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PETROLOGY, ORIGIN AND TRACE ELEMENT GEOCHEMISTRY OF THE ADA FORMATION, SEMINOLE AND PONTOTOC COUNTIES, OKLAHOMA

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CONTENTS

Page

TABLES

ILLUSTRATIONS

Figure		Page

Plate

Plate		Page

PETROLOGY, ORIGIN AND TRACE ELEMENT GEOCHEMISTRY OF THE ADA FORMATION, SEMINOLE AND PONTOTOC COUNTIES, OKLAHOMA

INTRODUCTION

The Ada Formation crops out in both Seminole and Pontotoc Counties, Oklahoma, in a north-south belt 1 to 4 miles wide. The extension of the Ada and overlying Vanoss Formation is mapped as a single stratigraphic rock unit in southern Okfuskee County, north of the area of investigation. The formation ranges in thickness from 250 feet to 60 feet, from south to north respectively. The variation in thickness is due to: (1) less deposition northward, (2) topography of the floor of the environment of deposition, and (3) to channeling at the base of the overlying Vanoss Formation.

The writer has subdivided the Ada Formation into four members on the base of their lithologic characteristics. They are: lower sandstone member, middle conglomerate member, upper sandstone member, and the uppermost shale member.

The Ada Formation unconformably overlies the Pawhuska Formation in Okfuskee County, the Vamoosa in

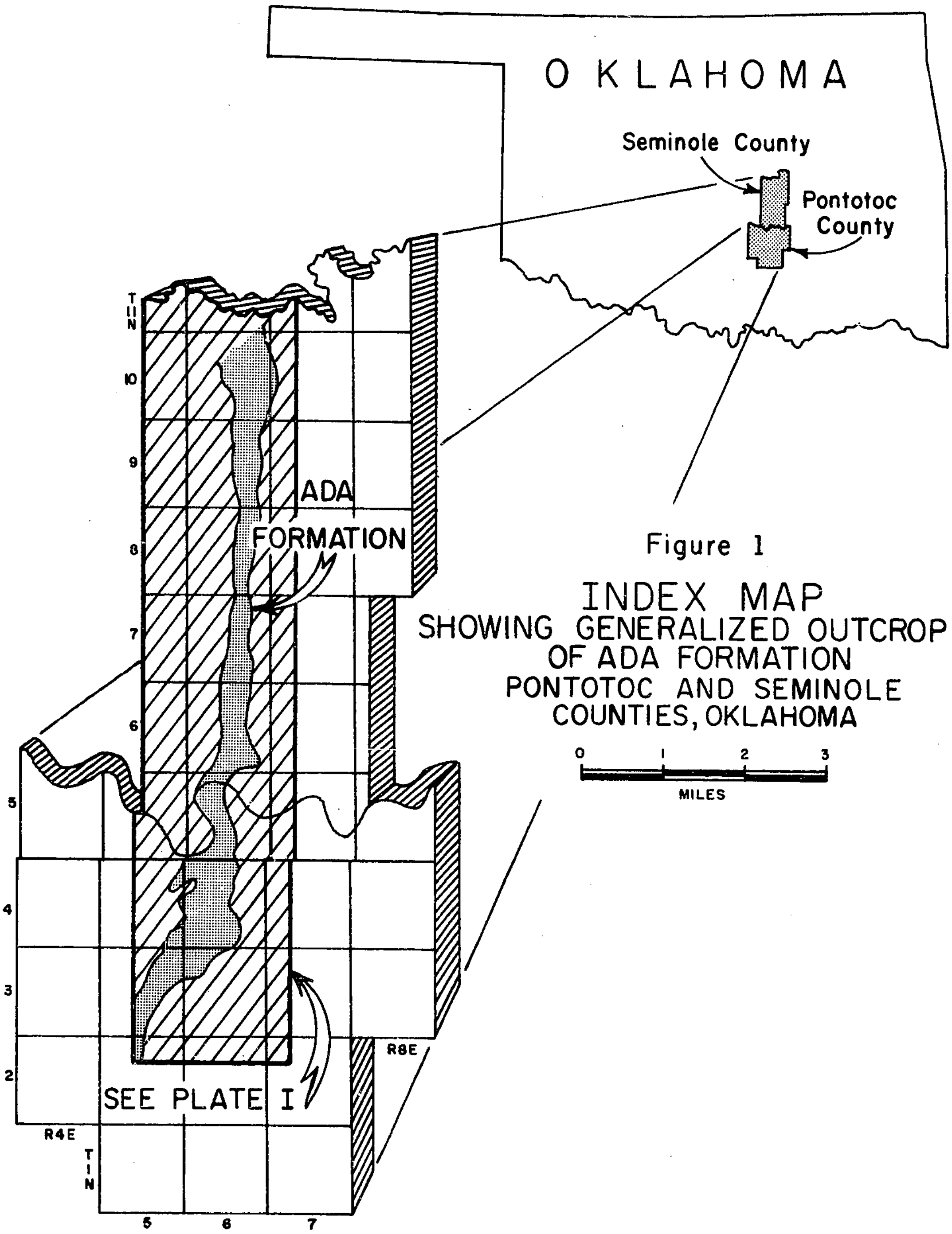


Figure 1

INDEX MAP
SHOWING GENERALIZED OUTCROP
OF ADA FORMATION
PONTOTOC AND SEMINOLE
COUNTIES, OKLAHOMA

Seminole, and northern parts of Pontotoc County, the Hilltop Formation, Bell City Formation, Francis Formation, Seminole Formation, and Viola and Simpson Group in the central and southern parts of Pontotoc County.

The middle conglomerate member is composed of limestone pebble-cobble conglomerate (calclithite), derived from the Arbuckle area. Examination of lithologic affinities of the limestone clastics from Ada conglomerate, and their shape-index analysis provided information about the regional tectonic setting of the source area, and the environment of deposition.

The entire formation grades from a conglomeratic sandstone and limestone conglomerate in the south into fine sandstone, siltstone, and shale to the north. The increasing coarseness of the detrital material occurs in the same direction as the increasing total unit thickness, but in a direction opposite to that of increasing thickness of the shale member.

Quantitative studies of the heavy mineral suite in the Ada sandstones and shales show that their distribution in the environment of deposition of the Ada sediments is governed by their specific gravities.

Petrographic investigation shows that Ada sandstone is a silty, calcareous, clayey, and siliceous, bimodal to trimodal, immature to mature impure orthoquartzite. Feldspar is absent, or present in trace amounts. The apparent cyclic nature of deposition of the coarse sandstone, siltstone, and shale units can not be attributed to any specific cause; it may reflect diastrophic, climatic, or eustatic changes.

The uppermost shale member of the Ada Formation consists of four distinctive shale units. From bottom to the top they are: Ca-montmorillonite predominates at the base; kaolinite and Na-montmorillonite overlies the basal shale unit; the upper shale unit, which consists mainly of illite, and chlorite; and the uppermost shale unit, which is composed predominantly of mixed-layered illite-montmorillonite and chlorite.

Trace element analyses were made for boron, thorium, zirconium, chromium, titanium, vanadium, nickel, copper, manganese, magnesium, and calcium. The results are employed in the interpretation of the depositional environment.

Purpose of Investigation

This investigation has been undertaken to provide information about the following aspects of the geologic history of the Ada Formation.

1. Character of the source area which supplied the detritus (lithology, climate, and relief).

2. Physico-chemical character of the depositional environment (distribution of lithic types and their interrelationships).

3. Mechanism of diagenesis with particular emphasis

on carbonates, clays, and quartz grains.

4. Determination of the origin and paragenesis of the silica versus carbonate cement and clay constituents in the Ada sandstones.

5. The factor or factors that were responsible for the variation of environmental conditions from very coarse to very fine clastics and subsequent deposition of the orthochemical rocks.

Previous Investigations

Investigation of the Ada Formation has been confined primarily to the regional studies of the Virgilian Series in southeastern Oklahoma. The writer has found no published detailed work on the petrology and geochemistry of the Ada Formation.

The name Ada was applied by Morgan (1924) to a series of 100 feet of sedimentary rocks composed of clay, shale, sandstone, and limestone conglomerate. The type area lies within and to the west of the town of Ada. Morgan also mapped the distribution of the Ada Formation in the Stonewall Quadrangle.

Morgan (1924) described the occurrence of the Ada Formation from a point south of Roff, continuously exposed northward across Pontotoc County into Seminole County, where it merges with the lower red beds. He dated the Ada Formation as Pennsylvanian (Monongahela) in age and correlated the lower part of the Buck Creek Formation and upper part of the Pawhuska Formation in northern Oklahoma, with that of the Ada Formation. He tentatively correlated the Ada Formation with Pueblo Formation of Texas, and lower part of Wabaunsee Group of Kansas. Morgan (1924) described the boundary between the Ada and Vamoosa north of the Canadian River as a conformable contact.

Morgan (1924) collected some marine fossils from the Ada Formation. Based on these marine fossils he suggested that the Ada Formation had been deposited in a marine environment. These fossils were collected from near the unconformable contact of the Ada and Francis Formations. Since the contact at that point is not clear, there is a possibility that they may have been derived from the Francis.

Miser (1926) based on his field work showed an abrupt termination of Ada outcrops in the southern part of Seminole County. This is illustrated on the Geologic Map of Oklahoma.

Leversen (1929) correlated the Pawhuska with the Ada Formation, tentatively. His suggestion was based on his field observations.

Green (1936) placed the Pawhuska Formation at the base, but within the Ada Formation.

In a guidebook prepared by the Shawnee Geological Society (1938) the Pawhuska is traced southward across Seminole County and demonstrates that it is older than the Ada Formation.

Tanner (1953) mapped Seminole County and in 1954 he published a paper describing the unconformable relationships between the Vamoosa, Ada, and Vanoss Formations. He found three major unconformities in the Virgilian Series as follows: at the base and within the Vamoosa Formation, at the base of the Ada, and between the Ada and Vanoss Formations. The map pattern made by these unconformities was interpreted by Tanner to reflect a shoreline during Virgilian time which trended east-west.

Giles (1963) mapped the outcrops of the Ada Formation in Pontotoc County, using Morgan's map as a base.

Method of Study

This project includes both field and laboratory investigations of a sedimentary rock unit that is composed mainly of terrigenous material with a few discontinuous chemical rocks. The field work involved section measurement, sample collection, and observations of lithic changes as well as stratigraphic and structural relationships of the Ada Formation. The field work was carried out in the fall of 1965.

For a detailed investigation of each rock type in the Ada Formation, the following procedures were employed.

Sandstones.--The procedures used for the study of the sandstones involve studies of thin sections (a format of a super-detailed thin section description was adapted from Folk, 1961). X-ray diffraction investigations and differential thermal analyses both were used to confirm the mineralogical data obtained from thin sections. In addition, grain size analyses and heavy mineral analyses were made by using the standard techniques.

Limestone Conglomerates.--Detailed studies were made on the composition of the pebbles and cobbles. The lithology of these coarse carbonate clastics were investigated under the binocular microscope, cut and polished surfaces, and thin sections. Both the allochemical and orthochemical constituents and their internal and external textures were studied for the evaluation of the source rocks. Size, shape index, roundness, sorting, and cementation of the limestone pebbles and cobbles were statistically analyzed in the field and laboratory. The data obtained by these methods were used for the interpretation of the depositional environment.

Shales.--Size fractionation was made by the methods of decantation, centrifuge, and pipette. X-ray diffraction studies were made using powder-pack, sedimented, solvated, and fired samples. In addition, differential thermal analyses, and thin sections were also used in studies of the Ada shale.

Emission spectographic analyses were made for trace element determination of selected shale and sandstone samples.

STRATIGRAPHY

Nomenclature

Morgan (1924) applied the name Ada to a sequence of about 100 feet of clay, shale, sandstone, and limestone conglomerate. He mapped the Ada (Middle Virgil age) to the northern boundary of the Stonewall Quadrangle. A thickness of about 60 feet is given for the Ada Formation in the northern part of the quadrangle. Morgan described the Ada Formation in this area as being composed of "clastic material" derived from the Arbuckle Mountains. His suggestion was based on fossils collected from shale and limestone conglomerate.

General Statement

The Ada Formation crops out in both Seminole and Pontotoc Counties in a north-south belt (Plate I) 1-4 miles wide. The city of Seminole and the western part of the town of Ada are located on the Ada Formation.

The formation is 60 to 250 feet thick, thickening and thinning irregularly. The variation in thickness is probably due in part to less deposition northward, being farther from the source area, irregular topography of the floor of the sea, and channeling at the base of the overlying Vanoss Formation.

The lateral correlation of the different rock units in the Ada Formation is practically impossible because of the lack of continuous, resistant beds throughout the area, and variation in thickness of the beds in short distances along the outcrop.

The Ada Formation can be divided into four members in both Seminole and Pontotoc Counties. They are the lower sandstone member, middle conglomerate member, upper sandstone member, and uppermost shale member.

The lowest unit of the Ada Formation is a characteristic beach-type sandstone, resembling the underlying Vamoosa Formation, and thus probably was in part derived from erosion of Vamoosa rocks during the subsequent marine transgression.

In southern Seminole County, the basal portion of the Ada is at many places conglomeratic. Its similarity to Vamoosa conglomerates suggest that, coarse Vamoosa clastics must have been exposed. The sea inundated the Vamoosa Formation, and most of the sediments deposited in this shallow environment were sand and clay-sized detrital materials with rare introduction of limestone pebbles, cobbles, and boulders. However, the majority of these terrigenous constituents were derived from the Arbuckle Mountains.

The lowest part of the Ada Formation consists of cross-bedded and contorted chert conglomeratic sandstones with a thickness ranging from 10 to 20 feet, and which crop out in the northern part of Pontotoc County and the southern portion of Seminole County. These chert conglomeratic sandstones are similar to the underlying rock units, and it is thus difficult to differentiate one from the other. A detailed field study is necessary to find the exact contact between the Ada and the underlying Vamoosa Formation.

The middle member of the Ada Formation consists of limestone pebble-cobble conglomerates, which are well exposed to the west of Ada. To the north in the southern part of Seminole the conglomerate member diminishes in both thickness and grain size. The limestone pebbles and cobbles are replaced in places by chert pebbles in the upper sandstone member, which in turn grade into shale. The conglomerate member is slightly cross-bedded, and contains some irregularly distributed sandstone lenses. Biotite flakes are present sporadically throughout the formation in various amount.

Bedding planes in the conglomerate member are obscured. The thickness of this member ranges from 15 feet down to zero.

The limestone beds of the Ada Formation are composed of irregularly-bedded, microcrystalline to cryptocrystalline calcite (micrite), with scarce, partially silicified marine fossil debris. The limestone layers are limited to the lower one-third of the formation. A typical limestone unit of the Ada Formation is exposed in the central part of Seminole County near Snomac.

More than 80 percent of the sandstones in Pontotoc County are heavily to moderately stained with asphaltic materials. The asphalt content in the sandstone units decreases northward.

The lower sandstone member of the Ada Formation is not completely exposed in the study area. However, the upper sandstone member is more or less well exposed in both Seminole and Pontotoc Counties. The upper sandstone member is a ripple-marked, cross-bedded, contorted, laminated to massive sandstone, interbedded with minor shale and siltstone. The silt content of the upper sandstone member occurs both as an admixt in the fine- to medium-grained sandstones, as platy- to thin-bedded siltstone layers, interbedded with the sandstones. The thickness of the beds in the upper sandstone member ranges from platy- to massive-bedded along the outcrop. The base of the upper sandstone member is gradational with the top of the middle conglomerate member. There is no evidence for the presence of an unconformable surface. The top of the upper sandstone member grades into the silty gray shale at the base of the uppermost shale member. Mean size tends to become finer in the upper sandstone member as compared to that of the lower member. The asphaltic sandstones are limited to the base of the upper sandstone member.

The uppermost shale member (fig. 2) of the Ada Formation consists of black to brownish gray claystone at the base, overlain with red and green shale, which in turn is interbedded with thin-bedded, calcareous sandstone and siltstone layers. The thickness of the shale member increases to the north. The alternation of the hard, well-cemented, resistant sandstone with soft shale gives a step-like outcrop pattern to the upper unit of the Ada on weathered surfaces. An excellent exposure of the Ada shale may be seen in the road-cut north of the Canadian River bridge (sec. 4, T. 5 N., R. 6 E.), measured section B, Plate I.

Regional Stratigraphic Relations

The Virgilian Series in southeastern Oklahoma consists of three distinctive stratigraphic units. The Vamoosa Formation (Early Virgilian in age) with a basal unconformity overlies the rocks of upper Pennsylvanian (pre-Virgilian age) (fig. 2). The top of the Vamoosa is likewise marked by an unconformity. The Ada Formation (Middle Virgilian in age) unconformably overlies the Vamoosa Formation. The truncation of the top of the Vamoosa by the basal sandstones of the Ada Formation occurs along an angular unconformity, which is characterized by its low and indistinct angular relationship. The unconformity between the Ada and Vamoosa Formations extends throughout Seminole County and the northern portion of Pontotoc County.

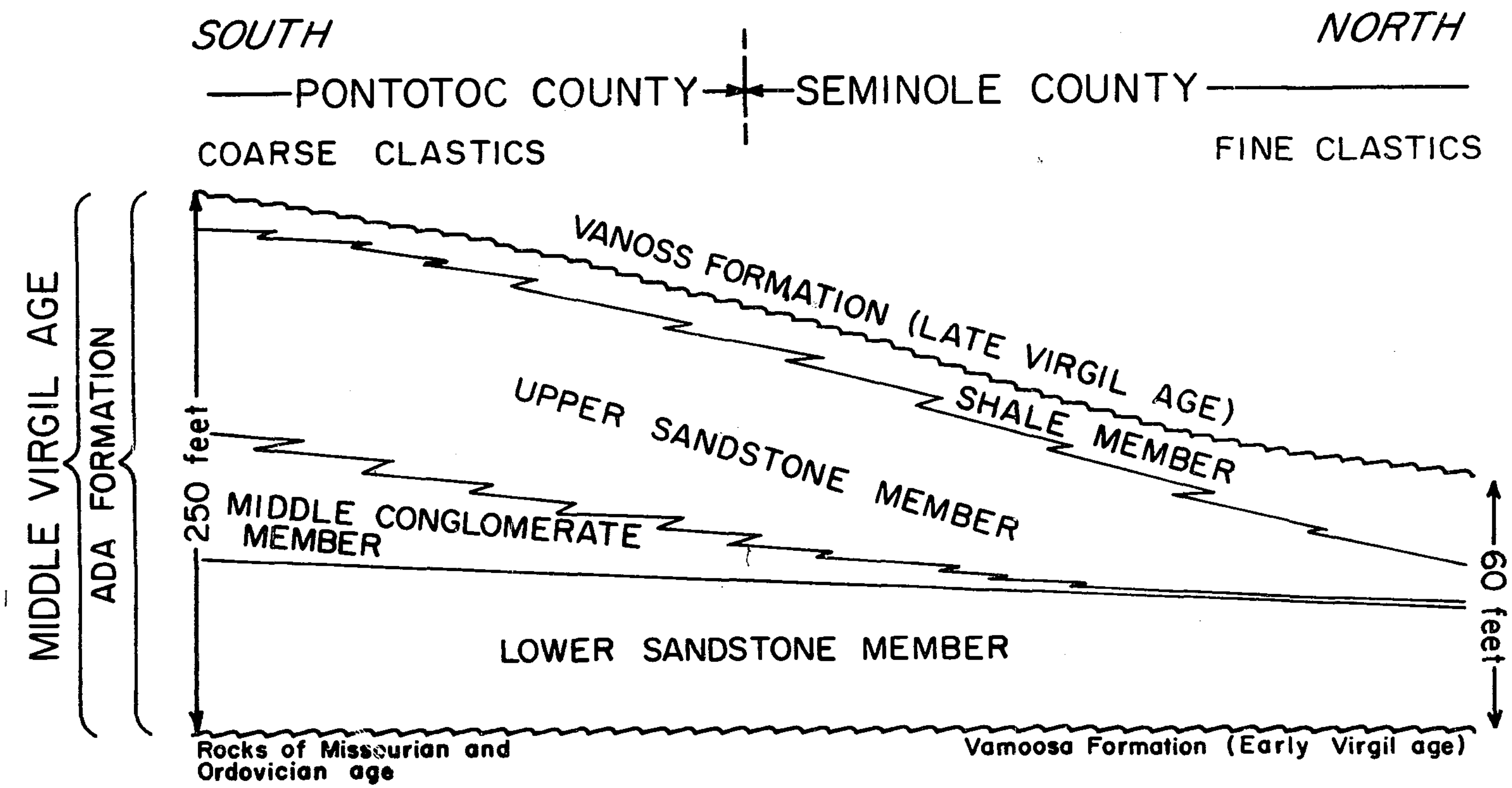


Figure 2
SCHEMATIC CROSS-SECTION OF ADA FORMATION
PONTOTOC AND SEMINOLE COUNTIES, OKLAHOMA
Assad Iranpanah - 1966

Morgan (1924) noted that north of the Canadian River the Ada Formation seems to rest conformably upon the Vamoosa, but toward the south it overlaps several underlying formations.

The Ada Formation unconformably overlies the following formations in Okfuskee, Seminole, and Pontotoc Counties:

Pawhuska Formation	Okfuskee County
Vamoosa No. 12 Vamoosa No. 11 Vamoosa No. 9 Vamoosa No. 8 or 5	Seminole County
Vamoosa No. 1 Hilltop Formation Bell City Formation Nellie Bly, Coffeyville } Francis Formation Seminole Formation Viola and Simpson Group (Ordovician)	Pontotoc County

The unconformity between the Ada and the underlying Vamoosa Formation represents an uplift in the source area, and probably marks the last important orogenic activity in Hunton arch.

The unconformable contact between the Ada and the overlying Vanoss Formation is only slightly curved, representing one or more, but smaller uplifts (Plate I). The Ada is completely cut-out by the Vanoss (fig. 3), which rests on the Cambrian and Ordovician rocks of the Arbuckle Group to the south. The trace of the unconformable contact between the Ada and the Vanoss in the central part of Pontotoc County and the central part of Seminole County is

PRESENT AND POSTULATED FORMER EXTENT OF VIRGILIAN SERIES IN SOUTHERN OKLAHOMA

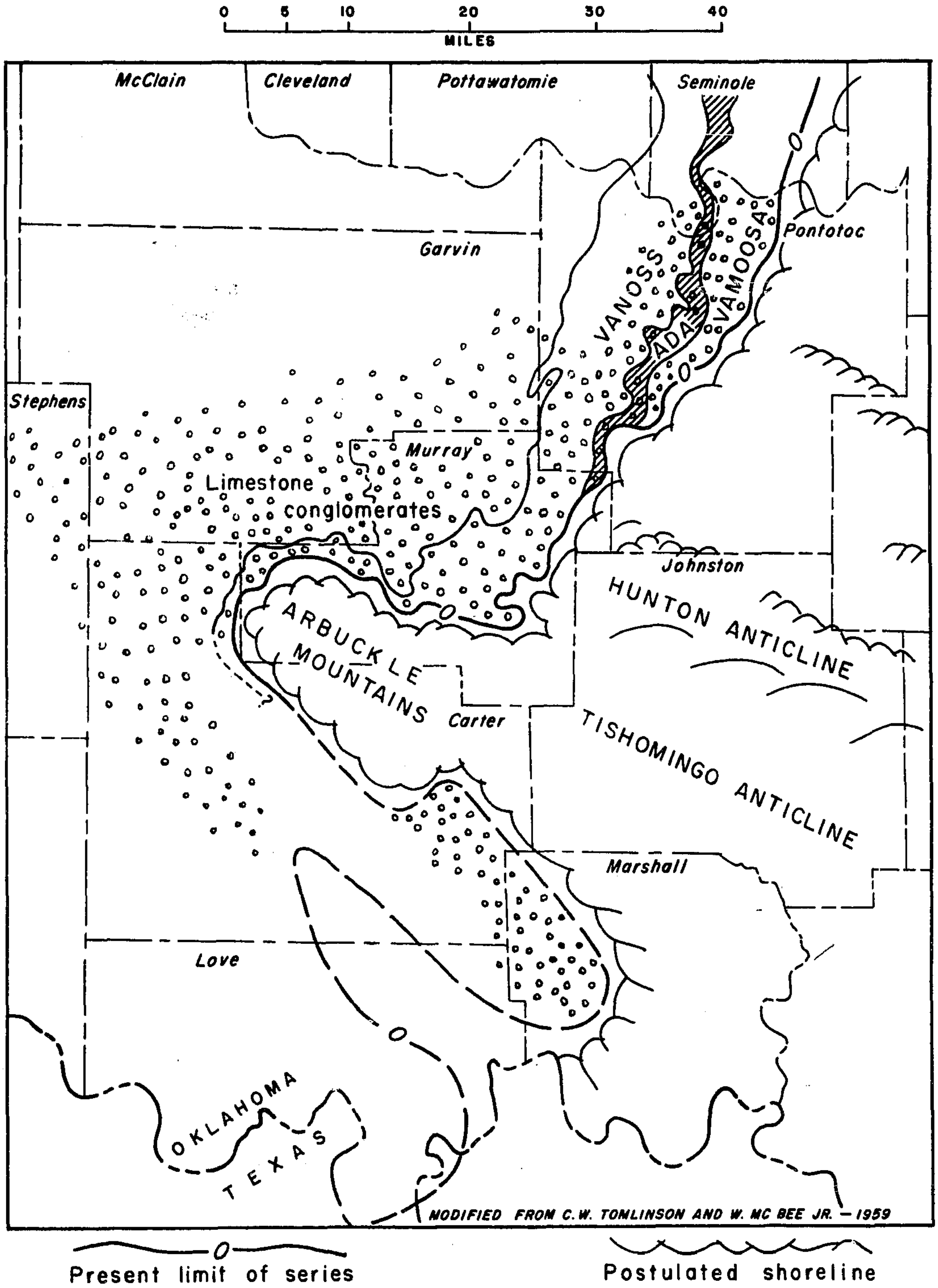


Figure 3.

characterized by channeling along irregular surfaces. The contact is difficult to distinguish in the northern part of Seminole County, and beyond the North Canadian River the Ada and Vanoss are grouped together and referred to as a single stratigraphic rock unit.

MIDDLE CONGLOMERATE MEMBER

General Statement

The middle conglomerate member of the Ada Formation lies conformably between the lower and the upper sandstone members. The maximum thickness of this member measured in section D, No. 13 is approximately 15 feet. The thickness of the conglomerate varies greatly from south to north on a local scale. In general, the thickness of the conglomerate decreases to the north. The limestone conglomerate grades into chert conglomeratic sandstone, and then into shale in the central and northern parts of Seminole County. The limestone conglomerates are well-developed in Pontotoc and the southern part of Seminole Counties. Chert pebbles and biotite flakes are common constituents in the southern outcrops of the Ada conglomerate.

The Ada conglomerate is a limestone pebble-cobble conglomerate derived from the Arbuckle Mountains. These coarse clastics of the middle Ada can be classified as "calclithites." According to Folk (1961), calclithites are terrigenous rocks containing more than 50 percent carbonate fragments.

In order to evaluate the factors such as source area and the environment of deposition, two different methods of investigation were employed.

I. A statistical investigation of the lithologic affinity of the carbonate clastics in the conglomerate was made to determine the location of the source area, the composition of the source rocks, and the distance of transportation.

II. Size-shape analyses were made in order to investigate the environment in which these coarse clastics were deposited.

I. Lithologic Affinities of the Limestone Conglomerate

The kind and proportion of 204 pebbles and cobbles, collected from both measured section D and sample location H (Plate I), were cut into smooth surfaces, and some polished surfaces were then made. Thin sections were made from every representative sample. These pebbles and cobbles were classified according to their lithology, and then compared with collections of rock types from the Arbuckle area for source-rock identification.

The limestone pebbles and cobbles of the Ada conglomerate were derived from all rocks older than Virgilian age, but mostly from the lower Paleozoic strata, which were exposed during the time of deposition of the Ada conglomerate (Plate I).

The results of the statistical studies of the lithologic affinity of 204 limestone pebbles and cobbles are plotted in a histogram (fig. 4), and the data are listed below:

Rock Group	Approximate thickness in Arbuckle Mountains, in feet	Percent
Arbuckle Group	6,500	41.7
Simpson Group	2,000	21.6
Viola Group	700	23.5
Hunton Group	350	9.3
Wapanucka Formation	300	4.0
		Total: 100.1

The lithologic characteristics of each rock group or formation is summarized below:

The Arbuckle Group, Cambrian-Ordovician in age, attains an average thickness of about 6,500 feet in the Arbuckle area. During middle Virgilian time it contributed pebbles, cobbles, and a few boulder-sized limestone clastics into the environment of deposition of the Ada Formation. These coarse clastics from the Arbuckle Group, can be classified into at least four different rock types according to their lithologic and faunal characteristics.

The most predominant limestone fragments derived from the Arbuckle Group are characterized by their clastic texture, which are composed of intraformational limestone conglomerate (Plate II, fig. B), intraclastic calcarenite,

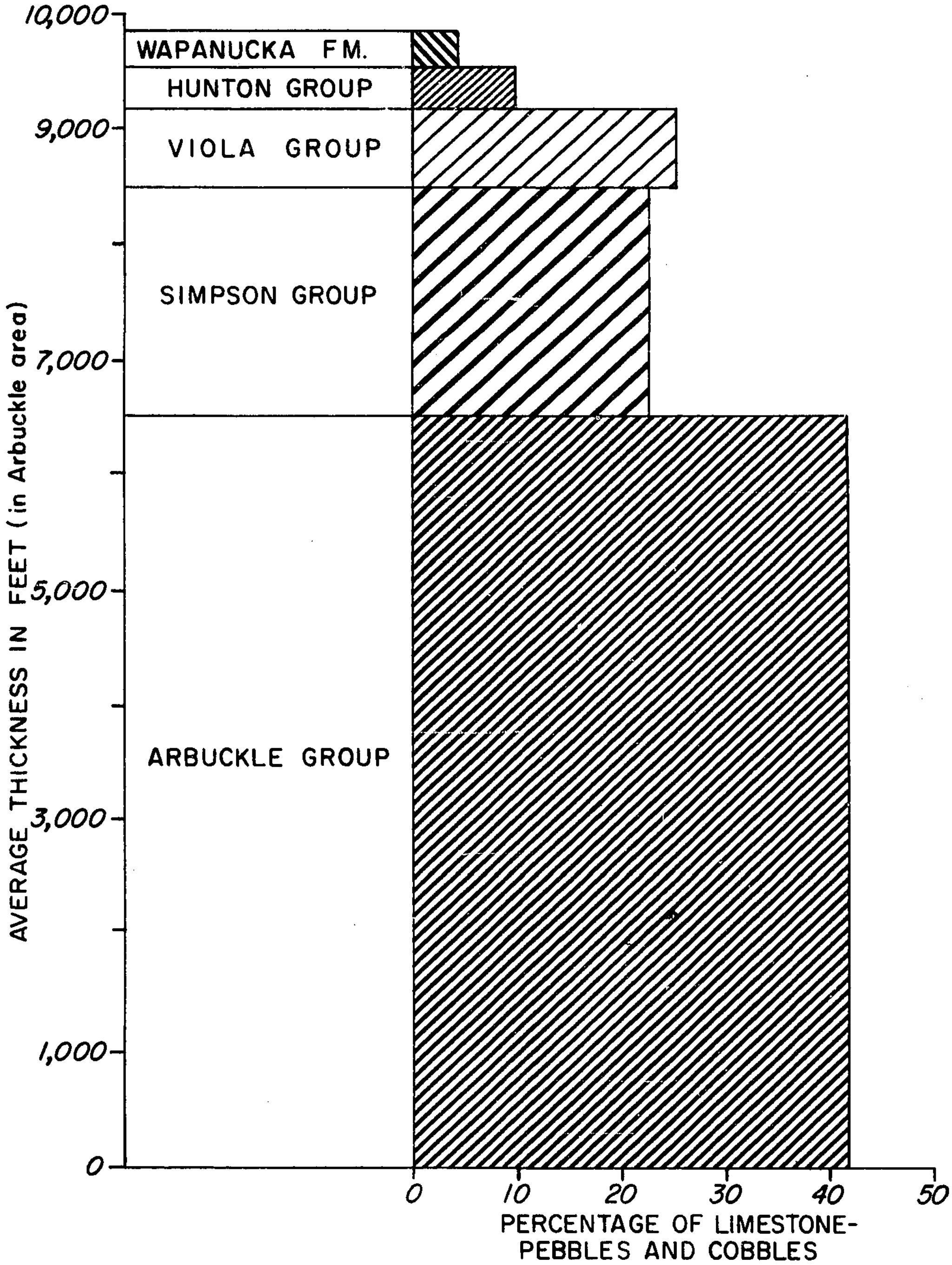


Figure 4. Histogram; Average thickness of source rocks in the Arbuckle Mountains plotted versus the percentage of limestone-pebbles and cobbles.

and calcirudite, in both intramicrite, intramicrudite, and intrasparrudite forms (Plate II, figs. A, B, D, E and F). These intraclasts are also associated with some transported grains, such as quartz, feldspar, and oolites. These coarse limestone fragments are essentially non-skeletal although some gastropods were found associated with the intraclasts (Plate II, fig. A).

The second most abundant pebbles and cobbles derived from the Arbuckle Group are composed of limestone characterized by having well-rounded fine intraclasts, distributed in micritic and poorly-washed sparry matrix, without preferred orientation. This limestone has been identified by Ham (1950) in the Arbuckle area, where he has referred to it as limestone pelite in reference to its fine grain size (Plate II, fig. C). Few fossil remains were found associated with this rock-type.

The third important lithic type derived from the Arbuckle Group, consists of non-fossiliferous, argillaceous limestone. It is a mixture of the first and second types, differing from them by having higher clay-sized detritus. The secondary dolomite is present in less than 10 percent and occurs in irregular patches throughout the rock-type.

The fourth important and quantitatively predominant limestone pebbles and cobbles originating from the Arbuckle Group is composed of stromatolitic algal limestone, probably derived from Cool Creek and West Spring Formations (Plate II,

PLATE II

PHOTOGRAPHS OF LIMESTONE PEBBLES AND COBBLES FROM MIDDLE CONGLOMERATE MEMBER OF ADA FORMATION

A. Polished surface of gastropod-bearing intraformational conglomerate - intrasparrudite, derived from Arbuckle Group (Cambrian-Ordovician), Arbuckle Mountains. x 1/2.

B. Polished surface of very fine to coarse, poorly-sorted intraformational conglomerate; non-fossiliferous intrasparrudite, derived from Arbuckle Group (Cambrian-Ordovician), Arbuckle Mountains. x 1/2.

C. Polished surface of fine, moderately-sorted intraclastic calcarenite, intrasparite, or pelite (Ham, 1950), derived from Arbuckle Group, Arbuckle Mountains. x 1/2.

D. Polished surface of fine to coarse, poorly-sorted, intraclastic calcirudite; poorly washed intrasparrudite, derived from Arbuckle Group (Cambrian-Ordovician), Arbuckle Mountains. x 1/2.

E. Polished surface of very fine to very coarse, pelite-bearing, intraclastic calcirudite-moderately-washed intrasparrudite, derived from Arbuckle Group (Cambrian-Ordovician), Arbuckle Mountains. x 1/2.

F. Polished surface of fine to coarse calcirudite; intramicrudite, derived from Arbuckle Group (Cambrian-Ordovician), Arbuckle Mountains. x 1/2.

G. Polished surface of algal, stromatolitic, silty, oolitic poorly-washed biosparrudite. Note silt occurs predominantly on the northwest corner of the cobble, and the oolites are associated with algal mats, derived probably from Cool Creek and/or West Spring Creek Formations, Arbuckle Group (Cambrian-Ordovician), Arbuckle Mountains. x 1/2.

H. Polished surface of algal (blue algae), stromatolitic, moderately well-washed biosparrudite, dismicritic, probably derived from Cool Creek and/or West Spring Creek Formations, Arbuckle Group (Cambrian-Ordovician), Arbuckle Mountains. x 1/2.

I. Polished surface of algal, stromatolitic, gastropod-bearing biosparrudite. Note the fine-grained fossil debris in the matrix, probably derived from Cool Creek and/or West Spring Creek Formations, Arbuckle Group (Cambrian-Ordovician), Arbuckle Mountains. x 1/2.

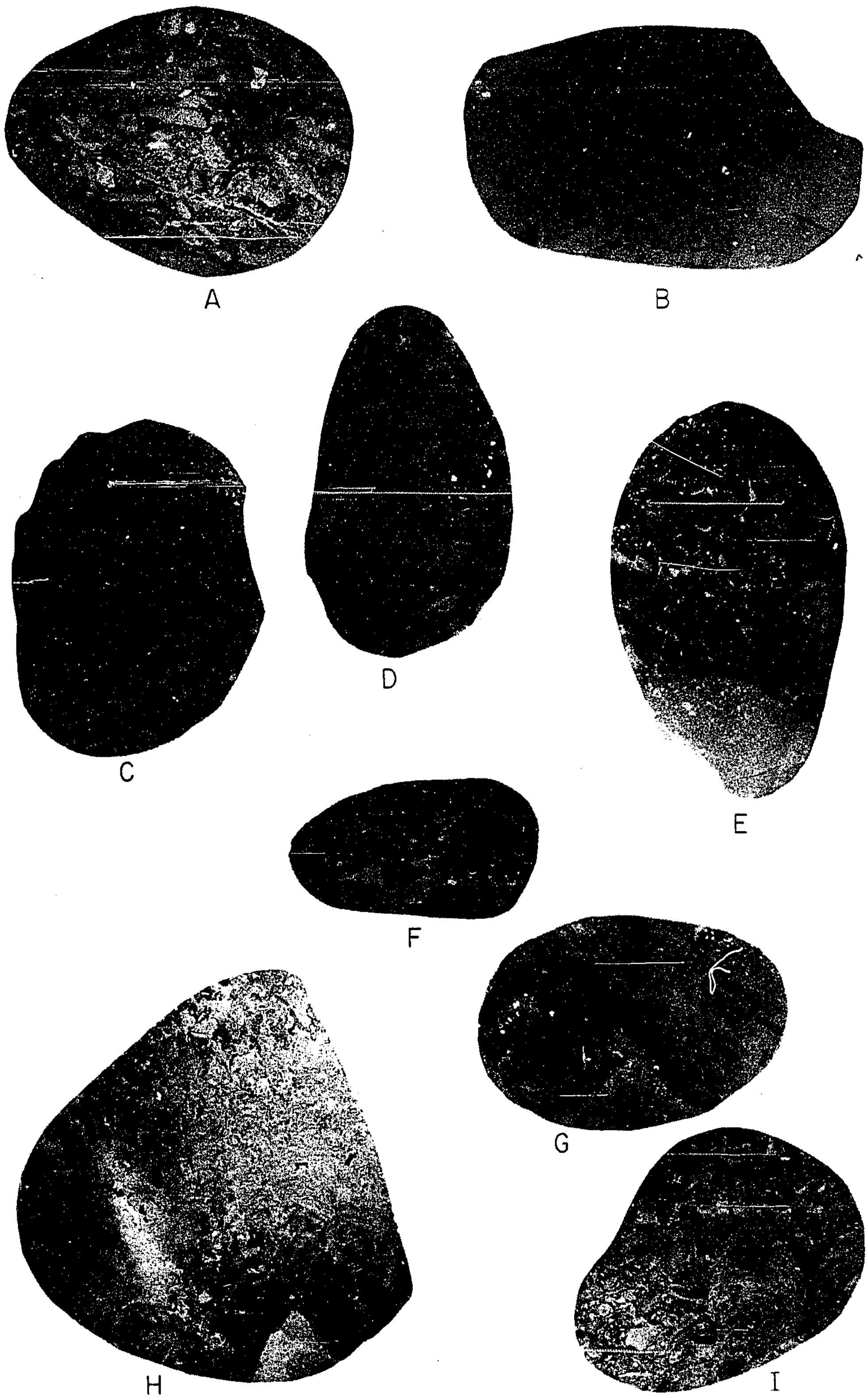


PLATE II

figs. G, H, and I).

The Simpson Group of Ordovician age has an average thickness of 2,000 feet in the Arbuckle Mountains. It has provided both coarse and fine clastics into the environment of deposition of the Ada Formation. Pebble- and cobble-sized clastics derived from the Simpson Group are composed of carbonates, although a few sandstone pebbles were found in both the middle conglomerate and the upper sandstone member. Sandy formations from the Simpson Group apparently did not contribute pebble- and cobble-sized detritus into the depositional environment, as the friable sandstones would disaggregate into fine bimodal sands during a relatively short, but rapid transport in turbulent water. Consequently, the detrital sands derived from the Simpson Group, were deposited both as the lower and the upper sandstone members, and as matrix in the conglomerate member.

Pebble- and cobble-sized carbonate clastics derived from the Simpson Group, comprises a total 21.6 percent of the coarse detritus in the limestone conglomerate. The majority of the pebbles show a lithologic affinity to that of the McLish and Bromide Formations, upper and lower Simpson respectively. The pebbles and cobbles derived from the McLish Formation consist of so-called "birdseye" limestone, which is an algal dismicrite (Plate III, figs. J, H, and K). Some other characteristic pebbles and cobbles derived from the McLish formation are composed of Girvanella rich calcarenite (Plate III, figs. G and I). The pebbles and cobbles derived from the Bromide Formation are characterized by compact limestone, micrite, and with a trace amount of silicified fossil debris. The coarse carbonate clastics derived from the Bromide Formation comprise only a small percentage of total pebbles and cobbles derived from the Simpson Group.

The Viola Group, Late Ordovician in age, has an average thickness of 700 feet in the Arbuckle area. It has contributed pebbles, cobbles, and a few boulder-sized carbonate fragments into the depositional environment. These coarse clastics from the Viola Group may be grouped into three major lithic types. They are described in the order of decrease in abundance.

The most abundant pebbles and cobbles derived from the Viola Group are those which are composed of non-fossiliferous micrite and microsparite. These non-skeletal limestone fragments in places contain some transported detrital pellets and carbonate intraclasts. Skeletal debris occurs in trace amount and mostly consists of fragments of crinoid plates (Plate IV, fig. H).

The second most important limestone pebbles and cobbles derived from the Viola Group are composed of siliceous, moderately laminated micrite, which are characterized by their "pinch and swell" structures (Plate III, figs. A, and B).

The third important lithic type derived from the Viola Group consists of coarsely crystalline, fossiliferous limestone (poorly-washed biosparrudite).

The Viola Group rock-types comprise 23.5 percent of the total limestone pebbles and cobbles in the middle conglomerate member of the Ada Formation.

The Hunton Group, Devonian in age, has an average thickness of 350 feet in the Arbuckle Mountains. It has contributed a total of 9.3 percent limestone pebbles and cobbles into the environment of deposition of the Ada Formation. From four formations described in the Hunton Group by previous workers, the Chimneyhill Formation was the source of the majority of the coarse carbonate fragments derived from this group. The pebbles and cobbles derived from the Chimneyhill Formation are composed of medium to coarse stylolitic, pink crinoid-bearing, glauconitic, and oolitic calcarenite (Plate III, fig. F).

From three important members present in the Chimneyhill Formation, the "glauconite," and "pink crinoid" members have provided the major representative rock-types. The lower "oolite" member which has the smallest geographical distribution introduced the least amount of coarse fragments into the environment of deposition of the Ada Formation.

The Haragan Limestone was the source of fewer clastic particles than the Chimneyhill Formation, but more than the Frisco Limestone. The latter contributed only one percent of the total limestone pebbles and cobbles in the Ada conglomerate.

The Wapanucka Formation, Early Pennsylvanian in age, has an average thickness of 300 feet in the Arbuckle area. It constitutes only 4 percent of the total pebbles and cobbles of the middle conglomerate member of the Ada Formation. The coarse clastics derived from the Wapanucka Formation are composed of cherty, sandy, commonly glauconitic, intraclastic calcarenite, grading to calcareous sandstone (Plate III, figs. D and E).

