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LITHOSTRATIGRAPHY AND CARBONATE PETROLOGY OF THE VIOLA GROUP (ORDOVICIAN), ARBUCKLE MOUNTAINS, SOUTH-CENTRAL OKLAHOMA

A DISSERTATION

SUBMITTED TO THE GRADUATE FACULTY

in partial fulfillment of the requirements for the

degree of

DOCTOR OF PHILOSOPHY

BY

GERALD CLEMENT GLASER

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1965

LITHOSTRATIGRAPHY AND CARBONATE PETROLOGY OF THE

VIOLA GROUP (ORDOVICIAN), ARBUCKLE MOUNTAINS,

SOUTH-CENTRAL OKLAHOMA

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The writer expresses his sincerest thanks to Mr. L. P. Alberstadt, project co-worker, who is studying the biostratigraphy of the Viola Group. He has enlightened the writer on many points and stimulated interesting discussions while sharing the problems associated with this study.

Finally, this study could not have been brought to completion without the continuous assistance of my wife, Gae L. Glaser.

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LITHOSTRATIGRAPHY AND CARBONATE PETROLOGY OF THE VIOLA GROUP (ORDOVICIAN), ARBUCKLE MOUNTAINS, SOUTH-CENTRAL OKLAHOMA

INTRODUCTION

The investigations for this report on the Viola Group (Trenton, Eden-Maysville?, and Richmond) were conducted in the Arbuckle Mountains of south-central Oklahoma. The study area covers a tract about 35 miles long and 60 miles wide, with an area of approximately 32 townships or roughly 1,200 square miles. Figure 1 illustrates the geographical location of this area.

Rocks of the Viola Group, formerly divided into the Viola Limestone and the "Fernvale" Limestone, were studied in 18 surface localities where they crop out in portions of Pontotoc, Johnston, Coal, Murray, and Carter Counties. Plate 6 illustrates the outcrop pattern of the group and the location of the measured stratigraphic sections. Besides the occurrence in the Arbuckle Mountains, part of this distinctive

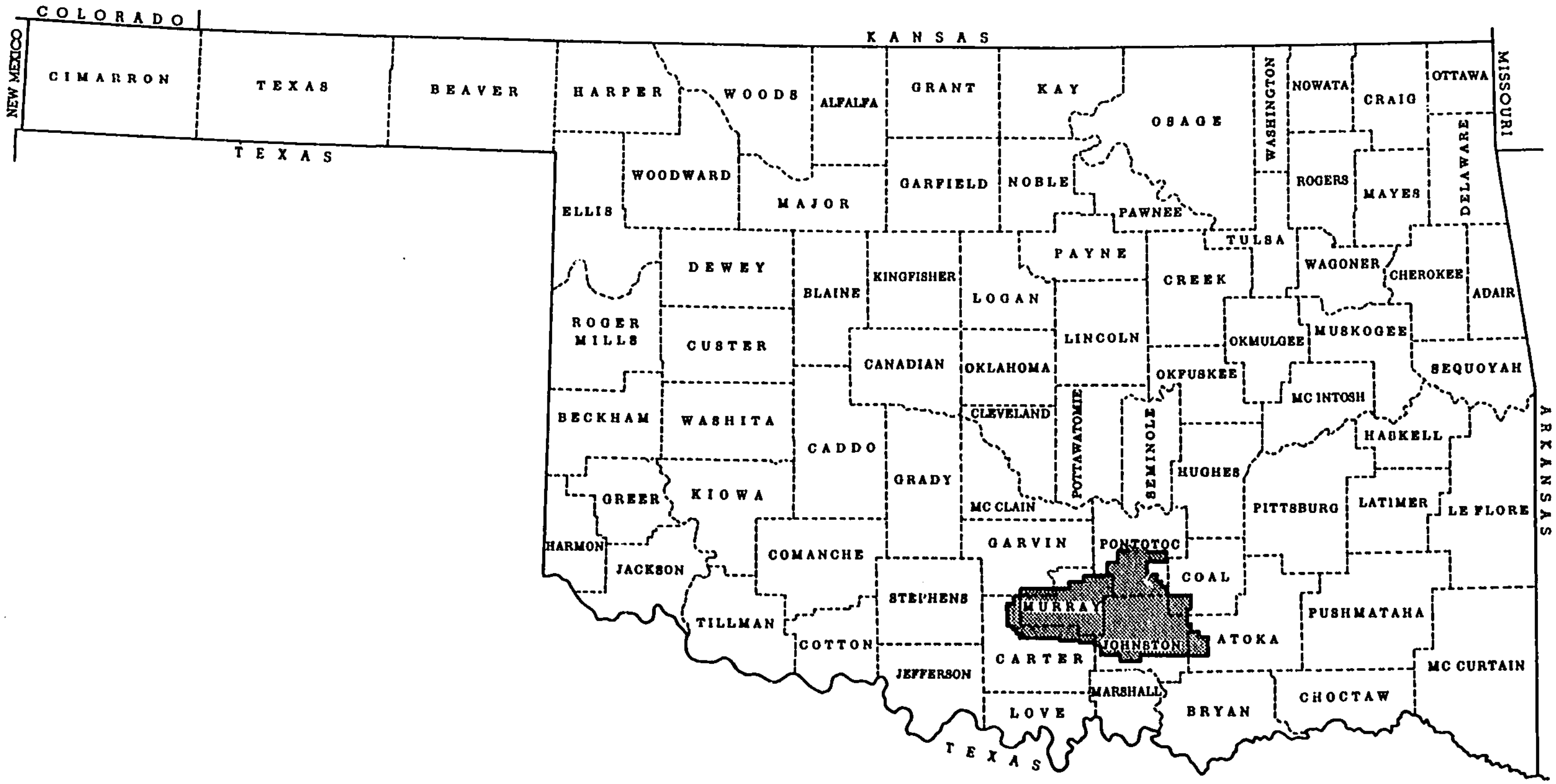


FIGURE 1

INDEX MAP OF OKLAHOMA SHOWING LOCATION OF ARBUCKLE MOUNTAINS

lithologic unit is present also in the Wichita Mountains (Decker, 1933) and has been penetrated by numerous wells in the Mid-Continent region. According to Wengerd (1948, p. 2185) "Viola beds have been found in the subsurface as far north as South Dakota, southward in Texas, and westward in Colorado." Rocks of the Viola Group also crop out in the Criner Hills of southern Oklahoma and a few feet of the "Fernvale" is exposed in northeast Oklahoma (Huffman, 1958).

Based upon the integrated data from field measurements, thin-section and hand-specimen studies, a southwestern basin province and a northeastern shelf province are established with the line separating them trending N. 42° W. approximately 3½ miles west of Section N near Mill Creek. (See fig. 3, p. 40.) The group thickness in the basin province ranges from 550 to 895 feet whereas the shelf province thickness ranges from 339 to 422 feet.

Three distinct lithostratigraphic units, two of which have equally distinct facies, are recognized. Unit 1L at the base is composed of siliceous laminated mudstones which, toward the northeast, pass into Unit 1C, composed of coarse-grained skeletal calcisiltites. Unit 2 is comprised of calcarenitic mudstones in both the southwest and northeast provinces and constitutes the middle of the sequence. Unit 3C is composed of coarse-grained skeletal calcarenites formerly called "Fernvale" Limestone. In the extreme southwest, the Unit 3CM facies, consisting of calcarenitic mudstones interbedded with coarse-grained skeletal calcarenites, is present.

The contacts of Unit 1L with Unit 2 and Unit 2 with Unit 3C seem to be gradational and transitional, and evidence for unconformities of regional extent has been found only at the base of the Viola Group where it is in contact with the Corbin Ranch Formation (Bromide "dense") of the Simpson Group, and at the top where it is in contact with the Sylvan Shale. No physical evidence for unconformities has been found elsewhere in the sequence.

This study is part of a joint project with Mr. Leonard Alberstadt, also a candidate for the degree of Doctor of Philosophy, at the University of Oklahoma. His study is concerned with the biostratigraphy of the Viola Group. Although most of the field work was undertaken jointly, each portion of the study represents a separate entity in itself and the writer takes full responsibility for the views expressed herein.

Purpose of Investigation

The main objectives of this study were: (1) to establish a lithostratigraphic framework for the limestones of the Viola Group in order to understand better their regional stratigraphic relations; (2) to investigate the possibility of a meaningful subdivision of the Viola strictly from surface studies; (3) to reconstruct original environmental conditions and sedimentation patterns using thin-section examination to (a) determine origin and relative proportions of constituent particles, and (b) classify rock types present and outline their vertical and horizontal distribution.

An attempt also was made during field investigations to find physical evidence for the unconformity referred to by Edson (1930) within the Viola Group which might be used to represent the time elapsed during the Eden and Maysville stages. However, this effort produced no positive results and a determination of actual presence or absence of such a break can be made only after the companion biostratigraphic study is completed.

Previous Investigations

A brief chronologic sequence of the historical development and background of studies concerned with the Viola-

"Fernvale" is presented below.

1902: J. A. Taff first described the Viola Limestone from an outcrop near the old village of Viola in Johnston County. He recognized the limestone as a continuous but slightly variable deposit approximately 700 feet thick; he included the coarsely crystalline limestones at the top as part of the Viola.

1903: J. A. Taff recognized a tripartite subdivision of the Viola based upon faunal studies made by E. O. Ulrich with the lower and upper parts each approximately one-third of the 700-foot thickness. Furthermore, he observed irregular bands and nodular masses of chert most often found in the lower and middle parts of the limestone. Too, he described bituminous limestone from two localities near Buckhorn Creek.

1911: E. O. Ulrich, subsequent to his identification of fossils for Taff, pointed out that the Fernvale Formation at few places exceeds 25 feet and is recognized in the Arbuckle uplift at the top of the Viola Limestone as a 2- to 3-foot bed with exactly the same lithologic and faunal characters that mark it in southeastern Missouri.

1931: C. E. Decker and C. A. Merritt subdivided and described the underlying Simpson Group. At the top of the Simpson Group they included about 200 feet of limestones that Taff had assigned to the basal part of the Viola Limestone. This restriction, based in part on work done by Ulrich in 1927, has been accepted in all subsequent publications on the Viola and Simpson Groups in the Arbuckle Mountains. The beds in question are in the upper part of Decker's Bromide Formation, including at the top the Corbin Ranch Formation (Bromide "dense") of Harris (1957).

1933: C. E. Decker made a paleontologic analysis of the Viola Limestone using the graptolite fauna and concluded that the age determination by Taff in 1903 (Trenton and Richmond) was valid.

1934: Ruedemann and Decker, in a further study of the graptolites, noted that zones of *Diplograptus nexus*, *Diplograptus recurrens*, and *Climacograptus lorrainensis* are present in the Viola Limestone in the western, middle, and eastern parts of the Arbuckle Mountains. These zones were correlated by Ruedemann and Decker with the lower and middle Lorraine (Eden) in western Ontario and northwestern New York.

1936: H. A. Ireland, in the course of his insoluble residue work, noted that the general surface section of the Viola showed three divisions: an upper 50 to 100 feet of coarsely crystalline limestone; a middle 400 to 600 feet of fine-grained somewhat cherty limestone; and 200 feet of dense lithographic limestone.

1948: S. A. Wengerd measured six surface sections of Viola-"Fernvale," but most of his work dealt with examination of subsurface cuttings and insoluble residue studies which form the basis for his division of the Viola into four members. More importantly, he recognized a platform- and basin-type framework onto and into which the Viola-"Fernvale" sediments were deposited.

Besides the regional unconformity between the "Fernvale" and Viola recognized by Ulrich (1911), various workers through the years (Edson, 1930; Decker, 1936; Ham, 1955; Cooper, 1956) have recognized a post-Bromide, pre-Viola unconformity. Edson (1930) also recognized an unconformity between the "Fernvale" and Sylvan Shale.

Methods of Investigation

The study of aerial photographs to determine suitable areas for investigation represented the first phase of the work. Upon completion of this study, field work was begun on the selected locations and continued throughout the project to check on specific problems which arose during the course of the investigation. Eighteen stratigraphic sections were measured, some by taping methods, most by plane table and alidade. A few sections were double-checked using both methods and results obtained are in close agreement. Of the eighteen sections, twelve are complete, and a number of these show fair to excellent exposures of contacts at the base with the underlying Corbin Ranch Formation (Bromide "dense") of the Simpson Group and at the top with the overlying Sylvan Shale; two do not have the base exposed; two have the base faulted out; one has only the upper coarsely crystalline limestone well exposed and was selected solely because of the excellent fauna present. Most of these sections are well-exposed and five of them (Sections A, D, H, O, Q) are displayed in either quarry or highway cuts. Of course, outcrops in a few are of poor to fair quality in part, and in general all exposures are degraded somewhat during the late spring and throughout the summer by thick vegetational cover.

Some 170 hand specimens were collected from these sections from which 134 thin sections were prepared. Each hand specimen was slabbed and polished; one part was etched in 10 percent dilute hydrochloric acid and another part was varnished. Both surfaces then were studied with the binocular microscope. Two-inch by two-inch thin sections were prepared from the remaining rock; half of each thin section was left uncovered, etched for five seconds, and then stained with alizarine red S to aid in recognition of dolomite. All thin sections were examined petrographically. (See Appendix for detailed descriptions.)

Rock chips from thin sections also were available for X-ray analysis, and approximately 28 patterns were run to determine overall mineralogic content and to check for dolomite in those cases where petrographic and staining evidence was not diagnostic. Qualitative X-ray fluorescence was run on one stratigraphic section. Some samples were checked for clay content by using appropriate separation techniques and then analyzing the residues by normal X-ray means. Results of this and other X-ray data appear elsewhere in this report.

Spot checks were made on a few samples for insoluble residues, and a few acetate peels were prepared to study textures.

Detailed laboratory charts were prepared from the petrographic, petrologic, and field studies. These were utilized in the construction of the regional stratigraphic diagram (Plate 7) and aided in the subdivision of the limestones of the Viola Group.

Terminology

Here the writer wishes to define terms used in this report in order to dispel any confusion or apprehension resulting from such terminology.

Bedding thickness (thin, medium, etc.) was used according to the classification scheme proposed by McKee and Weir (1953) and modified by Ingram (1954).

Uneven bedding refers to irregular beds which pinch and swell or are broken into a nodular appearance and may tongue out between bedding planes in a short distance or even coalesce with beds above or below as the intervening bedding plane disappears (Dunbar and Rodgers, 1957). It is used synonymously with wavy-bedded in this report.

Even bedding refers to those beds which present a regular appearance, generally can be traced for long distances, and between which there is no coalescence of beds. It is used synonymously with planar-bedded in this report.

Mud refers to calcite mudstone and has an upper size limit of 10 microns.

Laminites refer to those rocks which have a more or less distinct alternation of material, in this instance silica and calcium carbonate, which differ from one another in grain size and composition and impart to the rock a well-laminated appearance. It implies no limit as to thickness of lamina or bed and does not necessarily imply a periodicity in the recurrence of laminae.

Recrystallization refers to that process by which carbonate material has been converted from its original grain size by some post-depositional mechanism or mechanisms to another, usually coarser grain size. The criteria used for recognition of this phenomenon are in decreasing order of clarity: (1) totally unsupported and isolated mud or fossil fragments located in a sparry calcite mass; (2) patchy distribution of coarse and fine spar throughout the specimen; and (3) extreme irregularity of sparry calcite boundaries. Bathurst (1958, 1959) discusses these criteria in detail. Fossil debris in some specimens shows evidence for recrystallization of the original shell material.

Pellet-forms refers to those particles of mud which represent lumps, aggregates, or fecal pellets. However, in many of the thin sections studied, the author feels that these forms are the result of a recrystallization process in which much of the mud has recrystallized to fine spar leaving only isolated remnants of mud with extremely diffuse boundaries and as such, resembling the grumeleuse structure of Cayeux (1935).

Organic material refers to a light- to dark-brown isotropic substance present in extremely minor amounts in approximately 60 percent of the thin sections studied. Unfortunately, enough of this material could not be collected to analyze by X-ray or DTA techniques. However, W. E. Ham of the Oklahoma Geological Survey has seen material similar to this in some of his studies and believes it to be organic (personal communication, 1965).

Classification of Carbonate Rocks

In recent years much work has been done on carbonate rocks, and a number of classifications have been proposed (Bramkamp and Powers, 1958; Folk, 1959; Dunham, 1962). Although it must be agreed that the carbonate rocks represent a complex gradational continuum in any classification scheme, different workers in this field generally have been able to classify limestones uniformly using somewhat the same parameters. It matters not that the final name applied by different individuals is dissimilar as long as the name conveys a clear picture of the particular rock.

The carbonate classification in this report is modified slightly from the scheme used in a course in carbonate petrology at The University of Oklahoma. This classification is based as fully as possible on purely descriptive parameters, but allows for genetic interpretations where they can be inferred reasonably. The classification appears in Table 1. Notes for the working usage of this classification appear below:

Notes:

1) If the rock contains more than 10 percent terrigenous material or authigenic constituent, "sandy," "silty," or an appropriate modifier prefixes the rock name. ("Sandy" and "silty" here refer to terrigenous particles.)

TABLE 1

Mudstone and Muddy Limestones		
>50% mud matrix grain size <10 microns	<50% mud matrix grain size 10-62 microns	<50% mud matrix grain size 62-2000 microns
calcilutite (calcite mudstone)	muddy calcisiltite	muddy calcarenite
dolomitized equivalents		
Nonmuddy Limestones		
10-62 microns	62-2000 microns	2000 microns
calcisiltite	calcarenite	calcirudite
dolomitized equivalents		
Special Types		
pervasively recrystallized limestone and dolomite		

2) If the rock contains more than 10 percent replacement dolomite, "dolomitized" is added in parentheses after the rock name; if the dolomite is of uncertain origin, substitute "dolomitic" for "dolomitized."

3) Rocks with obvious structures have appropriate modifiers such as "burrowed" or "cross-laminated."

4) If the rock has undergone more than 10 percent recrystallization, "partially recrystallized" is added in parentheses after the rock name; if more than 50 percent recrystallized, "extensively recrystallized" is used.

5) If the rock contains more than 10 percent fossil debris, "skeletal" is used as a modifier.

6) If one faunal element is significantly dominant, it should be used in the rock name rather than the term "skeletal."

7) If the rock contains more calcite spar than mud, "sparry" is used in the rock name.

8) Calcisiltite (calcisiltitic) and calcarenite (calcarenitic) refer to the size of the skeletal grains.

9) If two faunal elements are significantly dominant, the first-mentioned is subordinate to the second (e.g. sparry bryozoan-echinoderm calcarenite; the bryozoan content is less than the echinoderm content).

Several examples to clarify usage are presented below:

Burrowed sandy skeletal calcarenitic mudstone (partially recrystallized)
(The rock is burrowed, contains 10 percent or more both of quartz sand and skeletal debris which is in the arenite size range, 50 percent or more calcite mudstone, and has undergone 10 percent or more recrystallization.)

Sparry echinoderm calcarenite
(The rock is spar-cemented; echinoderms are dominant and in the arenite size range.)

Muddy spar-cemented skeletal calcisiltite
(The rock contains less than 50 percent mud, more spar, which cements the rock, than mud, and greater than 10 percent skeletal debris which is in the silt-size range.)

Although no scheme can be entirely satisfactory because of the complete gradational series existing in carbonate rocks, the classification here presented is easy to use and should be as applicable as any yet proposed. It requires no memorization of the meaning of coined words as do other schemes because it employs common geologic terms familiar to all students of geology.

STRATIGRAPHY

General Statement

The limestones of the Viola Group in the Arbuckle Mountains can be subdivided into three distinct units of which two have equally distinct facies. Also, a southwestern basin province and a northeastern shelf province are established for these rocks in this area (fig. 2). Furthermore, these limestones represent a distinct cycle of completely marine carbonate sedimentation.

Although arbitrary designations have been given to the individual rock types, the differences between each are real, and field recognition is relatively easy. The basal unit in the basin province is well developed on the Arbuckle and Tishomingo anticlines and is composed of siliceous laminated mudstones (laminites) characterized by planar bedding, high silica content and a fauna dominated by graptolites, sponge spicules, and trilobites. This unit is designated Unit 1L with the L referring to "laminites." In the northeastern shelf province, the rocks of Unit 1 are coarse

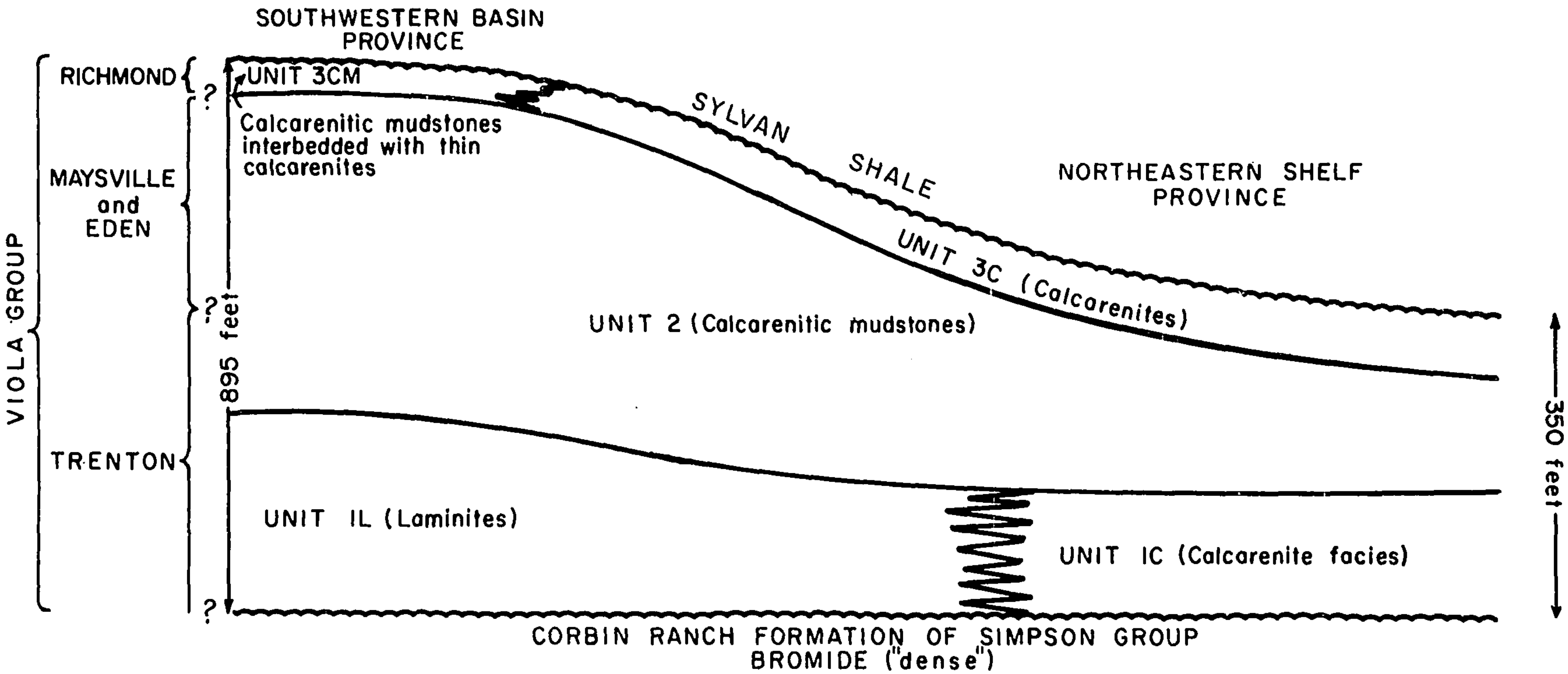


FIGURE 2
DIAGRAMMATIC SECTION OF THE VIOLA GROUP
ARBUCKLE MOUNTAINS, OKLAHOMA

Gerald C. Glaser-1965

skeletal calcisiltites and fine skeletal calcarenites best developed on the Hunton anticline and characterized by slightly wavy bedding, minor chert in the form of nodules, and a fauna dominated by echinoderms and in places bryozoans. This unit is designated Unit 1C with the C referring to "calcarenites."

The middle calcarenitic mudstone is the only unit which has been found throughout the mountains; it thins markedly from the basin onto the shelf. This unit in both the basin and shelf provinces is a skeletal calcarenitic mudstone characterized by wavy bedding, variable skeletal content, predominance of calcite mud over spar cement, high chert content in the form of irregular nodules, and a fauna dominated by echinoderms, trilobites, and brachiopods. This unit is designated Unit 2.

In the northeastern shelf province the rocks of Unit 3 are well-washed coarse calcarenites best developed on the Hunton anticline. They are characterized by massive beds, absence of chert and calcite mud, and a fauna dominated by echinoderms, trilobites, and brachiopods which are commonly silicified. This unit is designated Unit 3C with the C referring to calcarenites. Unit 3C encompasses those rocks called "Fernvale" in this area. The upper unit in the basin province is composed of skeletal calcarenitic mudstones interbedded with thin, fine to medium calcarenites. These calcarenitic mudstones are similar to those of Unit 2 and are virtually indistinguishable from them; the calcarenites are not well washed in that they contain minor percentages of calcite mud. This unit is characterized by slightly wavy bedding, chert in the form of nodules in the calcarenitic mudstones, and a fauna dominated by echinoderms, trilobites, and brachiopods which are commonly silicified; the designation for these rocks is Unit 3CM with the CM referring to "calcarenitic mudstones."

Not only is the southwestern basin province distinctly set apart from the northeastern shelf province on the basis of the different lithologies developed in upper and lower Viola strata, but also it is distinguished from the shelf province by substantial differences in thicknesses. In the basin the total thickness for the group ranges from about 600 to 895 feet; on the shelf the group thickness ranges from 339 to 422 feet. The maximum thickness for the basal laminites in the basin and in the Arbuckle Mountains is 382 feet, although in most sections it is about 200 feet thick; equivalent rocks on the shelf average about 150 feet. In the basin the maximum thickness for Unit 2 is 473 feet with the average about 450 feet; this same unit on the shelf is roughly 130 feet thick. Although the trend of thicker units in the basin and thinner units on the shelf is true for the basal and middle units, this relation is reversed for the upper unit whose shelf deposits are thicker than the basin deposits. The maximum thickness for Unit 3C on the shelf and in the mountains is 112 feet although commonly it is between 60 and 80 feet in thickness; rocks of this unit in the basin range from 15 to 49 feet in thickness.

In addition to the facts that the limestones of the Viola Group are divisible into three distinct units and the area is divisible into shelf and basin provinces, the Viola Group is underlain at the base and overlain at the top by unconformities of regional extent. The base rests disconformably on the massive calcilutite of the Corbin Ranch Formation (Bromide "dense"), and the top is disconformably overlain by the Sylvan Shale. Evidence for these unconformities was obtained during the field investigations and is discussed in a later section.

These limestones of the Viola Group represent a cycle of marine carbonate sedimentation which began throughout most of the southwestern basin province in deeper and less agitated waters in which the laminated mudstones were deposited, progressed through intermediate water and energy conditions during deposition of the calcarenitic mudstones, and ended with deposition of coarse calcarenites in relatively shallow and highly agitated waters. However, a different pattern existed in the northeastern shelf province where rocks of the basal division are coarse calcisiltites and fine calcarenites instead of laminites. Thus, on the shelf the Viola sequence begins with the deposition of high-energy calcarenites, continues with the deposition of lower energy calcarenitic mudstones, and then reverts to high-energy calcarenites. Calcarenites comprise about two-thirds of the thickness of the Viola Group on the shelf, whereas they comprise less than 10 percent in the basin.

Based upon earlier paleontologic studies, it is believed that the Trenton, Eden-Maysville, and Richmond stages are represented in the limestones of the Viola Group.

Upper Calcarenites and Equivalents (Units 3C and 3CM)

The upper unit of the Viola Group is represented by two distinct facies. The first is a well-washed noncherty spar-cemented coarse calcarenite (Unit 3C) attaining a maximum thickness of 112 feet in the shelf province at Robertson

Creek, but normally averaging 60 to 80 feet; it ranges down to 15 to 20 feet in the basin. Petrographically, this rock is the equivalent of Dunham's (1962) grainstone and Folk's (1959) biosparite. Abundant echinoderms and common trilobites and brachiopods dominate the fauna. Replacement dolomite and burrowing features are uncommon; quartz sand, where present in individual specimens, ranges from 3 to 7 percent. This unit contains less than 1 percent insoluble residues except where the fossils have been silicified in which case the percentage of insolubles may be as high as 15 although 3 to 5 percent is more common. Chemical analysis of a channel sample taken from the Ideal Portland Cement Quarry shows 97.68 percent calcium carbonate, 0.98 percent magnesium carbonate, and only 1.25 percent silica.

The second facies consists predominantly of cherty calcarenitic mudstones interbedded with thin, fine to medium muddy calcarenites (Unit 3CM) and ranges in thickness from a maximum of 49 feet in the extreme southwestern part of the basin province to a minimum of 26 feet on U. S. Highway 77; echinoderms, trilobites, and silicified brachiopods dominate the fauna. Replacement dolomite, burrowing features, and chert are present. Insoluble residue and chemical analyses on the calcarenitic mudstones of this unit are not available although these rocks are similar to other calcarenitic mudstones (Unit 2) found in this group. Chemical analyses of those mudstones indicate insoluble contents on the order of 10 percent with about 87 percent calcium carbonate.

The calcarenites of Unit 3C are normally coarser textured and more loosely packed in the shelf area of what is now the Hunton anticline. Virtually the whole rock is composed of skeletal debris cemented by coarse sparry calcite. The average specimen contains by area estimate about 60 percent spar and 40 percent skeletal debris. Of the fossils found in these rocks, echinoderm fragments are most abundant and consist of individual columnals and crown plates. Although it is impossible to ascertain in every case from which type of echinoderm these were derived, the writer believes that the pelmatozoans, especially the crinoids and cystoids, must have been the main contributors. Trilobites are common, especially in the upper few feet of this unit at most localities where they normally constitute from 7 to 10 percent of the specimen. Brachiopods are equally as common as trilobites and are best observed on the outcrop where they are commonly silicified. Large numbers of shells of well-preserved, completely silicified specimens can be obtained from blocks of this rock upon solution with hydrochloric acid.

Other faunal elements are less common in this unit. These include bryozoans, cephalopods, and ostracodes. All of these skeletal elements are rounded and abraded attesting to the high energy environment in which the calcarenites were formed.

Rounded to well-rounded straight extinction quartz sand commonly is found in these calcarenites and may contribute up to 7 percent in some specimens. Locally it is concentrated in animal burrows and may represent an infilling. Chert is noticeably absent in the calcarenites.

Little calcite mud is found in this unit giving further testimony to the energy conditions which prevailed at the time of deposition, that is, any calcite mud that may have been present, probably was washed away. Skeletal grains supporting each other were surrounded by open pore space which was subsequently filled by coarse sparry calcite cement. However, toward the basin the calcarenites of Unit 3C become fine- to medium-textured and contain varying quantities of calcite mud. The skeletal debris in these basin calcarenites probably was washed in from the carbonate bank on the shelf on which the well-washed calcarenites were formed.

Dolomite and burrowed structures are observed in this unit although neither is present in great amounts. The dolomite occurs as discrete euhedral crystals replacing skeletal debris and, as such, is demonstrably secondary. The burrows are present as long, slender, tube-like extensions having the infilling material arranged in an arcuate manner. These infilled tube-like extensions are normally of a different color than the rock.

The calcarenites of Unit 3C range in thickness from 15 feet in the Lake Classen area to 112 feet on Robertson Creek. On the shelf, the range is from 62 feet to 112 feet; in the basin, from 15 to 22 feet. This again emphasizes the difference between shelf and basin except that in this case, the thickest sequence is on the shelf instead of the basin. Only for this unit is this reversal true.

A study of the insoluble residues of all calcarenites, including those from Unit 1C, shows that these rocks have extremely low percentages if silicified skeletal debris is not present in the original sample. Every sample chosen which contained no silicified material had less than 1 percent insoluble residue which consisted of finely disseminated silica and clay.

Similarly, a chemical analysis of a channel sample of approximately 65 feet of Unit 3C ("Fernvale") collected in the Ideal Portland Cement Quarry near Lawrence, Oklahoma, shows that these rocks contain extremely high percentages of calcium carbonate. Specifically, the analysis shows 97.68 percent $CaCO_3$, 0.98 percent $MgCO_3$, 1.25 percent SiO_2, and 0.07 percent Al_2O_3. Roughly 1.34 percent of this sample is insoluble material, a figure that agrees well with the insoluble residue analysis.

In the basin province, the rocks equivalent to the well-washed calcarenites of the shelf are predominantly calcarenitic mudstones interbedded with thin, fine to medium muddy calcarenites (Unit 3CM). These rocks are best developed in the southwestern part of what is now the Arbuckle anticline. The calcarenites of this unit are unlike those of the shelf in that they contain 10 to 20 percent calcite mud, are finer textured, and range in thickness from 5 to 12 feet. A calcarenite which increases in thickness from 5 to 7 to 9 feet toward the southwest is present at the base of the unit. Above this is from 21 to 37 feet of calcarenitic mudstones. In the southwesternmost section, at West Spring Creek, another 3 feet of fine muddy calcarenite, not observed at other sections in this province, is present atop the calcarenitic mudstones. Although the calcarenites of the basin are unlike those of the shelf in content of mud and texture, they are similar to those on the shelf faunally. On the other hand, the calcarenitic mudstones of Unit 3CM are composed predominantly of calcite mud and skeletal debris with the former contributing on the average 40 to 50 percent and the latter, 30 to 40 percent. The remainder of the rock is composed of microspar and dolomite, together with terrigenous and authigenic constituents. Of the fossils found in these rocks, echinoderm fragments are dominant and are mainly columnals and body plates. Brachiopods and trilobites rank next in importance and again, many brachiopods are silicified. Trilobite remains are mostly comminuted; other fossil types are extremely sparse. The fauna of this unit is less abraded, and individual grains are more angular than those observed in the calcarenites. This suggests a lower energy environment.

Subangular quartz of silt size, with straight extinction, is found in this unit together with finely disseminated silica and irregular chert nodules. Dolomite is more common in this rock type than in the clacarenites, and in some specimens constitutes 10 to 15 percent of the sample. It exists as discrete euhedral crystals and is demonstrably of replacement origin. Whorled structures representing traces of animal burrows are common in this type of rock.

Middle Calcarenitic Mudstones (Unit 2)

The middle division of the Viola Group is represented by a distinct unit which is found throughout the Arbuckle Mountains. In this respect it is unlike the lower and upper units, each of which has two separate facies.

This middle unit of the Viola Group (Unit 2) normally consists of burrowed cherty and noncherty wavy-bedded skeletal calcarenitic mudstones in which the amount of fossil debris is variable throughout the section. Chemically, both insoluble residue studies and chemical analyses indicate this rock type contains about 10 percent insoluble material, 87 percent calcium carbonate, and 2 percent magnesium carbonate. Petrographically this rock is the equivalent of Dunham's (1962) wackestone and packstone and Folk's (1959) biomicrite.

At a number of localities, particularly in the east and northeast, these calcarenitic mudstones are gradational into fine muddy calcarenites which themselves are transitional into the overlying coarse, well-washed calcarenites.

This unit ranges in thickness from 119 feet on the shelf to 473 feet in the basin. On the shelf, the present-day Hunton anticline, it ranges from 119 to 199 feet; in the basin, the Arbuckle anticline region, it increases in thickness toward the southwest and is rather uniform, ranging from about 380 to 473 feet and more commonly from 459 to 473 feet in the extreme southwest. This unit shows the greatest amount of thinning toward the northeast.

The fauna of the calcarenitic mudstones is similar to that of Units 3C and 3CM in that echinoderms, brachiopods, and trilobites are dominant. Bryozoans, graptolites, gastropods, and sponge spicules are of minor importance. However, the fossils are less rounded and less abraded indicating an environment of deposition with lower energy than that associated with the calcarenites. Silicified shells are not common in this unit although some were observed. Again, as in the calcarenites, brachiopods are most easily silicified and some bedding surfaces are covered with shells from this phylum. As should be expected in these mudstones, calcite as spar cement is not common. On the average, fine calcite mud constitutes from 45 to 65 percent of individual specimens with about 25 to 35 percent skeletal debris.

Fine subangular to subrounded straight extinction quartz silt normally is present in amounts ranging from 2 to 4 percent. Large irregular chert nodules are characteristic of this unit and are demonstrably secondary replacements. On the outcrop the chert transects sedimentary features and is itself extremely fractured; petrographically, it is seen to contain fossil shells. In some localities on the Arbuckle anticline chert is noticeably absent in the lower half of this unit although this same distinction cannot be carried throughout the mountains. Burrowed features are the most common sedimentary structures exhibited by rocks in this part of the sequence. These rocks show evidence of burrowing activity by organisms that lived on the sea floor. Whorled structures, local concentrations of quartz silt and sand, and irregular, curved and concentrically-lined "tubes" all present ample testimony to the intense reworking of these once-soft sediments.

Replacement dolomite is most common to this lithostratigraphic unit both in number of occurrences and percentages of that mineral. It is more commonly associated with the fine calcite mud fraction and also occurs as discrete euhedral crystals replacing fossil shells. Virtually every specimen of the calcarenitic mudstones contains some dolomite although it may be less than 1 percent in most specimens; about 20 percent dolomite was the maximum observed for this rock type.

The bedding in this unit is extremely uneven and wavy and is nodular at some localities. A paste-like material with shaly structure occurs between the nodules of limestone where exposures are good. X-ray data and staining techniques indicate much of this material, which may be the "plastic clay" of Wengerd (1948), is dolomite. In many of the measured sections, a few beds near the top of the unit have an intricate network of solution holes. Adjacent rocks under apparently similar conditions of exposure do not exhibit this honeycombed feature which was noted also by Tillotson (1924). It is thought that this feature represents surface solution.

A study of the insoluble residues shows that the calcarenitic mudstones contain, on the average, about 8 percent acid insolubles with a range between 1 and 20 percent. However, both of these extremes seem to be exceptional rather than normal cases. The insoluble material is predominantly fine quartz silt and finely disseminated silica.

Similarly, a composite average of six bulk samples taken from this unit approximately one-half mile northwest of the Dolese Brothers Rayford Quarry (Section Q) shows that these rocks contain 10.06 percent SiO_2, 87 percent $CaCO_3$, 1.88 percent $MgCO_3$, and 0.57 percent Al_2O_3. Roughly 11 percent of this bulk sample is insoluble material, a figure that agrees well with the insoluble residue analysis.

Lower Laminites and Equivalents (Units 1L and 1C)

The lower unit of the Viola Group is represented by two distinct facies. The first is a planar-bedded cherty siliceous laminated calcite mudstone (Unit 1L) attaining a maximum thickness of 382 feet in the basin province at West Spring Creek, but normally averaging between 135 and 229 feet in that province. Graptolites, trilobites, sponge spicules, and linguloid brachiopods dominate the fauna. Replacement dolomite, burrowing features, and a shelly fauna are noticeably absent. Quartz silt is present, but sparse; finely disseminated silica is the most characteristic insoluble material, ranging from 2 to 4 percent in the weakly laminated mudstones and from 20 to 47 percent in the well laminated ones. Although chemical analyses on rocks from this unit are not available, the insoluble residue work suggests that virtually the entire rock is composed of silica and calcium carbonate. Using an average insoluble residue content for the well laminated mudstones gives 33 percent silica and 67 percent calcium carbonate. On the other hand, an insoluble content of 4 percent silica in the weakly laminated mudstones gives 96 percent calcium carbonate assuming no appreciable content of other minerals.

The second facies consists predominantly of coarse skeletal calcisiltites and fine to coarse skeletal calcarenites (Unit 1C) similar to those of Unit 3C. This unit is found only in the northeastern part of the shelf province where it ranges in thickness from 162 to about 170 feet. Echinoderms and bryozoans dominate the fauna although brachiopods and trilobites also are important. Chert is present in layers and as nodular masses; replacement dolomite, quartz silt, and burrowing features are present, but are not important. The insoluble residues and chemical analyses have been discussed under the upper calcarenites of Unit 3C. That is, they contain about 98 percent calcium carbonate and less than 1 percent insoluble material if no silicified fossil shells are present in the original sample; presence of silicified shells may increase the insoluble content to 15 percent.

The typical laminites of Unit 1L occur in the Tishomingo and Arbuckle anticlines. They are rhythmically bedded deposits with individual beds ranging from 3 to 6 inches in thickness. Each bed possesses numerous laminations and in general is separated from adjacent beds by ¼- to ½-inch layers of limestone which possess a shaly structure and have all the appearances of argillaceous limestone although X-ray patterns do not indicate any clay. The laminations are normally continuous, but disrupted laminae are present. The bedding is even and regular, and the silica content is nearly always high as shown by etched specimens and insoluble residue analyses. In virtually every specimen the silica is finely disseminated throughout the rock and on an etched specimen may be smeared with the finger. Some of this material was collected and an X-ray pattern run for absolute identification. The pattern resulting from this analysis indicates beyond doubt that the substance is a fine quartz dust.

Some of these rocks show cross-laminations whereas others show a small scale "pinch-and-swell" structure. This may indicate that shifting bottom currents were effective at certain times in creating micro-ripples and then, through mechanical deposition, forming cross-laminated deposits in these ripples (Harbaugh, 1959).

Layered chert is the common type found in the laminites although a few irregular chert nodules are present in some localities; quartz silt is present in minor amounts. Graptolites and trilobites are the dominant faunal elements of this unit with sponge spicules and linguloid brachiopods of secondary importance. A typical specimen of this rock type contains about 1 percent skeletal debris, 35 percent silica, and 64 percent calcium carbonate.

A few feet of laminites is present also in the northeastern shelf province representing a temporary incursion of the environment associated with these rocks into the area where the calcarenites of Unit 1C were being deposited. Two feet of these laminites is present on Oklahoma State Highway 99 about 1 foot above the base of the Viola Group; 10 feet of laminites is present on Mosely Creek about 40 feet above the base of the group. These laminites are similar to those of the basin province except for the fact that their silica content is much lower.

The calcarenites of Unit 1C are well developed in the shelf area of what is now the Hunton anticline. They are uneven and slightly wavy-bedded and are virtually indistinguishable from the calcarenites of Unit 3C except for the fact that they may contain up to 20 percent bryozoans. These calcarenites are spar-cemented and contain by area estimate about 50 to 55 percent spar and 45 to 50 percent skeletal debris. Of the fossils found in these rocks, echinoderm plates together with bryozoans are most abundant. Trilobites, brachiopods, and ostracodes are also present. As in Unit 3C, some silicification of shells was observed although this feature is not so pronounced as in the upper calcarenites.

