. The series is cut by numerous eruptives, both basic and acidic, of which granite is the most prominent. As to the relations of the clastic series to the Burnetian (Archean), they are believed by Comstock to be unconformably above it. They are separated by a great unconformity from the Cambrian sandstone. Comstock correlates the Texian with the entire Grand canyon clastic section, which, if true, and the above supposed relations correct, make the Fernandian rather low Algonkian.

MEDICINE BOW RANGE.

In the Medicine Bow mountains, the clastic series of Medicine and Mill peaks, consisting of slates, cherts, siliceous limestones, quartzites, and conglomerates, all of considerable thickness, appear to be conformable with the more crystalline granite-gneiss complex. The only evidence that there is a break between the two is the presence of granite and gneiss fragments in the lower parts of the clastic series. In degree of crystallization and lithological character this Algonkian series is like the Lower Huronian of the lake Superior country.

SOUTHWESTERN MONTANA.

In southwestern Montana the Algonkian is probably represented by two series. The upper series consists of 12,000 or 15,000 feet of unaltered strata, mostly shales. The lower consists of completely crystalline regularly bedded gneisses, quartz-schists, quartzites, chlorite schists and mica-schists. The upper series, the topmost of the Algonkian, is separated from the Archean by a great unconformity. The relations of the lower series of the Algonkian to the basal complex are unknown, but it is known to lie unconformably below the Cambrian. Also the two Algonkian series are not found in contact, but that there are two series is indicated by the facts that one of them is conformably below the Cambrian while the other is not, and the first is nearly unaltered while the second is crystalline. There is no sufficient information upon which to correlate either of the Algonkian series with the region about lake Superior. The affinities of the Upper Algonkian are rather with probable Algonkian series to the west yet to be considered.

THE UINTA MOUNTAINS.

An ancient clastic series in the Uinta mountains covers an area of several thousand square miles. This series, 12,500 feet in thickness, is one of red quartzites and sandstones, interstratified with layers of slate and ferruginous shale. It rests upon the upturned, truncated edges of a thoroughly crystalline complex which is probably the equivalent of the Archean of other regions. It is unconformably below the Carboniferous. There is, then, no definite evidence upon which this series can be referred to the Algonkian. It, however, in lithological character, absence of fossils, and position, is more nearly analogous with the quartzite series of the Upper Huronian than any other to the east, but the distance which separates it from the Upper Huronian is so great as to render correlation on this ground very unsafe. The series may, with more probability, be regarded as the equivalent of the slates of southwestern Montana and the probable Upper Algonkian of the Wasatch to be considered. Also it is possible that it may not be Algonkian at all, but Cambrian or Silurian.

THE WASATCH MOUNTAINS.

In the Wasatch mountains the Algonkian is probably represented by one series, and perhaps by two. The supposed Upper Algonkian is a series of quartzites, sandstones, and micaceous shales and mica-schists 12,000 feet in thickness. It is possible that below this series, separated by an unconformity, is another more ancient and crystalline series which belongs with the Algonkian, represented by the small area of quartzites and quartz-schists at the foot of the Cottonwood canyons. The Upper Algonkian is separated by a great unconformity from the Archean. Its relations to the supposed older series of clastics in the lower Cottonwood are not made out, but it rests conformably under the Olenellus Cambrian, and therefore if not Cambrian is uppermost Algonkian. This series occupies the same position as the series of slates in southwestern Montana, and the two, as has been said, are perhaps the equivalent of the Uinta series.

PROMONTORY RIDGE, ANTELOPE AND FREMONT ISLANDS.

In this range are a series of mica-schists, quartzites, argillites, which are occasionally calcareous, rocks which are probably clastic and therefore represent the Algonkian. The relations of this series to the Archean complex are not known. At Promontory point it rests unconformably under the Weber. The rocks on Antelope and Fremont islands are regarded as of the same age because of their likeness to the Promontory point rocks and they are believed to be pre-Cambrian because no Cambrian or post-Cambrian rocks in this region are more than indurated.

THE AQUI MOUNTAINS.

In the Aqui mountains the probable Algonkian consists of a series of quartzites 6,000 feet thick containing beds of conglomerate with argillaceous schists and imperfect mica-schists. This series rests upon the granite, which is presumably a part of the basal complex. It is conformably below the basal Cambrian, stands as Upper Algonkian, and may be correlated with the Wasatch Algonkian.

SCHELL CREEK, EGAN, POGONIP OR WHITE PINE, AND PIÑON RANGES.

In the Schell creek range the probable Algonkian is represented by heavy bodies of quartzite. In the Egan range the probable Algonkian is represented by a series of thoroughly vitrified quartzites several thousand feet thick, containing quartzitic and micaceous schists. In the Pogonip range it is represented by micaceous, arenaceous, and argillaceous slates and shales and by vitreous quartzite, the series being of undetermined thickness. In the Piñon range it is represented by quartzites underlain by mica-schists and quartzitic schists having a total thickness of 5,000 feet. In all of these ranges these series rest unconformably upon the Archean and are conformably under basal Cambrian. They therefore are probably Upper Algonkian and stand as the equivalent of the Wasatch Algonkian.

FRONT RANGE OF COLORADO.

In the district of Ralston, Coal, Boulder, and Thompson creeks of the Front range of Colorado the Algonkian is represented by quartzites, quartz-schists, mica-schists, and schist-conglomerates, the thickness of the series being unknown, but certainly more than 1,000 feet. The series has become very nearly crystalline. Its structural relations to the basal complex are not surely known. It appears to grade downward into these rocks, but this may be merely a superinduced conformity. The series of schistose rocks in the Front range, referred by King to the Huronian and estimated at 25,000 feet thick, probably belong in large part to the fundamental complex.

THE QUARTZITE MOUNTAINS.

In the Quartzite mountains the Algonkian is represented by a series of quartzites, interstratified with slates several thousand feet thick. The series had suffered powerful dynamic action, being turned on end and deeply truncated before Carboniferous time. The relations of this series to the Archean are not certainly known, but all the evidence points toward the conclusion that the Algonkian is of later age and that between it and the Archean is a great unconformity.

GRAND CANYON OF THE COLORADO.