The Deese Conglomerate, chiefly Desmoinesian and possibly Early Missourian in age, has an average thickness of 1,950 feet in the Arbuckle Mountains. The pebbles and cobbles derived from Deese rocks are characterized by having a conglomeratic texture in the conglomerate pebbles and cobbles. The fragments comprising Deese cobbles are composed of any rocks older than Missourian in age. The oldest pebbles found in the boulders from Deese Conglomerates are of Simpson (McLish "birdseye" limestone), and some limestone fragments which are probably derived from the uppermost part of the Arbuckle Group (Plate III, fig. C).

The pebbles and cobbles derived from the Deese Conglomerate comprise less than one percent of the total coarse clastics in the Ada conglomerate. They were probably transported from the Mill Creek graben and the northeast flank of the Arbuckle anticline.

PLATE III

PHOTOGRAPHS OF LIMESTONE PEBBLES AND COBBLES

FROM MIDDLE CONGLOMERATE MEMBER OF

ADA FORMATION

A. Polished surface of poorly-laminated, slightly-intraformational-conglomeratic, intramicrudite, derived from Arbuckle Group (Cambrian-Ordovician), Arbuckle Mountains. x 1/2.

B. Polished surface of siliceous, moderately-laminated micrite. Note "pinch and swell" structure, derived from Viola Group (Ordovician), Arbuckle Mountains. x 1/2.

C. Polished surface of a cobble derived from Deese Conglomerate, which forms a conglomerate in conglomerate (chiefly Desmoinesian). The coarse carbonate clastic in the lower west corner is identified as being derived from the McLish Formation of the middle Simpson Group. Fine, subangular grains with lighter tones are chert fragments scattered throughout the matrix. Derived from Arbuckle Mountains. x 1/2.

D. Polished surface of very sandy, glauconitic, hematitic calcarenite grading into impure calareous sandstone, derived from Wapanucka Formation (Early Pennsylvanian), Arbuckle Mountains. x 1/2.

E. Polished surface of sandy, glauconitic calcarenite-poorly-washed sandy intrasparite, derived from Wapanucka Formation (Early Pennsylvanian), Arbuckle Mountains. x 1/2.

F. Polished surface of highly stylolitic biomicrite. Note the top of the grain cut along a stylolite surface. Derived from Chimneyhill Formation, Hunton Group (Devonian), Arbuckle Mountains. x 1/2.

G. Polished surface of well-washed, algal, biosparrudite. Note blue algae (Girvanella) occurs around nucleus which is formed of red algae on the right side of the pebble. Gastropod, branchiopod, and ostracod debris occur throughout the pebble. Derived from McLish Formation, Simpson Group (Ordovician), Arbuckle Mountains. x 1/2.

H. Polished surface of algal dismicrite ("birdseye" limestone). Note the excellent example of geopetal structure. Green clay occurs at the base of the structure and the rest of the space is filled by pore-filling, coarse, sparry calcite, indicating top-direction. Note also the coarse, pore-filling, sparry calcite which occurs along the fractures. Derived from McLish Formation, Simpson Group (Ordovician), Arbuckle Mountains. x 1/2.

I. Polished surface of well-sorted Girvanella-rich, argillaceous, biosparrudite, derived from McLish Formation, Simpson Group (Ordovician), Arbuckle Mountains. x 1/2.

J. Polished surface of "birdseye" limestone algal dismicrite, derived from McLish Formation, Simpson Group (Ordovician), Arbuckle Mountains. x 1/2.

K. Polished surface of "birdseye" limestone; algal dismicrite. Note the poor sorting character of the attached pebbles and cobble. Note also the association of finer subangular chert grains with coarser well-rounded carbonate intraclasts. Derived from McLish Formation, Simpson Group (Ordovician), Arbuckle Mountains. x 1/2.

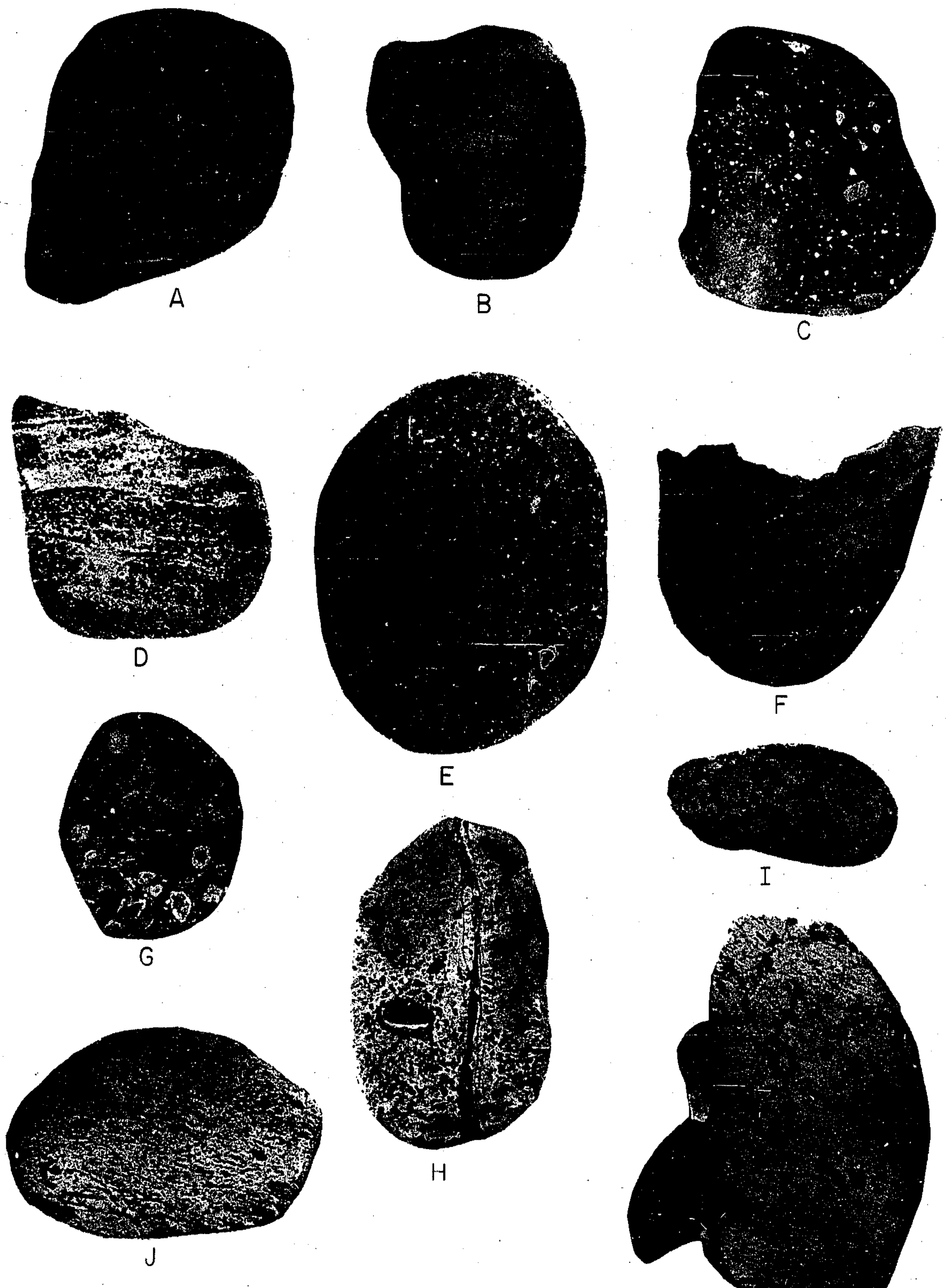


PLATE III

Discussion of the Data

The results obtained from the statistical investigation of the lithologic affinities of the limestone pebbles and cobbles can not be considered as a direct reflection of the relative abundance of these rock-units in the Arbuckle Mountains. If this assumption was true, then the ratio of percentage over the average thickness of the rock-unit must be a constant. This ratio has been calculated and listed below:

Rock Group	(Percentage of pebbles and cobbles / Avg. thickness in the Arbuckle Mountains) x 100
Arbuckle Group	0.64
Simpson Group	1.04
Viola Group	3.35
Hunton Group	2.65
Wapanucka Formation	1.33

An examination of these ratios shows that the Arbuckle Group with its greatest thickness did not contribute more than any other rock group in the source area. In fact it has the lowest ratio of 0.64 when it is compared to that of the other rock-units. This is probably due to the fact that only the upper formations of the group were exposed during deposition of the Ada sediments, and therefore they were available to erosion and transportation. This is suggested by the absence of the rock-fragments older than the McKenzie Hill Formation.

PLATE IV

PHOTOMICROGRAPHS OF THE LIMESTONE PEBBLES AND COBBLES FROM THE ADA CONGLOMERATE

A. 926.- Biosparrudite. Note bryozoan replaced by chert. A cobble derived from Frisco Limestone (Devonian in age). Plane polarized light X20.

B. 926.- Biosparrudite. Note bryozoan, crinoid plates, pellets, and the sparry calcite mosaic. The sample is the same as A. Plane polarized light X20.

C. 918.- Feldspar overgrowths replaced by the calcite cement. Nicols crossed X20.

D. 923.- Algal biosparrudite. Note the core of girvanella is composed of pelecypod shell. Coarse mosaic calcite replacing the algal mat along a plane of weakness (fracture zone). A pebble derived from Simpson Group. Nicols crossed X20.

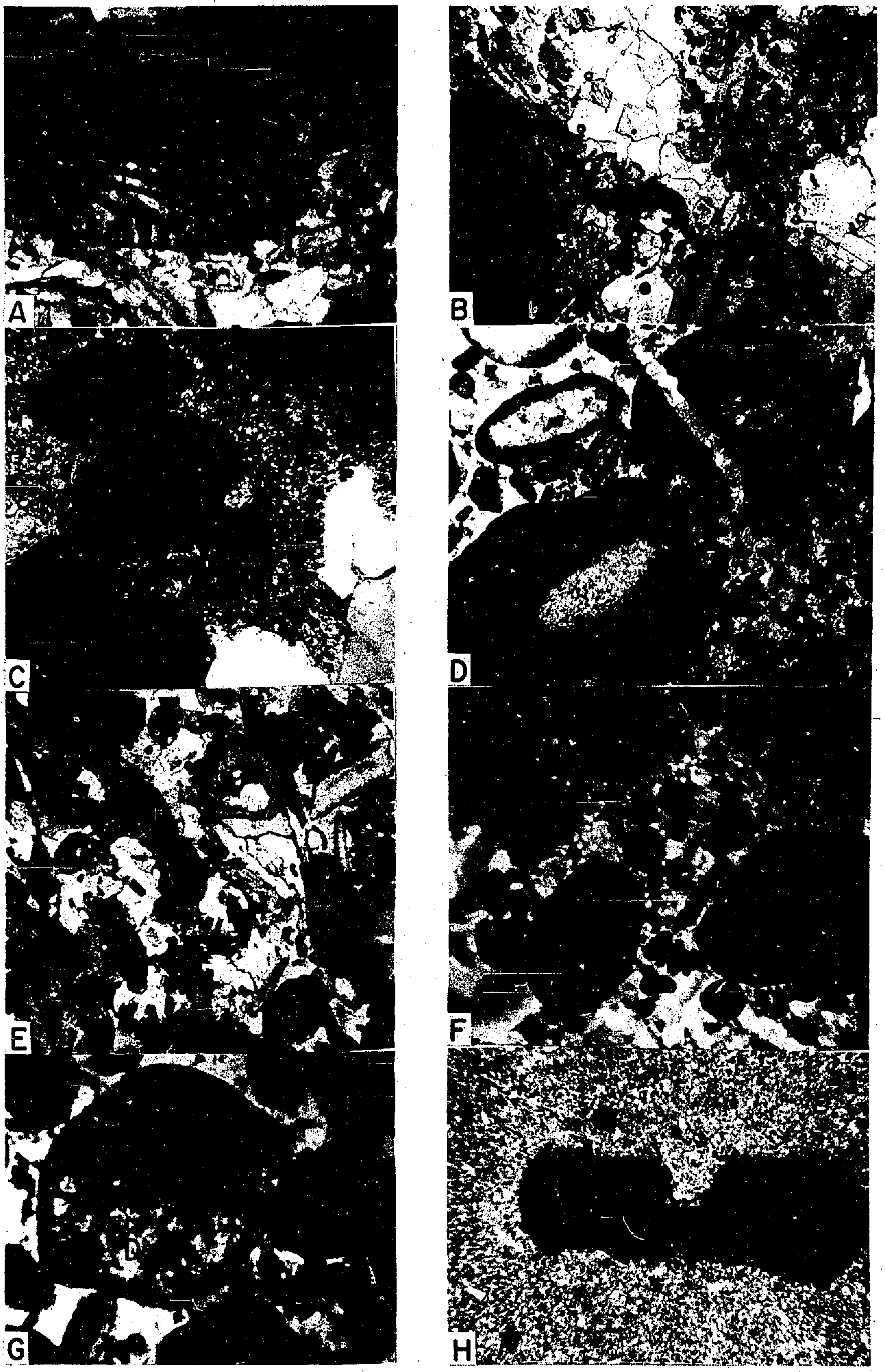
E. 926.- Biosparrudite. Note the partial replacement of fossil-fragments by chert. Nicols crossed X20.

F. 919.- Non-skeletal calcirudite (intrasparrudite). Note the bimodality of the carbonate intraclasts. A cobble derived from the Arbuckle Group. Nicols crossed X20.

G. 825.- Intrasparrudite. Note the coarse dolomite rock-fragment, corners of the dolomite rhombs are rounded during transportation. A cobble derived from Chimneyhill Formation (Devonian). Nicols crossed X50.

H. 927.- Crinoid bearing micrite. Note the embayment in the crinoid plate, caused by partial recrystallization of the plate. A pebble derived from Viola Group. Nicols crossed X50.

PLATE IV



The explanation that the Simpson Group did not introduce quantitatively enough coarse clastics to the environment of deposition of the Ada Formation is two fold: (1) during middle Virgilian time, the Simpson Group was mainly covering the Hunton Anticline and did not contribute coarse clastics because the Hunton Anticline was tectonically in a semistable position and topographically low; and (2) the lithology of the Simpson Group in most places is not adequate for the formation of pebbles and cobbles except where limestone is present.

The Viola Group contributed quantitatively and relatively more than any other rock unit, probably because of its lithologic characteristics and relief.

The Hunton Group and the Wapanucka Formation did not provide as much as the Viola Group because of their smaller geographical distribution and thickness in the Arbuckle area.

Examination of the data received from the investigation of the lithologic affinities of the limestone pebbles and cobbles has further suggested that the abundance of these coarse clastics may change by the variation of: (1) the composition of the source rocks, (2) the texture of the source rocks, such as presence of certain directional rock-cleavage (foliation, lineation, schistosity, and type of the bedding), (3) the structure of the source rocks (presence or absence of joint patterns, the regional structure, and topography), (4) resistance to abrasion, (5) the thickness of the particular rock unit, (6) tectonic stability of the source area, and (7) the degree of accuracy in identification, and many other factors.

However, the data does provide some information about the availability of these rock-types, and to some degree a measure of the extent of uplift of the Arbuckle Mountains, and dependent depth of erosion. During deposition of the Ada sediments both uplifting of the source area and the depth of erosion were controlled by tectonism.

The proposed conditions necessary for inhibiting the disintegration and solution of the limestone fragments are those marked by high relief, rapid erosion, and short distance of transportation. This is commonly marked by the poor sorting of the Ada conglomerate and the associated sandstones. The proportion of the pebble- and cobble-sized limestone rock-fragments increases with increasing the immaturity of the associated sandstones. This seems to be a function of relief, climate, and hence tectonism.

II. Shape Index Analyses

Introduction.--The shape of the pebbles and cobbles of the Ada conglomerate vary greatly, but most of the particles have shapes in the range of disk (oblate), to roller (prolate). Without exception all the pebbles and cobbles are well-rounded. The excellent rounding in these limestone pebbles and cobbles is not believed to be a measure of long travel as it is more logically indicative of pebbles derived from hard rocks.

In an attempt to assign an environment in which the Ada pebbles and cobbles were deposited, the writer has made a statistical analysis by a new method using one parameter suggested by Williams (1965), so that shape may be treated as single statistical variable.

Statistical shape analysis.--A shape index derived by Williams (1965) was employed in this investigation. She has suggested a new method of statistical analysis which indicates to what extent a pebble or cobble approximates an oblate or prolate spheroid. This factor may be treated as a single statistical variable. Many workers in the field of sedimentation have made reference to the observed tendency for pebbles and cobbles subjected to wave action to become flattened or oblate, whereas river action tends to produce more roller-shaped or prolate pebbles. Among them are; Blatt (1959), Fraser (1935), Landon (1930), and Russell (1939).

In attempt to assign an environment in which the Ada pebbles and cobbles were deposited, the writer made a statistical study by a method using the one parameter described by Williams (1965) so that shape may be treated as a single statistical variable. "Size-shape" studies in particular are considered important by Moss (1962), and Sneed and Folk (1958).

Method of study.--In this classification the terminology of Potter and Pettijohn (1963) is followed and the longest axis of a pebble is designated A, the intermediate axis B, and the shortest axis C. Williams (1965) has assumed (after Krumbein, 1941) that although pebbles are not triaxial ellipsoids, statistically they may be approximated by such a form.

Thus if A,B,C are axes of an ellipsoid such that $A \gg B \gg C$, as $B \longrightarrow A$ the ellipsoid tends to become oblate, that is: $A/B \longrightarrow 1$ (1)

As $B \longrightarrow C$ the ellipsoid tends to become prolate that is: $B/C \longrightarrow 1$ (2)

Comparing (1), and (2), she found that the term:

$$B/C/A/B = B^2/AC$$

is a diagnostic index of shape.

If $B^2/AC > 1$ the ellipsoid is tending to oblate.
If $B^2/AC < 1$ the ellipsoid is tending to prolate.
If $B^2/AC = 1$ the ellipsoid is a sphere or blade.

Furthermore:

$$\text{Shape Index} = W = (1 - AC/B^2) \text{ when } B^2 > AC$$

$$W = (B^2/AC - 1) \text{ when } B^2 \ll AC$$

This gives one parameter which varies from -1 to +1.

As W increases from 0 to 1 the pebble shape becomes increasingly oblate. As W decreases from 0 to -1 the pebble shape is increasingly prolate. When W = 0 the pebble is a sphere or blade. The main disadvantage of Williams' classification is that the W does not distinguish between sphereroid and bladed pebbles.

Figure 5, shows a sample of 100 pebbles and cobbles from the Ada conglomerate plotted on a size-shape diagram. A rough indication of pebble and cobble shape associated with shape index is shown on the right of the diagram which is adapted from Williams (1965). The diagram shows a clear tendency for the pebbles and cobbles to be flattened as well as a small variation in grain size. About 80 percent of the pebbles have a nominal diameter in the range of 40 to 80 millimeters. Only 25 percent of the limestone clastics have negative shape-indices, ranging from - 0.02 to - 0.54. Only one percent of the grains approximates spheroids or are bladed.

Seventy-four percent of the pebbles and cobbles have positive shape-indices ranging from + 0.03 to + 0.63. The mean of these 100 pebbles and cobbles was calculated to have a nominal diameter of about 58 millimeters, and a shape index of about + 0.2.

Coarse pebbles and cobble-sized limestone clastics (above 12.7 mm in diameter, Marshall, 1929) were probably worn by "abrasion" (rubbing) and tend to become flat with rounded edges. Marshall (1929) on his studies of beach gravels did not do a quantitative determination of roundness, but he suggested that the pebbles less than 12.7 mm in

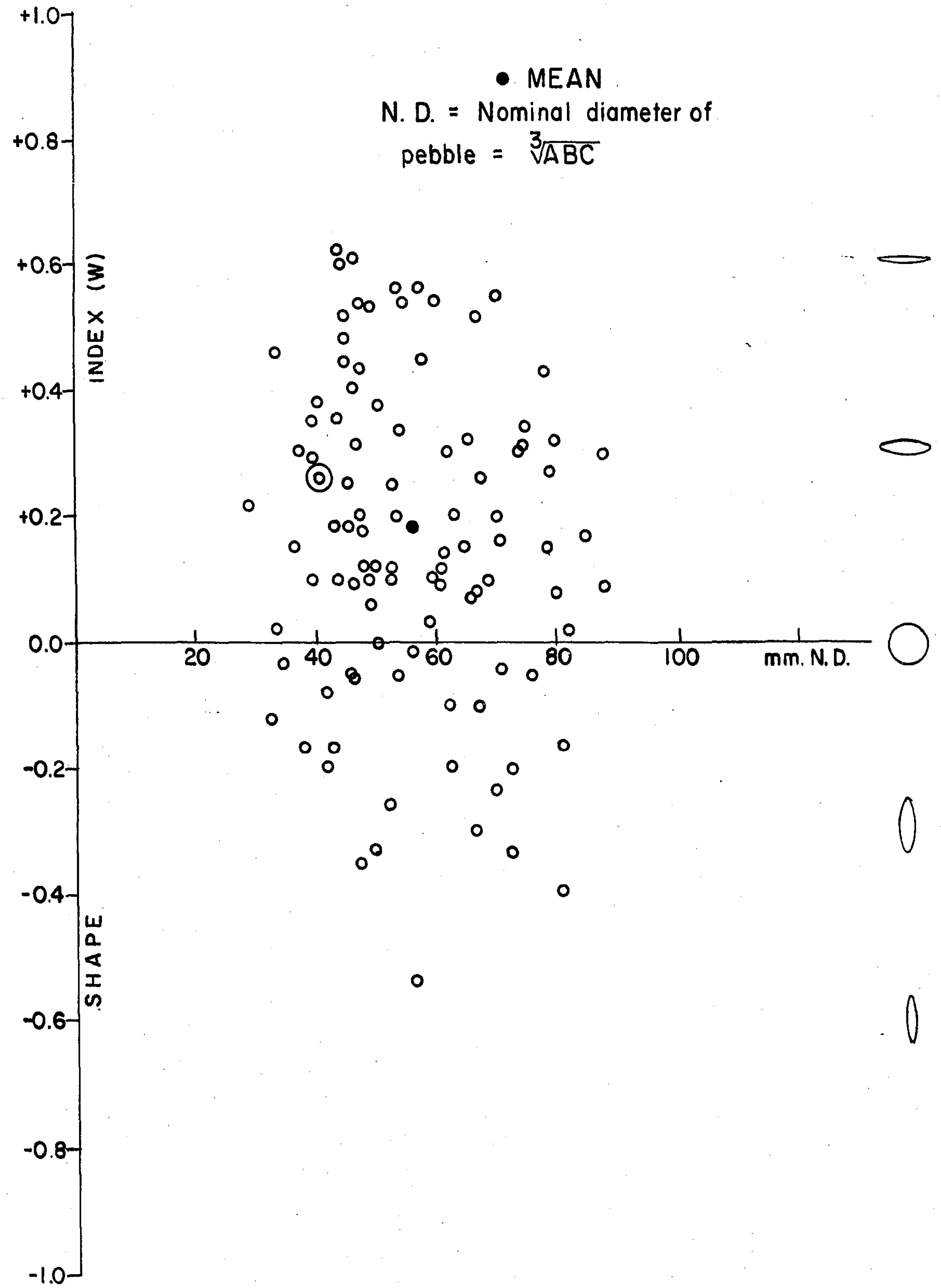


Figure 5. Size-shape distribution of 100 pebbles and cobbles from Ada conglomerate.

diameter become spheroidal and the coarser fragments become disk-shaped. He describes the flat shape of the large fragments to the fact that they only move occasionally and then by sliding. These coarse fragments would then be worn on their exposed surfaces by the sliding action. The clastics less than one-half an inch in diameter will be lifted by the incoming waves and dropped so that they are worn uniformly.

However the results from this investigation suggest that not all cobbles and large pebbles will become necessarily flattened by beach abrasion; in the Ada conglomerate some roller-shaped cobbles are associated with disk-shaped pebbles. The mineralogical composition as well as the isotropy of the composition of the source rocks is believed to be an important factor controlling the shape of the pebbles and cobbles of the Ada conglomerate.

Landon's study (1930), shows that the predominance of flat pebbles on beaches may be at least partly the result of sorting.

The results of the shape-index analysis suggest that the Ada conglomerate was deposited in a beach environment as the majority of the pebbles and cobbles fall in the positive shape-index area (oblate). The results obtained from shape-index analysis are also in agreement with the other conclusions which were indirectly used for the interpretation that the environment of deposition was a beach.

Texture.--The poor sorting character of the limestone pebbles and cobbles in the Ada conglomerate is probably due to the fact that transportation was mainly by traction in which large and small particles traveled together. The large particles after deposition imprisoned the smaller ones within their interstices and protected them from removal (Plate III, fig. K). Moreover, when decrease of competency caused the deposition of these tractional loads, the coarsest particles are deposited, and simultaneously the smaller particles dropped into the interstices from the suspended load. The finer particles which form the matrix of the Ada conglomerate are composed of well-rounded, calcareous, argillaceous sandstones.

The maximum diameter of the individual well-rounded cobbles in the Ada conglomerate commonly does not exceed 25 cms. However, a few boulders were found in the central part of Pontotoc County.

The pebbles and cobbles are in places imbricated in an irregular pattern and commonly lack a preferred orientation. The individual pebbles and cobbles locally exhibit a low angle imbrication of less than 5^{o} in a general north and northwest direction. However, in some localities, the limestone clastics show a crowded, unoriented arrangement in which the clastics are tilted against each other in an upright position similar to the clastic deposits dumped into a marine environment from a stream.

However, the imbrication structure was not used as an environmental indicator in this investigation, because it is present in both beach and fluvial deposits. Whether, the angle of dip of such imbrication is diagnostic is not known, although Twenhofel (1947) suggested that the angle of imbrication of the beach pebbles ranges from 5^{o} to 32^{o}. However, the direction of dip of the fluvial gravels at least is significant in that it is upcurrent (Pettijohn, 1957).

The Ada conglomerate is moderately well-cemented, and is stratified, massive-bedded to slightly cross-bedded.

Geologic History

The Ada conglomerate probably accumulated as the result of wave action on a rocky or gravelly shore beneath a permanent water body. The pebbles and cobbles were the coarsest products of erosion and moved shorter distances from the Arbuckle Mountains. These conglomeratic materials are limited to more narrow zones of deposition than sand and clay. However, part of these coarse clastics were probably discharged into the sea by the relatively short and rapidly eroding, turbulent rivers originating in the Arbuckle Mountains.

The results of the statistical analysis of the shape-index (74 percent oblate), presence of some marine fossils, its limited thickness, low angle of imbrication, and field observations of its stratigraphic relationship, are evidences that the Ada conglomerate was deposited during a single physiographic cycle in a shallow marine environment.

Barrel (1925) has also noted that the thickness of the gravels forming essentially in the beach environment can not be great except under the condition of rising sea level. Twenhofel (1947) suggested that the marine conglomerates are commonly less than 15 feet thick, and in the extreme as much as 50 feet, although some other workers raised this extreme to 100 feet. The writer agrees with this statement, but qualifies this generalization by the excluding those sea bottoms over which deep water extends to the shore. The greater thickness of the Ada Formation toward the coastal belt is probably due to one or more of the above-mentioned ideas.

The presence of the limestone conglomerate in the Ada Formation indicates that the transporting agent had sufficient competency to bring particles from a not too distant a source.

The well-rounded limestone pebbles of the Ada conglomerate are not indicative of long distance of transportation. Whereas, pebbles derived from hard rocks to achieve the same degree of roundness must be transported great distances.

The greater thickness of the conglomerate member on southern outcrops of the Ada Formation in Pontotoc County is because of the proximity of the source area.

The results of studies of the lithologic affinity of 204 pebbles and cobbles from the Ada conglomerate, suggest that during deposition of the Ada sediments, the Hunton Anticline was in a substatic position, and had relatively low topography. This is indicated by the absence of dolomite pebbles and cobbles in the Ada conglomerate. But the Arbuckle and the Tishomingo Anticlines were tectonically in an active stage and provided the coarse clastics into the environment of deposition of the Ada Formation. The Hunton Anticline was probably uplifted during Mcalster in a constant and slow uplift (Ham, 1966).

It is believed that during deposition of the Ada sediments the Arbuckle Mountains were in an unstable and tectonically active phase. It is under such conditions that limestone pebbles and cobbles of the Ada conglomerate may have become permanently preserved with stationary sea level. Under normal condition, marine planation ultimately destroys all coarse materials especially carbonate pebbles. The stability of the source area repeatedly modified the power of erosion and supply of clastics into the environment of deposition of the Ada Formation. Variation in climate can be considered as another factor that controlled the mechanical power of erosion.

Ham (1954) suggested that the Collings Ranch Conglomerate was deposited simultaneously with a part of the Ada Formation. Assuming the Collings Ranch Conglomerate is correlative with the Ada conglomerate in time and space, the greater thickness of the Collings Ranch Conglomerate compared to the Ada Conglomerate probably indicates that the southern part of the landmass in the Arbuckle Anticline had the most pronounced relief during the deposition of the Ada conglomerate. The case is reversed when one compares the thickness of the Vanoss conglomerate on the northern and southern flanks of the Arbuckle Anticline. The presence of the conglomerate member in the Vanoss Formation on the northern flank indicates that the north part of the landmass had the most pronounced relief during deposition of the Vanoss sediments (McKinley, 1954).

The parameters such as distribution, grain size, and the thickness of the Collings Ranch, Ada, and Vanoss conglomerates were compared. It seems that during deposition of the Ada sediments the western Arbuckle Mountains formed an exposed landmass. This landmass was extended asymmetrically in a north-south direction, with a "high" rapidly eroding south side which furnished more coarser materials to the south, and an area of relatively less slope on the north, which furnished only small amounts of clastics to the northward flowing streams.

However, the uplifting of the Arbuckle Mountains were continued before the deposition of the Vanoss sediments, and the topography of the Arbuckle Anticline was reversed (compare the thickness of the Ada and Vanoss conglomerate). This was probably due to the faulting of pre-Pennsylvanian and Early Pennsylvanian time. Therefore, the

Vanoss conglomerate deposited only on the north flank of the Arbuckle Anticline. The absence of the Vanoss conglomerate on the south flank of the Arbuckle Anticline, suggests that during deposition of the Vanoss sediments the northern part of the landmass had the most pronounced relief (McKinley, 1954).

LOWER AND THE UPPER SANDSTONE MEMBERS

Sedimentation

Grain size analysis.--Grain size investigations were employed as a supplementary tool to determine modes of transportation and environment of deposition. Seventeen samples were selected from the Ada sandstones at four measured stratigraphic sections from south to north. The samples were analyzed by standard grain-size analytical techniques. Results are summarized in Table 1.

Data were plotted on cummulative curves and statistically analyzed. Scatter diagrams were also prepared (figs. 7, 8, 9 and 10) by using various statistical data such as mean grain size, standard deviation, skewness, and kurtosis.

The inclusive mean size values of the samples range from 2.60 Ø to 3.50 Ø or fine to very fine sand. The average mean size for all seventeen samples is 2.75 Ø, or fine sand. Five out of nine samples from the most northern outcrops of the Ada Formation in the central part of the Seminole County have mean grain size values over 3.00 Ø or very fine sands. None of the samples from the southern sections have mean grain-size values finer than 3.00 Ø.

TABLE 1

GRAIN SIZE DATA FROM THE ADA FORMATION

Sample No.	Mean Size Ø	Standard Deviation	Skewness	Kurtosis
A-819	2.57	0.97	0.20	2.27
A-2	2.42	0.46	0.25	0.64
B-7	2.72	0.38	-0.44	1.11
B-10	2.60	0.40	-0.29	0.57
D-1	2.77	0.50	-0.20	1.23
D-3	2.93	0.35	0.47	1.60
D-7	2.26	0.56	0.00	0.91
D-16	2.37	0.40	0.33	0.66
F-3	3.07	0.44	0.36	2.08
F-3	3.02	0.50	0.16	2.74
F-5	3.26	0.58	0.50	1.28
F-7	3.50	0.60	0.44	1.44
$F\text{-}8_1$	2.72	0.30	-0.55	1.22
$F\text{-}8_2$	2.73	0.28	0.06	2.05
$F\text{-}8_4$	3.00	0.36	0.15	2.41
F-10	2.44	0.44	0.27	0.66
F-11	2.50	0.40	0.52	0.73

There is an obvious variation in grain-size relative to the areal distribution of the Ada Formation from south to north. Coarser clastics, such as limestone conglomerate, and conglomeratic sandstone diminish northward, and wedge out into thin rock-sequences. The shale member of the Ada Formation increases in thickness to the north. The average mean grain-size for the sandstones from measured sections in southern Pontotoc County is about 2.53 Ø (sections D and A). In the southern part of the Seminole County at measured section B, this value is about 2.66 Ø. In the central part of the county the average mean grain-size is 2.91 Ø. These data show a rather uniform decrease in grain size from south to north.

Throughout a single stratigraphic section there is a tendency for a decrease in grain size upward, with the exception of the uppermost samples, which are probably contaminated with minor coarse modes introduced into the environment, after a new minor pulsation and uplift in the source area.

In order to assure the accuracy of the results of the grain size analysis, two samples from the same rock unit, F-3, were analyzed. The results show that the mean size in these two samples ranges from 3.07 Ø to 3.02 Ø.

Examination of all samples collected in the area for their range of grain size suggests that the most common grain size is in the fine sand class.

The average mean size plotted versus the sample location shows that the overall grain size distribution of Ada sandstones, analyzed from the measured sections D, A, B, and F, decreases from south to north respectively (fig. 6). The Ada sandstone becomes coarser down slope reflecting the increasing power of the breaking waves in the vicinity of the ancient beach. Sands and silts are progressively finer to the north with increasing distance from the shore line, which probably corresponds with increasing water depth and decreasing power of undertow. Only the finer-grained materials were able to be transported far from the shore.

The sorting or inclusive standard deviation (σ_I; Folk and Ward, 1957) ranges from extremes of 0.28 to 0.97, or very well-sorted to moderately-sorted. Out of seventeen samples, sixteen sandstones had sorting coefficients of 0.35 to 0.50 or within the well-sorted class, typical of recent beaches and dunes (Mankin, 1958). Three samples fall in the moderately-sorted class (0.50 to 1.00). Only one sample has a sorting value in excess of 0.60 which is a silty muddy fine sandstone (A-819) which has a sorting value of 0.97. A plot of sorting versus location of samples did not reveal a significant trend. A plot of sorting versus mean size shows a general trend of increasing mean grain size around 2.80 Ø. Finer and coarser than 2.80 Ø the degree of sorting decreases (fig. 7).

The inclusive graphic skewness (SK_I; Folk and Ward,

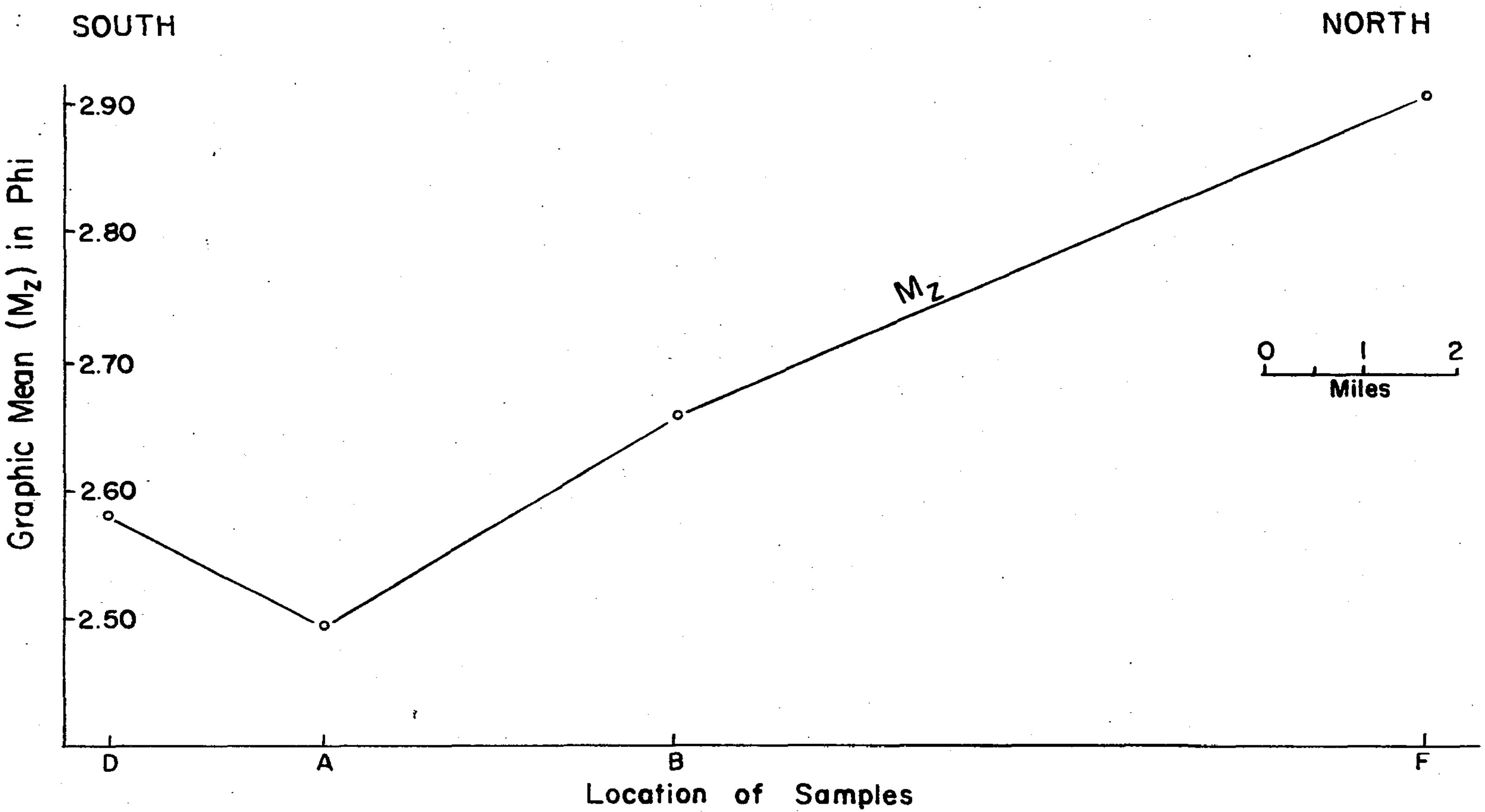


Fig. 6.-- Graphic mean plotted versus sample location. Graph shows overall grain size distribution of Ada sandstones from south to north.

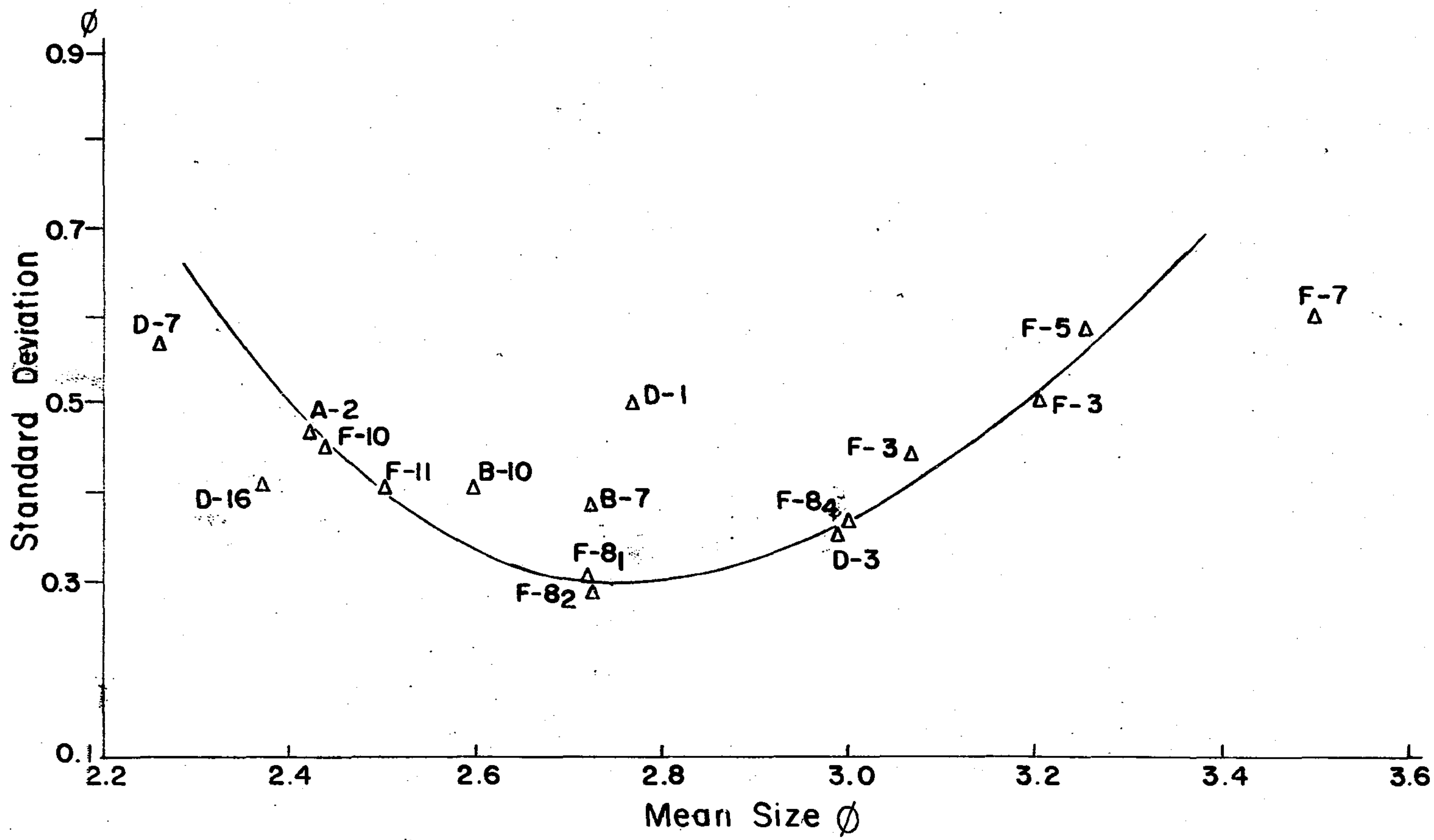


Fig. 7.-- Comparison of Sorting Values vs. Mean Grain Size for the Ada sandstones.

1957) or asymmetry of frequency curve values range from -0.55 to +0.52, strongly coarse-skewed to strongly fine-skewed. Only one sample has a skewness value of 0.00, that place it in symmetrical class. Six of the samples have skewness ranging from 1.30 to 0.10, or fine-skewed, which are typical of dune sands on the Texas coast (Mason and Folk, 1958). Only four samples have SK_I values in the -0.10 to -1.0 class, coarse to strongly coarse-skewed, which are characteristic of beach environments. A plot of the average skewness value in each measured section versus location of the sample did not provide a significant trend.

In figure 8 skewness is plotted against kurtosis for differentiating beach and river sands, using the phi (Ø) scale. The kurtosis provides a second dimension for the plot, but it is believed that it is not diagnostic of the depositional environment (Friedman, 1961), whereas the skewness is particularly sensitive to the environment. Part of the dashed line in figure 8 was modified from Friedman (1961) which shows an approximate boundary line between "River" and "Beach" environments. However, the writer believes that all the samples examined in this study are from a marine environment, but they have not reached equilibrium in the depositional environment. This probably is the result of the rapid rate of deposition as indicated by many pertinent observations explained in this investigation.