Quartz sand, replacement dolomite, burrowing features, and calcite mud are of minor importance in this unit.

Dolomite is present as distinct beds only in Unit 1C and only at one locality, Mosely Creek (Section L). Approximately 100 feet of it occurs beginning about 75 feet above the base of the Viola Group. Also, the top sample from the upper calcarenite (Unit 3C) is completely dolomitized. The petrographic study shows that practically all original textures have been obliterated by pervasive recrystallization of the limestone. The rock now is a porous, medium- to coarse-textured crystalline dolomite. Nothing even resembling this is seen in the other measured sections. Dolomite in these other locations occurs mostly as scattered rhombohedra.

One possible reason for the occurrence of dolomite beds at Mosely Creek and not elsewhere is the prominent joint patterns evident on a large scale aerial photograph (8 inches = 1 mile). The most conspicuous set of joints strikes between N. 75° and 85° E.; measurements from the photograph show that these are extremely closely spaced (approximately 100 feet apart over the whole Viola outcrop area of about 2 square miles). A related though not so prominent set strikes N. 20° to 30° W. with roughly the same spacing. A still younger joint pattern which transects these other two strikes N. 30° to 40° E.; spacing between these joints is much greater, on the order of 2,000 feet between joints.

Although the possibility exists that perhaps this is a tectonic dolomite, it should be pointed out that this explanation would leave unexplained the fact that beds above and below this interval are themselves not replaced by a coarse mosaic of crystalline dolomite. The writer believes that this mass of dolomite may be due to the action of solutions along the closely spaced joints.

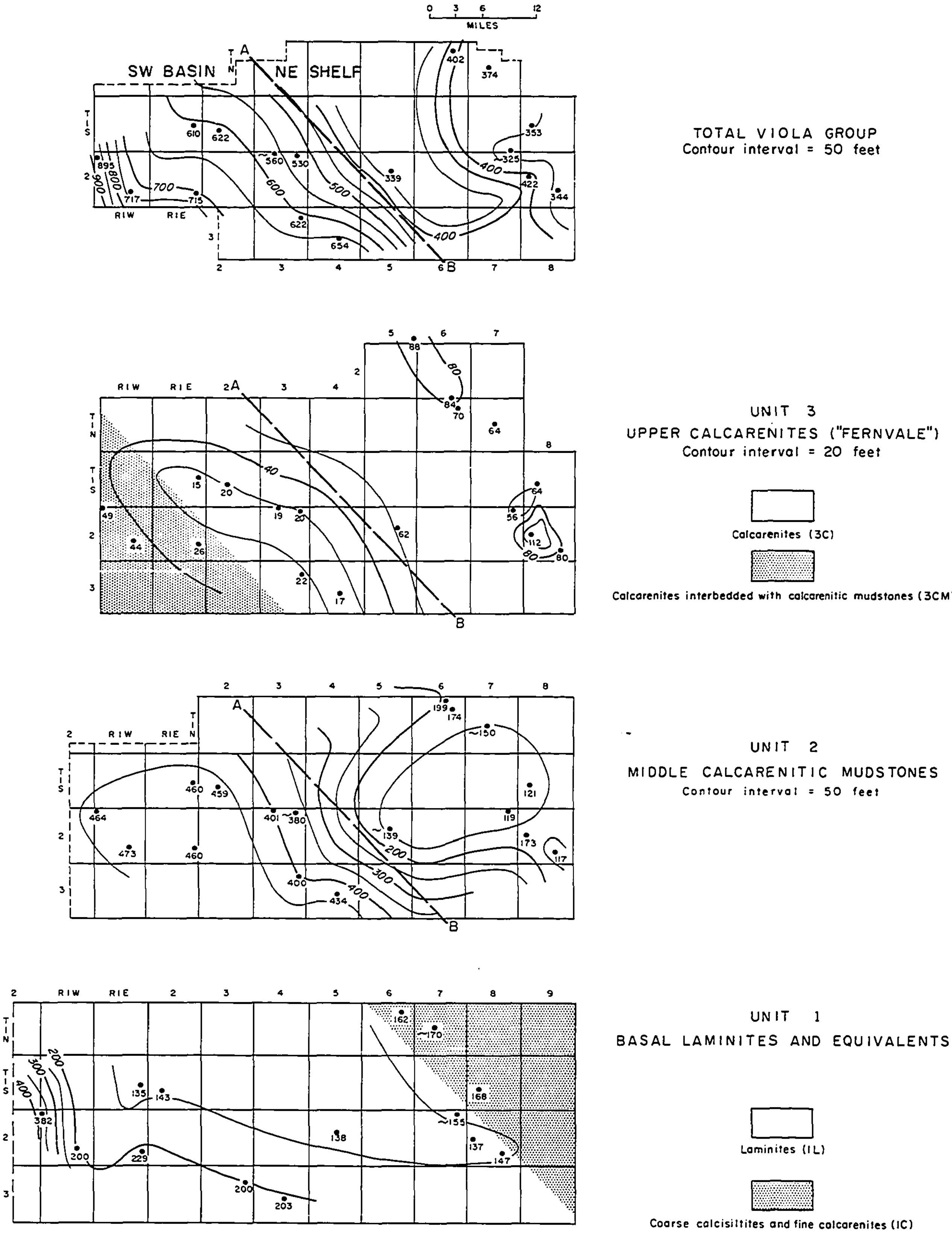
Thickness Maps

Thickness maps for the total Viola Group and individual units are presented in Figure 3. On the basis of thickness differences and distinctive lithologic types, the study area is divided into a southwestern basin province of thick, generally deeper water deposits now found in the Arbuckle and Tishomingo anticlines, and a northeastern shelf province of thin, generally shallower water deposits now found on the Hunton anticline. As a result of the different environments of deposition, the rock sequences encountered in these areas today are somewhat different beginning with laminites in the basin and progressing upward through calcarenitic mudstones and finally muddy calcarenites interbedded with more calcarenitic mudstones; on the other hand, the sequence on

FIGURE 3

THICKNESS MAPS OF VIOLA GROUP

Gerald C. Glaser - 1965



the shelf begins and ends with calcarenites between which occur calcarenitic mudstones.

The approximate line of demarcation (AB in fig. 3) which separates the basin and shelf provinces trends N. 42° W. and has the same geographic location on the upper three maps of Figure 3. This is meaningful in that it clearly indicates some sort of boundary or hingement separating the thick basin and thin shelf deposits. Evidence presented on these thickness maps suggests that this particular hingement probably was developed subsequent to the deposition of Unit 1C in the northeastern shelf province. In each case this line (AB) separates the thick southwestern basin province from the thin northeastern shelf province. On the thickness map for Unit 1, however, the line has no significance and is not shown. But a line with the same trend is shown farther east by the pattern which distinguishes the laminite and calcarenite facies of that unit. Similarly, on the map for Unit 3 the pattern distinguishing the calcarenitic mudstone and calcarenite facies of that unit parallels line AB. These lines have all been drawn with the same direction in order to simplify the concepts of the thicker basin versus the thinner shelf and the change in environments or facies. However, even though these lines may and probably do vary slightly from the indicated directions and are not linear, inspection of Figure 3 shows that the possible limits for variation in direction do not destroy the basic concept illustrated therein.

During deposition of Unit 1 no distinct demarcation of the basin and shelf provinces was extant except perhaps for the interfingering laminite and calcarenite facies which show no appreciable thickness differences. Some sort of hingement was probably present in the extreme southwest where a sudden increase in thickness occurs between Sections R and I. However, beginning with deposition of Unit 2 a definite division between basin and shelf was manifested. In the same manner this division persisted during deposition of Unit 3 with one important difference. The areas of thick and thin rocks are reversed for this unit with the thicker calcarenites in the northeast and the thinner, in the southwest. Although this unit has certainly been affected by the pre-Sylvan unconformity throughout the area, the thickness difference is probably due in part to a shoaling environment in the northeast which was amenable to the development of a thicker sequence of well-washed calcarenites and which supplied some calcarenitic material to the basin.

Northeastern Shelf Province

As defined in this work, the shelf province for the Viola Group is comprised of that part of the present Arbuckle Mountains which lies to the northeast of a somewhat arbitrary line (AB in fig. 3) trending N. 42° W. and approximately paralleling the line between the towns of Sulphur, Mill Creek, and Reagan.

The limestones of the Viola Group deposited in the northeastern shelf province are thin in comparison with the sequence deposited in the basin, representing only about 40 percent of the total section present in the basin province. The average total thickness for the group in the shelf province based upon surface measurements is 350 feet. Of this thickness, approximately 50 percent is represented by the basal unit (Unit 1C), 30 percent is represented by the middle unit (Unit 2), and 20 percent is represented by the upper unit (Unit 3C). No sharp distinction between shelf and basin can be made for Unit 1 using thicknesses alone; however, the obvious differences in lithologies between the laminites in the basin and the calcarenites on the shelf render demarcation between these provinces an easy task.

A typical shelf sequence in the extreme northeastern part of the province consists of about 165 feet of the lower calcarenites of Unit 1C resting disconformably upon the Corbin Ranch Formation (Bromide "dense") of the Simpson Group; these calcarenites are overlain by approximately 120 feet of the middle calcarenitic mudstones of Unit 2, which is in turn overlain by about 65 feet of the upper coarse calcarenites of Unit 3C; the Sylvan Shale rests disconformably upon these upper calcarenites. In the southwestern part of the shelf province the lower calcarenites of Unit 1C are replaced by about an equal thickness of laminites of Unit 1L by facies change somewhere in the vicinity of the southeast corner of T. 1 S., R. 7 E. This change must occur just north of the Dolese Brothers Quarry at Bromide where the laminites are present and south of Mosely Creek (Section L) where the calcarenites represent the basal unit.

Southwestern Basin Province

The basin province for the Viola Group is that part of the Arbuckle Mountains lying southwest of a somewhat arbitrary line which trends N. 42° W. The limestones of the Viola Group deposited in the southwestern basin province crop out in the Arbuckle and Tishomingo anticlines and are approximately 2½ times thicker than the equivalent sequence deposited on the shelf. Although the maximum thickness for the group in the basin and in the Arbuckle Mountains is 895 feet at West Spring Creek in the extreme southwest, 650 to 700 feet is the normal range for the province. These measurements, like those on the shelf, were obtained by using taping or plane table and alidade methods.

A typical 650-foot section of the Viola Group in the basin is composed of about 200 feet of the basal laminites of Unit 1L resting disconformably upon the Corbin Ranch Formation (Bromide "dense") of the Simpson Group; the laminites are overlain by about 430 feet of the middle calcarenitic mudstones of Unit 2 which in turn are overlain by about 20 feet of the upper calcarenites of Unit 3C; the Sylvan Shale rests disconformably upon these upper calcarenites. In the southwestern part of the basin province the calcarenites of Unit 3C change facies into a sequence of predominantly calcarenitic mudstones interbedded with thin fine muddy calcarenites. This sequence is Unit 3CM which increases in thickness toward the southwest from 26 to 49 feet. The facies boundary is indefinitely located northeast of U. S. Highway 77 (Section H) and southwest of the Lake Classen area (Section S).

Regional Stratigraphic Relations

Three distinct units, two of which have equally distinct facies, have been proposed for the subdivision of the

Viola Group. These are the lower laminites of deeper, less agitated waters and their shallower, higher energy equivalents; the middle calcarentic mudstones of intermediate energy and water depths; and the upper, shallower water and higher energy calcarenites and their equivalents. Similarly, a southwestern basin province of thick deposits now exposed in the Arbuckle and Tishomingo anticlines, and a northeastern shelf province of thin deposits now exposed in the Hunton anticline, are established.

Furthermore, the depositional pattern for the Viola Group begins and ends with unconformities. In sharp contact with the basal beds of the group is the noncherty and, in general, nongraptolitic massive calcilutite of the Corbin Ranch Formation of the Simpson Group. The uppermost beds of this formation have conspicuous burrows and are covered by a corrosion zone clearly indicating a disconformable contact with the overlying Viola Group. This burrowed calcilutite is interpreted to represent a shallow-water deposit of extremely fine calcite mud. At the top of the Viola Group evidence, presented in the discussion of Units 3C and 3CM, also exists for a disconformable relation at the sharp contact of the calcarenites of Unit 3C with the overlying Sylvan Shale. That shale is greenish gray to dark gray, is thinly laminated, and contains abundant graptolites at many localities. Obviously, this unit had a much different environment of deposition from that of the well-washed high-energy calcarenites in Unit 3C. In a relative sense, it is thought that the Sylvan Shale represents a deeper-water environment than the calcarenites.

Units 1L and 1C

The basal division of the Viola Group is represented by two equally distinct facies: the siliceous laminated mudstone or laminite facies (Unit 1L), most prominently developed on the Arbuckle and Tishomingo anticlines, and the coarse skeletal calcisiltite and fine skeletal calcarenite facies (Unit 1C) developed on the Hunton anticline (Plates 7 and 8). The approximate line which separates these facies can be seen in Figure 3 on the thickness map for Unit 1.

In sections measured by the writer, the laminites range in thickness from a minimum of 137 feet at Robertson Creek in the southeast to a maximum of 382 feet at West Spring Creek near the western extremity of the mountains. Dunham (1951) measured 135 feet (Section S) in the Lake Classen area. Except for the West Spring Creek locality, the thickness of this unit on the Arbuckle anticline is normally about 200 feet.

The basal laminites are disconformable upon the Corbin Ranch Formation; the upper contact with the calcarenitic mudstones is not sharply defined, but rather is gradational although the change from the planar bedding of the laminites to the wavy bedding of the mudstones is distinctive.

The calcisiltites and calcarenites of Unit 1C are well and totally exposed only in Section D and L where that unit is 162 feet and 168 feet thick respectively. Unlike the coarse calcarenites in Unit 3C, these lower calcarenites contain chert in layers and as nodules.

Like the laminites, the lower contact is disconformable upon the Corbin Ranch Formation; the contact with the overlying calcarenitic mudstones is better defined than it is between the laminites and the mudstones.

Unit 2

The calcarenitic mudstones of Unit 2 range in thickness from 117 feet in the tributary to Sandy Creek at Section M to 473 feet in Section I at Mountain Lake. In general, they contain abundant chert nodules throughout although a noncherty lower phase was observed in a few sections (J, Q, and H). As seen in Plates 7 and 8, the great thickening in the Viola Group occurs primarily in this unit. Whereas the ratio of maximum to minimum thickness for Unit 1 is 2.8 (382 feet/137 feet), this same ratio for Unit 2 is 4.0 (473 feet/ 117 feet). This demonstrates the increased amount of thickening during Unit 2 depositon. On Plate 7, the extreme thinning shows well between Sections J and N. Another obvious interpretation for the thinning in this unit is that of an unconformity at the top of the mudstones at Section N and continuing to the east and northeast. Two independent lines of evidence argue against such an interpretation. First, no physical evidence to support an unconformity was found in the field at any of the sections studied. Second, Ruedemann and Decker (1934) have described a number of graptolite zones, one of which (Climacograptus lorrainensis) is of middle Lorraine (Eden) age and occurs 46 feet below the top of the Viola Group on West Spring Creek, 32 feet below the top on U. S. Highway 77, and 70 feet below the top 5 miles north of Bromide. In these three localities the zone is 30 feet, 34 feet, and 30 feet thick respectively. Besides indicating an Eden age for the zone, the occurrence of this graptolite zone indicates equivalence of these calcarenitic mudstones which occur just below the "Fernvale" in both the basin and shelf provinces. This suggests that the rapid thinning is not due to truncation and, therefore, the existence of such an unconformity is extremely unlikely. As mentioned previously, the lower contact of the calcarenitic mudstones with the laminites is somewhat gradational. In many of the sections the upper calcarenitic mudstones are gradational with fine muddy calcarenites which themselves are transitional with the characteristic coarse calcarenites of Unit 3C. At no locality is the contact between mudstones and calcarenites sharply defined, with the possible exception of West Spring Creek (Section R).

Units 3C and 3CM

The upper division of the Viola Group is represented by two distinct facies (Plates 7 and 8): a normally nonmuddy coarse calcarenite facies (Unit 3C) developed everywhere except the southwestern extremity of the basin province, and a facies consisting predominantly of calcarenitic mudstones interbedded with thin fine to medium muddy calcarenites (Unit 3CM). The thickness map for Unit 3 in Figure 3 illustrates these facies. The calcarenitic mudstones of this facies are exactly similar to those from Unit 2 and are virtually indistinguishable from them. The only possible difference is that Unit 3CM mudstones may contain slightly more skeletal debris.

Unit 3C calcarenites range in thickness from 15 feet in the Lake Classen area to 112 feet on Robertson Creek. On the other hand, Unit 3CM thicknesses range from 26 feet on U. S. Highway 77 to 49 feet on West Spring Creek. The same line, AB, which separates Unit 2 into thick and thin areas has exactly the same geographic location and separates thin and thick calcarenites of Unit 3C (fig. 3). However, the idea of a ratio of maximum to minimum thickness is not valid in this case because of post-Unit 3C, pre-Sylvan Shale erosion.

Convincing evidence for the disconformity between Unit 3 and the overlying Sylvan Shale exists in several forms. Atop this unit in Section Q is a 3-inch bed of a pyritic phosphate conglomerate which contains numerous small shells of an inarticulate chitino-phosphatic linguloid brachiopod. This bed is in contact with Unit 3C below and the abundantly graptolitic Sylvan Shale above. A slabbed specimen of this material shows numerous small pebbles; the thin section (Plate 3, fig. 5) shows abundant pyrite, phosphate, vein-filled quartz, and minor dolomite. The X-ray pattern on this material indicates calcium phosphate ($Ca_4P_2O_9$). This occurrence represents a time break subsequent to the deposition of the calcarenites and prior to deposition of the Sylvan. A similar oxidized-pyrite occurrence at the top of Unit 3C is present at Section J although linguloid brachiopods and the abundant phosphate were not observed.

Aside from these more obvious indications of disconformity, other evidence exists to support this idea. In the southeasternmost measured sections (E, F, and M, Plates 7 and 8), a marked range in thickness of Unit 3C occurs. In section E, it is 56 feet thick; in Section F, a maximum for the studied area of 112 feet; and in Section M, 80 feet. Section E and M are only about 3 miles distant from Section F. The most obvious conclusion is that post-Unit 3C erosion has removed some of the upper calcarenites at least from Section M which occurs in the same structural outcrop belt as Section F. (See Plate 6.) If the datum in Plate 7 were the top of Unit 3C rather than the base of the Viola Group, a synclinal feature in the vicinity of Section F would show this concept of erosion of some of the top calcarenites more clearly. Also, although Unit 2 is thicker in Section F, the highest chert observed in that section and in Section M is 55 feet and 53 feet below Unit 3C respectively, indicating that the thickening at F had ceased before deposition of the calcarenites began. However, the possibility of renewed thickening at F during deposition of Unit 3C must not be overlooked.

Other convincing evidence for this disconformity exists in the southwesternmost measured sections (R, I, and H) where Unit 3CM is developed. In these sections a progressive thickening takes place from east to west; at H this unit is 26 feet thick with 5 feet of basal calcarenite; at I it is 44 feet thick with 7 feet of basal calcarenite; and at R it is 49 feet thick with 9 feet of basal calcarenite and 3 feet of calcarenite at the top. The remaining thicknesses in these sections are calcarenitic mudstones. The calcarenite at the base of this unit is apparently the same in the three sections. However, the top calcarenite in Section R is absent in Sections H and I by truncation.

In conclusion, the writer believes that ample evidence exists for disconformities at the base and top of the Viola Group. However, none of the outcrops studied show any indication of an intra-group unconformity, particularly one between Unit 2 and Unit 3 ("Fernvale"), although the faunal study which is a companion project with this investigation may indicate otherwise.

Environments of Deposition

Irwin (1965) has discussed the general theory of epeiric clear water sedimentation in contrast to oceanic, coastal deposition. Whereas the former occurs in shallow marine seas with great width of shelves of extremely low slope, the latter occurs where steep bottom slopes prevail.

Although his model of this type of deposition is dissimilar to the Viola Group in that it culminates with the formation of evaporites, it is sufficiently similar to what is envisioned for the limestones of the Viola Group that some comparisons can be made.

The laminites were formed in an environment which represents the deepest water and the lowest energy for the entire Viola Group. No actual depth can be given although it must have been below wave base. A number of factors lend support to this interpretation. First, the laminations indicate that these sediments were formed below wave base, and marine currents were the only form of hydraulic energy which acted upon them. Second, the fauna is dominated by graptolites, trilobites, sponge spicules, and linguloid brachiopods; the shelly fauna is noticeably absent as is any burrowing. The probable reason for this is that the fauna is dominated by graptolites and trilobites, or in other words, a burrowing-type benthonic fauna was virtually absent. Third, both the carbonate material and the skeletal debris is of extremely fine silt- and clay-size. The laminites, therefore, fit nicely into Irwin's Zone X, a hundreds-of-miles wide, low-energy area occurring in the open sea and characterized by animal skeletal calcisiltites and pellets.

On the other hand, the calcarenitic mudstones of Unit 2 were formed in an environment of energy and water depth intermediate to those of the laminites and the calcarenites. Wave base probably fluctuated above and below the depositional surface. These mudstones contain varying amounts of skeletal debris including a shelly fauna throughout the sequence. Locally graptolites and trilobites are common. Too, these rocks have been extensively burrowed in every section examined. This intermediate environment does not fit well into Irwin's scheme which makes no provision for any environment between low and high energy. This only points out that any classification cannot possibly have a "pigeon-hole" for every occurrence no matter what is being classified. The writer believes, however, that the environment for these mudstones would be something between Irwin's Zone X and Zone Y (calcarenites).

The calcarenites were formed in a well-washed high-energy environment of shallowest water depth for the entire Viola Group. The shelly fauna which dominates these rocks is abraded and rounded, attesting to the action of the waves and currents which must have acted on them. Rarely, these calcarenites are burrowed also. This environment agrees well with Irwin's Zone Y, a high-energy belt, tens-of-miles wide, beginning where the waves first impinge on the sea floor. Neither evaporites nor syngenetic chalky dolomite was observed near the top of the Viola Group.

In summary, the environments of deposition for the limestones of the Viola Group represent a progressive change both from lower to higher energy and deeper to shallower water. Certain ideas of the general theory of epeiric clear water sedimentation proposed by Irwin are readily applicable to Viola Group limestones although the concept of a low-energy zone containing dolomite and evaporites landward of the calcarenites is not substantiated by any evidence in this work.

Geologic History

Much of the information for the geologic history of the Viola Group in the Arbuckle Mountains has been presented elsewhere in this work, and therefore, only a summary will be presented here. Although deposition of the individual units of the Viola Group most certainly did not begin and end in the basin and shelf provinces at the same time, this section is presented with that implication merely to simplify the writing and the concept. However, the reader should keep in mind the fact that no intent of "layer-caking" is intended.

Subsequent to the erosional period following final deposition of the Corbin Ranch Formation, sediments of calcite mudstone with an extremely high silica content were deposited in the relatively deeper water of the basin to the southwest, while in the northeast coarse skeletal calcisiltites and fine calcarenites were being deposited in the shallower water on the shelf. Greater subsidence occurred in the basin to the far southwest where a maximum for the mountains of 382 feet for Unit 1 occurs.

Following this initial period of deposition, mudstones with varying amounts of skeletal debris were deposited in both the basin and shelf provinces. This represented a relative increase in energy and decrease in water depth for the basin and a relative decrease in energy and increase in water depth for the shelf. Benthonic forms thoroughly ingested and burrowed much of these sediments. During this depositional period, subsidence reached its maximum development in the basin as it received 4 times the amount of sediments that the shelf did.

This cycle was followed by a shoaling condition over most of the area resulting in relatively shallow water and high energy which helped produce well-washed calcarenites. These deposits formed on the shelf where the organic and chemical activity was greatest; sedimentation coupled with concurrent subsidence beneath the continuously shallow water (Irwin, 1965) to form thick sequences of calcarenites. Some of this debris was washed into the basin province to be interbedded with fossiliferous muddy sediments in the far southwest.

Subsequently, the sea retreated from the area and truncation of the upper beds occurred prior to deposition of the Sylvan Shale.

THIN-SECTION PETROGRAPHY

Previous knowledge of the Viola Group limestones was based primarily on examination of cuttings, electric logs, and insoluble residues (Wengerd, 1948).

As a result of the petrographic study and the X-ray and chemical analyses undertaken in this work, it can be shown that the limestones of the Viola Group are wholly marine rocks and, except for the high silica content in most of the laminites and some of the calcarenitic mudstones, contain as much as 87 to 98 percent calcium carbonate. An average laminite, on the other hand, may contain as low as 67 percent calcium carbonate. Dolomite is present as discrete rhombohedra in many of the specimens, but in few of these does it exceed 10 percent by area estimate. Whereas the calcium carbonate content is high, the magnesium carbonate content is about 1 percent in the calcarenites and about 2 percent in the calcarenitic mudstones.

The petrographic investigation indicates that chert, finely disseminated silica, quartz silt and sand, phosphate, secondary hematite and pyrite, rare to absent glauconite, and organic material are the only noncarbonates present. Of these, chert and disseminated silica are clearly dominant.

Laminations and burrows represent the main sedimentary structures observed in these limestones; laminations are confined primarily to the laminites; burrows occur predominantly in the calcarenitic mudstones although they are present to a lesser extent in the calcarenites.

Silicification is the most important of the replacement phenomena observed. This process is manifested by abundant chert occurring in layers and as irregular nodules and by the alteration of fossil shells. Phosphatization and dolomitization are important locally.

Recrystallization is believed to have affected all of these limestones, but only to a minor extent. In no instance has the original texture been obliterated by this process even though these are Ordovician rocks of considerable age which have undergone some folding and faulting.

Carbonate rocks are a complex group to describe, classify, and interpret because of the profound influence which diagenesis exerts on them. Some of the main problems associated with these rocks are questions as to whether sparry calcite cement represents cementation in original void spaces or recrystallization of original lime mud; when and how dolomitization, silicification, and recrystallization occur; whether pellets are mud aggregates, are of fecal origin, or are clasts. These and many other associated problems are evident to all who work in carbonate petrography. A good summary of these problems is presented by Ham and Pray (1962).

Particle Size

Both skeletal and nonskeletal particles in the studied limestones show considerable size variation, ranging from mud- to sand-size grains.

In this work everything less than 10 microns is considered mud; material greater than 10 microns but less than 62 microns is considered silt-size; particles between 62 microns and 2000 microns are considered sand-size. "Calcisiltitic" is used for particles of silt-size, "calcarenitic" for particles of sand-size. Measurements on particles were taken uniformly from the smallest dimension. It should be noted here that although some particles exceed 2000 microns in their shortest dimension and thus fall in what is the calcirudite class, none of the thin sections or hand specimens can properly be called calcirudites. On the other hand, if measurements were taken uniformly from the largest dimension, many of the specimens called calcarenite would become calcirudites. However, the writer believes usage of the largest dimension is misleading since many of the fossil fragments such as trilobites, brachiopods, and ostracodes possess shells much longer than they are wide. Therefore, they act as the hydraulic equivalent of much smaller particles. It is for this reason mainly that the writer has not used a modifier for the sorting in the description of these rocks. Too, one cannot know for certain if different sizes of material actually were available for sorting or whether the sorting is due to an overwhelming amount of a particular dominant-size material in the original rock. For example, a rock which contains abundant echinoderm fragments predominantly of one size may appear well sorted, but in fact may not be sorted at all if this were the only material available in the original deposit.

Both the mudstones and the coarsely crystalline limestones contain calcarenitic skeletal debris giving rise to the calcarenitic mudstones and the coarse calcarenites. The most common particle size ranges between 350 and 450 microns (0.35 to 0.45 mm). Some few examples of calcisiltitic skeletal debris do occur, particularly on the Hunton anticline in the coarse skeletal calcisiltites of Unit 1C. Most of the skeletal material in the laminites is also calcisiltitic although in general those rocks are not abundantly fossiliferous except for sponge spicules, graptolites, and trilobites.

Pellets are generally in the coarse silt- to fine sand-size range. Pellet-forms on the other hand have diffuse boundaries which made precise measurements impossible although they normally are of coarse silt-size. Intraclasts are rare, but where present are normally larger than 2000 microns.

The detrital quartz noted in the calcarenites is practically all of sand-size although in the laminites and mudstones quartz silt is dominant.

Constituents of the Limestones

Skeletal particles are the most important constituents in these rocks and, on the average, contribute 40 to 50 percent of the total area displayed in thin section. Chert is important in the laminites and the calcarenitic mudstones. Nonskeletal, terrigenous, and authigenic particles are important locally. All of these particles are either set in a calcite mud matrix or are cemented by sparry calcite cement. Open pore space is not common except in the few completely dolomitized specimens from Mosely Creek.

Skeletal Particles

Echinoderms, trilobites, and brachiopods are the main skeletal elements in the limestones of the Viola Group. The echinoderms are by far the most common and are predominant in the calcarenitic mudstones and the calcarenites. Graptolites and sponge spicules dominate the fauna of the laminites; locally, bryozoans are common in the lower calcarenites, and gastropods, cephalopods, and corals do occur, but are of minor importance. Extremely rare occurrences of the dasyclad alga, Ischadites sp., were noted as were a few small burrowed algal colonies belonging to the family Solenoporaceae.

The calcarenites are abundantly fossiliferous, but no evidence exists for any reefs or biohermal masses in the study area. Rather it seems that the calcarenites were formed as part of a shallow carbonate bank.

Echinoderms. Particles from members of this faunal element are easily recognized by their unit extinction under crossed nicols, and are commonly surrounded by a syntaxial overgrowth of clear calcite cement. Although the echinoderms appear to be almost totally lacking in the laminites, they clearly dominate the calcarenitic mudstones and the calcarenites. Columnals are abundant, primarily in the calcarenitic mudstones and more specifically near the top of that lithologic unit. Individual plates are also abundant.

In general, the echinoderms occurring in the mudstones have not been abraded extensively as evidenced by some of the long, slender arm plates still intact. In many of the fragments mud is present in the canals, and a thin mud coating surrounds others. These mud-filled skeletal particles sometimes occur in a cement of sparry calcite and give testimony to probable washing away of some of the mud. In other instances the mud clearly is recrystallized.

On the other hand, the echinoderms occurring in the calcarenites generally show more rounding, greater comminution, and virtual absence of mud in the canals. Also, whereas the total echinoderm content of the mudstones is normally between 2 and 20 percent, that of the calcarenites is roughly 25 to 35 percent.

The echinoderms in these limestones do not seem to be readily susceptible to silicification. However, in some cases where they are silicified, the fragments are delicately preserved, beautifully showing the structure; in other cases, silicification has obliterated all structural detail.

Dolomite rhombohedra have been observed partially replacing echinoderms in some instances; completely and partially phosphatized fragments also were noted.

Trilobites. Trilobites in few cases form more than 10 percent of any specimen with the range normally between 0 and 4 percent. Most commonly the trilobites occur in greatest numbers in the top part of Unit 3C. This marked increase was noted in seven of the localities where sections were measured and samples taken for thin-sectioning.

Recognizable genera occur only in hand specimens and include *Cryptolithoides* sp., which is most common, and *Robergia* sp. In thin section, trilobite fragments can be identified as such although the degree of rounding and comminution precludes any generic classification. Trilobites occur throughout the Viola Group, but are relatively more abundant in the calcarenitic mudstones and the calcarenites than in the laminites. They occur also in the laminites with the graptolites and sponge spicules, but are subordinate to those faunal elements.

The trilobite particles are almost nowhere altered, and only if the rock has undergone considerable silicification are they affected.

Brachiopods. Brachiopods are an important constituent in the limestones of the Viola Group, particularly in the calcarenites; they are exceedingly rare in the laminites.

Furthermore, in the top part of Unit 3C, the brachiopods are silicified in virtually every stratigraphic section visited. In thin section they constitute in few places more than 7 percent of any sample, and generally the percentage is much less. However, this is somewhat misleading because bedding planes literally covered with brachiopod shells occur in a few places, notably on Oklahoma State Highway 99 in Section D. Therefore, although the percentage may seem low, the brachiopods perhaps represent the most important faunal element and are the subject of the companion study to this work on the biostratigraphy of the Viola Group.

Punctate, pseudopunctate, and impunctate forms were observed in thin section. In hand specimen genera recognized by the writer include Lepidocylus, Rafinesquina, Sowerbyella, and Austinella.

In thin section the shells have been broken and disarticulated more often than not, although some articulated shells were observed. On the other hand, the calcarenites of Unit 3C, upon treatment with hydrochloric acid, have yielded beautifully preserved, articulated silicified brachiopods.

Of all the skeletal particles, brachiopods are the most susceptible to alteration by silicification. However, not every individual is affected in the same rock specimen, and the replacement apparently is selective. Rarely, dolomite crystals were observed replacing parts of brachiopod shells.

Bryozoa. Bryozoa are important locally and constitute as much as 15 to 20 percent of some thin sections. Stratigraphically, these bryozoan-rich rocks are confined to the lower calcarenites of Unit 1C; geographically, they occur on the Hunton anticline, and more specifically, in stratigraphic sections C, D, K, and L. Other than these occurrences, bryozoans generally comprise less than 1 to 2 percent of any thin section. In one instance a bryozoan was observed attached to the convex side of a brachiopod shell (Plate 1, fig. 9).

The filamentous Bryozoa are the most common type and exhibit extreme parallelism to the bedding in the calcarenites. Although these skeletal elements occur mainly in the calcarenites, mud is associated with and contained in their skeletal framework. This mud has been recrystallized to fine calcite spar at many places. Silicified bryozoans were not observed in thin section, but were noted on the outcrop on the Hunton anticline.

Ostracodes. Ostracodes normally do not constitute more than 1 to 2 percent of any specimen. On Oklahoma State Highway 99 (Section D), however, the ostracodes comprise 20 percent of one specimen (Plate 2, fig. 3). One hand specimen from Mosely Creek (Section L, sample L-6) contains roughly 5 to 10 percent ostracodes and occurs 84 feet above the base of that section. These fossils do not seem to be confined to any one rock type in the Viola Group, although they occur in minor numbers throughout the mudstones, but only rarely in the laminites. They attain their highest percentages in some of the calcarenites.

Graptolites. Graptolites are most common in the laminites and are abundant locally. They occur less frequently in the calcarenitic mudstones and were not observed in the calcarenites. As one of the two major faunal constituents in the laminites, they comprise from 1 to 5 percent of some specimens and practically cover whole bedding surfaces in some places. In thin section, however, rarely do more than one or two specimens occur in any one sample.

The graptolites previously have been studied in detail and serve as the basis for a zonation of what was then termed the Viola Limestone (Ruedemann and Decker, 1934; Decker, 1936, and Decker, 1936a).

Sponge Spicules. Sponge spicules, together with the graptolites, are the most prominent skeletal elements which occur in the laminites. Rarely do they comprise more than 10 percent of any specimen, and the usual range is from 1 to 5 percent. Most of the spicules are composed of calcite although some are siliceous. In thin section they appear as small circular mosaics of crystalline calcite where they have been cut transversely. In a few instances, junctures between adjoining rays were observed.

Gastropods and Cephalopods. Gastropods are not volumetrically important in the Viola Group, and the cephalopods are even less so. The gastropods seem to be present only in the calcarenitic mudstones, and where present locally, constitute up to 1 percent of the total rock. The most common type is a high-spired form (Plate 1, fig. 5). Cephalopods, though few, occur primarily in the calcarenites.

Corals. Corals are virtually absent in both the hand and thin sections. They are present and have been observed, however, in the road cut exposed on Oklahoma State Highway 99 (Section D). The largest ones observed are 1- to 1½-inches long and are solitary rugose corals.

Algae. *Ischadites* sp. was the only identifiable alga observed by the writer, and it is not common; it was not identified in thin section but on the outcrop. This alga occurs in a few sections, but is displayed most prominently on Oklahoma State Highway 99 (Section D). At that locality a few algal colonies 2-inches X 2-inches occur in the upper part of Unit 1C. They, too, like the calcarenitic mudstones, show excellent burrowed features. Volumetrically these algae are unimportant.

A few coated grains were observed and perhaps the mud coating was induced by algal activity (Plate 1, fig. 8). Conclusive evidence for this is lacking.

Nonskeletal Particles

In the limestones of the Viola Group the most important nonskeletal particles are pellets which are here considered to be of fecal origin if they are structureless, distinctly ovoid or rounded, and possess a well-defined boundary. What the writer has called pellet-forms, on the other hand, are structureless masses of mud with diffuse boundaries which resemble pellets. They are commonly set in microspar and may be similar to the "angular aggregates" of Powers (1962). Intraclasts do occur, but are rare.

<u>Pellets</u>. Pellets were found most commonly in the burrowed calcarenitic mudstones although they are present in the laminated calcisiltitic mudstones of Unit 1L. They

normally occur in the size range between 60 and 200 microns; few are smaller or larger. They are commonly oval or almost round in thin section, and are distinct structureless masses. Although proof that they are of fecal origin is lacking, their uniform size, shape, and good sorting, together with their usual occurrence in the burrowed calcarenitic mudstones, suggest that they are a result of reworking of unconsolidated lime sediments by bottom-dwelling organisms.

Pellet-Forms. Like the pellets of supposed fecal origin, the muddy masses here called pellet-forms occur primarily in the calcarenitic mudstones. They have been called pellet-forms because they resemble pellets somewhat in their subcircular form although the pellet-form boundaries are extremely diffuse. In general, they are slightly larger than pellets. The writer believes that these pellet-forms are remnants of recrystallized mud which now are set apart from neighboring mud masses by intervening microspar. Folk (1962, p. 65) recognized this same possibility when he mentioned, ". . . some pellet-appearing objects may form by recrystallization processes, a sort of auto-agglutination of once-homogeneous calcareous mud. . ." These pellet-forms are similar to Cayeux's (1935) grumeleuse structure of secondary origin. Perhaps the most accurate translation of "grumeleuse" would be "mud clot." A portion of Cayeux's text from page 271 is presented below:

> Structure grumeleuse d'origine secondaire.--La structure grumeleuse est remarquablement développée dans l'assise de Visé, où elle atteint sa plus grande fréquence, ainsi que dans l'assise de Namèche. Lorsqu'elle est réalisée dans la perfection, elle montre de tout petits éléments calcaires, à pâte extrêmement fine, se détachant en gris sombre, de forme générale globuleuse ou irréguliere, dont les contours ne sont jamais franchement arrêtés, et sans différenciation d'aucune sorte (fig. 68, a). Ces matériaux, dont la microstructure est invariablement cryptocristalline, sont plongés dans une gangue de calcite incolore et grenue (fig. 68, b). L'ordre de grandeur de ces grumeaux est de $0^{mm},05$, c'est-à-dire qu'ils sont notablement plus petits que les oolithes et les fausses oolithes.

This description exactly fits the material observed in thin sections of this study. Also, the examples pictured in Cayeux's figures 68a and 68b bear a striking resemblance to this author's pellet-forms.

Intraclasts. Mud intraclasts having self-contained skeletal debris are rare and have been positively identified from a few feet of rock in the upper part of the calcarenitic mudstone sequence of Section C. This location is approximately 1½ miles northwest of Section D and ¾ mile west of Oklahoma State Highway 99. The intraclasts occur in a fine skeletal calcarenite which represents an exceedingly rare occurrence in the mudstone portion of the section. The bed from which the sample was taken is only about 2 inches thick, and the calcarenite, 1½ inches thick, is bounded on top and bottom by a skeletal calcarenitic mudstone of exactly similar appearance to the intraclasts themselves. It is noteworthy that this bed occurs roughly 25 feet below the base of the coarse calcarenites of Unit 3C. The presence of the intraclasts in this fine thin calcarenite is interpreted to represent a disruption of a weakly consolidated mud during a temporary incursion of a higher energy environment. The remaining 25 feet above this calcarenite are calcarenitic mudstones. The larger intraclasts average 5 mm across their shortest dimension and 25 mm across their longest dimension (Plate 2, fig. 5), and present a conglomeratic appearance. As would be expected by their occurrence with a well-washed calcarenite, their long axes are parallel to the bedding. The smaller intraclasts also are similar to the mudstones which bound the calcarenite and are generally less than 2 mm. In this rock, they present no problems in recognition. However, in other rocks it is impossible to make an objective distinction between what may be either small intraclasts or pellets.

Calcite Mud Matrix

Calcite mudstone is the predominant material in the laminite sequence where it constitutes the bulk of the rock.

In the calcarenitic mudstones, it serves as the matrix in which the skeletal and terrigenous particles are set, and, as such, contributes on the average between 25 and 35 percent of the total area seen in thin section. It is present in minor amounts in some of the calcarenites and probably represents a residual fraction of the fine calcite mud which has not been washed completely from these rocks.

Crystalline Calcite Cement

The calcarenites prominently display the clear calcite cement. In some of the looser-packed calcarenites from the Hunton anticline, and in particular those of Unit 3C from the Ideal Portland Cement Quarry near Lawrence, this crystalline calcite comprises up to 50 to 60 percent of individual thin sections. As might be expected, this pore-filling calcite is much less abundant in the calcarenitic mudstones and laminites, although Bathurst (1958) claims that originally discrete mud grains may be welded together by rim cementation. Although this process can and probably does occur, it was not recognizable because of the fine sizes involved.

Terrigenous Particles

Quartz silt and sand are the predominant terrigenous particles observed in the limestones of the Viola Group. The silt-size particles occur most commonly in the calcarenitic mudstones and less commonly in the laminites. They are normally subangular to subrounded (Powers, 1953) and under crossed nicols show straight extinction when examined with the petrographic microscope. A much finer quartz silt approaching the clay-size fraction is apparent in the insoluble residue work. It is so fine that it is virtually not recognizable under the petrographic microscope and only X-ray diffraction supplies a positive answer to its identity. This fine silt too is most often found in the mudstones.

Quartz sand, on the other hand, occurs most frequently in the calcarenites. It is normally rounded to well-rounded and also shows straight extinction under crossed nicols. In some instances, quartz sand has been concentrated by the activity of burrowing organisms and lines old burrow traces (Plate 3, fig. 4). This same feature is seen also in the burrowed mudstones, but the quartz is commonly of silt-size in them.