The Algonkian in the Grand canyon region is represented by three series, the Chuar, the Grand canyon, and the Vishnu. The Chuar series consists of shales and limestones, over 5,000 feet thick. It contains a fauna of a pre-Cambrian type, including at least five distinct forms. The Grand canyon series is of sandstones, with basic lava flows in its upper part, and is nearly 7,000 feet thick. The Vishnu series consists of bedded quartzites and schists, cut by intrusive granite, and is known to be at least 1,000 feet thick, but how much thicker has not been determined, as it has not been measured to its base. The Chuar rests upon the Grand canyon and between the two is a minor unconformity. The Grand canyon rests upon the Vishnu and between the two is another unconformity. The Chuar and Grand canyon sediments are wholly unmetamorphosed, while the Vishnu sediments are indurated quartzites and semicrystalline schists. Between these series as a whole and the underlying Archean complex is a very great unconformity. Between the Chuar and the Tonto sandstone (Upper Cambrian) there is another unconformity sufficient to have caused the cutting across of at least 10,000 feet of the flexed beds of the Grand canyon and Chuar series. In this region is the fullest known succession of Algonkian rocks in the United States, with the exception of the lake Superior region. The statement would not be warranted that the series here found stand as the equivalent of like series in the latter region, but there is a remarkable lithological likeness both in the detrital and eruptive material of the Chuar and Grand canyon to the Keweenawan. Also these series occupy a position of unconformity below the Upper Cambrian, as does the Keweenawan, and is separated by an unconformity from a series of quartzites and quartz-schists which are analogous to the Huronian. This latter, Vishnu series, is not well known, so that it is unsafe to assert whether it is nearer like the Lower or the Upper Huronian of the lake Superior region.

BRITISH COLUMBIA.

The recent work of Dawson appears to show that in British Columbia there is a widespread series of Algonkian of great thickness. It consists of argillites, argillite-schists, quartzites, conglomerates, and limestones. Between this series and the Archean there is evidence of a great physical break, although the two are in apparent conformity. The series in one section rests conformably below the Olenellus Cambrian and the whole is regarded by Dawson as Cambrian, but as terms are used in this paper it is probably in part or in whole Upper Algonkian. By Dawson the series is compared with the Wasatch Algonkian and the Chuar and Grand canyon series.

THE ADIRONDACKS.

In the Adirondacks is a core of gabbro about which in a peripheral manner is a great series of regularly bedded gneisses, quartz-schists, and crystalline limestones which are often ferruginous or graphitic. At times in the gneissic series are beds of graphitic schist of sufficient richness to serve as graphite mines. While the interior structure of the rocks of this series now shows no positive clastic characteristics, the limestones, graphitic schists, and regularity of what appears to be bedding in the gneisses leave but little doubt that the series was originally clastic and belongs with the Algonkian. The studies of Walcott render it probable that there is here also a basal complex, and along the contact lines of the series Walcott has discovered evidence of an unconformity. This Algonkian is so remarkably like the not far distant original Upper Laurentian in the neighborhood of Ottawa that one can not doubt that the two are or once were continuous.

OTHER ALGONKIAN AREAS.

Besides the foregoing list of areas in which it is certain, or nearly certain, that there are Algonkian rocks, the indefinite knowledge available of many other districts indicates the presence of series which probably fall within this period. In much of the work in the West the pre-Cambrian rocks are treated as a unit, being spoken of as the metamorphic group, absolutely no attempt being made to treat them upon a structural basis. This was natural in pioneer work, but the fact that so many extensive areas of pre-Cambrian clastics have been discovered in districts where closer work has been done, suggests that in the future there will be discovered many new series of pre-Cambrian clastics. The most extensive areas which will be found to swell this system will doubtless be found in the vast stretches of pre-Cambrian rocks of Canada, but similar series may be found in central New Brunswick, in Gaspé peninsula, in the Wind river and Teton ranges of Wyoming, in a number of the desert ranges of Utah and Nevada, in Southern California, and in the Appalachians. In this last and most difficult region, the recent work of Prof. Pumpelly's corps appears to indicate that a subdivision of the pre-Cambrian will be accomplished in Vermont, and it is rather probable that in the southern Appalachians are areas of pre-Cambrian clastics.

SUBDIVISIONS OF ALGONKIAN.

The foregoing review of the occurrences of pre-Cambrian clastic rocks makes apparent the propriety of introducing the term Agnotozoic or Proterozoic to cover the series between the Paleozoic and Archean. The desirability of dividing the group into several systems is also apparent, but it is equally apparent that our limitations of knowledge at the present time make it impossible to do this for the whole of North America, hence, as with Archean, it is unavoidable that a single system term shall be used for the Proterozoic group, and as already explained, Algonkian is given this place. However, the major subdivisions of this Algonkian system, in volume of rocks and time duration, are equivalent to the systems of the Paleozoic. For instance, the Keweenawan, Upper Huronian, and Lower Huronian series of lake Superior are each of them parallel in volume to the Carboniferous, Devonian, Silurian, or Cambrian. The same may be said of the Grand Canyon and Chuar series. If in the future it shall be possible to subdivide the Agnotozoic or Proterozoic group on a systematic universal basis, as the Paleozoic is subdivided, the term Algonkian must be replaced by Wasatchian, Keweenawan, Upper Huronian, Lower Huronian, etc.

COMPARISON WITH OTHER CLASSIFICATIONS.

The major classification proposed in this paper differs in some respects from any previously given, although it accords closely with that advocated by Irving, and does not differ radically from that proposed by Selwyn in 1879, but afterwards abandoned. Irving did not recognize that within the formations called Huronian there is a structural break, which properly divides them into two series, Upper and Lower Huronian, although he realized that unconformably below rocks which he denominated Huronian are clastics, which were supposed to be inseparable from the Laurentian. As a consequence of this and of the failure to appreciate that in this lower series, as well as in the Upper Huronian, there are abundant evidences of life, he excluded from the Agnotozoic a part of this Lower Huronian, placing it with the clastics of the original Laurentian. In the lake Superior Lower Huronian there are carbonaceous and graphitic schists and beds of iron carbonate. In the original (Middle) Laurentian of the East there are great beds of limestone, regularly bedded gneisses, quartzites, quartz-conglomerates, graphitic schists, and also very graphitic limestones. While the evidence of life is not quite so conclusive as with the Upper Huronian, it is so strong that one who believes in its existence in the latter series can hardly doubt its existence in the Lower Huronian of lake Superior and the Laurentian of the East, although no fossils universally recognized as such, nor any hydrocarbons have been discovered. The reasons for the introduction of the term Agnotozoic to cover the Keweenaw, an Upper Huronian and equivalent series as clearly demand that it shall also cover other pre-Cambrian clastic series. Once started on the downward way toward the fundamental complex there is no plane at which to stop until this is reached.

This places the boundary between the Proterozoic and Archean at the plane placed by Selwyn between the Laurentian and Huronian. In the regions in which Selwyn and most other Canadian geologists have studied, they in general find no unconformity between the Huronian and Laurentian. It has been seen that similar apparently conformable relations and gradations obtain in various areas in the United States. However, in many cases, as has been seen, there are easily discoverable structural breaks between the Proterozoic and Archean.