In figure 9 the third moment (skewness) is plotted

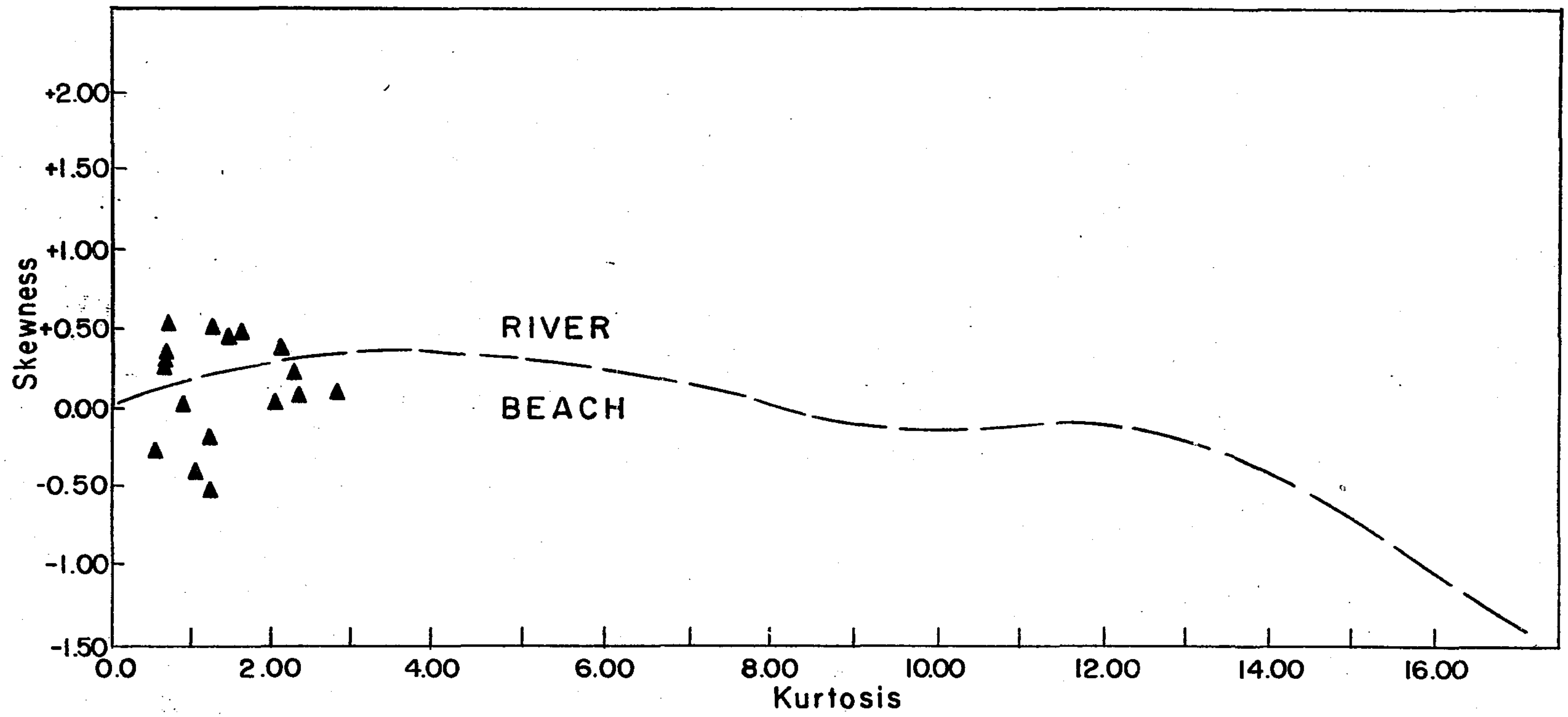


Fig. 8.-- Plot of Skewness vs. Kurtosis. Graph shows the distribution of beach versus river sands. Dashed line is reconstructed from G. M. Friedman, 1961.

versus the standard deviation which is a measure of the degree of sorting. The dashed line is reconstructed from (Friedman, 1961) which differentiates beach from river environments in the recent sediments. The samples of positive skewness have low numerical values for the standard deviation and as indicated in figure 9 can be used for environmental interpretation. Eight samples fall into the beach area and six are in the border between beach and river environments, probably along a coastal plain. Only three of the points fell in the area for river environments. The latter samples are not believed to be true river sands because of several observations listed in this investigation. One must keep in mind that there is a small chance for ancient sediments to fall exactly in the areas where the sediments of the recent environments fall in Friedman's diagram. This is the result of the fact that the sand grains in the ancient sediments have experienced a long period of diagenetic change which results in a great variation of the textural properties of the sands. In the case of the Ada sandstones, the majority of the sand grains are diagenetically corroded by the carbonates and/or dissolved under a certain set of pH, pressure, and temperature. Silica was removed from the environment in solution, and deposited in the adjacent strata where the physico-chemical conditions were appropriate for the precipitation of the silica. In such an environment, the silica was then deposited as quartz

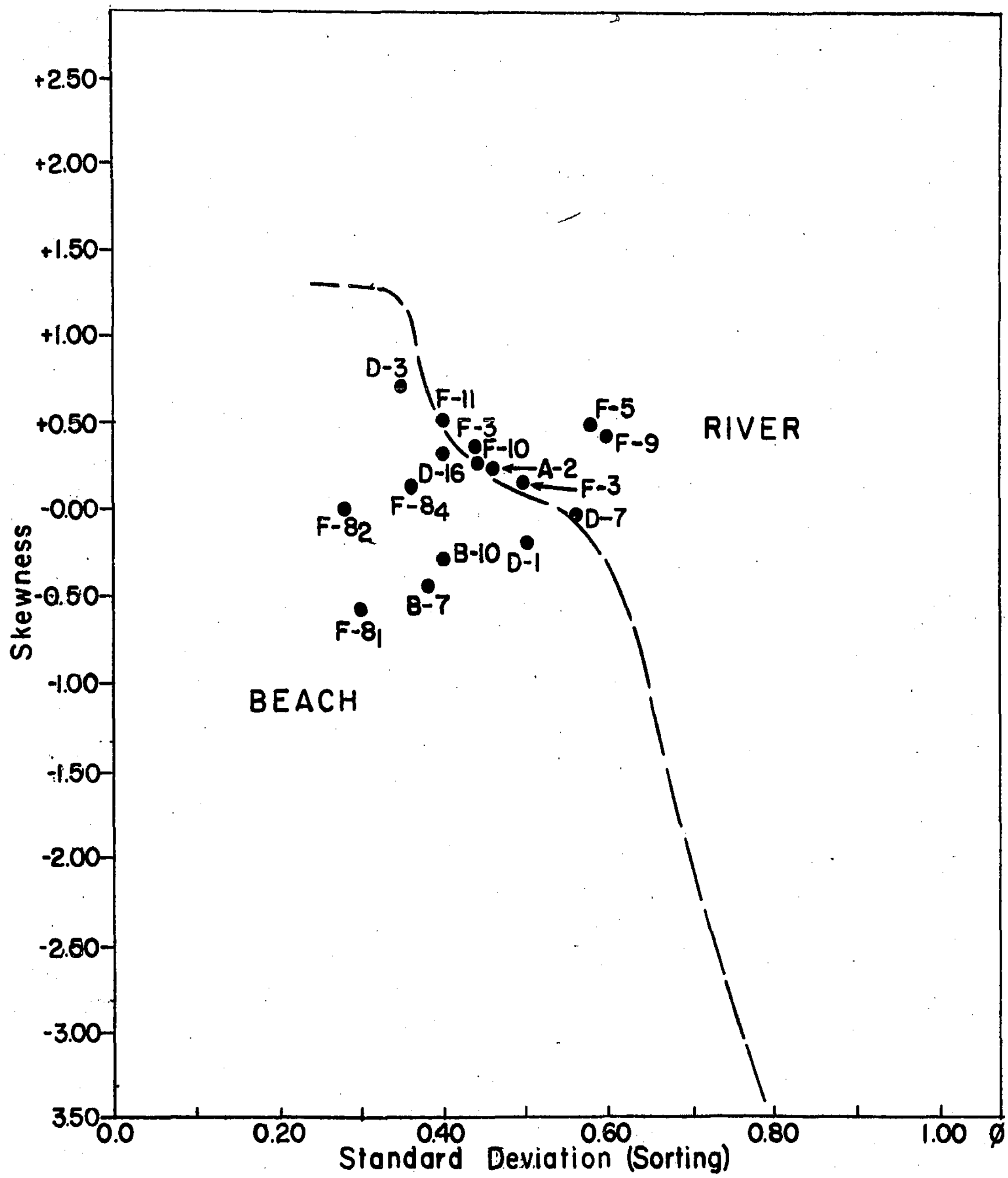


Fig. 9. Plot of Skewness versus Standard Deviation. Graph shows the distribution of beach versus river sands. Dashed line is reconstructed from G. M. Friedman, 1961.

overgrowths. These variations in textural properties seem to be small as one examines the grains in two-dimension under a petrographic microscope. Volumetrically, however, in three-dimensions it is large enough to produce appreciable changes in the textural properties of the detrital sand grains.

A plot of skewness versus mean grain size shows that the majority of the samples have tendency to reflect dune environment, a textural property which may have been inherited from the source rock (fig. 10).

The third moment (skewness) is considered by many workers to be the major textural factor in defining the environment of deposition; beach - positive skewness, dune and river - negative skewness. It is believed by some workers (Friedman, 1961) that the mineralogy of the sands does not affect the calculated skewness. Friedman suggested that the skewness for all sands reflect their environment of deposition, regardless of their mineralogical composition.

The Kurtosis (K_G) value (Folk and Ward, 1957) for the Ada sandstones, or the ratio between the sorting in the tail and the body of the curve, ranges from 0.57 to 2.74, or very platykurtic to very leptokurtic. Four samples fall in the very platykurtic class, one sample falls in the platykurtic class, two samples in the mesokurtic class, four in the leptokurtic class, and the rest of the samples have values which place them in the very leptokurtic class.

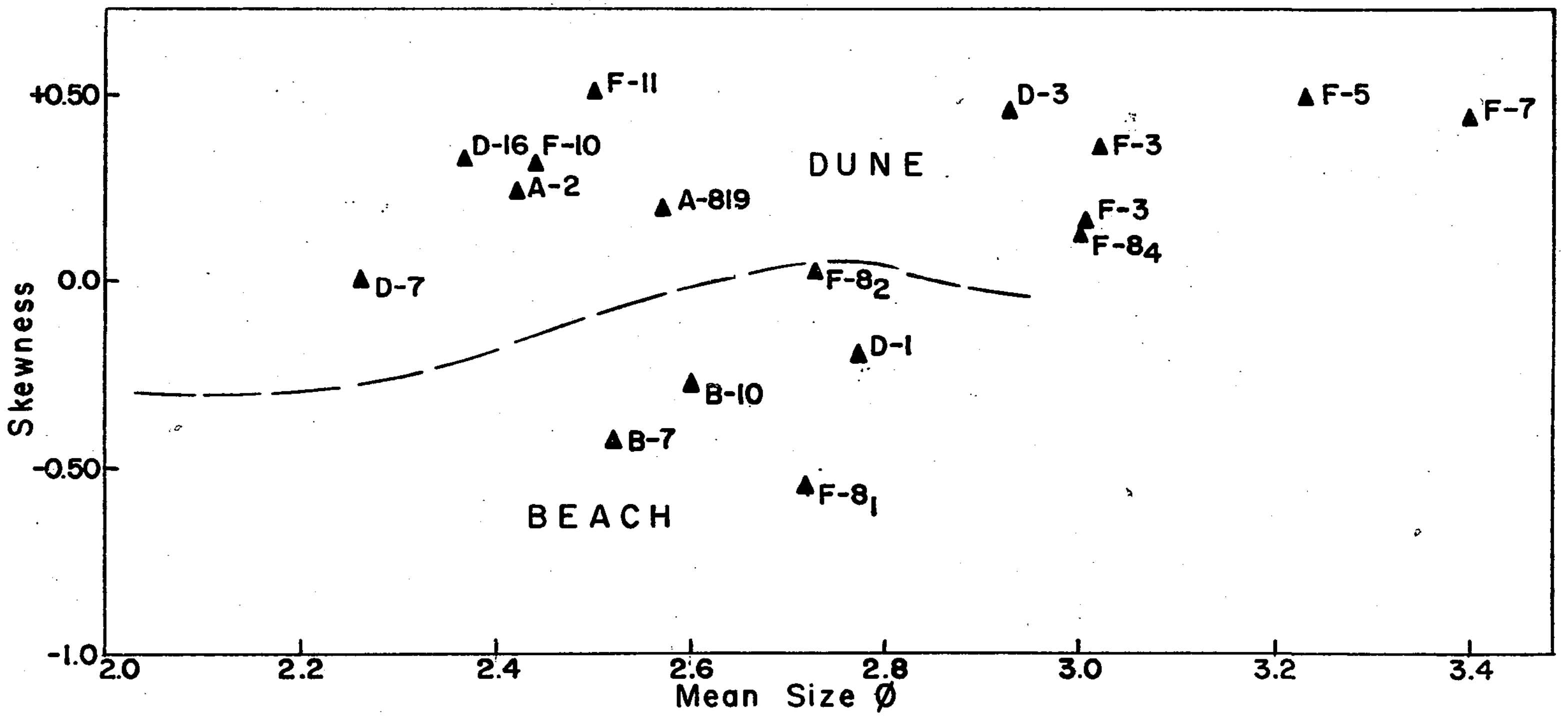


Fig. 10.-- Plot of Skewness vs. Mean Grain Size. Graph shows the distribution of beach versus dune sands. Dashed line is reconstructed from G. M. Friedman, 1961.

<u>Discussion of results</u>.--The textural parameters of sandstones from the Ada Formation were studied to discover the mode of transportation and the energy of the transporting medium. Four samples from Ada sandstones are negatively skewed, but the majority show skewness values between 0.0 and 1.00, which is characteristic of beach environments. The beach sands of the Ada were deposited in an environment of greater competency. These samples lack fine fractions because in beach environments two forces of unequal strength are acting in opposite directions and thus have winnowed out all the finer-grained particles. These forces are the incoming waves and the outgoing wash (Friedman, 1961). However, most of the sandstones in the Ada Formation contain considerable amounts of clay- and silt-sized particles trapped between the fine to coarse sand-sized clastics. This may be due to the rapid rate of deposition which in turn prevents the winnowing process.

The grain size distribution of each sample was analyzed by preparing a frequency curve, or cumulative curve. Examination of these curves show that the majority of the sandstones in the Ada Formation have bimodal to trimodal size distribution.

Five explanations can be presented for the deviation of the textural properties from normal distribution for the Ada sandstones.

First, availability or size range availability from the source area, that is, the bulk of the source area was primarily admixed with finer fractions. This would develop a bimodal sediment in the source area. The Ada sandstones are derived from reworking of sedimentary rocks of Early Paleozoic age from the Arbuckle Mountains.

The second possibility, that is present is multiple source areas. The chert conglomeratic sandstones from the lowest part of the formation are trimodal sandstones, containing some clastics similar to those present in the underlying rock units in the Vamoosa Formation. It is believed that an additional mode of size has probably been introduced into the Ada sediments when the shallow transgressive sea was advancing over the outcrops of the Vamoosa Formation. Based on this similarity, Morgan (1924) has suggested that north of the Canadian River in Seminole County, the Ada Formation lies conformably upon the Vamoosa Formation.

However, land was exposed along the eastern border of the sea which probably introduced some fine clastics into the environment of deposition. Assuming this suggestion is true, it is believed that, quantitatively, a small portion of the terrigenous constituents of the Ada sediments were probably derived from the east. But an examination of mineralogical composition of these sandstones in thin section showed no compositional evidence for a dual and/or triple source; therefore this possibility is disregarded.

A third possibility exist by the trapping of fine particles as a result of rapid rate of deposition. This would cancel the effect of the energy influence for winnowing out the fine particles in a relatively high energy environment. Fluctuation in the energy of the depositional and/or transporting medium is probably the major cause for the deposition of the poorly-sorted portions of the Ada Formation. These fine admixes occur as discontinuous thin laminations in the fine- to medium-grained sandstones (Plate VII, fig. F).

The fourth possibility is that of faulty sampling procedure. This could occur by sampling along the contact of two layers deposited under different energy conditions, each of which is well-sorted, but together would represent a poorly-sorted bimodal sample. Microscopic graded-bedding is common in the Ada sandstones which shows alternative layers of silty sandstone and medium to fine sandstone. In addition, the megoscopic graded-beds are common in the outcrops of the Ada sandstones.

A fifth possibility also exists in which the process of carbonate corrosion (diagenesis) would reduce the size of the detrital quartz grains. The rate of reduction of the fine sand-sized fractions seems to be more rapid than the medium or coarse sand-sized particles, because of the greater surface area of the former. Because the majority of the sand grains in the Ada Formation range in mean size from very fine to medium, the effect of diagenesis is believed to be rather important in the alteration of the primary grain size distribution. Moreover, quartz overgrowth development which is probably an indirect result of carbonate corrosion, effects the grain size distribution in the other direction, and enlarges the coarser grains and as a result increases the degree of bimodality.

In addition, the incomplete mixing or incomplete sorting of the particles by natural agencies might produce bimodal samples. The presence of minor coarse fractions in fine sandstones is probably due to this factor.

When the interrelation of the textural properties were compared relative to each other, only the plot of mean size versus standard deviation showed the helical trend, the others did not. Folk and Ward (1957) suggested that there is a somewhat helical trend between the mean size, standard deviation, skewness, and kurtosis. Nine samples from section F exhibit a helical trend (fig. 7). However, the samples from the other sections did not show a complete helical relationship, but this may be because of insufficient data.

The results obtained from grain size analysis, such as increase in grain size to the south, thickening of the limestone conglomerate member and the other terrigenous constituents to the south, slight thickening of the shale member to the north, and many other minor factors all strongly suggest the presence of a shore-line and source area to the south.

Heavy Mineral Studies

Introduction.--Eighteen samples from Ada sandstones were disaggregated by dissolving the calcareous cement in dilute HCl. The samples then were separated into grain size fractions by sieve and pipette analysis. Size fractions in the range of 3.50 Ø to 3.75 Ø were chosen for the heavy mineral separation. These grain sizes approximately correspond to the largest size fractions suitable for microscopic identification, and the appropriate maximum size of occurrence of heavy mineral grains. The relative enrichment of the heavy minerals in the finest fractions is probably due to the fact that the lighter minerals have been winnowed away and transported farther to the sea in considerable quantity.

Apatite is present in small amount in the heavy mineral suites, but biotite, muscovite, and chlorite are essentially absent. The reason is that their ranges of specific gravities overlap that of tetrabromethane (specific gravity equal or more than 2.90). However, most of the apatite grains was probably leached out during acid treatment.

Nine non-opaque and at least five opaque heavy minerals were identified from the Ada heavy minerals suite. The non-opaque heavies consist of zircon, tourmaline, garnet, epidote, rutile, apatite, kyanite, and sphene. In addition trace amount of micas (biotite, muscovite, and chlorite), and staurolite were identified. Leucoxene, ilmenite and/or magnetite, hematite, and pyrite constitute the opaque fractions. No attempt has been made to distinguish between magnetite and ilmenite because of their similarity in physical properties. X-ray analysis have not been made because of the small amount of sample.

Opaque heavy mineral suite.--Opaque heavy minerals are present in all eighteen slides in amounts ranging from 24 to 82 percent. Leucoxene is by far the most abundant opaque heavy mineral.

The percentage of the opaque minerals increases as the grain size decreases. In samples F-3 two different grain sizes such as 3.50 Ø and 3.75 Ø were analyzed for their heavy mineral content. Results of the heavy mineral investigation is summarized in Table 2. It shows that the opaque fraction increases from 30.82 to 79.22 percent as the grain size decreases from 3.50 Ø to 3.75 Ø, respectively. Magnetite and ilmenite slightly increase in percentage with decreasing grain size, but hematite increases rapidly and leucoxene occurs in large amounts in very fine-grained sandstones.

The opaque minerals in their order of decreasing abundance are: leucoxene, hematite, magnetite and/or ilmenite, pyrite, and limonite. In many samples, both fresh and altered magnetite and ilmenite are present. The magnetite

TABLE 2

HEAVY MINERAL DATA FROM THE ADA FORMATION

Sample No.	Grain size Phi	opaques	rutile	tourmaline	zircon	epidote	garnet	apatite	sphene	monazite	kyanite
A-819	3.75	72.30	2.87	3.45	17.81	0.57	1.50	___	___	1.50	___
A-2	3.50	26.90	6.28	7.17	50.22	3.85	4.48	0.45	___	0.45	0.45
B-7	3.75	28.19	7.69	4.48	51.92	3.20	3.85	___	0.64	___	___
B-7	3.50	32.88	8.55	9.87	23.68	8.89	11.18	___	2.28	1.97	0.65
B-10	3.50	42.50	6.36	3.88	36.75	4.94	4.59	___	0.35	0.70	0.35
D-1	3.75	50.85	2.85	1.72	36.20	3.45	3.45	0.86	0.86	___	___
D-3	3.75	41.23	8.25	10.82	17.01	18.55	4.12	___	___	___	___
D-7	3.50	24.21	1.86	3.10	52.80	3.72	9.32	___	___	4.35	0.62
D-16	3.75	32.00	___	8.00	12.00	20.00	16.00	8.00	___	___	1.00
F-3	3.50	30.82	4.16	2.50	40.42	6.25	15.83	___	___	___	___

TABLE 2--Continued

Sample No.	Grain size Phi	opaques	rutile	tourmaline	zircon	epidote	garnet	apatite	sphene	monazite	kyanite
F-3	3.75	79.22	3.85	1.54	6.15	4.61	2.30	2.30	___	___	___
F-5	3.75	47.24	1.57	3.94	19.68	5.51	22.05	___	___	___	___
F-7	3.75	46.82	0.90	6.30	23.42	10.81	7.20	___	0.90	1.80	1.80
$F\text{-}8_1$	3.75	54.32	3.26	4.26	21.21	8.52	4.17	___	2.17	___	2.04
$F\text{-}8_2$	3.75	32.06	5.66	9.43	18.25	9.43	22.64	___	___	2.50	___
$F\text{-}8_4$	3.50	29.32	4.29	11.56	28.85	6.72	18.92	___	___	1.34	___
F-10	3.75	34.87	0.94	4.71	34.90	3.77	14.15	0.94	1.88	1.88	0.94
F-11	3.00	82.19	2.73	4.11	2.73	1.37	4.11	1.03	___	1.70	___

and ilmenite were altered into hematite and leucoxene respectively. The magnetite grains show a gradational stage of alteration. They are characterized by being partially covered with a hematite skin and thick coat of hematite. In some sandstones hematite, derived from the alteration of magnetite, surrounds magnetite grain in concentric layers a fraction of millimeter thick. Ilmenite is also characterized by its partial alteration to leucoxene. Limonite occurs in small amount and is believed to be derived from the alteration of biotite and some other iron-bearing minerals.

The largest discrepancy in quantity concerns the opaque minerals; specially limonite. It occurs rather predominately as stain, authigenic cement in minor amount, and as detrital grains in the sandstones, but it is present in only small amounts in the heavy mineral suite. It was probably lost during treatment of the samples with HCl. In some of the well-cemented sandstones in order to achieve complete disaggregation prolonged acid treatment may have dissolved most of the limonite content in the samples.

The grain-size range is uniform among the opaque minerals; however, they are slightly coarser than the average zircon grains.

Authigenic pyrite is observed in some of the locally asphalt-stained very fine sandstones. The sequence of events in its formation is interpreted as follows: (1) introduction and migration of asphaltic materials into the sandstone during or after the tectonic activity in the source area (Arbuckle Mountains); (2) ferric iron was then reduced to ferrous iron which is more soluble; (3) most of the ferrous iron was then removed in solution, but some was precipitated as pyrite due to the introduction of sulfur which was present in the asphaltic materials.

Non-opaque heavy mineral suite.--Non-opaque heavy minerals are present in all eighteen slides in an amount ranging from 18 to 76 percent. Zircon is by far the most abundant non-opaque heavy mineral.

Zircon is present in all slides and ranges from 15.35 percent to as much as 73.79 percent of the non-opaque fraction (Plate V, fig. A). The majority of the samples contain less than 30 percent zircon in their heavy mineral fraction. Zircon occurs in the form of prisms terminated by pyramids (euhedral), and rounded and rerounded (anhedral) (Plate V, figs. G, H and I). Both colorless and pink varieties are present. The fact that there is no gradational variation in the form of the zircon grains from euhedral to anhedral suggests the possibility of dual source. Zircon generally decreases northward, figure 12, while kyanite slightly increases to the north, figure 11. The other heavy minerals show rather irregular variations in quantity from south to north.

Tourmaline is present in all samples and ranges from 3.50 percent to as much as 23.11 percent of the non-opaque

Fig. 11.--Average grain percentages of predominant individual non-opaque minerals of specific gravities 3-4, calculated for groups of samples from their 3.50 and 3.75 Ø fractions. Horizontal scale: 1" = 4 miles.

Fig. 12.--Average grain percentage of individual non-opaque minerals of specific gravities 4-5. Composite samples consist of 3.50 and 3.75 Ø fractions of stratigraphically collected units. Horizontal scale: 1" = 4 miles.

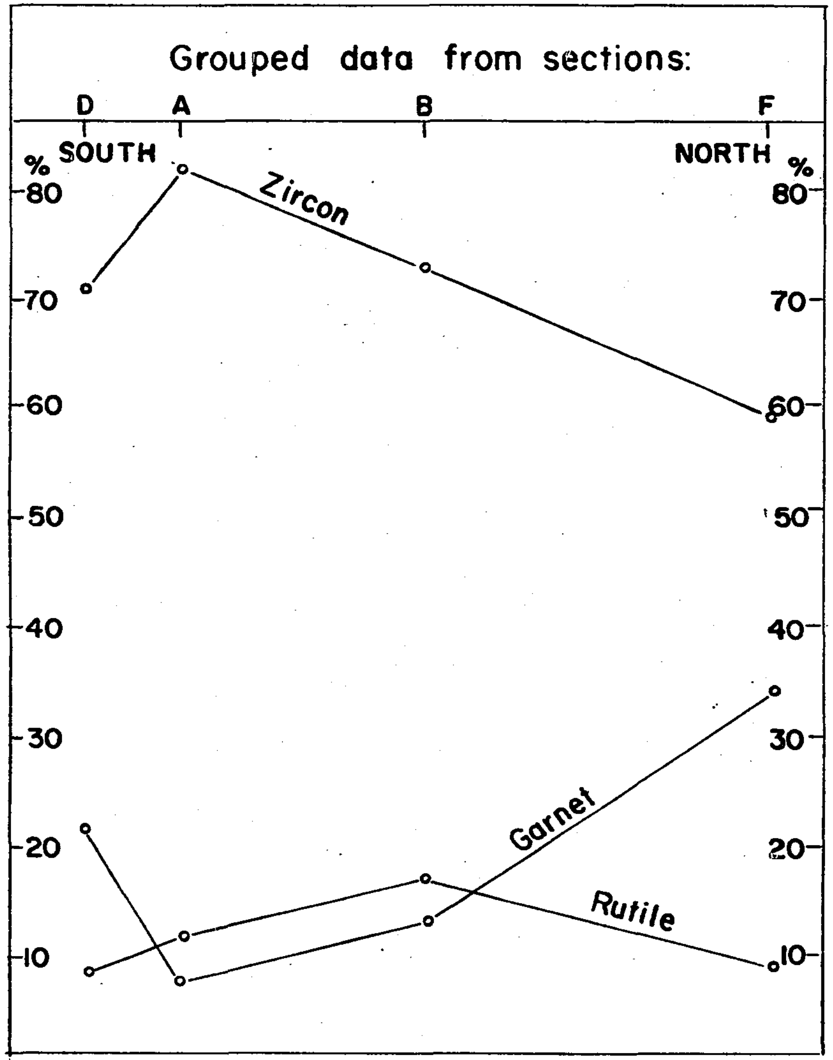


Figure 12.

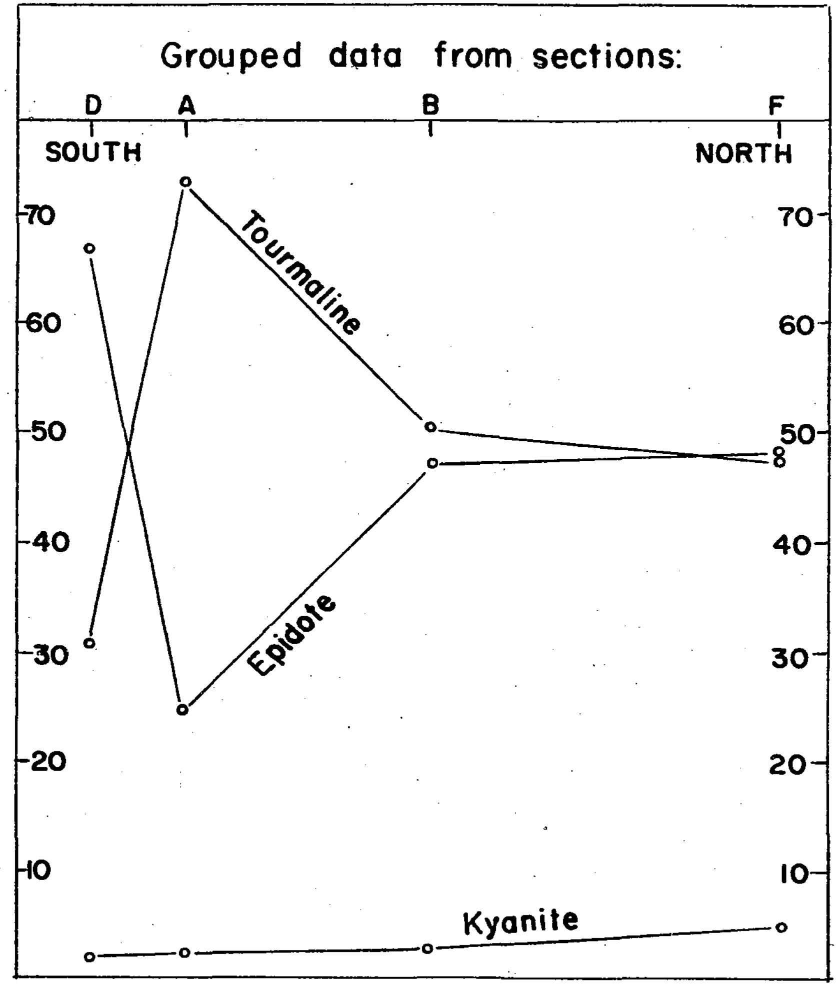


Figure 11.

fraction (Plate V, figs. A and J). Most of the slides contain less than 5 percent tourmaline in the heavy mineral fraction. The grains of tourmaline occur in subhedral to anhedral forms. The grains are entirely well-rounded except in the finer fractions, which are subrounded to subangular as well as euhedral. The tourmaline grains can be divided into four groups based on the color properties examined in plane - polarized light. In order of abundance they are: red-brown, green, blue, and olive-drab. The latter two are absent in most of the slides. But the red-brown variety occurs predominately in almost all samples. Green tourmaline is absent in some of the slides.

Well-rounded, black tourmaline occurs only in the heavy mineral suite of the shale member; and is absent in the sandstones.

Relative abundance of tourmaline and epidote are in inverse relationship to each other (fig. 11). Tourmaline increases rather rapidly toward the proposed "shelf" environment of the sea, measured section location A, whereas, epidote decreases. Tourmaline decreases to the north, but epidote increases in percentage northward. This is probably because of the fact that epidote would be destroyed more rapidly in coarser grains in the high energy zones, because of its physical properties. Epidote grains have at least two distinct fracture planes, whereas tourmaline grains show only a weak basal fracture plane, and therefore, do not

PLATE V

PHOTOMICROGRAPHS FROM THE ADA SANDSTONES AND HEAVY MINERALS

A. B-7.- A typical heavy mineral suite from Ada sandstone, tourmaline, zircon, and opaque heavy minerals. Plane polarized light X50.

B. C-15.-Calcite cemented quartz sandstone. Banded, alternating the organic matter rich siltstone (collophane), and fine to medium calcareous sandstone; graded-bedded. Plane polarized light X50.

C. C-17.-Calcareous orthoquartzite. Note the abundance of fine sand-sized carbonate rock-fragments. Bimodal. Plane polarized light X50.

D. D-8.- Bimodal to trimodal calcareous orthoquartzite. Note the selectivity of the replacement of detrital quartz by calcite at the center of the figure. Note also the abundance of carbonate rock-fragments. Some of these intraclasts are composed of pelmicrite. Plane polarized light X50.

E. D-7.- Strongly etched garnet showing crystal face development. Plane polarized light X200.

F. B-16.-Poorly etched euhedral garnet showing little or no leaching. Plane polarized light X200.

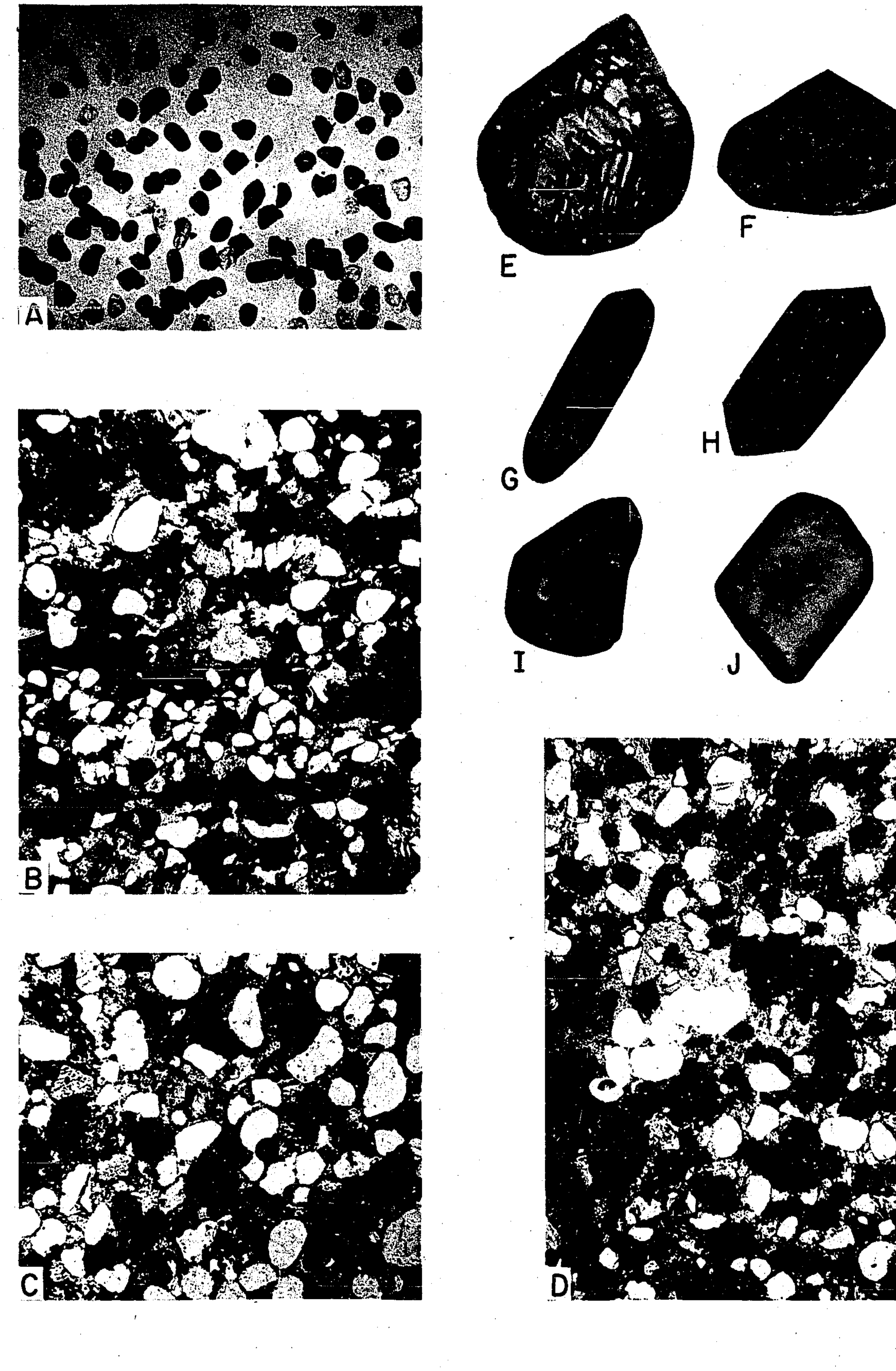
G. F-3.- Subhedral, acicular zircon from upper sandstone member. Note the presence of microlite in the grain. Plane polarized light X200.

H. B-18.-Euhedral zircon. Sample the same as F. Plane polarized light X200.

I. A-2.- Anhedral well-rounded zircon from lower sandstone member. Plane polarized light X200.

J. D-8.- Well-rounded tourmaline grain from lower sandstone member. Note absence of etching to form crystal faces. Plane polarized light X200.

PLATE V



alter or fragment in coarser grains as fast as the epidote. The finer the grains are the more stable; therefore their relative percentage increases in the finer sediments, or to the north.

Garnet is present in all samples, in amounts ranging from 5.36 percent to as much as 41.8 percent of the non-opaque heavy mineral fractions. It occurs in two distinctive varieties; colorless and pink. The colorless varieties are more predominant than the pink ones. The pink garnet is absent in some slides. In poorly cemented sandstones the garnet grains are strongly etched leaving a characteristic aggregate of crystal faces on the grain (Plate V, fig. E.). The pink variety of garnet, when present, shows extreme etching compared to that of colorless ones. This probably indicates that pink garnet has more of a tendency to decompose chemically; its absence in these sediments is probably due to this property.

The process of leaching of garnet grains is post-depositional in origin because: (1) the leached garnet shows sharp angular crystal faces, indicating that the grain was not subjected to transportation after alteration; and (2) the highly leached garnet grains are more predominant in poorly-cemented sandstones than in the well-cemented sandstones. It is believed therefore, that the low pH ground-waters were primarily responsible for the interstitial solution.

The process of leaching is probably intensified during acid treatment. In order to examine the degree of importance of this process and to check the effect of cementation, two samples of Ada shale (B-16 and B-18) were examined for their heavy mineral content. Garnet grains in these shales show slightly less etched crystal faces as compared to those in the sandstones.

Epidote, pistacite variety, is present in all samples, ranging in percentage from 2.05 to as much as 31.7 of the non-opaque fraction. The grains are slightly well-rounded, yellow green, pleochroic in plane-polarized light, and characteristically highly birefrengent, and Persian carpet-color in crossed-nicols. Coarse-grained epidote grains decrease rapidly in size in the high energy zone of deposition along the measured section location A, and its percentage increase toward the deeper environment as it becomes finer-grained.

Rutile is present in all samples examined from the Ada sandstones and shales and ranges in percentage from 1.44 to 18.64 of the non-opaque fraction. It comprises less than 9 percent of the total heavy mineral suite. The grains are well-rounded to subrounded; and have a uniform grain size. Both red and yellow varieties are present. The red variety is more abundant than the yellow. The cloudy gray variety of rutile was not found in the Ada Formation.

The relative proportion of rutile, garnet, and zircon is plotted as the fraction of the heavy minerals with specific gravities ranging from 4-5 along the north-south direction (fig. 12). It seems that rutile increases outward from the "shore," and then decreases to the north into the "deeper" environment. Its maximum percentage occurs farther north along the section B compared to that of zircon which occurs at A, figure 12. The only explanation is that the mean grain size of rutile is comparable with the light mineral fractions at section B, whereas, zircon occurs with coarser detritals at A ("Rittenhouse ratio").

Monazite is present only in ten samples, ranging from a trace to as much as 9.56 percent of the non-opaque fraction. Most of the samples contain less than 2 percent of the total heavy mineral fraction. All the grains are well-rounded, and none show original crystal forms.

Kyanite is present in eight slides in amounts not more than 5 percent of the non-opaque heavy mineral fraction. The grains are colorless, angular to subangular, and have pronounced right angle cleavages. The angularity of kyanite is an indication of a relatively high energy environment. Because kyanite occurs in small percentage, omission by chance is probably the main reason for the absence of kyanite in the other samples.

Six samples contain apatite, Table 2. It ranges in percentage from less than 1 to not more than 6 of the non-opaque fraction. The apatite occurs in both subhedral, anhedral, and tabular form with some basal sections. Both varieties occur in subequal amounts. The occurrence of apatite is sporadic, but there is a general increase in percentage northward from 0.45 to 1.03.

Sphene is present in seven samples, in an amount not more than 5 percent of total non-opaque fraction. It occurs in rhombic basal sections, with characteristic two-directional cleavage, high relief, and light brown in crossed-nicols. It is commonly fragmented along two distinct cleavage directions which leaves a rhombic outline to the grain. No well-rounded and/or subrounded sphene was found.

Interpretation suggested by data.--A quantitative study of the heavy mineral fraction from the Ada Formation showed that their distribution was governed by their specific gravities. The heavier minerals increase in quantity more rapidly outward from the "shore" and then decrease gradually in the deeper zones. The sharp increase of the heavier minerals in the shallow environment is somewhat comparable to that of marked increases in grain size from D to A (figs. 6, 13 and 14). Both data indicate a relatively shallow and high energy environmental condition in the southern margin of the depositional environment. The amount of heavier minerals decrease outward from A to B and to F. Furthermore, from the "beach" across the inner shelf and deeper zones the heavier minerals give way progressively to the lighter ones (fig. 14).

In order to determine the trends of areal distribution of the heavy minerals from south to north, the mineral group percentages of the 3.50 Ø and 3.75 Ø fractions were calculated for each sample. The results were then combined to obtain the average value for sample number 2, 3, 4 and 9 from the sections A, B, D, and F respectively. Only the combined values were used in this study. It was found useful for the interpretation of the laboratory data to prepare diagrams showing the distribution of heavy mineral groups and the individual minerals within these groups, each on an appropriate scale (figs. 11, 12, 13 and 14). The percentage of the various heavy mineral fractions in each sample from a related measured section is tabulated in Table 2.

Heavy mineral sources for the Ada Formation.--Based upon several observations the writer believes that the majority of the terrigenous sediments in the Ada Formation were reworked from rocks of Early Paleozoic age which were exposed in the Arbuckle Mountains. The border-land along a northeast-southwest direction also provided some terrigenous constituents to the environment of deposition. However, because of its low topography, the introduction of the clastics from the border-land is believed to be small. Rocks of Simpson Group in the Arbuckle Area, seem to have been the major source for the sandstones and heavy minerals which were deposited in the transgressive marine environment. The primary source of the heavy minerals in the Ada

Fig. 13.--Average percentage of opaque and non-opaque heavy minerals. Composite samples composed of 3.50 and 3.75 Ø fractions of stratigraphically collected units. Horizontal scale: 3 cm = 4 miles.

Fig. 14.--Average percentage of non-opaque minerals of specific gravities 3-4 and 4-5. Calculated for groups of samples from their 3.50 and 3.75 Ø fractions. Horizontal scale: 3 cm = 4 miles.

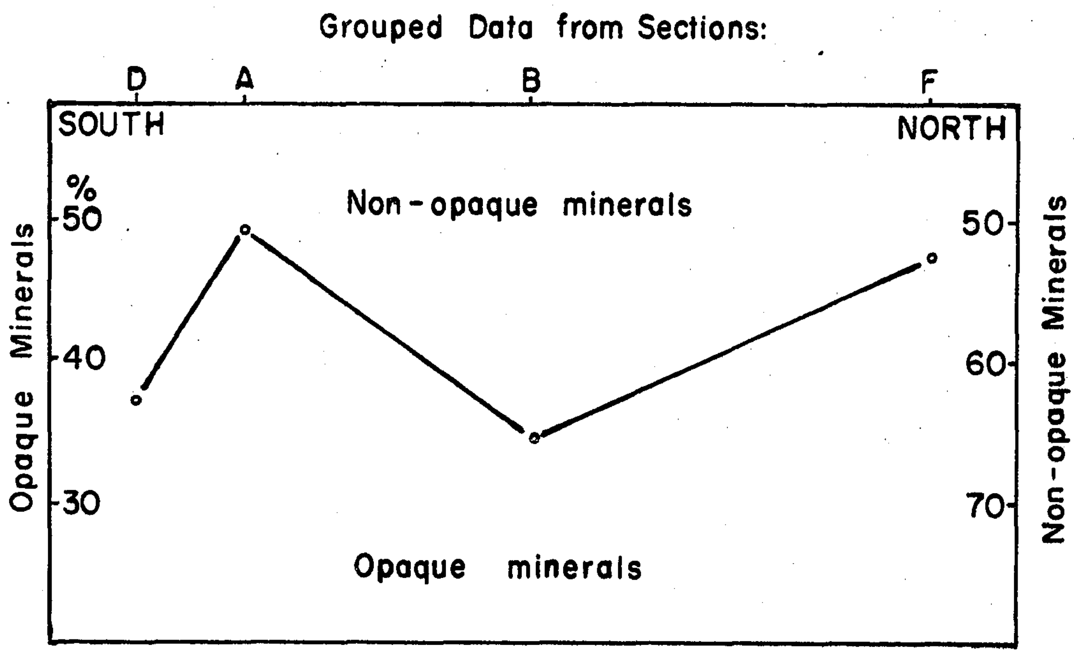


Figure 13.