Terrigenous quartz in the laminites is rather sparse and of extremely fine silt-size. Practically nowhere does it exceed 1 percent in those rocks. In contrast, the quartz silt and sand content in the calcarenitic mudstones and the calcarenites reaches 20 percent in some cases although it is normally less than 10 percent.

Chert

Silicification is the most important type of replacement phenomenon in these rocks. Nodular chert, layered chert, and silicified fossil shells represent the manifestation of this process. Whereas the chert nodules are almost wholly confined to the calcarenitic mudstones, the layered chert is normally associated with the planar-bedded laminites which contain still another form of quartz, finely disseminated silica. Although nodular and layered chert are demonstrably secondary (Biggs, 1957; Van Tuyl, 1918) because of their contained fossils and replacement structures in the limestone, the origin of the finely disseminated silica in the laminites is less certain. This type of silica, occurring in distinct laminae, together with variations in grain size in the extremely fine mud, gives rocks of Unit 1L their characteristic laminated feature and hence their name in this report. Evidence on the origin of this silica is lacking although current observations indicate that it is detrital. The laminites contain numerous calcite spicules which originally may have been siliceous, but desilication of these spicules could not provide enough silica to account for the present abundance of quartz in its various forms throughout these rocks. However, present-day evidence on the amount of silica supplied to the oceans from weathering of igneous rocks alone would be adequate to account for the large amount of silica deposited with marine rocks. Of course, present-day oceans are undersaturated with respect to silica because it is used by silica-secreting organisms; this may not have been true to the same extent in the Ordovician sea covering this area. The abundance of chert as nodules and as layers in limestones of the Viola Group, coupled with the data indicating that even the noncherty limestones have high silica contents, shows that more than enough silica was deposited with these rocks to account for all of the chert. Apparently it remained only to be redistributed into nodules and layers subsequent to deposition.

Most of the chert in the nodules and replacement layers consists of minute equant grains of microcrystalline quartz in random orientation. Chalcedonic quartz in radiating bundles of fibers more typically is associated with the replacement of skeletal debris. Folk and Weaver (1952) discuss these varieties of quartz.

Silicified fossils occur most commonly in the upper calcarenites of Unit 3C although examples of this feature are present in some of the calcarenitic mudstones. Perhaps much of this is due to surface silicification. Brachiopods seem to be most easily silicified followed by echinoderms and trilobites where the rock has undergone a greater amount of silicification.

It is noteworthy that the coarse calcarenites are completely devoid of any chert nodules or layers although silicified fossils are common. This fact suggests some unknown relationship between the muddy rocks and replacement silica. It seems that the finely disseminated silica is confined to the muddy rocks, and because this material has been removed from the higher energy environment in which the calcarenites were formed, no silica was available for redistribution into chert nodules.

Authigenic Particles

Original rock textures in limestones of the Viola Group have been altered in varying degrees by: (1) silicification (see "Chert"); (2) dolomitization; (3) phosphatization; (4) recrystallization to mosaic calcite; (5) cementation by clear crystalline calcite; and (6) drusy acicular calcite around skeletal debris. Glauconite is exceedingly sparse and was observed at only one locality (Buckhorn Ranch, Section G) where it occurs in the calcarenitic mudstones partially replacing fossil fragments. Secondary hematite and (or) limonite are ubiquitous, but normally constitute an insignificant portion of any specimen. Pyrite was noted at a few localities.

Silicification was discussed under the previous heading; dolomitization and phosphatization are treated under "Replacement Phenomena."

Mosaic Calcite

Calcite mud is most susceptible to this type of alteration which is probably the result of recrystallization of the fine material to a coarser, but still finely crystalline calcite. Mud grains originally less than 10 microns apparently are enlarged into a network of interlocking crystals on the order of 30 to 40 microns. This feature is common to practically all of the mudstones in the Viola Group to a greater or lesser degree. Rarely is a mudstone unaffected by this alteration.

Drusy Acicular Calcite

A coating of drusy acicular calcite was noted surrounding skeletal debris in a few calcarenites. These calcite crystals are needle-like and grow normal to the coated particles (Powers, 1962). Volumetrically, this is the least important of the calcite types found in these limestones.

Sedimentary Structures

Both syngenetic and epigenetic sedimentary structures (Krumbein and Sloss, 1963) are present in the limestones of the Viola Group. In decreasing order of relative frequency, these features include laminations, burrows, veins, geopetal structures, cross-laminations, cross-bedding, stylolites, graded-bedding, and minor folds and faults. Also a corrosion zone (Weiss, 1954; Weiss, 1958) which is an epigenetic feature, was noted in the uppermost bed of the Corbin Ranch Formation at a number of localities throughout the mountains. This is the "discontinuity surface" of Jaanusson (1961) who has illustrated this feature at the contact of the Corbin Ranch Formation with the base of the Viola Group on Oklahoma State Highway 99.

Laminations

Laminations (Plate 3, fig. 6) are the most common and most important syngenetic sedimentary structures. They are found in the rocks of Unit 1L and seem to be restricted to that unit. This feature is best developed on the Arbuckle and Tishomingo anticlines. In stratigraphic sections E and F near Bromide, Oklahoma, the rocks of Unit 1L display the same type of siliceous banding observed at other localities, but are only weakly laminated (Plate 4, fig. 2). However, just southwest of Wapanucka at Section M, three miles distant from Section F and in the same structural outcrop belt as that section, the laminations again are well developed (Plate 4, fig. 5). Cross-laminations are rare, but do occur.

Burrows

Burrows are the most common and most important epigenetic sedimentary structure; they are found predominantly in the calcarenitic mudstones although some traces of burrowing were observed in the calcarenites. Organic activity in the form of mud ingestion apparently was so intense in the mudstones that no vestige of original bedding is seen in rocks of that type.

Replacement Phenomena

Silicification, dolomitization, and phosphatization are three types of replacement observed in limestones of the Viola Group. Of these, silicification is by far the most common; it is discussed in detail under the heading "Chert." Minor patchy dolomite of replacement origin is observed in many cases, and virtually complete dolomitization occurs through a considerable thickness at Mosely Creek (Section L). Phosphatized skeletal debris, though only an extremely small percentage of any specimen, is concentrated locally as in the basal sample from Section D on Oklahoma State Highway 99.

Dolomitization

Alteration of original texture and composition by partial dolomitization through the addition of discrete dolomite rhombohedra is fairly common although not extensive in any one specimen with the exception of the Mosely Creek locality. Perfect euhedral crystals and transecting contacts with skeletal grains are two types of evidence which lend overwhelming support to a secondary origin for the dolomite. As mentioned previously, the finer mud fractions are preferentially dolomitized, and therefore the calcarenitic mudstones contain proportionately more dolomite than the calcarenites. The laminites, although primarily extremely fine calcite mud, contain little or no dolomite. At Mosely Creek, a thickness of 101 feet of nearly completely dolomitized limestone with virtually no original texture preserved is present in Unit 1C. The dolomite is present as a crystalline mosaic of medium to coarse euhedral and anhedral crystals.

Enough remnants of original texture are discernible with difficulty, however, so that the rock can be classified with a fair degree of certainty.

Recent studies on dolomite (Berner, 1965; Deffeyes and others, 1964; Gwinn and Bain, 1964; Illing and Wells, 1964; Lucia and others, 1964; Peterson and others, 1963; Schlanger, 1963; Skinner, 1963; and Shinn and Ginsburg, 1964) suggest that it may form penecontemporaneously with calcium carbonate by evaporation of sea water and formation of gypsum with concomitant increase in the magnesium-to-calcium ratio and subsequent replacement of calcite sediments by these magnesium-rich solutions. No evidence for an origin of this type is suggested for the dolomite in the Viola Group. The thick sequence of dolomite at Mosely Creek is probably due to action of solutions. The exact mechanism for the origin of the discrete dolomite rhombohedra in the calcarenitic mudstones and some calcarenites is unknown although the possibility exists that the necessary magnesium may have been derived from the abundant echinoderms which today are known to contain up to 20 mole percent magnesium carbonate.

Phosphatization

Phosphatization is important locally at the base of Section D where an X-ray pattern on the material indicates the carbonate apatite, francolite. According to Ames (1959), apatite replacement of calcium carbonate occurs in a nondepositional environment with calcite sediments or limestone available for replacement which proceeds from the surface toward the center. This strengthens the idea of an unconformity at the base of the Viola Group at Section D on Oklahoma State Highway 99.

Echinoderms and gastropods apparently are phosphatized easily and appear as light- to dark-brownish masses when examined petrographically.

Recrystallization

Another type of alteration in original texture is caused by recrystallization which involves a change in grain size whereby larger calcite crystals grow at the expense of smaller ones. Normally, this involves no change in composition. Also, by this process the original microstructure of some fossil shells is lost and they are converted into a mosaic of interlocking crystals.

In no case was original texture rendered unrecognizable because of complete recrystallization. However, virtually every thin section examined showed some signs of at least minor recrystallization.

Criteria used in this work for the recognition of recrystallization include patchy distribution of fine spar, variability in spar grain size from one place to another in the same specimen, irregularity of spar grain boundaries, and isolated, unsupported remnants of mud and (or) fossils in irregular spar. These criteria are discussed in more detail by Bathurst (1958).

Evidence indicates that recrystallization has been most active in the laminites and the calcarenitic mudstones. Many of the latter approach a muddy calcarenite because the mud and spar serving as matrix are so nearly equal in amount. The point here is that the writer believes that much, though not all spar contributing to the muddy calcarenite appearance, is actually recrystallization spar which has grown at the expense of the original fine mud. This points out the ever-present problem of whether the sparry calcite is cement in original void space or the result of recrystallization of an original calcite mud.

Many of the laminites and calcarenitic mudstones show the effect of recrystallization by the presence of microspar and isolated, rounded patches of mud with diffuse boundaries called pellet-forms in this report. On the other hand, evidence for any appreciable recrystallization in the well-washed calcarenites is lacking.

Sparry calcite, besides serving as cement, is found also as secondary filling in voids and fractures in the original rock and is normally distinguished from spar cement by its cross-cutting relation with the original rock fabric.

CHEMICAL DATA

A number of different analytical methods were employed in an attempt both to identify questionable minerals and to gather useful information for the characterization of the different rock types present in the Viola Group. These methods included X-ray analysis, X-ray fluorescence analysis, insoluble residue analysis, and chemical analysis.

The X-ray analysis was performed mainly to confirm the mineral identifications made during petrographic examination. Results of the X-ray study indicate that in addition to calcite, all samples from this group contain some quartz and most contain minor dolomite. Indications of other minerals are lacking except for an occurrence of francolite, a carbonate apatite, in one sample, and a calcium phosphate in another.

The X-ray fluorescence study was undertaken initially to determine strontium variation. Although a general correlation can be made from this study between calcite mud and strontium content, the main value of this work was that it showed the variation in elements throughout a stratigraphic section.

A study of insoluble residues was made in an attempt to characterize the different rock types by percentage and type of residue. In all specimens studied, the insoluble material was finely disseminated quartz and (or) silicified skeletal debris. The laminites of Unit 1L contain the highest percentages of insolubles (33 percent average), and the calcarenites of Units 1C and 3C the lowest (less than 1 percent not including silicified skeletal debris); the calcarenitic mudstones of Unit 2 contain percentages of insolubles intermediate between these (about 8 percent).

The chemical analysis is given to elaborate on the data contained in the insoluble residue study. The analyses show that the calcarenites devoid of silicified material contain as much as 97.68 percent $CaCO_3$ with 0.98 percent $MgCO_3$ and only 1.25 percent SiO_2 and 0.07 percent Al_2O_3. An average calcarenitic mudstone may contain 87.00 percent $CaCO_3$ and 1.88 percent $MgCO_3$ with 10.06 percent SiO_2 and 0.57 percent Al_2O_3. On the other hand, siliceous laminated mudstones on the average contain 33 percent SiO_2 and only 67 percent $CaCO_3$. These figures are based upon the insoluble residue work because a chemical analysis for this rock type was not available.

X-ray Analysis

Approximately 28 samples were run on a Norelco X-ray diffraction unit using Cu K alpha radiation. The X-ray study was deemed necessary in order to check on those hand specimens and thin sections in which the absolute identify of dolomite was uncertain because of a nondiagnostic stain or fine grain size. Also, such a sampling provided an overall idea of general composition of the limestones from the Viola Group.

Of the limestones with questionable dolomite picked for analysis, none showed any indication of appreciable quantities of that mineral. Roughly 25 percent of those on which patterns were run, however, gave a weak reflection for the strongest line of dolomite at about 30.9° 2θ. On the other hand, samples with known appreciable dolomite content gave the other characteristic reflections for that mineral.

Results of the X-ray study show that the limestones of the Viola Group contain virtually no other minerals except calcite, quartz, and dolomite. Quartz sand and silt appear throughout the section in varying amounts (normally from 0 to 10 percent); dolomite is patchily distributed both in individual rock specimens and throughout the section. At least one X-ray pattern does indicate the presence of the carbonate apatite, francolite. The sample on which this pattern was made was taken from the base of the group on Oklahoma State Highway 99 (Section D). There a gray-green, slightly oxidized, glauconitic, reworked(?) detrital shale (Harris, 1957) represents a disconformable surface between the Simpson and Viola Groups. Thin section D-1 (Plate 2, fig. 8) shows the contact between this gray-green material and the overlying Viola beds. The abundance of this phosphatized material plus the physical evidence corroborates the disconformity between the Simpson and Viola Groups recognized by earlier workers and picked by Harris (1957) on the basis of his study of ostracodes.

Another X-ray pattern on a sample from a 3-inch pyritic bed atop Unit 3C at Section Q (Dolese Brothers Rayford Quarry) shows calcium phosphate ($Ca_4P_2O_9$). A freshly broken piece of this sample reveals a large number of small inarticulate linguloid brachiopods which have a chitino-phosphatic shell. The writer believes that the presence of this bed, which is so drastically different from the coarse calcarenite below, is supporting evidence for the unconformity cited by others (Decker, 1933) between the so-called "Fernvale" and the overlying Sylvan Shale. A similar pyritic bed was noted atop Unit 3C at Section J on Sycamore Creek. Other evidence for this unconformity between Unit 3C and the Sylvan Shale is presented under the section headed "Stratigraphy."

X-ray Fluorescence Analysis

Besides determining the mineral content by running diffraction patterns on selected samples, the writer studied the variation in the different elements present in a suite of samples taken from one measured stratigraphic section. Section H on U. S. Highway 77 was chosen for this investigation because lithologies of the three units described in this work are well displayed there and the section is well known and easily accessible. In figure 4, samples H-1, 2, and 3 are laminites from Unit 1L; H-4, 5, and 6 are calcarenitic mudstones from Unit 2, and H-7 and H-8 are a calcarenite and calcarenitic mudstone respectively from Unit 3CM.

Preparation of the samples for analysis consisted of grinding a small portion of each rock to less than 80 mesh and then admixing enough polyvinyl alcohol (binding material) so that it constituted 10 percent by weight of the mixture. This preparation was shaken thoroughly to insure homogeneity and then subjected ultimately to 15 tons of pressure to make a sample briquet. A Siemens X-ray fluorescence unit with a chromium-target tube and lithium fluoride and gypsum analyzing crystals were used in the study of each briquet. This was a qualitative study in which sufficient accuracy was obtained by automatic scanning of the spectrum with the output fed to a chart recorder. Elements detected in each of the studied samples include calcium, iron, potassium, silicon, aluminum, titanium, barium, strontium, and sulfur. Magnesium is almost certainly present, but was not detected. It is one of the lighter elements and has a long wavelength; consequently its characteristic radiation is much absorbed by both the sample itself and the counter window. Although magnesium is detectable with the Siemens unit used in this study, separate tests using different panel settings, longer counting times, and different chart speeds were not conducted.

Figure 4 shows the results of this study which, although qualitative, do permit comparisons between successive samples. This is possible because all samples were prepared in the same way and contain an equal weight percentage of polyvinyl alcohol. Furthermore, and perhaps more important, each briquet was analyzed in the same sample holder with identical panel settings on the fluorescence unit. Therefore, relative concentrations of the different elements are readily apparent even though the exact amounts of each were not determined.

It should be noted here at the outset, however, that

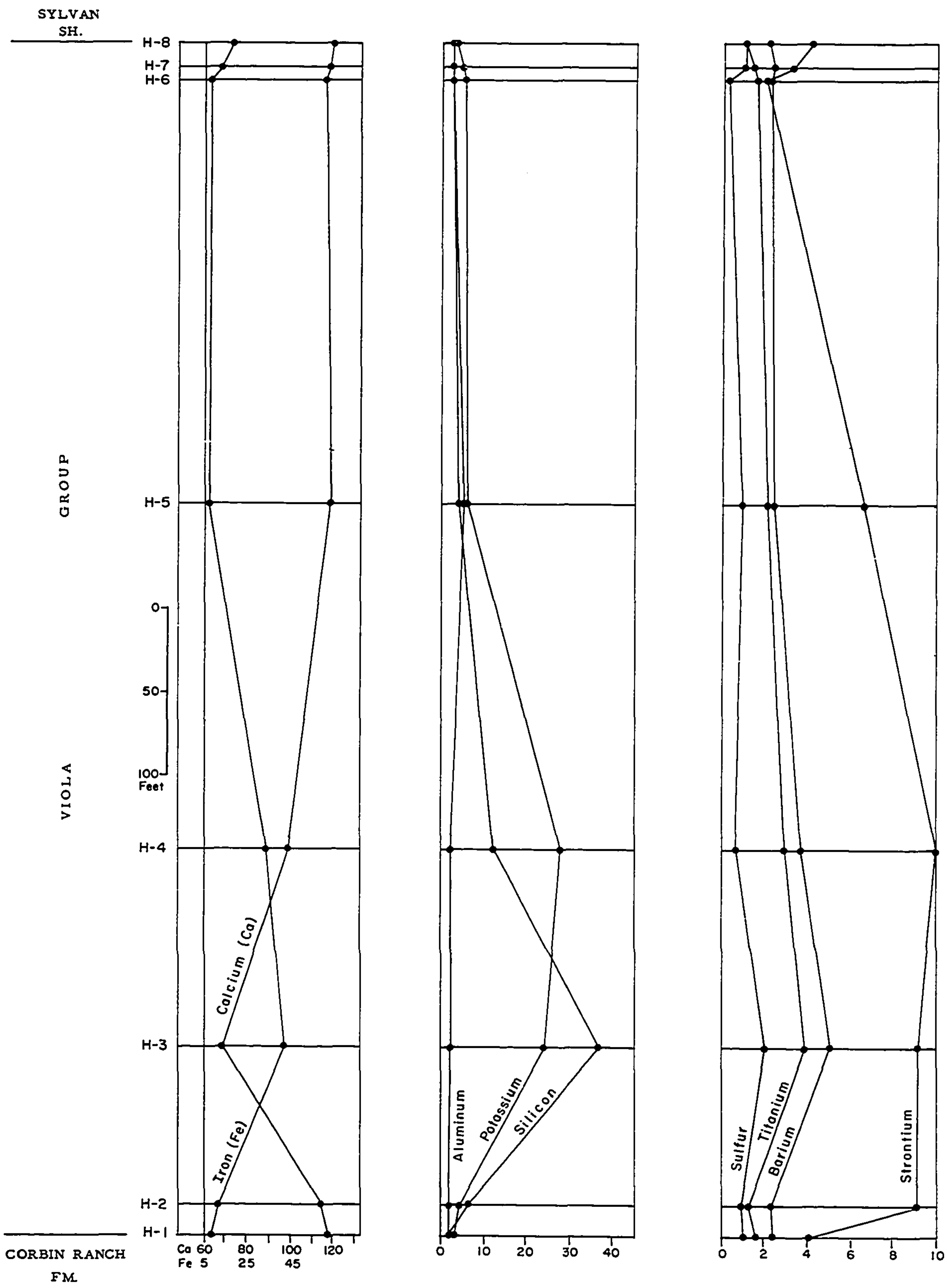


FIGURE 4
FLUORESCENT ANALYSIS OF SECTION H
(Sample Elements versus Peak Height in Millimeters)
All radiations are 1st order K_{a_1} except Calcium (1st order K_{b_1}), Barium (1st order L_{a_1}), and Titanium (1st order K_{b_1}).

no one-to-one correspondence or linear relationship between any of the elements is implied or intended in any of what follows. This is so for a number of reasons. First, the intensity is related directly to the atomic number of an element and through it indirectly to its wavelength. Second, the peaks printed on the chart recorder represent a statistical count and can be expected to vary slightly. Therefore, fluorescent radiation from the lighter elements with longer wavelengths can be expected to be attenuated or absorbed more than fluorescent radiation from the heavier elements with shorter wavelengths.

Some interesting aspects of figure 4 deserve comment and require interpretation. First, calcium and iron are inversely related, that is, iron content is low where calcium is high and vice versa. The ionic radii of ferrous iron and calcium in six-fold coordination are 0.74 and 0.99 angstroms respectively. Two of the factors which determine the extent to which atomic substitution can take place are the nature of the structure and the closeness of ionic size of the substituting and substituted ions. Ferrous iron is amenable to the carbonate structure; it occurs in siderite ($FeCO_3$) and substitutes for magnesium (ionic size in six-fold coordination, 0.66 angstroms) in the ferroan dolomite known as ankerite. Considering size, the ion of ferrous iron is actually a better fit for substituted calcium in the calcite lattice since it resembles the calcium ion more closely than does the magnesium ion. Therefore, the inverse relationship of calcium and iron indicated by analysis of samples from Section H is interpreted to mean that iron is substituting for calcium in the calcite lattice. Minor excess iron may be present as limonite and (or) hematite in the upper sample where the iron content increases and the calcium content remains virtually constant. An interesting observation which seems to lend support to the above interpretation is presented in Table 2. Peak height in millimeters for the second order calcium K_{b_1} reflection and the first order iron K_a reflection have been tabulated and their sum calculated. This table indicates that the sum of the peak heights is nearly constant, varying between 110 and 139 mm with a mean of 127 mm. Only samples H-3 and H-8 differ appreciably from the mean value. An interpretation for the deviation of sample H-8 was given above, that of possible excess iron in the form of limonite and (or) hematite.

From figure 4 it is clear that in sample H-3 all of the elements are presumably at or near their maximum values although calcium is at its minimum. Notable peak height

TABLE 2

(Peak Heights in Millimeters)

Sample	2d order Ca K_{b_1}	1st order Fe K_a	Total of Ca plus Fe
H-1	118	8	126
H-2	115	11	126
H-3	68	42	110
H-4	99	34	133
H-5	120	7	127
H-6	118	8	126
H-7	120	12	132
H-8	121	18	139

increases over sample H-2 occur for potassium, silicon, sulfur, titanium, and barium. However, the peak height for aluminum remains virtually constant. The etched specimen of sample H-3 shows a considerable amount of extremely fine material which X-ray diffraction indicates is quartz. This probably accounts for a greater portion of the increase in silicon. The increase in potassium is not so easily explained. Although the writer prepared sedimented slides on the less than 5 micron fraction from this sample, and no clay material was evident, it is thought that the potassium increase is due either to finely disseminated glauconite, orthoclase feldspar, muscovite, or illite. Conclusive evidence in the form of petrographic or X-ray analysis for the occurrence of any of these is lacking. The increase in barium and sulfur and the relatively high strontium content could mean minor amounts of barite and (or) celestite are present although again no conclusive evidence exists. The titanium is probably present as an oxide.

One additional observation should be made on figure 4 regarding the strontium content. In both the field examination and petrographic investigation, the mud content was observed to decrease toward the top of the section. Generally the strontium content also decreases higher up in the section. The inference made here is that in a general way the strontium content is higher in the muddier rocks with the implication being that it possibly gives an indication that at least some of the mud was deposited originally as aragonite. The strontium cation, because of its ionic radius, is amenable to the orthorhombic structure of that mineral and not to the hexagonal structure of calcite. Other strontium-bearing minerals were not detected in any of the samples checked by X-ray diffraction.

Insoluble Residue Analysis

Twenty-one samples were selected to determine weight percentages of insoluble residues. The method consisted of breaking and dissolving in hydrochloric acid approximately 15 grams of each specimen, care being taken not to include any replacement chert. This precaution was taken to insure that no bias was introduced into the final weight percentages. Each sample was treated with acid until all carbonates were dissolved. Additional acid was added and the samples heated for 30 minutes to insure that the reaction was completed. All insoluble contents were filtered using heavy weight filter paper, dried, and then weighed. Approximately seven samples were chosen from each lithologic unit of the Viola Group with as wide a geographic distribution as possible. The main purpose of this endeavor was an attempt to characterize the different units quantitatively by their percentage of HCl acid insolubles and by the type and form of the insoluble material. Field investigations and hand-specimen studies suggested high insoluble contents in the laminites, lower amounts in the mudstones, and the lowest percentage of insolubles in the calcarenites.

Results of this study in the form of weight percentages of HCl insolubles are presented in Table 3; figure 5

TABLE 3

Weight Percent HCl Insolubles

Sample	Laminites	Mudstones	Calcarenites
I-1	47 lacy-		
H-3	20 network		
M-1	31 silica		
F-1	2 and minor		
D-2[#]	4 fine quartz		
[°]L-9A[#]	12 silt		
J-2		20	
H-4		8 mainly fine	
G-4		8 quartz silt	
A-2		3 with minor	
D-16		2 lacy-network	
J-4		1 silica	
L-11		2	
L-1[*]			0.4 clay and
A-13			0.6 fine quartz
D-6[*]			0.8 silt
M-3			0.7
L-3[*]			15 predominantly
D-9[*]			5 silicified
H-7			3 fossil
J-8			3 debris

[#] Denotes laminites from calcarenite facies (Unit 1C).

[*] Denotes calcarenites from Unit 1C; remaining calcarenites from Unit 3C.

[°] Sample L-9A was collected on a subsequent visit to Mosely Creek and is not related to the original sample L-9 from that locality.

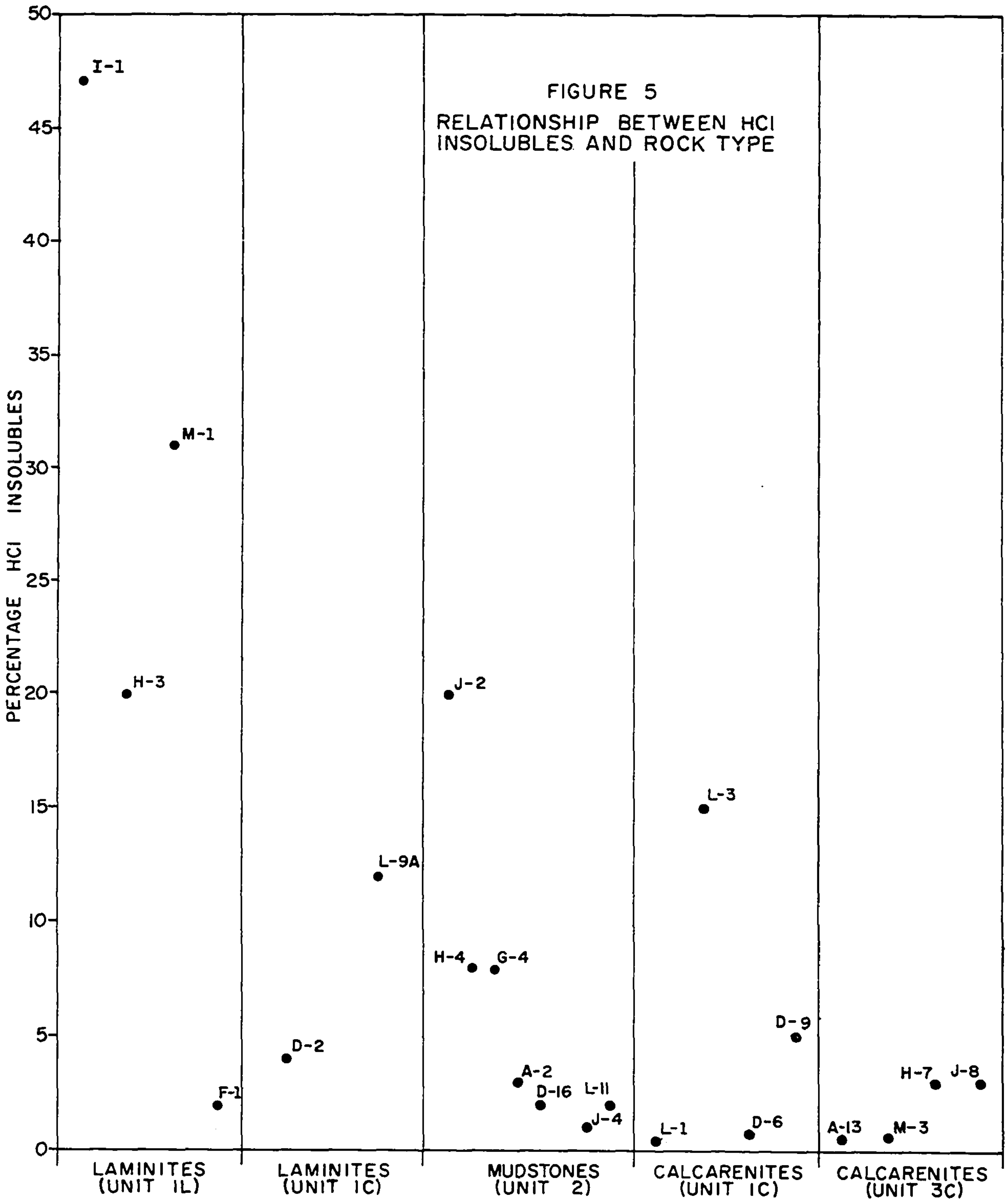


FIGURE 5
RELATIONSHIP BETWEEN HCI INSOLUBLES AND ROCK TYPE
PERCENTAGE HCI INSOLUBLES
50
45
40
35
30
25
20
15
10
5
0
I-1
M-1
H-3
F-1
D-2
L-9A
J-2
H-4
G-4
A-2
D-16
L-11
J-4
L-3
D-9
L-1
D-6
H-7
J-8
A-13
M-3
LAMINITES (UNIT 1L)
LAMINITES (UNIT 1C)
MUDSTONES (UNIT 2)
CALCARENITES (UNIT 1C)
CALCARENITES (UNIT 3C)

shows a graphical illustration of the data.

The well-laminated rocks are highly siliceous mudstones in which the layering results in part from alternating carbonate-rich and carbonate-poor laminae. Samples I-1, M-1, and H-3 contain respectively 47, 31, and 20 percent by weight acid insolubles in the form of microcrystalline silica that within an individual lamina is uniformly distributed as a lacy network throughout recrystallized carbonate. The microcrystalline silica is not land-derived quartz silt, but seems to be a recrystallized form of an original, but unknown high silica material. On the other hand, the weakly laminated mudstones such as D-2 and F-1 are extremely low in acid insolubles; even the etched specimens do not display the typical laminations seen in the laminites from the Arbuckle anticline. Sample L-9A from Unit 1C on the Hunton anticline is well laminated, but differs from the typical laminites by having thin interlayers of fine skeletal calcarenite and a somewhat lower percentage of acid insolubles. The writer believes that the large variation in insolubles in the laminites is directly related to the degree of lamination; that is, the well-laminated mudstones have higher acid-insoluble contents, and the weakly laminated mudstones, lower acid-insoluble contents.

In the samples tested from the calcarenitic mudstones, HCl insolubles range from 1 to 20 percent. The greater percentage of this is represented by land-derived fine quartz silt although a minor amount of lacy-network silica is present.

The calcarenites generally contain less than 1 percent acid insolubles consisting primarily of fine quartz sand. Where the percentage is higher it is due to an increased amount of silicified fossil debris. Samples L-3, D-9, H-7, and J-8 all contain silicified material in varying amounts, accounting for their relatively high insoluble content. On the other hand, the remaining calcarenites contain virtually no silicified shells, and their acid insolubles are accordingly lower.

Clay minerals were not detected in the X-ray study. According to Grim (1953), the determination of the clay minerals in limestones and dolomites is particularly difficult because it is normally necessary to dissolve away the carbonate in order to concentrate the clay minerals to get adequate analytical data; but some of the clay minerals themselves are fairly soluble in acid. Illite is normally present in most limestones and the writer believes that clay mineral is present in the Viola Group limestones in at least minor quantities. It may be admixed with the fine carbonate mud.

Characterization of Rock Types by Residues

The calcarenites are distinct from the laminites and the calcarenitic mudstones and can be characterized generally as relatively pure limestones with extremely minor land-derived quartz silt and clay. In some instances secondary silicification of skeletal debris degrades the purity somewhat, but this feature also is most characteristic of the calcarenites.

The residue which characterizes the laminites is lacy-network silica which is readily apparent on etched hand specimens. It is apparently reconstituted silica which is interstitial to the recrystallized fine spar and microspar of the mudstone. This material is so fine that an X-ray diffractogram was necessary to identify it with certainty. Although the X-ray pattern confirmed the material's identity as quartz, a petrographic study of a small amount of the insoluble residue immersed in oil was necessary to determine the form in which it exists. This study revealed that the material is not land-derived quartz silt, but a form of microcrystalline silica. Furthermore, its form and distribution as distinct laminae suggest that it is not a replacement phenomenon. Neither the hand specimens nor the thin sections present any evidence of cross-cutting of the fabric of the rock by the lacy silica. One possibility is that silica was present initially in such amounts as to allow concentration by the life processes of silica-secreting organisms. Krauskopf (1956, 1959), Okamoto and others (1957), and Siever (1957) all have done work regarding the properties of silica in water and in sedimentary environments. Siever concluded that the major source of soluble silica in the early diagenesis of sediments is the dissolution of remains of siliceous organisms. Krauskopf believes that most precipitated silica is disseminated widely through sediments. Riedel (1959) noted that siliceous skeletal remains, principally of diatoms and radiolarians with smaller amounts of sponge spicules and silicoflagellates, constitute up to approximately 40 percent of some Recent pelagic sediments. These observations are consistent with the possibility that the highly siliceous nature of the laminites is due to a reconstitution of the remains of siliceous organisms. However, the writer believes that the number of siliceous organisms necessary to account for all of the observed silica probably was prohibitive.

In contrast to the laminites, the insoluble residues which characterize the calcarenitic mudstones are predominantly land-derived quartz silt and fine sand with a minor amount of lacy-network silica. The calcarenitic mudstones are not laminated and generally are burrowed.

The weakly laminated mudstones of Sections E and F bear some similarities to both the typical laminites and the calcarenitic mudstones. They are common with the latter in that they contain more skeletal debris, have virtually no laminations, have a much lower percentage of acid insolubles, and contain only minor lacy silica. Like the typical laminites, however, they contain common spicules and are not burrowed.

Chemical Analysis

Chemical analyses made available to the writer through the courtesy of the Oklahoma Geological Survey and W. E. Ham, who collected the samples, are presented to supplement the insoluble residue and fluorescent analysis work. The analyses include a channel sample of the so-called "Fernvale" from the Ideal Portland Cement Company Quarry (Section A) near Lawrence, Oklahoma, and a composite average from six bulk samples of the calcarenitic mudstones. Unfortunately, a chemical analysis from the laminites is not available. The samples from the mudstones were taken along the east cut of the Santa Fe Railroad on the south limb of the Dougherty anticline in NE¼ SE¼ SW¼ sec. 21, T. 1 S., R. 2 E., Murray County, Oklahoma. This locality is approximately one-half mile northwest of Section Q in the Dolese Brothers Rayford Quarry (formerly Rayford Stone Company). The original descriptions by Ham of the rocks from this exposure were checked, and they correspond closely to the mudstones exposed in the Dolese Brothers Quarry. They are compact, uneven-bedded limestones with highly irregular, wavy-bedding surfaces that impart to the beds a nodular appearance; chert in the form of thin beds 1- to 2-inches thick and as isolated nodules occurs throughout most of the exposure. The trilobite, <u>Cryptolithoides</u> sp., and inarticulate linguloid brachiopods, are present throughout. Of the 332 feet of partially measured section from which samples were collected by Ham, the upper 262 feet contain chert nodules and chert layers; the lower 70 feet contain no chert. Below this 70-foot interval is roughly 100 feet of similar noncherty limestones. This represents the noncherty and cherty phases of the calcarenitic mudstones observed in the quarry face by the writer.

Small samples for analysis of the limestone were collected every three inches or so through the 332-foot section. It should be noted here that chert was included in the samples if it occurred along the line of sampling. In the writer's insoluble residue work, however, chert was not included in the original undigested sample.

The composite average for the mudstones is presented below.

SiO_2	10.06
Al_2O_3	0.57
Fe_2O_3	0.51
TiO_2	0.03
P_2O_5	0.04
CaO	48.74
MgO	0.90
SO_3	0.07
S	0.05
L.O.I.	39.28
Total	100.25

Recalculating the CaO and MgO to $CaCO_3$ and $MgCO_3$ respectively gives 87.00 percent $CaCO_3$ and 1.88 percent $MgCO_3$. This analysis corroborates the evidence which had been gathered from the thin section and X-ray studies. That is, the $MgCO_3$ available for dolomite constitutes only a small percentage of the total rock in which dolomite is most likely to occur, the mudstones.

This most likely occurrence refers here only to replacement dolomite and not detrital dolomite which may have been washed into the original sediment. This indicates that roughly 11 percent of this composite average consists of insoluble residues. This percentage is only slightly higher than the normal figure obtained for the mudstones, exclusive of chert, in the insoluble residue study. The low percentage of Al_2O_3 precludes the possibility of any great amount of clay minerals.

Chemical analysis of the channel sample taken from the "Fernvale" Limestone in the Ideal Portland Cement Quarry indicates that it is a relatively pure high-calcium limestone. The limestone there is massive bedded, coarsely crystalline, and is composed mostly of fossil fragments. It is noncherty in contrast to the underlying limestones. The analysis for this channel sample is presented below.

SiC_2	....	1.25
Al_2O_3	....	0.07
Fe_2O_3	....	0.25
Mn_2O_3	....	0.09
P_2O_5	....	0.09
CaO	....	54.72
MgO	....	0.47

S	....	0.10
L.O.I.	....	43.15
	Total	100.19

Recalculating the CaO and MgO to their respective carbonate equivalents gives 97.68 percent $CaCO_3$ and 0.98 percent $MgCO_3$. This indicates that roughly 1.34 percent of the total channel sample represents insoluble residues. This figure agrees well with the results obtained in the insoluble residue work where the coarse calcarenites from the equivalent section contain less than 1 percent insolubles where the silicified skeletal debris is missing (see Table 3). Here again, the $MgCO_3$ content is low, being roughly one-half the content in the mudstones and serving to accentuate the generality that dolomite is less likely to be found in the calcarenites than in the mudstones.

The other oxides are all present in minor amounts both in the calcarenite and the mudstone analyses. The iron is probably in the form of secondary hematite and (or) limonite; the phosphate, in partially phosphatized skeletal debris.

Although no analysis for the laminites is available, the writer believes a crude approximation is afforded through the combined work on acid insolubles, thin-section analysis, and X-ray data. In this rock type, virtually everything is either silica or calcium carbonate; dolomite is extremely sparse in the laminites. Using the average insoluble residues for the typical well-laminated rocks in the Arbuckle anticline, the content would be:

SiO_2 .... 33.0

CaO .... 37.5 (equals 67 percent $CaCO_3$)

The weakly laminated mudstones of Unit 1L are generally purer, however, having insoluble contents on the order of 4 percent.

SiO_2 .... 4.0

CaO .... 53.7 (equals 96 percent $CaCO_3$)

This points out the vast difference in both silica and calcium carbonate content in the well-laminated and weakly laminated mudstones of Unit 1L. The writer believes that this difference is directly related to the presence or absence of laminations because, as mentioned previously, this feature occurs in these rocks only where an alternation between carbonate-rich (silica-poor) and carbonate-poor (silica-rich) layers occur. As a result, the silica content is high and the carbonate content low where laminations are present with the reverse situation true where they are absent.

Two observations should be made here concerning these results. First, whereas the specimens of the laminites contain only a minor amount of skeletal calcite, those of the mudstones contain much larger amounts. In this respect any comparison of either acid insolubles or chemical analyses suffers somewhat because it would be more desirable to analyze a skeletal-free mudstone to determine just what percentage of only the fine mud fraction is insoluble silica. In this way a better comparison of the mud from the laminites and the mud from the mudstones could be made. The presence of the skeletal debris has biased the result somewhat because, in all probability, it has served to lower the percentage of insoluble residues by its presence in the undigested samples from the mudstones. Second, the chemical analysis of the composite average of the six bulk samples from the mudstones includes chert whereas the samples used in the insoluble residue work did not. Chert should be excluded also in order to obtain an accurate comparison of insolubles from the mud fraction. However, the writer believes that the results obtained are valuable and would not differ appreciably had a chert- and skeletal-free mudstone been used in the analysis.

It remains now to discuss the reason for the variation in silica content of the six bulk samples from which the composite average was prepared for the mudstones. The silica content of each sample is listed in Table 4 in the same sequence as the rocks appear in the field, from bottom to top. The six arbitrary divisions used in the collection, their thicknesses, and whether or not chert was observed are listed also. Divisions one through five are in the cherty phase of Unit 2 whereas division six is in the noncherty phase. The 262 feet of cherty mudstones here recorded from the measurements of Ham in 1944 is incredibly close to the 263 feet of this phase measured by the writer in the Dolese Brothers Quarry.

TABLE 4

Division		Thickness in Feet	% SiO_2	Chert
Top	1	52	15.70	Yes
	2	50	13.31	Yes
	3	50	5.45	None observed
	4	50	5.50	Yes
	5	60	9.78	Yes
Bottom	6	70	10.63	No

Several observations can be made from Table 4. The silica content in division six in which chert does not occur is higher than that of divisions four and five in which chert is present. In fact, it is almost double that of division four. Chert was not observed in division three which has the lowest silica content. The maximum content at the top of the sequence varies to a minimum near the middle and then approaches another maximum at the bottom. The salient fact evident from this table is that the noncherty mudstones also can have relatively high silica contents which approach and even surpass some of those of the cherty mudstones. (See also noncherty mudstone sample J-2, Table 3 and fig. 5.) Another surprising fact is that even though some mudstones (division 4) have associated chert, their silica contents can be relatively low. This apparent paradox is possibly explained by varying amounts of land-derived quartz silt and sand and finely disseminated silica. Although one might expect higher silica contents in the cherty rocks, the writer sees no reason why this must be the case, and the analyses presented above support this observation.

With these data the writer concludes that in general it is impossible to differentiate the calcarenitic mudstones of the cherty and noncherty phases on the basis of silica content by means of either chemical or insoluble residue analyses.