As to the positions of Whitney and Wadsworth and Hunt, my conclusions are so radically different that little need be said. The reasons for the conclusions reached have appeared in the summary of the literature and in this discussion. To attempt to disprove the positions of these authors would be merely to repeat the arguments already presented. It may, however, be remarked that both of these positions can not be correct, and recently Wadsworth has found evidence which has led him to change entirely his views from those expressed in the "Azoic System." One maintained the absolute indivisibility and complete lack of life in all pre-Potsdam rocks, while the other maintained an invariable aqueous succession of pre-Cambrian rocks, consisting of seven different series, separated by unconformities. The position here taken is in some degree intermediate, that is to say, there is abundant evidence of various pre-Potsdam clastic series which bear the evidence of life, but no reason in the facts of occurrence nor in the principles of geology which indicates for all regions an invariable succession. It is not worth while to discuss whether in 1884, the time when Whitney and Wadsworth's account of the Azoic rocks appeared, evidence was available which would prove the divisibility of the pre-Potsdam rocks. If any one desires to answer this question for himself he will consider only that part of the literature which was extant prior to this time. This comparison will show that within the last decade has appeared a volume of evidence upon the existence of pre-Potsdam life and upon the divisibility of the pre-Cambrian rocks which far surpasses that obtained before. At the present time the evidence in favor of these positions is simply overwhelming. With the discouraging view taken by Whitney and Wadsworth as to the state of pre-Cambrian geology, I have had no sympathy. They said that the chances of "having at some future time a clear understanding of the geological structure of northeastern North America would be decidedly improved if all that has been written about it were at once struck out of existence." Crude methods have frequently led to crude results, but often even in unsatisfactory reports are contained facts which serve as clews to later workers. Further, much that was written before the present decade is as good work in proportion to the light at hand—the only proper method of comparison—as any since. The only way to get well on a road or to a goal is to start. Also it must be insisted, in opposition to Whitney and Wadsworth, that stratigraphy and classification are possible without paleontology. Both of these preceded this branch of geological science, and paleontology is useful only as it is guided by stratigraphy. Forgetting this, fossil evidence has frequently been misused. In dealing with the pre-Cambrian rocks we are exactly in the position that geologists are among the post-Cambrian rocks where fossil evidence is lacking. Each district must be studied stratigraphically by its formations and discordances. The lack of fossils is most keenly felt in correlation. However, the protests of Whitney and Wadsworth against many of the subdivisions of the pre-Cambrian and the principles upon which they were made are well founded.

As to the supposed invariable aqueous succession of Hunt, the writer can only say that so far as he is familiar with North America he knows of no region in which this succession does occur in its fullness; while every complex region with which he is familiar contradicts it at one or more fundamental points. As one illustration among many which might be mentioned, the Labradorian, supposed to be a part of the invariable succession, is demonstrated beyond all question to be an eruptive rock. Large areas of this rock are associated with or underlie the earliest pre-Cambrian and it also occurs in the form of great flows in series as late as the Keweenawan. The whole scheme is one which is highly theoretical and seems to have been evoked by laboratory study rather than from a consideration of the actual rock successions within the pre-Cambrian in the field. The chance that a scheme evolved in this manner should accord with the facts of the world is indefinitely small.

PRINCIPLES APPLICABLE TO ALGONKIAN STRATIGRAPHY.

The clearest discussion of the principles which, from the writer's point of view, are most applicable to the classification, correlation, and mapping of the pre-Cambrian rocks are the structural and lithological principles enunciated by Irving, Pumpelly, and Dale. Accepting these in the main, a few supplementary remarks may be made.

In the stratigraphical work of the past, methods have oftentimes been defective. Instead of giving close lithological descriptions of a series of rocks, noting carefully the relations of the different strata, in case they are found to have strata, to each other, and giving a detailed account of the relations which actually obtain between the series considered and surrounding series, writers have too often called the rocks of regions far distant from the original localities to which the terms have been applied Laurentian, Huronian, etc. Sometimes this is done on the ground that a series as a whole has a certain color, which has been thought to be characteristic of the period. At other times the abundance of volcanic material has been the reason for the reference. Again, quartzites from the Appalachians to the Black hills have been correlated on no other ground than lithological likeness, as though thick sandstone formations which subsequently have been cemented to quartzites have been produced but once in the history of the world. To some geologists the degree of crystallization has been the controlling fact. In other cases the occurrence of some mineral or association of minerals has been the ground upon which the reference of the containing formation is made to some specific period. This has gone so far at times as to lead to the conclusion that a single rare mineral, such as chondrodite, is proof of the pre-Cambrian age of the containing formation.

As a natural result of work of this kind, rocks of a certain lithological character or degree of crystallization, or containing certain constituents, have been called Arvonian, Huronian, Norian, Laurentian, as the case may be, which have afterwards proved to be high in the Paleozoic. Other series, which are now known to be pre-Cambrian, have been called Triassic, because of a prevailing red hue.

Any of the above characteristics may be a valuable guide in a given district, or with qualifying and guiding facts of a different character in a region; but it is their use in an indiscriminate manner on the assumption that rocks of a given time are everywhere alike that is protested against. When it is everywhere recognized that, considering the continent as a whole, age is no guide to the chemical or mineral composition, texture, color, degree of crystallization, or any other property of a formation, or vice versa, we shall be on the way to use the properties of rocks in districts and regions as guides to age. For the most part this principle has been recognized, if not practically, at least theoretically; but at one point this is less true than with the others. Degree of crystallization, because often so useful in a district, has been used by many as a general guide in correlation, although the elder Hitchcock, Rogers, Adams, and others gave early warning against such practices. It can not be too strongly insisted upon that contact action of great masses of eruptive rocks and dynamic action accompanying this, or dynamic action without accompanying volcanic activity, are prime and perhaps the chief causes in the majority of cases of the production of crystallization, not age and depth of burying, although these may be contributory causes and at times the predominant ones. A stratum which is strongly conglomeratic at the axis of a fold, within a short distance upon the legs may have become so completely crystalline as to obliterate every trace of original fragmental character, because of the movement of the particles over each other, as for instance, in the Cambrian at Hoosac mountain. In strong contrast to this may be mentioned the occurrence of quartzites in the lower part of the Upper Huronian of lake Superior, which show no evidence whatever of dynamic action, the particles of quartz not even being arranged with their longer axes in the same direction, and the induration being wholly due to the process of renewed growth and cementation. Yet this and the adjacent rocks have been buried under the entire thickness of the Upper Huronian and the Keweenawan series many thousands of feet and subjected to a pressure beyond the crushing strength of any rock, a condition in which they must have been latently plastic. Rocks as late as Devonian in the Appalachians have become so completely crystalline that not one vestige of the original fragmental material remains. Contrasting with this occurrence are the Chuar, Grand Canyon, and Keweenaw series, all wholly unaltered, yet pre-Cambrian.