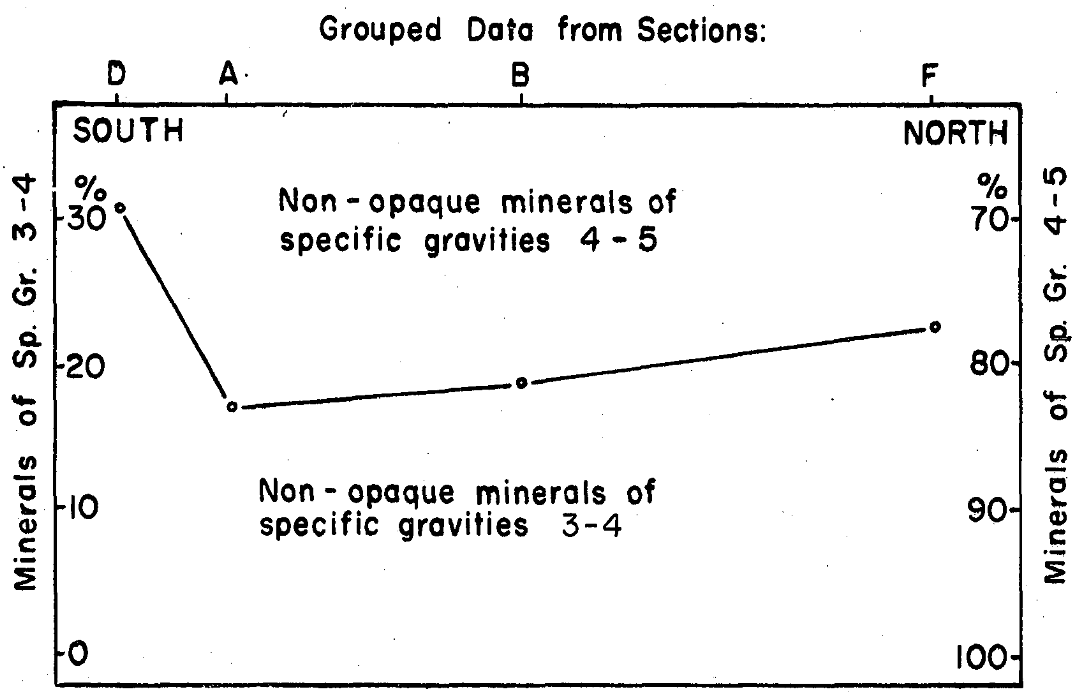


Figure 14.

Formation can not be discussed in here, because of lack of sufficient data. However, the presence of epidote, kyanite, as well as bent - micas (MRF), suggest that at least part of the original source was a metamorphic rock unit. On the other hand, the abundance of zircon, tourmaline, and some monazite suggests that a rock sequence composed of granite and gneiss must have been present in the primary source area from which the Simpson Group was derived. Most of the heavy minerals present in the Ada Formation are reported by the previous workers from the Simpson Group.

Petrography of Sandstone

General statement.--The lower and the upper members of the Ada Formation are composed in general of fine- to medium-grained sandstone. Individual beds are composed of well-rounded to subangular, bimodal to slightly trimodal, poorly-sorted, poorly-packed, calcareous, siliceous, and clayey orthoquartzite. Asphalt stain is present in the lower sandstone member, and sparcely developed at the base of the upper sandstone. The asphaltic materials are composed of reddish brown, non-crystalline organic matter. No attempt was made to identify the individual organic compound.

Quartz.--The amount of the detrital quartz in the Ada sandstones ranges from approximately 30 percent to as much as 80 percent in the non-cemented to poorly-cemented sandstones. The grains range in size from fine to medium sand, although there are cases where the mode of very fine sands and/or coarse sands are present. Silt-sized quartz grains occur in variable amount in more than 90 percent of the sandstones examined. The quartz grains are well-rounded to subangular, and some are wedge shaped. The roundness is probably controlled by both mean diameter of the detrital grains, as very fine and fine sands tend to become subrounded and subangular, whereas medium and coarse-grained sands are well-rounded.

The majority of the sandstones are poorly sorted, bimodal to trimodal. However, the examination of the textural properties of the sandstones in thin section revealed that more than 80 percent of the sandstone samples have trapped fine particles along some discontinuous layers (Plate VII, fig. F). These discontinuous layers consist of very fine sandstone and some siltstone. The presence of these fine layers in a medium sandstone developed a bimodal curve in a grain-size analyses. One explanation for the presence of the trapped fines is that the rapid rate of sedimentation prevented the removal of the fine-grained sands from the intersticies of the medium and coarse sands.

Without exception, the sandstones containing abundant carbonate cement are characterized by being not grain-supported and are therefore poorly packed.

The majority of the quartz grains in the Ada sandstones have straight to slightly undulose extinction and/or are plutonic quartz types. The undulose, composite, and the semicomposite quartz grains are less common. The stretched grains are present in trace amounts in the sandstones examined.

The most common inclusions in the sand grains are liquid bubbles and to a lesser extent, vacuoles. Microlites, rutile needles, and zircon inclusions occur in an average of less than 20 percent of the detrital quartz grains. Negative crystals were found in less than one percent of the quartz grains.

Feldspar.--The feldspar content of the samples studied does not exceed a few tenths of a percent. In most cases the feldspar is moderately fresh and consists of microcline, perthite, orthoclase, and albite. Authigenic feldspar is not present in the sandstones. However, some of the feldspar grains are highly vacuolized and/or kaolinitization is well-developed. The grain size of the feldspar ranges from fine to medium sands (2.50 Ø to 1.50 Ø). They are well-rounded and partially replaced by carbonate cement.

Chert.--Detrital chert occurs in fine sand-sized grains to granules and pebbles in the Ada sandstone. The lowermost part of the lower sandstone member contains abundant chert pebbles and granules in a sandstone matrix. In the uppermost part of the upper sandstone member chert occurs as pebbles and granules grading into limestone pebbles toward the base of the member. The chert fragments are commonly composed of cryptocrystalline to microcrystalline, xenotopic silica, where it contains abundant inclusions of liquid bubbles and organic matter. The chert grains in the Ada sandstones develop a porphyrotopic texture. The grains are commonly coarser than the sandstone matrix and are with few exceptions, subangular to subrounded and are partially replaced by carbonates. Rhombohedral carbonates occur in places as inclusions in the chert grains (Plate VII, fig. D).

Clay.--The clay content of the Ada sandstone varies greatly depending on the stratigraphic position of the samples. Those beds of sandstones which have a close contact with the shale member, are characterized by having more clays in their matrix. Most of the clay particles present in the sandstone members are aligned parallel to the surface of the grains. Authigenic clay is found in small amounts in the samples that were examined. They are mainly illite and kaolinite. It is believed that at least part of the authigenic clay in these sandstones are replaced with calcite cement and are indistinct from the latter. Clays coating the surface of the detrital quartz grains can easily be detected if the clay particles are not optically aligned parallel with the associated quartz grains. In this case, when the quartz grains are in extinction position, under crossed nicols, the clay coating shows a distinctive birefrengence.

The weathered surfaces are high in clay content and are dark brown because of the presence of limonite.

Clay is absent in most of the carbonate rich sandstones; it is abundant only where the sandstones are poorly cemented. It is therefore believed that most of the clay, particularly clay occurring as coating on the surface of the sand grains was derived from the Simpson Group and replaced by calcite.

Carbonate rock-fragments.--Calcite and dolomite fragments are present both in the form of allogenic and authigenic constituents in the samples studied. The limestone rock fragments range in grain size from fine sand to granules and pebbles in the sandstone members of the Ada Formation. They occur in two distinctive forms. The most abundant occurring limestone intraclasts are well-rounded and composed of microcrystalline calcite. Other carbonate rock fragments are subrounded to subangular and composed of coarsely-crystalline calcite. These coarse clastics were fragmented mechanically along the twin planes of the sparry calcite into straight edges and subrounded to subangular (Plate VIII, fig. A).

The percentage of the allochemical limestone in the Ada sandstones ranges from 0.0 to as much as 20 percent. The intraclasts, composed of microcrystalline calcite, are in most instances recrystallized into equigranular to subequigranular microsparite. The allochems composed of coarsely crystalline calcite are commonly replaced by rhombohedral carbonates, probably dolomite (Plate, VIII, fig. A).

The carbonate rock fragments are commonly well-sorted within a single thin section, although they have consistantly slightly larger grain sizes than the associated quartz.

Detrital dolomite rhombs are present in some sandstones in a maximum amount of less than 10 percent. The dolomite clastics show weathered surfaces covered largely with limonite and minor amount of clay. It is believed that most of the limonitic clay was probably brought in by meteoric waters. The limonitic-clay coating is exclusively limited to the detrital dolomites in the sandstones examined. This strongly suggests that the limonite stain was introduced on the surface of the detrital dolomite in an environment other than the present.

Micas.--Coarse-grained, bent, brown biotite is the most predominantly occurring mica in the Ada sandstones and conglomerate. Its bend character and consequently, undulose extinction, may suggest that it has been derived from a metamorphic source rock (MRF).

Muscovite and the variety of chlorite with anomalous interference colors (Berlin Blue) are present in the sandstone members.

The percentage of micas in the Ada sandstones is commonly less than one.

Glauconite.--Fine to very fine sand-sized glauconite grains occur in the Ada sandstones in a total amount of less than one percent. The grains are well-rounded and have an average grain size less than the mean grain size of the associated quartz grains.

Porosity.--Pore spaces occur along some irregularly distributed patches in most of the non-cemented, and poorly-cemented sandstones. The extreme abundance of the pore spaces in some of the slides is probably due to the removal of the clay matrix from the surface of the rock during preparation of the thin-section.

Cementation and Diagenesis in Carbonate-Cemented Sandstones

The percentage of orthochemical calcite in the Ada sandstones ranges from 0.0 percent to as much as 60 percent. The authigenic calcite is the main cementing constituent, and consists of both microcrystalline and coarse sparry calcite. The inter-relationship between the fine and coarse calcite cement may be described in two textural forms. First, a porphyroid texture which is formed due to conversion of small crystal into large ones by the growth of a few large crystals in a static groundmass (porhyroid neomorphism, Folk, 1965). Second, a uniform crystal size developed due to recrystallization of the calcite cement and/or limestone rock-fragments as a result of gradual enlargement. This process forms equigranular to slightly subequigranular microspar. The texture developed in this fashion is referred to (Folk, 1965) as a coalescive texture and/or coalescive neomorphism. Microspar is distinguished in these sandstones from normal micrite and the pore-filling sparry calcite cement on the basis of its grain size. Microspar has a grain size limited between 4-30 microns. However, there is a gradational relationship between microspar and pseudospar with a grain size in the order of 30 microns. Furthermore, this distinction is an arbitrary one, because microspar may occur even in the range of 30 microns, or pore-filling calcite may develop with a crystal size less than 4 microns, if the available pores were in the order of microns (Folk, 1965). The overall grain shape of the microspar crystals in the Ada sandstones is equant.

In many sandstones the calcite cement occurs in the form of large crystals with optical continuity, which enclose several quartz grains. This is called a poikilotopic texture (Plate VI, fig. G).

Orthochemical dolomite occurs as secondary or replacement form in the Ada sandstones, ranging from 0 to as much as 20 percent.

Both calcite and dolomite show strong evidence of replacement in their contact with detrital quartz. The process of corrosion seems to be more effective along zones of weakness, such as the surface between detrital quartz grains and quartz overgrowths. These are commonly characterized by having liquid inclusions along the original surfaces

PLATE VI

PHOTOMICROGRAPHS FROM ADA SANDSTONES AND CONGLOMERATES

A. A-835.- Well-rounded, clayey, clacarous, bimodal to trimodal orthoquartzite. Note the replacement of detrital quartz grains along the fractures. Sample was taken from conglomerate member, a pebble derived from Simpson Group. Nicols crossed X50.

B. C-11.- A typical example of a bimodal to slightly trimodal quartz sandstone from the Ada Formation. The coarser the grains are the better they are rounded. Nicols crossed X50.

C. A-835.- Bimodal calcareous orthoquartzite. The same sample as A. Nicols crossed X50.

D. A-835.- Clayey quartz sandstone. Note the abundance of the authigenic clay. The same sample as A. Nicols crossed X50.

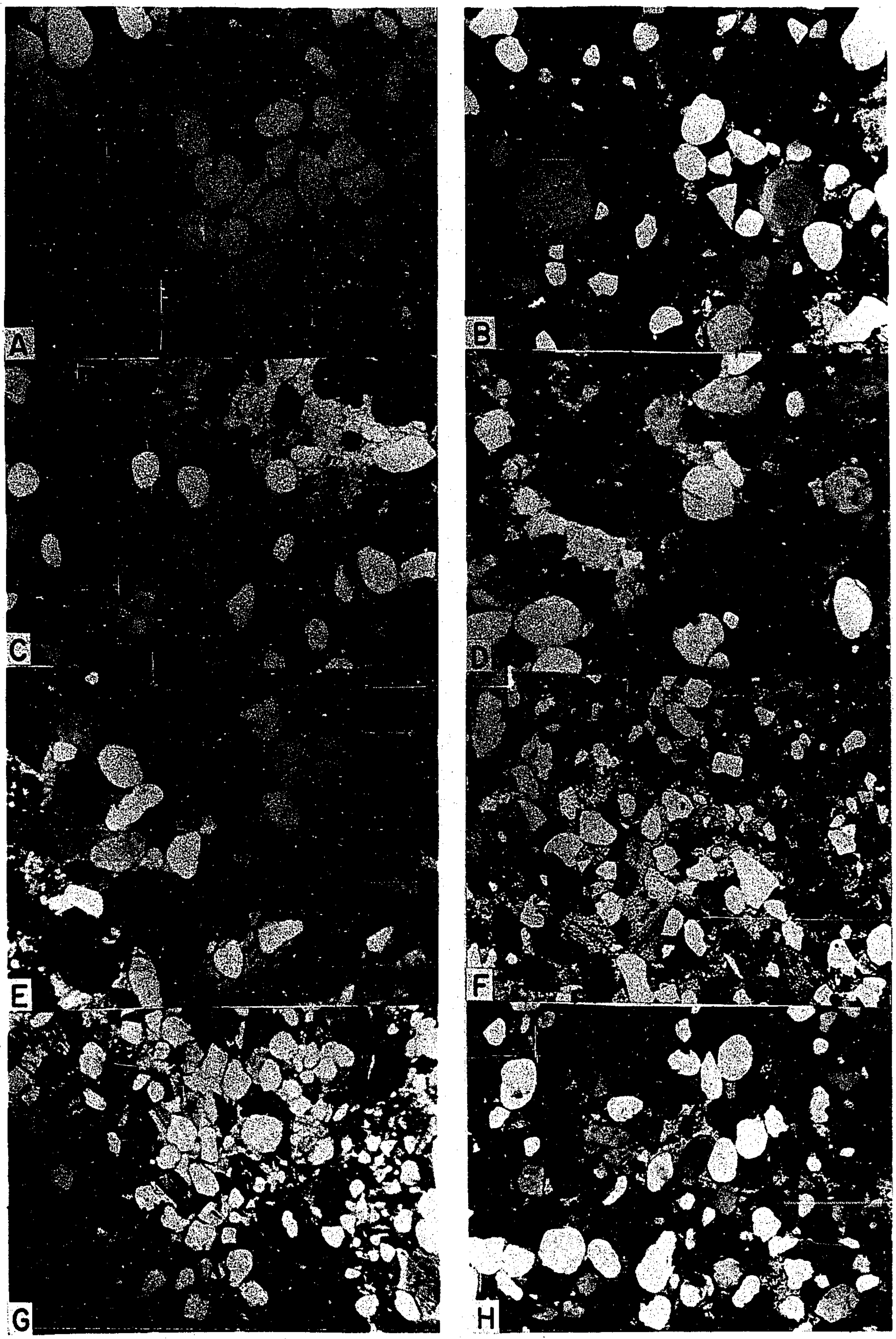
E. C-15.- Clayey, organic-matter bearing quartz sandstone. Note the replacement of quartz overgrowths by calcite, and undisturbed detrital quartz grains. Nicols crossed X50.

F. D-8.- Calcareous fine orthoquartzite. Note the abundance of fine carbonate rock-fragments. Plane polarized light X50.

G. C-15.- Poikilotopic texture in very fine to fine calcareous orthoquartzite. Note the optical continuity of the calcite cement. The same sample as E. Nicols crossed X50.

H. A-824.- Calcareous fine orthoquartzite. Bimodal. Note detrital dolomite at the center of the figure which is replaced by calcite. Pseudomorph of dolomite rhomb remaining because of the incipient limonite coat on the dolomite grain. Nicols crossed X50.

PLATE VI



of the detrital grain (Plate VIII, figs. E and F). However, deep embayments are common in most quartz grains where the calcite cement probably penetrated along some plane of weakness. A small percussion mark or fracture serves as a convenient location for replacement (Plate VI, fig. A). At the advanced stage of replacement, part of the quartz grain remains enclosed in calcite cement, leaving a vague boundary of a quartz pseudomorph. The textural evidence indicates that the rate of replacement is the same in both quartz overgrowths, and detrital grains. The reason that the process of corrosion is more common in secondary quartz is because of the fact that its surface is readily exposed to the calcite cement.

Quartz overgrowths.--The amount of secondary quartz ranges from 0.0 percent to 3 percent in the Ada sandstones. These overgrowths can be seen at a magnification of about 100x with a binocular microscope, with 10x hand lens, as well as in thin-section. A single grain of quartz when it is observed from a proper orientation reflects light from parallel crystal faces on several small facets. These small facets probably represent the initial stage of overgrowth formation.

Two different environments are possible for the development of the silica cement. Some overgrowths were developed in the source area and some were formed in the present environment. There is no easy way to differentiate between the two groups, except the overgrowths from the source area are characterized by irregular surfaces, developed probably during transportation. Those from the present environment show more or less smooth crystal faces (Plate VIII, fig. E). However, partial corrosion by calcite cement in the present environment may result in an irregular boundary over the quartz overgrowths.

Secondary quartz has apparently replaced clay particles coating sand grains. Evidence for this is the absence of clay between detrital quartz and overgrowth, and its presence where the overgrowth is absent (Plate VIII, figs. E and F). The clay could not have been formed after the secondary quartz in these specimens because the surface of the overgrowths are not coated with clay. However, there are some sand grains in which clay particles are present between sand grains and overgrowths; these are associated with abundant liquid inclusions. This probably indicates that the overgrowth has not completely replaced the clay. In places, the overgrowths are incompletely developed leaving a layer of clay on the surface of the detrital grain.

Many workers believe that no secondary quartz would form if the detrital quartz grain is coated with a thick clay rim. This may explain the fact that silica cement is absent or occurs in trace amounts on the argillaceous sandstones in the Ada Formation. The overgrowths present in the sands within the argillaceous sandstones are characterized by their irregular surfaces. This suggests that they were probably formed in an environment other than the present.

The contact between the detrital quartz grains and the secondary overgrowths is marked in most instances by the abundance of liquid inclusions, less than a micron in size (Plate VIII, figs. E and F). In places clay dust is also associated with the bubbles. The presence of abundant liquid bubbles along the rim of detrital grains is probably due to excess water released from clay minerals as they were replaced by silica. It may also be from trapped water at the time of diagenesis. When the liquid bubbles are small fractions of a micron, the identification is based upon the milky appearance under reflected light. However, bubbles are distributed randomly throughout the quartz grains and some secondary quartz in every slide examined.

Liquid inclusions are probably true indicators of temperature of formation and the abundance of these bubbles in the secondary quartz and the absence of gas bubbles in the inclusions (dancing bubbles) probably indicate that they were formed in a low temperature environment. However, there is a great diversity of opinion about the reliability of fluid inclusions in geologic thermometry (Skiner, 1953; Smith, 1954; and Richer, 1954).

Source of silica cement.--In addition to quartz overgrowths formed in the source area and then transported

PLATE VII

PHOTOMICROGRAPHS OF THE ADA SANDSTONES AND CONGLOMERATES

A. 922.- Incipient layering in chert fragments showing its replacement origin. Sample was taken from the conglomerate member; a pebble derived from Simpson Group, Arbuckle area. Plane polarized light X50.

B. D-7.- Partial replacement of detrital quartz by coarsely crystalline euhedral calcite (Q=quartz, and C=calcite). Note also complete replacement of the detrital quartz by finely crystalline anhedral calcite, leaving a pseudomorph of quartz. Note also the absence of quartz overgrowths. Poorly-packed. Plane polarized light X200.

C. D-7.- Replacement of quartz overgrowths and detrital quartz grains by calcite. Note the pseudomorph of quartz grain, incompletely replaced (Q=quartz, and C=calcite). Nicols crossed X200.

D. C-3.- Poorly-sorted, bimodal, slightly calcareous, clayey, fine orthoquartzite. Note the dolomite rhomb enclosed in detrital chert. Chert grains occur porphyrotopically in this fine sandstone. Nicols crossed X50.

E. C-3.- Very fine quartz sandstone, graded-bedded. Note the selective enrichment of clay particle in the silt-sized layer, and clacite cementing the fine sand grains. Plane polarized light X50.

F. A-835.-Interbedding of the argillaceous siltstone with fine to medium sandstone. Nicols crossed X50.

G. B-13.- Mudstone. Note the absence of the preferred orientation of the clay particles, and the presence of clay galls and silts. Plane polarized light X50.

H. C-11.- Contact between claystone and calcareous sandstone. Note burrowing track which is filled with coarse calcite mosaic. Nicols crossed X50.

PLATE VII

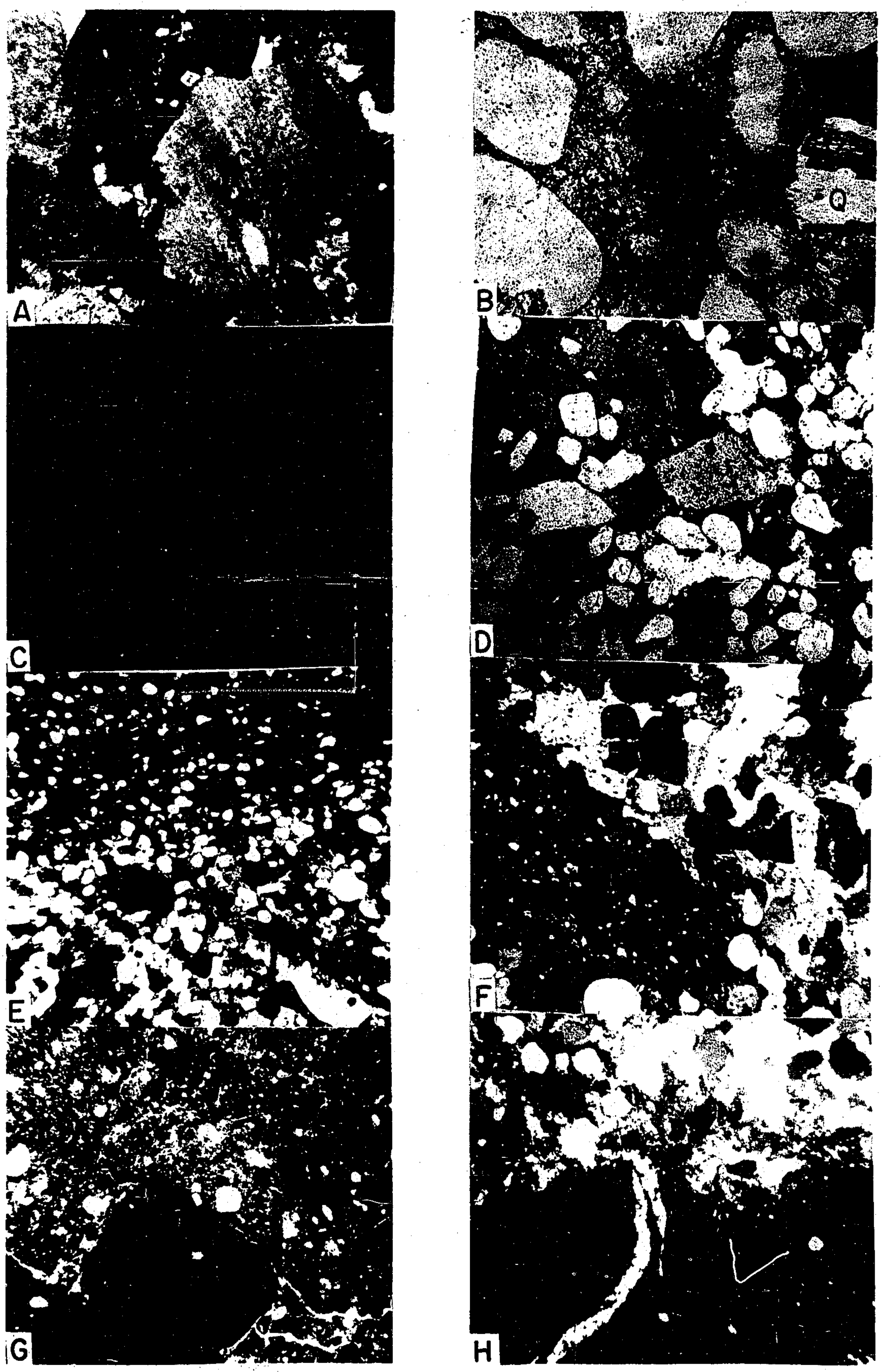


PLATE VIII

PHOTOMICROGRAPHS OF THE ADA SANDSTONES AND CONGLOMERATES

A. D-7.- Two different kinds of carbonate intraclasts in the Ada sandstone derived from the Arbuckle area. First, coarsely crystalline cacite, subangular to subrounded showing calcite twin planes; the second, composed of microcrystalline calcite, well-rounded. Note the replacement of the former by dolomite rhomb. (C=calcite, and D=dolomite). Nicols crossed X200.

B. C-17.- Pseudomorph of detrital quartz after replacement by subhedral to anhedral calcite cement (C=calcite). Nicols crossed X200.

C. 922.- Carbonate intraclasts replaced by chert (Ch=chert). Sample was taken from the conglomerate member; a cobble derived from Wapanucka Formation. Nicols crossed X50.

D. D-9.- Bryozoan replaced by chert (B=bryozoan). Note the coarse carbonate rock-fragment composed of microcrystalline calcite and some spherulites, well-rounded. Plane polarized light X50.

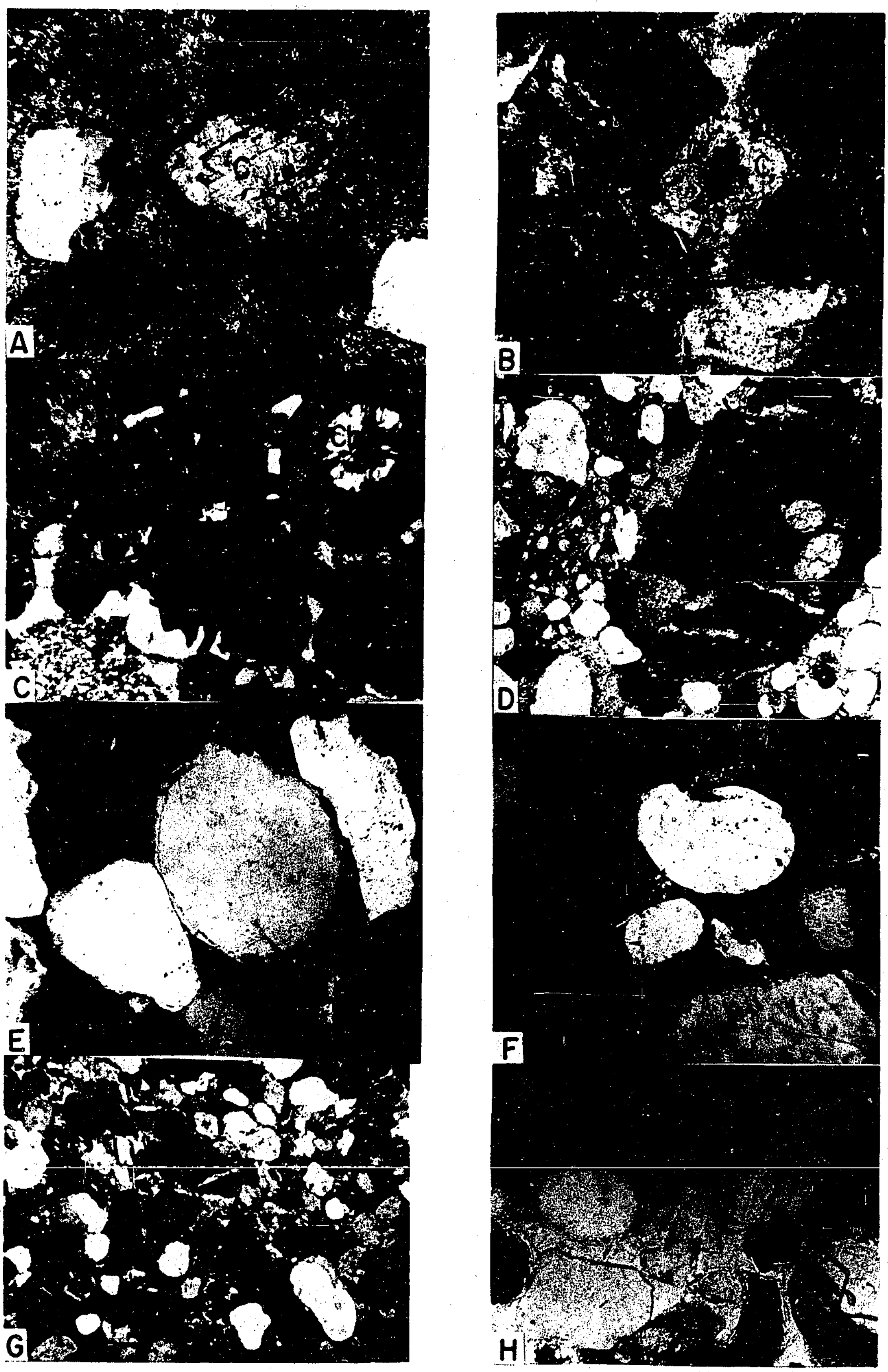
E. B-851.-Clayey fine orthoquartzite. Note the absence of carbonate cement, and the abundance of quartz-overgrowths. Note also the smooth crystal faces on the overgrowths, strongly suggesting that it is formed authigenically in the environment of deposition of the Ada Formation. Clay and liquid inclusions are present between the overgrowth and the detrital quartz grain. Nicols crossed X200.

F. A-824.-Calcite replacing detrital quartz and the quartz overgrowths. Note that the replacement occurs along a surface of weakness between the detrital quartz and the quartz overgrowth, along which liquid bubbles are common. Nicols crossed X200.

G. B-856.-Calcite-cemented fine orthoquartzite. Note the replacement of chert by calcite along a fracture zone pushing the chert apart. Nicols crossed X50.

H. B-862.-Replacement of detrital quartz and quartz overgrowths by calcite. Note the quartz pseudomorphs in the large crystals of calcite (poikilotopic texture). Note also large dolomite rhomb showing slight zonation (D=dolomite). Nicols crossed X50.

PLATE VIII



into the present environment. There are three other ways of introducing silica into the Ada sandstones.

First, silica may have been dissolved in an environment where the environmental conditions such as pH, temperature, and pressure were not in favor of the stability of silica. Mason (1958) states that the solubility of silica increases with pH from 5 to 9 and meteoric water with such a pH would dissolve the silica and transport it away in solution.

The second possible explanation is that the silica was replaced by the calcite cement. Silica would then be released from one area and deposited in another.

The third mechanism which would dissolve silica in one place and deposit it as authigenic quartz in another place is the process of pressure solution. Pressure solution is not considered an important mechanism in the Ada sandstones because of their poor-packing and the presence of abundant carbonate cement. Pressure solution when it is present is marked by stylolitic surfaces. Sandstones, where pressure solution is the only agent of release of silica, are characterized by the association of pressure solution features with quartz overgrowths. Because the chemistry of the environment is not the active agent, and dissolving takes place only under a mechanical pressure, "Rieche Principle."

1. Silica replacement.--Petrographic investigations

of the Ada sandstones, show that there is a close relationship between the presence of calcite cement and the authigenic siliceous precipitates in adjacent strata. The association of the replaced quartz grains with authigenic silica in the same beds and the absence of quartz overgrowths in the majority of the non-cemented sandstones, suggests a probable genetic relationship between the two components. That is, silica was released due to replacement by calcite, and then authigenically precipitated somewhere close to that area.

The detrital quartz grains are commonly partially to completely replaced by carbonate cement leaving pseudomorphs (Plate VII, figs. B and C). Apparently, the replacement did not greatly affect the outline of the detrital grains, as their boundaries remain as a ghost feature. The boundaries of the clastic grains are preserved either because of the abundance of inclusions along the outline of the grain or due to the textural difference between the replacement carbonate from that of pore-filling cement. However, the outline of the detrital grains is not commonly preserved, and the pore-filling carbonate grades into the replacement type. The ghost of the detrital grain can be easily observed in plane polarized light. The pseudomorphs can be readily discriminated from the carbonate intraclasts by the fact that the latter lacks a well-defined boundary, is rounded, and has a mean grain size slightly larger than the mean size of the associated sandstones.

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It is obvious that the relict features of the fine sands and silts will not be preserved because they completely disappear in the replacement process due to the fine grain size. Figures B and C from Plate VII, shows a gradual stage and incomplete replacement of detrital quartz by coarse, sparry calcite. Part of the replacement undoubtedly occurred in an environment other than that of the present. It is impossible to suggest quantitatively how much of the replacement occurred in the present environment and how much was in the source area. However, one fact is certain, there is enough textural evidence to suggest that both replacement and quartz overgrowths formed in the present environment.

Selectivity in replacement.--Examination of the quartz grains in the Ada sandstones reveals that the process of replacement is probably multidirectional, but unequal in rate and selectivity. For instance, certain mineral species such as quartz are replaced more readily, whereas feldspars show less tendency for replacement than they do for alteration. In a single quartz grain, the secondary overgrowths show more of a tendency for replacement than the detrital grain. Walker (1960), in his study of the Minturn Formation (Pennsylvanian), showed that microcline feldspar is replaced by calcite more readily than quartz, and the quartz grains were essentially unaffected by replacement. The feldspars from the Ada sandstones are less affected by replacement than quartz grains. Comparison of these two observations may suggest that the selectivity of replacement is probably controlled by some other factor.

There is also selectivity in the order of replacement of the minerals with different mineralogical composition. Calcite replaces silica at the primary stage of replacement, then dolomite replaces the calcite. However, this order may change to some extent, when for instance the carbonate becomes less stable under a low pH condition, and is replaced by silica, which is stable. A good example of this is found in the Ada sandstones where microcrystalline silica (chert) has replaced the carbonate bioclasts.

Correns (1950) has suggested that carbonate replacement of cryptocrystalline silica (opal) occurs in response to pH variations in interstitial waters. According to Correns data, opal increases in solubility with increase in pH. The range which is suggested to be geologically important is pH 5 through pH 9. According to Correns data with increasing pH, SiO_2 becomes more stable whereas $CaCO_3$ precipitates. Decreasing the pH will favor the solution of calcium carbonate and precipitation of silica.

However, the laboratory data obtained by other workers are not in agreement with that of Correns, suggesting that there are some additional factors, such as high temperature, and pressure in deep burial which may be important in the process of silica replacement.

2. Pressure solution.--Pressure solution occurs at

grain contacts of specimens with less "minus-cement porosity." The term "minus-cement porosity" is the porosity which would be present if a specimen contained no chemical cement (Heald, 1965). The pressure solution is characterized by irregular penetration surfaces which are oriented approximately perpendicular to the bedding. The process of penetration between the detrital grains in the Ada sandstones is accomplished only by pressure solution as indicated by the lack of any fracture planes. In most of the thin sections examined in this study, the grain contacts are not irregular, although a few are stylolitic. This is because of the presence of a large amount of calcite cement in the Ada sandstones, in some specimens as much as 60 percent. Pressure solution is prevented by the calcite cement and instead, corrosion by calcite is enriched. In general, the amount of pressure solution is small in the Ada sandstones.

The field investigation showed that the closer the sandstones are to the fault zones, the more completely cemented they are with calcite. But some unfractured beds of sandstone contain appreciable amounts of calcite cement. The results of this investigation show that; (1) apparently carbonate cement is related in part to the faulting, and (2) the silica cement seems to be unrelated to the faulting, because the quartz overgrowths are fragmented together with the detrital grains, indicating that the overgrowths are older than fracturing. However, close examination of the thin sections shows that the intensity of granulation is less on some of the overgrowths, compared to the detrital grains, suggesting that at least part of the secondary quartz developed after or at the latest stages of fracturing.

There is no regular variation in the amount of silica cement in the sandstones adjacent to the shale units in the Ada Formation. This probably suggests that the shale units did not introduce silica into the sandstone.

Surface texture.--The surface texture of the sand grains was examined both in thin sections and individual grains under the binocular microscope. In general, most of the sand grains are frosted and pitted. Some of the grains, after etching with dilute HCl, show irregular surfaces. Examination of the same specimen in thin section reveals that the abnormally irregular outlines of the detrital quartz is due to the process of replacement by carbonate cement. A small portion of these irregular surfaces are formed by pressure solution, and suturing, because the majority of the sandstones are poorly packed and thus they lack grain contacts. However, as mentioned previously, part of the corrosion probably occurred in the source area.

The frosted surfaces in the sand grains are due to abrasion, pressure solution, and/or incipient overgrowths in the source rocks which give the sand a pseudo-frosted appearance. Carbonate corrosion can also be listed as another agent effective in producing frosted quartz grains, in the poorly packed sandstones.

UPPERMOST SHALE MEMBER

General Statement

The typical shale of the Ada Formation crops out on the north side of the Canadian River bridge on Highway 99 (sec. 4, T. 5 N., R. 6 E., measured section B). It consists of dark gray, yellow gray, pale red, and grayish orange shales interbedded with fine-calcareous sandstones. The shale units are poorly-fissile, to non-fissile, and platy- to nodular-bedded.

The petrographic investigation of these shale units show that they are composed of non-oriented clays, containing microscopic clay-galls and some silicified fossil fragments. Except for the lower shale unit which is slightly cemented by calcite, the rest of the shale units are moderately- to well-cemented with calcite and some dolomite. The shale units also contain appreciable amounts of silt-sized detrital quartz and are moderately- to poorly-indurated. The shale units also are locally associated with some marl and limestone.

The mineralogical composition of the clay-mineral content of the Ada shale was determined by means of X-ray diffraction. Supplemental data were obtained by differential thermal analyses.

Clay mineral analyses show that the Ada shale has gradations in clay mineral contents. The clay size fraction of the Ada shale consists of five major clay minerals: montmorillonite, illite, mixed-layer illite-montmorillonite, a 14 angstrom clay mineral (chlorite), and kaolinite.

Montmorillonite predominates in the basal unit of the shale member and is associated with some kaolinite. Chlorite is essentially absent at the base of the shale member and carbonate impurities occur in trace amounts. The basal unit of the uppermost shale member is followed stratigraphically higher by a transition zone composed of more illite and kaolinite and associated with a poorly-crystalline 14A clay (montmorillonite). This unit contains little or no chlorite in its clay-mineral suite. The next unit stratigraphically higher consists of illite, chlorite, and a lesser amount of kaolinite, associated with some mixed-layer illite-montmorillonite. This suite is succeeded by a zone which is ordinarily the highest clay-mineral suite. It is well exposed at the top of measured section B, in the uppermost shale member. It consists predominantly of mixed-layer illite-montmorillonite, abundant chlorite, and some kaolinite.

Detailed clay mineral analyses and differential thermal analyses were made for various size fractions in the four distinctive shale suites. These samples were collected from the type locality of the Ada shale (measured section B).

From the base of the uppermost shale member to the top, the following units are defined: basal shale unit, lower shale unit, upper shale unit, and the uppermost shale unit.

1. Lowermost Shale Unit

The basal shale unit of the Ada shale consists predominantly of montmorillonite, and some kaolinite, and minor to trace amount of illite. The 14A clay (chlorite) which occurs in the upper shale units is absent in this interval. The montmorillonite in the basal unit is characterized by a dioctahedral lattice as indicated by its asymmetrical peak at 4.67A (fig. 15). It contains a divalent cation in the inter-layer position probably Ca^{+2} (Ca-montmorillonite), as indicated by its DTA pattern. This pattern is characterized by a large de-watering endotherm peaking slightly above 100°C with a second smaller de-watering endotherm superimposed on the high temperature side of the first and peaking slightly below 200°C. However, a smaller amount of Na may also occur in the interlayer sites.

Montmorillonite is an expandable clay in polar solvents. Its c-axis 14-angstrom d-spacing is due in part to interlayer water. The c-axis d-spacing of dehydrated montmorillonite depends upon the composition of the interlayer ions. Montmorillonite from Ada shale is identified from X-ray diffraction patterns, by the fact that their

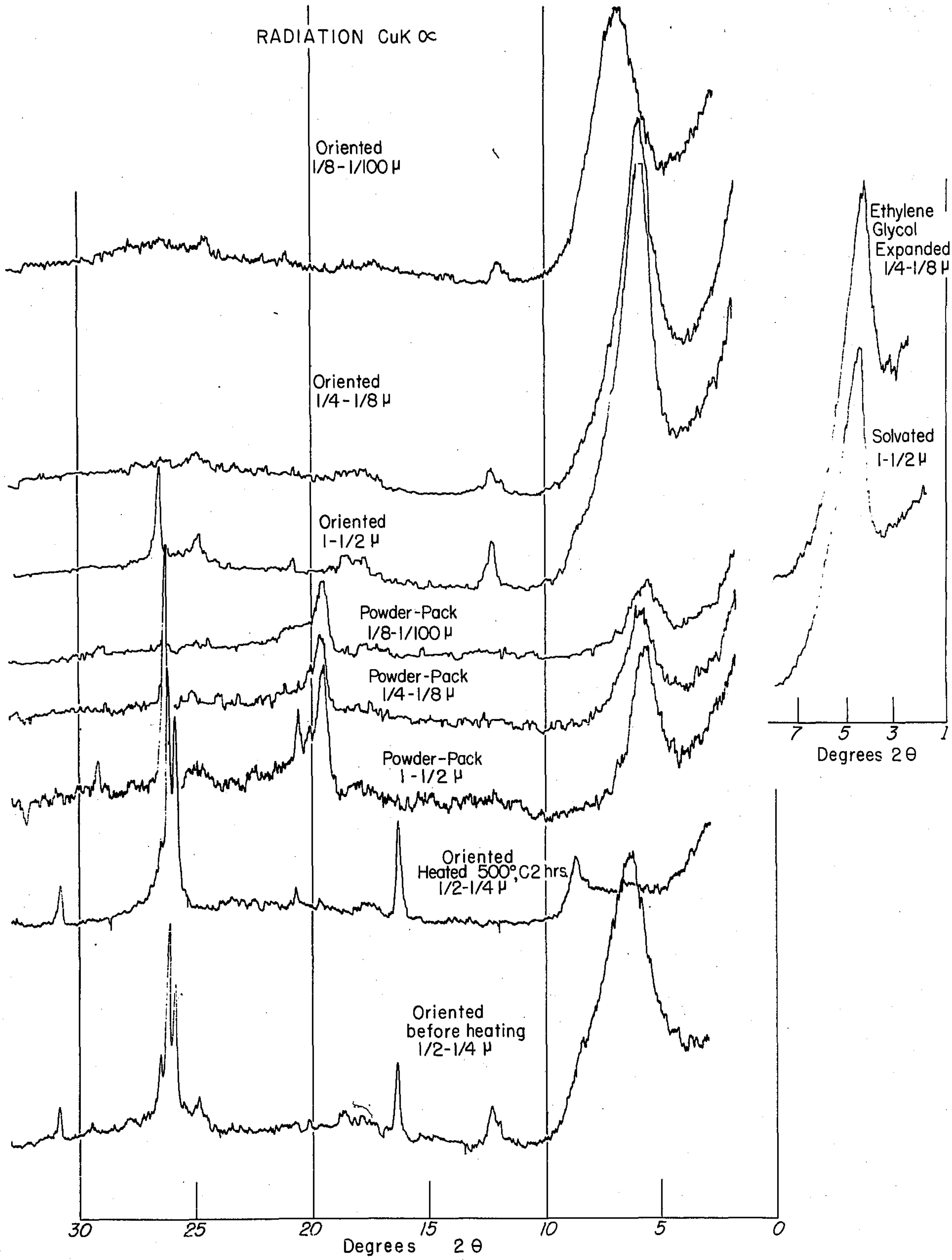

Figure 15.-X-ray diffraction scans of Lowermost Shale Unit (B-13), Ada Formation

first order reflection expands from about 14A at normal atmospheric humidities to about 17A when saturated with ethylene glycol (fig. 15).