SUMMARY

The original purposes of this investigation have been satisfied in that a lithostratigraphic framework for the limestones of the Viola Group has been established, a meaningful subdivision using only surface studies has been attained, and original environmental conditions and sedimentational patterns have been reconstructed.

The Viola Group limestones fall naturally into three main rock types: (1) siliceous laminated mudstones (laminites); (2) skeletal calcarenitic mudstones; and (3) coarse skeletal calcisiltites through coarse skeletal calcarenites. One instance of a relatively thick sequence of dolomite was found, but the writer believes that this occurrence is due to secondary processes.

These limestones are wholly marine deposits and, in general, represent a classic cycle in sedimentation. On the basis of thickness and rock type, they are subdivided in the Arbuckle Mountains into a southwestern basin province and a northeastern shelf province. The basal unit is composed of

siliceous laminated mudstones deposited in an environment of deeper water and lower energy. The middle unit consists of burrowed skeletal calcarenitic mudstones deposited in an environment with shallower water and slightly more energy than the laminites. Finally, the upper unit is comprised of coarse skeletal calcarenites deposited in the shallowest water and highest energy environment for the whole limestone sequence. This simple picture is slightly complicated in the northeast where the initial deposits were coarse skeletal calcisiltites and fine calcarenites deposited in an environment similar to that of the calcarenites. There the depth cycle was shallower-deeper-shallower and the energy cycle higher-lower-higher. Similarly, in the extreme southwest, the upper unit consists predominantly of calcarenitic mudstones interbedded with thin fine to medium calcarenites indicating that in this area the shoaling water and higher energy condition which prevailed over most of the whole area was not realized in the extreme there.

Based upon these observations, the Viola Group is subdivided into three units of which the basal and uppermost have distinct facies. These units are given arbitrary designations and are: Unit 1L (basin laminites) and Unit 1C (shelf calcarenites equivalent to the laminites); Unit 2 (calcarenitic mudstones found throughout the Arbuckle Mountains); and Unit 3C (coarse calcarenites) and Unit 3CM (basin calcarenitic mudstones interbedded with thin calcarenites equivalent to Unit 3C).

Conclusive evidence exists for disconformities at the base and top of the group. The uppermost beds of the underlying Corbin Ranch Formation are burrowed, have a corrosion zone, and in at least one locality are overlain by a thin greenish-gray clay-like zone containing abundant phosphatized material. The top of the group in at least one locality has a pyritic phosphate conglomerate containing abundant linguloid brachiopods. Also, evidence exists for truncation of the uppermost beds in the southeast near Robertson Creek and in the southwest near West Spring Creek. Evidence for other unconformities within the Viola Group is lacking. This is important in view of the fact that for a long time an unconformity representing the Eden-Maysville stages has been placed below the coarse calcarenites of Unit 3C ("Fernvale" Richmond) and the underlying Viola (Trenton). In virtually every stratigraphic section, however, the rocks indicate a transitional sequence from the mudstones to the calcarenites. Too, the graptolite zonation in the Arbuckle Mountains by Ruedemann and Decker (1934) shows a middle Eden horizon which apparently has not been recognized by any later workers. In any case, physical evidence does not suggest an unconformity although the yet to be completed co-study of the biostratigraphy may indicate otherwise.

The petrographic work shows that echinoderms far outrank any other fossil found in these limestones. Trilobites and brachiopods are next in importance although bryozoans are abundant locally in the lower calcarenites. All of the above-mentioned skeletal elements are found more commonly in the calcarenites although the echinoderms, trilobites, and brachiopods are plentiful in the calcarenitic mudstones. Graptolites, sponge spicules, linguloid brachiopods, and trilobites dominate the laminite fauna. Silicified brachiopods occur most commonly in Units 3C and 3CM although a few occurrences in Unit 2 were noted.

Insoluble residue work indicates that, in general, the laminites contain the greatest percentages of acid insolubles. Calcarenitic mudstones are next in abundance with the calcarenites containing the least amount where their silicified fossil content is not high.

Chemical analyses show that the calcarenites are practically pure high-calcium carbonates where silicified debris is absent. On the other hand, the calcarenitic mudstones contain an average of about 10 percent silica. X-ray analyses corroborate these observations. For the most part they indicate only calcite, quartz, and extremely minor dolomite.

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PLATES 1-5

PHOTOMICROGRAPHS OF LIMESTONES FROM THE VIOLA GROUP

PHOTOMICROGRAPHS

Photographs of all thin sections are X15 and were taken in ordinary light. Field diameter was 4 mm. Hand-specimen photographs are X0.6. All photographs have their top oriented upward except where otherwise indicated. Numbers such as I-1 indicate the stratigraphic section and sample number above the base. For a more complete discussion of each thin-section photomicrograph, see the detailed descriptions which follow these plates. The names given for the hand specimens are field-laboratory descriptions.

PLATE 1

1. I-1, siliceous laminated mudstone: fine mud and recrystallized fine spar with irregular calcite-filled vein in center. Unit 1L.

2. E-2, spicular-pellet calcisiltitic mudstone: abundant transversely and longitudinally cut spicules. Unit 1L.

3. D-2, burrowed slightly laminated mudstone: geopetal structure with part of spar-filled cavity of burrow now floored with skeletal debris all surrounded by a halo of lighter-colored mudstone with small echinoderm fragments. Laminite from Unit 1C. (Top is toward upper right.)

4. L-9A, laminated mudstone interstratified with fine skeletal-pellet-intraclast calcarenite: small dark spots are

pellets and (or) intraclasts in sparry cement; darker strips at top, middle, and bottom are mudstone laminae. Laminite from Unit 1C.

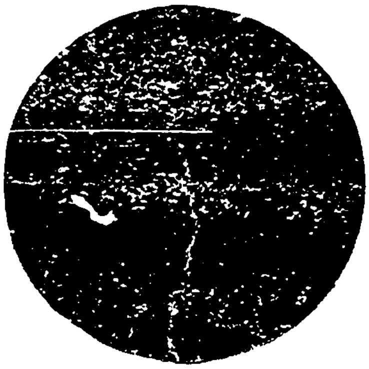
5. D-15, calcite mudstone: gastropod with mud in interior recrystallized to spar; echinoderm at top edge; good example of Dunham's wackestone. Unit 2.

6. D-17, skeletal calcarenitic mudstone: shows pellet-forms, grumeleuse structure, and recrystallization of mud in and around trilobite shell. Unit 2.

7. G-4, burrowed skeletal calcarenitic mudstone: mud-filled burrow in center surrounded by calcarenitic skeletal debris. Unit 2.

8. D-15, calcite mudstone: partially coated (extremely dark band in top half) bryozoa with most of mud recrystallized and all cut by calcite-filled vein. Unit 2.

9. C-6, skeletal calcarenitic mudstone: Bryozoa growing on pseudopunctate brachiopod shell; small rhombohedra of replacement dolomite below brachiopod. Unit 2.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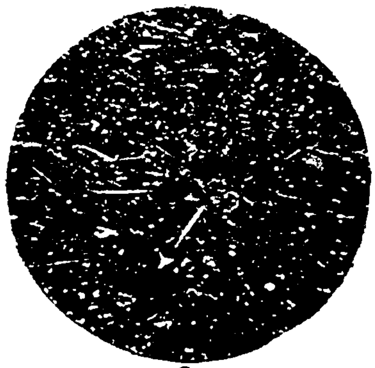
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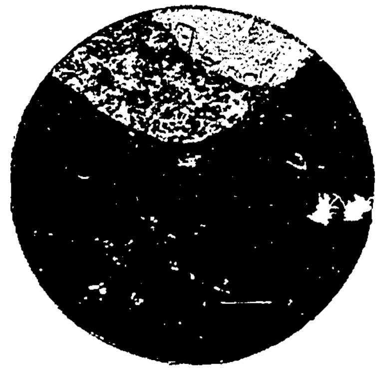
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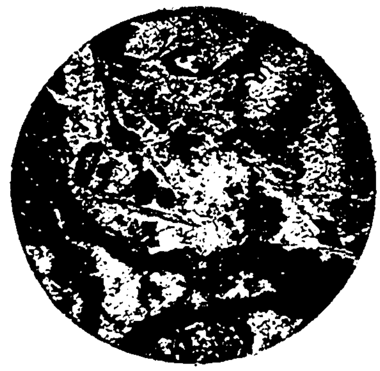
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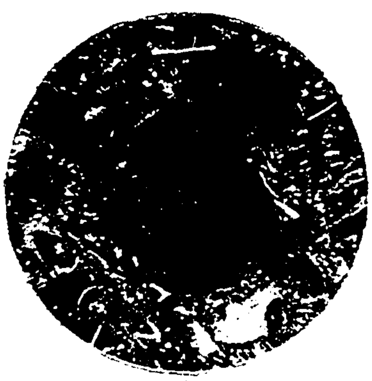
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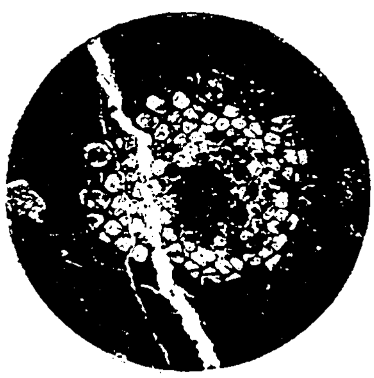
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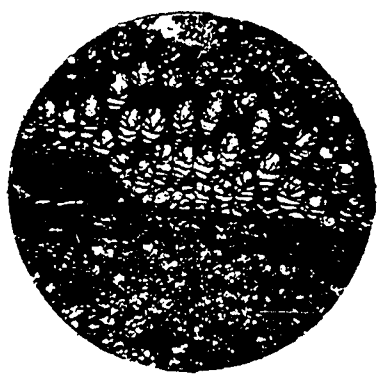
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PLATE 1

PLATE 2

1. L-6, phosphatized-silicified sparry skeletal calcarenite: delicately preserved silicified echinoderm fragments. Unit 1C.

2. K-1, sparry echinoderm-bryozoan calcarenite: shows echinoderm and abundant bryozoan fragments in coarse spar. Unit 1C.

3. D-11, sparry ostracode calcisiltite: abundant ostracode shells set in sparry cement. Unit 1C.

4. J-8, sparry echinoderm calcarenite: echinoderm fragments and replacement dolomite in center. Unit 3C.

5. C-11, sparry skeletal-intraclast calcarenite: dark intraclasts set in skeletal calcarenite. Unit 2. This is a unique specimen in two respects: (1) it represents the only obvious intraclastic rock, and (2) it is the sole example observed of a relatively clean calcarenite existing in Unit 2.

6. I-9, skeletal calcarenitic mudstone: large echinoderm fragments showing mud in canals all set in mud matrix. Unit 3CM. Compare with Unit 2 calcarenitic mudstones.

7. H-7, sparry echinoderm calcarenite: shows slightly muddy nature of basin-type calcarenite. Unit 3CM.

8. D-1, phosphatized sparry skeletal calcarenite: shows irregular contact of crumbly greenish-gray material below and phosphatized skeletal-intraclast calcarenite at disconformable Corbin Ranch Formation-Viola Group contact on Oklahoma State Highway 99. Unit 1C.

9. L-4, dolomite: large dolomite rhombohedra and some skeletal debris which has not been replaced; silicification after dolomitization in white areas such as the middle and eastern portions. Unit 1C.

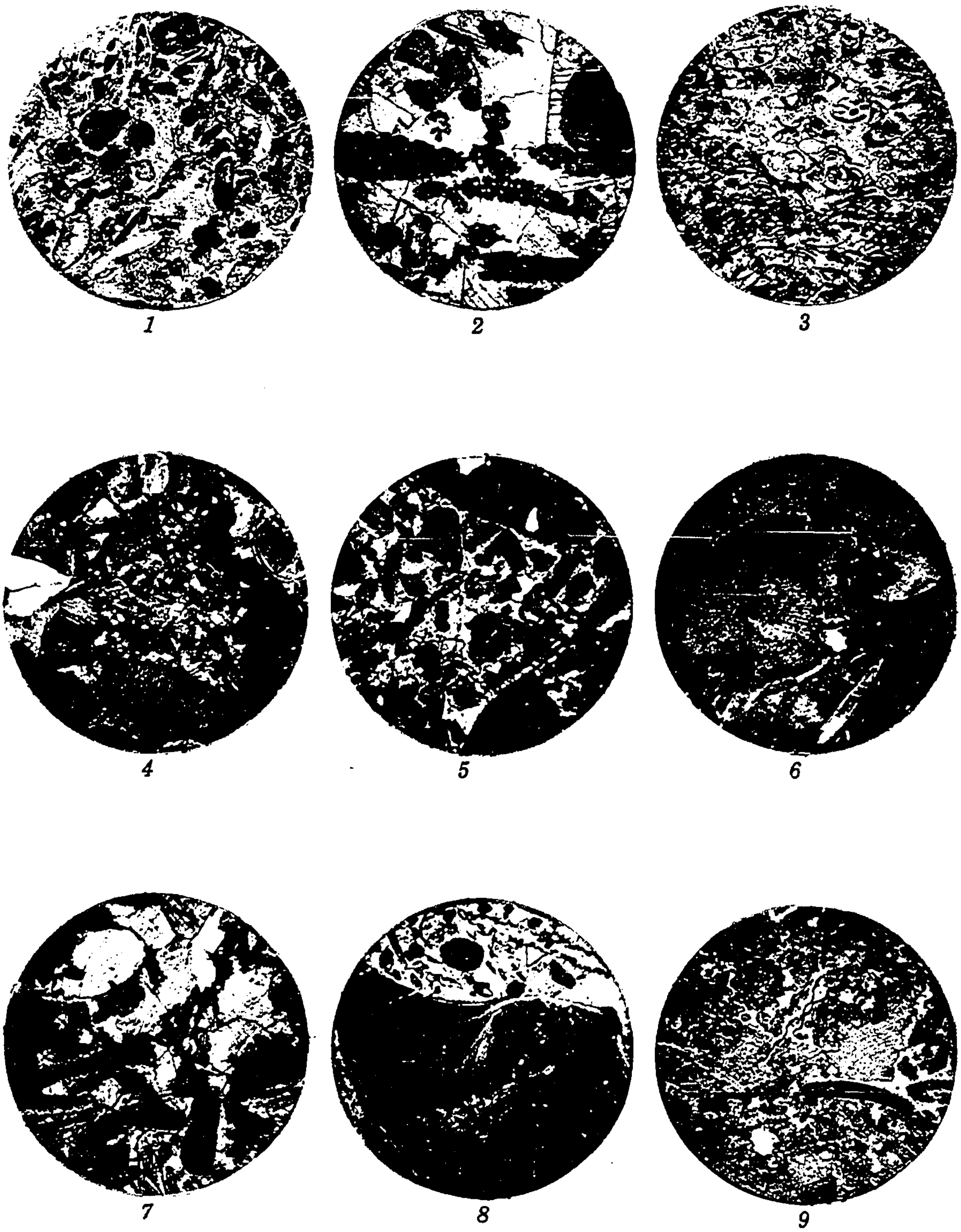


PLATE 2

PLATE 3

1. A-2, pellet mudstone: irregular recrystallized spar surrounding unsupported, isolated mud. Unit 2.

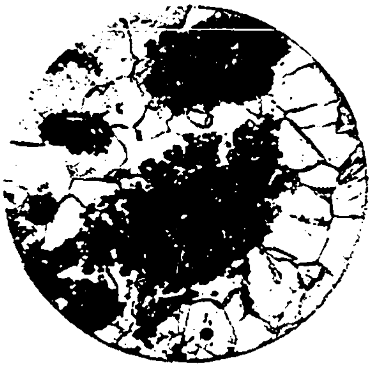
2. J-3, skeletal-pellet calcisiltitic mudstone: encroaching replacement chert (light) in contact with calcisiltitic mudstone (dark); unreplaced mud appears as dark circular spots near contact in area of chert. Unit 2.

3. J-3, same as above, but different view: Shows complete (dark) and partial (light) replacement by chert of skeletal calcarenitic mudstone. Unit 2.

4. L-13, burrowed muddy spar-cemented skeletal calcarenite: local concentric quartz concentration in burrow now filled with fine mosaic calcite. Unit 3C.

5. Pyritic phosphate conglomerate: large carbonate-filled fracture in center with minor dolomite; black is pyrite, and lighter material is phosphate; veins near top are filled with quartz; paragenetic relations suggest carbonate first, followed by phosphatization, and finally quartz infilling of veins. Three-inch layer separating Unit 3C and overlying Sylvan Shale.

6. I-1: siliceous laminated mudstone: lighter material, which shows a greater concentration at "a" is fine insoluble silica dust; note "pinch-and-swell" structure in carbonate material. Unit 1L, etched specimen.



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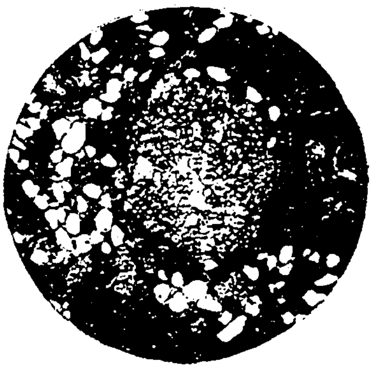

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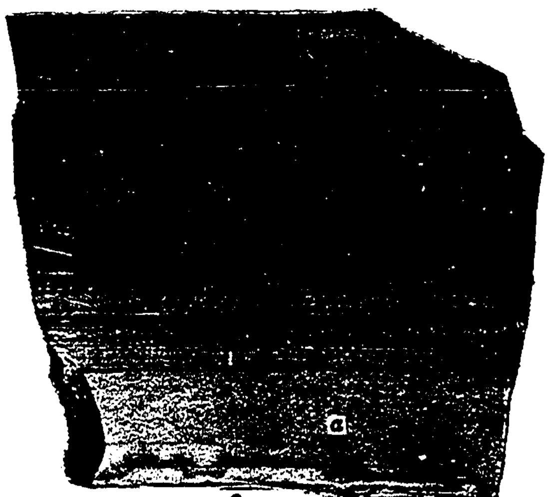

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PLATE 3

PLATE 4

1. H-4, burrowed silty calcisiltic mudstone: whorled structures due to extensive burrowing; lighter areas are insoluble silica. Unit 2, etched specimen.

2. E-2, weakly laminated calcisiltitic mudstone: replacement chert at "a," calcium carbonate at "b." Unit 1L, etched specimen.

3. I-9, clacarenitic mudstone: dolomite-filled burrow just to the right of center; white material is echinoderm debris. Unit 3CM, varnished specimen.

4. G-4, burrowed calcarenitic mudstone: lighter areas are silica dust and fine silt. Unit 2, etched specimen.

5. M-2, sandy burrowed muddy skeletal calcarenite: cause of mottling unknown; local concentrations of quartz sand in burrows as in dark circular patches in top left. Unit 2 near contact with Unit 3, etched specimen.

6. D-17, calcarenitic mudstone: abundant brachiopods in fine mud with quartz silt (dark areas in lower right). Unit 2, etched specimen.

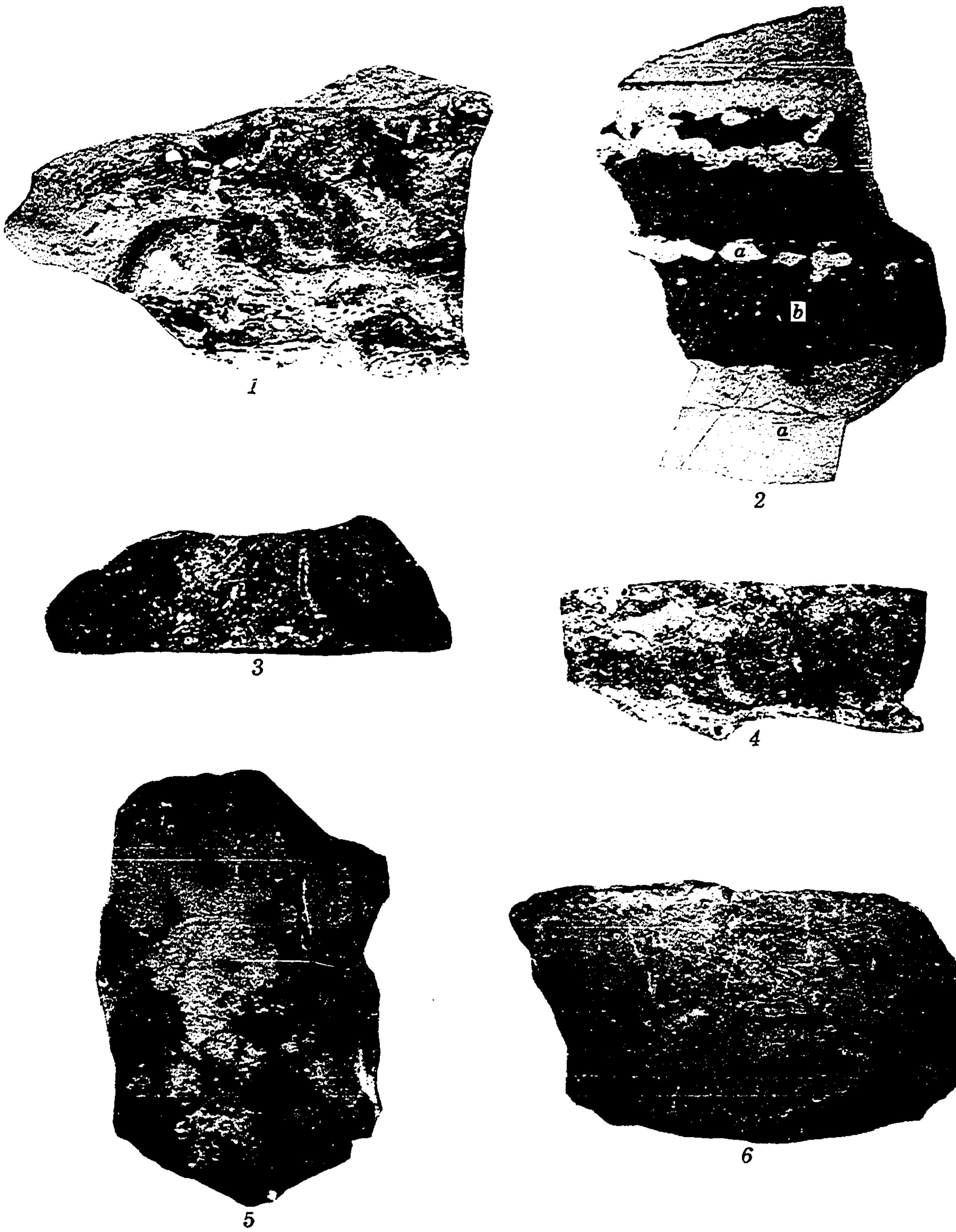


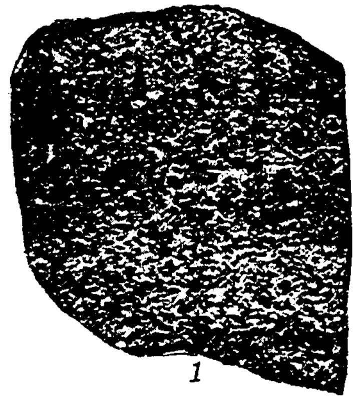
PLATE 4

PLATE 5

1. J-8, coarse calcarenite: coarse skeletal debris. Unit 3C, varnished specimen.

2. M-1, siliceous laminated mudstone: "a" is replacement chert; "b" is replacement chert in intermediate stage of development; "c" is laminated mudstone with insoluble silica dust. Unit 1L, etched specimen.

3. C-11, calcarenitic mudstone ("a") bounding skeletal-intraclast ("a") calcarenite. Unit 2 just below contact with Unit 3C, varnished specimen.



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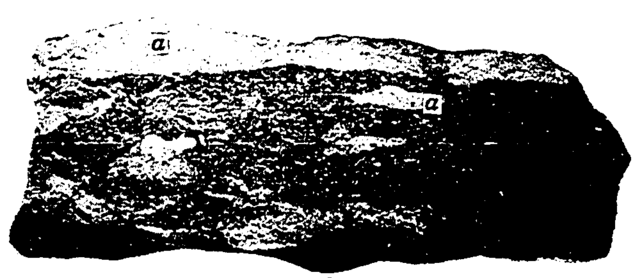

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PLATE 5

THIN SECTION DESCRIPTIONS

The following descriptions are a combination of both petrographic and binocular examinations. The first part of each description deals with information obtained through study of thin sections; the remainder, with information from the study of varnished and etched hand specimens. The following form was used:

> Sample number, stratigraphic position above base; rock name (underscored; see text for terminology): percentage of each constituent, observations regarding recrystallization (if any) and other pertinent petrographic features. Color of fresh rock (color code); skeletal grain size extremes (smallest and largest); median skeletal grain size; gross observations of pertinent features in hand specimen.

An example of this scheme is given below:

D-13, 159' above base; sparry skeletal calcarenite: 20% echinoderms, 3% trilobites, 7% bryozoa, 1% brachiopods, 1% ostracodes, 60% spar, 1% mud; minor organic matter and mollusks; about 4% of shells phosphatized; ghosts of recrystallized fossils; thin coating of mud around ghosts and a few other fossil fragments; faintly cross-bedded.
Pinkish gray (5 YR 8/1) speckled dark gray (N 3); .25-3.00 mm; .65 mm; parallelism of trilobite fragments to bedding.

Percentages given are visual estimates obtained by using the charts prepared for this purpose by Terry and Chilingar (1955) and Folk (1951). Colors and their appropriate code numbers were taken from the Rock Color Chart, 1948, distributed by the National Research Council, Washington, D. C. Skeletal grain-size extremes and median were measured using a calibrated ocular micrometer disc mounted in a binocular microscope.

The columnar sections found with the measured stratigraphic sections indicate the units to which these thin sections correspond.

SECTION A: NW¼ sec. 36, T. 3 N., R. 5 E., Pontotoc County; Ideal Portland Cement Quarry near Lawrence, Oklahoma, just east of Oklahoma State Highway 12. (Base not exposed)

A-15, 139' above basal exposure; sparry trilobite-echinoderm calcarenite: 30% echinoderms, 5% brachiopods, 15% trilobites, 1% bryozoans, 45% spar; minor mud, ostracodes and traces of organic matter; fossil ghosts rare; minor recrystallization and sutured contacts between calcite spar.
Yellowish gray (5 Y 8/1); extremely friable when weathered; .10-3.00 mm; .22 mm.

A-14, 125' above basal exposure; sparry trilobite-echinoderm calcarenite: 40% echinoderms, 6% trilobites, 1% mud, 1% secondary hematite, 50% spar; minor silicification of fossils; mud possibly indicates incomplete washing as it is present in the interstices between fossil fragments and appears as a thin coating on some; minor brachiopods, ostracodes, collophane, and quartz silt.
Light gray (N 7); .10-3.00 mm; .38 mm.

A-13, 101' above basal exposure; sparry echinoderm calcarenite: 35% echinoderms, 2% trilobites, 55% spar; minor brachiopods, bryozoans, and ostracodes.
Grayish orange (10 YR 7/4); .20-.82 mm; .35 mm.

A-12, 94' above basal exposure; sparry echinoderm calcarenite: 35% echinoderms, 5% trilobites, 55% spar, 1% collophane; minor brachiopods, bryozoans, and ostracodes; small amount of silicification and phosphatization with rare silica cement.
Yellowish gray (5 Y 8/1); .15-2.25 mm; .45 mm.

A-11, 88' above basal exposure; sparry echinoderm calcarenite: 30% echinoderms, 1% trilobites, 60% spar; minor brachiopods, bryozoans, ostracodes, and rounded quartz sand; loosely packed and slightly silicified with rare fossil ghosts and some recrystallization of fossil fragments.
Yellowish gray (5 Y 8/1); .15-4.50 mm; .38 mm.

A-10, 82' above basal exposure; sparry echinoderm calcarenite: similar to A-11. Contains silicified fossils; .15-.75 mm; .30 mm.

A-9, 76' above basal exposure; sparry echinoderm calcarenite: similar to A-10 and A-11.

A-8, 70' above basal exposure; sparry echinoderm calcarenite: similar to A-9 through A-11 with about 50-60% spar and loose packing.
Pinkish gray (5 YR 8/1); .15-1.85 mm; .70 mm.

A-7, 62' above basal exposure; sparry echinoderm calcarenite: similar to A-8 through A-11.
Light gray (N 7); .10-.85 mm; .40 mm.

A-6, 49' above basal exposure; sparry echinoderm calcarenite: 40% echinoderms, 3% subrounded to rounded, straight extinction quartz sand with one grain showing chalcedonic overgrowth extending into an echinoderm fragment; 35% spar and minor brachiopods, trilobites, and bryozoans.
Medium bluish gray (5 B 5/1); .07-1.50 mm; .38 mm.

A-5, 45' above basal exposure; sparry echinoderm calcarenite: 30% echinoderms, 5% mud, 5% dolomite, some of which

partially replaces quartz grains, 6% rounded, straight extinction quartz sand, 40% spar; minor brachiopods, trilobites, bryozoans, ostracodes, secondary hematite, and organic matter.
Yellowish gray (5 Y 8/1); .20-1.40 mm; .35 mm.

A-4, 37' above basal exposure; skeletal calcarenitic mudstone (dolomitized): 7% echinoderms, 3% subrounded, straight extinction quartz sand, 15% dolomite of which some replaces echinoderm fragments and some attains large crystal size (.14 mm); 65% mud; minor fracture-filled spar and other skeletal debris including rare spicules; stylolite.
Yellowish gray (5 Y 8/1); .07-.55 mm; .22 mm.

A-3, 32' above basal exposure; replacement chert: original textures preserved; rare spicules, echinoderm fragments, and quartz sand observed in chert mass. Unaltered skeletal mudstone in uneven contact with this chert. Small hand specimen shows gradual and partial replacement of limestone to chert.

A-2, 24' above basal exposure; pellet mudstone (partially recrystallized): 5% echinoderms, 1% trilobites, 20% mud, 5% rounded, straight extinction quartz sand, 35% pellets, 5% dolomite, 20% coarse spar containing isolated and unsupported mud; minor spicules and recrystallized fossil shells; dolomite in mud fraction with some rhombohedra replacing coarse spar; isolated mud patches in spar indicate recrystallization; pellets are distinct ovoid to rounded masses.
Yellowish gray (5 Y 8/1); .10-1.05 mm; .30 mm. Plate 3, fig. 1.

A-1, 12' above basal exposure; skeletal calcarenitic pellet mudstone: 1% echinoderms, 2% spicules, 60% pellets, 30% mud plus microspar; minor ostracodes and quartz silt, partial recrystallization of mud to microspar with pellet-mud-microspar relationship resembling the grumeleuse structure of Cayeux (1935, Plate XVIII, figs. 67 and 68).
Yellowish gray (5 Y 8/1); .03-1.30 mm; .08 mm.

SECTION B: SE¼ SW¼ sec. 5, T. 2 N., R. 6 E., Pontotoc County; along tributary to South Fork Creek. (Base not exposed)

B-6, 64' above basal exposure; sparry trilobite-echinoderm calcarenite: 35% echinoderms, 4% trilobites, 5% ferruginous material; 50% spar; minor bryozoa, brachiopods, ostracodes, mud, and organic matter; contact between fine and coarse sparry calcarenite with coarser one loosely packed.
Grayish orange (10 YR 7/4); .08-1.50 mm; .55 mm.

B-5, 42' above basal exposure; sparry echinoderm calcarenite: 30% echinoderms, 2% trilobites, 5% hematite, 55% spar; minor dolomite, ostracodes, and brachiopods; loosely packed with numerous fossil ghosts.
Very pale orange (10 YR 8/2); .10-5.25 mm; .40 mm.

B-4, 40' above basal exposure; sparry echinoderm calcarenite: 30% echinoderms, 3% trilobites, 2% bryozoa, 60% spar, minor brachiopods and ostracodes; loosely packed.
Pinkish gray (5 YR 8/1) with trilobite fragments exhibiting parallelism to bedding and to each other; .10-1.80 mm; .38 mm.

B-3, 25' above basal exposure; sparry echinoderm calcarenite: 30% echinoderms, 1% trilobites, 3% mud, 7% subrounded to rounded straight extinction quartz sand, 50% spar; minor bryozoans and brachiopods.
Yellowish to light olive gray (5 Y 7/1); .08-1.70 mm; .70 mm.

B-2, 24' above basal exposure; echinoderm calcarenitic mudstone: 40% echinoderms, 5% subrounded straight extinction quartz sand, 30% mud plus microspar, 10% secondary hematite; minor trilobites and ostracodes; contains some spar although mud predominates with some recrystallization to microspar.
Very pale orange (10 YR 8/2); solution holes well developed on weathered surface with interconnection between individual holes in rock interior; .10-1.80 mm; .18 mm.

B-1, from basal exposure; skeletal calcarenitic mudstone: 7% echinoderms; 2% spicules, 5% subrounded to rounded straight extinction quartz sand, 65% mud with a few

pellet-form aggregates; minor trilobites, bryozoa, ostracodes, ferruginous material, and recrystallized shells; slightly burrowed showing a few whorled structures.
Grayish orange (10 YR 7/4) mottled pale yellowish brown (10 YR 6/2); .10-1.05 mm; .22 mm.

SECTION C: NW¼ sec. 2, T. 1 N., R. 6 E., Pontotoc County; approximately ¾ miles west of Oklahoma State Highway 99 along unnamed creek. (Fault contact at base with Simpson Group; fault contact at top with Hunton Group)

C-15, 297' above basal exposure; sparry trilobite-echinoderm calcarenite: 20% echinoderms, 10% trilobites, 3% brachiopods, 60% spar; minor shell phosphatization, and mud especially localized by shelter effect in a large curved trilobite fragment.
Pinkish gray (5 YR 8/1) speckled dark yellowish orange (10 YR 6/6), friable when weathered, .22-7.85 mm; .60 mm.

C-14, 237' above basal exposure; sparry trilobite-echinoderm calcarenite: 30% echinoderms, 5% trilobites, 2% rounded, straight extinction quartz sand, 60% spar; minor brachiopods, ostracodes, and bryozoans; one irregular dolomite seam extends across much of the thin section and coats two trilobite fragments possibly representing dolomitization of an original mud coating.
Pinkish gray (5 YR 8/1); .15-4.12 mm; .65 mm.

C-13, 214' above basal exposure; sparry echinoderm calcarenite: 30% echinoderms, 60% spar, 3% well-rounded, straight extinction quartz sand (one grain showing chalcedonic overgrowth); minor trilobites, bryozoans, and brachiopods.
Very pale orange (10 YR 8/2) with solution holes; .15-2.25 mm; .45 mm.

C-12, 204' above basal exposure; pellet-skeletal calcarenitic mudstone: 15% echinoderms, 2% spicules, 70% mud plus microspar, 1% rounded, straight extinction quartz sand, 7% pellets; minor trilobites, bryozoans, hematite, and fine dolomite; a few recrystallized fossil shells and recrystallization of mud to microspar; similar in appearance to Cayeux's grumeleuse structure.

Pinkish gray (5 YR 8/1); .10-7.50 mm; .65 mm; solution holes, geopetal structure, burrows.

C-11, 189' above basal exposure; skeletal calcarenitic mudstone in contact with sparry skeletal-intraclast calcarenite: 8% echinoderms, 2% trilobites, 7% bryozoans, 1% spicules, 20% intraclasts, 55% spar; minor brachiopods and quartz sand; dolocasts in both mudstone and calcarenite; intraclasts similar to mudstone below and probably derived from it; minor silicification and recrystallization of shells.
Light olive gray (5 Y 6/1) and pinkish gray (5 YR 8/1); .10-7.50 mm; .60 mm, conglomeratic, possibly burrowed. Plate 2, fig. 5 and Plate 5, fig. 3.

C-10, 183' above basal exposure; skeletal calcarenitic mudstone: 15% echinoderms, 1% spicules, 60% mud, 15% dolocasts representing sites of former dolomite rhombohedra; minor trilobites, bryozoans, and quartz silt.
Pinkish gray (5 YR 8/1) mottled pale yellowish orange (10 YR 8/6); .10-.75 mm; .45 mm; solution holes, a few small gastropods and burrows.

C-9, 168' above basal exposure; skeletal calcarenitic mudstone (dolomitized): 3% echinoderms, 1% spicules, 40% mud, 35% dolomite; minor quartz silt, bryozoans, trilobites, brachiopods, and hematite; approximately 10% muddy material resembling pellets, but perhaps due to recrystallization phenomenon in which microspar-spar completely encircles and isolates mud from surrounding matrix. This type occurrence is seen in numerous other slides and resembles Cayeux's grumeleuse structure.
Pinkish gray (5 YR 8/1) with iron stains (Liesegang bands) between dusky yellow (5 Y 6/4) and moderate yellow (5 Y 7/6); .20-1.12 mm; .45 mm; numerous small gastropods; burrowed.

C-8, 37' above basal exposure; brachiopod calcarenitic mudstone (dolomitized): 10% brachiopods, 1% bryozoans, 35% dolomite, 45% mud; minor echinoderms, trilobites, spicules, hematite, and fossil silicification; dolomitization extensive and probably responsible for porosity evidenced in thin section.
Pinkish gray (5 YR 8/1) to light olive gray (5 Y 6/1); .10-1.50 mm; .50 mm; numerous brachiopods on bedding

surface; fossil shells appear chaotically arranged; possibly burrowed.

C-7, 34' above basal exposure; <u>skeletal</u> <u>calcarenitic</u> <u>mudstone</u>: 3% echinoderms, 3% spicules, 90% mud of which 5-10% may be dolomite, but the extremely fine crystal size renders exact determination impossible; dolocasts are frequent; minor trilobites, ostracodes, brachiopods, bryozoans, quartz silt, organic matter, and fossil silicification.
Yellowish gray (5 Y 8/1); .20-.75 mm; .45 mm; frequent small gastropod shells; burrowed.

C-6, 21' above basal exposure; <u>skeletal</u> <u>calcarenitic</u> <u>mudstone</u> (dolomitized): 10% echinoderms, 7% brachiopods, 1% trilobites, 1% bryozoans, 32% mud, 45% dolomite, 1% dark brown organic matter; structure with brachiopod sheltering mud.
Yellowish gray (5 Y 8/1) mottled pinkish gray (5 YR 8/1); .20-1.20 mm; .50 mm; abundant brachiopods on bedding surface. Plate 1, fig. 9.

C-5, 14' above basal exposure; <u>skeletal</u> <u>calcarenitic</u> <u>mudstone</u>: 7% echinoderms, 5% spicules, 5% brachiopods, 25% mud plus microspar, 40% pellet-forms; minor bryozoans, trilobites, ostracodes, and organic matter; dolocasts are abundant; a few shells have been recrystallized whereas others are partially silicified; this specimen resembles the <u>grumeleuse</u> structure of Cayeux and the pellet structure may actually be due to recrystallization of mud.
Medium light gray (N 6) speckled grayish yellow (5 Y 8/4); .20-1.50 mm; .37 mm; burrowed.

C-4, 13' above basal exposure; <u>sparry</u> <u>skeletal</u> <u>calcarenite</u> (partially recrystallized): 15% echinoderms, 2% brachiopods, 1% trilobites, 7% bryozoa, 2% mud, 60% spar; minor gastropods and ostracodes; ghost structures are frequent--many shells are recrystallized and practically all have a thin coating of mud; too, even the canals of the echinoderm fragments are for the most part filled with mud; approximately 5% of the shells have been silicified to some extent.
Yellowish gray (5 Y 8/1); .30-35.0 mm; .60 mm; numerous large fossil shells, some showing excellent geopetal

structures such as floored interiors overlain by coarse spar and sheltering of entrapped mud by convex shells.

C-3, 8' above basal exposure; sparry skeletal calcarenite (partially recrystallized): 20% echinoderms, 2% bryozoans, 2% trilobites, 5% mud, 70% spar; totally unsupported and isolated mud in center of coarse spar indicates recrystallization; few recrystallized shells. Yellowish gray (5 Y 8/1); .30-70 mm; .75 mm; large (70 mm) helically-coiled gastropod with geopetal structure on interior surface; numerous brachiopods on weathered surface; burrowed.

C-2, 2' above basal exposure; sparry skeletal calcarenite (partially recrystallized): similar to C-3 and C-4 but containing 1% dark brown organic matter and 2% phosphatized shells, mostly echinoderm fragments; recrystallized spar has irregular crystal boundaries and patchy distribution; minor dolocasts.
Medium light gray (N 6); .12-.75 mm; .27 mm; possibly burrowed.

C-1, from basal exposure; sparry echinoderm-bryozoan calcarenite: 25% echinoderms, 20% bryozoans, 2% trilobites, 1% brachiopods, 45% spar, 4% phosphatized shell material; a few bryozoans attached to trilobite fragments; most bryozoan fragments appear muddy and may have acted as sediment baffles.
Yellowish gray (5 Y 7/2) speckled grayish orange (10 YR 7/4); .20-4.00 mm; .60 mm; faintly cross-bedded with alternating directions indicating possible current and (or) wave action.

SECTION D: NW¼ sec. 12 and NE¼ sec. 11, T. 1 N., R. 6 E., Pontotoc County; basal 212' measured along Oklahoma State Highway 99; remaining offset section measured just east of Sheep Creek in section 11.

D-20, 362' above base; sparry trilobite-echinoderm calcarenite: 25% echinoderms, 6% trilobites, 1% brachiopods, 65% spar; minor bryozoans; loosely packed; stylolites. Pinkish gray (5 YR 8/1); .20-3.00 mm; .55 mm.

D-19, 306' above base; sparry echinoderm calcarenite: 35% echinoderms, 60% spar, 3% rounded, straight extinction quartz sand, minor brachiopods and trilobites; loosely packed.
Yellowish gray (5 Y 8/1); .25-13.50 mm; .65 mm; solution holes.

D-18, 275' above base; burrowed sandy skeletal calcarenitic mudstone (partially recrystallized): 15% echinoderms, 10% subangular to rounded, straight extinction quartz sand, 35% mud, 35% recrystallized fine spar, 2% pellet-forms; minor spicules, trilobites, and bryozoa.
Yellowish gray (5 Y 8/1); .25-1.40 mm; .45 mm; extensively burrowed.