No one would think of maintaining that in post-Cambrian time a rock of a certain composition is of a definite age; neither would any one think of referring a rock to the Devonian, Silurian, or Cambrian upon the degree of its crystallization. To suppose that the plane of the basal Cambrian is a *magic* one, below which new conditions of sedimentation prevailed and an entirely different set of principles apply in stratigraphy, is to assume a revolution in the conditions of the world at this time for which there is not one particle of warrant. Those who believe in evolution must believe that for eras of time before the Cambrian there were cycles of deposition of the various classes of sedimentary rocks and the slow evolution of life to the high degree of perfection and the great variety of types including all important branches except the vertebrates found in the Olenellus fauna.

It may be said that the foregoing applies equally well to the separation of the Algonkian and Archean. Revolutionary methods can not be applied here more than elsewhere. To this it can only be said that this plane is the most remote and difficult to define of any. It may be that it is wrongly defined. Without question it will in the future be much more accurately defined. Rocks now placed in the Archean will be found to be Algonkian, just as series are being found to be Cambrian, Silurian, or Devonian in the Appalachians which have commonly been regarded as Huronian or Laurentian. While the distinctions made may not be complete, they are based upon the knowledge available, are not dogmatic, and do not, it appears to the writer, contradict the laws of geology. The law of uniformity, if rightly understood, does not imply that the causes now at work have always had the same relative value. When the laws of geologic forces are fully comprehended, it will be found that each is not absolutely uniform in power, but that each involves variables. These variables may be so small that the cumulative change in the effect in any case may not be discoverable in an epoch or even in a period; but that the amount of this effect perceptibly changed in eras, can not be doubted. A standard clock if observed for a day may seem to run with an invariable and correct rate, but if observed long enough it is found to lose or gain, and this not regularly. The law of its variation may finally be partly ascertained, but usually it is too complex to be fully covered by a formula. Just so each geological force when more accurately known will be found to involve an irregular rate of change. The increment in an individual case for a certain length of time may be added or substracted, but it is not probable in any case that the addition or substraction will fully cover the real law, although this may be a second approximation to the truth as the so-called law of uniformity was a first approximation. If we go far enough back a geological force may have been multiplied or divided by two or three or a larger number. Igneous rocks are now a far less abundant geological product than are sedimentary rocks. That these relations are true for all past time can no more be assumed than it can that organic and mechanical sediments have the same relative volume for the pre-Cambrian that they have for the Cretaceous or Tertiary. If the generally accepted hypothesis as to the origin of the globe represents the facts, in all probability rocks of igneous origin must become relatively more important in very ancient times. If we but go back far enough they may become predominant; and in still earlier time for continental areas they may be the only rocks.

The problem then of the stratigraphy of the pre-Cambrian clastics is a problem to be treated precisely as that of the Paleozoic. It is, upon the whole, a more difficult problem; for, while in any particular locality it can not be premised from the degree of crystallization that the rocks are pre-Cambrian or post-Cambrian; taking the world as a whole, the rocks become more crystalline in passing to lower series; so that it is to be expected and is the fact that a greater proportion of pre-Cambrian rocks than of the Paleozoic are highly crystalline. This, however, is not the most serious difficulty with which pre-Cambrian stratigraphy has to contend; it is the sparseness of the remains of life in definitely recognizable forms. It has been seen that a beginning of a pre-Cambrian fauna has already been found, and when it is remembered how rapidly definite paleontological knowledge has extended downward in the past decade it may be reasonably hoped that before long assistance will be derived from paleontology in the classification of the pre-Cambrian rocks, but it can not be expected that fossils will ever be so important and controlling a guide as in the post-Cambrian; for probably the farther we go back from the Cambrian the sparser and sparser will the recognizable life-remains become.

As a result of the average greater crystalline character of the pre-Cambrian rocks, and the frequency in them of secondary structures, the principles of working out stratigraphy in regions in which cleavage foliation occurs with partial or total obliteration of stratification are of the utmost importance. The failure to clearly recognize and apply these principles has left the crystalline Cambrian and post-Cambrian series of the Appalachians in a state of confusion for many years. Within the last decade, by a recognition and a close application of them a new start has been made in the study of this difficult region.

That it will not do to regard slaty cleavage or foliation as bedding has long been recognized, although it has often occurred that in regions in which this has been distinctly stated it has also been said that bedding and cleavage do correspond without any evidence of such correspondence being given. If tangential thrust be assumed as the cause of foliation, unless the resultant folding be close, bedding and cleavage will usually not correspond for any considerable area; for cleavage and foliation have a tendency to develop transverse to the lines of pressure, while bedding is initially in the lines of pressure. In the closely folded series in which it may be said that resultant foliation and sedimentation correspond throughout, the use of the term bedding ought to be dropped, as there is no longer a basis upon which to estimate thickness, because in this case there must have been such an amount of movement of the particles within the beds over each other as to render it doubtful if bedding does still exist.

By the foregoing it is not meant to imply that the foliation of thoroughly crystalline rocks may not widely correspond with bedding, but only that this is not usually the case when tangential thrust is the cause of the foliation. However, Smyth (H. L.) has discovered when there is an alternation of beds of different degrees of massiveness that these often control the movements of accommodation during the folding of the series, and that the slipping of the particles over each other parallel to the bedding develops schistose structure along the same planes. It is not impossible that deeply buried beds may become thoroughly crystalline, with foliation and bedding parallel when superincumbent pressure and metasomatic changes are the predominant forces. A sufficient degree of heat for recrystallization may be engendered by very deep burying or by laccolitic intrusions. In such cases the structure of the recrystallized rock will naturally conform to the bedding, and it is probable that differences in the original characters of the layers will be preserved in the metamorphosed rock. A mica-schist or gneiss thus derived from a shale or an arkose, now showing in its interior structure no evidence of clastic character, might be underlain by a quartzite which was produced by the cementation of a quartzose sandstone. The quartzite at the present time would reveal its detrital origin, while the mica-schist or gneiss might not. Some such explanation seems to fit the thick beds of mica-schist (the structures of which unmistakably correspond with bedding) which overlie the quartzites of the Penokee series of Michigan and Wisconsin. A crystalline series of the origin suggested, which subsequently reached the surface by denudation, might be folded, but not sufficiently to produce a new secondary structure, when the different bands of different characters would truly represent sedimentary beds. Some such explanation seems to fit the gently folded thoroughly crystalline mica-schists and gneisses of the Blue ridge west of Old fort, North Carolina. In the Adirondacks, where the schistose structure and bedding of the Algonkian rocks appear to correspond, the great laccolites or batholites of gabbro are probably the chief cause of the metamorphism.