The DTA patterns (fig. 16) of the basal shale unit (B-13) illustrates a Ca-montmorillonite (interlayer cation) doublet de-watering endotherm with a broad, large curve peaking at 110°C and a small peak at 170°C. The absence of a broad, low exothermic reaction which commonly occurs at 870°C suggests a low iron content for the octahedral layer. Thus the absence of a relatively weak iron-hydroxl bond may account for the presence of distinct dehydroxllization and lattice destruction endotherm at about 530°C.

Non-clay minerals present in B-13 are quartz, calcite, sulfides (pyrite), and trace amount dolomite. The amounts of the carbonates and quartz decrease as the grain size decreases. Two different kinds of sulfides are present in this shale unit. First, pyrite which occurs more predominantly in the coarser fractions (1-1/2 micron), and second, an unknown sulfide in which the peak becomes higher and slightly sharper as the grain size decreases.

2. Lower Shale Unit

The lower shale unit consisted mainly of poorly-crystallized Na-montmorillonite, some kaolinite, and illite. The 14A clay (chlorite) is absent in this unit. The Na-montmorillonite has a dioctahedral structure as indicated by its asymmetrical peak at 4.67 A (fig. 17). It also contains some divalent cation in the interlayer. Montmorillonite from this unit is identified by its property of expandability in an ethylene glycol atmosphere (fig. 17).

The 7A clay mineral in this unit is identified as kaolinite. The kaolinite as a group of clay minerals exhibits a two-layer sheet structure. The basic structural unit is composed of one layer of silica tetrahedrons and one layer of aluminum octahedrons. Kaolinite in the lower shale unit is dioctahedral, as are all the kaolinite minerals, and it is believed that there has been little or no substitution in the lattice. Kaolinite in this unit is identified from X-ray diffraction data (fig. 17) and confirmed by DTA curves (fig. 16).

The DTA curves of the lower shale unit are illustrated in figure 16. The curves show a typical montmorillonite, kaolinite, and illite pattern. The presence of a slight, secondary low temperature endothermic reaction at about 170°C may indicate the presence of a small amount of divalent cations in the interlayer, probably Ca^{+2}. The sulfide (chalcopyrite) increases in peak-height as the grain size decreases, but the amount of the carbonates (calcite) decreases in quantity as the particle size decreases (fig. 16). The sulfide in the lower shale unit is identified as chalcopyrite because of the abundance of copper-content (300 ppm, Table 3) in B-14, and its exothermic reaction at about 350°C (fig. 16).

The exothermic peak of illite becomes distinct and is shifted to a higher temperature and accompanies high temperature endothermic reaction which ordinarily occurs just before the exothermic reaction (fig. 16).

Kaolinite is identified by its prominent basal reflections at about 7A (001) and 3.57A (002) in the X-ray diffraction patterns.

In order to differentiate kaolinite and chlorite, the third order reflection at about 4.7A is examined to indicate the presence of chlorite. However, chlorites rich in iron commonly give weak first- and third-order reflections and differentiation from kaolinite is particularly difficult (Grim, 1953). In order to resolve this problem, a sample was sedimented on a porcelain slide and an X-ray diffraction patterns was run. Then the same slide was heated to 500°C for a period of 2 hours. Another X-ray pattern was run after heating, and the results were compared (fig. 16). Kaolinite on heating to 500°C tends to lose its crystalline character (collapse), whereas chlorite at this temperature is only partially dehydrated, causing an increase in the intensity of the 14A reflection (Grim, 1953).

Moreover, differential thermal analysis was employed to confirm this identification. DTA curves of kaolinite show an intense, moderately sharp endothermic reaction corresponding to the loss of OH water. This reaction begins at about 400°C, and the peak occurs at about 540°C, which is characteristic of moderately well-crystalline kaolinite. The intensity of the reaction, and hence the size of the peak slightly, increases as the grain size decreases, whereas, the peak temperature decreases slightly to lower temperatures as the particle size decreases. At temperatures above 600°C the kaolinite structure collapses to a great extent, forming a so called "amorphous" metakaolinite (fig. 16). The material actually maintains some degree of order. The exothermic reaction of kaolinite at high temperature is probably superimposed and/or affected by that of illite. The exothermic reaction of illite predominates more in finer particle size (fig. 16), and the DTA curves become a typical illite-montmorillonite pattern.

Non-clay minerals particularly detrital quartz, calcite, and dolomite (occur in small amount) decrease as the particle size decreases, as indicated by their peak height on the X-ray diffraction patterns and DTA curves (figs. 16 and 17). The endothermic peaks of the carbonate minerals in DTA curves from lower shale unit decrease in intensity, and shift to lower temperatures as the particle size decreases. The sharpness and intensity of the exothermic peak of sulfide at 340°C increases as the particle size decreases (fig. 16).

3. Upper Shale Unit

The upper shale unit of the Ada shale consists of illite, chlorite, some mixed-layer illite-montmorillonite,

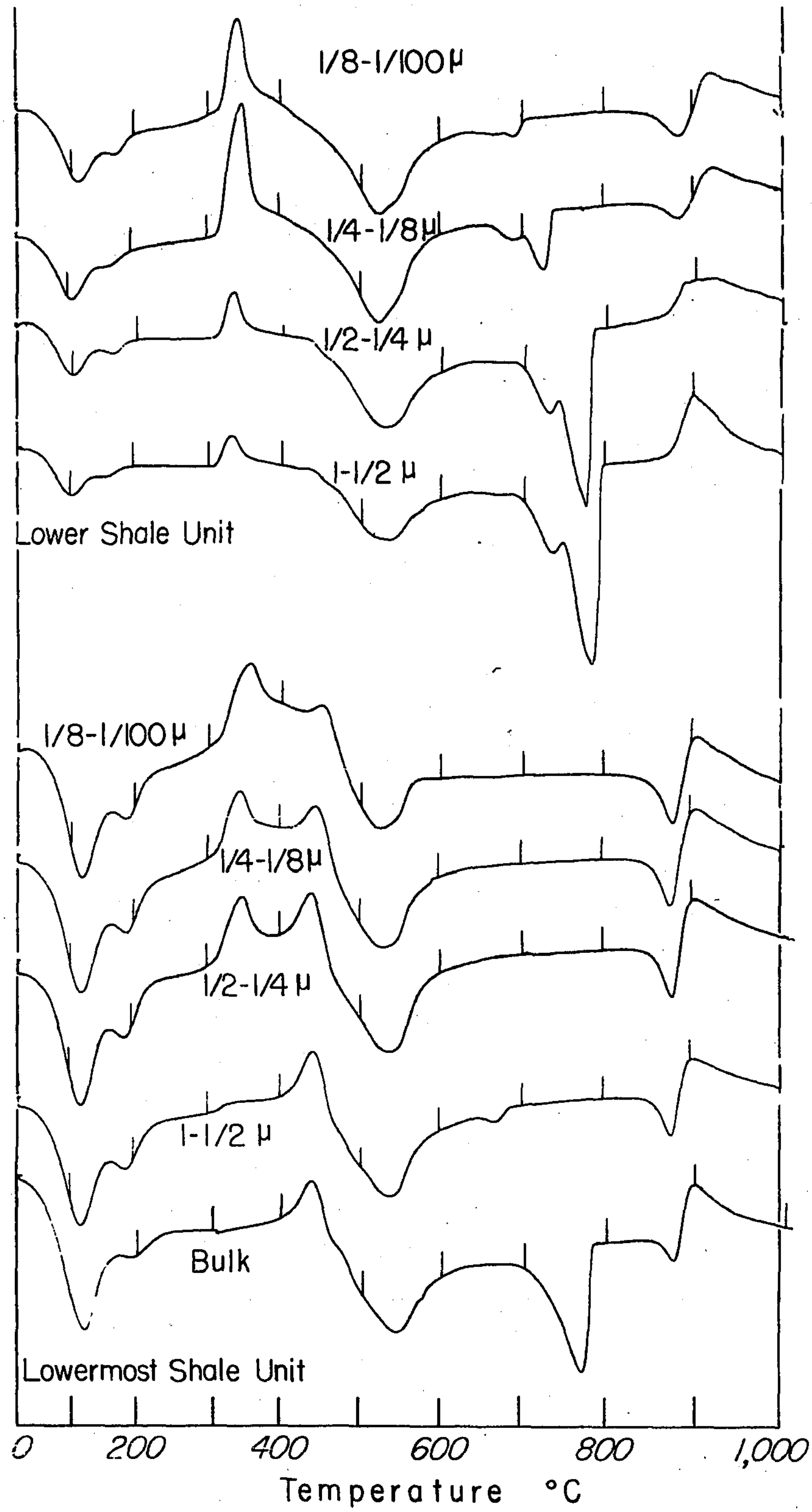

Figure 16. Differential thermal curves of lowermost and lower shale units, Ada Formation

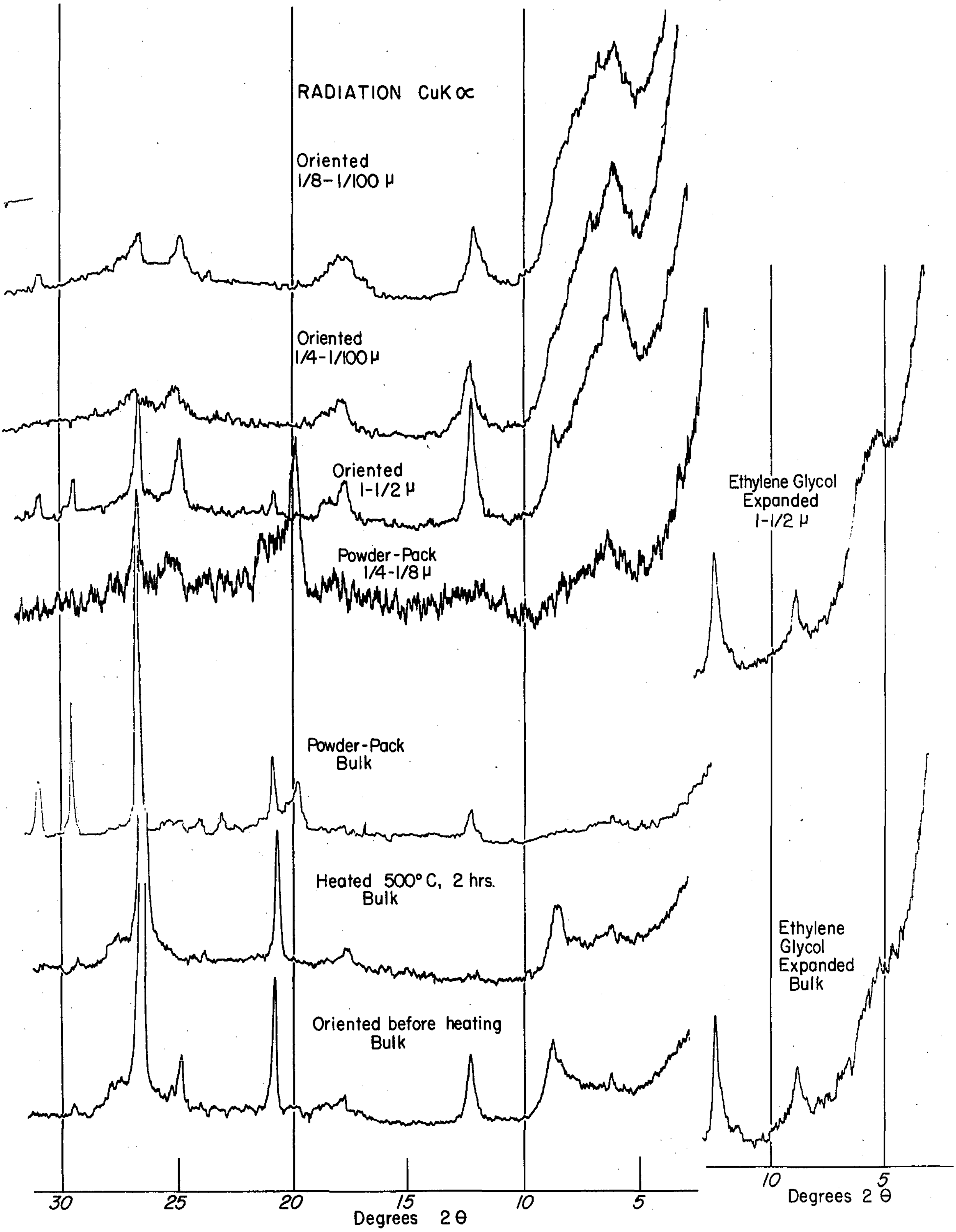

Figure 17.-X-ray diffraction patterns of Lower Shale Unit (B-14), Ada Formation

and little or no kaolinite (fig. 18). The amount of chlorite and illite increases appreciably from the lower shale unit (B-14) to the upper shale unit (B-16), and montmorillonite decreases. It seems that in the higher units of the Ada shale the coarser clays such as chlorite, illite and some kaolinite predominates, and the finer clays (montmorillonite) disappear.

The term illite as used in this study refers to a mica type clay mineral with a 10A c-axis spacing which shows substantially no expanding-lattice characteristics. The basic structural unit of the micas is a layer composed of two silica tetrahedral sheets and a central octahedral sheet. This structure is similar to that of montmorillonite except some of the silicon is always replaced by aluminum and the resulting charge deficiency is balanced by potassium ions.

Differential thermal analyses of various size fractions from the upper shale unit are illustrated in figure 19. DTA curves show an initial endothermic reaction corresponding to the loss of interlayer water, a second endothermic reaction beginning at about 450°C with a peak between 550°C and 650°C (fig. 19). A third endothermic reaction between 850°C and 920°C occurs clearly in finer particle size and is modified by impurities, such as the endothermic reactions of carbonate in the coarser size fractions (fig. 19). The third endothermic reaction is followed by an exothermic reaction

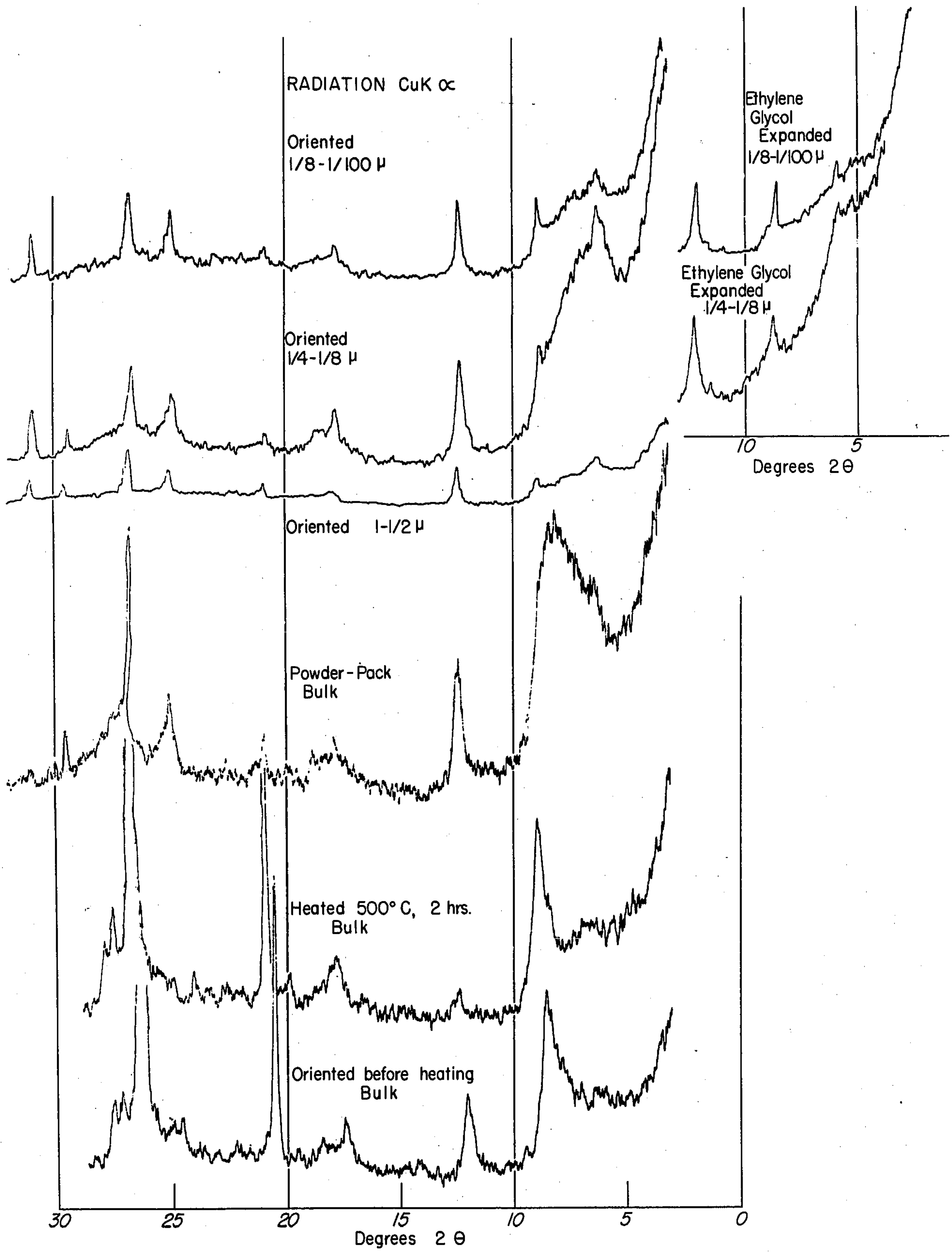

Figure 18.-X-ray diffraction patterns of Upper Shale Unit (B-16), Ada Formation

at a higher temperature of above 900°C and below 1000°C.

The intensity of the reaction and hence size of the peak as well as the peak temperature of the second endothermic reaction is decreased slightly as the particle size decreases (fig. 19). The size and temperature interval of the second endothermic peak, corresponding to the loss of OH lattice water varies in different samples, so the final part of the curve shows considerable variation.

The amount of non-clay minerals, such as quartz, calcite, and some dolomite decrease by decreasing the particle size, as indicated in both X-ray diffraction analyses and DTA curves (fig. 19). The exothermic peak of sulfides become sharper and higher as the particle size decreases.

4. Uppermost Shale Unit

The uppermost shale unit of the Ada shale is composed predominantly of mixed-layer illite-montmorillonite and chlorite. Illite and kaolinite is present in trace amounts or completely absent. Heating the sample to 500°C for a period of two hours did not destroy the crystalline character of the 7A reflection. Instead, the sample became partially dehydrated, causing an increase in intensity of the 14A reflection (fig. 20). X-ray identification of chlorite is based upon the regular alternation in intensities of the orders of the 001 reflection, which seems to be well developed in the X-ray pattern from the uppermost shale member from measured section G. The 14A peak is moderately small

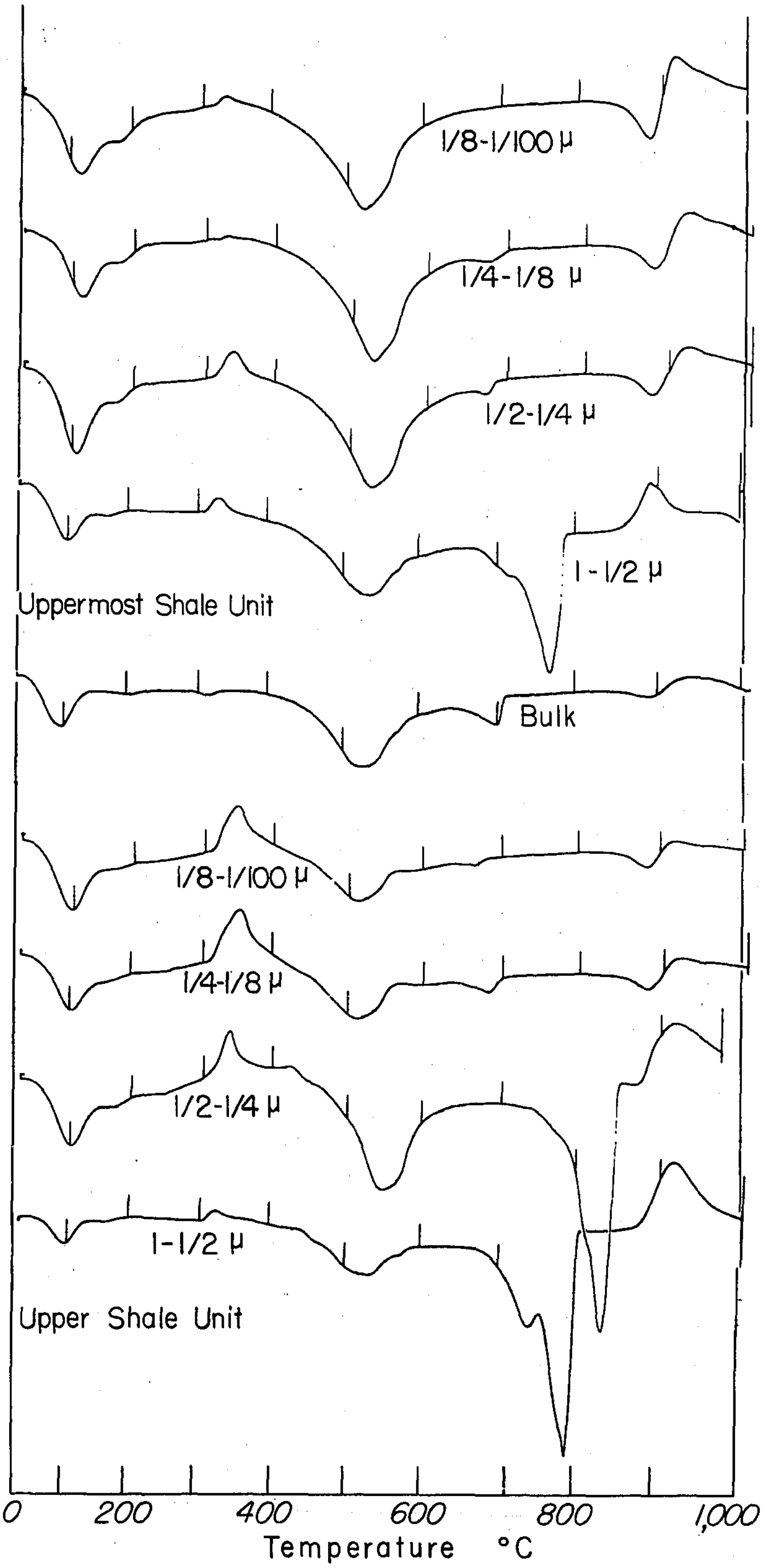

Figure 19. Differential thermal curves of upper and uppermost shale units, Ada Formation

in intensity and is poorly defined because of the overlap of montmorillonite-illite mixed-layers. But, the 7A peak is the most intense and 3.5A peak is intermediate between 14A and the 7A peaks in intensity.

The chlorite structure is composed of a regular alternation of layers of the three-layer clay structure and a brucite structure. The three-layer portion of the chlorite in the uppermost shale unit seems to be dioctahedral.

Chlorite has no de-watering endotherm in the DTA pattern. The dewatering curve at about 100°C belongs to illite, and mixed-layer illite-montmorillonite present in the uppermost shale unit. The first endotherm between 500°C and 600°C corresponds to the breakdown of the brucite structure in the chlorite. The endothermic peak becomes sharper, although remains at the same general peak temperature as the particle size decreases (fig. 19).

The amount of carbonate admixture decreases as the particle size decreases. The exothermic reaction of sulfides (pyrite) becomes sharper as the particle size decreases, and then disappears in the finest particle size.

Examination of the X-ray diffraction pattern of the uppermost shale unit, from measured section G reveals that chlorite and illite characteristically compose the major clay-mineral suite.

Depositional History

The two main hypotheses concerning the origin and geographic distribution of clay minerals as suggested by many workers are as follows; (1) diagenesis is the primary factor in controlling the clay mineral assemblage, and (2) the contribution from the source area is the primary factor.

Distribution of the various clay-mineral constituents in the Ada shale were examined vertically and laterally along a north-south section. Montmorillonite occurs predominantly in the basal unit of the shale and decreases upward. Illite and chlorite increase toward the top of the shale member. Montmorillonite predominantly occurs in the shales collected from the southern outcrops (measured section C). In the most northern outcrops the clay-mineral suite consists mainly of illite and chlorite.

Assuming that the source materials are the primary factor in determining the character of the marine clay suite, then we have to accept the fact that the majority of the clay minerals are not altered to any extent in a marine environment. In this case, the vertical and lateral variation of the clay-mineral suite must then be controlled by the site of active sedimentation which was shifting to the north and was advancing to the northwest. The clay-mineral suite of the outer neritic environment which is dominantly composed of montmorillonite (B-13), is overlain by a clay suite formed dominantly of kaolinite, which is a characteristic clay suite of nearshore and fluvial environments. This is overlain by clays which commonly are deposited in

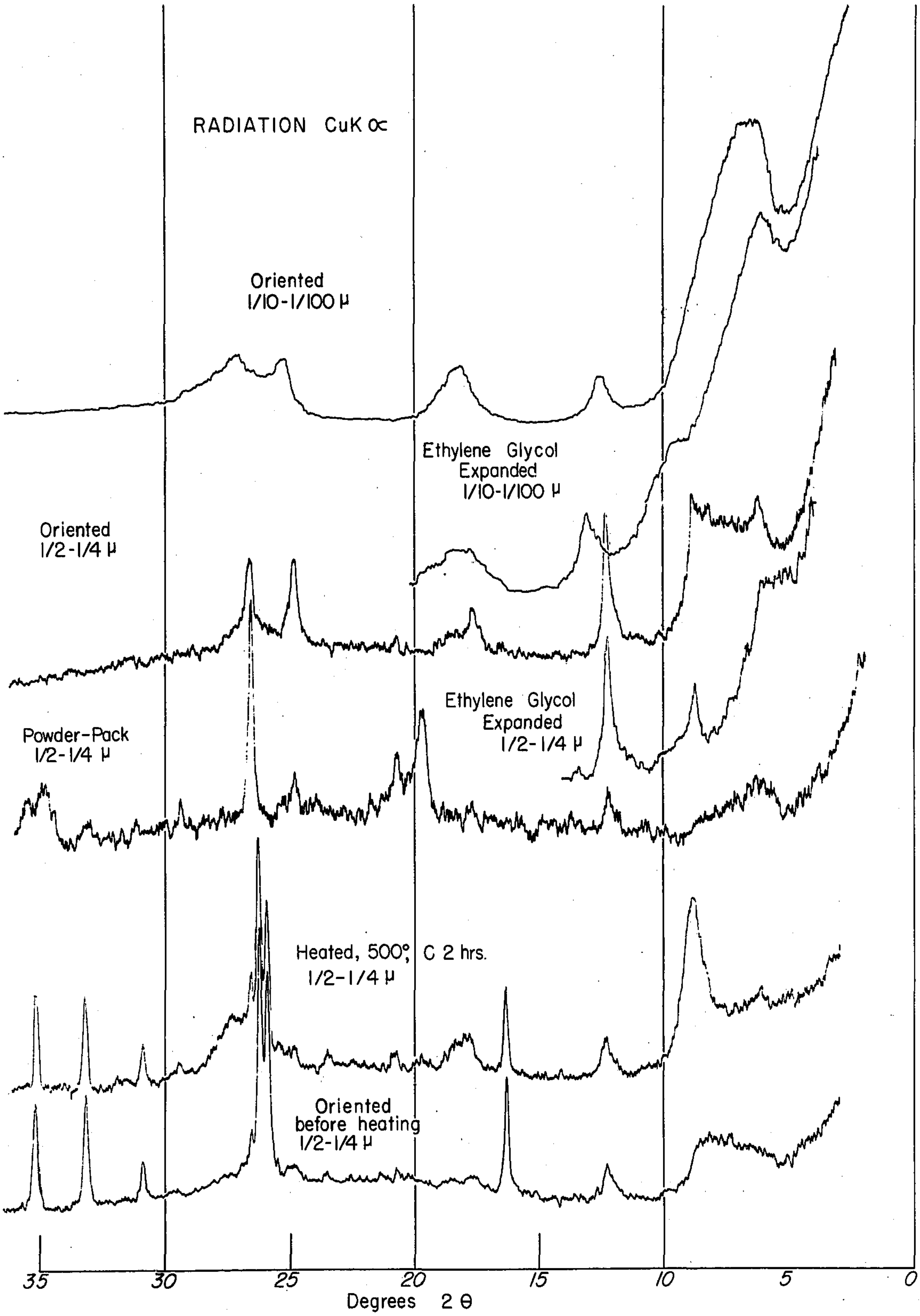

Figure 20.-X-ray diffraction scans of Uppermost Shale Unit (B-18), Ada Formation

the inner neritic environment, and are composed of nearly equal amounts of kaolinite, mixed-layer montmorillonite-illite, and chlorite. The chlorite content increases to the top of the shale member, which is also characteristic of near-shore environments because of its coarse particle size.

Montmorillonite commonly occurs in much smaller particle-size than either kaolinite, illite, or chlorite, and will be kept in suspension by much weaker agitation. Consequently, kaolinite, illite, and chlorite will settle out first, if they are introduced into the depositional environment together from the source area. The process of flocculation is also another important factor which is controlled by salinity. Whitehouse (1952) and Whitehouse and Jeffrey (1955) have demonstrated that kaolinite and illite form large floccules in relatively low salinity immediately upon entering the marine environment, whereas montmorillonite requires high salinities and then will only flocculate slowly.

Grim and his co-workers (1949, 1955, 1956) concluded that diagenetic changes were the most important factors in clay mineral distribution. In this context marine diagenesis is perhaps the most important factor and may be used to explain the variation of the clay-mineral suite in a single environment. However, Grim and Johns (1958) on the basis of their work on the Mississippi Delta, concluded that diagenesis was much less important. Montmorillonite which is one of the easier clay minerals to alter is present in the Ada shale in substantial quantity. If diagenesis was the main factor of alteration, the montmorillonite would have been the first to alter. The examination of the clay mineral suite of the Ada shale suggests to the writer that the factor of source area is perhaps the most important in determining the mineralogical composition of the clays in the marine environment, but the process of diagenesis must not be neglected. During diagenesis the chemical composition of clays can be modified as a result of chemical equilibration (Degens, 1965). The process of alteration is kinetically slow but the result is significant when the environmental conditions are in favor of alteration over geologic time. Factors such as increase in weight of overburden (water or rock), and temperature (geothermal gradient) will probably accelerate the reactions (Degens, 1965).

Interpretation of provenance clay petrology indicates that the lateral and vertical distribution of the clay-mineral suite in the Ada shale is mostly controlled by the source area and partially is related to the process of diagenesis.

GEOCHEMISTRY

Geochemical analyses were made on samples of shale and sandstone from the Ada Formation. Because the shale units consist of several different clays and mixed-layer clays, the determination of the chemistry of the clays by means of X-ray fluorescence, as well as a meaningful measurement of their cation exchange capacities was impossible. The geochemical investigation is therefore limited to an emission spectrographic analysis of the trace elements in the Ada shales and sandstones.

Trace Element Analyses

Introduction.--A semiquantitative emission spectrographic analysis of 28 selected samples from Ada shales and sandstones was performed by Mr. Kenneth Sargent (graduate student, University of Oklahoma). The samples were chosen to include all shale types and the representative sandstones in order to give some idea about the chemical variations during deposition in both a vertical and lateral north-south direction. The trace elements were investigated in both bulk and finer fractions less than one micron for the shales from type locality (measured section B, Plate I).

The results of the trace element analysis of the samples are tabulated in Table 3. Data show that some elements are enriched in particular groups of rocks, although a high degree of separation was not achieved during the deposition of the sediments. Boron, thorium, copper, nickel, chromium are more abundant in the shale units. The abundance of zirconium in the shale units may provide some information about their source. Calcium and magnesium are concentrated almost the same amount in both sandstones and shales, except for those that lack carbonate cement or carbonate rock fragments. Results obtained from the trace element analysis of the sandstones seems to be meaningless, because of their wide variability in proportion of grains and matrix materials and in the relative amount of clay minerals, carbonates (both as cement and allochems), and organic materials (asphaltic sandstone). Results may be improved by separation of the clay content of the sandstones and making separate evaluations of the trace element content. In this study the bulk samples were examined for an understanding of the total variation of the trace element concentration in the sandstones relative to shales.

<u>Discussion of results</u>.--The purpose of the trace element analysis was to investigate the chemical variations in the environment of deposition, and to determine the limit of depositional environment.

The application of fossils as an environmental

TABLE 3

TRACE ELEMENT ANALYSES OF ADA SEDIMENTS

Sample No.	Size (microns)	Concentration of Elements (ppm)										
		B	Ti	Mn	Cu	V	Ni	Cr	Zr	Th	Ca	Mg
A-1	Bulk	ND	200	50	<1	25			ND	500	1000	500
A-4	Bulk	ND	80	75	<1	25			ND	400	>1000	300
B-6	Bulk	10	200	ND	<1	25	1	10-25	50	200	200	1000
B-7	Bulk	5	75	ND	1	10	ND	10-25	ND	400	75	300
B-10	Bulk	ND	50	ND	<1	<10			ND	300	100	50
B-13	Bulk	10	350	50	1	75	5	50	100	400	1000	>1000
B-13	1/2-1/4	<10	100	ND	1	10	<5	ND	ND		300	1000
B-14	Bulk	20	400	75	300	50	40	50	150	300	>1000	>1000
B-14	1/8-1/100	<10	100	ND	75	25	<5	<25	ND		300	1000
B-16	Bulk	10	300	50	50	50	1	<50	200	400	1000	>1000
B-16	8-16	<10	200	50	1	10	5	ND	ND		>1000	>1000
B-18a	Bulk	20	400	75	50	75	10	<50	150	400	>1000	>1000
B-18b	Bulk	75	350	75	50	50	10	<50	200	350	>1000	>1000

TABLE 3--Continued

Sample No.	Size (microns)	Concentration of Elements (ppm)										
		B	Ti	Mn	Cu	V	Ni	Cr	Zr	Th	Ca	Mg
B-18	1/8-1/100	10	75	ND	50	25	5	25	ND		200	1000
C-1	Bulk	ND	250	75	50				75	300	>1000	>1000
C-1b	Bulk	ND	150	100	1				100	400	>1000	>1000
C-4	Bulk	1	100							350	>1000	>1000
C-10	Bulk	1	100							550	>1000	>1000
D-6	Bulk	1	75							500	>1000	>1000
D-7	Bulk	1	50							350	>1000	>1000
D-22	Bulk	1	75							300	>1000	1000
D-23	Bulk	1	200							350	1000	>1000
E-4a	Bulk	50	1000	75	10	200	50	50	300	550	1000	>1000
E-4b	Bulk	25	300	100	1	100	40	1	350	600	800	>1000
F-5	Bulk	ND	75							300	1000	>1000
F-7	Bulk	10	400							400	1000	1000
F-84	Bulk	ND	75							500	>1000	500
G-8	Bulk	ND	300							550	300	500

indicator is limited in this study, because the Ada Formation is sparsely fossiliferous.

Petrographic studies, shape-index analysis, and examination of various textural properties provided some criteria useful for environmental interpretations. However, as has been pointed out, most of these clastic features studied in hand specimen or under the petrographic microscope are related primarily to the source area and mechanical processes of sedimentation.

Trace element analyses of samples from the Ada Formation provided some criteria for the interpretation of the environment of deposition. The most important elements used in this study are boron, titanium, thorium, manganese, nickel, chromium copper, vanadium, zirconium, calcium, and magnesium. The concentration of elements such as strontium, gallium, lithium, rubidium, flourine, and sulfur which are characteristic elements used for the interpretation of marine versus non-marine environments were not measured because of technical difficulties. Boron seems to be a better element for environmental determinations than sulfur and fluorine because it occurs in the sediments in a relatively insoluble form, but fluorine and sulfur are both more susceptible to post-depositional removal. The probable form of combination of boron in the clay mineral structure has been shown by Degens et al. (1957, 1958a) that boron is fixed in the octahedral layers of the clay structure in such a way that it can not be removed by treatment of the clay by hydrochloric acid. Boron is, in part, in similarly insoluble form in modern marine muds (Goldberg and Arrhenius, 1958).

Degens, et al. (1958) suggested that tourmaline may form by reaction between ocean water and clay minerals. Boron and Na (or lithium) being supplied from the sea and alumina and silica from clays.

The boron content in the Ada sediments ranges from a value of about 1 ppm in the sandstones, to as much as 75 ppm in shale units. In general, the boron content increases in the shale units northward from an average of about 20 ppm to 38 ppm in an irregular manner. The maximum boron content was found to be 75 ppm, which is present in the uppermost shale unit.

Comparison of the boron content within the Ada shale units show that boron increases to the top of the formation in a single section (measured section B) as does the illite content. Frederickson and Reynolds (1960) suggested that in clay minerals boron is preferentially associated with illite.

The clay fractions in the Ada sediments may have had three possible sources: (1) as detrital particles or aggregates brought into the basin of deposition through erosion and redistribution of previously existing sedimentary rocks; (2) by <u>in situ</u> alterations of unstable detritus; and (3) by deposition from solution as cement in the intergranular pores of sediments during diagenesis. The clay fractions in the Ada shale probably originated through processes such as (1) and (3). Little clay may have been contributed by *in situ* alteration because of the lack of unstable minerals such as feldspars and other ferro-magnesian minerals in the sediments.

The clay fractions derived in the form of detritus from the source area are closely related to the physico-chemical condition of the primary basin, and/or owe their composition to the rocks, soil, and climate of the source area. Although some modifications may take place in order the sediments to become into an equilibrium position with the new environment, such as adsorption, recrystallization, and other chemical reactions. Determination of the degree to which sediments have approached equilibrium with the new environment and a quantitative evaluation of how much of the clay fractions was derived from source and/or deposited authigenically is difficult. It is therefore believed that application of the trace element analyses data in a reworked sediments such as Ada must be carried under extreme caution.

The abundance of boron in marine sediments has been used by many workers for the environmental interpretation. Landergren (1945) suggested that boron can be used as an indicator of paleosalinity.

Boron in the Ada sediments may have been transported into the environment of deposition of Ada, from alteration of the primary source rocks, in the structure of illitic clays, or in the form of hydrolyzates or oxides. The results of this investigation showed that the amount of boron decreases as the particle size decreases. The carbonate fraction of the shale units also decreases by decreasing the size-fraction. However, the writer found no relationship between the two. According to Sahama (1945), boron might be precipitated in the sea as relatively insoluble calcium and magnesium borates. However, Landergren (1945), suggested that boron in the sediments occur in a relatively readily volatile form.

The results of the analyses of the thorium content was found to be unsatisfactory, as it shows surprisingly little deviation from one sample to the other.

The calcium and magnesium content for most samples is more than 1000 ppm, except those that they lack carbonate cement.

Nickel content was found to be a maximum of 1 ppm in sandstones and 40 ppm in the shales. Nickel generally is more predominant in a marine environment than in fresh water. During weathering, nickel remains largely in the solid products of disintegration and is deposited in the hydrolyzate sediments (Rankama, 1950).

Copper was found to be present in an amount of 1 ppm in the sandstones, but 1 to 300 ppm in the shale units. The abundance of copper in the lower shale unit is compatible to the presence of rather sharp endothermic peak at about 350°C in the DTA patterns (fig. 16). This peak is believed to belong to a sulfide compound, probably chalcopyrite.

The remainder of the semiquantitative data listed in Table 3 show no definite pattern of variation in concentration of the trace elements.

Although the results obtained from semiquantitative analyses of the trace elements in the Ada Formation are not by any means complete and exact, they partially substantiate the history of the environment of deposition of the Ada sediments.

SUMMARY

The Ada Formation (Middle Virgilian age) is subdivided into four informal members on the basis of their lithologic characteristics. They are as follows; lower sandstone member, middle conglomerate member, upper sandstone member, and the uppermost shale member. The Ada Formation consists of sandstone, limestone conglomerate, siltstone, claystone, clay-shale, and some limestone.

Detailed field and laboratory investigation confirms that the Ada Formation unconformably overlies the Vamoosa Formation (Early Virgilian age) in Seminole and the northern part of the Pontotoc Counties. It also unconformably underlies the Vanoss (Late Virgilian age) in both Seminole and Pontotoc Counties. The unconformable contact between the Ada and Vanoss becomes indistinct in the northern part of Seminole County and beyond the North Canadian River the Ada and Vanoss are grouped together and referred to as a single stratigraphic rock unit.

The middle conglomerate member lies conformably between the lower and upper sandstone members, and consists of limestone pebbles, cobbles, and some boulders derived from the Arbuckle area. The thickness of the conglomerate

decreases to the north.

The result of the statistical analysis of 204 pebbles and cobbles indicated that the Arbuckle Mountains were the prime source for the introduction of these coarse detrital materials. The carbonate fragments were derived from the following rock-units, which were exposed to erosion at the time of deposition of the Ada Formation; Arbuckle Group, Simpson Group, Viola Group, Hunton Group, and the Wapanucka Formation. The data obtained from this study suggest that the Hunton Anticline was in a substatic position and had relatively low topography as indicated by the absence of dolomite pebbles and cobbles in the Ada Formation. But the Arbuckle and Tishomingo Anticlines were tectonically in an active stage and it was under such conditions that the limestone pebbles and cobbles of the Ada conglomerate were permanently preserved. Changes in stability of the source area repeatedly modified the power of erosion and the supply of coarse clastics into the environment of deposition. Variation in climatic factors may be considered as another condition which controlled the mechanical power of erosion and subsequent transportation.

Ham (1953) reported that the Collings Ranch Conglomerate was deposited penecontemporaneously with the Ada Formation. Assuming it is correlative with the Ada conglomerate in time and space, the greater thickness of the Collings Ranch compared to that of Ada may suggest that the southern part of the landmass in the Arbuckle Anticline had the most pronounced relief during this interval of time. The situation is reversed when one compares the thickness of the Vanoss conglomerate on the northern and southern flanks of the Arbuckle Anticline.

It seems that during deposition of the Ada sediments the western Arbuckle Mountains formed an exposed landmass. This landmass was extended asymmetrically in a north-south section, with a "high" rapidly eroding on the south side which furnished more of the coarse materials to the south. The north flank was an area of relatively less slope which furnished only small amounts of clastics to the northward flowing streams.

However, the uplifting of the Arbuckle area continued before the deposition of the Vanoss sediments, and the topography of the Arbuckle Anticline became reversed, probably due to faulting in Early Pennsylvanian time. Therefore, the Vanoss conglomerates were deposited only in the northern flank of the Arbuckle Anticline, suggesting that the northern part of the mass had more pronounced relief during deposition of the Vanoss conglomerate.

The results of the statistical analysis of the shape-index (74 percent oblate) presence of trace amounts of marine fossils, and other pertinent facts discussed in this investigation suggest that the calclithites from the Ada Formation probably accumulated as a subaqueous deposit beneath a permanent water body. The pebbles and cobbles were the coarsest products of erosion and moved shorter distances from the source area (Arbuckle Mountains).

The greatest thickness of the Ada Formation toward the coastal belt is probably due to the deposition of the pebbles and cobbles of the Ada in a gravelly shore, as a result of wave action.

Based upon field observations and the stratigraphic relationships, it seems that the Ada conglomerate was deposited during a single physiographic cycle in a shallow marine environment.

The well-rounded character of the limestone pebbles and cobbles is not indicative of a long distance of transportation as it would be for the pebbles and cobbles derived from the more resistant rocks.