D-17, 212' above base; skeletal calcarenitic mudstone (partially recrystallized): 1% each of echinoderms and trilobites, 7% brachiopods, 30% mud, 25% spar, 10% pellets(?); minor gastropods, ostracodes, bryozoans, spicules, and fossil silicification; although some mud has pellet form and some are pellets, much is believed due to recrystallization of mud to spar to give grumeleuse structure; a number of shells have been recrystallized and others clearly have a coating of mud.
Yellowish gray (5 Y 8/1); .25-2.25 mm; .60 mm; numerous brachiopods on bedding surfaces with convex sides up giving mud-shelter effect and some good geopetal structures. Plate 1, figs. 6 and 8 and Plate 4, fig. 6.

D-16, 207' above base; skeletal calcarenitic mudstone: 85% mud, 4% brachiopods, 3% spicules, 1% bryozoans, 1% gastropods; minor echinoderms, trilobites, ostracodes, quartz silt, and hematite; contains a few recrystallized shells.
Pinkish gray (5 YR 8/1); .25-3.00 mm; .37 mm; similar to D-16 in hand specimen; one pebble (approximately 32 mm wide) of same type mudstone with included fossils found in silty portion of specimen from which thin section prepared.

D-15, 186' above base; calcite mudstone: 95% mud, minor spicules, ostracodes, trilobites, brachiopods, echinoderms, and quartz silt; skeletal debris recrystallized; porous and without bedding--probably burrowed.
Pinkish gray (5 YR 8/1); .03-3.75 mm; .40 mm. Plate 1, fig. 5.

D-14, 169' above base; skeletal calcarenitic mudstone: 15% echinoderms, 4% trilobites, 2% bryozoans, 2% brachiopods, 35% mud, 5% dolomite, 30% spar; minor ostracodes, organic matter, fossil silicification and phosphatization; porous near dolomitized portions; this specimen is a borderline case between a calcarenitic mudstone and a muddy calcarenite.
Yellowish gray (5 Y 8/1); .20-2.25 mm; .65 mm; iron-stained and pyritic on bottom portion; slightly burrowed.

D-13, 159' above base; sparry skeletal calcarenite: 20% echinoderms, 3% trilobites, 7% bryozoans, 1% brachiopods, 1% ostracodes, 60% spar, 1% mud; minor organic matter and mollusks; about 4% of shells phosphatized; ghosts of recrystallized fossils; thin coating of mud around ghosts and a few other fossil fragments; faintly cross-bedded.
Pinkish gray (5 YR 8/1) speckled dark gray (N 3); .25-3.00 mm; .65 mm.

D-12, 140' above base; sparry bryozoan calcarenite: 15% echinoderms, 15% bryozoans, 5% trilobites, 60% spar; minor brachiopods; about 3% phosphatization of shells; filamentous bryozoan and trilobite fragments exhibit extreme parallelism to bedding.
Grayish orange pink (5 YR 7/2); .30-2.50 mm; .70 mm; thinly layered.

D-11, 122' above base; sparry ostracode calcisiltite: 2% echinoderms, 20% ostracodes, 70% spar, 1% phosphatization; minor brachiopods; one cherty, silicified patch with relic fossil debris; irregular spar boundaries suggest possible recrystallization.
Yellowish gray (5 Y 8/1); .04-.33 mm; .16 mm. Plate 2, fig. 3.

D-10, 120' above base; ostracode-pellet calcisiltite: 4% ostracodes, 7% pellets, 2% ferruginous material, 80% mud plus microspar and fine spar; irregular fine spar boundaries and diffuse nature of mud suggest recrystallization; cross-laminated (also visible in hand specimen); pellets better observed in stained portion of thin section.
Yellowish gray (5 Y 8/1) and brownish gray (5 YR 4/1) banding; .05-.32 mm; .10 mm; stages of partial and complete chertification.

D-9, 118' above base; sparry bryozoan calcarenite: 3% each of echinoderms and trilobites, 20% bryozoans, 60% spar, minor mud and brachiopods; 10% of specimen silicified and 3% of fossils phosphatized; bryozoans large and rounded; fine spar oriented perpendicular to fossils has irregular boundaries.
Yellowish gray (5 Y 8/1) .22-15 mm; .70 mm; large recrystallized shells and a few geopetal structures; parallelism of filamentous bryozoans and brachiopods to bedding.

D-8, 115' above base; skeletal calcarenitic mudstone (dolomitized): 10% echinoderms, 6% bryozoans, 50% dolomite, 30% pore space; minor ostracodes, spicules, brachiopods, trilobites, and silicification; dolomite growing into some echinoderm fragments from mud fraction.
Pinkish gray (5 YR 8/1); .30-2.25 mm; .65 mm.

D-7, 38' above base; cross-laminated sparry skeletal calcarenite: 2% echinoderms, 2% brachiopods, 1% trilobites, 12% ferruginous material, 2% phosphatized shells, 50% spar, 25% pore space; minor bryozoans and quartz sand.
Varicolored with yellowish gray (5 Y 8/1), grayish yellow (5 Y 8/4), and dusky yellowish brown (10 YR 2/2) predominating; .22-.45 mm; .37 mm; at top and bottom are silty, ferruginous layers which join at edge of rock and pinch off cross-laminated interior part; six sets of cross-laminae are present in regularly alternating pattern; pinch out interpreted as some type of compaction feature.

D-6, 30' above base; sparry ostracode-echinoderm calcarenite: 15% echinoderms, 7% ostracodes, 2% trilobites, 65% fine spar, 5% pore space; minor brachiopods and bryozoans; 3% phosphatization of shell material, mostly ostracodes; minor shell recrystallization.
Yellowish gray (5 Y 8/1); .20-1.12 mm; .37 mm; faintly cross-laminated.

D-5, 16' above base; no thin section prepared; limestone with replacement chert; hand specimen similar to D-4.

D-4, 12' above base; sparry pellet(?) calcisiltite: 10% pellets(?), 1% spicules, 20% pore space, 65% microspar; similar to grumeleuse structure; this specimen may be

extensively recrystallized and the pellets (?) simply may be unrecrystallized, isolated mud.
Yellowish gray (5 Y 8/1); .03-.10 mm; .06 mm.

D-3, 5' above base; no thin section prepared--chert sample; replacement chert with manganese dendrites and rare fossil fragments.

D-2, 1' above base; burrowed slightly laminated mudstone: 1% spicules, 95% mud, 2% ferruginous material; minor graptolites and silicification; burrowed in upper part; geopetal structure with pellet material flooring cavity and being overlain by coarse spar.
Yellowish gray (5 Y 8/1); clay size material; burrows are nearly circular and are filled with concentrically arranged calcarenitic fossil debris; some are filled with pyrite. Plate 1, fig. 3.

D-1, from base; phosphatized sparry skeletal calcarenite in unconformable contact with greenish calcarenitic brachiopod clay-like material: 4% echinoderms, 1% trilobites, 3% brachiopods, 15% phosphatization (X-ray determination indicates francolite), 65% spar; minor graptolites, bryozoans, and quartz sand; algal(?) coating on clay-like surface; irregular contact and distinct coating indicate break in sedimentation; Girvanella-like mass in greenish clayey material.
Pale yellowish brown (10 YR 6/2) and pale yellowish green (10 GY 7/2); .20-2.25 mm; .45 mm; abundant graptolites on bedding surface. Plate 2, fig. 8.

SECTION E: NE¼ SW¼ sec. 2, T. 2 S., R. 7 E., Johnston County; Witch Hole (Camp Simpson Campground); on Delaware Creek near dam.

E-9, 275' above base; sparry echinoderm calcarenite: 30% echinoderms, 1% bryozoans, 65% spar; minor brachiopods, ostracodes, quartz sand, and silicification; spar extensively twinned with twins extending across fossil fragments.
Pinkish gray (5 YR 8/1); .20-4.12 mm; .70 mm.

E-8, 246' above base; sparry echinoderm calcarenite: 35% echinoderms, 4% rounded, straight extinction quartz sand, 55% spar, 2% mud plus microspar, 1% trilobites;

minor bryozoans, hematite, and phosphatization; sand concentrated in circular arrangement in some instances indicating burrowing.
Pinkish gray (5 YR 8/1); .20-2.25 mm; .45 mm.

E-7, 243' above base; muddy spar-cemented echinoderm calcarenite: 35% echinoderms, 20% mud plus microspar, 40% spar, 2% rounded, straight extinction quartz sand; minor trilobites, bryozoans, ostracodes, and brachiopods.
Yellowish gray (5 Y 8/1); .15-2.00 mm; .33 mm; burrowed; solution holes on outcrop surface.

E-6, 226' above base; burrowed pellet-skeletal calcarenitic mudstone: 10% echinoderms, 5% pellets, 4% rounded, straight extinction quartz sand concentrated in burrows in some cases, 30% spar, 50% mud; minor trilobites and brachiopods; evidence for recrystallization in unsupported, isolated mud in spar, recrystallized shells, mud coating on shells now engulfed in spar.
Yellowish gray (5 Y 8/1); .28-2.60 mm; .60 mm; extensively burrowed; solution holes on outcrop surface.

E-5, 183' above base; skeletal calcisiltitic mudstone (dolomitized): 4% echinoderms, 2% spicules, one small cephalopod, 80% mud of which approximately 30% is dolomite; minor fossil silicification, secondary hematite, and quartz silt.
Pinkish gray (5 YR 8/1); .10-2.60 mm; .55 mm; burrowed.

E-4, 76' above base; skeletal calcisiltitic mudstone: 95% mud plus microspar, 1% spicules; minor graptolites, ostracodes, and trilobites; silicified patch with peculiar arch 2 cm wide parallel to bedding and with most of original texture preserved; some mud resembles pellets although some has been recrystallized to microspar; it is thought this specimen represents something similar to the initial stage of formation of Cayeux's (1935) *grumeleuse* structure.
Light olive gray (5 Y 7/1); .05-1.00 mm; .10 mm.

E-3, 60' above base; no thin section prepared; similar to E-4 and to E-2 with much silicification.
Field classification: siliceous graptolitic mudstone.

E-2, 6' above base; spicular-pellet calcisiltitic mudstone: 15% pellets, 10% spicules, 40% mud plus microspar, 2% trilobites, 2% quartz silt; minor echinoderms; chert replacement over half of specimen.
Light olive gray (5 Y 6/1); .03-.33 mm; .18 mm; extensively silicified in hand specimen; few graptolites. Plate 1, fig. 2 and Plate 4, fig. 2.

E-1, 2' above base; sparry skeletal calcarenite: 20% echinoderms, 2% ostracodes, 1% trilobites, 65% spar; minor bryozoans and dolomite; minor recrystallization evident by patchy and irregular spar unevenly distributed throughout specimen; 3% fossil silicification.
Yellowish gray (5 Y 8/1) and light olive gray (5 Y 6/1); .15-5.25 mm; .70 mm; layering produced by variation in fossil sizes from coarse to finer material through at least two cycles.

SECTION F: NW¼ NE¼ sec. 19, T. 2 S., R. 8 E., Johnston County; along Robertson Creek; approximately ½ mile west of Oklahoma State Highway 7.

F-6, 378' above base; sparry echinoderm calcarenite: 25% echinoderms, 70% spar, 1% trilobites; minor ostracodes, bryozoans, brachiopods, and quartz sand; stylolite.
Yellowish gray (5 Y 8/1); .25-3.00 mm; .55 mm; coarse fossil material at bottom grading into finer material toward top.

F-5, 330' above base; muddy spar-cemented skeletal calcarenite: 25% echinoderms, 10% mud, 4% trilobites, 1% brachiopods, 2% rounded, straight extinction quartz sand, 55% spar; minor bryozoans and ostracodes; 1% each fossil silicification and phosphatization; mud encloses some fossils possibly indicating poor washing.
Light olive gray (5 Y 6/1); .28-4.35 mm; .55 mm; abundant columnals and trilobite fragments.

F-4, 309' above base; sparry echinoderm calcarenite: 30% echinoderms, 1% trilobites, 65% spar; minor bryozoans, ostracodes, quartz sand, silicification and phosphatization; stylolite.
Pinkish gray (5 YR 8/1); .25-3.00 mm; .50 mm.

F-3, 283' above base; sandy skeletal calcarenitic mudstone: 20% echinoderms, 1% trilobites, 7% rounded, straight extinction quartz sand, 25% spar, 40% mud, 3% ferruginous material (in mud); minor brachiopods, ostracodes, organic matter, and dolomite in ferruginous mud; quartz concentrated in thin, tabular stringers; this specimen is a borderline case and could also be called a muddy spar-cemented skeletal calcarenite.
Olive gray (5 Y 4/1) mottled yellowish gray (5 Y 7/1); .25-4.50 mm; .45 mm.

F-2, 249' above base; burrowed skeletal calcarenitic mudstone: 7% echinoderms, 2% spicules, 75% mud, 3% pellets, 2% rounded, straight extinction quartz silt, 2% ferruginous material in mud; minor gastropods, ostracodes, brachiopods, and dolomite (in mud); some recrystallization indicated by unsupported, isolated pellets in spar.
Light olive gray (5 Y 7/1); .30-2.25 mm; .45 mm; extensively burrowed with numerous whorled structures.

F-1, 20' above base; slightly laminated mudstone: 90% mud plus microspar, 5% spicules, 1% ostracodes; minor trilobites, quartz silt, fine dolomite, and secondary hematite; some mud resembles pellets although the rock is more similar to grumeleuse structure.

SECTION G: NW¼ NE¼ sec. 4, T. 2 S., R. 3 E., Murray County; on Buckhorn Ranch along dry tributary to Little Buckhorn Creek; north limb of unbreached anticline. (Base not exposed)

G-14, 420' above basal exposure; sparry echinoderm calcarenite: 30% echinoderms, 2% ostracodes, 60% spar, 1% ferruginous matter; minor trilobites.
Pinkish to light brownish gray (5 YR 7/1); .03-1.50 mm; .10 mm. This is an atypical example of the top part of Unit 3. It is a fine calcarenite, is not friable when weathered, and does not contain the common trilobite fragments noted in other sections; in hand specimen it looks like a mudstone.

G-13, 418' above basal exposure; sparry trilobite-echinoderm calcarenite: 25% echinoderms, 7% trilobites, 65% spar; minor bryozoans, brachiopods, ostracodes, organic matter,

phosphatization, and silicification; a few ferruginous, stylolitic seams and rare dolomite rhombohedra in minor mud; fossils abraded and slightly displaced, especially trilobites; irregular distribution of fossils suggests burrowing.
Light olive gray (5 Y 6/1); .22-3.75 mm; .70 mm.

G-12, 411' above basal exposure; sparry echinoderm calcarenite: 35% echinoderms, 4% trilobites, 4% mud with fine dolomite, 50% spar, 1% bryozoans; minor brachiopods and ostracodes; 2% fossil silicification; mud surrounds some dolomite apparently recrystallized from mud.
Light brownish gray (5 YR 7/1); .22-2.60 mm; .60 mm; common trilobite fragments in hand specimen.

G-11, 409' above basal exposure; muddy spar-cemented skeletal calcarenite (dolomitized): 25% echinoderms, 55% spar, 20% mud of which about 10% is recrystallized to dolomite; minor brachiopods, trilobites, ostracodes, organic matter, and silicification; dolomite in brownish, ferfuginous(?) part of mud.
Light brownish gray (5 YR 7/1); .22-1.50 mm; .30 mm; common trilobite fragments in hand specimen.

G-10, 400' above basal exposure; muddy spar-cemented skeletal calcarenite (partially recrystallized): 15% echinoderms, 15% mud, 65% spar; minor ostracodes, trilobites, brachiopods, organic matter, silicification, and dolomite in mud fraction; irregular clots may either represent intraclasts or reworking by burrowing organisms.
Light gray (N 7); .25-2.25 mm; .27 mm.

G-9, 200' above basal exposure; muddy spar-cemented skeletal calcarenite (dolomitized and partially recrystallized): 15% echinoderms, 3% trilobites, 55% spar, 10% mud, 10% dolomite; minor ostracodes, brachiopods, bryozoans, quartz silt, and silicification; 40% recrystallized; euhedral dolomite crystals, some replacing spar cement.
Light olive gray (5 Y 7/1); .25-4.50 mm; .40 mm.

G-8, 111' above basal exposure; no thin section prepared; frequent trilobites and columnals in muddy matrix of hand specimen.
Light olive gray (5 Y 7/1); .10-2.25 mm; .60 mm.

G-7, 99' above basal exposure; muddy spar-cemented skeletal calcarenite (dolomitized and partially recrystallized): 2% echinoderms, 4% trilobites, 2% subangular to subrounded, straight extinction quartz sand, 25% mud, 15% dolomite, 50% spar; minor bryozoans, ostracodes, gastropods, spicules, and phosphatization; 30% recrystallized.
Pinkish gray (5 YR 8/1) and dusky yellow (5 Y 6/4); .20-3.00 mm; .35 mm; slightly burrowed.

G-6, 87' above basal exposure; burrowed skeletal calcarenitic mudstone: 95% mud plus microspar, 1% trilobites, 1% spicules, 2% quartz silt; minor echinoderms.
Light olive gray (5 Y 6/1); .06-2.00 mm; .15 mm; extensively burrowed; thinly laminated where burrowing less intense.

G-5, 72' above basal exposure; burrowed skeletal calcarenitic mudstone (partially recrystallized): 55% mud plus microspar, 35% spar, 4% trilobites, 2% echinoderms, 1% spicules; minor ostracodes, bryozoans, brachiopods, organic matter, quartz silt, dolomite, and silicification; about 40% recrystallized.
Light olive gray (5 Y 6/1); .18-3.00 mm; .20 mm; extensively burrowed.

G-4, 32' above basal exposure; burrowed skeletal calcarenitic mudstone (dolomitized): 90% mud of which about 60% is recrystallized to fine dolomite, 3% echinoderms, 1% bryozoans, 1% quartz silt; minor brachiopods, trilobites, ostracodes, spicules, and graptolites; trace of glauconite, silicification, and phosphatization; glauconite partially replaces fossils.
Light olive gray (5 Y 6/1); .20-3.50 mm; .40 mm; extensively burrowed. Plate 1, fig. 7 and Plate 4, fig. 4.

G-3, 31' above basal exposure; burrowed skeletal calcarenitic mudstone (dolomitized): similar in all respects to G-4.

G-2, 9' above basal exposure; muddy spar-cemented skeletal calcarenite (partially recrystallized): 10% echinoderms, 1% trilobites, 50% spar, 30% mud, 3% rounded, straight extinction quartz sand; minor silicification, glauconitization, and phosphatization; about 40% recrystallized; minor dolomite.
Light brownish gray (5 YR 6/1); .15-2.25 mm; .40 mm; burrowed.

G-1, 4' above basal exposure; burrowed mudstone (dolomitized): 95% mud, microspar, and fine dolomite (approximately 35%); minor skeletal elements with spicules predominating.
Light olive gray (5 Y 7/1); .06-1.50 mm; .15 mm; graptolites; quartz dust on etched specimen.

SECTION H: central E½ sec. 25, T. 2 S., R. 1 E., Carter County; along U. S. Highway 77 and Tulip Creek 9½ miles south of Davis, Oklahoma.

H-8, 710' above base; sparry trilobite-echinoderm calcarenite: 15% echinoderms, 7% trilobites, 7% mud (?with minor fine dolomite), 1% brachiopods, 60% spar; minor ostracodes, bryozoans, and organic matter; 4% of fossils silicified.
Light olive gray (5 Y 6/1); .10-1.50 mm; .38 mm; looks like typical mudstone in hand specimen.

H-7, 695' above base; sparry echinoderm calcarenite: 20% echinoderms, 1% brachiopods, 2% dolomite in 7% ferruginous mud, 55% spar; minor bryozoans, trilobites, and silicification; minor recrystallization indicated by isolated mud in spar.
Light olive gray (5 Y 6/1); .25-4.50 mm; .55 mm; much silicification in hand specimen. Plate 2, fig. 7.

H-6, 688' above base; sparry skeletal calcarenitic mudstone (extensively recrystallized): 50% mud plus microspar, 25% spar, 20% echinoderms, 1% each of trilobites, bryozoans, and ostracodes; minor brachiopods, spicules, organic matter, and silicification; fine spar, patchy distribution, and irregular mud-spar boundaries throughout specimen indicate greater than 50% recrystallization; one void-filled cavity lined with coarse sparry calcite, but with center filled with silica cement.
Olive gray (5 Y 5/1); .10-3.00 mm; .30 mm; dolocasts on etched surface although X-ray pattern indicates no dolomite; slightly burrowed.

H-5, 436' above base; sparry skeletal calcisiltitic mudstone (partially recrystallized): 70% mud plus microspar, 15% spar, 2% spicules, 1% each of echinoderms, trilobites, and quartz silt, 5% pellet-forms; minor ostracodes; most of mud recrystallized to microspar.
Olive gray (5 Y 5/1); .03-.33 mm; .06 mm.

H-4, 231' above base; burrowed silty skeletal calcisiltitic mudstone: 75% mud plus microspar, 10% fine spar, 7% subrounded quartz silt, 5% spicules; minor echinoderms, ostracodes, graptolites, and organic matter; minor recrystallization indicated by isolated mud in spar and patchy distribution of fine spar.
Light brownish gray (5 YR 6/1) and pale olive (10 Y 6/2); .03-.40 mm; .06 mm; burrowed. Plate 4, fig. 1.

H-3, 113' above base; siliceous laminated mudstone: 95% mud plus microspar, 2% spicules; minor graptolites, organic matter, and quartz silt; faintly cross-laminated with some laminae having minor disruptions; a few laminae recrystallized to slightly coarser spar than typical microspar.
Yellowish gray (5 Y 8/1); etched specimen high in insoluble content; portion of sample digested in 10% cold HCl and examined by X-ray methods which indicate insoluble material is quartz dust.

H-2, 20' above base; siliceous laminated mudstone: similar to H-3; contains dark brown to black organic material in hand specimen with asphaltic smell and numerous hairline fractures filled with sparry calcite.

H-1, 1' above base; siliceous laminated mudstone (partially recrystallized): 50% mud plus microspar, 40% spar, 5% pellet-forms; minor spicules, ostracodes, organic matter, and silicification; cross-laminated; pellet-forms may be a result of recrystallization to spar around mud; muddy layers alternate with sparry layers.
Light olive gray (5 Y 6/1); .10-.45 mm; .32 mm.

SECTION I: E½ SW¼ sec. 22, T. 2 S., R. 1 W., Carter County; west of Mountain Lake approximately 2½ miles north of Woodford, Oklahoma.

I-9, 691' above base; skeletal calcarenitic mudstone (dolomitized): 20% echinoderms, 15% spar, 50% mud plus microspar, 10% dolomite in dark brown, ferruginous mud; minor trilobites, ostracodes, brachiopods, bryozoans, organic matter, and silicification; mud appears to be recrystallized to fine spar, but it may be fine dolomite; atypical of top part of Unit 3.

Light brownish gray (5 YR 6/1); .10-2.25 mm; .45 mm; slightly burrowed; numerous trilobite fragments. Plate 2, fig. 6 and Plate 4, fig. 3.

I-8, 684' above base; burrowed skeletal calcarenitic mudstone: 15% echinoderms, 7% spicules, 75% mud plus microspar; minor gastropods, brachiopods, bryozoans, trilobites, and ostracodes; recrystallized shells.
Light brownish gray (5 YR 6/1); .10-1.50 mm; .30 mm; extensively burrowed.

I-7, 674' above base; muddy spar-cemented skeletal calcarenite: 20% echinoderms, 2% trilobites, 1% each of bryozoans and brachiopods, 25% mud, 50% spar; minor dolomite and phosphatization; 25% silicified; slightly recrystallized.
Light brownish gray (5 YR 6/1); .20-6.00 mm; .70 mm; irregular dolomite patches, geopetal structure.

I-6, 620' above base; muddy spar-cemented skeletal calcarenite (partially recrystallized): 15% echinoderms, 30% mud plus microspar, 50% spar, 1% trilobites; minor spicules, bryozoans, ostracodes, organic matter, and dolomite in mud; two large areas of coarse spar containing some isolated mud and having fossil fragments project into it; plain grain boundaries suggest drusy infilling (Bathurst, 1958), but totally unsupported fossil fragments and mud indicate recrystallization.
Light olive gray (5 Y 6/1); .22-1.00 mm; .50 mm; silicification.

I-5, 454' above base; sparry skeletal calcarenitic mudstone (extensively recrystallized): 10% echinoderms, 7% trilobites, 45% mud plus microspar, 35% spar; "pseudobreccia" of Bathurst (1959); patchy distribution and irregular size of spar strongly indicate recrystallization.
Light olive gray (5 Y 6/1); .15-2.25 mm; .65 mm.

I-4, 309' above base; burrowed sandy skeletal calcarenitic mudstone: 10% echinoderms, 2% each of trilobites and spicules, 10% subrounded, straight extinction fine quartz sand, 70% ferruginous mud; minor gastropods; 5% phosphatization.
Light olive gray (5 Y 6/1); .08-.70 mm; .15 mm; extensively burrowed.

I-3, 278' above base; sparry skeletal calcarenitic mudstone (extensively recrystallized): similar to I-5, but containing 4% phosphatized shells (mainly gastropods), 1% quartz silt, and 10% pellet-forms which are probably the result of preferential recrystallization.
Light olive gray (5 Y 6/1); .22-3.00 mm; .35 mm; slightly burrowed.

I-2, 175' above base; skeletal calcisiltitic mudstone: 85% ferruginous mud, 10% fine skeletal debris with spicules predominating, 3% quartz silt; 5% silicification.
Dusky yellow (5 Y 6/4) and light olive gray (5 Y 6/1); .03-.15 mm; .06 mm; slightly burrowed.

I-1, 49' above base; siliceous laminated mudstone: 2% spicules, 95% mud; minor graptolites, quartz silt, organic matter, and recrystallization; faintly cross-laminated into pinch-and-swell structure (2 mm high); possibly indicates mechanical deposition due to slight bottom currents which induced small ripples.
Medium gray (N 5) with grayish black (N 2) laminations; < .03 mm; X-ray pattern indicates powdery insoluble material on etched specimen is quartz. Plate 1, fig. 1 and Plate 3, fig. 6.

SECTION J: SE¼ sec. 27, T. 3 S., R. 4 E., Johnston County; along Sycamore Creek.

J-9, 654' above base; sparry trilobite-echinoderm calcarenite: 40% echinoderms, 10% trilobites, 1% bryozoans, 45% spar; minor ostracodes, brachiopods, mud, ferruginous material, and silicification; parallelism of trilobite fragments; mud in echinoderm fragments.
Light brownish gray (5 YR 7/1); .20-1.80 mm; .45 mm; one burrow 40 mm long exhibiting arcuate infilling.

J-8, 638' above base; sparry echinoderm calcarenite: 40% echinoderms, 2% bryozoans, 1% trilobites, 45% spar, 4% dolomite; minor brachiopods, pyrite, silicification and mud in echinoderm fragments; large dolomite rhombohedra (.20 mm wide).
Yellowish gray (5 Y 8/1) with dark gray (N 3) fossil fragments; .15-2.20 mm; .38 mm. Plate 2, fig. 4 and Plate 5, fig. 1.

J-7, 636' above base; sparry echinoderm calcarenite (partially recrystallized): 30% echinoderms, 1% trilobites, 4% mud, 60% spar; minor ostracodes, bryozoans, organic matter, silicification, phosphatization, and ferruginous material; patchy mud distribution and irregular spar suggest recrystallization; minor dolomite.
Light brownish gray (5 YR 6/1); .20-1.50 mm; .38 mm.

J-6, 450' above base; skeletal calcarenitic mudstone (dolomitized): 15% echinoderms, 3% trilobites, 60% mud and dolomite, 15% recrystallized spar; minor ostracodes, bryozoans, ferruginous matter, and quartz; slightly burrowed; dolomite extremely fine-grained.
Light olive gray (5 Y 6/1); .15-3.00 mm; .45 mm; minor glauconite; dolomite rhombohedra.

J-5, 440' above base; sparry skeletal calcarenitic mudstone (partially recrystallized): 15% echinoderms, 3% trilobites, 35% spar, 40% mud plus microspar; minor dolomite and quartz silt.
Light olive gray (5 Y 6/1); .15-1.60 mm; .45 mm; minor glauconite and chert replacement.

J-4, 402' above base; sparry skeletal calcarenitic mudstone (partially recrystallized): 4% echinoderms, 5% trilobites, 45% mud, 30% spar, minor gastropods, ostracodes, spicules, and brachiopods; 2% phosphatized shells, minor silicification, quartz silt, and organic matter; unsupported mud in spar and irregular spar grain boundaries indicate recrystallization.
Light olive gray (5 Y 6/1); .03-2.62 mm; .57 mm; slightly burrowed.

J-3, 364' above base; skeletal-pellet calcisiltitic mudstone (partially recrystallized and partially replaced by chert): 10% pellets, 5% ostracodes, 1% spicules, 30% mud, 15% spar, 30% chert replacement; minor trilobites, echinoderms, graptolites, organic matter, and quartz silt; relict ostracodes and graptolites preserved in chert replacement.
Light olive gray (5 Y 5/1); .03-.25 mm; .06 mm; slightly burrowed. Plate 3, figs. 2 and 3.

J-2, 205' above base; burrowed silty skeletal calcisiltitic mudstone: 16% fine skeletal debris, 7% straight

extinction, subrounded quartz silt, 50% mud, 20% spar; minor organic matter; faintly cross-laminated.
Grayish olive (10 Y 4/2); .04-1.50 mm; .06 mm; extensively burrowed.

J-1, 37' above base; siliceous laminated mudstone: 95% mud plus microspar, 4% fine skeletal debris including spicules, graptolites, and ostracodes; cross-laminated.
Olive gray (5 Y 4/1); less than .06 mm; insoluble quartz dust on etched specimen.

SECTION K: S½ sec. 16, T. 1 N., R. 7 E., Pontotoc County; Rhyne Ranch. (Poorly exposed except for the coarsely crystalline limestone at top)

K-5, 374' above base; sparry echinoderm calcarenite: 40% echinoderms, 5% trilobites, 50% spar; minor bryozoans, ostracodes, and phosphatization; 20% of rock silicified.
Yellowish to light olive gray (5 Y 7/1) with light bluish gray (5 B 7/1) subcircular ring of silicification; .15-1.10 mm; .25 mm.

K-4, 312' above base; slightly muddy spar-cemented echinoderm calcarenite: 25% echinoderms, 5% mud, 3% rounded, straight extinction quartz sand, 60% spar; minor trilobites, bryozoans, brachiopods, ostracodes, and fine dolomite.
Very pale orange (10 YR 8/2); .07-3.75 mm; .24 mm; solution holes on surface.

K-3, 164' above base; burrowed skeletal calcisiltitic mudstone: 90% mud plus microspar, 2% echinoderms, 2% spicules; minor trilobites and ostracodes; grumeleuse structure with recrystallization of mud to microspar to give pellet appearance.
Yellowish to light olive gray (5 Y 7/1); .02-1.00 mm; .06 mm; gastropods frequent; extensively burrowed.

K-2, 40' above base; skeletal calcarenitic mudstone: 85% mud plus microspar, 1% each of spicules, trilobites, gastropods, brachiopods, and echinoderms; minor ostracodes, bryozoans, and fossil silicification; many fossils completely recrystallized; geopetal structures; articulated columnals good evidence for low energy

environment.
Pinkish to light brownish gray (5 YR 7/1); .10-3.75 mm; .25 mm; gastropods frequent; burrowed.

K-1, 11' above base; sparry echinoderm-bryozoan calcarenite: 15% echinoderms, 20% bryozoans, 60% spar, 1% trilobites; minor brachiopods, ostracodes, and phosphatization; bryozoans exhibit extreme parallelism with bedding; loose packing.
Pinkish gray (5 YR 8/1); .20-7.5 mm; .40 mm. Plate 2, fig. 2.

SECTION L: S½ secs. 19 and 20, T. 1 S., R. 8 E., Coal County; along Mosely Creek.

L-15, 345' above base; dolomite: 80% dolomite, 1% rounded, straight extinction quartz sand, 15% skeletal ghosts (predominantly echinoderms); minor phosphatization and silicification of fossils; silicification after dolomitization.
Grayish orange pink (10 R 8/2) to pale red (10 R 6/2); .10-6.00 mm; .40 mm; echinoderm, brachiopod, and trilobite fragments recognized on etched portion of hand specimen; varnished portion has the appearance of a sparry calcarenite with some mud sheltered by a brachiopod shell.

L-14, 304' above base; sparry echinoderm calcarenite: 30% echinoderms, 4% trilobites, 5% mud in echinoderm canals and pore spaces, 55% spar, 1% bryozoans, 3% well-rounded, straight extinction quartz sand; minor brachiopods, dolomite, and phosphatization.
Pinkish gray (5 YR 8/1); .10-5.25 mm; .40 mm; common pelmatozoan columnals.

L-13, 300' above base; burrowed muddy spar-cemented skeletal calcarenite: 25% echinoderms, 1% ostracodes, 20% mud plus microspar, 45% spar, 7% rounded, straight extinction quartz sand increasing to 50% locally in burrows; minor trilobites, bryozoans, and brachiopods.
Yellowish gray (5 Y 8/1); .08-1.50 mm; .25 mm; solution holes common. Plate 3, fig. 4.

L-12, 289' above base; burrowed sandy skeletal calcarenitic mudstone (partially recrystallized): 15% echinoderms, 20% rounded, straight extinction quartz sand evenly distributed, 40% mud plus microspar, 20% recrystallized fine spar; minor trilobites; boundaries between fine spar and mud extremely diffuse and irregular.
Pinkish gray (5 YR 8/1); .08-2.25 mm; .25 mm; extensively burrowed.

L-11, 248' above base; burrowed skeletal calcarenitic mudstone (partially recrystallized): 15% echinoderms, 2% trilobites, 1% brachiopods, 45% mud plus microspar, 30% recrystallized fine spar; minor bryozoans, ostracodes, and fine dolomite crystals in mud fraction; boundaries between fine spar and mud extremely diffuse and irregular; under low magnification (X24) similar to grumeleuse structure.
Yellowish gray (5 Y 8/1); .08-3.75 mm; .20 mm.

L-10, 180' above base; calcisiltitic pellet mudstone: 20% rounded, calcisiltitic pellets, 60% mud plus microspar, 10% fine spar, 5% skeletal debris including echinoderms, ostracodes, and trilobites; minor quartz silt and organic matter.
Pinkish gray (5 YR 8/1); .06-2.25 mm; .16 mm; gastropods common on outcrop.

L-9, 163' above base; dolomite: 95% medium-textured dolomite; minor quartz silt and rare echinoderm ghosts; practically all of the original texture of the rock has been obliterated by the pervasive recrystallization of the limestone; 5% open pore space.
Light olive gray (5 Y 6/1); .15-1.50 mm; .37 mm; echinoderm fragments visible in hand specimen.

L-8, 144' above base; dolomite (pervasively recrystallized skeletal calcarenite): 85% coarse-textured dolomite, 7% skeletal ghosts including trilobites, but predominantly echinoderm fragments; 8% open pore space.
Pinkish gray (5 YR 8/1); .08-3.00 mm; .40 mm; trilobite-echinoderm calcarenite in hand specimen.

L-7, 106' above base; dolomite: 80% fine-textured dolomite, 20% open pore space; pervasively recrystallized limestone; original texture obliterated.

Pinkish gray (5 YR 8/1); no fossils visible in apparent muddy limestone of hand specimen.

L-6, 84' above base; phosphatized-silicified sparry skeletal calcarenite: 15% echinoderms, 3% trilobites, 2% each of bryozoans and ostracodes, 30% spar, 40% chert, 5% mud; minor organic matter and fine dolomite in ferruginous mud; 20% of fossils phosphatized; paragenic relations suggest silicification after phosphatization. Moderate brown (5 YR 4/4) in ferruginous areas, medium bluish gray (5 B 5/1) in silicified areas; .08-9.75 mm; .40 mm; ostracodes common in hand specimen. Plate 2, fig. 1.

L-5, 80' above base; dolomite: 90% medium- to coarse-textured dolomite, 10% open pore space; pervasive recrystallization of limestone has obliterated original texture; a few well-formed dolomite rhombohedra are unsupported in large single crystals of calcite (dolomite?). Pinkish gray (5 YR 8/1) and very pale orange (10 YR 8/2); .30-1.50 mm; .60 mm; rare echinoderm fragments are recognizable in hand specimen.

L-4, 76' above base; cherty dolomite: 60% medium- to coarse-textured dolomite, 30% microcrystalline to fine quartz and chalcedony, 5% open pore space, 4% skeletal debris not completely altered; paragenic relations indicate silicification after dolomitization. Pinkish to light brownish gray (5 YR 7/1); .06-2.25 mm; .37 mm; echinoderms, trilobites, and bryozoa are present in hand specimen. Plate 2, fig. 9.

L-3, 31' above base; sparry bryozoan-echinoderm calcarenite: 30% echinoderms, 6% bryozoans, 60% spar; 10% of shells phosphatized, particularly the echinoderms; minor trilobites, quartz silt, and silicification. Pinkish gray (5 YR 8/1) to light bluish gray (5 B 7/1); .25-.90 mm; .40 mm.

L-2, 10' above base; sparry pellet-echinoderm calcarenite: 25% echinoderms, 15% pellets, 7% trilobites, 2% bryozoans, 45% spar; 10% of skeletal debris phosphatized; minor ostracodes, brachiopods, mud, and quartz silt; contact in specimen between fine and medium calcarenites; some replacement chert in which skeletal debris

recognizable.
Pinkish gray (5 YR 8/1) to yellowish gray (5 Y 8/1); .08-1.50 mm; .35 mm; slightly cross-laminated in hand specimen.

L-1, 1' above base; sparry echinoderm calcarenite: 35% echinoderms, 1% each of trilobites and bryozoans, 60% spar.
Pinkish gray (5 YR 8/1); .20-1.50 mm; .50 mm.

SECTION M: NE¼ SE¼ sec. 27, T. 2 S., R. 8 E., Johnston County; along dry tributary to Sandy Creek approximately 1¾ miles southwest of Wapanucka, Oklahoma.

M-3, 335' above base; sparry trilobite-echinoderm calcarenite: 35% echinoderms, 7% trilobites, 55% spar; minor gastropods, ostracodes, bryozoans, organic matter, and shell phosphatization; extensively twinned spar predominantly as syntaxial overgrowths.
Yellowish gray (5 Y 8/1); .08-2.25 mm; .37 mm.

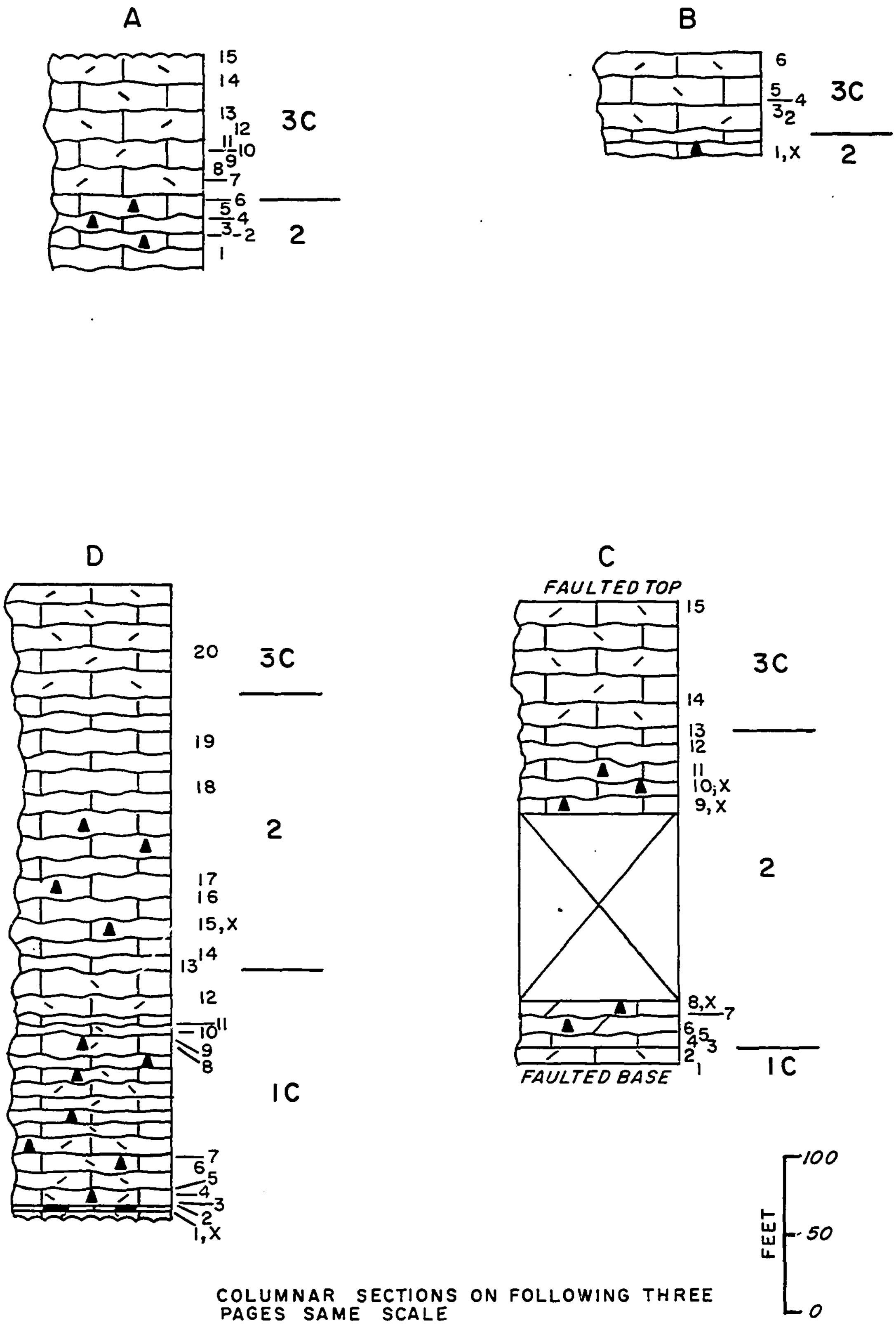
M-2, 243' above base; burrowed sparry muddy skeletal calcarenite: 10% echinoderms, 35% mud, 45% spar, 4% pelletforms, 1% dolomite in iron-stained mud, 1% subrounded, straight extinction quartz sand; minor spicules and organic matter; dolomite and quartz sand concentrated in whorled structures produced by burrowing organisms; fine spar with irregular boundaries, unsupported skeletal fragments, and isolated mud all indicate recrystallization; this specimen is a borderline case and could be called a skeletal calcarenitic mudstone.
Mottled dusky yellowish brown (10 YR 2/2) and yellowish gray (5 Y 8/1); .06-1.5 mm; .35 mm. Plate 4, fig. 5.