In crystalline series, when but one structure can be found, it is safe only to assume that it is foliation. Not only will it not do to use cleavage for working out structure, but an actual regular alternation of mineral constituents in schistose and gneissoid rocks can not be regarded as any evidence of sedimentation. The great series of regularly banded gneisses in which alternate zones of nearly pure quartz and feldspar and other zones in which the bisilicates are concentrated, if taken as due to sedimentation would result in the conclusion that the thickness of the beds in which these structures occur is incredibly great. In thoroughly schistose rocks it is manifest that the best and most reliable means upon which to base a conclusion as to strikes and dips is to find contacts between thick beds of rocks of a fundamentally different character, as a layer of quartzite, quartz-schist, or mica-schist, with limestone, or either of these with gneiss.

The clearest, briefest, and most comprehensive enunciation of the principles applicable to a formation in which are cleavage foliation and stratification foliation known to the writer is that of Dale and Pumpelly (see pp. 768–770), which is here quoted in substance, slight modifications being made to fit the change of setting:

I. Lamination in schist or limestone may be either stratification foliation or cleavage foliation, or both, or sometimes "false bedding." To establish conformability the conformability of the stratification foliations must be shown.

II. Stratification foliation is indicated by: (*a*) The course of minute but visible plications; (*b*) the course of the microscopic plications; (*c*) the general course of the quartz laminæ whenever they can be clearly distinguished from those which lie in the cleavage planes.

This statement was made with reference to a particular district. It is of course wholly possible that some other substance should play the same rôle as quartz. In the application of these criteria it must be premised that the parting is not a second or third cleavage. If an earlier cleavage existed the criteria might give the direction of this first one rather than the bedding, which might have become obliterated at the time of the development of the first cleavage.

III. Cleavage foliation may consist of: (*a*) Planes produced by or coincident with the faulted limbs of the minute plications; (*b*) planes of fracture, resembling joints on a very minute scale, with or without faulting of the plications; (*c*) a cleavage approaching slaty cleavage in which the axes of all the particles have assumed either the direction of the cleavage or one forming a very acute angle to it, and where stratification foliation is no longer visible; (*d*) a secondary cleavage, resembling a minute jointing may occur.

IV. The degree and direction of the pitch of a fold are indicated by those of the axes of the minor plications on its sides.

V. The strike of the stratification foliation and cleavage foliation often differs in the same rock, and are then regarded as indicating a pitching fold.

VI. Such a correspondence exists between the stratification and cleavage foliations of the great folds and those of the minute plications that a very small specimen properly oriented gives, in many cases, the key to the structure over a large portion of the side of a fold.

It is to be noted that the statement of these principles has been inspired by a study of formations which have proved to be wholly Cambrian or post-Cambrian.

The principles of lithological correlation enunciated by Irving are as follows, except that series is here substituted for group and Algonkian for Huronian so as to make the terminology correspond with that here used:

Lithological characters are properly used in classification:

(1) To place adjacent formations in different series, on account of their lithological dissimilarities when such dissimilarities are plainly the result of great alteration in the lower one of the two formations, and are not contradicted by structural evidence, or, if used as confirmatory evidence only, when such dissimilarities are the result of original depositional conditions.

(2) To collect together in a single series adjacent formations because of lithological similarities when such similarities are used as confirmatory evidence only.

(3) To correlate series and formations of different parts of a single geological basin when such correlations are checked by stratigraphy, and particularly by observations made at numerous points between the successions correlated.

They are improperly used:

(1) To place adjacent formations in different series on account of lithological dissimilarities when such dissimilarities are merely the result of differences in original depositional conditions, and when such evidence of distinction is not confirmed by or is contradicted by structural and paleontological evidence.

(2) To collect in a single series adjacent formations because of lithological similarities when such similarities are not confirmed by or are contradicted by other evidence.

(3) To establish general correlations between the clastic series of different geological basins, except possibly when the gneissic and true crystalline-schist basement formation of one region is compared with the similar basement formation of another.

(4) To establish and determine any world-wide subdivisions of the noneruptive basement crystallines, i. e., those which underlie the clastic series here called Algonkian, at least until very much more definite evidence of the existence of such subdivisions be gathered than has hitherto been done.

In applying these principles it must not be forgotten that a bed of one character may thin out and disappear; may gradually change from a limestone to a shale, from a shale to a sandstone or conglomerate; and that sometimes the change may be abrupt, as perhaps upon the opposite sides of an axial ridge, one side of which faces toward the ocean and the other toward an interior sea. All formations, however widespread, terminate somewhere. A single formation of a certain lithological character can only be assumed to be the same bed in a district when it has been demonstrated to be persistent over a wide area. When several characteristic formations occur in a definite order in different parts of the same district the probability that they are of identical age is greater than with single beds found to be lithologically alike at separate points.

The principles applicable to correlation by unconformities are given by Irving as follows:

The structural breaks called unconformities are properly used in classification:

(1) To mark the boundaries of the rock series of a given region.

(2) To aid in establishing correlations between the formations of different parts of a single geological basin.

(3) To aid in the establishment of correlations between the series of regions distantly removed from one another; but caution is needed in attempting such correlations in proportion as the distances between the regions compared grow greater.

They are improperly ignored:

(1) When the evidence they offer as to separateness is allowed to be overborne by anything but the most complete and weighty of paleontological evidence.

Irving's discussion leading to these principles shows that oftentimes unconformities are the most widespread and important of any of the means available to obtain starting planes for comparisons and that they have the place of first importance in making the major subdivisions for the origin of the pre-Cambrian clastic rocks. An erosion interval can only occur as a result of the raising of a district above the sea, a time of degradation, and then a depression below the sea; and if there is a true unconformity there must also have been an orographic movement and erosion long enough continued to truncate the folds. The erosion interval, if extended over a large area, implies a considerable time break; while the unconformity, if it is marked, can hardly be less than regional in extent. When the newer series is undisturbed, an unconformity is one of the easiest of phenomena to detect, but more frequently than not among the pre-Cambrian rocks the older and newer series have again been folded, and this folding has oftentimes gone so far as to produce a cleavage or foliation, which cuts across both older and newer series and makes their most prominent structure in absolute conformity. Even if this degree of folding has not occurred and the process has not gone far enough to produce prominent secondary structures, the discordance in angle of inclination is more likely to be overlooked than when the series are in an undisturbed condition.