The data obtained from grain size analyses show that the detrital grains become finer toward the north. This factor is probably controlled by the proximity of the source area. The apparent cyclic nature of the deposition of the coarse sandstone, siltstone, shale, and conglomerate can not be attributed to any specific cause. It may reflect diastrophic, climatic, or eustatic pulsations. The presence of considerable amounts of clay- and silt-sized particles in the sandstones is probably due to a rapid rate of deposition which in turn prevents a winnowing effect. Five explanations for the deviation of the textural properties from a normal distribution for the Ada sandstone are: (1) availability, (2) double or triple source areas, (3) trapping of fines, (4) faulty sampling, and (5) diagenetic alteration.

A quantitative study of the heavy mineral suite of the Ada Formation shows that their distribution in the environment of deposition was governed by their specific gravities. The mineralogical composition of the heavy mineral suite of the Ada Formation suggests a primary complex plutonic and metamorphic source.

Petrographic investigations suggest that the silica cement in the Ada sandstones may have been derived either by (1) pressure solution, (2) replacement of detrital quartz by calcite, and/or (3) dissolving of silica by meteoric water with a pH between 5 and 9. It seems that mechanism number one was not the major process responsible for releasing and subsequent deposition of silica in the form of overgrowths in the Ada sandstones.

The absence of fresh feldspars, and granite pebbles and cobbles in the Ada Formation suggests that during the deposition of the Ada, the Tishomingo Anticline was still covered by the sediments, and the lower part of the Arbuckle Group was not yet available for erosion. The presence of granite rock-fragments, and fresh feldspars in the overlying Vanoss Formation suggests that during Vanoss time the Tishomingo Anticline was bare to granite.

The contribution of the source area was found to be the primary factor in variations of the clay-lithology in the Ada shale. The result of this investigation does not suggest neglecting the factor of diagenetic alteration, but suggests it to be less important than the contribution of the source area.

The lithologic distribution of the clay minerals in the Ada Formation suggests a shift in active depositional sites during the deposition of the Ada Formation, as the shallow water was advancing to the southwest.

Trace element analyses of samples from the Ada Formation provided some criteria for the interpretation of the environment of deposition. Comparison of the boron content within the Ada shale units show that boron increases to the top of the formation in single section (measured section B) as does the illite content. Frederickson and Reynolds (1960) suggested that in clay minerals boron is preferentially associated with illite. It is concluded therefore, that boron in the Ada sediments may have been transported into the environment of deposition of Ada, from alteration of the primary source rocks, in the structure of illitic clays or in the form of hydrolyzates or oxides.

Although the results obtained from semiquantitative analyses of the trace elements in the Ada Formation are not by any means complete and exact, they partially substantiate the history of the environment of deposition of the Ada sediments.

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APPENDIX

MEASURED SECTIONS

Introduction

Seven stratigraphic sections were measured in the study area during the Fall of 1965. The rock units, described in the field, are listed on the following pages. Columnar sections have been prepared for all the measured sections. (See Plate I for the location of the sections.) Outcrop measurements were made with a 6-foot steel tape, Jacob Staff, and Brunton Compass. 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 E, F, and G; these rock units were examined in the field and laboratory under the binocular microscope.

Detailed sampling was made at all significant lithologic changes. Only one or two samples were collected throughout the lithologically massive and persistent rock units.

In general, the weathered color of the rocks in the Ada Formation ranges from brownish black (5 YR 2/1) to moderate red (5 R 5/4). The bedding is commonly medium to massive, although some beds are thin and platy. However, the bedding is not persistent laterally, and thickness changes locally and rapidly along the exposure.

The following set of thickness values were employed to describe the beds in the Ada Formation (Mankin 1958):

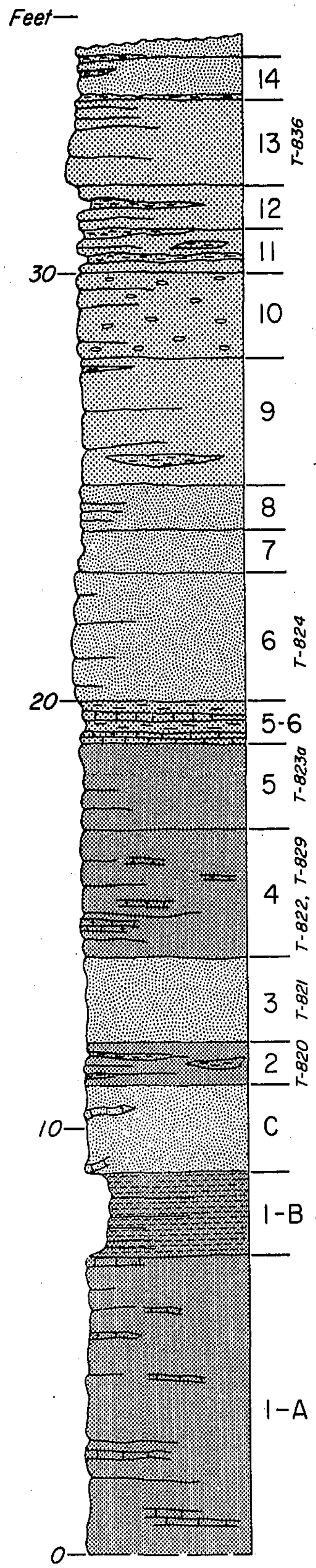
Laminated	Less than 1 in.
Platy-bedded	1-3 in.
Thin-bedded	4 in. - 1 ft.
Medium-bedded	1-2 ft.
Massive	More than 2 ft.

Both weathered and fresh colors are described. Colors of samples were compared with the Rock-Color Chart (Goddard, et al., 1963).

The grain size values were obtained by comparing samples to a standard set of sieved grains. The nomenclature used for describing the grain size was taken from Folk (1961).

SECTION A

Sec. 26, T. 4 N., R. 6 E.



MEASURED SECTION A

Location.- Highway 13, going north before the Sandy River bridge (sec. 26, T. 4 N., R. 6 E. Pontotoc County). The traverse begins at the base of the outcrop on the east side of the highway (Plate I).

The section was measured by A. Iranpanah (October, 1965).

Unit No.	Description	Thickness in feet
	Top of Hill	
15	Quartz sandstone: thin-bedded, dendritic, grayish orange (10 YR 7/4) weathering to pale brown (5 YR 5/2), well-indurated, well-cemented, less calcareous toward the top, very fine- to fine-grained (3.75 Ø to 2.25 Ø), slightly poorly-sorted.	0.25
14	Silty quartz sandstone: cross-bedded, contains discontinuous, pale green shale layers, grayish orange (10 YR 7/4) to olive gray (5 Y 4/1), indurated, well-cemented, calcareous, siliceous, and clayey, very fine- to fine-grained (3.75 Ø to 2.25 Ø), moderately to poorly-sorted. .	1
13	Quartz sandstone: thin- to medium-bedded, contains less than 5% mica flakes (MRF), irregularly distributed, light brownish gray (5 YR 6/1) weathering to medium gray (N 5), friable, poorly-cemented, calcareous, fine- to medium-grained (2.75 Ø to 1.25 Ø), with minor mode of coarse sands (0.50 Ø), poorly-sorted.	2
12	Quartz sandstone: thin-bedded, lenses of clay galls occur parallel to the bedding plane, slightly dendritic around the clay-lenses, grayish orange (10 YR 7/4) weathering to light brownish gray (5 YR 6/1), well-indurated, well-cemented, calcareous, siliceous, fine- to coarse-	

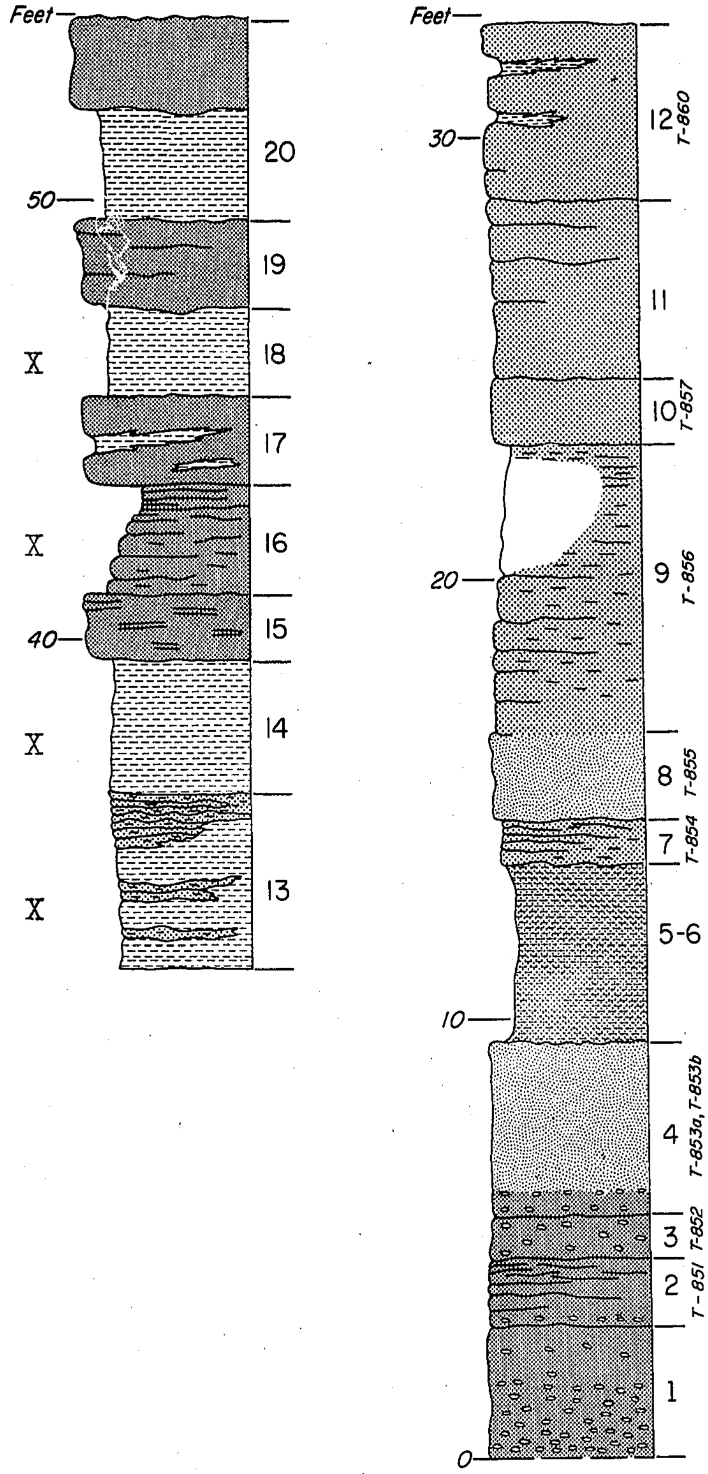
Unit No.	Description	Thickness in feet
	grained (2.75 Ø to 0.50 Ø), poorly-sorted	1
11	Quartz sandstone: thin-bedded, contains platy-bedded discontinuous layers of pale green silty shale, vague on the weathered surface, pale yellowish brown (10 YR 6/2) weathering to light brownish gray (5 YR 6/1), extremely hard, well-cemented, highly calcareous, and argillaceous, fine-grained (2.50 Ø), moderately-sorted	1
10	Quartz sandstone: thin- to medium-bedded, clay pebbles and granules are distributed parallel to the bedding plane, dendritic, grayish yellow (5 Y 8/4) weathering to pale yellowish brown (10 YR 6/2), well-indurated, well-cemented, clayey, calcareous, and siliceous, fine- to medium-grained (2.50 Ø to 1.50 Ø), poorly-sorted.	2
9	Silty quartz sandstone: medium-bedded, yellowish gray (5 Y 7/2) weathering to pale red (10 R 6/2), contains discontinuous pale green silty shale stringers, well-indurated, moderately well-cemented, calcareous, clayey, very fine- to fine-grained (3.75 Ø to 2.50 Ø), poorly-sorted.	3
8	Quartz sandstone: thin- to medium-bedded, randomly cross-bedded, and graded-bedded, interbedded with silty shale, iron oxides stain the top of the sandstone layers, and penetrates into the porous sandstone from the overlying shale, which colors the upper 1.50 in. of the sandstone reddish orange, yellowish gray (5 Y 7/2) and pinkish gray (5 YR 8/1) weathering to pale brown (5 YR 5/2) and pale red (10 R 6/2), well-indurated, well-cemented, calcareous, siliceous, and argillaceous, fine- to medium-grained (2.75 Ø to 1.25 Ø), poorly-sorted	1
7	Quartz sandstone: cross-bedded, contains discontinuous stringers of pale green silty shale, pale yellowish brown (10 YR 6/2) weathering to pale brown (5 YR 5/2),	

Unit No.	Description	Thickness in feet
	moderately well-indurated, well-cemented, calcareous, argillaceous, and siliceous, fine- to coarse-grained (2.75 Ø to 0.50 Ø), poorly-sorted.	1
6	Quartz sandstone: medium-bedded, randomly cross-bedded, color-banded, contains small discontinuous pale green silty shale stringers, grayish orange pink (5 YR 7/2) weathering to light brown (5 YR 6/4), well-indurated, well-cemented, clayey, calcareous, slightly siliceous, fine- to medium-grained (2.75 Ø to 1.50 Ø), poorly-sorted.	3
5 & 6	Quartz sandstone: cross-bedded, dendritic close to the top of the unit, alternating bands of clay-rich and carbonate-rich layers, pinkish gray (5 YR 8/1) weathering to olive black (5 Y 2/1), moderately-well indurated, argillaceous, calcareous, and slightly siliceous, very fine- to fine-grained (3.75 Ø to 2.50 Ø), poorly-sorted	1
5	Quartz asphaltic sandstone: thin- to medium-bedded, graded-bedding in places, and ripple-marked, color-banded, alternating asphaltic and clean sandstone, grayish orange (10 YR 7/4) and medium dark gray (N 4) weathering to medium light gray (N 6), moderately-indurated, silica- and carbonate-cemented, very fine- to very coarse-grained (3.75 Ø to - 0.25 Ø), poorly-sorted	2
4	Quartz asphaltic sandstone: medium-bedded, brownish black (5 YR 2/1) and medium dark gray (N 4) weathering to light gray (N 7) and dark gray (N 3), spotted, clean sands are scattered throughout the asphaltic layers, and in places occur along irregular, and discontinuous bands, unindurated to poorly indurated, poorly-cemented, slightly calcareous, fine- to coarse-grained (3.0 Ø to 0.25 Ø), poorly-sorted	3

Unit No.	Description	Thickness in feet
3	Quartz asphaltic sandstone: cross-bedded, graded-bedded, and color-banded along some irregular patches, clean yellowish white sands and, dark gray asphaltic sands, medium gray (N 5) weathering to medium dark gray (N 4), slightly well-indurated, carbonate, and silica-cemented, fine- to coarse-grained (3.0 Ø to 0.25 Ø), poorly-sorted.	2
2	Quartz asphaltic sandstone: thin- to medium-bedded, dark gray (N 3) inter-bedded with minor wavey layers of very pale orange (10 YR 8/2), weathering to dark greenish gray (5 GY 4/1), very poorly-indurated, moderately-cemented, calcareous, siliceous, poorly-sorted. . .	1
1-C	Quartz asphaltic sandstone: cross-bedded, slightly graded-bedded, color-banded, contains small lenses of car-bonate rich sandstone, pale yellowish brown (10 YR 6/2) weathering to olive gray (4 Y 4/1), well-indurated, silica- and carbonate-cemented, very fine- to coarse-grained (3.50 Ø to 0.75 Ø), poorly-sorted	2
1-B	Silty claystone: thin- to massive-bedded, non-fissile, yellowish gray (5 Y 7/2) weathering to light olive gray (5 Y 6/1), moderately-indurated, carbonate-cemented.	2
1-A	Quartz sandstone: massive- to medium-bedded, brownish gray (5 YR 4/1) weathering to light olive gray (5 Y 6/1), moderately-indurated, poorly-cemented, siliceous, calcareous, very fine-to very coarse-grained (3.25 Ø to - 1.0 Ø), poorly-sorted	7
	Base of the unit not exposed at roadbed.	
	Total section. . . .	35.25

SECTION B

Sec. 4, T. 5 N., R. 6 E.



MEASURED SECTION B

Location.- North of the Canadian River bridge, at the southernmost part of Seminole County, Highway 99 (sec. 4, T. 5 N., R. 6 E.) (Plate I).

The section was measured by A. Iranpanah (November, 1965).

Unit No.	Description	Thickness in feet
	Top of Hill	
21	Quartz silty sandstone: thin-bedded, dendritic, grayish orange (10 YR 7/4) weathering to pale red (5 R 6/2), moderately well-indurated, calcareous, argillaceous, grain size ranges from coarse silt to fine sand (4.0 Ø to 2.0 Ø), poorly-sorted.	2
20	Silty clay-shale; laminated to thin-bedded, pale red (10 R 6/2) interlayered with minor yellow gray (5 Y 8/1) weathering to pale red (5 R 6/2), poorly fissile, moderately indurated, carbonate-cemented .	2.5
19	Quartz sandstone; silty, thin-bedded, dendritic, grayish orange (10 YR 7/4) weathering to pale red (5 R 6/2), moderately well-indurated, carbonate- and clay-cemented, grain size from coarse silt to fine sand (4.0 Ø to 2.0 Ø), slightly poorly-sorted	2
18	Clay shale: laminated to platy, yellow gray (5 Y 8/1) interbedded with pale red (10 R 6/2) weathering to grayish red (5 R 4/2), slightly fissile, moderately indurated, carbonate-cemented.	2
17	Quartz sandstone: thin- to medium-bedded, contains discontinuous pale red clay stringers, parallel to the bedding planes, well indurated, well-cemented, calcareous, siliceous, and slightly	

Unit No.	Description	Thickness in feet
	clayey, fine- to coarse-grained (2.50 Ø to 0.75 Ø), poorly-sorted.	2
16	Silty claystone: laminated to platy, and nodular-bedded, non-fissile to slightly-fissile, grayish red (10 R 4/2) weathering to light brownish gray, poorly-indurated.	2.5
15	Quartz sandtone: thin- to medium-bedded, dendritic toward the top, pinkish gray (5 YR 8/1) weathering to pale red (10 R 6/2), extremely hard, well-cemented, calcareous, siliceous, and dolomitic, very fine- to fine-sand (3.50 Ø to 2.25 Ø), slightly poorly-sorted	1.5
14	Mudstone: platy- to nodular-bedded, pale red (5 R 6/2) weathering to light brownish gray (5 YR 6/1), poorly-indurated, silty, dolomitized, calcareous	3
13	Slightly silty shale: laminated to nodular-bedded, non-fissile, slickensided, dark greenish gray (5 G 4/1) weathering to medium gray (N 5), poorly-indurated.	4
12	Quartz sandstone: medium- to massive-bedded, randomly cross-bedded, contains discontinuous silty yellowish green shale stringers parellel to the bedding planes, yellowish gray (5 Y 8/1) weathering to light brownish gray (5 YR 6/1), moderately indurated, poorly-cemented, calcareous, slightly siliceous, and clayey, grain size ranges from very fine- to fine-sand (3.75 Ø to 2.25 Ø), poorly-sorted.	4
11	Quartz sandstone: thin- to medium-bedded, yellowish gray (5 Y 8/1) weathering to grayish red (10 R 4/2), moderately well-indurated at the bottom, grading to an unindurated sandstone at the top, poorly-cemented, calcareous, and slightly dolomitized, fine- to medium-grained (2.75 Ø to 1.50 Ø), poorly-sorted.	4

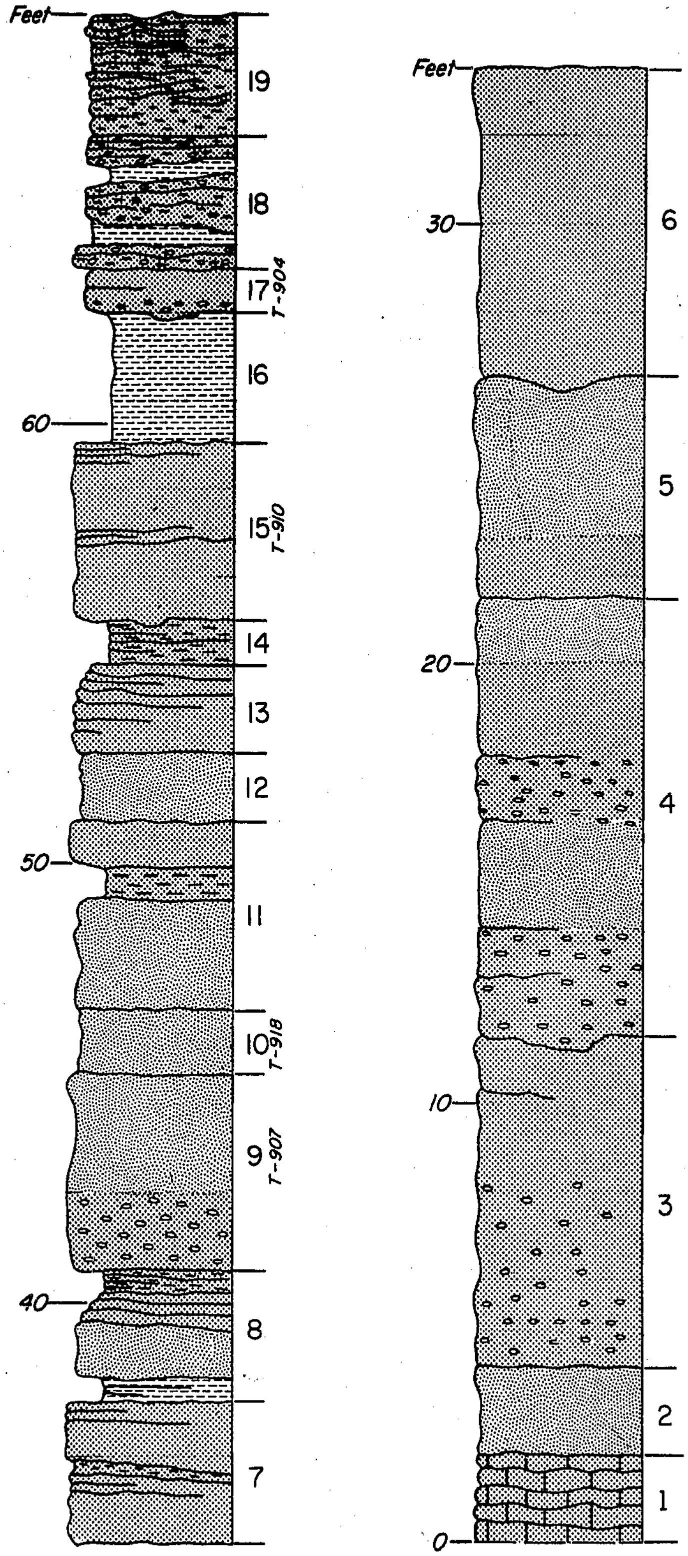
Unit No.	Description	Thickness in feet
10	Quartz sandstone: medium-bedded, grayish pink (5 R 8/2) weathering to grayish red (10 R 4/2), moderately indurated, poorly-cemented, calcareous, siliceous, and slightly argillaceous, grain size ranges from very fine- to fine-sand (3.50 Ø to 2.25 Ø), poorly-sorted. . . .	1.5
9	Argillaceous quartz sandstone: thin-bedded, interbedded with laminated to platy-bedded red and green shale, and hard, well-cemented sandstone, pale brown (5 YR 5/2) in fresh and weathered surface, covered on the top, moderately-cemented, argillaceous, calcareous, limonitic, and slightly dolomitized, grain size ranges from fine- to medium-sand (2.75 Ø to 1.25 Ø), poorly-sorted .	6.5
8	Quartz sandstone: thin- to medium-bedded, banded, alternating fine-grained sandstone (dark), and coarse-grained sandstone (light), pale brown (5 YR 5/2) weathering to light brown (5 YR 6/4), extremely hard, well-cemented, calcareous, siliceous, dolomitized, at the top, grades into a friable sandstone 0.5 feet thick, grain size ranges from very fine- to fine-sand (3.75 Ø to 2.50 Ø) with minor mode of medium-sands (1.50 Ø), poorly-sorted.	2
7	Argillaceous quartz sandstone: thin-bedded, color-banded, spotted, grayish orange (10 YR 7/4) and very pale orange (10 YR 8/2) weathering to pale olive (10 Y 6/2) and very pale orange (10 YR 8/2), very poorly-indurated, very poorly-cemented, slightly siliceous and clayey, grain size ranges from very fine- to fine-sands (3.75 Ø to 2.50 Ø), moderately-sorted.	1
5 & 6	Argillaceous siltstone and silty claystone; interbedded, laminated to nodular-bedded, non-fissile to slightly fissile, yellowish gray (5 Y 7/2) and pale olive (10 Y 6/2) weathering greenish gray (5 GY 6/1), poorly-indurated. .	4

Unit No.	Description	Thickness in feet
4	Quartz sandstone: thin- to medium-bedded, conglomeratic, chert pebbles and granules occur at the base of the unit, grading into thin- to massive-bedded, and cross-bedded, fine unindurated sandstone. Coarse sand-sized chert fragments occur in an indistinct pattern throughout the unit, yellowish gray (5 YR 7/2) at the bottom, pinkish gray on top, weathering to moderate brown (5 YR 3/4) at the bottom, and pale reddish brown (10 R 5/4) on top, poorly-cemented, slightly siliceous, and clayey, poorly-indurated, grain size ranges from fine to medium (2.50 Ø to 1.50 Ø), poorly-sorted. . . .	4
3	Conglomeratic sandstone: graded-bedding, banded, alternating layers of chert-bearing coarse sandstone, and fine sandstone with no chert granules, spotted, light brownish gray (5 YR 6/1) weathering to dark reddish brown (10 R 3/4), moderately indurated, well-cemented, calcareous, siliceous, and argillaceous, fine- to coarse-grained (2.75 Ø to 0.50 Ø), poorly-sorted.	1
2	Quartz asphaltic sandstone: conglomeratic at the base, thin- to platy-bedded, asphalt stain is present in the upper and the lower boundary of the unit, asphaltic layers are olive gray (5 Y 4/1), and the non-asphaltic beds are pinkish gray (5 YR 8/1), and grayish orange pink in fresh surface, weathering to grayish black (N 2), well-indurated, well-cemented, calcareous, siliceous, dolomitized, clayey, fine- to medium-grained (2.75 Ø to 1.25 Ø), with minor coarse fraction (0.50 Ø), slightly poorly-sorted	1.5
1	Sandy conglomerate; chert and limestone pebbles and granules comprise the coarse fraction, medium- to massive-bedded, light olive gray (5 Y 6/1) weathering to pale brown (5 YR 5/2), moderately well-indurated, carbonate-cemented, grain size	

Unit No.	Description	Thickness in feet
	ranges from fine sand to pebble (2.50 Ø to 2.0 Ø), poorly-sorted.	3
	Base of the section not exposed in the measurement area.	
	Total section. . . .	54

SECTION C

Sec. 35, T. 4 N., R. 5 E.



MEASURED SECTION C

Asphalt Quarry Section

Location.- One mile west of Ada, in asphalt quarry, sec. 35, T. 4 N., R. 5 E., Pontotoc County, Oklahoma.

The section was measured by A. Iranpanah (November, 1965).

Unit No.	Description	Thickness in feet
	Top of quarry	
19	Calcareous, silty claystone: laminated- to thin-bedded, non-fissile, yellowish gray (5 Y 8/1) and grayish red (5 R 4/2) weathering to dark greenish gray (5 GY 4/1) and grayish red (10 R 4/2), moderately- to well-indurated, well-cemented, calcareous, and argillaceous	2.75
18	Quartz sandstone: silty, and conglomeratic, laminated- to thin-bedded, alternating claystone, conglomerate, and green shale, light olive gray (5 Y 6/1) weathering to pale red (10 R 6/2), poorly-indurated, hard conglomeratic sandstone stands out from the weathered surface of the outcrop, slightly well-cemented, argillaceous, and clayey, grain size ranges from clay-sized materials up to pebbles (9.0 Ø to -4 Ø), poorly-sorted.	3
17	Quartz sandstone: conglomeratic, thin- to medium-bedded, yellowish gray (5 Y 8/1) and pale red (5 R 6/2) weathering to pale red (10 R 6/2), moderately well-indurated, well-cemented, calcareous, and siliceous, very fine- to coarse-grained (3.75 Ø to 0.50 Ø), poorly-sorted.	1
16	Shale: laminated- to nodular-bedded, greenish gray (5 GY 6/1) weathering to	

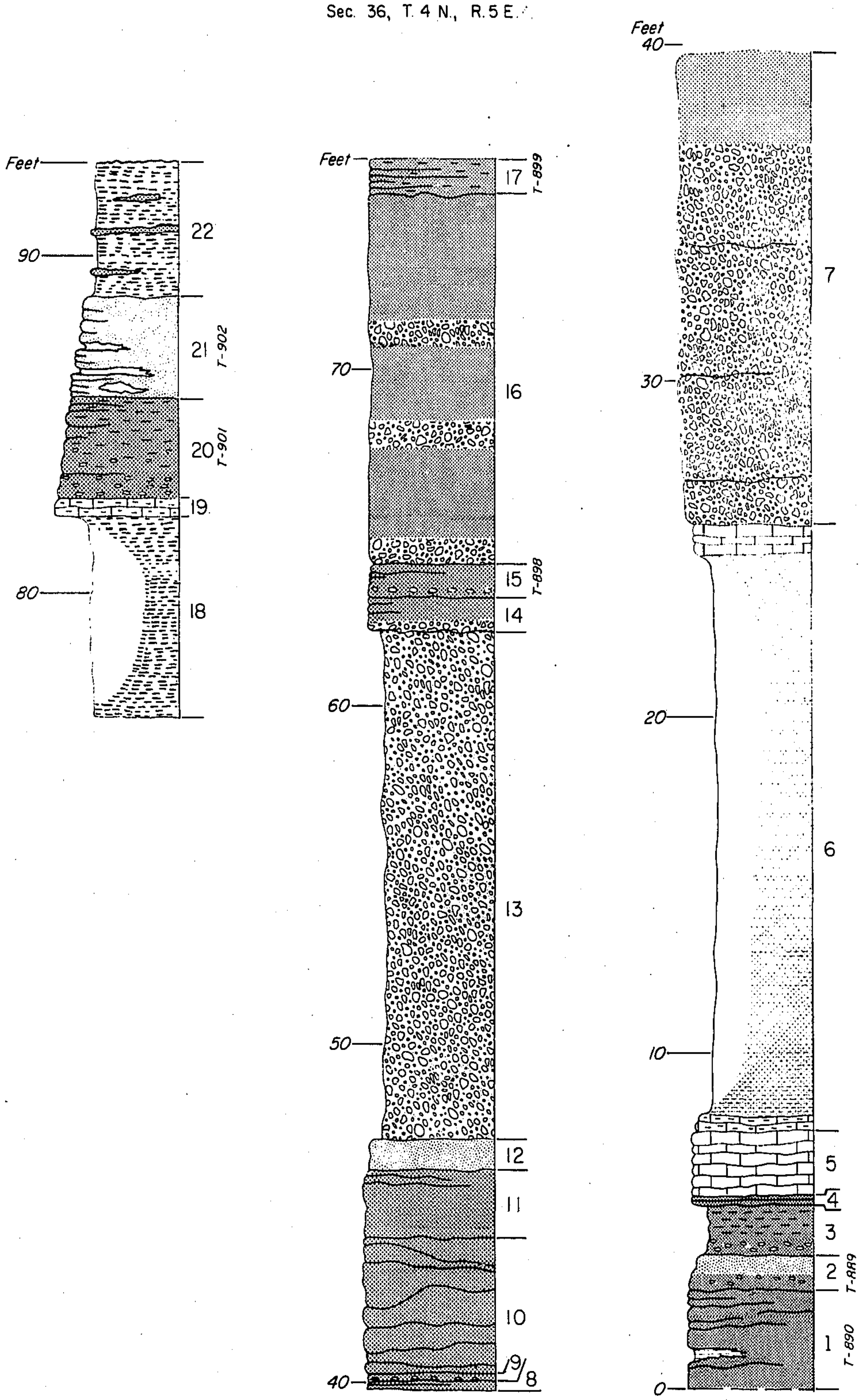
Unit No.	Description	Thickness in feet
	pale greenish yellow (10 Y 8/2), poorly-fissile, slightly indurated	3
	Top of quarry southwest scarp face	
15	Quartz asphaltic sandstone: platy- to massive-bedded, color-banded, dusky yellowish brown (10 YR 2/2) weathering to light olive gray (5 Y 6/1), slightly well-indurated, moderately-cemented, calcareous, siliceous, very fine- to medium-grained (3.50 Ø to 1.50 Ø), poorly-sorted	4
14	Silty claystone: laminated- to thin-bedded, slightly fissile, light greenish gray (5 GY 8/1) weathering to very light gray (N 8), poorly-indurated.	1
13	Quartz asphaltic sandstone: slightly laminated- to thin-bedded, color-banded, alternating asphaltic sandstone, and clean sandstone, grayish black (N 2) and medium dark gray (N 4) weathering to greenish gray (5 GY 6/1), well-indurated, well-cemented, calcareous, and siliceous, grain size ranges from fine- to medium (2.75 Ø to 1.25 Ø), poorly-sorted.	2
12	Quartz asphaltic sandstone: thin- to medium-bedded, color-banded, alternating clean and asphaltic sandstone, cross-bedded in places, brownish black (5 YR 2/1) and medium gray (N 3) weathering to light olive gray (5 Y 6/1), well-indurated, well-cemented, calcareous and siliceous, grain size ranges from fine to medium (2.75 Ø to 1.25 Ø), poorly-sorted	1.5
11	Quartz sandstone: at the top, thin-bedded asphaltic sandstone with an approximate thickness of 1 foot, underlain by a laminated green silty shale of about 0.75 foot thick, which in turn is underlain by 2.5 feet of cross-bedded, color-banded, and	

Unit No.	Description	Thickness in feet
	graded-bedded sandstone, contains small discontinuous pale green clay stringers, moderately-indurated, slightly well-cemented, calcareous, clayey, fine- to medium-grained, poorly-sorted.	4.25
10	Silty sandstone: thin-bedded, cross-bedded, and slightly ripple-marked, yellowish gray (5 Y 8/1) weathering to greenish gray (5 GY 6/1), moderately indurated, carbonate-cemented, grain size ranges from coarse silt to medium sand (4.5 Ø to 1.5 Ø), slightly poorly-sorted.	1.5
9	Silty asphaltic sandstone: medium-bedded, discontinuous lenses of clean sands occur irregularly throughout the unit, conglomeratic at the bottom, brownish black (5 YR 2/1) weathering to light olive gray (5 Y 6/1), moderately-indurated, well-cemented, calcareous, coarse silt to medium sand (4.5 Ø to 1.50 Ø), poorly-sorted	4.5
8	Quartz sandstone: partially asphaltic, platy- to medium-bedded, cross-bedded, green silty-shale of 0.5 foot thick occurs both at the top and bottom of the unit, brownish black (5 YR 2/1) and yellowish gray (5 Y 8/1) weathering to medium dark gray (N 4), well-indurated, well-cemented, calcareous, and siliceous, grain size ranges from fine- to medium-sand (2.75 Ø to 1.50 Ø), slightly poorly-sorted	3
7	Quartz asphaltic sandstone: laminated- to massive-bedded, 1.5 feet of asphaltic sandstone, thin- to medium-bedded, underlain with 0.25 feet of laminated white to green silty-shale, which in turn is underlain by 1.5 feet of cross-bedded, massive to poorly-laminated asphaltic sandstone, brownish black (5 YR 2/1) weathering to medium dark gray (N 4), well-indurated, well-cemented, calcareous, siliceous, grain size ranges from	

Unit No.	Description	Thickness in feet
	fine- to coarse-sand (2.50 Ø to 0.50 Ø), poorly-sorted	3.25
6	Quartz asphaltic sandstone: thin- to medium-bedded, irregularly-banded, alternating clean and asphaltic sandstone, 1 foot thick, on the top, underlain by 6 feet of medium- to massive-bedded asphaltic sandstone, black (N 1) weathering to brownish gray (5 YR 4/1), moderately- indurated, moderately cemented, calcareous, slightly siliceous, medium-grained (1.50 Ø), slightly well-sorted	7
5	Quartz sandstone: slightly asphaltic, thin- to medium-bedded, cross-bedded, color-banded, alternating clean and asphaltic sandstone, brownish gray (5 YR 4/1) weathering to yellowish gray (5 YR 8/1), well-indurated, well-cemented, calcareous, and siliceous, fine- to medium-grained (2.50 Ø to 1.50 Ø), poorly-sorted	5
4	Conglomeratic quartz sandstone: alternating layers of conglomerate and sandstone, medium- to massive-bedded, randomly cross-bedded, and graded-bedded, brownish gray (5 YR 4/1), and very light gray (N 8) weathering to medium gray (N 4), moderately-indurated, well-cemented, calcareous, fine- to medium-grained (2.50 Ø to 1.50 Ø), moderately-sorted	10
3	Quartz sandstone: conglomeratic, slightly-asphaltic, medium- to massive-bedded, randomly- cross-bedded, pale yellowish brown (10 YR 6/2) weathering to very pale orange (10 YR 8/2), well-indurated, well-cemented, calcareous, dolomitized, fine- to medium-grained (2.75 Ø to 1.50 Ø), poorly-sorted. . . .	7.5
2	Silty quartz sandstone: slightly asphaltic, thin- to medium-bedded, cross-bedded, color-banded, alternating asphaltic and clean sandstones, brownish	

Unit No.	Description	Thickness in feet
	gray (5 YR 4/1) and very light gray (N 8) weathering to medium gray (N 5), well-indurated, well-cemented, calcareous, siliceous, and dolomitized, fine- to medium-grained (2.75 Ø to 1.25 Ø), poorly-sorted	2
1	Fossiliferous, sandy calcirudite: medium-bedded, patches of asphaltic material irregularly distributed throughout the limestone layers, pinkish gray (5 YR 8/1) weathering to olive gray (5 Y 4/1), well-indurated	2
	Total section	68.25

SECTION D
Sec. 36, T. 4 N., R. 5 E.



MEASURED SECTION D

Smith's Ranch Section

Location.- West of Ada, east of the asphalt quarry, approximately 0.5 mile south of Highway 13 from the Sandy River bridge, going north (sec., 36, T. 4 N., R. 5 E., Pontotoc County, Plate I). Traverse started at the bank of the river.

The section was measured by A. Iranpanah (November, 1965).

Unit No.	Description	Thickness in feet
	Top of the hill	
22	Silty shale: laminated-to thin-bedded, slightly fissile, grayish yellow (5 Y 8/4) weathering to yellowish gray (5 Y 7/2), moderately-indurated	4
21	Argillaceous asphaltic quartz sandstone: platy- to thin-bedded, flaggy, and cross-bedded, contains discontinuous, pale green shale stringers, brownish gray (5 YR 4/1) weathering to pale olive (10 Y 6/2) and olive gray (5 Y 4/1), well-indurated, well-cemented, calcareous, intraclastic, and glauconitic, grain size ranges from coarse-silt to medium sand (4.50 Ø to 1.50 Ø), moderately-sorted.	3
20	Argillaceous quartz sandstone: thin- to medium-bedded, coarse asphaltic, and conglomeratic-sandstone occurs at the base of the unit, chert granules are predominant in the asphaltic-sandstone, pinkish gray (5 YR 8/1) weathering to greenish gray (5 GY 6/1), moderately-indurated, well-cemented, calcareous, and dolomitized, fine- to medium-grained (2.75 Ø to 1.50 Ø), poorly-sorted	3

Unit No.	Description	Thickness in feet
19	Argillaceous, bioclastic calcirudite: slightly dismicritic, platy-bedded, yellowish gray (5 Y 7/2) weathering to moderate red (5 R 5/4), well-indurated.	0.5
18	Covered, mudstone: nodular-bedded, yellowish gray (5 Y 7/2)	6
17	Silty quartz sandstone: thin-bedded, grayish-brown (5 YR 3/2) weathering to dark greenish gray (5 G 4/1), well-indurated, well-cemented, calcareous, dolomitized, intraclast-bearing, coarse silt- to fine-sand (4.25 Ø to 2.50 Ø), poorly-sorted.	1
16	Slightly asphaltic quartz sandstone: massive-bedded, graded-bedding, alternating layers of cherty sandstone, and asphaltic sandstone, pale yellowish brown (10 YR 6/2) at the base of the unit, light olive gray (5 Y 6/1) on top, weathering to dark gray (N 3), unindurated at bottom, poorly indurated on the top, poorly-cemented, calcareous, fine- to coarse-grained (2.50 Ø to 0.50 Ø), poorly-sorted	11
15	Conglomeratic quartz sandstone: slightly-asphaltic, thin- to medium-bedded, chert-rich layers occur randomly throughout the unit, brownish gray (5 YR 4/1) weathering to medium gray (N 5), moderately-indurated, well-cemented, siliceous, calcareous, and dolomitized, very fine- to coarse-grained (3.50 Ø to 0.50 Ø), poorly-sorted	1
14	Sandy conglomerate: medium-bedded, brownish gray (5 YR 4/1) weathering to yellowish gray (5 Y 8/1), poorly-indurated, poorly-cemented, calcareous, grain size ranges from fine-sand to pebble (2.50 Ø to -4 Ø), poorly-sorted.	1
13	Limestone pebble cobble conglomerate: massive-bedded, slightly cross-bedded,	

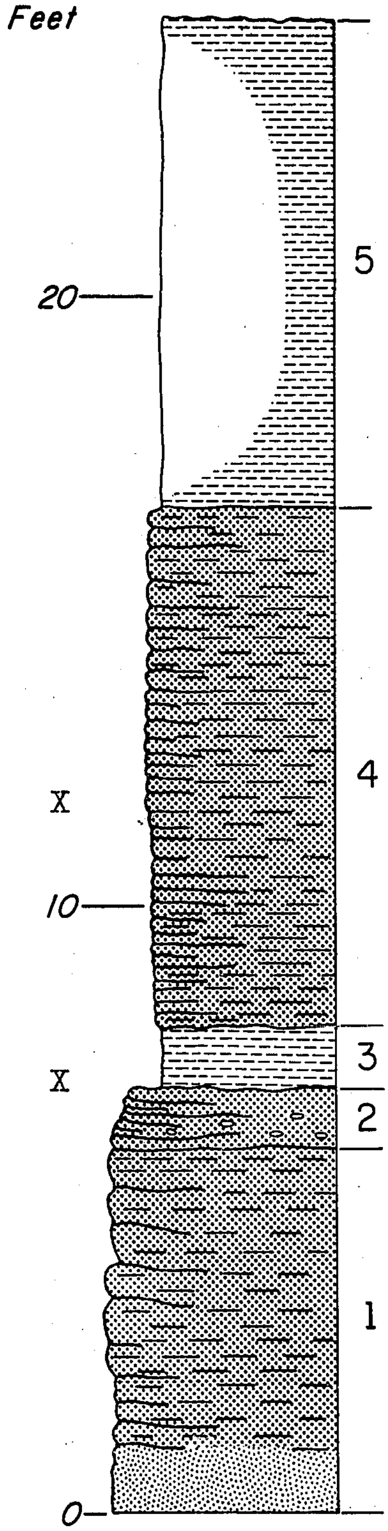
Unit No.	Description	Thickness in feet
	yellowish gray (5 Y 8/1) weathering to olive gray (5 Y 4/1), randomly imbricated, grain size ranges from fine-sand (2.50 Ø), to cobble (- 6 Ø), poorly-sorted.	15
12	Quartz sandstone: thin-bedded, thickness of the unit is variable, slightly-cross-bedded, and graded-bedding, dark yellowish brown (10 YR 4/2) weathering to brownish gray (5 YR 4/1), well-indurated, carbonate-cemented, fine- to medium-grained (2.75 Ø to 1.50 Ø), poorly-sorted.	1
11	Quartz sandstone: slightly asphaltic, thin to medium-bedded, light olive gray (5 Y 6/1) weathering to olive gray (5 Y 4/1), well-indurated, carbonate-cemented, fine- to medium-grained (2.25 Ø to 1.50 Ø), moderately-sorted.	2
10	Quartz sandstone: slightly asphaltic at the base of the unit, thickness of the beds varies from thin (4 in. to 1 foot), to massive (more than 2 feet) laterally in a 6 foot distance, yellowish brown (10 YR 6/2) at the base, very pale orange (10 YR 8/2) on the top, weathering to greenish gray (5 GY 6/1) at the bottom, and medium light gray (N 6) on the top of the unit, well-indurated, carbonate-cemented, fine- to medium (2.50 Ø to 1.50 Ø), moderately-sorted	4
9	Quartz sandstone: laminated, and graded-bedded, pinkish gray (5 YR 8/1) and pale yellowish brown (10 YR 6/2) weathering to light brownish gray (5 YR 6/1), moderately-indurated, carbonate-cemented, very fine- to medium-grained (3.50 Ø to 1.50 Ø), poorly-sorted.	0.25
8	Quartz sandstone: laminated, flaggy, grayish orange pink (5 YR 7/2) weathering to pale red (10 R 6/2), well-	

Unit No.	Description	Thickness in feet
	indurated, carbonate-cemented, and dolomitized, fine- to medium-grained (2.25 Ø to 1.25 Ø), poorly-sorted.	0.25
7	Conglomeratic quartz sandstone: in places silty, massive- to tendency for graded-bedding, chert pebbles are both randomly distributed throughout the sandstone, and aligned along a single surface (or line along the surface of the outcrop), thickness of the unit varies rapidly along the horizontal plane, from 14 feet to 6 feet in a lateral distance of about 20 feet, pinkish gray (5 YR 8/1) weathering to olive black (5 Y 2/1) and dark gray (N 3), well-indurated, carbonate-cemented, grain size ranges from coarse silt to pebbles (4.25 Ø to -4 Ø), poorly-sorted.	14
6	Silty shale: very poorly exposed, is more sandy at the top, bioclastic calcarenite is present at the uppermost 1 foot of the section, associated with some silicified fossile-debris, and carbonate intraclasts, light gray (N 7) weathering to olive gray (5 Y 4/1), better-indurated at the top.	18
5	Bioclastic coarse calcirudite (biosparrudite): thin- to medium-bedded, stylolitic, pinkish gray (5 YR 8/1) weathering to olive gray (5 Y 4/1), well-indurated.	2
4	Quartz sandstone: silty, platy- to thin- bedded, iron oxides occur approximately parallel to the bedding plane, yellowish gray (5 Y 8/1) weathering to dark greenish gray (5 GY 4/1), moderately indurated, well-cemented, calcareous, and siliceous, grain-size ranges from coarse silt to medium sand (4.25 Ø to 1.50 Ø), poorly-sorted.	0.25
3	Quartz sandstone: very silty, slightly chert-conglomeratic at the	

Unit No.	Description	Thickness in feet
	base, poorly-laminated- to thin-bedded, tendency for graded-bedding, yellowish gray (5 Y 8/1) weathering to greenish gray (5 G 6/1) and olive gray (5 Y 4/1), moderately indurated, well-cemented, calcareous, and siliceous, coarse silt to medium sand (4.25 Ø to 1.50 Ø), poorly-sorted.	1.5
2	Quartz sandstone: silty, and chert-bearing, thin- to medium-bedded, cross-bedded, and tendency for graded-bedding, color-banded, very light gray (N 8) weathering to olive gray (5 Y 4/1), well-indurated, carbonate-cemented, grain size ranges from very fine- to medium-sand (3.25 Ø to 1.50 Ø), poorly-sorted	1
1	Quartz sandstone: in places silty, massive- to poorly-laminated, and graded-bedding, contains small discontinuous layers of pale green silty shale, yellowish gray (5 Y 8/1) weathering to greenish gray (5 GY 6/1), moderately-indurated, carbonate- and silica-cemented, argillaceous, fine-grained (2.50 Ø), moderately-sorted. . . .	3
	Total section	92.75

SECTION E

Sec. 34, T. 9 N., R. 6 E.



