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CARBONATE PETROLOGY OF THE FORAKER FORMATION

(LOWER PERMIAN), NORTH-CENTRAL OKLAHOMA

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INTRODUCTION

Purpose of Investigation

The primary purpose of this investigation was to make a detailed petrological study of the Foraker Limestone in north central Oklahoma, and to establish an interpretation for the environment of deposition for this formation. In the course of this study the variation in thickness and facies changes of carbonate and terrigenous rocks were examined. Another aspect of this investigation was a study of some trace elements in an effort to establish their relationships to environmental and diagenetic factors. A study of the diagenesis of carbonate rocks in general proved to be significant in interpreting the original depositional environment of the Foraker Formation.

Location

The area under study is located in Osage and Pawnee Counties (Figure 1). The length of outcrop from the Kansas-

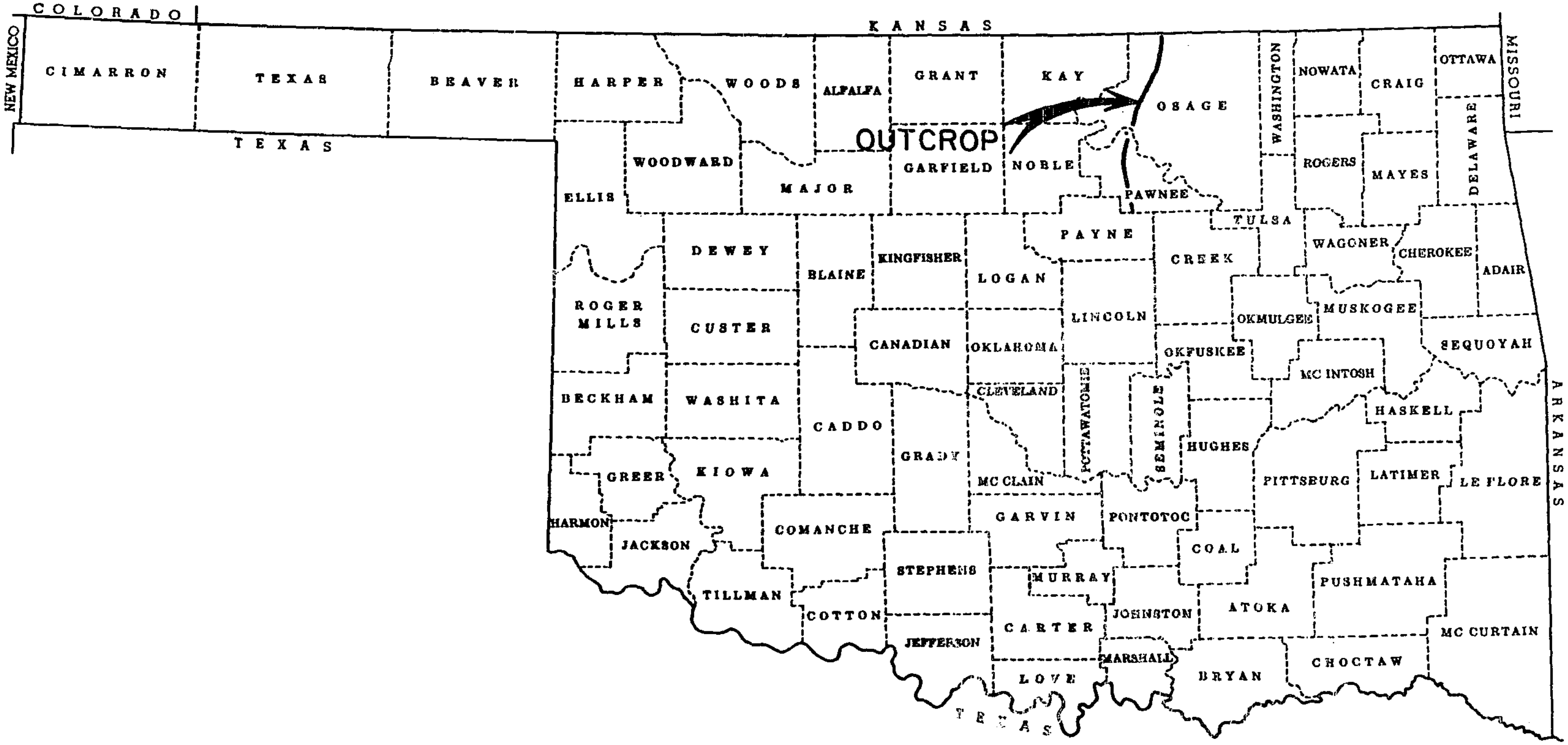


Figure 1. Index map of Oklahoma showing location of Foraker outcrop of studied area

Oklahoma line southward to T. 20 N., R. 5 E., in Pawnee County, is approximately 47 miles.

The Foraker Formation in most parts of the area is covered. Seven stratigraphic sections were measured, but only five are complete; the others are partially covered or eroded. In the study area the most complete exposure of Foraker is in the Phillips Lake Spillway. This section was selected as the type locality by Vosburg (1954, p. 35).

Previous Investigations

The following chronological sequence represents the original history and development of terminology and other studies associated with the Foraker Formation.

1896: M. Z. Kirk proposed the name Americus Limestone for exposures near Americus, Lyon County, Kansas. He described the Americus as two thin beds of limestone separated by approximately four feet of shale.

1916: K. C. Heald named the Foraker Limestone for the Foraker Quadrangle, Osage County, Oklahoma.

1919: W. H. Twenhofel published a paper on "The Chert of the Wreford and Foraker Limestones along the State Line of Kansas and Oklahoma" and proposed several origins for the chert.