Since unconformities are so valuable in structural work, it is important that the principles be clearly recognized upon which they may be established in disturbed regions. This subject has been discussed at length by Irving, and from his paper the substance of much which follows is taken. An unconformity between series implies a difference in number of orographic movements with intervening erosion. This difference in number may be one or more than one. Even when the difference of orographic movements to which the series have been subjected is but one the time gap between the two must have been very considerable, and it may have been of vast duration. Consequently discordant series may differ in degree of consolidation, in the development of cleavage and foliation, and in their relations to eruptives. At the beginning of the deposition of the newer series basal conglomerates are often formed.

Hence, as guiding phenomena in the discovery of unconformities, we have (1) ordinary discordance of bedding; (2) difference in the number of dynamic movements to which the series have been subjected; (3) discordance of bedding of upper series and foliation of lower; (4) relations with eruptives; (5) difference in degree of crystallization; (6) basal conglomerates; (7) general field relations.

(1) In cases of ordinary discordance of bedding nothing need be said, except to state that unconformities should not be inferred from a single small contact where the apparent discordance may be due to false bedding or to local currents or very local minor disturbances. Also, the discordances caused by faulting may be mistaken for an unconformity if care is not taken. The amount of evidence for the unconformity should be sufficient to show a real discrepancy of bedding for a considerable area. Within a short distance the amount of discordance of bedding between two series may vary greatly. Frequently a dynamic movement mainly relieves itself along a comparatively narrow zone. This zone is one of uplift and consequently of great denudation. The adjacent plain may be little folded and not deeply eroded. When a new series is deposited upon this older series the former lies approximately parallel to the bedding of the older upon the plain, but along the zone of disturbance the first may lie directly athwart the bedding of the second.

(2) Difference in the number of dynamic movements to which the series have been subjected is often an important means of determining unconformities. In order that an unconformity shall occur the older series must have been subjected to at least one more orographic movement than the newer. In the most favorable case the older series has undergone two or more orographic movements while the newer series has undergone but a single one. When the lines of these movements are in the same direction and result in folding the only difference between the two series consists in steepness of inclinations; but in case the earlier movements were in a different direction from the last the older series will show a compound series of folds due to the resultant effect of the two or more movements, while the newer series will be simply folded. As a matter of course, in this discrimination, bedding must be used rather than foliation. Oftentimes it will happen that the latest movement has produced a prominent cleavage or foliation which is common to both older and newer series; and under these circumstances the real discordance which may exist between the two series is particularly apt to be overlooked, and a district will be described as having a simple monoclinal structure, or one in which the series is reproduced by faulting, when evidence is at hand for two or more discordant series.

The orographic movements, instead of producing folding, may cause jointing or faulting, these results, as suggested by Willis, being perhaps due to insufficient load. These phenomena are, however, serviceable in discovering an unconformity, for the sets of faults or joints produced in the older series before the newer series was formed are not found in the latter. When there have been later orographic movements which have produced faults or joints in both series the unconformity will be shown by the presence in the older series of two sets of joints or faults in different directions, provided the directions of thrust were different, while the newer series will be affected by joints or faults only in a single direction. If the jointing or faulting is in the same direction in both the newer and older movements they will not be of much service in detecting an unconformity, the only difference being their greater frequency in the older series.

When one of the orographic movements has resulted in folding and the other in faulting or jointing, the combination of phenomena are as easily used to detect an unconformity as when effects of the same kind are produced by both movements.

(3) Discordance of the bedding of an unfoliated series with the cleavage or foliation of an adjacent series may be taken as evidence of unconformity, if the former is such that it would take on cleavage or foliation as readily as the latter; for whatever the origin of the altered series the development of cleavage or foliation, which must have developed before the new series was deposited, required much time. An unconformity could not be inferred from the fact that a heavy formation of quartzite or of limestone cuts across the cleavage or foliation of an argillite or mica-schist, for clayey rocks very much more readily take on secondary structures. In the same series it often happens that more massive beds escape foliation, which may be prominently developed in other members. But if a formation with slaty or schistose structure is overlain by another formation without secondary structure which from its composition is as likely to take on foliation as the underlying formation, a discordance, while not demonstrated, is a probability for which other evidence should be sought.

(4) Eruptive rocks are often an important guide in determining structural discordances. These are valuable when the older series has passed through an epoch of eruptive activity before the newer series was deposited. In such cases bosses, contemporaneous or intrusive beds, volcanic fragmental material or dikes may occur in the older series, which nowhere are associated with the newer. It is possible, of course, that eruptives may penetrate the inferior members of a series and never reach the higher formations; but if it is found that the supposed inferior series is associated with abundant material of igneous origin which never passes beyond a certain plane, it is almost demonstrative evidence of the later age of the newer series. A notable instance of this is found in the Doe river section of eastern Tennessee, where the granitic rocks supposed to be older than the associated clastics are cut by very numerous schistose dikes which never

intrude the latter. It might be reasonably inferred, if it were not for these dikes, that the granitic rock is an eruptive later than the clastics (although the absence of contact phenomena would be against this), but as the basic dikes are unquestionably intrusives of later age than the granites, and yet never cut the slates, this explanation can not possibly apply. Evidence of this kind is particularly decisive if the dikes are traced up to the plane of contact and have been found to be eroded or disintegrated, as is the case in the Stamford dike at Clarksburg mountain, Massachusetts, described by Pumpelly, which enabled this author to determine positively what had been believed before, that the granitoid gneiss is unconformably under the Cambrian quartzite.

(5) Closely connected with (3) and (4) is degree of crystallization as a guide to unconformities. It has been seen that crystalline character is often taken on in proportion as dynamic action occurs. When the folding, which has affected only the older series, has been severe, it as a whole will be more crystalline in character than the newer. Also the presence of igneous material is often a potent factor in the production of crystalline character. As, however, recrystallization is also produced by metasomatic change, this criterion must be used with caution and as a cause to search for other evidences of an unconformity rather than alone as a basis upon which to infer an unconformity. But even difference of amount of metasomatic change, if the rocks are equally likely to be affected by these processes, may be evidence of difference in age. In determining degree of crystallization the modern petrographical methods serve one of their most useful purposes, since many rocks which in exposure or in hand-specimen appear to be about equally crystalline, are shown in thin section to be of a fundamentally different character. A completely crystalline rock sometimes can not be discriminated macroscopically from one which is merely indurated by cementation. For instance, a thoroughly crystalline granite and a recomposed rock built up of the débris of this granite, especially when the particles are in the form of individual minerals, rather than pebbles, present much the same appearance in mass, but a glance at sections of the two under the microscope shows the thoroughly crystalline interlocking character of the one and the clastic character of the other. Another case quite as marked is the discrimination between much foliated eruptive rocks which have passed over into fissile schists and ordinary argillaceous slates and graywackes. In the latter class the particles of quartz and feldspar may be seen with their oval forms as regular as the day in which they were deposited, while in the other case an entirely different appearance is presented.