MEASURED SECTION E

Location.- Highway 99, approximately one mile south of Seminole townsite (sec. 34, T. 9 N., R. 6 E., Seminole County).

Traverse started at the base of the section on the east side of the highway.

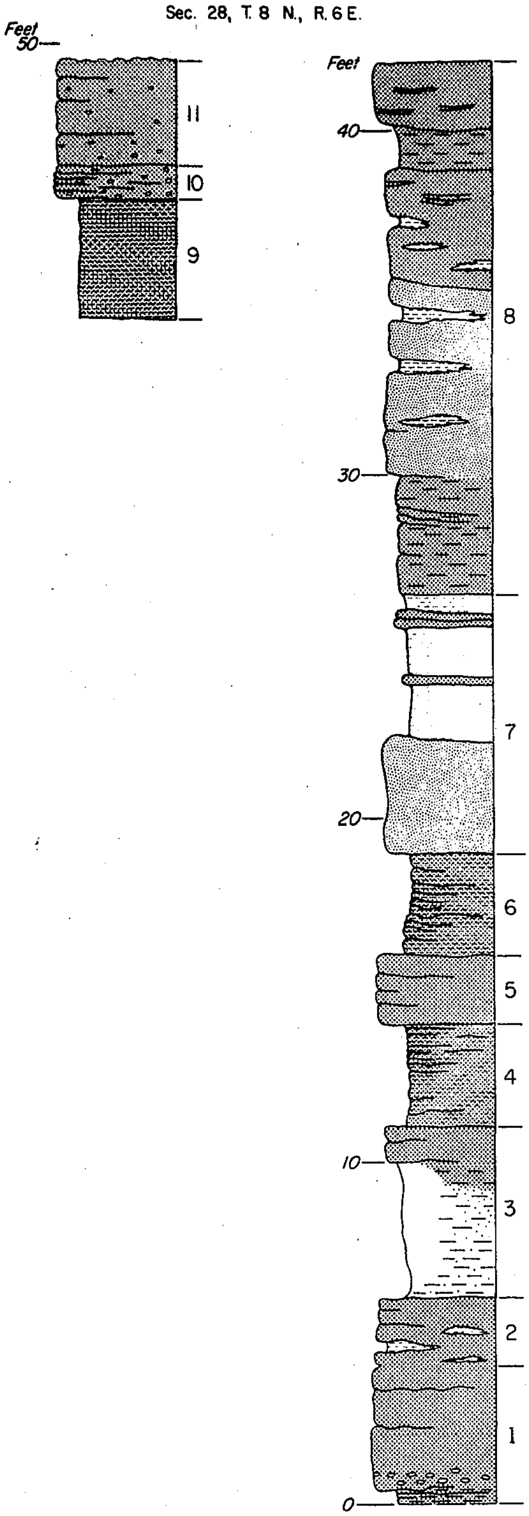
The section was measured by A. Iranpanah (November, 1965).

Unit No.	Description	Thickness in feet
	Top of hill	
5	Covered: calcareous silty-shale, non-fissile, poorly-indurated.	8
4	Silty clay-shale: laminated- to medium-bedded, poorly-fissile, silty at the base, pinkish gray (5 YR 8/1) interbedded with light grayish gray (5 G 8/1) weathering to grayish red (10 R 4/2), 0.5 foot thick; at the top grayish yellow green (5 GY 7/2) weathering to grayish red (10 R 4/2), consisting of clay-shale of approximately 8 feet thick, well-indurated, calcareous	8.5
3	Claystone: laminated, non-fissile, light-greenish gray (5 GY 8/1) weathering to yellowish gray (5 Y 8/1), poorly-indurated	1
2	Argillaceous quartz sandstone: chert-bearing, thin- to platy-bedded, alternating layers of fine- to medium-sand and silty very fine sand, yellowish gray (5 Y 8/1) weathering to yellowish gray (5 Y 7/2), well-indurated, carbonate-cemented, very fine- to medium-grained (3.25 Ø to 1.25 Ø), poorly-sorted.	1

Unit No.	Description	Thickness in feet
1	Argillaceous quartz sandstone: silty, thin- to massive-bedded, cross-bedded at the base, spotted, color-banded, pale brown (5 YR 5/2) at the base, greenish orange (10 YR 7/4) on the top, weathering to brownish black (5 YR 2/1), and olive gray (5 Y 4/1) respectively, moderately-indurated, carbonate-cemented, fine- to medium-grained (3.25 Ø to 1.50 Ø), poorly-sorted	6
	Base of the section not exposed, and the top is eroded, in the measurement area.	
	Total section	24.5

SECTION F

Sec. 28, T. 8 N., R. 6 E.



MEASURED SECTION F

Location.- Highway 99, approximately 5 miles south of the town of Seminole (sec. 28, T. 8 N., R. 6 E., Seminole County).

Traverse started at the base of the outcrop on the east side of the highway.

The section was measured by A. Iranpanah (November, 1965).

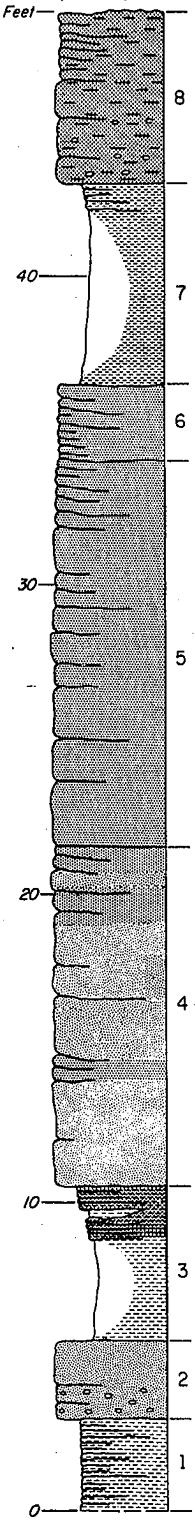
Unit No.	Description	Thickness in feet
	Top of the hill	
11	Quartz sandstone: slightly asphaltic, chert-bearing, medium- to massive-bedded, dark yellowish brown (10 YR 4/2) weathering to dusky brown (5 YR 2/2), poorly-indurated, poorly-cemented, calcareous, fine- to medium-grained (2.75 Ø to 1.25 Ø), poorly-sorted.	3
10	Conglomeratic quartz sandstone: chert-bearing, thin-bedded, color-banded, moderate brown (5 YR 3/4) and pale yellowish brown (10 YR 6/2) weathering to moderate yellowish brown (10 YR 5/4) and dark yellowish brown (10 YR 4/2), well-indurated, carbonate- and silica-cemented, very fine- to fine-grained (3.50 Ø to 2.50 Ø), slightly poorly-sorted	1
9	Silty clay-shale: laminated- to nodular-bedded, poorly-fissile, moderate red (5 R 5/4) weathering to grayish red (10 R 4/2), moderately-indurated.	3.5
8-4	Argillaceous quartz sandstone: massive-bedded, alternating clay-rich and carbonate-rich layers of sandstone, gives a pseudo-laminated	

Unit No.	Description	Thickness in feet
	texture to the rocks at the weathered surface, clay-galls occur also as lenticular inclusions throughout the rock-unit, poorly-indurated, poorly-cemented, calcareous, and siliceous, fine- to medium-grained (2.50 Ø to 1.50 Ø), poorly-sorted	
8-3	Quartz sandstone: silty, contains discontinuous, pale green clay-lenses parallel to the bedding plane, laminated- to massive-bedded, cross-bedded, and graded-bedding, pinkish gray (5 YR 8/1) and yellow pale orange (10 YR 8/2) weathering to brownish gray (5 YR 4/1), moderately-indurated, carbonate-cemented, very fine- to fine-grained (3.25 Ø to 2.75 Ø), moderately-sorted	
8-2	Quarts sandstone: silty, and chert-bearing contains small discontinuous pale green clay stringers, massive-bedded, randomly cross-bedded, slightly color-banded, yellowish gray (5 Y 7/2) and grayish orange pink (5 YR 7/2) weathering to grayish red (10 R 4/2) and brownish black (5 YR 2/1), moderately-indurated, carbonate-cemented, very fine- to medium-grained (3.25 Ø to 1.50 Ø), poorly-sorted.	
8-1	Argillaceous quartz sandstone: massive-bedded, and poorly laminated, spotted, grayish orange pink (5 YR 7/2) weathering to grayish red (10 R 4/2), well-indurated, carbonate-cemented, very fine- to medium-grained (3.50 Ø to 1.50 Ø), poorly-sorted	
	Total for the unit $F-8_1$ through $F-8_4$ . . .	15.5
7	Argillaceous quartz sandstone: laminated- to thin-bedded, randomly cross-bedded, alternating quartz sandstone, and white greenish-siltstone which in turn is interlayered	

Unit No.	Description	Thickness in feet
	with white greenish shale at the top of the unit, light greenish gray (5 G 8/1) and yellowish gray (5 Y 8/2) weathering to grayish red (10 R 4/2) and grayish red (5 R 4/2), moderately indurated, carbonate-cemented, very fine- to fine-grained (3.5 Ø to 2.75 Ø), moderately-sorted	7.5
6	Silty shale: laminated- to thin-bedded, alternating grayish yellow green (5 GY 7/2) interbedded with pinkish gray (5 YR 8/1) weathering to pale red (5 R 6/2), poorly-fissile, well-indurated	3
5	Quartz sandstone: thin-bedded, yellowish gray (5 Y 5/2) weathering to pale brown (5 YR 5/2), well-indurated, carbonate-cemented, fine- to medium-grained (2.50 Ø to 1.75 Ø), moderately-sorted.	2
4	Sandy shale: laminated- to platy-bedded, randomly cross-bedded, color-banded, non-fissile, grayish yellow green (5 GY 7/2), interlayered with pinkish gray (5 YR 8/1) weathering to pale red (5 R 6/2), moderately-indurated, carbonate-cemented	3
3	Silty quartz sandstone: laminated- to thin-bedded, covered at the base, silty claystone grading into sandstone on top, yellowish gray (5 Y 7/2), pinkish gray (5 YR 8/1), and light gray (N 7) weathering to pale red (5 R 6/2) and brownish gray (5 YR 4/1), well-indurated, very fine- to fine-grained (3.50 Ø to 2.50 Ø), moderately-sorted	5
2	Argillaceous quartz sandstone: thin-bedded, contains discontinuous lenses of pale green shale, yellowish gray (5 Y 7/2) weathering to pale red (5 R 6/2), well-indurated, carbonate- and silica-cemented,	

Unit No.	Description	Thickness in feet
	very fine- to fine-grained (3.50 Ø to 2.75 Ø), moderately-sorted.	2
1	Quartz sandstone: slightly asphaltic, chert-bearing, alternating red, and green shale at the base of the unit, grading into sandstone to the top, medium-bedded, dark yellowish brown (10 YR 4/2) weathering to dusky brown (5 YR 2/2), poorly-indurated, poorly-cemented, slightly calcareous, fine- to medium-grained (2.25 Ø to 1.50 Ø), poorly-sorted	4
	Base of the section not exposed in the measurement area, and top is partially-eroded.	
	Total section	49.5

SECTION G
Sec. 21, T. 7 N., R. 6 E.



MEASURED SECTION G

Location.- Highway 99, approximately 10 miles south of the Seminole townsite (sec. 21, T. 7 N., R. 6 E., Seminole County).

Traverse started at the base of the road-cut, east side of the highway.

The section was measured by A. Iranpanah (November, 1965).

Unit No.	Description	Thickness in feet
	Top of hill	
8	Chert-bearing argillaceous quartz sandstone: thin- to massive-bedded, dark yellowish brown (10 YR 4/2) weathering to dark greenish gray (5 GY 4/1), moderately- to poorly-indurated, poorly-cemented, calcareous, very fine- to medium-grained (3.50 Ø to 1.50 Ø), poorly-sorted	5.5
7	Covered: laminated- to medium-bedded, interbedded red shale and pale green shale, very poorly fissile, poorly-indurated	6.5
6	Quartz sandstone: thin-bedded, dark yellowish brown (10 YR 4/2) and pale yellowish brown (10 YR 6/2) weathering to olive gray (5 Y 4/1), poorly-indurated to unindurated, abundant sedimentary dikes, and/or mud-cracks, the major set of dikes have a general strike of N 70°E, very fine- to medium-grained (3.50 Ø to 1.50 Ø), poorly-sorted. . . .	2.5
5	Quartz sandstone: thin- to massive-bedded, pale yellowish brown (10 YR 6/2) weathering to olive gray (5 Y 4/1), fine-grained	

Unit No.	Description	Thickness in feet
	(2.75 Ø), and better-cemented at the base, becomes coarser, and poorly-cemented, and poorly-indurated toward the top, fine- to coarse-grained (2.75 Ø to 0.50 Ø), poorly-sorted.	12.5
4	Quartz sandstone: thin- to massive-bedded, randomly cross-bedded, and ripple-marked, abundant sedimentary dikes, and/or mud-cracks locally, moderate yellowish brown (10 YR 5/4), weathering to olive gray (5 Y 4/1), moderately-indurated, very fine- to medium-grained (3.50 Ø to 1.50 Ø), poorly-sorted	11
3	Argillaceous silty quartz sandstone: thin- to massive-bedded, spotted, covered at the base of the unit, 2 feet of interlayered red and green shale, non-fissile, poorly-indurated at the top, pale yellowish brown (10 YR 6/2) weathering to olive gray (5 Y 4/1), well-indurated, carbonate-cemented, fine- to very fine-grained (2.75 Ø to 3.25 Ø), moderately-sorted.	5
2	Silty quartz sandstone: slightly conglomeratic, thin-bedded, randomly cross-bedded, spotted, grayish orange pink (5 YR 7/2), and moderate yellowish brown (10 YR 5/4) weathering to pale-red (5 R 6/2), and olive black (5 Y 2/1), moderately indurated, carbonate-cemented, fine- to medium-grained (2.25 Ø to 1.50 Ø), poorly-sorted.	2.5
1	Clay-shale: laminated- to thin-bedded, poorly-fissile, pinkish gray (5 YR 8/1) interbedded with greenish gray (5 G 8/1), and overlain by grayish yellow (5 Y 8/4) weathering to grayish red (10 R 4/2), and grayish yellow green (5 GY 7/2), poorly-indurated	3

Unit No.	Description	Thickness in feet
	Base of the section not exposed in the measurement area, and the top is eroded.	
	Total section . . .	48.5

SELECTED THIN SECTION DESCRIPTIONS

Format Of Terrigenous Rock Descriptions:

I. Sample number and location: Reference number of measured section, stratigraphic position of the sample within the section.

II. Megascopic properties: Sedimentary structures, color, hardness, rock type.

III. Microscopic properties:

A. Texture.--Grain size (extreme smallest and largest clastics), grain shape, textural maturity.

B. Authigenic cement.--Kind(s), percentage, relative distribution, paragenetic and diagenetic relations.

C. Mineral composition.--

1. Quartz: percentage, type, approximate abundance of each type, properties
2. Feldspars: percentage, type, properties
3. Chert: percentage, type, properties
4. Carbonate rock-fragments: percentage, type, properties
5. Miscellaneous terrigenous material: type, percentage, properties
6. Pore spaces: percentage, distribution throughout the slide

D. Remarks.--

IV. Name of the rock: Following the pattern as; grain size, roundness, sorting of the allochemical constituents, packing, textural maturity, notable or unusual transported constituents, prominent orthochemical cement, main rock name.

(Modified from Folk, 1961)

I. A-1(819a).- Ada Formation: Measured Section A, 3 feet of sandstone, 4 feet above the base of the section.

II. Massive- to medium-bedded, brownish gray (5 YR 4/1) on fresh surface, poorly indurated, asphaltic sandstone.

III. A. Fine to coarse, slightly conglomeratic, well-rounded to subrounded, poorly sorted, bimodal, poikilotopic to subpoikilotopic, mature terrigenous rock.

B. 1. Silica cement: Quartz overgrowths, total 2%, present on almost all grains, but lack interlocking with adjacent grains. First cement to form.

2. Limonite stain: total 3% occurs throughout the slide, formed after quartz overgrowths and before the calcite cement.

3. Calcite cement: total 18% pore-filling coarsely crystalline, anhedral, with optical continuity (poikilotopic), locally recrystallized into fine equigranular microsparite. Replacing quartz and chert.

4. Dolomite cement: secondary, total about 1% euhedral to subhedral. Replacing calcite.

C. 1. Quartz: total 53%; common, 45%; undulose, 6%; composite, 2%. More than 40% of the grains contain microlites (zircon and rutile). Liquid bubbles and vacuoles are present in almost all grains.

2. Feldspars: absent.

3. Chert: total 3% present in very coarse sand- to pebble-sized detrital grains, porphyrotopic, subangular to angular, chalcedonic, patches of sparry calcite are enclosed. Contains appreciable amounts of hematite, limonite and liquid inclusions.

4. Carbonate rock-fragments: total 15%, medium- to coarse sand, partially to completely recrystallized into subequigranular microsparite, organic matter rich and pseudopelletic.

5. Fossils: trace amount.

6. Pore spaces: total 5% occur in irregular patches.

IV. Fine to coarse, conglomeratic sandstone: well-rounded to subrounded, bimodal, mature, moderately well-packed, siliceous, limonitic, calcareous, intraclastic orthoquartzite.

I. A-2(820).- Ada Formation: measured Section A, 1 foot of asphaltic sandstone, 11 feet above the base of the section.

II. Thin- to medium-bedded, dark gray (N 3), interbedded with minor layers of very pale orange (10 YR 8/2) on fresh surface, very poorly indurated, asphaltic sandstone.

III. A. Fine- to coarse-grained, well-rounded to angular, poorly sorted, unimodal, poikilotopic, immature to submature terrigenous rock.

B. 1. Quartz overgrowths: comprises a small portion of total cement. Present on about 30% of the quartz grains, incompletely developed, clean without inclusions.

2. Calcite cement: total 29%; pore filling, fine- to coarsely-crystalline, replacement, anhedral to subhedral, poikilotopic, partially recrystallized into subequigranular microsparite.

3. Dolomite cement: secondary, total 12%; medium- to coarsely-crystalline, euhedral to subhedral.

C. 1. Quartz: total 55%; undulose, 10%; composite, 3%. Only 12% of the grains have microlites (some euhedral zircon, rutile needles) and negative crystals are present in less than 1% of the detrital quartz. Liquid and gas bubbles are common.

2. Feldspars: absent.

3. Chert: cryptocrystalline to chalcedonic, total 1%; medium- to coarse-sand.

4. Carbonate rock-fragments: total 9%; micro-crystalline and medium- to coarsely-crystalline, partially recrystallized into subequigranular grains, and partially replaced by the secondary dolomite.

5. Collophane: trace amount.

6. Pore spaces: total 6%; distributed irregularly throughout the slide.

IV. Fine to medium sandstone: well-rounded to subangular, poorly sorted, unimodal, poorly packed, immature to submature, siliceous, calcareous, hematite stained, clayey orthoquartzite.

I. A-3(821).- Ada Formation: Measured Section A, 2 feet of asphaltic sandstone, 12 feet above the base of the section.

II. Cross-bedded, graded-bedded, medium gray (N 5), on fresh surface, slightly well-indurated, asphaltic sandstone.

III. A. Fine to coarse, well-rounded to angular, bimodal. Poikilotopic, submature terrigenous rock.

B. 1. Quartz overgrowths: incompletely developed on less than 2% of the grains.

2. Calcite cement: total 34%; fine- to coarsely crystalline, subhedral to anhedral, occurs in patches with optical continuity (poikilotopic), pore-filling.

3. Dolomite cement: secondary, total 13%; subhedral to euhedral, medium- to coarsely-crystalline.

4. Illite: pore-filling, total 3%.

C. 1. Quartz: Total 45%; undulose, 2%; semicomposite, 2%. Microlite inclusions are present in less than 30% of the grains. Liquid and gas bubbles are common. Partially replaced by calcite.

2. Feldspars: absent.

3. Chert: microcrystalline, angular (wedge-shaped), liquid and organic matter inclusions

are common, total 3%; chatter-marked, partially replaced by calcite.

4. Dolomite rock-fragments: coarse-grained, subrounded, total 2%.

5. Fossils: Fragments of ostracods can be identified, trace amount.

IV. Fine to coarse sandstone: well-rounded to angular, bimodal, submature, poorly-packed, siliceous, calcareous, intraclastic, organic-matter bearing, clayey orthoquartzite.

I. A-4(822).- Ada Formation: Measured Section A, 3 feet of sandstone, 14 feet above the base of the section.

II. Medium-bedded, brownish black (5 YR 2/1) on fresh surface, friable sandstone.

III. A. Fine to coarse, bimodal. grains are well-rounded to angular. Submature to mature, poikilotopic terrigenous rock.

B. 1. Quartz overgrowths: incompletely developed, makes a small portion of the total cement, but occurs on more than 60% of the detrital grains.

2. Calcite cement: total 24%; pore-filling, fine to coarsely crystalline, poikilotopic to subpoikilotopic, porphyrotopic, partially recrystallized into equigranular sparry calcite, heavily stained in places with asphaltic materials.

C. 1. Quartz: total 53%; common, 44%; undulose, 9%; stretched composite, trace amount. Microlites, gas, and liquid bubbles occur in more than 20% of the grains. Partially replaced by calcite.

2. Feldspars: absent.

3. Chert: trace amount, cryptocrystalline.

4. Carbonate rock-fragments: total 2%; medium sand, well-rounded, partially recrystallized into fine equigranular sparry calcite.

5. Pore spaces: total 7%; occur in irregular patterns.

IV. Fine to coarse sandstone: well-rounded to angular, bimodal, moderately well-packed, siliceous, calcareous, organic-matter bearing (asphaltic), intraclastic orthoquartzite.

I. A-4(824).- Ada Formation: Measured Section A, 1 foot of sandstone, 19 feet above the base of the section.

II. Thin- to medium-bedded, cross-bedded, grayish orange pink (5 YR 7/2) on fresh surface, hard sandstone.

III. A. Coarse silt to medium sand, poorly sorted, bimodal to slightly trimodal, well-rounded to subangular, mature to submature, subpoikilotopic to poikilotopic, terrigenous rock.

B. 1. Calcite cement: total 30%; consists of fine- to coarsely-crystalline sparry calcite, anhedral, pore-filling, partially recrystallized into equant grains, replaces detrital quartz. Coarse grains are characterized by their optical continuity. The major cementing constituent in the rock.

2. Illite: less than 1%; occurs as patches with a diameter less than 2 mm, partially replaced by calcite.

C. 1. Quartz: total 51%; straight to slightly undulose, 48%; undulose and stretched grains, 2%; semicomposite, 1%. Liquid bubbles and vacuoles are present in more than 80% of the grains. Microlites or rutile needles occur only in 5% of the detrital quartz grains.

2. Feldspars: absent.

3. Chert: trace amount.

4. Carbonate rock-fragments: total, 30%; composed of calcite in both forms: coarse sparry calcite, and microcrystalline calcite, former angular to subangular, and the latter is well-rounded. Partially to completely replaced by very coarse pore-filling calcite cement with optical continuity. Detrital dolomite, total

5%; occurs in fine to medium grains of subrounded to rounded dolomite rhombs, which are coated by limonite.

5. Micas: muscovite is present in trace amount, very fine-grained.

6. Fossils: indistinct; trace amount.

7. Pore spaces: absent.

IV. Very fine to medium sandstone: well-rounded, to angular, poorly-sorted, bimodal, poorly-packed, intraclastic, calcareous orthoquartzite.

I. A-4(829).- Ada Formation: Measured Section A, 1.5 feet of sandstone, 13.5 feet above the base of the section.

II. Thin- to medium-bedded, banded (alternating asphaltic sandstone and clean sandstone), medium dark gray (N 4) on fresh surface, friable sandstone.

III. A. Fine to medium, bimodal, well-rounded to subangular. Subpoikilotopic, submature terrigenous rock.

B. 1. Calcite cement: total 18%; fine to coarse, pore-filling, patches with optical continuity, partially recrystallized into equigranular anhedral grains.

2. Quartz overgrowths: comprises a small percentage of the cement, present on less than 20% of the grains. Incompletely developed around the detrital quartz, irregular surfaces.

3. Opal cement: total 2%; occurs as pore-filling patches.

4. Kaolinite - Illite: total 6%; occur in patches as a poorly crystallized, pore-filling clay; stained by asphaltic material.

5. Organic matter (asphaltic material): occurs as pore-filling matrix and reddish dark brown stain on the detrital grains and cement.

C. 1. Quartz: total 68%; mostly straight to slightly undulose (common), less than 1% stretched grains. Vacuoles and liquid bubbles are present in almost all the grains. Very few grains contain inclusions, either microlites or rutile needles.

2. Feldspars: trace amount, perthite. Moderately vacuolized and kaolinitized, fine-sand.

3. Chert: less than 1%; cryptocrystalline, subangular to subrounded.

4. Carbonate rock-fragments: total 4%; occur in the forms of coarsely crystalline, subhedral to euhedral rhombic carbonates, and well-rounded microcrystalline calcite.

5. Pore spaces: total 3%; occur in the form of patches unevenly distributed throughout the slide.

IV. Fine to medium sandstone: well-rounded to subangular, bimodal, moderately well-packed, submature, calcareous, siliceous, asphaltic orthoquartzite.

I. A-5(823a).- Ada Formation: Measured Section A, 2 feet of sandstone, 17 feet above the base of the section.

II. Thin- to medium-bedded, graded-bedded in places, grayish orange (10 YR 7/4) on fresh surface, banded, moderately indurated sandstone.

III. A. Very fine to coarse, bimodal, well-rounded to subrounded, subpoikilotopic, mature to submature terrigenous rock.

B. 1. Quartz overgrowths: trace amount; occurs on less than 3% of the grains. Partially replaced by calcite. Contain no inclusions.

2. Calcite cement: total 38%; occurs as pore-filling, and replacement anhedral crystals, with optical continuity, subpoikilotopic, porphyrotopic, partially recrystallized into fine-grained equigranular microsparite.

3. Dolomite cement: total 4%; secondary in origin, replacing the calcite mosaics, euhedral.

C. 1. Quartz: total 45%; common 44%; semicomposite 1%. Only 3% of the grains have microlite inclusions (rutile needles). Liquid and gas bubbles are present in more than 80% of the grains.

2. Feldspars: absent.

3. Chert: total 1%; angular, composed of microcrystalline silica, abundant inclusions, partially replaced by calcite.

4. Carbonate rock-fragments: total 5%; mostly composed of microcrystalline calcite, partially to completely recrystallized into equigranular microsparite.

5. Pore spaces: total 7%; irregular patches, randomly distributed throughout the slide.

IV. Very fine to coarse sandstone: very well rounded to subrounded, bimodal, mature to submature, calcareous, intraclastic, orthoquartzite.

I. A-13(836).- Ada Formation: Measured Section A, 2 feet of sandstone, 32 feet above the base of the section.

II. Thin- to medium-bedded, light brownish gray (5 YR 6/1) on fresh surface, friable sandstone.

III. A. Fine to medium, with a minor coarse fraction, poorly-sorted, bimodal. Poikilotopic, mature terrigenous rock.

B. 1. Calcite cement: total 29%; occur in coarsely crystalline, pore-filling, unequigranular, anhedral, with optical continuity. Partially recrystallized into finely crystalline, anhedral, equigranular calcite. Replaces the detrital quartz grains.

2. Quartz overgrowths: present on less than 5% of the grains, incompletely developed, vague on the edges, form no interlocking contacts between the grains.

3. Hematite-limonite: total 3%; occurs as both coating on the detrital dolomite, and authigenic cement.

C. 1. Quartz: total 51%; common, straight to slightly undulose and quartz with undulose extinction are present in appreciable amount. Composite and stretched grains, less than 1%. Inclusions: liquid bubbles and vacuoles occur in more than 50% of the grains, microlites are present in less than 30% of the detrital quartz grains.

2. Feldspars: trace amount; orthoclase and perthite, vacuolized and corroded by calcite cement, fine sand.

3. Chert: total 5%; coarse-grained, cryptocrystalline, angular to subrounded, replaced by calcite only along the fractures.

4. Carbonate rock fragments: total 5%; calcite clastics comprises 4% of the total, medium- to fine sand, well-rounded, composed of microcrystalline calcite, partially recrystallized. Dolomite rock-fragments, 1%; composed of fine sand, subhedral to anhedral grains, coated with limonite and hematite.

5. Pore spaces: total 8%; irregularly distributed throughout the slide.

IV. Fine to coarse sandstone: well-rounded to subrounded, poorly-sorted, bimodal, poorly-packed, mature, calcareous, siliceous orthoquartzite.

I. B-2(851).- Ada Formation: Measured Section B, 1.5 feet of conglomeratic sandstone, 3 feet above the base of the section.

II. Grayish orange pink (5 YR 7/2) on fresh surface, massive, conglomeratic at the base, alternating layers of sandstone, chert, clay rich bands at the top. Unindurated, conglomeratic calcareous sandstone.

III. A. Fine to medium, with a very minor coarse fraction, and granules and pebbles, poorly sorted, bimodal. Immature to submature porphyrotopic terrigenous rock.

B. 1. Silica cement: Quartz overgrowths, incompletely developed, around the detrital grains. Occurs on more than 5% of the grains. Form slight interlocking contact between the grains. Comprises a small percentage of total rock.

2. Illite-Kaolinite: total 12%; developed in patches less than 1 mm in diameter, probably after or contemporaneous with the development of quartz overgrowths and calcite.

3. Calcite cement: total 1%; occurs in small patches, probably contemporaneous with illite, finely crystalline, anhedral, pore filling.

C. 1. Quartz: total 72%; common, equal amount of straight to slightly undulose, undulose and semicomposite undulose. Less than 1% stretched grains with composite undulose extinction. Liquid bubbles and vacuoles are present in almost all grains. Microlite or rutile inclusions occur in less than 15% of the detrital quartz.

2. Feldspars: less than 1%, perthite and sodium plagioclase, highly vacuolized and kaolinitized. Fine sand, rounded.

3. Chert: total 9%; granule to fine sand. Rounded to subangular, cryptocrystalline, and finely crystalline, inclusions, and bubbles.

4. Micas: muscovite, trace amount, very fine-grained.

5. Pore spaces: total 6%; occur in irregularly distributed patches.

IV. Fine to coarse conglomeratic sandstone: well rounded to subangular, poorly sorted, bimodal, well packed, immature to submature, siliceous, argillaceous, slightly calcareous, porous orthoquartzite.

I. B-3(852).- Ada Formation: Measured Section B, 1 foot of conglomeratic sandstone, 4.5 feet above the base of the section.

II. Graded-bedded, light brownish gray (5 YR 6/1) on fresh surface, moderately-indurated sandstone.

III. A. Fine to coarse, and conglomeratic, poorly-sorted, bimodal to trimodal. Mature to submature, porphyrotopic terrigenous rock.

B. 1. Quartz overgrowths: comprises a small proportion of total cement. Occurs on more than 60% of the grains, incompletely developed, clean without inclusions, partially with vague nucleus boundaries.

2. Illite: approximately 4%; occurs in patches with diameter more than 1 mm.

3. Chert: less than 1%; occurs in the form of fibrous overgrowths on the face of the microcrystalline to cryptocrystalline chert grains.

4. Calcite cement: total 13%; coarsely crystalline, single crystal larger than 2 mm in diameter, poikilotopic, unequigranular, pore-filling, anhedral calcite mosaic.

5. Dolomite overgrowths: less than 2%; euhedral, encloses clay- and iron oxide-coated detrital dolomite rhombs, forming zoned dolomites.

C. 1. Quartz: total 64%; common, straight to slightly undulose quartz constitutes the majority of the grains, stretched grains, less than 1%. Microlites and rutile needles are present in less than 20% of the grains. Vacuoles and liquid inclusions are common in almost all grains in varying amounts. Well-rounded to subangular, very fine sand-sized grains tend to be more angular than the medium and coarse sands. More than 90% of the grains are partially replaced by calcite.

2. Feldspars: absent.

3. Chert: total 10%; cryptocrystalline to fibrous, and chalcedonic, coarse sand to granule, subrounded to angular. Replaced by calcite only along the fractures.

4. Carbonate rock-fragments: total 2%; composed of detrital dolomite rhombs, coated by clay, hematite, and limonite. Fine to medium, occurs along certain zones throughout the slide.

5. Pore spaces: approximately, 2%; occur in small patches, irregularly distributed.

IV. Fine to coarse, conglomeratic sandstone: well-rounded to subangular, bimodal to trimodal, moderately poorly-packed, mature to submature, calcareous, dolomitized, siliceous orthoquartzite.

I. B-4(853a).- Ada Formation: Measured Section B, 3 feet of sandstone, 5.5 feet above the base of the section.

II. Thin- to medium-bedded, yellowish gray (5 Y 7/2) on fresh surface, slightly friable sandstone.

III. A. Fine to medium, poorly-sorted, slightly bimodal. Submature to immature terrigenous rock.

B. 1. Quartz overgrowths: constitute a small portion of total cement; present on more than 50% of the grains, incompletely encloses the detrital quartz grains, in places well-developed and interlocking the adjacent grains.

2. Kaolinite - Illite: total 5%; distributed in patches, scattered irregularly throughout the slide, diameter of the patches does not exceed 1 mm.

C. 1. Quartz: total 84%; common, straight to slightly undulose, and undulose constitute the majority of the grains; stretched grains, trace amount. Vacuoles and liquid bubbles are common inclusions. Microlites and/or rutile needles are present in less than 10% of the grains.

2. Feldspars: trace amount; orthoclase, and perthite, highly vacuolized, fine sand, well-rounded.

3. Chert: total 1%; fine to medium, subrounded. Inclusions and liquid bubbles are common.

4. Pore spaces: total 8%; irregularly distributed. The abundance of pore spaces in thin section, and its scarcity in the handspecimen is probably due to partial removal of the clay constituents from matrix during the thin section preparation.

IV. Fine to medium sandstone: subrounded to subangular, submature, moderately well-packed, siliceous, clayey, porous(?) orthoquartzite.

I. B-4(853b).- Ada Formation: Measured Section B, 1-3 feet of sandstone, 8.5 feet above the base of the section.

II. Medium- to massive-bedded, pinkish gray (5 YR 8/1) on fresh surface, slightly friable sandstone.

III. A. Fine to medium, poorly-sorted, bimodal. Submature to immature porphyrotopic terrigenous rock.

B. 1. Quartz overgrowths: comprises a small percentage of total cement, present on more than 70% of the grains. Forms slightly interlocking texture.

2. Illite - Kaolinite: total 5%; occur in patches not larger than 0.5 mm in diameter.

C. 1. Quartz: total 85%; composed mainly of common, and/or straight to slightly undulose, stretched grains about 1%. Liquid and vacuoles are the major inclusions in the detrital quartz grains. Microlites are present in less than 10% of the grains.

2. Feldspars: trace amount, highly kaolinitized, and vacuolized. Fine sand, rounded.

3. Chert: total 1%; cryptocrystalline, fine to medium, subrounded.

4. Pore spaces: total 8%; part of the pore spaces probably result from the removal of clay constituents from matrix during thin section preparation.

IV. Fine to medium sandstone: subrounded to subangular, bimodal, submature to immature, moderately well-packed, siliceous, clayey, porous(?) orthoquartzite.

I. B-7(854).- Ada Formation: Measured Section B, 1 foot of argillaceous sandstone, 13.5 feet above the base of the section.

II. Thin-bedded, grayish orange (10 YR 7/4) to very pale orange (10 YR 8/2) on fresh surface, friable sandstone.

III. A. Very fine to fine, poorly-sorted, unimodal, subrounded to rounded. Immature terrigenous rock.

B. 1. Quartz overgrowths: comprise a small percentage of the rock, occur in almost all grains, but generally do not completely enclose the detrital grains, clear, without inclusions, slightly interlocked.

2. Limonite cement: total 3%; formed later than silica cement, encloses the overgrowths, occurs locally in abundance.

3. Clay and clay-sized detrital quartz, total 19%; occur as pore-filling matrix.

C. 1. Quartz: total 71%; common, straight to slightly undulose 51%; undulose to slightly undulose, 19%, stretched grains, less than 1%. The majority of the grains contain liquid bubbles, vacuoles, and microlite inclusions.

2. Feldspars: trace amount, perthite, strongly vacuolized, rounded.

3. Chert: trace amount, cryptocrystalline, fine sand, rounded.

4. Glauconite: trace amount, well-rounded, very fine sand.

5. Pore spaces: total 7%; irregularly distributed throughout the slide.

IV. Very fine to fine, silty sandstone: subrounded to angular, poorly-sorted, immature, moderately well-packed, limonitic, siliceous, argillaceous orthoquartzite.

I. B-8(855).- Ada Formation: Measured Section B, 1.5 feet of calcareous sandstone, 14.5 feet above the base of the section.

II. Thin- to medium-bedded, cross-bedded, pale brown (5 YR 5/2) on fresh surface, hard to friable sandstone.

III. A. Very fine to fine with minor medium mode, poorly-sorted, bimodal, very well-rounded to subangular. Mature terrigenous rock.

B. 1. Quartz overgrowths: comprise a small portion of total rock. Occur in less than 20% of the detrital quartz grains, characterized by the irregular boundaries, partially replaced by calcite. Authigenic chert occurs in trace amount, both in pore-filling and replacement forms.

2. Dolomite overgrowths: total 16%; coarsely-crystalline, euhedral to subhedral, poikilotopic, large single crystals more than 1 mm in diameter.

3. Calcite cement: total 9%; coarse to medium crystalline, anhedral, partially replaced by secondary dolomite, subpoikilotopic to poikilotopic.

4. Hematite cement: total 4%; hematite also stains the carbonate rock-fragments, unevenly distributed throughout the slide.

5. Illite and Kaolinite: total 2%; occur as patches with maximum diameter of 1 mm. Clay content occurs as both cement and matrix.

C. 1. Quartz: total 50%; mostly common, straight to slightly undulose; trace amount of stretched grains with composite undulose extinction. Vacuoles, and liquid bubble inclusions are present in almost all grains. Microlites, and rutile needles occur in less than 20% of the detrital quartz grains.

2. Chert: total 1%; cryptocrystalline, subangular, medium sand.

3. Carbonate rock-fragments dolomite clastics: total 16%; fragmented along the rhomboidal cleavage direction, hematite stained probably before transportation into the environment of deposition, since stain is present in only dolomite rock-fragments. Overgrowths, later in the environment of deposition formed zoned-dolomite. Part of the hematite cement is probably introduced from the coats of the carbonate clastics, and redeposited as authigenic cement.

4. Feldspars: absent.

IV. Very fine to medium sandstone: very-well rounded to subangular, bimodal, submature to mature, poorly-packed, siliceous, dolomitic, calcareous, hematitic orthoquartzite.

I. B-9(856).- Ada Formation: Measured Section B, 1 foot of dolomitic sandstone, 16.5 feet above the base of the section.

II. Thin-bedded, pale brown (5 YR 5/2) on fresh surface, hard sandstone.

III. A. Fine to medium sandstone: well-rounded to angular. Submature terrigenous rock.

B. 1. Quartz overgrowths: comprise a small percentage of total rock. Present on less than 4% of the grains, irregular boundaries, partially replaced by secondary dolomite.

2. Hematite and Limonite: total 4%; formed authigenically after silica cement.

3. Dolomite cement: total 14%; occurs as overgrowths, and secondary or replacement dolomite. Fine to coarse, euhedral to slightly subhedral.

4. Calcite cement: total 8%; coarse to finely-crystalline, anhedral, pore-filling, and replacement. Partially replaced by euhedral secondary dolomite.

5. Illite and Kaolinite: total 5%; occurs both as cement and detrital matrix, present in patches, with a diameter of less than 1 mm.

C. 1. Quartz: total 58%; majority of the grains are composed of common, straight to slightly undulose, less than 5% composite undulose. Microlites occur in less than 50% of the grains, liquid bubbles and vacuole inclusions present in almost all grains.

2. Feldspars: trace amount; orthoclase and microcline, highly vacuolized.

3. Chert: about 1%; cryptocrystalline, angular to subrounded, fine sand, partially replaced by calcite.

4. Carbonate rock-fragments: total 10%; composed of coarsely-crystalline, euhedral dolomite, and anhedral to subhedral calcite grains. Partially to completely coated with hematite and limonite.

5. Micas: less than 1%; composed of bent brown biotite (MRF), and trace amount of chlorite.

IV. Fine to medium sandstone: well-rounded to angular, bimodal, submature, poorly-packed, dolomitic, calcareous, limonitic, clay-bearing orthoquartzite.