M-1, from base; siliceous laminated spicular mudstone: 10% spicules, 85% mud plus microspar; minor trilobites, brachiopods, graptolites, and quartz silt; shows contact of encroaching siliceous replacement of mudstone; cross-laminated locally; elongate mud clots are present and parallel the laminations.
Light olive gray (5 Y 6/1); < .03 mm. Plate 5, fig. 2.

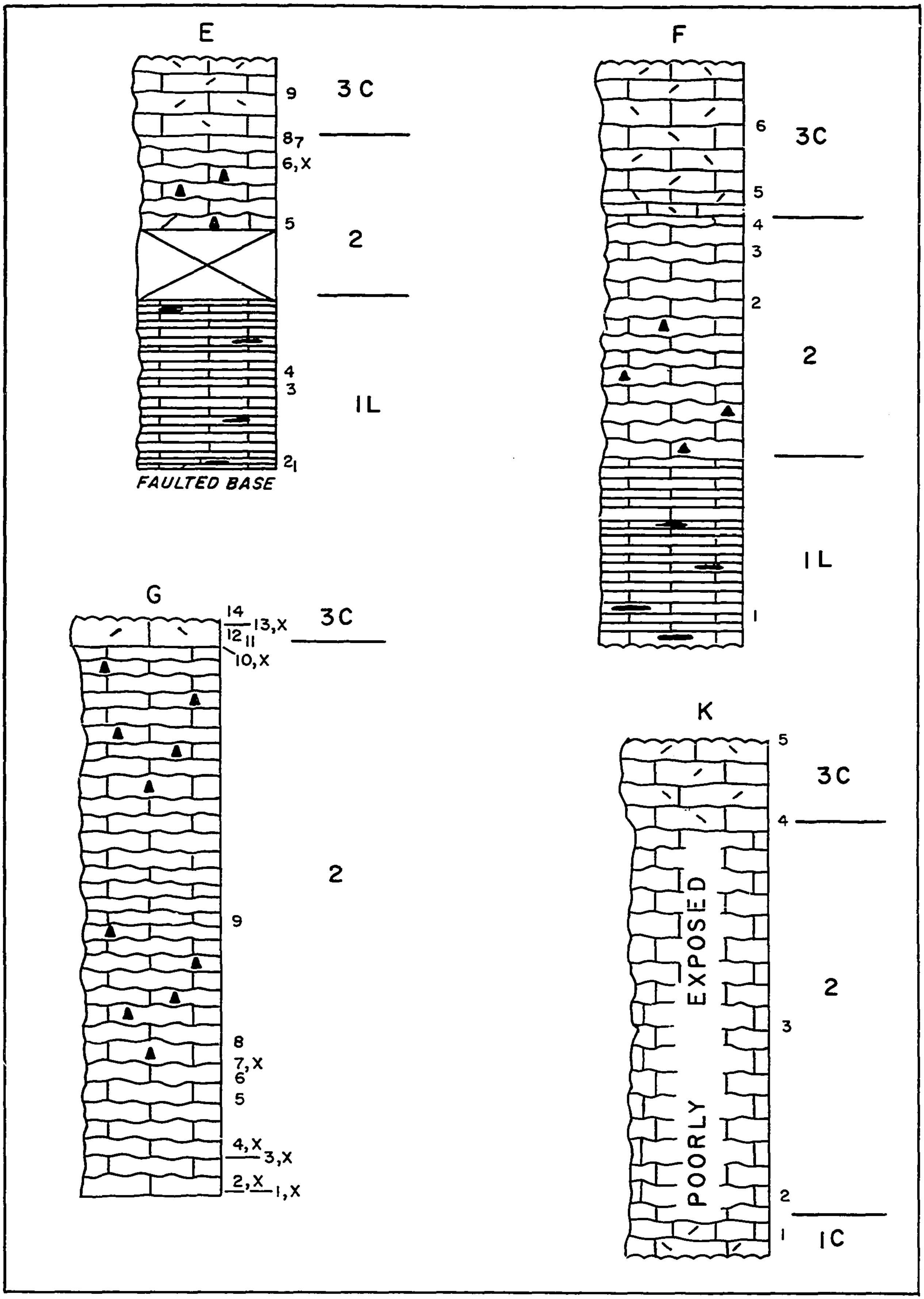
MEASURED STRATIGRAPHIC SECTIONS

Eighteen stratigraphic sections were measured in the study area and are described on the following pages. Columnar sections have been prepared for sixteen of these; an additional measured section by Dunham (1951) also is presented in the written descriptions. (See Plate 6 for the locations of these sections.) The vertical location of a sample in a particular stratigraphic section is designated by a number such as "7" which refers to the seventh sample collected above the base of the section. The symbols used are the same as those for Plates 7 and 8. If an X-ray diffraction pattern was run on a particular sample, the letter "X" is affixed either to the sample number or placed next to the appropriate location on the columnar section. No thin sections were prepared on samples taken from sections N, Q, and R as these rocks were examined in the field.

Samples were collected at all significant lithologic changes. The subdivisions in the thick monotonous limestone sequence of the Viola Group are few, and the limestone types



COLUMNAR SECTIONS ON FOLLOWING THREE PAGES SAME SCALE


E
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3C
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7
6,X
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FAULTED BASE
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G
14
13,X
12
11
10,X
3C
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9
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7,X
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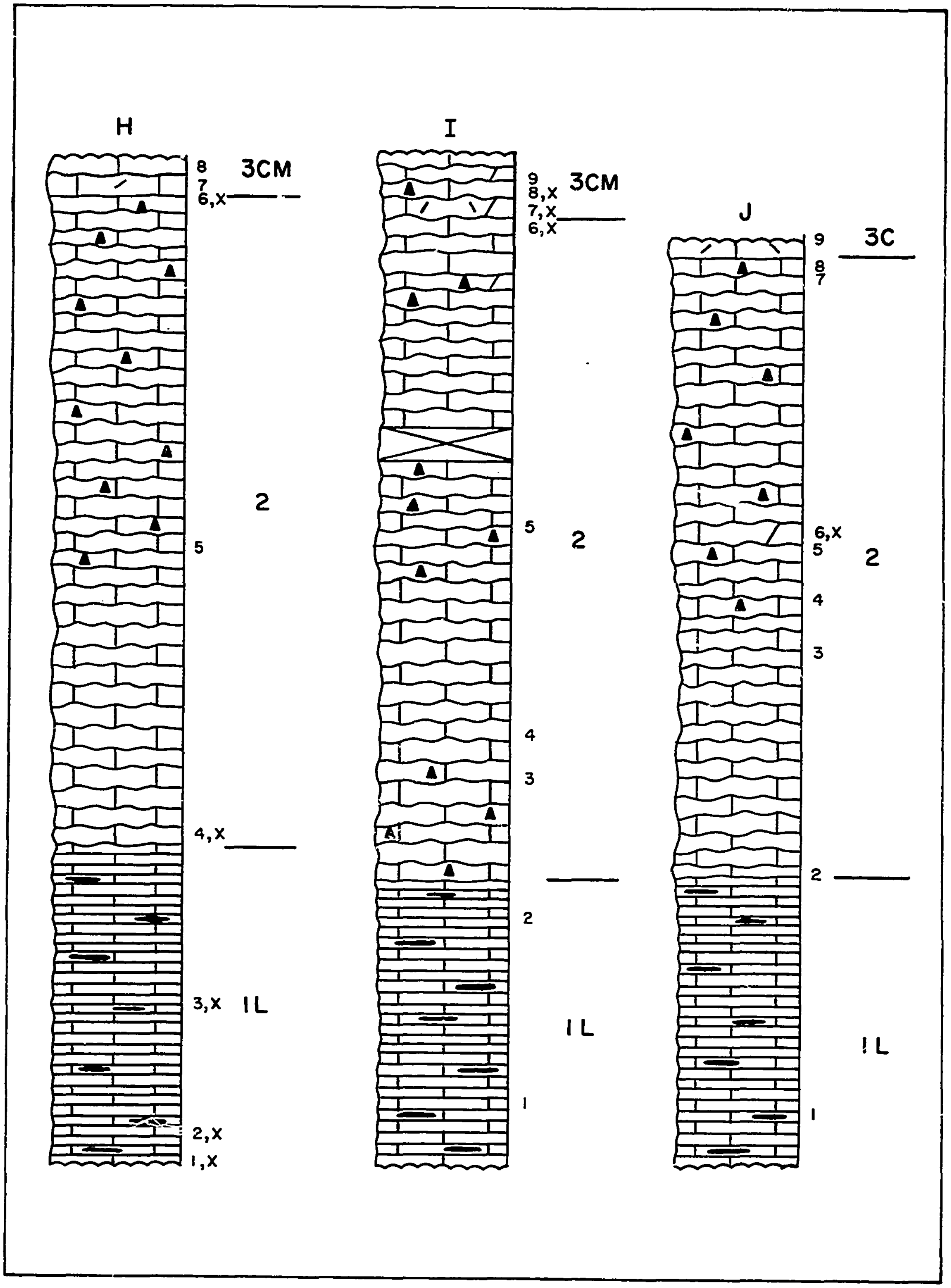
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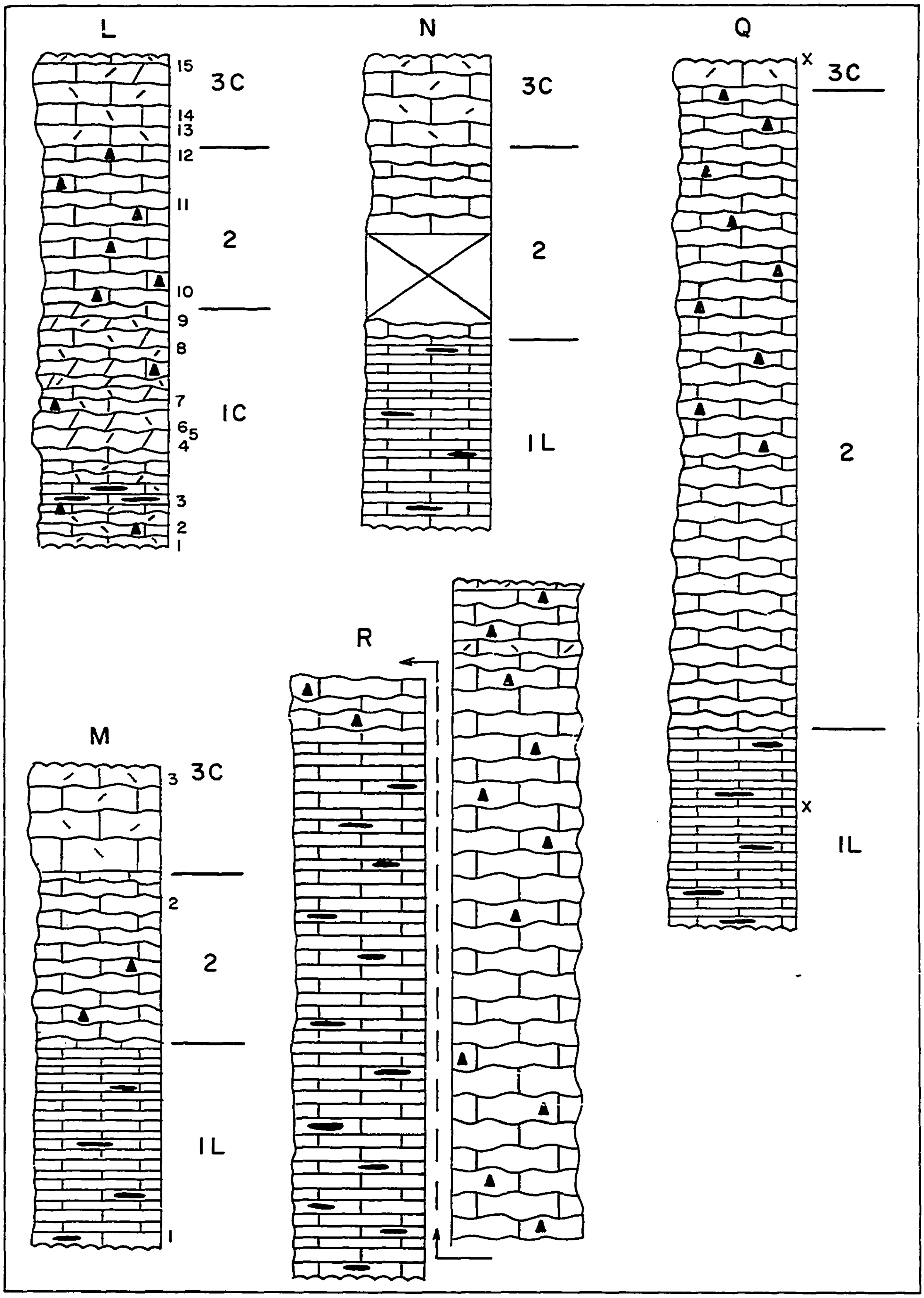

L
N
Q
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M
3C
2
1L

are strikingly persistent through hundreds of feet of section. Therefore, in some instances it was necessary only to collect one or two samples throughout the unchanging interval.

In general, the weathered color of the limestones of the Viola Group is a medium dark gray (N 4) which color persists throughout the studied area. The bedding is generally medium although some beds are thin, and a few of the calcarenites are thick to massive, particularly on the Hunton anticline.

In the field descriptions which follow, the limestones of the Viola Group have been subdivided into three units. Unit 1L refers to the siliceous laminated calcite mudstones found at the base of the section on the Arbuckle and Tishomingo anticlines; Unit 1C, to the fine to coarse skeletal calcarenite facies developed on the Hunton anticline; Unit 2 refers to the calcarenitic mudstones characterizing the middle of this limestone sequence; Unit 3C refers to those coarsely crystalline fossiliferous limestones formerly referred to the "Fernvale" Limestone; Unit 3CM refers to the cherty calcarenitic mudstones interbedded with Unit 3C to the west. In a future publication the writer and Mr. Leonard Alberstadt, co-worker on this project, will give formal names to these units.

A majority of the sections have been marked with yellow paint at intervals along the line of stratigraphic measurement to aid future workers in location of these sections.

Section A: NE¼ sec. 36, T. 3 N., R. 5 E., Pontotoc County; in Ideal Portland Cement Quarry 5.9 miles southwest of the southwest corner of Ada along State Highway 12 as measured from the junction between that highway and State Highway 19. The bottom 100 feet of the exposed section was measured on the west quarry face from the lower and upper levels; the top 40 feet was measured on the east quarry face. All measurements were made along an east-west line where the ramp from upper to lower level reaches the quarry floor; this line is essentially coincident with the northern boundary of section 36. This locality is on the Lawrence uplift. The strata strike N. 12° E. and dip 4° SE, as measured by three point problem in the east quarry face. Section measured by G. Glaser and L. Alberstadt, October 1964.

	Feet
Unit 3C. Coarse skeletal calcarenite, light gray, slightly wavy-bedded, massive, containing silicified brachiopods; contact with overlying Sylvan Shale covered.	88
Unit 2. Calcarenitic mudstone, olive-gray, wavy-bedded; slightly sandy with irregular chert nodules and minor dolomite in lowest 36 feet. Base covered.	52
Total	140

Section B: SW¼ NW¼ sec. 6, T. 2 N., R. 6 E., Pontotoc County; measured along northeastward-flowing tributary to South Fork Creek. To reach this section go approximately 6.2 miles southwest from Ada on State Highway 12 and turn eastward on the unpaved road leading to Lawrence and proceed 1.7 miles (0.9 miles beyond Lawrence) by winding road. From this point the exposure is reached by walking approximately 0.6 miles due south across an open field to the creek. Measurements of the upper part of the Viola Group were made in and along the creek bed. This locality is on the Lawrence uplift approximately one mile north of the Franks graben. The strata strike N. 40° W. and dip 7° NE. Section measured by G. Glaser and L. Alberstadt, October 1964.

	Feet
Unit 3C. Coarse skeletal calcarenite, olive-gray to pinkish-gray, wavy-bedded, sandy in lower 12 feet; contact with overlying Sylvan Shale covered.	49
Unit 2. Calcarenitic mudstone, dark gray, wavy-bedded, sandy; near top, gradational with fine muddy calcarenites which are transitional to Unit 3C; honeycomb network of solution holes ¼- to ½-inch in diameter toward top; base poorly exposed and not measured.	15
Total	64

Section C: NE¼ NW¼ sec. 2, T. 1 N., R. 6 E., Pontotoc County; measured along northeastward-flowing tributary to Sheep Creek. To reach this section, go 1.5 miles south of Fittstown on State Highway 99 and turn westward on the unpaved county line road for about 0.6 miles to where a gate on the south side of the road bounds an open pasture. From this point, the creek is reached by walking due south approximately 0.2 miles. This section is faulted at the base farther upstream to the west and at the top near the point of entrance. Measurements of the lower 213 feet were made in and along the creek bed; the remaining 84 feet were measured over a low rounded hill in an offset section approximately 200 yards south of the stream where is assumes a more easterly course. This locality is on the north limb of the Hunton anticline just south of the Franks graben. The strata strike N. 10° W. and dip 18° NE. Section measured by G. Glaser and L. Alberstadt, October 1964.

		Feet
Unit 3C.		
Coarse skeletal calcarenite, light gray, slightly wavy-bedded, containing silicified fossils near top in friable weathered portion; sandy near base; contact with overlying Sylvan Shale faulted out.		84
Unit 2.		
Calcarenitic mudstone, light gray, wavy-bedded, slightly sandy; honeycomb network of solution holes in top 17 feet; near top, gradational with fine muddy calcarenites which are transitional to Unit 3C.	23	
Conglomeratic-intraclast calcarenite, pinkish-gray, slightly wavy-bedded, containing echinoderms, trilobites, and bryozoans.	1	
Calcarenitic mudstone, yellowish-gray, wavy-bedded, burrowed, cherty, containing small gastropods.	27	
Covered.	122	
Calcarenitic mudstone, light gray, wavy-bedded, burrowed, dolomitic, cherty, with abundant brachiopods covering certain bedding planes.	26	
		199

Unit 1C.

Coarse skeletal calcarenite, yellowish-gray, slightly wavy-bedded, noncherty, containing abundant bryozoans and echinoderms, and a few large gastropods; slightly cross-bedded and burrowed in basal few feet; basal beds in fault contact with Ordovician McLish (?) Formation. 14

Total 297

Section D: NW¼ SW¼ sec. 12 and NE¼ SE¼ sec. 11, T. 1 N., R. 6 E., Pontotoc County; measured basal 212 feet up to high angle fault near northern limit of exposure along west side of State Highway 99, 3.3 miles south of Fittstown; the base of the section is in the northern half of the SW¼ of section 12. The remaining 190 feet of offset section were measured just east of Sheep Creek in section 11 along a north-south line approximately coincident with the east boundary of section 11 (west boundary of section 12). To reach this offset section, proceed 2.7 miles south of Fittstown; then walk due west across the grassy field approximately 0.3 miles. The rocks in this clearing represent the upper unit; the beginning of the offset is approximately 200 yards due south of this clearing. This locality is on the north limb of the Hunton anticline just south of the Franks graben. The strata strike N. 57° W. and dip 19° NE. Section measured by G. Glaser and L. Alberstadt, October 1964 and January 1965.

Feet

Unit 3C.

Coarse skeletal calcarenite, light gray, slightly wavy-bedded, friable when weathered, containing silicified brachiopods; contact with Sylvan Shale covered or faulted. 66

Unit 2.

Calcarenitic mudstone, light gray, wavy-bedded, burrowed, dolomitic; irregular chert nodules common in lower half;

honeycomb network of solution holes in top 32 feet; dolomite-shaly material appears as "pasty" infilling (? plastic clay of Wengerd, 1948) between nodular limestone; certain bedding planes covered with brachiopod shells as at 100 feet above base of unit; heavy iron stain from oxidizing pyrite along bedding surface 6 feet above unit base. 174

Unit 1C.

Coarse skeletal calcarenite, pinkish-gray, slightly wavy-bedded, noncherty, containing abundant bryozoans. 45

Coarse skeletal calcisiltite and fine skeletal calcarenite, pinkish-gray, slightly wavy-bedded, chert in layers and discrete nodules; skeletal debris mostly hash with ostracodes locally abundant. 85

Fine to medium calcarenite, pinkish-gray, slightly wavy-bedded; chert in layers; ostracodes, echinoderms, and small brachiopods dominate the fauna. 5

Coarse skeletal calcisiltite, pinkish-gray, slightly wavy-bedded; chert in layers and as nodules; skeletal hash. 25

Faintly laminated mudstone, gray, slightly siliceous, planar-bedded, with burrowed highly irregular bedding surface near middle suggestive of small unconformity; cherty; graptolites. This represents a temporary incursion of Unit 1L rocks into this area. 2

Coarse skeletal calcarenite, brown, slightly wavy-bedded, cherty, abundant skeletal phosphatization, irregular contact with olive green clay-like material suggestive of unconformable break; graptolites abundant along bedding surface; echinoderms dominate the calcarenite;

unconformable upon the Corbin Ranch Formation (Bromide "dense") at its type locality. 0.3

		162
Total		402

Section E: NE¼ SW¼ sec. 2, T. 2 S., R. 7 E., Johnston County; measured on and near Delaware Creek at Witch Hole (Camp Simpson Campground). To reach this locality, turn eastward onto an unpaved road from State Highway 99 at the Dolese Bros. Bromide Quarry sign 2 miles south of Connerville and proceed by winding road 5.9 miles in an easterly direction to Camp Simpson Campground located on the north side of the road. Enter the campground and go approximately 0.3 miles to the caretaker's quarters. The section was measured along an east-west line beginning directly behind the caretaker's home; just west of the small dam on Delaware Creek, the section was measured up the steep cliff face along the path made by the campers. The base of the section is faulted and the top contact, although covered, occurs down the dip-slope beyond the above-mentioned cliff face. This locality is on the north limb of the Belton anticline. The strata strike N. 35° W. and dip 19° SW. Section measured by G. Glaser and L. Alberstadt, October 1964.

Feet

Unit 3C.
Coarse skeletal calcarenite, pinkish-gray, slightly wavy-bedded, containing abundant echinoderms, sandy near base; contact with overlying Sylvan Shale covered. 56

Unit 2.
Calcarenitic mudstone, light gray, wavy-bedded, burrowed; sandy near top; dolomitic near bottom; honeycomb network of solution holes in top 19 feet; nodular chert in all but upper 33 feet. 69

Covered.	50	
		119
Unit 1L.		
Siliceous laminated mudstone, brown, planar-bedded, containing graptolites, trilobites, sponge spicules, and linguloid brachiopods; chert in layers and as nodules; interbedded 1- to 2-inch-thick limestones with shaly structure.	125	
Fine to medium calcarenite, light brown, slightly wavy-bedded, containing echinoderms and ostracodes; in fault contact with Ordovician McLish(?) Formation. This represents a temporary incursion of Unit 1C into this area.	0.3	
		125
Total		300

Section F: NW¼ NE¼ sec. 19, T. 2 S., R. 8 E., Johnston County; measured in and along the west bank of Robertson Creek in the upper part of the section and on the low rounded hill just to the west of the creek in the lower part of the section. To reach this locality, turn eastward onto State Highway 7 from State Highway 99 6 miles south of Connerville. From this junction go 8.4 miles to State Highway 7-D and then proceed north 0.3 miles and turn west on an unpaved road for approximately 0.2 miles where a small car path to the creek occurs on the south side of the road. From this point the exposures may be reached by crossing the fence and walking southwest along the cow path for about 150 yards. The first rocks observed represent the upper part of the section. The base of the group is located on the second ridge to the south and can be reached by walking in a southerly direction along the western slopes bordering the stream. This locality is on the north limb of the Belton anticline and on the south edge of the Wapanucka syncline. The strata strike N. 58° W. and dip 65° NE. Section measured by G. Glaser and L. Alberstadt, October 1964.

	Feet
Unit 3C. Coarse skeletal calcarenite, pinkish-gray, slightly wavy-bedded, containing abundant echinoderms; sandy near base; contact with overlying Sylvan Shale covered. This represents the maximum thickness for this unit in the Arbuckle Mountains.	112
Unit 2. Calcarenitic mudstone, tan to dark gray, wavy-bedded, burrowed; nodular chert in all but upper 55 feet; near top, gradational with fine muddy-sandy calcarenites which are transitional to Unit 3C; these fine calcarenites are light gray mottled dark brown, are burrowed, and are exactly similar to rocks from the same part of the sequence at Section M approximately 3½ miles to the southeast.	173
Unit 1L. Siliceous laminated mudstone, tan, planar-bedded, containing spicules and graptolites; chert in layers; excellent exposure of sharp contact with Corbin Ranch Formation.	137
Total	422

Section G: NW¼ NE¼ sec. 4, T. 2 S., R. 3 E., Murray County; measured in and along the northward-flowing tributary to Little Buckhorn Creek on Buckhorn Ranch. The base of the measured section is 400 yards south of the north boundary and 780 yards west of the east boundary to section 4. To reach this locality, go south from Sulphur on U. S. Highway 177 (formerly State Highway 18) 7.4 miles from the junction with State Highway 7 at the north entrance to Platt National Park; then turn westward on the unpaved road leading to Buckhorn Ranch and proceed 2.2 miles to the ranch headquarters. From this point, turn northwestward along a winding road and go about 0.6 miles to a man-made lake. From this point, proceed northeastward by foot approximately 0.4 miles along the creek to the first beds measured in this section. This locality is on the north limb of the Tishomingo anticline. The strata range in strike from N. 33° to N. 72° W. and increase in dip from 9° to 40° NE. toward the top of the section. Section measured by G. Glaser and L. Alberstadt, October 1964.

		Feet
Unit 3C.		
Coarse skeletal calcarenite, pinkish-gray to gray, wavy-bedded, nodular, slightly dolomitic, containing abundant echinoderms and trilobites; topmost bed is fine skeletal calcarenite which looks like calcarenitic mudstone in hand specimen; exact contact with overlying Sylvan Shale covered although typical Sylvan occurs in stream cut approximately 100 yards farther downstream.		19
Unit 2.		
Calcarenitic mudstone, yellowish-gray, wavy-bedded, nodular; chert in layers and as nodules.	105	
Calcarenitic mudstone, yellowish-gray, wavy-bedded, noncherty.	96	
Calcarenitic mudstone, yellowish-gray, wavy-bedded, burrowed, containing abundant brachiopods and pinkish-red trilobite hash in some beds; chert as nodules; near the top and bottom occur thin layers with high skeletal content and less than 50 percent mud which are medium muddy calcarenites.	99	
Calcarenitic mudstone, yellowish-gray, wavy-bedded, sandy, noncherty except for a few nodules in the lower 25 feet; extensively burrowed, dolomitic; interbedded with ½- to 1-inch-thick limestones with shaly structure; contains abundant brachiopods in some beds; probably close to		

base of unit although it is not exposed.	101	
		401
Unit 1L.		
Upper part partially exposed (about 10 feet) approximately 400 yards upstream, but not measured. It is the typical siliceous laminated mudstone.		--
Total		420

Section H: central E½ sec. 25, T. 2 S., R. 1 E., Carter County; measured along U. S. Highway 77 on the east side of the road and in Tulip Creek to the west of the road. This locality is approximately 11 miles south of the junction of State Highway 7 and U. S. 77 on the southwest side of Davis. Approximately the basal 100 feet were measured in the creek bed of Tulip Creek; the next 150 feet were measured on the highway exposures; the remainder of the section was measured in and along Tulip Creek. This locality is on the south limb of the Arbuckle anticline. The strata strike N. 68° W. and dip 49° SW. Section measured by G. Glaser and L. Alberstadt, October 1964.

		Feet
Unit 3CM.		
Calcarenitic mudstone, light brown, slightly wavy-bedded, containing abundant trilobite hash and echinoderms; contact with overlying Sylvan Shale covered.	21	
Coarse skeletal calcarenite, light gray, slightly wavy-bedded, slightly dolomitic, containing abundant echinoderms.	5	
		26
Unit 2.		
Calcarenitic mudstone, dark tan, wavy-bedded, burrowed, containing the trilobite		

Cryptolithus sp.; nodular chert; slightly sandy. 266

Calcarenitic mudstone, dark tan, wavy-bedded, burrowed, noncherty, containing graptolites and trilobites; slightly sandy. 194

460

Unit 1L.

Siliceous laminated mudstone, dark tan, planar-bedded, containing abundant graptolites, spicules, and trilobites; chert in layers; interbedded with frequent ½- to 1-inch layers of limestone with shaly structure; basal 65 feet is bituminous and has asphaltic odor when broken open; contact with underlying Corbin Ranch Formation sharp. 229

Total 715

Section I: E½ SW¼ sec. 22, T. 2 S., R. 1 W., Carter County; measured 0.3 miles northwest of the dam on Mountain Lake. To reach this locality, go 12.5 miles south of Davis on U. S. 77 and turn westward onto State Highway 53 and go 8 miles to Woodford; then turn northward and proceed about 3 miles to Mountain Lake. The section may be reached by ascending the steps on the west side of the dam and walking 0.3 miles to the base of the section in the NE¼ of the SW¼ of the section. This locality is on the south limb of the Arbuckle anticline. The strata strike N. 50° W. and dip 27° SW. Section measured by G. Glaser and L. Alberstadt, October 1964.

Feet

Unit 3CM.

Calcarenitic mudstone, tan, wavy-bedded, burrowed, dolomitic, containing echinoderms and trilobites; nodular chert near base; contact with overlying Sylvan Shale covered. 37

Coarse skeletal calcarenite, dark tan, slightly wavy-bedded, dolomitic, containing echinoderms, trilobites, and a few large cephalopods.	7	
		44
Unit 2.		
Calcarenitic mudstone, dark tan, wavy-bedded, burrowed, slightly dolomitic.	150	
Covered.	23	
Calcarenitic mudstone, dark tan, wavy-bedded, burrowed; nodular chert.	75	
Calcarenitic mudstone, tan, wavy-bedded, burrowed, sandy, noncherty.	148	
Calcarenitic mudstone, dark tan, wavy-bedded, burrowed, sandy; nodular chert.	77	
		473
Unit 1L.		
Siliceous laminated mudstone, brownish-gray, planar-bedded, containing graptolites, chert in layers; interbedded with ½- to 1-inch layers of limestone with shaly structure; basal 50 feet is bituminous and has asphaltic odor when broken open; excellent exposure of sharp contact with underlying Corbin Ranch Formation.		200
Total		717

Section J: NW¼ SE¼ sec. 27, T. 3 S., R. 4 E., Johnston County; measured in and along Sycamore Creek. To reach this section, go 17.5 miles south of Sulphur on U. S. 177 and turn eastward on the unpaved road at the south edge of the town of Baum and proceed 4 miles; then take the north fork in the road and proceed 2.5 miles on this winding road; then take the right fork in the road for another 1.5 miles. From this point, walk due east 0.4 miles to the outcrops on Sycamore Creek. This locality is on the south limb of the Sycamore Creek anticline. The strata strike N. 74° W. and dip 60° SW. Section measured by G. Glaser and L. Alberstadt, November 1964.

		Feet
Unit 3C.		
Coarse skeletal calcarenite, light gray, slightly wavy-bedded, slightly dolomitic, containing abundant trilobites, echinoderms, and some bryozoans; top bed burrowed and covered with iron stain from oxidizing pyrite; excellent exposure of sharp contact with overlying Sylvan Shale.		17
Unit 2.		
Calcarenitic mudstone, dark tan, wavy-bedded, burrowed, slightly dolomitic, containing echinoderms, trilobites, and nodular chert.	247	
Calcarenitic mudstone, light gray, wavy-bedded, burrowed, sandy to silty, noncherty, containing trilobite hash.	187	
		434
Unit 1L.		
Siliceous laminated mudstone, dark tan, planar-bedded, containing graptolites and sponge spicules; interbedded with ¼- to ½-inch layers of limestone with shaly structure; good exposure of sharp contact in stream with underlying Corbin Ranch Formation.		203
Total		654

Section K: SW¼ SE¼ SW¼ sec. 16, T. 1 N., R. 7 E., Pontotoc County; measured on Rhyne Ranch. To reach this locality, go 2.5 miles south of Fittstown on State Highway 99 and turn eastward on State Highway 61 for 3.8 miles; then turn south on the unpaved section-line road for 1 mile. From this point, the top of the section is 0.6 miles to the southwest. The exposures are poor. This locality is on the north limb of the Hunton anticline just south of the Franks fault zone. The strata strike N. 42° W. and dip 12° NE. Section measured by G. Glaser and L. Alberstadt, November 1964.

	Feet
Unit 3C.	
Coarse skeletal calcarenite, light gray, slightly wavy-bedded, containing echinoderms, trilobites, and silicified brachiopods; sandy at base; contact with overlying Sylvan Shale covered.	64
Units 2 and 1C. (Poorly exposed and undifferentiated)	
Calcarenitic mudstone, yellowish-gray, wavy-bedded, burrowed; occurs in upper half of undifferentiated sequence. (Estimated thickness: 150-170 feet)	
Coarse skeletal calcarenite, yellowish-gray, slightly wavy-bedded, containing abundant bryozoans in basal 27 feet; contacts with overlying calcarenitic mudstone and underlying Corbin Ranch Formation difficult to pick. (Estimated thickness: 140-160 feet)	310
Total	374

Section L: S½ secs. 19 and 20, T. 1 S., R. 8 E., Coal County; measured in and along Mosely Creek. To reach this locality, go 2 miles south of Connerville on State Highway 99 and turn eastward onto an unpaved road leading to the Dolese Bros. Bromide Quarry for 8 miles; then go 0.5 miles east of Bromide and turn northward for approximately 3 miles following the winding road past the Bromide school. The rocks at this point represent the upper unit. To reach the base of the group, walk westward along Mosely Creek for about 1.5 miles. This locality is on the western margin of the Clarita anticline. The strata strike N. 11° E. and dip 3° 38' SE as determined by three-point problem on the outcrop. Section measured by G. Glaser and L. Alberstadt, February and March 1965.

	Feet
Unit 3C.	
Coarse skeletal calcarenite, gray, slightly wavy-bedded, containing silicified brachiopods; topmost bed almost completely dolomitized in places; contact with overlying Sylvan Shale covered.	64
Unit 2.	
Calcarenitic mudstone, tan to gray, wavy-bedded, burrowed, containing gastropods, brachiopods, trilobites, and a few large cephalopods; nodular chert common; near top, gradational with fine muddy calcarenites which are transitional to Unit 3C.	121
Unit 1C.	
Dolomite, pinkish-gray, wavy-bedded; original texture and fabric almost wholly obliterated although what remains suggests original rock throughout this sequence probably was coarse calcarenites interbedded with a few calcarenitic mudstones; nodular chert in some beds; fauna consists of ostracodes, brachiopods, and trilobites. This represents the only occurrence of practically pure dolomite in any appreciable thickness in the Viola Group throughout the area studied in the Arbuckle Mountains. Other replacement occurrences generally are patchy, less than 15 percent of the rock, and usually are confined to the mud fraction.	101
Calcarenitic mudstone, dark brown, wavy-bedded, containing trilobites; exposed in stream.	7

Coarse skeletal calcisiltite, light gray, wavy-bedded, containing fossil hash and some nodular chert.	10
Siliceous laminated mudstone, dark gray, planar-bedded; interbedded with layers of coarse skeletal calcisiltite 1- to 2-millimeters thick. This represents a temporary incursion of Unit 1L into this area.	10
Coarse skeletal calcisiltite and fine skeletal calcarenite, pinkish-gray, slightly wavy-bedded, cherty, containing abundant bryozoans in some beds, but mostly fine fossil hash; exposure of contact with underlying Corbin Ranch Formation sharp although that formation appears to be thinner at this locality indicating possible greater amount of truncation here than seen at other sections.	40

168

Total 353

Section M: NE¼ SE¼ sec. 27, T. 2 S., R. 8 E., Johnston County; measured along dry tributary to Sandy Creek. To reach this locality, go 2 miles south of Wapanucka on State Highway 48 from its junction with State Highway 7 and turn westward for 1 mile and then northward for abcut 0.5 miles to a gate leading to an open field on the west side of the road. From the southwestern edge of this field, walk southwest approximately 300 yards along a cow path to the exposures. The rocks at this point represent the upper unit; the base of the group is approximately 100 yards farther to the southwest. This locality is on the south limb of the Wapanucka syncline. The strata strike N. 31° W. and are vertical. Section measured by G. Glaser and L. Alberstadt, March 1965.

	Feet
Unit 3C. Coarse skeletal calcarenite, dark gray, slightly wavy-bedded, containing echinoderms and trilobites; contact with overlying Sylvan Shale covered.	80
Unit 2. Calcarenitic mudstone, dark gray to tan, wavy-bedded, burrowed, sandy; nodular chert in all but upper 53 feet; near top, gradational with fine muddy calcarenites which are transitional to Unit 3C; these fine calcarenites are light gray mottled dark brown, are burrowed, and are exactly similar to rocks from the same part of the sequence at Section F approximately 3½ miles to the northwest.	117
Unit 1. Siliceous laminated mudstone, brown, planar-bedded, containing graptolites; chert in layers; exposure of contact with underlying Corbin Ranch Formation sharp.	147
Total	344

Section N: SE¼ SE¼ sec. 15, T. 2 S., R. 5 E., Johnston County; poor exposures measured over low rounded hill. To reach this locality, follow unpaved State Highway 7 to the southeast for 4.3 miles from the southeast corner of Mill Creek. At this point the road turns to the southeast, but follow the small farm road that continues eastward for approximately 0.1 mile; then go northward for 0.3 miles following the winding road leading to a small house and barn. The rocks at this point represent the contact between the Corbin Ranch Formation and the basal part of the Viola Group. This locality is on the south limb of the Mill Creek syncline. The strata strike N. 75° W. and dip 40° NE. Exposures are poor and the middle portion of the section is covered. Section measured by G. Glaser and L. Alberstadt, April 1965.

		Feet
Unit 3C.		
Coarse skeletal calcarenite, tan, slightly wavy-bedded, containing trilobites and echinoderms; slightly muddy in topmost bed; contact with overlying Sylvan Shale covered.		62
Unit 2.		
Poorly exposed calcarenitic mudstone, tan, wavy-bedded.	76	
Covered.	63	
		139 (approx.)
Unit 1.		
Siliceous laminated mudstone, light gray, planar-bedded; chert in layers; contact with overlying unit covered; excellent exposure of sharp contact with underlying Corbin Ranch Formation.		138 (approx.)
Total		339

Section O: SE¼ NW¼ sec. 11, T. 3 S., R. 3 E., Carter County; measured along U. S. Highway 177. To reach this locality, proceed south from Sulphur on U. S. 177 for 13.5 miles. The rocks exposed on the east side of the highway represent the basal unit and the lower part of the middle unit. The remainder of the section is well exposed in the high hill on the west side of the road. This section was measured by plane table and alidade. This locality is on the south limb of the Sycamore Creek anticline. The strata strike N. 68° W. and dip SW. Section measured by G. Glaser and L. Alberstadt, April 1965. This section was measured to check the thickness given by Wengerd (616 feet, 1948). The rocks were not examined in detail and only approximate thicknesses are given for each unit.

	Feet
Unit 3C. Coarse skeletal calcarenite; exact contact with overlying Sylvan Shale covered although typical Sylvan observed in stream cut approximately 100 yards west of highway.	22
Unit 2. Calcarenitic mudstone, wavy-bedded, containing nodular chert.	400
Unit 1L. Siliceous laminated mudstone, planar-bedded, with chert in layers; common graptolites; contact with Corbin Ranch Formation not observed.	200
Total	622

Section P: SE¼ SE¼ sec. 2, T. 2 S., R. 3 E., Murray County. To reach this locality, proceed south from Sulphur on U. S. Highway 177 for 7.3 miles and turn westward for 0.2 miles on the unpaved road leading to Buckhorn Ranch. The basal part of the Viola Group is exposed on the north side of this road approximately 100 yards beyond this point. The exposures are poor. This locality is on the north limb of the Tishomingo anticline. The strata strike N. 20° E. and dip 33° NW. Section measured by G. Glaser and L. Alberstadt, April 1965.

These exposures are too poor for exact measurements of individual units. This section was measured solely to obtain a total thickness for the Viola Group near the incompletely exposed Section G (420 feet plus) approximately 2½ miles to the northwest. The total thickness measured is 530 feet; the exposure of contact of Unit 1L with the underlying Corbin Ranch Formation is sharp although the contact of Unit 3C with the overlying Sylvan Shale is covered.

Section Q: NW¼ NE¼ sec. 28, T. 1 S., R. 2 E., Murray County; measured on west wall in lower level of Dolese Bros. Rayford Quarry. To reach this locality, go east from Davis on State Highway 7 approximately 3 miles and turn southward on the unpaved road at the Dolese Bros. Rayford Quarry sign; proceed southward for about 5 miles and then turn west for about 2 miles and then north for about 2 miles to the quarry. Signs to the quarry mark the way. This section was measured by plane table and alidade. This locality is on the south limb of the Doughtery anticline. The strata strike N. 45° W. and dip 63° SW. Section measured by G. Glaser and L. Alberstadt, April 1965.

	Feet
Unit 3C.	
Coarse to medium skeletal calcarenite, greenish-gray, with thin shaly partings between uneven subnodular beds, trilobite fragments common; 3- to 4-inch layer of pyritic phosphate conglomerate containing abundant small shells of a linguloid brachiopod separates this unit from the excellent exposures of overlying graptolitic Sylvan Shale.	20
Unit 2.	
Calcarenitic mudstone, light gray to olive gray, interbedded with lensing 1- to 2-inch-thick shaly limestones; irregular chert nodules common in upper half.	459
Unit 1L.	
Siliceous laminated mudstone, light gray to dark gray, planar-bedded, containing chert layers and disseminated silica; graptolites common; excellent exposure of sharp contact with Corbin Ranch Formation.	143
Total	622

Section R: NW¼ SW¼ sec. 6, T. 2 S., R. 1 W. and SE¼ SE¼ sec. 1 and NE¼ NE¼ sec. 12, T. 2 S., R. 2 W., Murray and Carter Counties respectively; measured in and along West Spring Creek. To reach this locality, go westward 8 miles on State Highway 53 from its junction with U. S. Highway 77; at Woodford turn northward and go about 2.3 miles and then turn westward along the winding, unpaved road for about 5.5 miles to reach West Spring Creek. This is a very general description; the roads are overgrown and only with a jeep is it possible to reach this locality. This locality is on the south limb of the Arbuckle anticline at the southwestern edge of the Arbuckle Mountains. The strata strike N. 35° W. and dip SW from 33° in the basal unit to 27° in the upper units. Section measured by G. Glaser, L. Alberstadt, and W. Ham, June 1965.