(6) Basal conglomerates are one of the most important means of determining a plane of unconformity, but it must be clearly shown that the conglomerate is really a basal one. Conglomerates may occur in other positions than at basal horizons, and it will not do to assume

that an unusually conglomeratic layer is basal. A conglomerate is likely to be basal when the major portion of the débris is derived from the immediately subjacent member; but even here the exception must be made that in case this subjacent member is a surface igneous rock the presence of the conglomerate is no evidence of a time break. If, however, the igneous formation is of such a character as does not originate except as a deep-seated rock, the fact that it is at surface and yields fragments to the overlying formation is evidence of a time gap. Also evidence of a break is just as decisive when the underlying rock has a foliation which has been produced prior to the deposition of the conglomerate. This may be determined from the fact that fragments broken from a foliated rock are apt to be longer in the direction of lamination, and when deposited in the overlying series they naturally lie with their foliation at an angle to that of the underlying series. It matters not whether the foliated rock of the inferior series be of sedimentary or of igneous origin. If sedimentary, a long time has been required to obliterate evidence of its fragmental character; if igneous, its foliation shows the effect of long-acting forces. While basal conglomerates are often found they are also often absent where other evidence shows that there are discordant relations between two series. This absence is explained, at least in some cases, by Pumpelly's disintegration theory, the encroaching shore line finding a set of disintegrated rocks in which the mass is ready to yield particles of the constituent minerals rather than pebbles.

(7) General field relations are often sufficient to establish discordant relations between series when all other lines of evidence are lacking. When in a region immense stretches of rocks of one series are always found in an undisturbed condition, while an adjacent series is always disturbed, discordant relations may be inferred. This is particularly evident when the horizontal series fills bays in the older rocks, or is found as inliers surrounded by the other rocks. Again, the general field relations may establish an unconformity even if both series are disturbed. One case of this is the occurrence of a uniform belt of stratified rocks which, perhaps with a monoclinal structure and a somewhat uniform strike and dip, runs for great distances, the rocks of the adjacent unconformable series being here of one kind and there of another kind. The evidence for the unconformity in this case is still further emphasized if the lower series, instead of having a simple structure, is folded in a complex manner. General field relations may betray unconformity even when the newer series has been folded in a more complex manner, as, for instance, having been subjected to two orographic movements, the first of which placed it in a monoclinal attitude, and the second of which, at right angles to this first force, gave it a fluted structure. The lower series, instead of having this regular structure, being subjected to still earlier orographic movements, would be more irregular in its foldings and faultings, and the difference

in simplicity of structure of the two series would increase in proportion to the number and intensity of the earlier movements. However, as the movements which have affected the newer series increase, the difficulty of discovering discordances by general field relations is increased. These and other cases of general field relations which show unconformity may not appear to the observer while doing detailed work, since no contacts or other ordinary indication of unconformity is found, but strongly appear when the work is platted. To the mind of the writer general field relations of the kinds above cited are sometimes more decisive evidence of unconformity than almost any kind of local relations. When the local proofs above considered, combined with general field relations, unite as evidences of unconformity, as is generally the case if the worker takes advantage of all the facts available, the accumulated evidence for discordant relations, even in difficult and folded regions, is often decisive.

Unconformities have been frequently inferred on insufficient ground. This has sometimes resulted from regarding surface igneous rocks as sedimentary, and the basal conglomerate overlying such a formation as evidence of unconformity. More frequently the misinterpreted evidence of unconformity is a discordance in foliation; sometimes cited as occurring in actual contact, but at other times being a discordance only in the strike and dip of foliation at some distance. A contact discordance of foliation or bedding may occur as a result of faulting. The strikes and dips of banded and contorted schists and gneisses often vary so greatly within short intervals that a difference of this kind can not be taken as an indication of discordances. This error has occurred because it has been assumed that cleavage foliation accords with sedimentation. When it is practically, not theoretically, recognized that this structure is secondary—may be produced in either sedimentary or igneous rocks—and that it generally does not correspond over large areas with bedding, such evidence will cease to be used as indications of structural discordance.

The application of the foregoing principles demands that in working out the structure of the crystalline formations the ground must be gone over in detail. No single section will be adequate to give a proper idea of the structure, nor will it do to consider that as a result of several or a dozen sections the structure of a large district may be worked out and the formations mapped, as has been too frequently done. Formations which outcrop in one section may not be exposed in another, or a formation between one section and the next may entirely change its character or disappear altogether. If the district is a difficult one the only safe way is to take advantage in the field of all available overground and underground facts, and to collect abundant material for supplementary office work. When only one structure is present and the character of that the least doubtful, it must not be assumed to be bedding. In regions in which the exposures are infrequent it may be impossible to work out the structure of crystalline rock series which have a true detrital succession, but it is better for the present and the future that no structure be presented than a false one.

After working out the structure of one district in a geological basin, adjacent districts may be mapped much more rapidly. Under proper checks the lithological character of individual beds may be assumed to remain the same. Sets of like formation occurring in the same order may be assumed to be the same group of formations. And perhaps most useful of all are discordant relations between series. In correlations from region to region, without the assistance of paleontology it will probably not be possible to carry the analogy further than series; and in far distant regions even the general lithological likeness and similarity of position of series is not sufficient warrant for placing them opposite each other in the time column.

If the foregoing principles are true, it is plain that in working out the structure of a new region local names should be applied to the formations and series. When the time comes that fuller knowledge enables them to be safely correlated with the series to which classical names have been applied, this may be done, and the local names will not be less serviceable to designate particular parts of these general series.