I. B-10(857).- Ada Formation: Measured Section B, 1.5 feet of sandstone, 23 feet above the base of the section.

II. Medium-bedded, grayish red (10 R 4/2) grading into grayish pink (5 R 8/2) on fresh surface, slightly well-indurated sandstone.

III. A. Very fine to fine, with minor medium mode, poorly-sorted, slightly bimodal. Submature to immature terrigenous rock.

B. 1. Quartz overgrowths: less than 1%; developed on more than 80% of the detrital grains, incompletely encloses the grains, irregular boundaries, clear without inclusions, forms interlocking mosaic.

2. Kaolinite and Illite: less than 6%, occur in patches with diameter not more than 0.50 mm.

C. 1. Quartz: total 86%; majority of the grains are composed of common, straight to slightly undulose, some undulose, and composite; less than 1% stretched grains. Microlite inclusions occur in more than 50% of the grains, liquid bubbles and vacuoles are common in almost all grains.

2. Feldspars: trace amount; highly vacuolized, perthite, rounded, very fine sand.

3. Chert: less than 1%; cryptocrystalline, rounded, fine sand.

4. Pore spaces: about 8%; part of these pore spaces were probably introduced during thin section preparation.

IV. Very fine to fine sandstone: rounded to subrounded, poorly-sorted, slightly bimodal, submature to immature, moderately-well-packed, porous(?) argillaceous orthoquartzite.

I. B-12(860).- Ada Formation: Measured Section B, 4 feet of argillaceous sandstone, 28.5 feet above the base of the section.

II. Medium- to massive-bedded, yellow gray (5 Y 8/1) on fresh surface, slightly friable sandstone.

III. A. Very fine to fine, slightly bimodal, with minor medium mode, subrounded to angular. Immature terrigenous rock.

B. 1. Illite: Authigenic, approximately 4%; widely distributed throughout the slide, in places occurs along sub-parallel zones.

2. Quartz overgrowths: comprise a small percentage of the rock, occurs on almost all grains, forms slightly interlocking grains.

3. Calcite cement: trace amount, finely-crystalline, anhedral grains.

C. 1. Quartz: total 76%; common, straight to slightly undulose, and undulose. Composite and stretched grains make less than 2% of the total detrital quartz. Liquid bubbles and vacuoles are present in almost all grains, a few grains contain microlites, and rutile needles.

2. Feldspars: about 1%; consist of microcline, and perthite. Moderately vacuolized, subrounded, fine sand.

3. Chert: about 2%; microcrystalline, contains inclusions and bubbles. Well-rounded, fine sand.

4. Pore spaces: total 14%; the majority of the pores are from removal of clays during the preparation of the slide.

IV. Very fine to fine sandstone: subrounded to angular, bimodal, immature, moderately well-packed, slightly calcareous, siliceous, argillaceous, porous(?) orthoquartzite.

I. C-17(904).- Ada Formation: Measured Section C, 1 foot of conglomeratic sandstone, 63 feet above the base of the section.

II. Thin- to medium-bedded, olive gray (5 Y 8/1) on fresh surface, moderately well-indurated sandstone.

III. A. Very fine to coarse, very well-rounded to subangular, and wedged, poorly-sorted. Submature, subpoikilotopic to poikilotopic, terrigenous rock.

B. 1. Calcite cement: total 36%; coarse to fine crystalline, pore-filling, partially recrystallized to equigranular, anhedral grains.

2. Dolomite: total 2%; secondary, coarsely-crystalline.

C. 1. Quartz: total 32%; mostly consists of common, straight to slightly undulose, less than 1% stretched grains. Liquid, vacuole, and microlite inclusions are present in more than 80% of the grains.

2. Feldspars: less than 1%; orthoclase and microcline, slightly fresh, partially replaced by calcite.

3. Chert: total 2%; cryptocrystalline to finely crystalline, angular to subrounded.

4. Carbonate rock-fragments: total 14%; medium to coarse sand, well-rounded. Two distinct varieties are present: (1) composed of microcrystalline calcite (micrite), and (2) coarsely-crystalline calcite with obvious calcite twins.

5. Micas: less than 1%; bent brown biotite (MRF).

6. Fossils: about 6%; consists of fragments of crinoid plates, partially recrystallized; and other indistinct fossil hash.

7. Glauconite: trace amount; fine sand.

8. Pore spaces: total 8%; occurs locally in irregular patches.

D. Remarks: The carbonate clastics formed of coarsely-crystalline calcite are angular, since they have been cleaved along their twin planes, in a relatively high energy environment. Slide shows a typical example of replacement of chert by calcite. Apparently, detrital quartz showed less tendency to replacement than chert.

IV. Fine to coarse sandstone: well-rounded to subrounded, bimodal to trimodal, mature, poorly-packed, calcareous, intraclastic, fissile, chert, glauconite, biotite bearing, porous orthoquartzite.

I. C-10(918).- Ada Formation: Measured Section C, 1.5 feet of calcareous sandstone, 44.25 feet above the base of the section.

II. Thin-bedded, cross-bedded, yellowish gray (5 Y 8/1) on fresh surface, moderately-indurated very silty sandstone.

III. A. Coarse silt- to medium-sand, very well-rounded to very angular, wedge-shaped. Submature to immature subpoikilotopic terrigenous rock.

B. 1. Calcite cement: total 15%; pore-filling, coarsely-crystalline calcite, partially recrystallized into fine subequigranular microsparite.

2. Quartz overgrowths: trace amount; poorly-developed.

3. Kaolinite: trace amount; pore-filling.

C. 1. Quartz: total 42%; mostly plutonic quartz, straight to slightly undulose, less than 1% stretched grains. Liquid bubbles and vacuoles occur as the major inclusions. Microlites are present in less than 10% of the grains.

2. Feldspars: less than 1%; slightly fresh, well-rounded, partially replaced by calcite, very fine sand.

3. Chert: total 4%; cryptocrystalline to finely-crystalline, angular to subangular.

4. Carbonate rock-fragments: total 7%; composed of microcrystalline calcite (micrite), well-rounded, medium- to fine-sand, partially recrystallized.

5. Micas: less than 5%; large bent brown biotite (MRF), and some fine muscovite flakes. Chlorite, variety with ultrablue interference color is present in less than 1%.

6. Clay: total 7%; detrital clay and clay sized particles occur as matrix. Clay is composed mostly of illite.

7. Glauconite: less than 1%; coarse silt to very fine sand-sized, subrounded to subangular.

8. Collophane: trace amount; tabular grains.

9. Pore spaces: more than 5%; distributed irregularly throughout the slide.

D. Clay content is hard to measure closely, because of the presence of carbonate cement, which is mostly replaced the clay constituents.

IV. Very fine to medium, silty sandstone: well-rounded to angular, bimodal, submature, poorly-packed, chert, glauconite, feldspar, organic matter bearing, calcareous, slightly dolomitized, micaceous, porous orthoquartzite.

I. C-9(907).- Ada Formation: Measured Section C, 4.5 feet of calcareous asphaltic sandstone, grading into microcrystalline calcite (micrite), 40 feet above the base of the section.

II. Medium-bedded, cross-bedded, brownish black (5 YR 2/1) on fresh surface, moderately well-indurated sandstone.

III. A. Coarse silt to medium sand, well-rounded to angular. Immature to submature terrigenous rock.

B. 1. Calcite cement: total 17%; calcareous sandstone grades into sandy, silty burrowed microcrystalline calcite (sandy dismicrite). The calcite content in this sample ranges from a minimum 17% to a maximum of 95%.

2. Dolomite: total 3%; secondary, coarsely crystalline.

3. Quartz overgrowths: less than 1%; incompletely developed, clear without inclusions. Occur on less than 40% of the grains.

C. 1. Quartz: total 40%; the majority of the grains composed common, straight to slightly undulose; stretched grains, less than 0.50%.

Some of the grains are stained with organic matter (asphaltic materials), and some are partially replaced by calcite cement. Liquid, and microlite inclusions are common in more than 50% of the grains. Vacuoles occur in more than 60% of the grains.

2. Feldspars: absent.

3. Chert: about 1%; medium to coarse sand, subangular.

4. Carbonate rock-fragments: total 16%; composed of both microcrystalline calcite (micrite), and coarsely-crystalline calcite. Carbonate clastics are in places, recrystallized into fine subequigranular anhedral calcite grains.

5. Micas: less than 1%; bent brown biotite.

6. Fossils: less than 1%; composed of crinoid plates, and some indistinct skeletal debris, partially recrystallized.

7. Indistinct grains, heavily stained with asphaltic material, total 9%; brown to yellow, and are restricted to the asphaltic zone.

8. Pore spaces: as much as 12%, irregularly distributed.

D. Remarks: The quartz overgrowths occurred definitely after the introduction of the asphaltic stain into the sandstone, as they are marked by the fact that the detrital grains are stained, whereas the overgrowths are clear. A layer of organic matter is present between the detrital grain and the overgrowth.

IV. Very fine to medium silty sandstone: well-rounded, to angular, bimodal, submature to-immature, moderately to poorly-packed, calcareous, intraclastic, porous, asphalt-stained orthoquartzite.

I. C-5(910).- Ada Formation: Measured Section C, 5 feet of calcareous sandstone, 21.5 feet above the base of the section.

II. Cross-bedded, color-banded, brownish gray (5 YR 4/1) on fresh surface, well-indurated, hard sandstone.

III. A. Fine to medium, with minor coarse mode, bimodal, well-rounded to subrounded. Mature to submature, poikilotopic terrigenous rock.

B. 1. Calcite cement: total 24%; fine to coarsely crystalline, anhedral to subhedral, locally recrystallized into equant anhedral grains, pore-filling and replacement.

2. Dolomite: less than 2%; secondary, medium to coarse, euhedral.

3. Quartz overgrowths: comprise a small percentage of the rock. Poorly interlocked grains, partially replaced by calcite cement.

C. 1. Quartz: total 60%; mostly common, straight to slightly undulose, stretched grains, trace amount. Microlites, rutile needles, liquid bubbles, and vacuoles occur in more than 50% of the grains.

2. Chert: total 2%; fine to medium sand, subrounded.

3. Carbonate rock-fragments: total 7%; composed of microcrystalline and coarsely crystalline calcite, derived probably from different source rock. Well-rounded to subrounded, medium sand.

4. Micas: trace amount; bent brown biotite.

5. Fossils: trace amount; indistinct fossil fragments.

6. Pore spaces: total 5%; irregularly distributed throughout the slide.

IV. Fine to medium sandstone: well-rounded, bimodal, mature to submature, moderately packed, slightly dolomitized, chert-bearing calcareous orthoquartzite.

I. D-1(890).- Ada Formation: Measured Section D, 3 feet of sandstone, at the top of the section.

II. Massive-bedded to poorly-laminated, graded-bedded, yellowish gray (5 Y 8/1) on fresh surface, moderately to well-indurated sandstone.

III. A. Fine sandstone, in places silty, with minor medium mode, bimodal, angular to subrounded. Immature to submature, poikilotopic terrigenous rock.

B. 1. Quartz overgrowths: makes a small percentage of the rock; first cement to form, occurs on less than 25% of the detrital quartz grains, poorly-developed, partially replaced by calcite, shows no interlocking between the grains, with few exceptions.

2. Calcite cement: total 27%; fine- to coarsely-crystalline, anhedral, some coarse crystals with optical continuity, pore-filling, and replacement.

3. Illite: less than 1%; developed in patches with less than 0.50 mm in diameter. Probably, partially replaced by calcite cement.

C. 1. Quartz: total 62%; majority consists of common, straight to slightly undulose; less than 15%; stretched composite with undulose extinction. Liquid bubbles, and vacuoles are present in more than 80% of the grains. Microlites, rutile needles occur in less than 25% of the detrital quartz grains.

2. Feldspars: less than 1% orthoclase. Partially kaolinitized, and partially replaced by calcite cement.

3. Chert: total 3%; cryptocrystalline, fibrous, and chalcedonic, fine- to medium sand, subangular to subrounded. Inclusions: very common, mostly liquid bubbles, partially replaced by rhombic carbonates.

4. Carbonate rock-fragments: less than 1%; consist of microcrystalline calcite, well-rounded, fine- to medium sand.

5. Pore spaces: total 3%; irregularly distributed throughout the slide.

IV. Fine, silty sandstone: angular to subrounded, slightly bimodal, submature to mature, moderately packed, calcareous, siliceous, clayey, orthoquartzite.

I. D-2(889).- Ada Formation: Measured Section D, 1 foot of calcareous sandstone, 83 feet above the base of the section.

II. Thin- to medium-bedded, graded-bedded and cross-bedded, very light gray (N 8) on fresh surface, hard sandstone.

III. A. Very fine to medium, well-rounded to angular. Submature to mature, poikilotopic terrigenous rock.

B. 1. Calcite cement: total 31%; very coarsely-crystalline, optical continuity, pore-filling, and replacement. Partially recrystallized into subequigranular grains.

2. Quartz overgrowths: trace amount; sparcely developed.

C. 1. Quartz: total 59%; mostly plutonic, straight to slightly undulose; undulose and composite undulose less than 10%. Vacuoles, and liquid bubbles occur in more than 90% of the grains. Microlites present in less than 15% of the detrital quartz. Strongly replaced by the calcite cement.

2. Feldspars: total 3%; orthoclase, microcline, and perthite. Moderately fresh, partially replaced by calcite cement. Fine- to coarse sand.

3. Chert: total 5%; cryptocrystalline, chalcedonic, and fine-grained, equigranular, fine- to medium sand, angular to subangular.

4. Carbonate rock-fragments: total 1%; mostly composed of coarsely crystalline calcite, a few fragments of finely-crystalline calcite, partially recrystallized.

5. Micas: trace amount; fine-grained muscovite.

6. Fossils: less than 1%; indistinct.

7. Pore spaces: less than 1%.

IV. Very fine- to medium sandstone: well-rounded to angular, bimodal to trimodal, immature, poorly- to moderately-packed, calcareous, chert and feldspar bearing orthoquartzite.

I. D-15(898).- Ada Formation: Measured Section D, 1 foot of conglomeratic sandstone, 58.25 feet above the base of the section.

II. Thin- to medium-bedded, brownish gray (5 YR 4/1) on fresh surface, moderately-indurated sandstone.

III. A. Very fine to coarse, with minor fraction of granule and pebble-sized grains, trimodal. Grains are very well-rounded to subrounded, and subangular in any size. Submature to mature, sub-poikilotopic to poikilotopic terrigenous rock.

B. 1. Quartz overgrowths: Makes a small percentage of the rock. Occurs on more than 50% of the detrital quartz grains. Partially to completely replaced by calcite cement.

2. Calcite cement: total 26%; fine- to coarsely-crystalline, anhedral, some large grains with optical continuity, pore-filling and replacement.

3. Dolomite: trace amount; secondary, euhedral to subhedral, medium- to coarsely-crystalline.

C. 1. Quartz: total 45%; common, 41%; straight to slightly undulose; semicomposite, 3%; undulose; less than 1% stretched grains. Liquid bubbles, and vacuoles are present in more than 90% of the grains. Microlites occur in less than 10% of the grains.

2. Feldspars: trace amount: microcline, moderately vacuolized, subangular, fine- to medium sand.

3. Chert: total 2%; fine- to very coarse sand, subangular to subrounded, fine calcite grains are scattered throughout the chert grains.

4. Carbonate rock-fragments: total 25%; composed of microcrystalline calcite, fine- to very coarse sand, and pebble-sized clastics. A few coarsely-crystalline carbonate rock-fragments, angular to subrounded. Some of the finely-crystallized clastics are composed essentially of pelmicrite, and some contain sand, silt and organic matter.

5. Fossils: total 1%; consist of fragments of crinoid plates, and some indistinct

brachiopod(?), and trilobite(?) fragments. The internal structure of the fossil fragments is destroyed by the process of recrystallization.

6. Pore spaces: total 2%; present in small irregular patches.

IV. Very fine to very coarse, conglomeratic sandstone: well-rounded to subangular, trimodal, submature to mature, poorly-packed, intraclastic orthoquartzite.

I. D-17(899).- Ada Formation: Measured Section D, 1 foot of sandstone, 71.25 feet above the base of the section.

II. Thin-bedded, grayish brown (5 YR 3/2) on fresh surface, well-indurated sandstone.

III. A. Coarse silt to fine sand, with a very minor medium fraction, poorly-sorted, slightly bimodal, well-rounded to angular. Submature, subpoikilotopic terrigenous rock.

B. 1. Quartz overgrowths: comprise a small percentage of the rock. Present on more than 40% of the grains, incompletely developed, partially replaced by calcite cement.

2. Calcite cement: total 25%; occurs as overgrowths on the carbonate clastics, pore-filling, and replacement. Coarse to fine, anhedral to subhedral. Widely distributed throughout the slide.

3. Dolomite: total 3%; secondary, euhedral.

C. 1. Quartz: total 51%; common, straight to slightly undulose, 45%; semicomposite, and undulose, 5%; stretched grains less than 1%. Liquid bubbles, and vacuoles occur in almost all grains. Microlites present in less than 25% of the grains.

2. Feldspars: less than 1%; orthoclase, and perthite, angular, rather fresh, fine sand.

3. Chert: less than 1%; cryptocrystalline, angular, inclusions and liquid bubbles common, slightly replaced by calcite.

4. Carbonate rock-fragments: total 15%; the majority of the clastics are composed of coarsely-crystalline calcite, lesser amount formed from microcrystalline calcite. Those composed of coarsely crystalline calcite are angular to subangular, and from that of microcrystalline calcite are well-rounded. This is controlled by the physical properties of calcite grains. Grain size ranges from fine sand to medium sand.

5. Fossils: less than 1%; consist of fragments of crinoid plates, and indistinct shell fragments. Partially recrystallized into equant pseudomicrosparite.

IV. Fine, silty sandstone: well-rounded, to angular, poorly-sorted, slightly bimodal, submature, poorly-packed, slightly calcareous, slightly dolomitized orthoquartzite.

I. D-20(901).- Ada Formation: Measured Section D, 3 feet of sandstone, 7 feet above the base of the section.

II. Thin- to medium-bedded, pinkish gray (5 YR 8/1) on fresh surface, well-indurated sandstone.

III. A. Fine to medium, bimodal, with minor coarse mode, subrounded to well rounded. Submature to mature, poikilotopic terrigenous rock.

B. 1. Calcite cement: total 39%; fine- to medium-crystalline, anhedral to subhedral, pore-filling, and replacement.

C. 1. Quartz: total 50%; common, straight to slightly undulose, 48%; stretched grains, and composite grains, less than 2%. Microlites, vacuoles, and liquid inclusions occur in more than 50% of the grains.

2. Feldspars: absent.

3. Chert: total 2%; cryptocrystalline to finely crystalline, contains inclusions, and bubbles. Medium- to coarse sand, angular to subrounded.

4. Carbonate rock-fragments: total 7%; composed of subequal amount of finely-crystalline, and

coarsely-crystalline carbonate clastics. Well-rounded to subangular, partially recrystallized into anhedral subsequant calcite.

5. Fossils: trace amount; indistinct.

6. Pore spaces: less than 1%; irregularly distributed.

IV. Fine to medium sandstone: well-rounded to subangular, bimodal to trimodal, mature, poorly packed, chert-bearing slightly dolomitized orthoquartzite.

I. D-21(902).- Ada Formation: Measured Section D, 3 feet of alternating sandstone and shale, 4 feet above the base of the section.

II. Platy- to thin-bedded (flaggy), cross-bedded, brownish gray (5 YR 4/1) on fresh surface, well-indurated sandstone.

III. A. Coarse silt to medium sand, well-rounded to angular. Submature to immature terrigenous rock.

B. 1. Quartz overgrowths: trace amount; poorly-developed.

2. Calcite cement: total 37%; pore-filling, and replacement, fine- to medium-crystalline, and microcrystalline, partially recrystallized into subequant grains.

C. 1. Quartz: total 44%; mostly plutonic quartz, straight to slightly undulose; composite, undulose, and stretched grains, trace amount. Partially to completely replaced by calcite cement.

2. Feldspars: trace amount: moderately fresh, fine sand to coarse silt, moderately well-rounded.

3. Chert: less than 2%; cryptocrystalline to finely-crystalline, subangular to subrounded, fine to medium sand.

4. Carbonate rock-fragments: total 6%; medium sand, composed of microcrystalline calcite, well-rounded, and coarsely-crystalline calcite, subrounded to angular.

5. Micas: less than 1%; bent brown biotite, fine-grained, probably of metamorphic source (MRF).

6. Kaolinite: total 3%; partially illitic, occurs as pore-filling matrix.

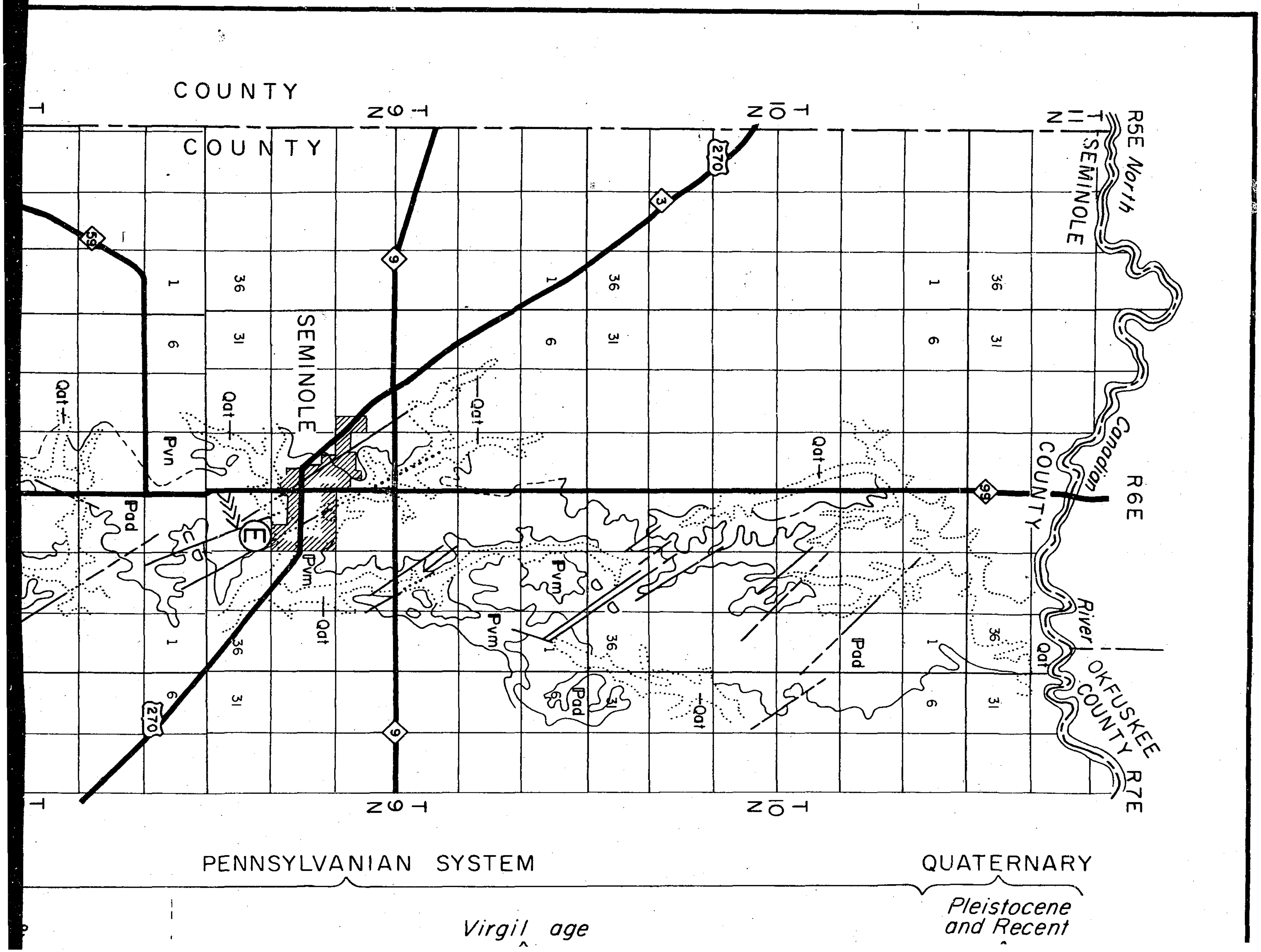
7. Glauconite: less than 1%; fine sand, subrounded.

8. Organic matter: about 1%; recrystallized fossil fragments, and collophane.

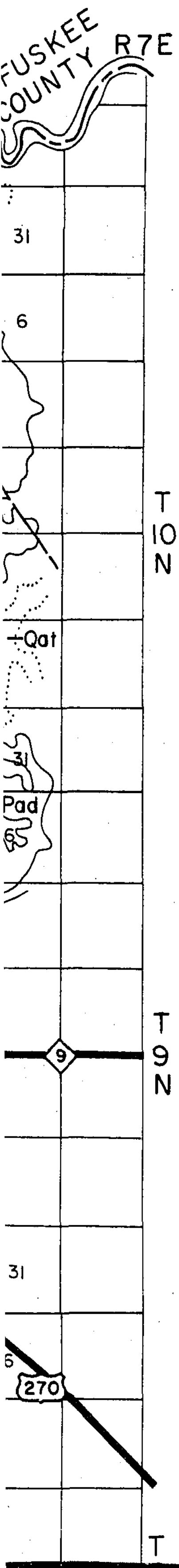
9. Pore spaces: about 4%; unevenly distributed throughout the slide.

D. Remarks: Identification, and close approximation of the percentage of the clay content is difficult, because of its association with calcite cement. Quartz grains replaced by calcite cement, are partially replaced by authigenic chert. This slide shows excellent example of replacement of quartz by calcite.

IV. Very fine to medium, silty sandstone: well-rounded to angular, bimodal, submature to immature, poorly-packed, calcareous, intraclastic, chert, organic matter, glauconite-bearing orthoquartzite.



COUNTY
COUNTY
SEMINOLE
SEMINOLE
COUNTY
OKFUSKEE COUNTY
North Canadian River
R5E
R6E
R7E
T 9 N
T 10 N
T 11 N
Qat
Pvn
Pad
Pvm
E
PENNSYLVANIAN SYSTEM
QUATERNARY
Virgil age
Pleistocene and Recent



EXPLANATION

QUATERNARY — *Pleistocene and Recent*

PENNSYLVANIAN SYSTEM — *Virgil age*

Qat

ALLUVIUM AND TERRACE DEPOSITS
(Sand, silt, clay, and gravel.)

~~~~ unconformity ~~~~

IPvn

VANOSS FORMATION
(Shale and sandstone in the northern part of Seminole County, grading into calcareous arkosic sandstone and conglomerate in the southern part. Thickness, 140-550 feet, thickening southward.)

~~~~ unconformity ~~~~

IPad

ADA FORMATION
(Varigated shale, siltstone, sandstone, and limestone with limestone conglomerate in the southern part of Seminole County and in the central and southern part of Pontotoc County.)

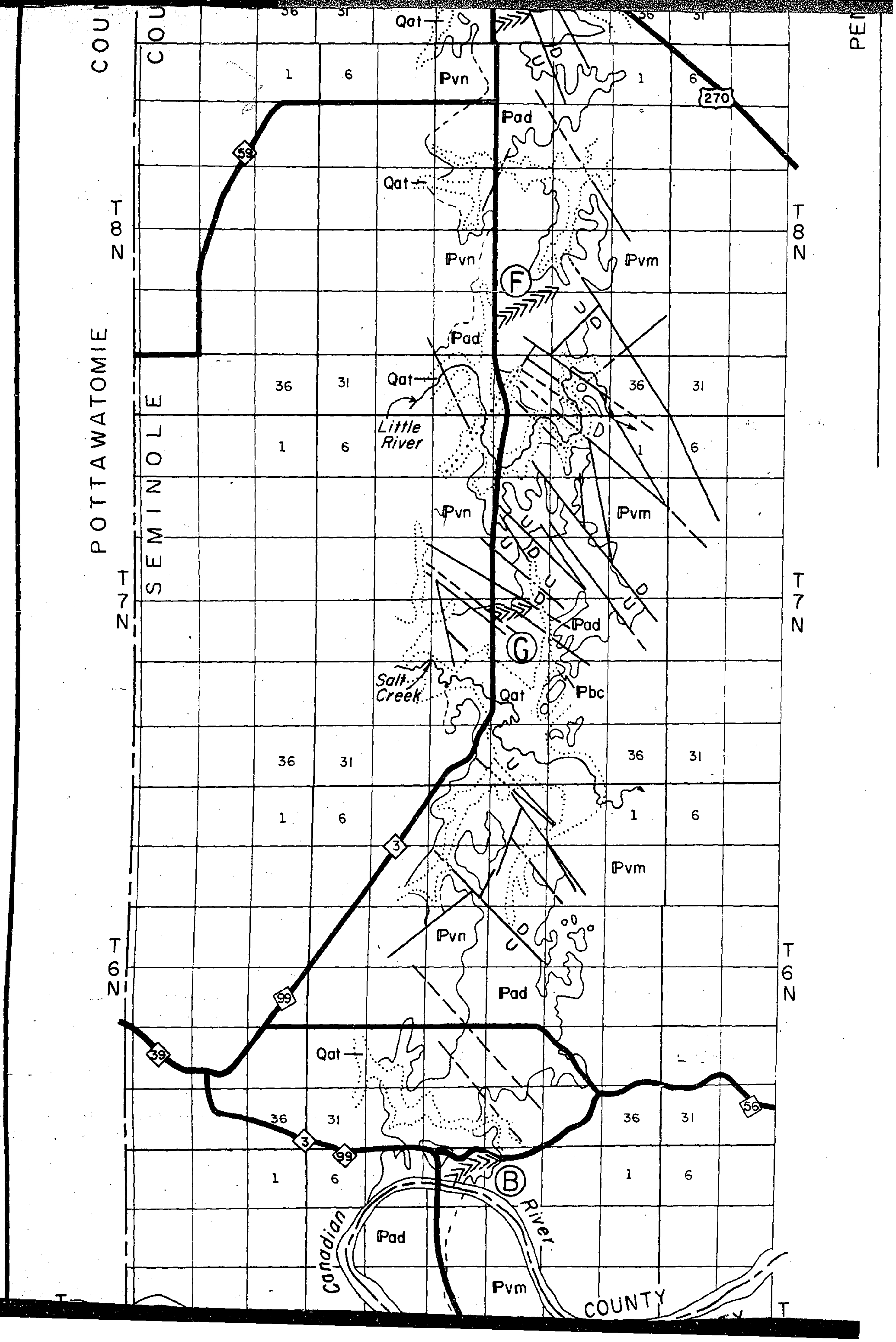
~~~~ unconformity ~~~~

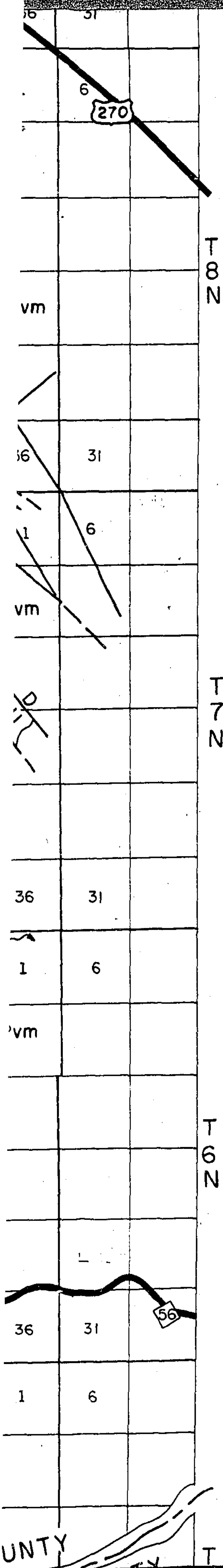
IPvm

VAMOOSA FORMATION
(Shale, sandstone, and chert conglomerates

~~~~ unconformity ~~~~

IPbc


POTTAWATOMIE
COUNTY
SEMINOLE
COUNTY
T 8 N
T 7 N
T 6 N
59
270
3
99
39
56
Qat
Pvn
Pad
Pvm
Pbc
F
G
B
Little River
Salt Creek
Canadian
River
COUNTY
U
D
36
31
1
6



PEN

Missouri age

VAMOOSA FORMATION
(Shale, sandstone, and chert conglomerates

unconformity

Pbc

BELLE CITY FORMATION
(Fossiliferous limestone. Maximum thickness, approximately 30 feet.)

Pfr

FRANCIS FORMATION
(Limestone, shale, sandstone, and conglomerate.)

U
D

FAULT
U, upthrown side, D, downthrown side. Dashed where inferred, dotted where concealed.

FORMATIONAL CONTACT
Dashed where inferred, dotted between Qts and older rocks.

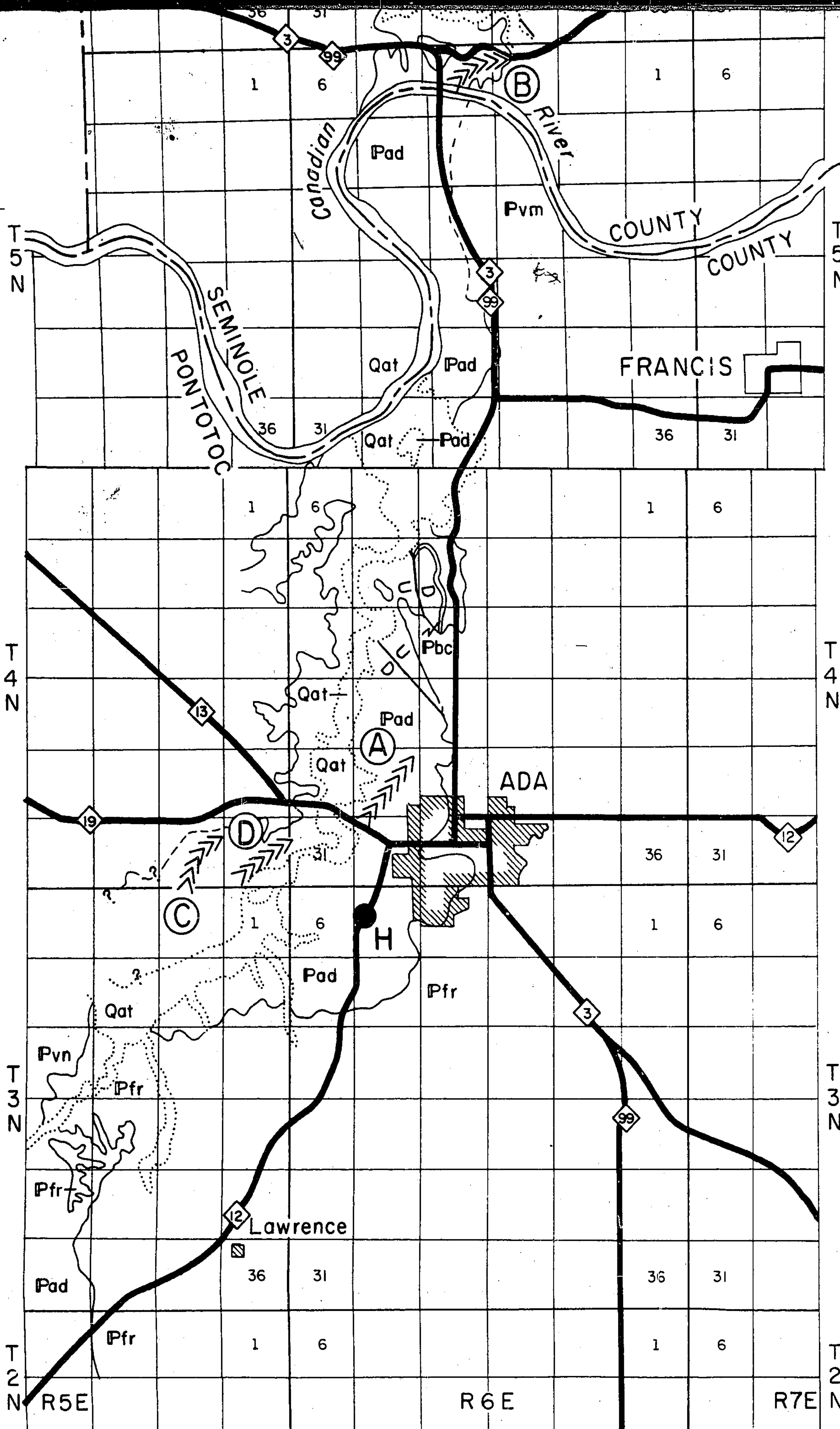
A — Measured section

H — Sample location

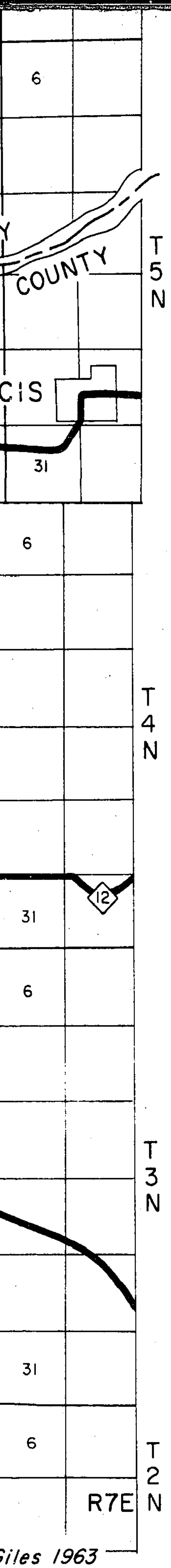
270 — U.S. highway

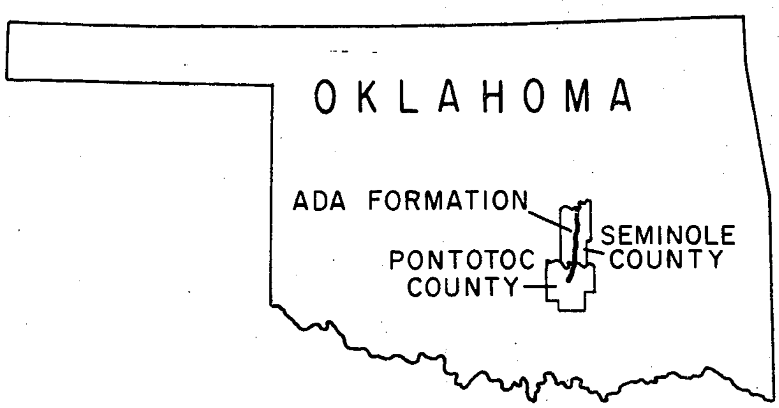
9 — State highway

Paved road

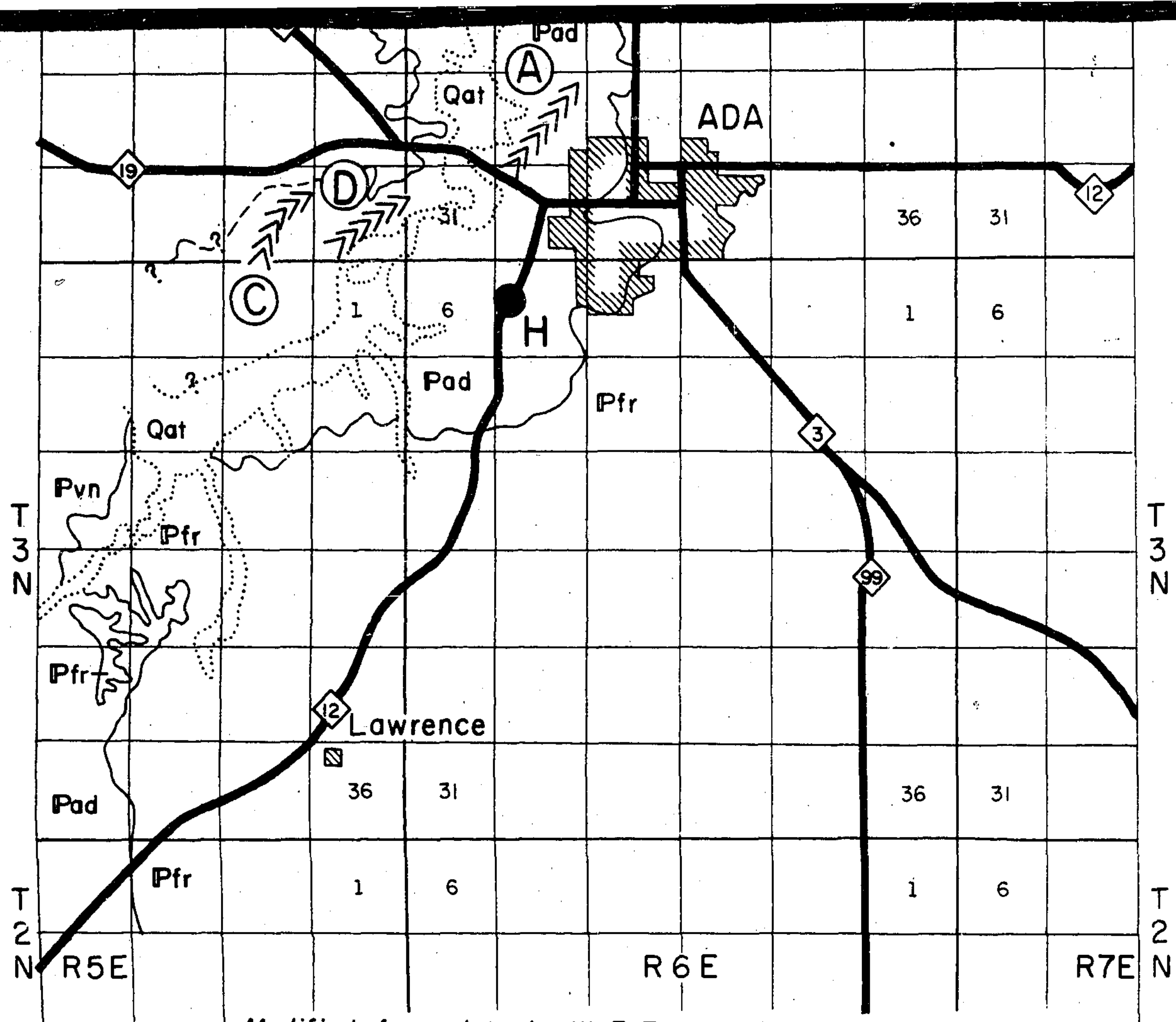


Modified from data by W. F. Tanner 1956 and A. H. Giles 1963





Index map showing location of Ada Formation in Seminole and Pontotoc Counties

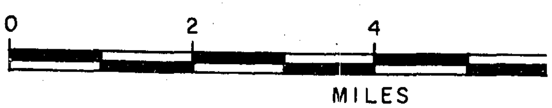


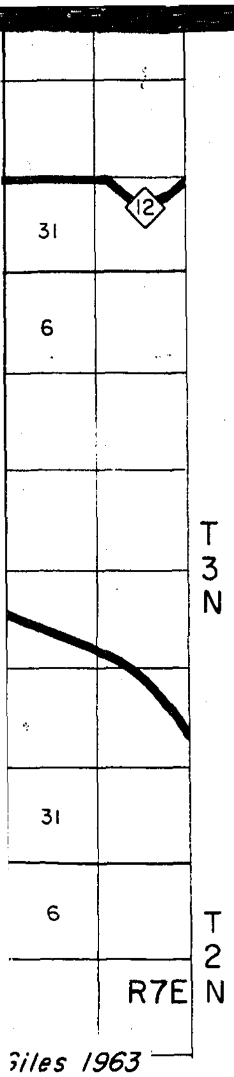
Modified from data by W. F. Tanner 1956 and A. H. Giles 1963

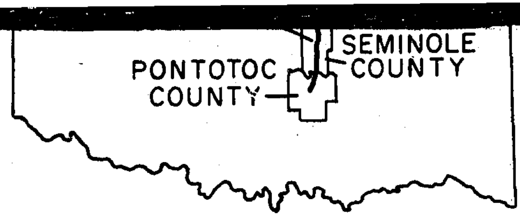
PLATE I

OUTCROP MAP OF ADA
IN
SEMINOLE AND PONTOT
OKLAHOMA

Assad Iranpanah — P







Index map showing location of Ada Formation in Seminole and Pontotoc Counties

PLATE I

) OF ADA FORMATION
IN
) PONTOTOC COUNTIES
)KLAHOMA

panah — Ph.D. — 1966