		Feet
Unit 3CM.		
Coarse skeletal calcarenite, light bluish-gray, slightly wavy-bedded, containing minor mud; echinoderm and trilobite fragments common; excellent exposure of sharp contact with overlying Sylvan Shale.	3	
Calcarenitic mudstone, gray-brown, wavy-bedded, cherty, containing large specimens of Lepidocyclus sp.	37	
Coarse skeletal calcarenite, light gray, wavy-bedded, slightly muddy; comminuted remains of trilobites, brachiopods, and echinoderms; contact with underlying mudstone fairly sharp.	9	
		49
Unit 2.		
Calcarenitic mudstone, gray to dark tan, wavy-bedded, irregular chert nodules common except for 50-foot interval near middle; fossils are variable throughout and are predominantly trilobites, graptolites, and brachiopods.		464

Unit 1L.
Siliceous laminated mudstone, dark tan, planar-bedded; chert layering and disseminated silica common; ¼- to ½-inch interbeds of limestone with shaly structure; contact with Corbin Ranch Formation covered. This represents the maximum thickness for this unit in the Arbuckle Mountains. 382

Total 895

Section S: NW¼ sec. 24, T. 1 S., R. 1 E., Murray County; Lake Classen area approximately 1¾ miles west of U. S. Highway 77. This locality is on the north limb of the Arbuckle anticline. The strata strike N. 27° W. and dip SE from 63° near the base to 43° toward the top. Section measured and described by Robert J. Dunham (1951). The descriptions of Dunham are paraphrased below with the equivalent names used in this work included in parentheses.

	Feet
Unit 3C. Coarsely crystalline limestone, light gray, massive with slight wavy-bedding, noncherty. (Coarse skeletal calcarenite)	0-15
Unit 2. Finely crystalline limestone, light gray, flaggy with very wavy-bedding along which lenticular partings of calcareous shale are distributed, containing many large chert nodules in all but the lowest part. (Calcarenitic mudstone)	460-475
Unit 1L. Very finely crystalline limestone, flat-bedded in 6- to 12-inch layers alternating with gray-brown laminated chert in ½- to 1-inch layers. (Siliceous laminated mudstone)	135
Total	610
	Maximum thickness

PLATE 6

VIOLA-SYLVAN OUTCROP MAP
ARBUCKLE MOUNTAINS
OKLAHOMA

by

Gerald C. Glaser – 1965

0 1 2 3 4 5 6
MILES

EXPLANATION

Outcrop of Sylvan Shale and Viola Group (undifferentiated)

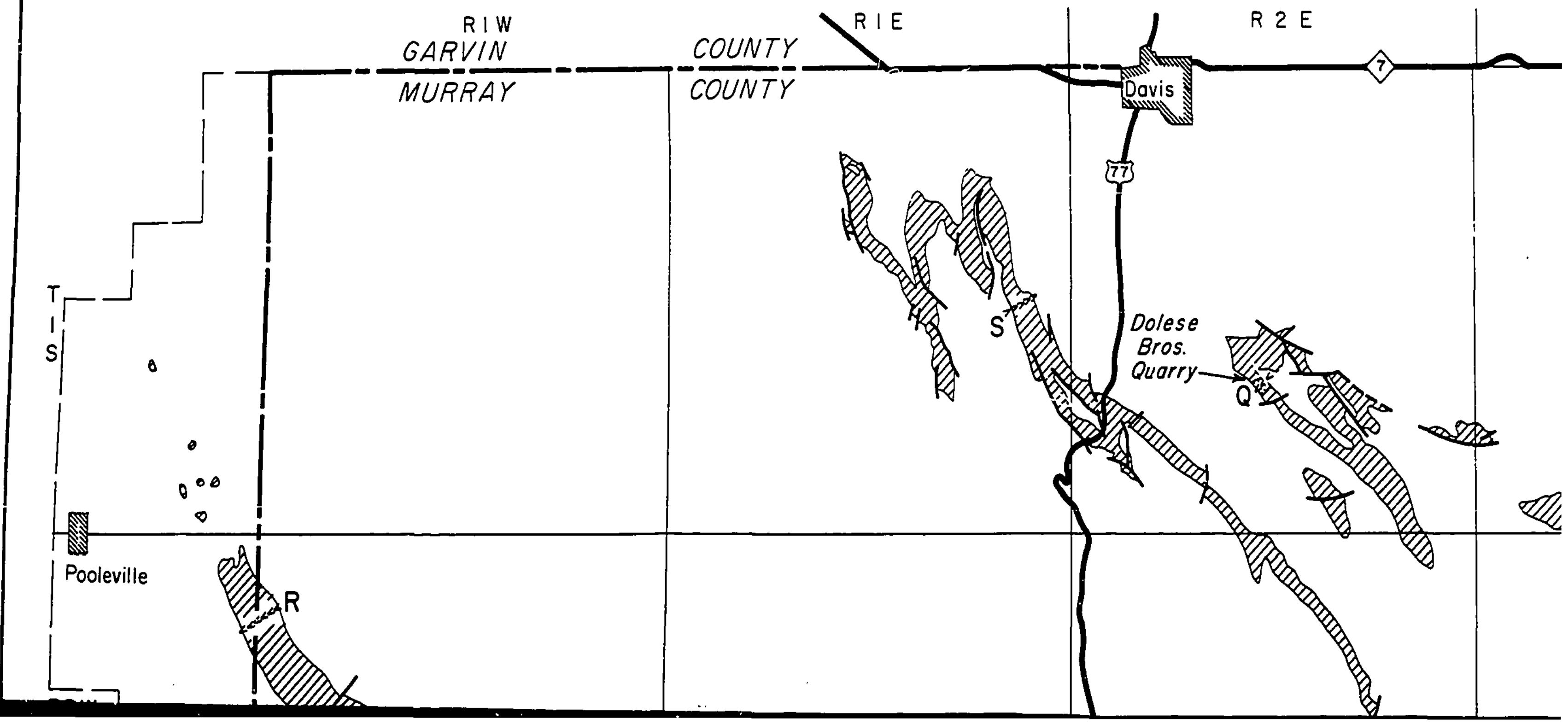
FAULT

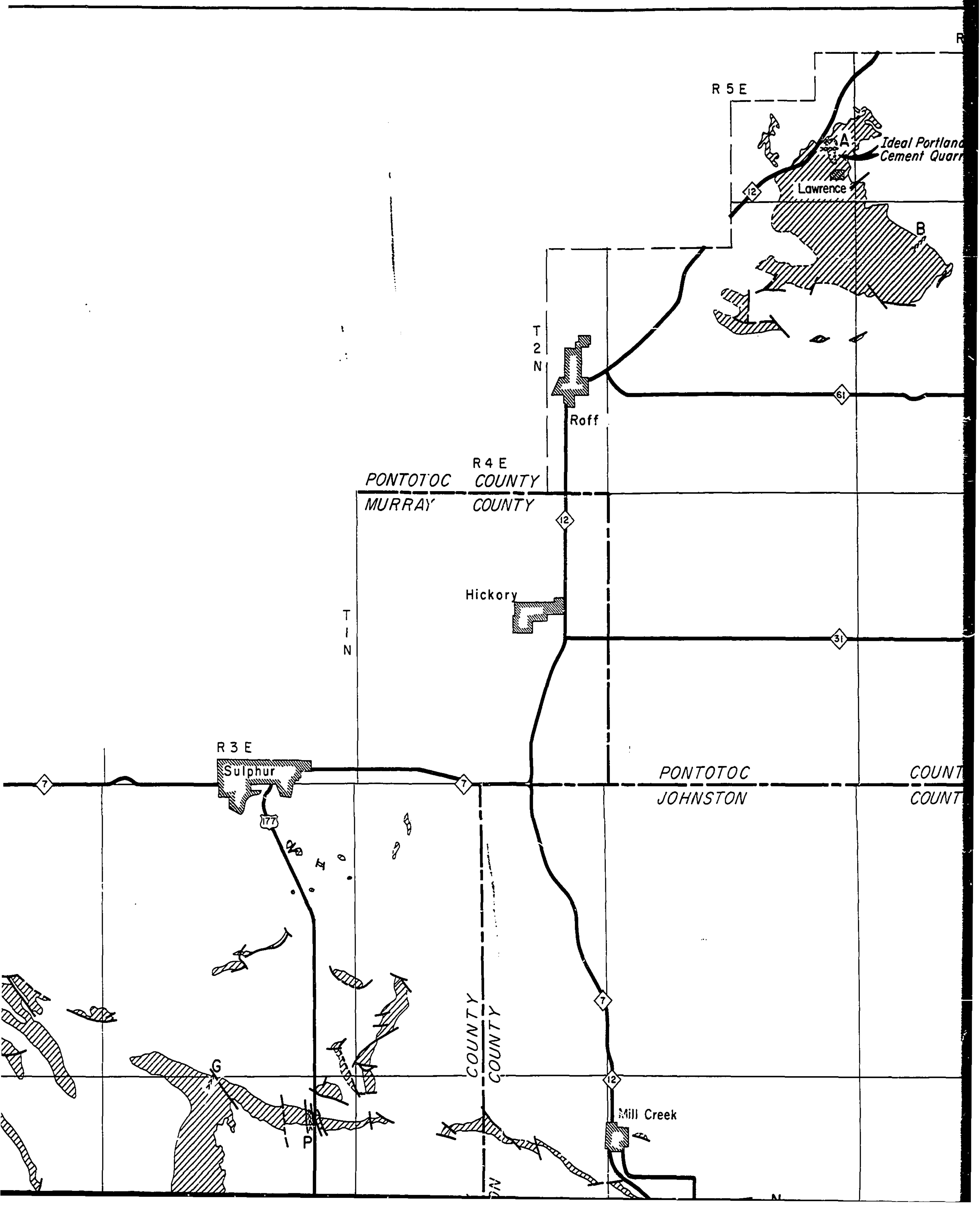
QUARRY

A

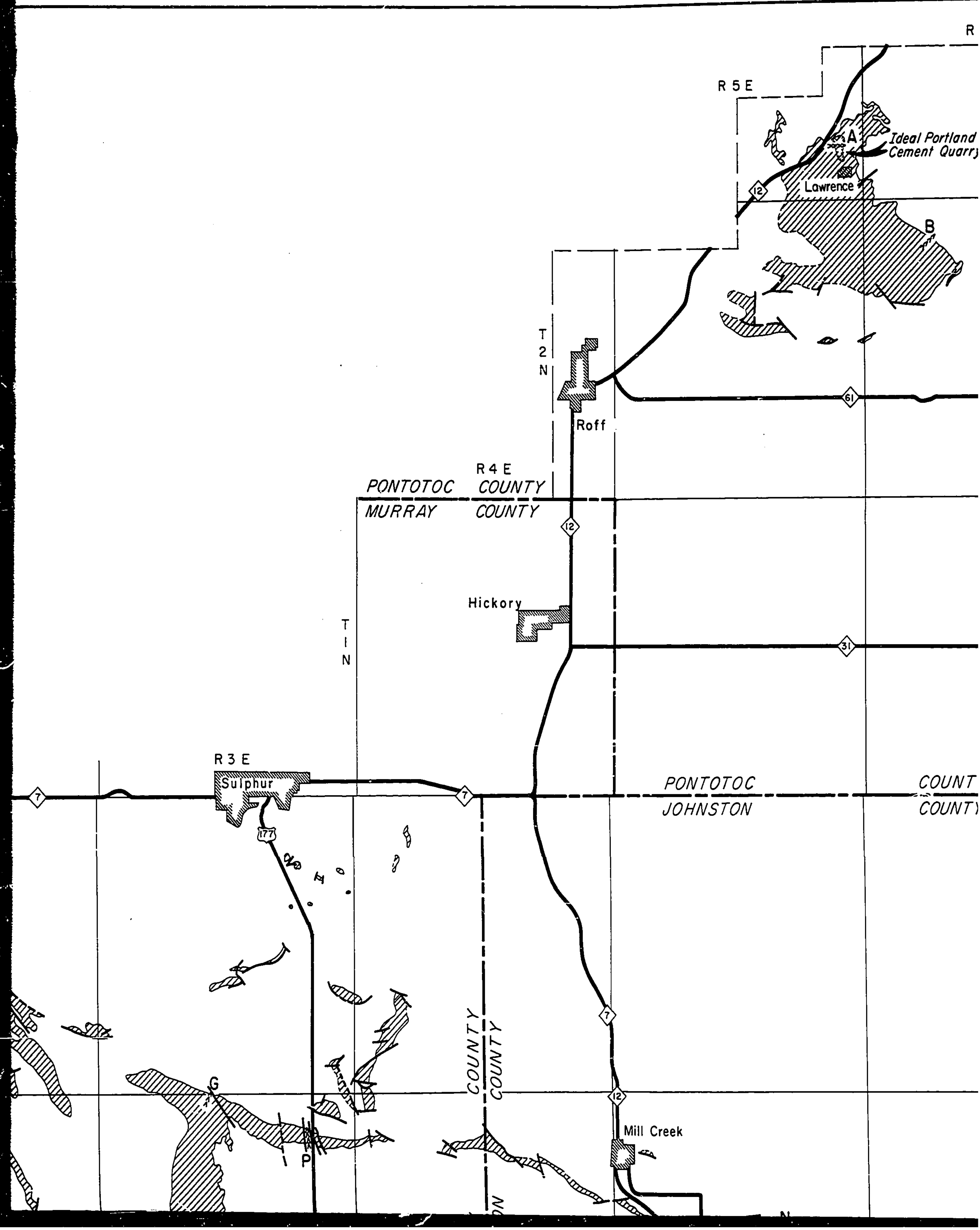
Location of measured sections (arrows indicate direction of dip)

Modified from Ham, McKinley, and others 1954





R 5 E
Ideal Portland
Cement Quarr
A
Lawrence
B
12
T
2
N
Roff
61
R 4 E
PONTOTOC COUNTY
MURRAY COUNTY
12
Hickory
T
1
N
31
R 3 E
Sulphur
7
7
PONTOTOC COUNT
JOHNSTON COUNT
177
COUNTY
COUNTY
7
12
G
P
Mill Creek



R
R 5 E
Ideal Portland
Cement Quarry
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Lawrence
12
B
T
2
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Roff
61
R 4 E
PONTOTOC COUNTY
MURRAY COUNTY
12
Hickory
T
I
N
31
R 3 E
Sulphur
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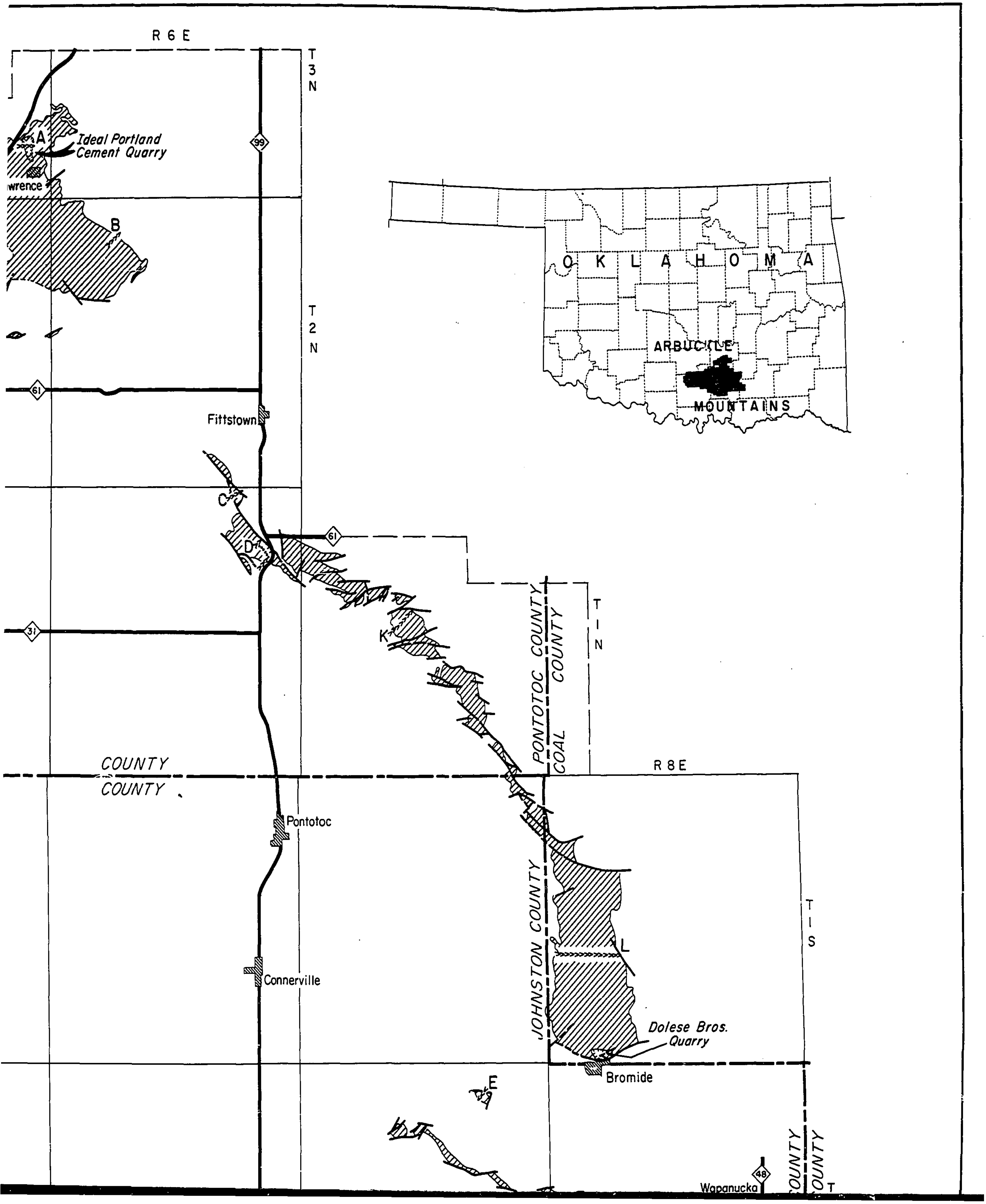
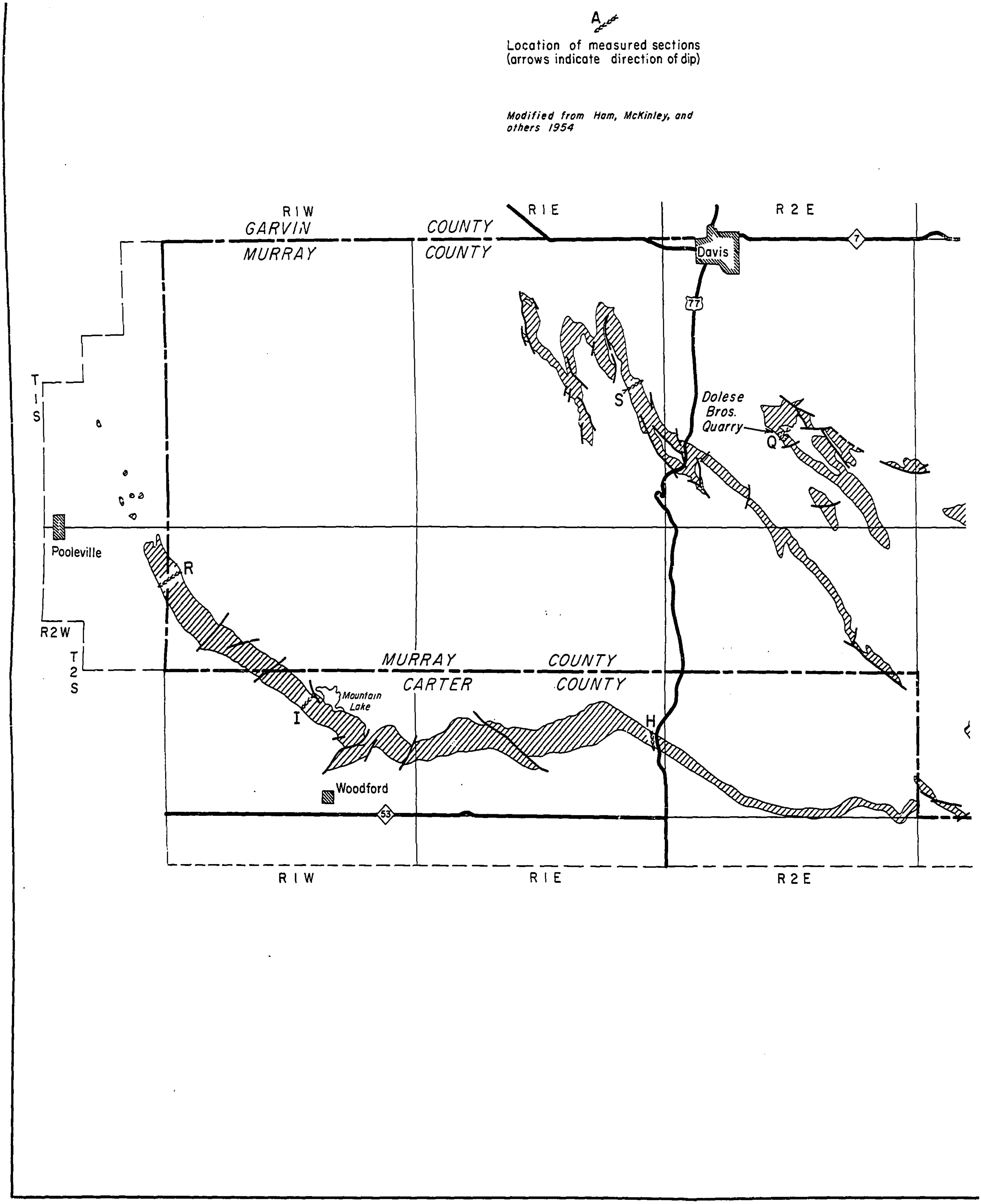
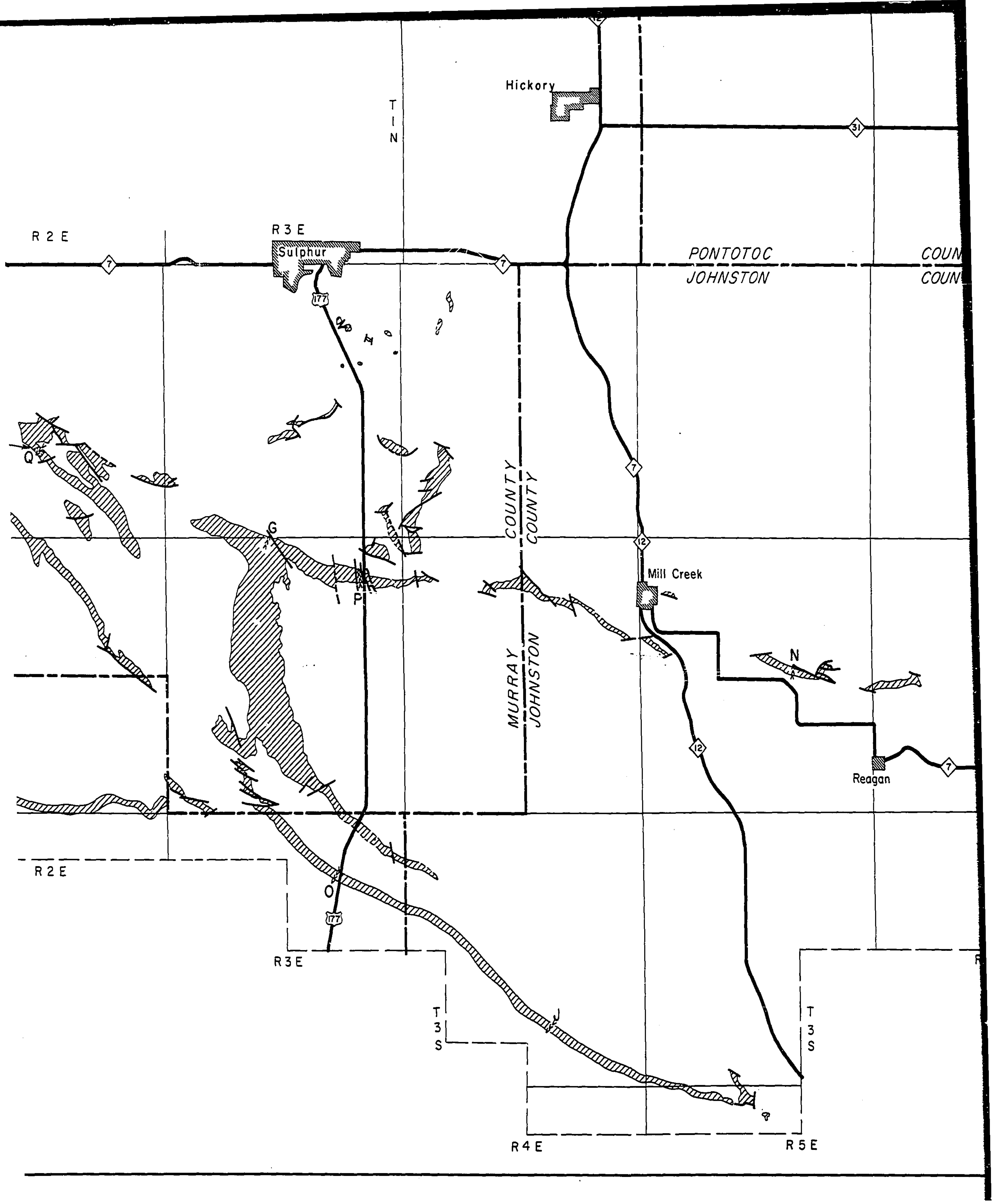
177
PONTOTOC COUNT
JOHNSTON COUNTY
COUNTY
COUNTY
7
12
Mill Creek
G
P

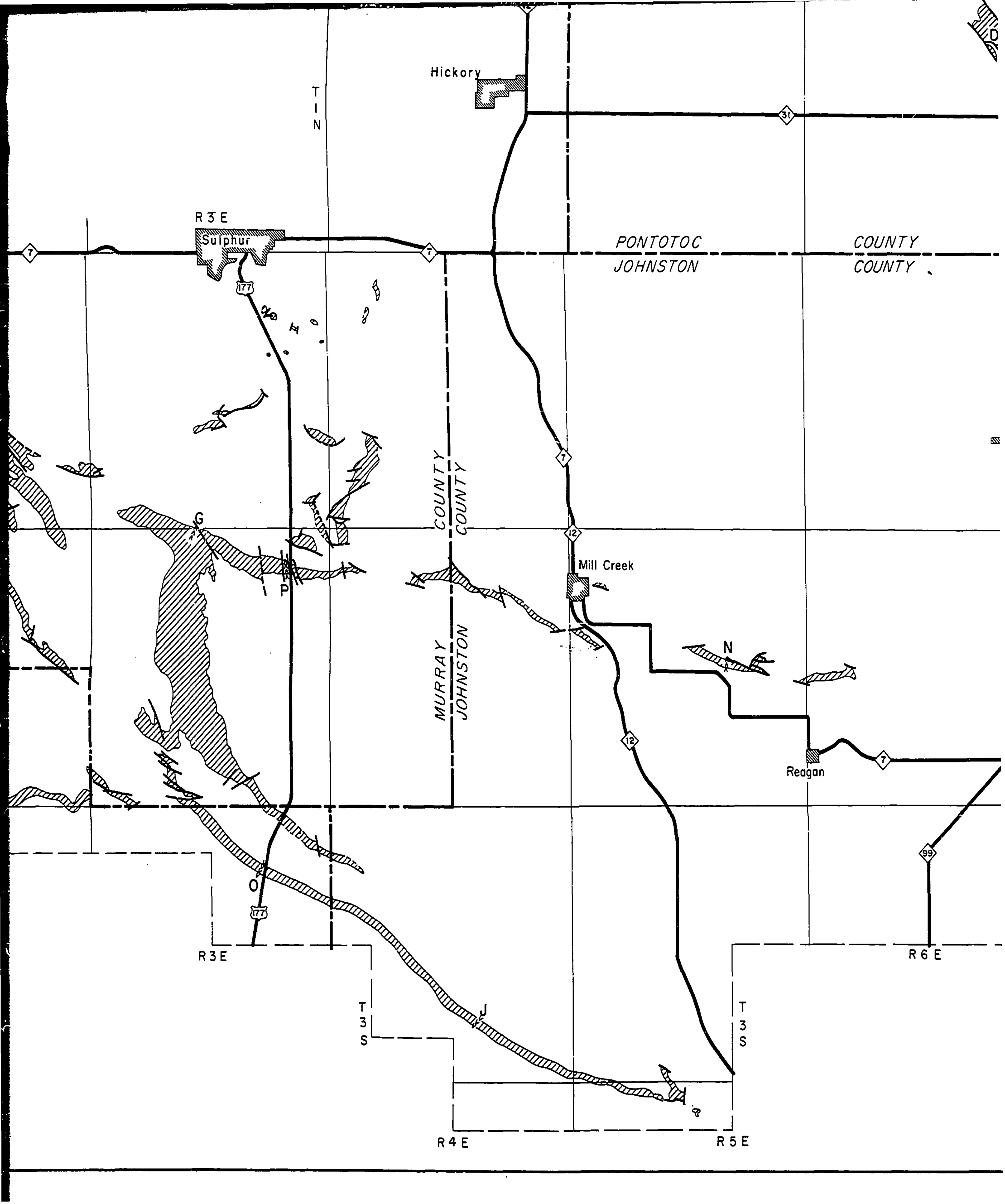

R 6 E
T 3 N
T 2 N
T 1 N
T 1 S
R 8 E
A
B
C
D
E
K
L
Ideal Portland Cement Quarry
Fittstown
Pontotoc
Connerville
Bromide
Wapanucka
Dolese Bros. Quarry
99
61
31
48
COUNTY
COUNTY
PONTOTOC COUNTY
COAL COUNTY
JOHNSTON COUNTY
OKLAHOMA
ARBUCKLE
MOUNTAINS



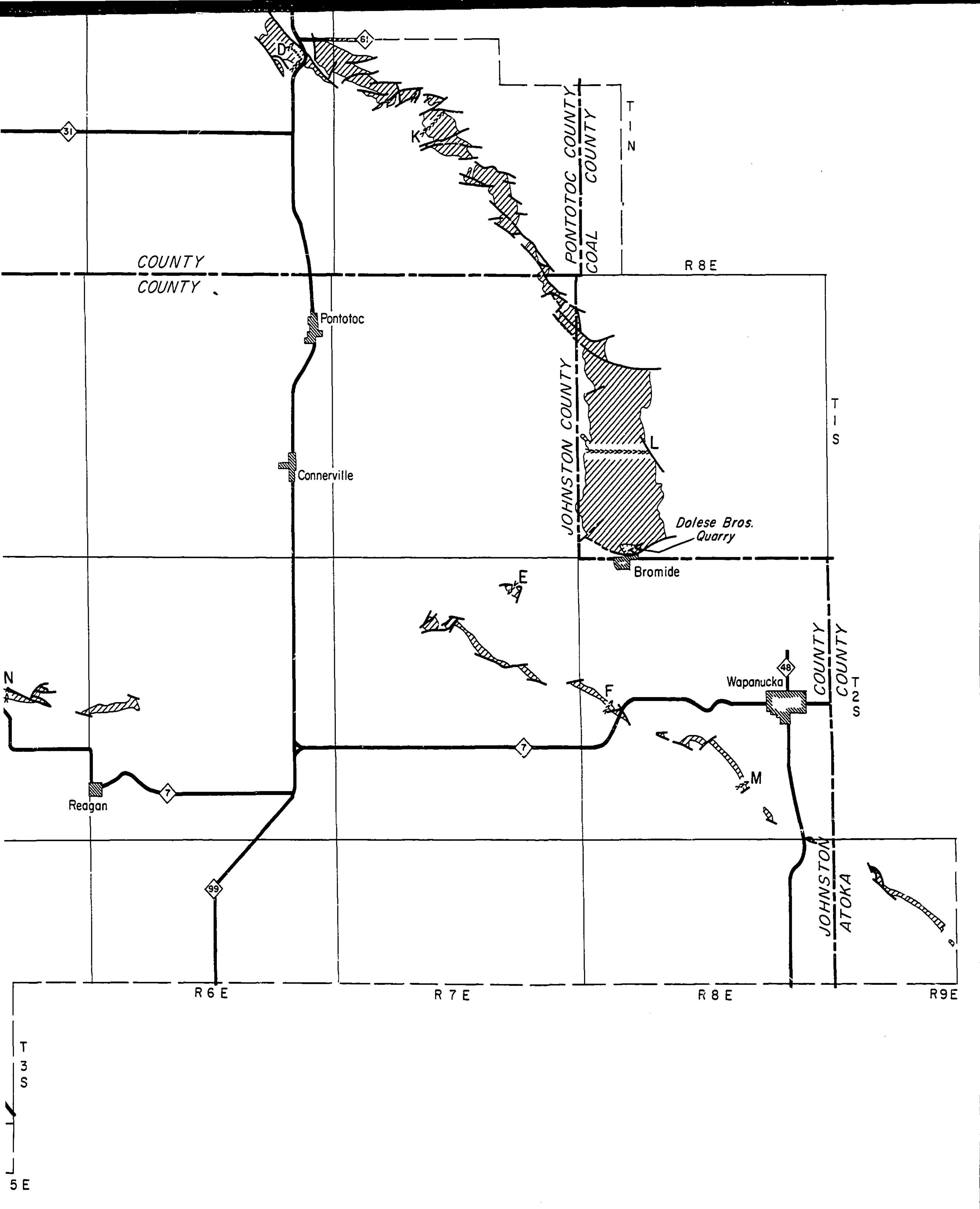
A
Location of measured sections
(arrows indicate direction of dip)
Modified from Ham, McKinley, and others 1954
R1W
R1E
R2E
GARVIN COUNTY
MURRAY COUNTY
Davis
7
77
T1S
S
Dolese Bros. Quarry
Q
Pooleville
R
R2W
T2S
MURRAY COUNTY
CARTER COUNTY
Mountain Lake
I
H
Woodford
53
R1W
R1E
R2E



Hickory
T 1 N
31
R 2 E
R 3 E
Sulphur
7
PONTOTOC
COUN
JOHNSTON
COUN
177
Q
G
P
COUNTY
COUNTY
MURRAY
JOHNSTON
12
Mill Creek
N
Reagan
R 2 E
O
R 3 E
T 3 S
J
T 3 S
R 4 E
R 5 E



Hickory
T
1
N
R3E
Sulphur
PONTOTOC
COUNTY
JOHNSTON
COUNTY
G
P
COUNTY
COUNTY
MURRAY
JOHNSTON
Mill Creek
N
Reagan
O
R3E
R6E
T
3
S
J
T
3
S
R4E
R5E



COUNTY
COUNTY
PONTOTOC COUNTY
COAL COUNTY
JOHNSTON COUNTY
JOHNSTON
ATOKA
COUNTY
COUNTY
T 1 N
T 1 S
T 2 S
T 3 S
R 8 E
R 6 E
R 7 E
R 8 E
R 9 E
5 E
Pontotoc
Connerville
Bromide
Dolese Bros. Quarry
Wapanucka
Reagan
D
K
L
E
F
M
N
61
31
7
7
7
48
99

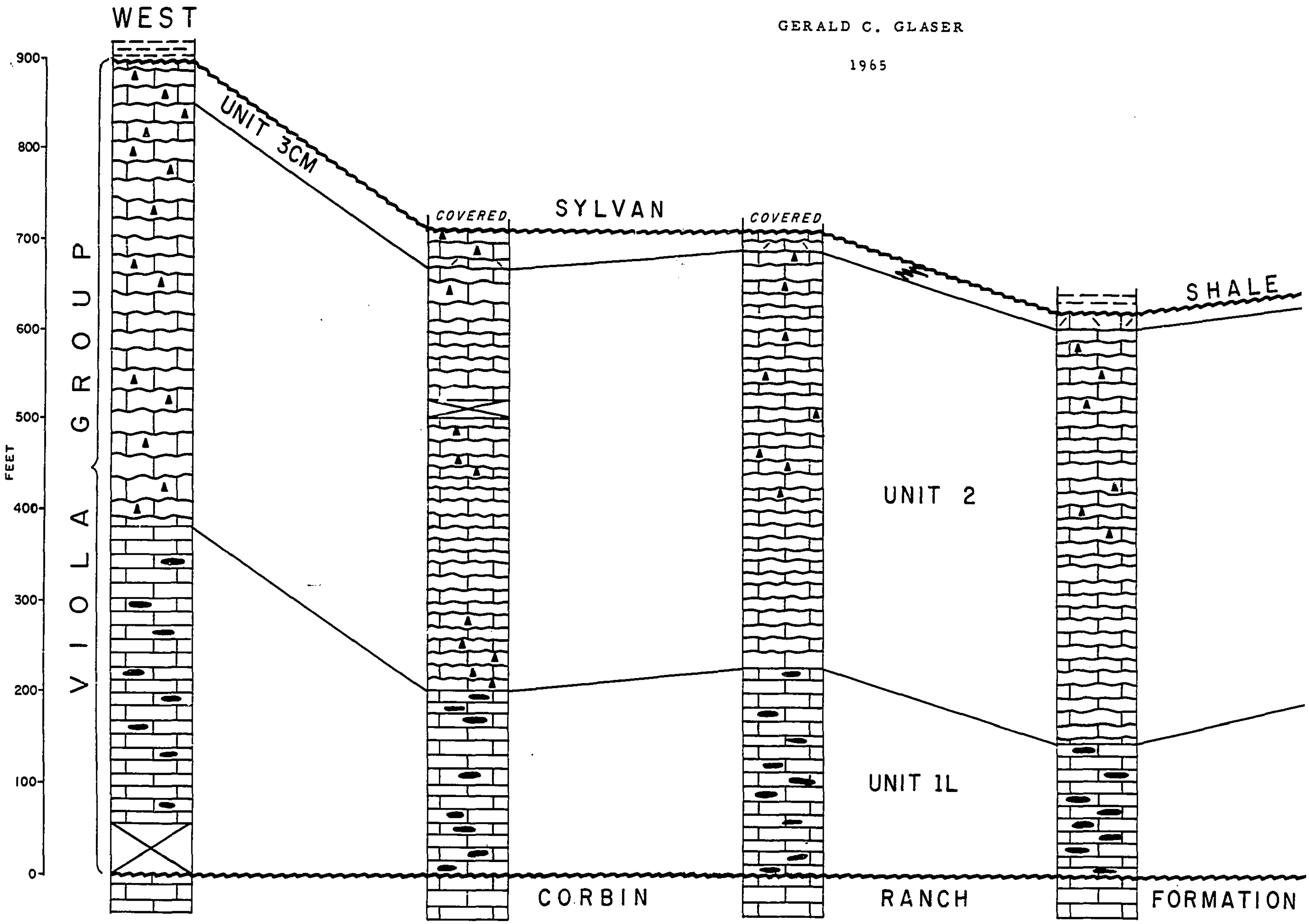
PLATE 7

REGIONAL STRATIGRAPHIC DIAGRAM OF THE VIOLA GROUP IN THE ARBUCKLE MOUNTAINS, OKLA

DATUM : BASE OF VIOLA GROUP

GERALD C. GLASER

1965



Section R

West Spring Creek

SE1/4 sec. 1, T. 1 S., R. 2 W.

Section I

Mountain Lake

E1/2 SW1/4 sec. 22, T. 2 S., R. 1 W.

Section H

U. S. Highway 77

Central E1/2 sec. 25, T. 2 S., R. 1 E.

Section Q

Rayford Quarry

NW1/4 NE1/4 sec. 28, T. 1 S., R. 2 E.

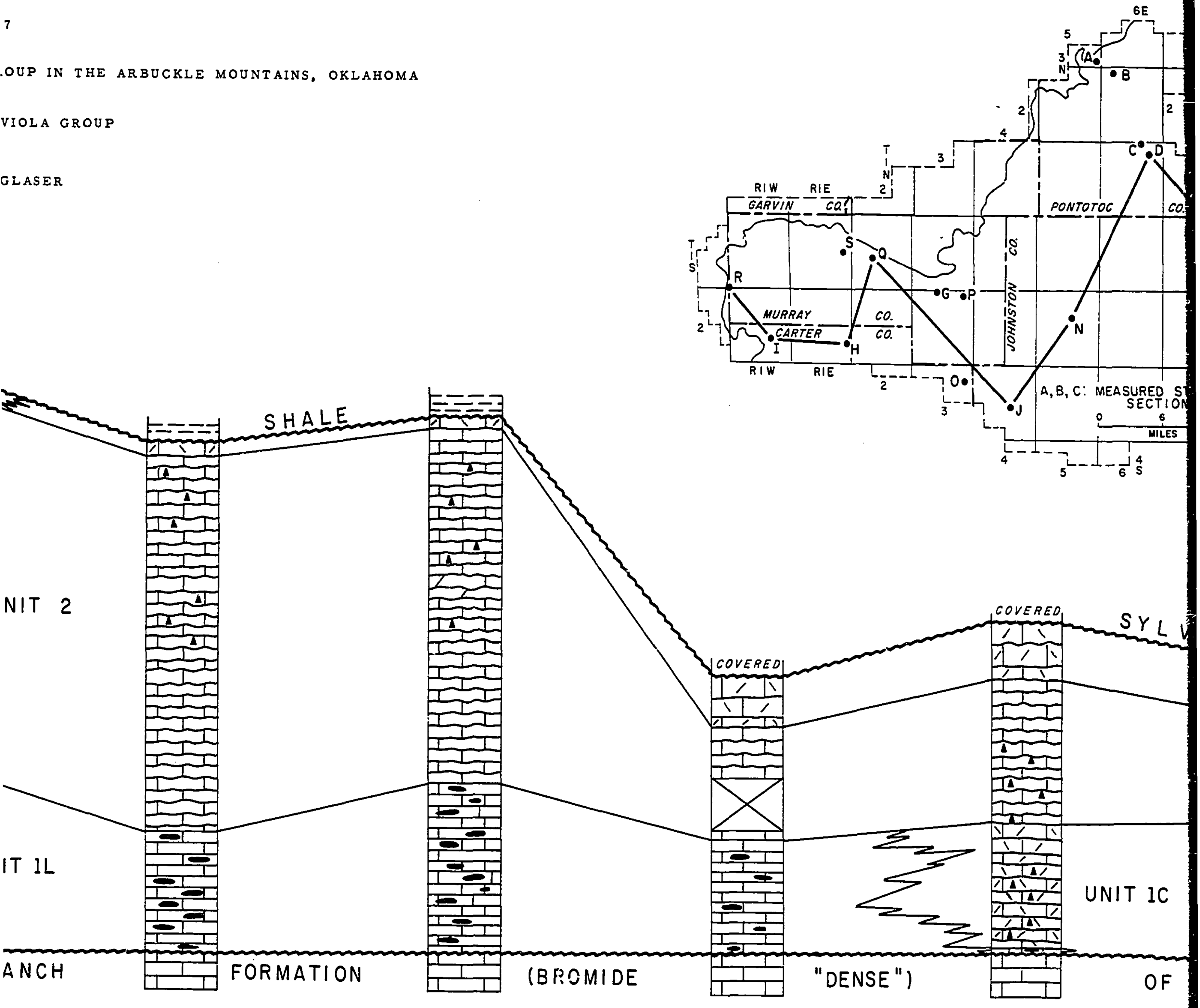
SE

7

.OUP IN THE ARBUCKLE MOUNTAINS, OKLAHOMA

VIOLA GROUP

GLASER



Section Q

Rayford Quarry

E. NW1/4 NE1/4 sec. 28, T. 1 S., R. 2 E.

Section J

Sycamore Creek

SE1/4 sec. 27, T. 3 S., R. 4 E.