The area in North America in which detailed mapping has been done with a resultant proper understanding of the structural relations of the pre-Cambrian is surprisingly small. Scarcely a crystalline area on the continent has escaped the rapid geologist who has passed over a region and upon a few facts of uncertain value publishes structural conclusions which are not to be verified by future work. The districts carefully studied include the original Huronian of lake Huron, several small areas about Ottawa and between the Ottawa river and lake Ontario, a few small areas about the lake Superior region, a small part of western Massachusetts and a part of Maryland. Even in these districts the work at many points is rather old and to a certain extent unsatisfactory. Before reliable maps can be obtained this old work must be thoroughly revised in the light of the recent advances in the methods of study of the crystalline rocks. By this it is not implied that the more general work done is not of superlative value and of necessity must precede the more accurate accounts. A beginning has been made in American pre-Cambrian stratigraphy, but the great mass of work remains for the future.

RESULTS IN AMERICA AND EUROPE COMPARED.

This volume has already become too long to attempt to make a detailed comparison between America and Europe as to the results reached in pre-Cambrian stratigraphy. Also, I am wholly unfamiliar with European ground and am but imperfectly acquainted with the literature; hence I would not be warranted in making the attempt, even if space permitted. It may, however, be well, without giving any detailed facts or reviews of literature, to mention the opinions which appear to be prevalent in reference to the pre-Cambrian of Europe.

In the first place, it is not universally held that in Europe there are pre-Cambrian clastics. It is probable that this difference of opinion results in part because it is not agreed as to the lower limit of the Cambrian. If this could be settled it would be comparatively easy to decide as to the existence of pre-Cambrian sedimentaries.

Nowhere has there been in the past a wider difference of opinion on this question than in Great Britain, but now the consensus of opinion appears to be that pre-Cambrian clastics, either water-deposited or volcanic, or both, occur at various places. The officers of the official survey have, until very recently, denied that such rocks occur; but the Director-General states, in a late paper, that in western Scotland, associated with the fundamental gneiss, are small areas of schist and limestones which are possibly sedimentary; that within the complex of rocks in Scotland, for which the term Dalradian is proposed, there are probably pre-Cambrian clastics both of sedimentary and volcanic origin, and that Callaway is correct as to the pre-Cambrian age of the Uriconian volcanics. Still more recently it has been announced that the Torridon sandstone, 8,000 or 10,000 feet thick, which contains traces of annelids and other obscure organic remains, lies unconformably below the Olenellus Cambrian and must therefore be classed as pre-Cambrian.

The head of the official survey of France, Michel-Lévy, states that in the pre-Cambrian are placed only those rocks which are completely crystalline and which antedate all the clastic series. The Cambrian is delimited below by the appearance of the first layers, which are incontestably clastic. It passes insensibly into the crystalline rocks regarded as pre-Cambrian. The Cambrian is delimited above by the overlying accordant or discordant strata-bearing fossils. The rocks placed in the Cambrian are for the most part nonfossiliferous, and, while clastic as a whole, are locally much altered by contact action and are more crystalline than the later formations. The foregoing positions are very different from those held by Barrois, another of the official geologists. This author holds that in France there is at least one series of pre-Cambrian rocks of clastic origin to which he has applied the term Huronian.

In Germany there is a radical difference of opinion between the leading geologists as to whether pre-Cambrian clastics exist, although a large majority maintains that belonging here are the Obermittweida conglomerate and similar rocks in other localities. Others hold that these rocks are in folded parts of the Cambrian or post-Cambrian. The commonly accepted classification of the pre-Cambrian rocks, according to Lossen, is as follows: (1) Urgneiss or fundamental gneiss, which in places is rather a granite than a gneiss. Toward the top, the formation takes in beds of limestone, quartzite, and amphibolite, generally, however, without any vestige of clastic character. Above the Urgneiss follows (2) the Urglimmerschiefer, which passes into (3) the Urthonschiefer or Phyllit, and this contains younger gneiss formations. This classification has a structural basis to a certain degree, but seems to be primarily lithological. Credner, in the last (seventh) edition of his Elemente der Geologie, places the Urgneiss as the equivalent of the Laurentian and the Urschiefer, including here the Urglimmerschiefer and Urthonscheifer as the equivalent of the Huronian of North America.

In Norway the director of the official survey, Dr. Reusch, considers that it has been shown that there are in that country pre-Cambrian clastics which are overlapped by the Cambrian. De Geer maintains that there are pre-Cambrian rocks in Sweden which are unconformably below the Cambrian. Reusch is inclined to exclude these rocks from the Archean, the latter being restricted to the fundamental complex. If these results be accepted it follows that in Scandinavia there are rocks which take a position represented in America by the Algonkian.

The inclination to limit the term Archean to the fundamental complex is rather widespread in Europe, without reference to whether pre-Cambrian clastics exist or not. Many of those who hold that pre-Cambrian clastics occur are disposed to give them distinctive names. As in America, no structural methods have been applied to the fundamental complex.

Rigidly defining the Archean to cover the basal crystalline complex and excluding from it all clastic rocks, we have in England, France, Germany, and Scandinavia equivalents of the Algonkian of America, if those geologists are right who maintain the pre-Cambrian character of the clastic rocks mentioned.

No attempt has been made, except in Great Britain, to subdivide into series the rocks equivalent to the Algonkian. The review of the facts in America has led to the conclusion that it is not practicable to make correlations over the whole continent of a more definite nature than Algonkian and Archean. If this be true, it is evident that correlations can not be more definitely made between European and American rocks. The application of such American terms as Huronian and Keweenawan to European series is wholly unwarranted.

If the suggestion be correct that the Archean is of a different character from any succeeding formation and has a continental extent in America, it may be safe to regard the fundamental complex of Europe as its equivalent. If this be done and Cambrian be delimited below by the Olenellus fauna, it would be safe to say that the intervening series of rocks occupy some position in the great Algonkian system. But any given series of the Algonkian of Europe can not safely be placed opposite a definite series in this country until there shall be found paleontological evidence for so doing.

Even if the Cambrian in Europe were rigidly delimited below by the

Olenellus fauna and all doubtful series barren of fossils were regarded as pre-Cambrian, it would still be true that the rocks thus referred to the Algonkian system would be insignificant in amount and extent as compared with the great areas and volumes here included in America. It would also be true that the structural work upon such series has not progressed so far. This is probably in large measure due to the non-occurrence of such volumes of Algonkian rocks in Europe as exist in America; but it is also due in part to the fact that in that portion of Europe which has been most closely studied there have been since Cambrian time repeated powerful dynamic movements and periods of great eruptive activity. The conditions are much the same as in the eastern United States, where a study of pre-Cambrian stratigraphy has barely begun. In the interior of the American continent the conditions have been far more favorable for a structural study of the pre-Cambrian rocks.

NOTES.

[1] Observations on the Geology of the United States Explanatory of a Geological Map, Wm. Maclure. Trans. Am. Phil. Soc., vol. VI, pp. 411–428. With a map.

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