Section N

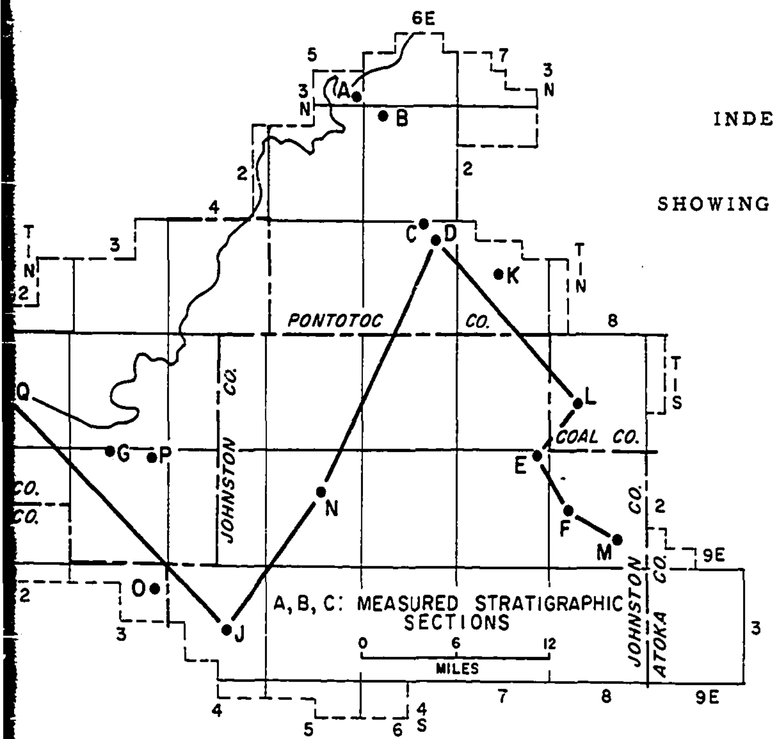
Southeast of Mill Creek

SE1/4 SE1/4 sec. 15, T. 2 S., R. 5 E.

Section D

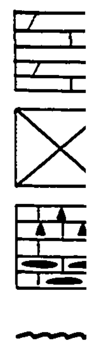
Oklahoma State Highway 99

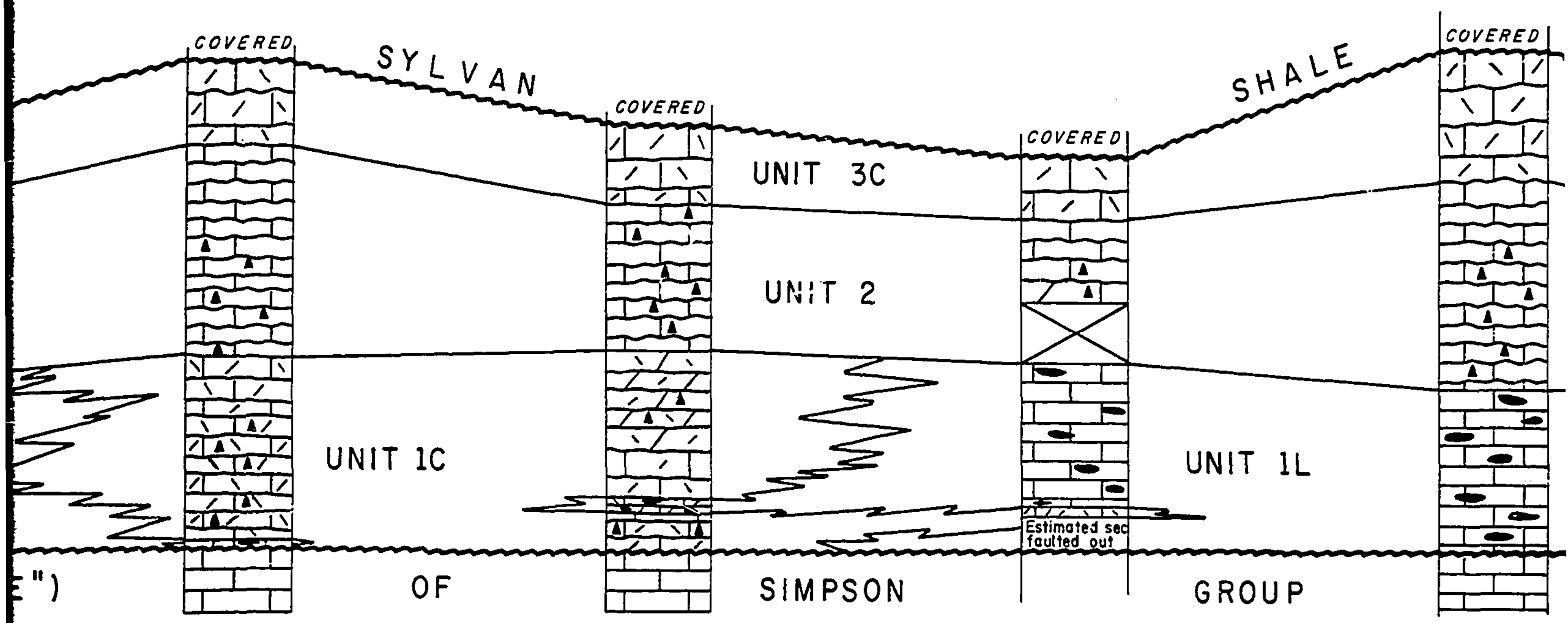
NW1/4 sec. 12 and NE1/4 sec. 11, T. 1 N., R. 6 E.



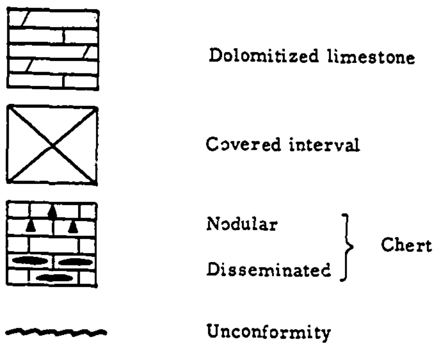
INDEX MAP OF ARBUCKLE MOUNTAINS

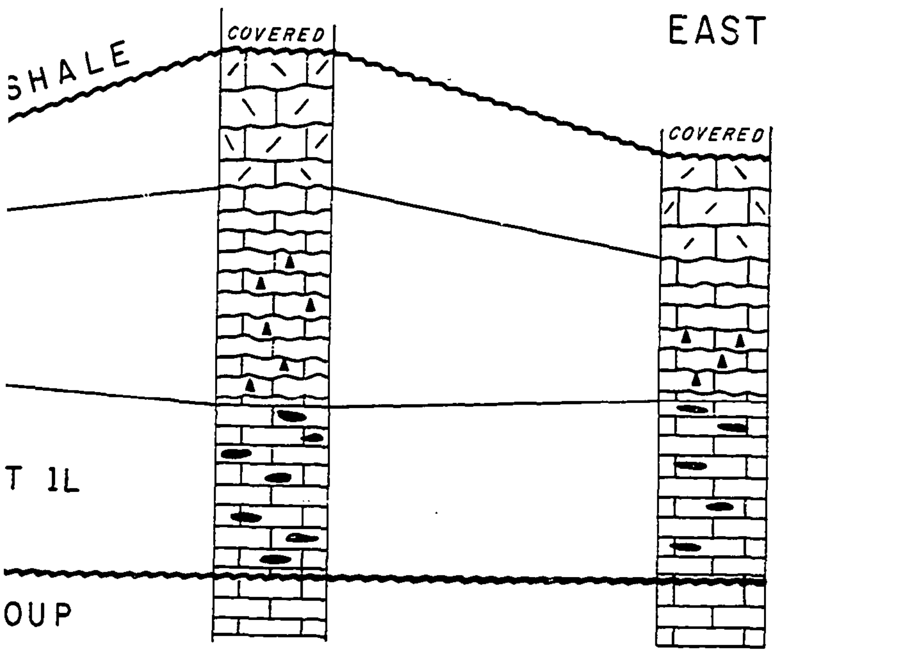
SHOWING LINE OF STRATIGRAPHIC DIAGRAM





Section D	Section L	Section E	Section F
Oklahoma State Highway 99	Mosely Creek	Witch Hole	Robertson Creek
NW1/4 sec. 12 and NE1/4 sec. 11, T. 1 N., R. 6 E.	S1/2 secs. 19 and 20, T. 1 S., R. 8 E.	NE1/4 SW1/4 sec. 2, T. 2 S., R. 7 E.	NW1/4 NE1/4 sec. 19, T.





Section F

Robertson Creek

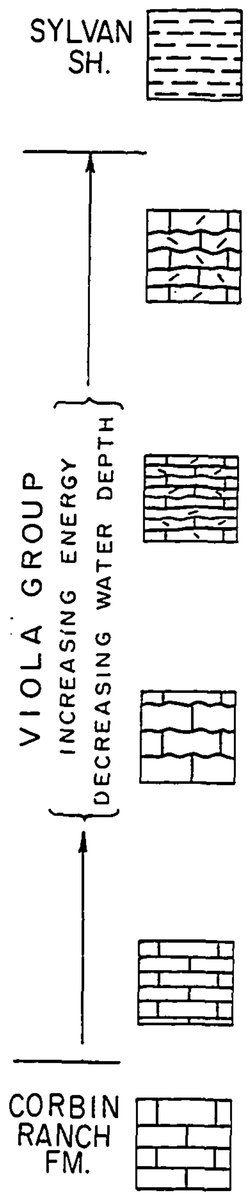
NW1/4 NE1/4 sec. 19, T. 2 S., R. 8 E.

Section M

Tributary to Sandy Creek

NE1/4 SE1/4 sec. 27, T. 2 S., R. 8 E.

EXPLANATION



Shale, greenish-gray to dark-gray, calcareous, even-bedded, generally containing abundant graptolites, indicating a moderately deep water depositional environment. At base locally is a 3-inch bed of pyritic phosphate conglomerate.

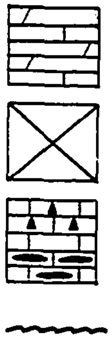
Sparry skeletal calcarenite, coarse- to medium-grained, uneven- to nodular-bedded, characterized by a dominance of echinoderm fragments together with trilobites, bryozoa, and brachiopods, all set in a cement of sparry calcite. Chert absent, but fossil shells locally are selectively silicified. This rock is a well-washed high-energy calcarenite indicating the shallowest water of the limestone depositional environment.

Skeletal fine-grained calcarenite and coarse-grained calcisiltite, uneven-bedded with constituent grains, generally in the size range from 40 to 80 microns, set in a cement of sparry calcite. Chert occurs as replacement layers, finely disseminated grains, and nodules. Faunal elements and depositional environment are essentially the same as those of the coarser calcarenites.

Burrowed skeletal calcarenitic mudstone in compact 4- to 6-inch uneven wavy-bedded layers, interstratified with discontinuous layers of shaly-bedded similar mudstones as much as 1/2 inch thick; dominant faunal elements are echinoderms, trilobites, and brachiopods, although graptolites are abundant in certain zones. Chert nodules are present locally and characterize thick sequences. This rock represents a depositional environment of intermediate energy and water depth.

Siliceous laminated calcite mudstone, even planar-bedded, characterized by a graptolite-trilobite-sponge spicule-linguloid brachiopod assemblage and absence of shelly fauna. Chert is present mainly as finely disseminated grains and as replacement layers. These characters indicate a depositional environment of lowest energy and deepest water for the limestone sequence.

Massive calcilutite, noncherty, containing ostracodes, sponges, and extremely sparse graptolites. Uppermost beds are burrowed and covered by a corrosion zone.

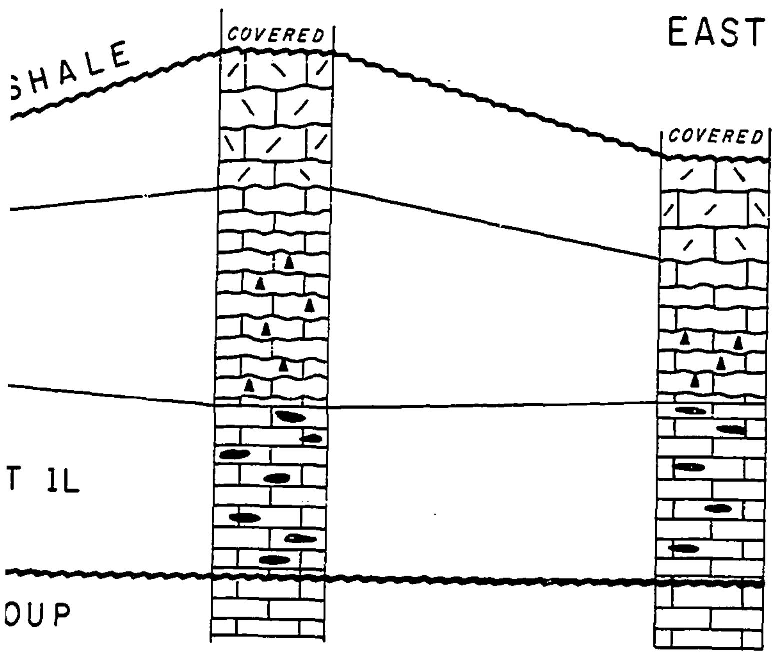


Dolomitized limestone

Covered interval

Nodular } Chert
Disseminated }

Unconformity



Section F

Robertson Creek

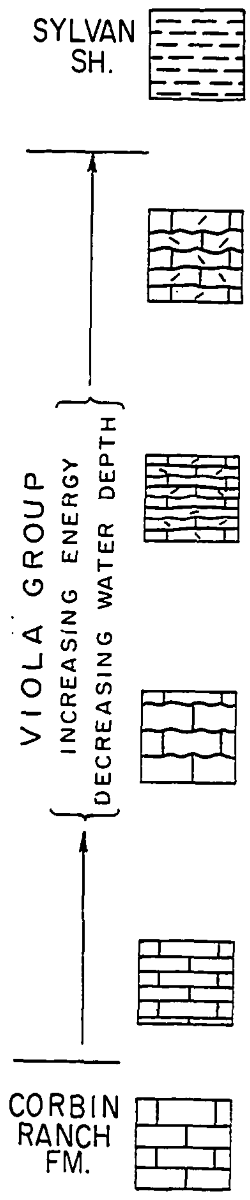
NW1/4 NE1/4 sec. 19, T. 2 S., R. 8 E.

Section M

Tributary to Sandy Creek

NE1/4 SE1/4 sec. 27, T. 2 S., R. 8 E.

EXPLANATION



Shale, greenish-gray to dark-gray, calcareous, even-bedded, generally containing abundant graptolites, indicating a moderately deep water depositional environment. At base locally is a 3-inch bed of pyritic phosphate conglomerate.

Sparry skeletal calcarenite, coarse- to medium-grained, uneven- to nodular-bedded, characterized by a dominance of echinoderm fragments together with trilobites, bryozoa, and brachiopods, all set in a cement of sparry calcite. Chert absent, but fossil shells locally are selectively silicified. This rock is a well-washed high-energy calcarenite indicating the shallowest water of the limestone depositional environment.

Skeletal fine-grained calcarenite and coarse-grained calcisiltite, uneven-bedded with constituent grains, generally in the size range from 40 to 80 microns, set in a cement of sparry calcite. Chert occurs as replacement layers, finely disseminated grains, and nodules. Faunal elements and depositional environment are essentially the same as those of the coarser calcarenites.

Burrowed skeletal calcarenitic mudstone in compact 4- to 6-inch uneven wavy-bedded layers, interstratified with discontinuous layers of shaly-bedded similar mudstones as much as 1/2 inch thick; dominant faunal elements are echinoderms, trilobites, and brachiopods, although graptolites are abundant in certain zones. Chert nodules are present locally and characterize thick sequences. This rock represents a depositional environment of intermediate energy and water depth.

Siliceous laminated calcite mudstone, even planar-bedded, characterized by a graptolite-trilobite-sponge spicule-linguloid brachiopod assemblage and absence of shelly fauna. Chert is present mainly as finely disseminated grains and as replacement layers. These characters indicate a depositional environment of lowest energy and deepest water for the limestone sequence.

Massive calcilutite, noncherty, containing ostracodes, sponges, and extremely sparse graptolites. Uppermost beds are burrowed and covered by a corrosion zone.

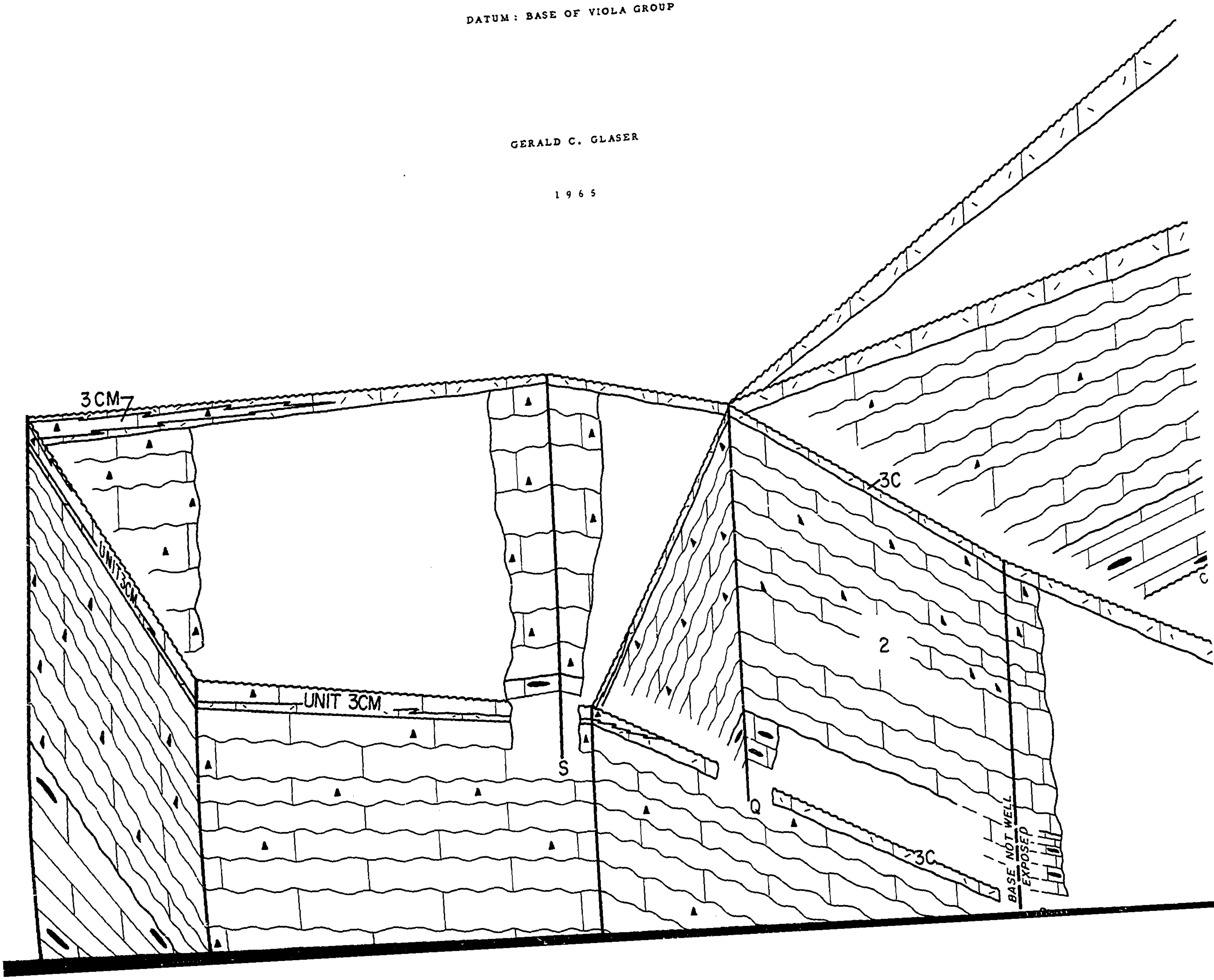
PLATE 8

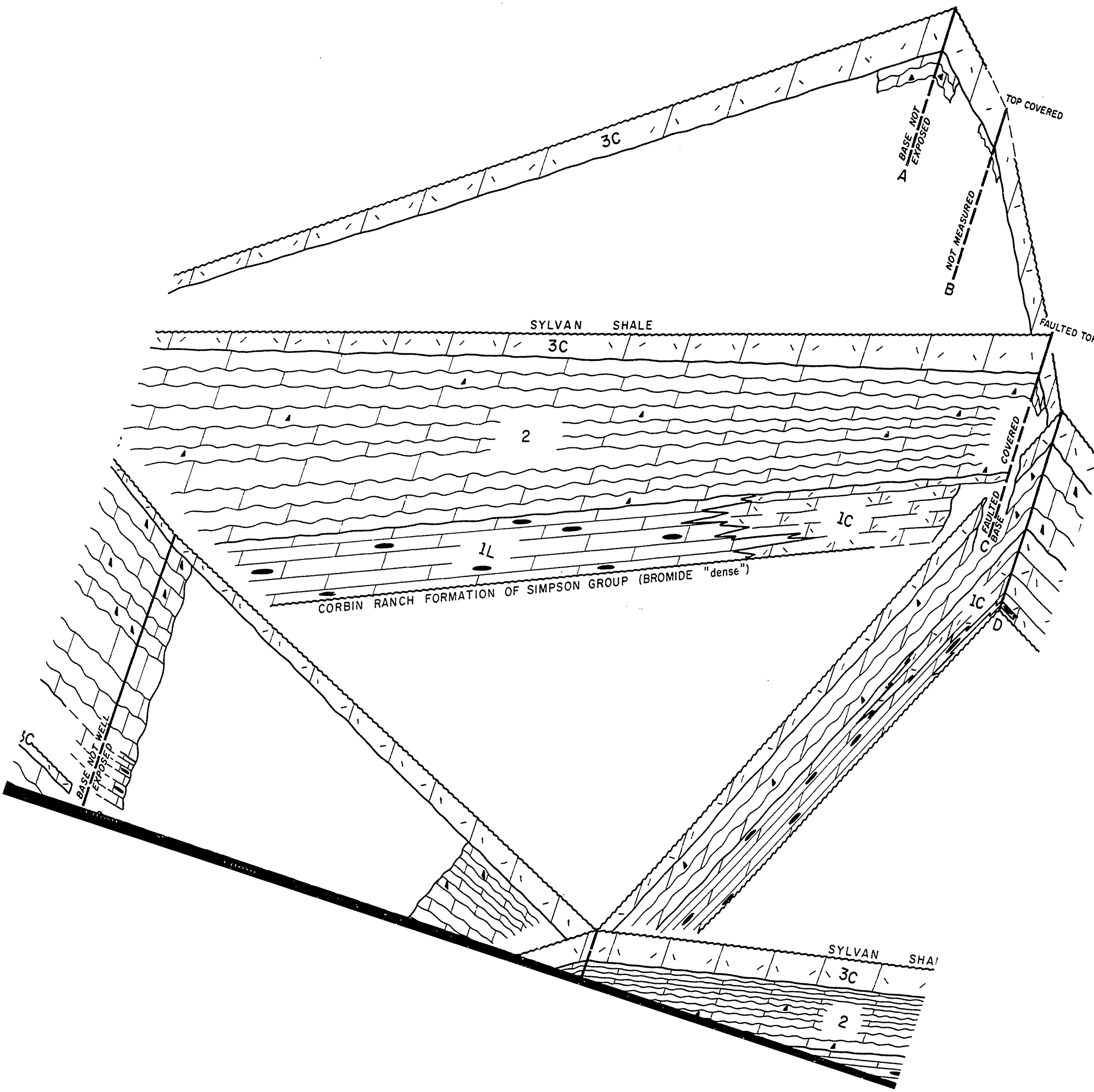
REGIONAL FENCE DIAGRAM OF THE VIOLA GROUP IN THE ARBUCKLE MOUNTAINS, OKLAHOMA
(LOCALLY RECONSTRUCTED)

DATUM: BASE OF VIOLA GROUP

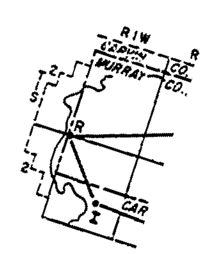
GERALD C. GLASER

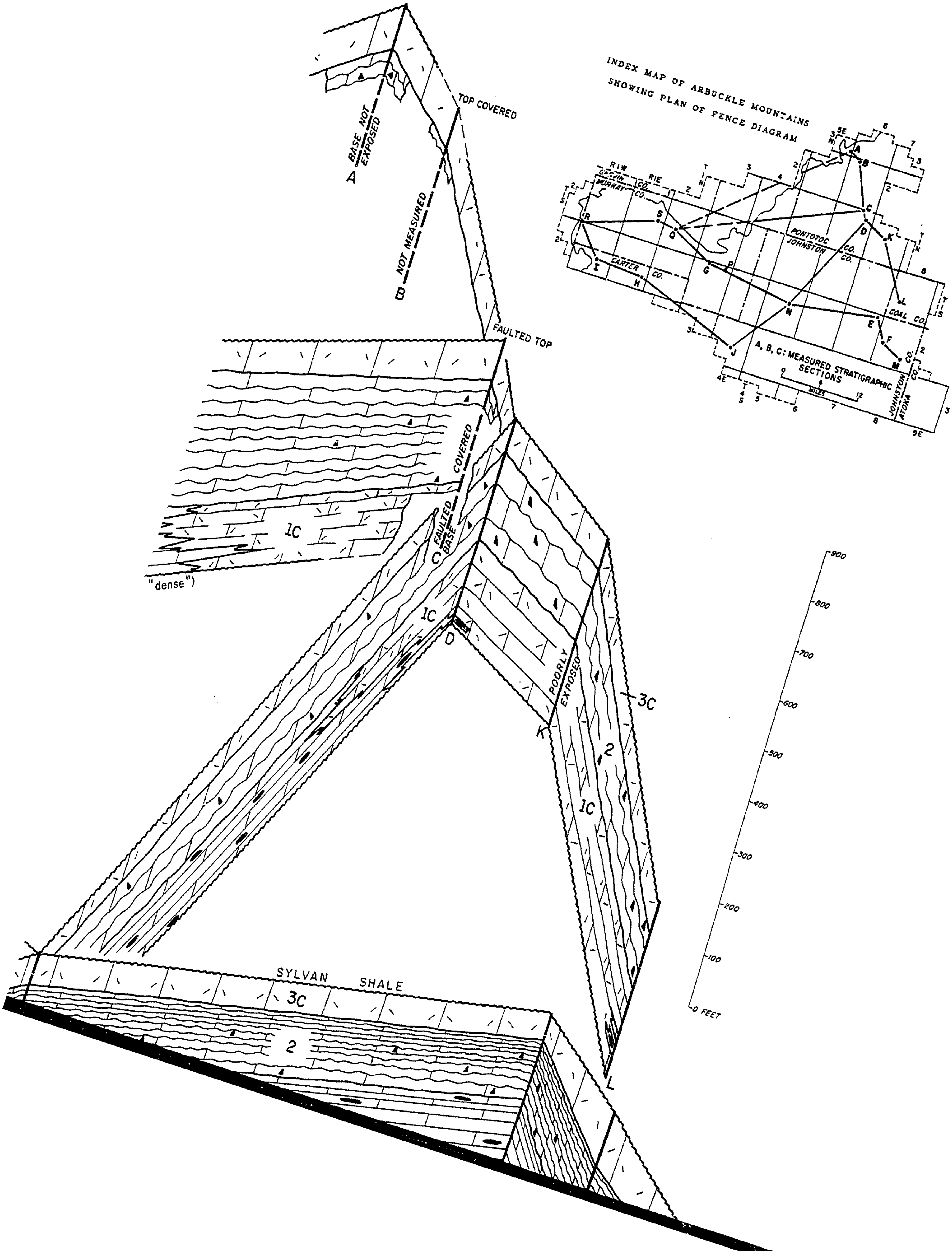
1965

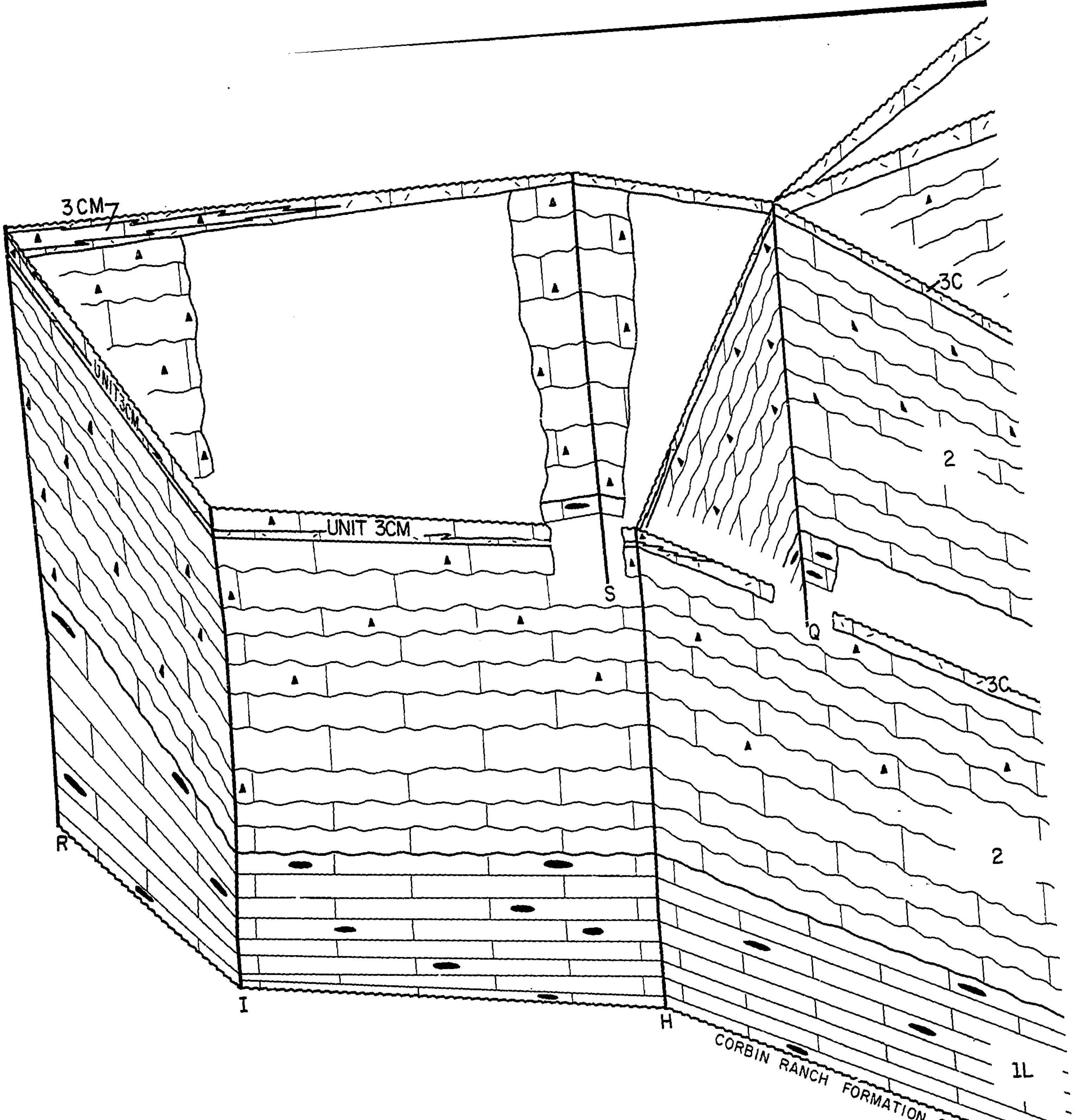


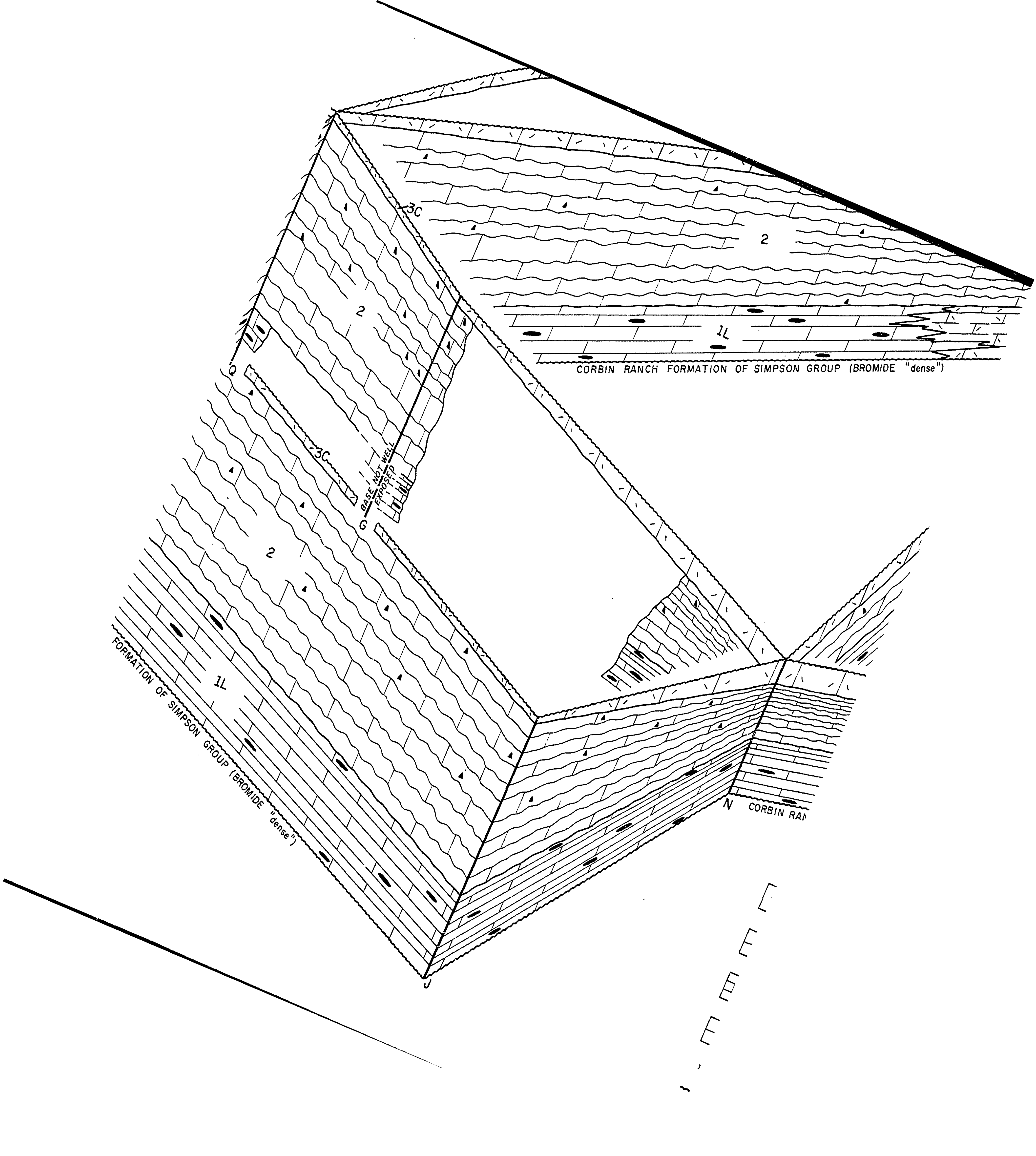


INDEX MAP OF
SHOWING PLA

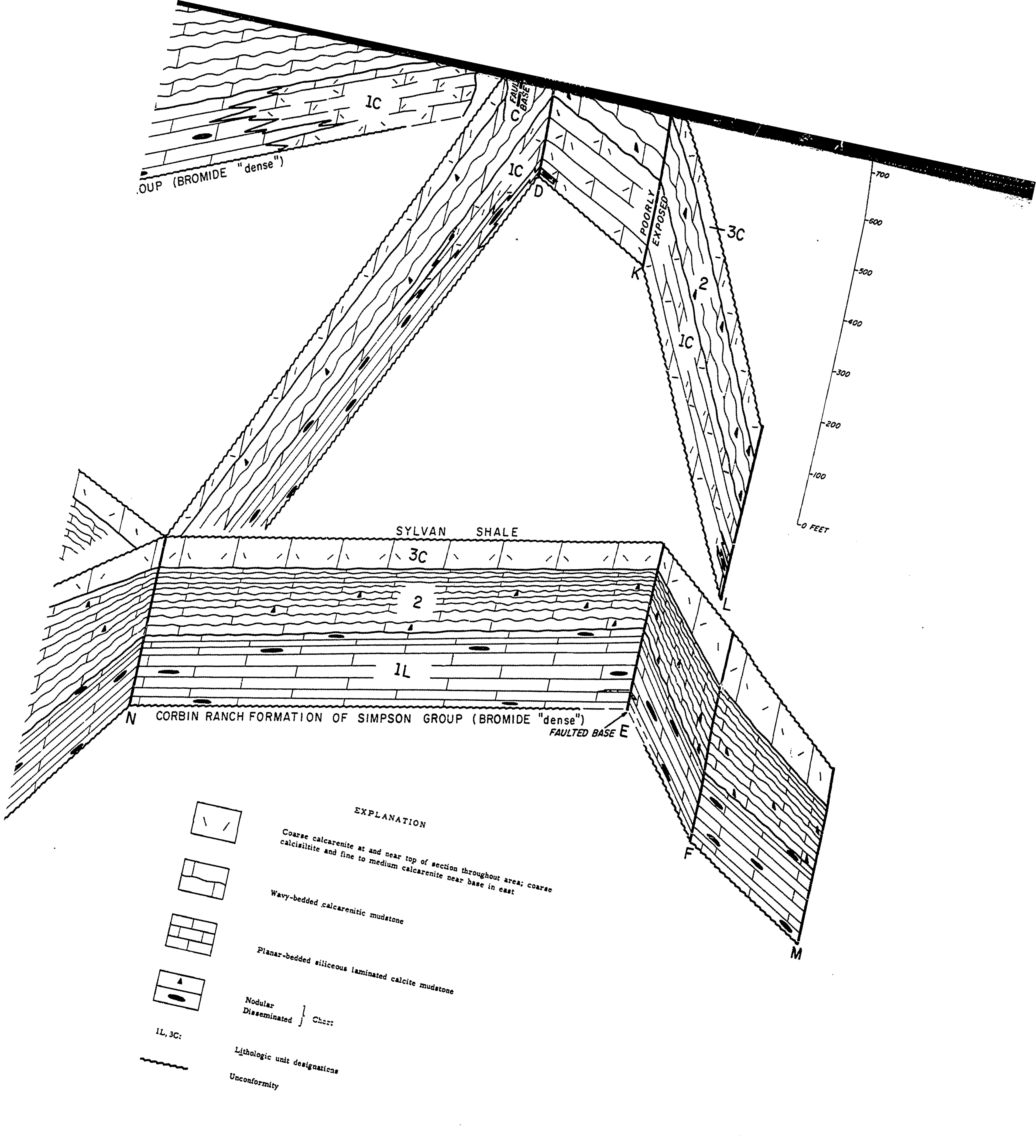



INDEX MAP OF ARBUCKLE MOUNTAINS
SHOWING PLAN OF FENCE DIAGRAM
MURRAY CO.
PONTOTOC CO.
JOHNSTON CO.
CARTER CO.
COAL CO.
ATOKA CO.
A, B, C: MEASURED STRATIGRAPHIC SECTIONS
MILES
BASE NOT EXPOSED
NOT MEASURED
TOP COVERED
FAULTED TOP
COVERED
FAULTED BASE
POORLY EXPOSED
"dense")
1C
2
3C
SYLVAN SHALE
A
B
C
D
K
L
0 FEET
100
200
300
400
500
600
700
800
900


3CM
UNIT 3CM
UNIT 3CM
S
3C
2
Q
3C
2
R
I
H
1L
CORBIN RANCH FORMATION OF SIMPSON GROU



3C
2
1L
CORBIN RANCH FORMATION OF SIMPSON GROUP (BROMIDE "dense")
Q
3C
BASE NOT WELL EXPOSED
G
2
1L
FORMATION OF SIMPSON GROUP (BROMIDE "dense")
J
N
CORBIN RAN



1C
FAULTED BASE
C
OUP (BROMIDE "dense")
1C
D
POORLY EXPOSED
K
3C
2
1C
L
700
600
500
400
300
200
100
0 FEET
SYLVAN SHALE
3C
2
1L
N
CORBIN RANCH FORMATION OF SIMPSON GROUP (BROMIDE "dense")
FAULTED BASE
E
F
M
EXPLANATION
Coarse calcarenite at and near top of section throughout area; coarse calcisiltite and fine to medium calcarenite near base in east
Wavy-bedded calcarenitic mudstone
Planar-bedded siliceous laminated calcite mudstone
Nodular
Disseminated
Chert
1L, 3C:
Lithologic unit designations
Unconformity