1927: G. E. Condra proposed the name Hughes Creek for sections along Hughes Creek, Nemaha County, Nebraska. He also named the Long Creek Limestone for exposures on Long Creek, west of Auburn, Nemaha County, Nebraska.

1953: R. C. Taylor wrote his M. S. thesis on the "Geology of the Foraker Area, Osage County, Oklahoma." His work was primarily concerned with mapping the Wolfcampian and Virgilian Series.

1954: D. L. Vosburg mapped the Foraker Limestone. This was a part of his M. S. thesis entitled "Geology of the Burbank-Shidler Area, Osage County, Oklahoma."

1956: H. C. Fisher, Jr., wrote his M. S. thesis on the "Surface Geology of the Belford Area, Osage County, Oklahoma." He mapped the Virgilian and Wolfcampian Series.

1959: B. Graig published the "Geology of Pawnee County, Oklahoma" (Oklahoma Geological Survey, Bulletin 83). The Foraker Limestone was mapped and some stratigraphic sections through the formation were measured.

1959: M. R. Mudge and R. H. Burton defined upper and lower contacts of the Americus Limestone member, and gave the following description: (p. 53)

"In the original classification the upper bed of limestone, northward from Wabaunsee County, is shaly limestone or in some exposures calcareous shale. Where it is calcareous shale it cannot be distinguished from the shale that lies above and below it. Also, this upper limestone closely resembles, in thickness, color and fossil content, the beds of limestone 2-5 feet above it in the Hughes Creek shale member as used by Moore and others (1951). The shale that underlies this upper limestone closely resembles the shale of the Hughes Creek shale member as used by Moore and others (1951).

Therefore the top of the Americus member is restricted to the lower limestone bed. The base of the Americus limestone member is thus at the base of the limestone that normally contains large masses of stromatolites and previously correlated as the Houchen Creek

Limestone member in Chase County."

It will be shown in the following discussions that the validity of correlation of different members of the Foraker Formation in Oklahoma, especially in Pawnee and Osage Counties by earlier workers, is questionable.

Method of Investigation

The field work for this study was completed in June and October of 1965. Due to partial exposures, only seven sections were measured and samples collected therefrom. Only five involved complete sections. Across the entire area the upper part of this formation, except at a few localities, was deeply weathered, and the middle member (Hughes Creek) was covered in many places.

In the course of this study the following methods were used (the procedures are described in the petrology section):

1. Approximately 100 samples were collected, the sampling interval for limestones being less than one foot. Many shale and sandstone samples were collected also.
2. A total of 60 thin sections were made from limestones and sandstones and were examined with a petrographic

microscope. A detailed description of each is in the appendix.

3. More than 80 X-ray patterns were run from limestone and shale samples for routine identification of the mineral content. In carbonate samples, X-ray diffraction was the most useful tool for positive identification of dolomite in small quantities. Different types of clay minerals were also identified by X-ray diffraction patterns from several shale samples.
4. A staining method was used for identification and determination of the distribution pattern of different carbonate minerals in hand specimen and thin section.
5. Twenty grams each of 47 samples were treated with cold hydrochloric acid (10 percent concentration) for dissolving calcite, and subsequently heated for dissolving dolomite. The weight percentage of insoluble material was then determined and this material was examined with a binocular microscope for identification and description.
6. Sieve analyses were run on several sandstone samples. Hydrochloric acid was used where carbonate cement was present.

7. Trace element analyses were run on 30 carbonate samples, using 1.5 meter Wadsworth Grating Spectrograph Model 78-000, made by the Jarrell-Ash Company. This phase of the study was designed to examine the variation, if any, of trace elements, especially strontium, in regard to the following aspects:

    a. Dolomitization

    b. Recrystallization

Carbonate Classification

The classification of carbonate rocks by Folk was used in this study, and proved to be applicable for all thin sections examined. This classification was chosen because it is purely descriptive and comprehensive, and contains proper parameters which lead toward a genetic understanding. The basic idea of this classification is that carbonate rocks are comparable primarily to sandstones and shales in their method of deposition. Current and wave energies control the texture of the carbonate rocks at the site of deposition. A high energy environment with vigorous current and wave action will produce well-winnowed, highly porous calcarenites in which sparry calcite cement later fills the pore spaces. This rock type is analogous to sandstones and conglomerates which form in high energy environments and have large amounts of pore spaces. Later, chemical cement fills these pore spaces. In a low energy environment, the current and wave action is not sufficient to winnow the carbonate mud; therefore, no appreciable amount of pore space is present. Consequently, there will be no sparry calcite cement and the result is a dense-matrixed calcilutite or "lithographic" limestone. This type of limestone is comparable in its mode of formation to that of shale or clayay sandstone that have little chemically precipitated cement. For a detailed description of this classification one may refer to Folk (1962), but some of the terms which have been used in this investigation are described as follows:

I. Allochems

These constituents are different from ordinary chemical precipitates, because they have undergone some degree of transportation. Four allochems are common in carbonate rocks:

(a) intraclasts, (b) oolites, (c) fossils, and (d) pellets. Oolites and fossils are self explanatory, but intraclasts and pellets are defined as follows:

1. Intraclasts: These are penecontemporaneous, consolidated carbonate sediments that have been

derived from "within" the environment of deposition; some show minor abrasion.

2. Pellets: These may be invertebrate fecal pellets, commonly rounded, spherical, elliptical, or ovoid aggregates of microcrystalline calcite mud without internal structure. The most common pellets vary in size from 40-80 microns. They are commonly brownish under convergent light because of the enrichment of organic matter and, therefore, may be differentiated from intraclasts.

II. Microcrystalline calcite ooze (micrite).

The term "micrite" refers to clay size calcite (1-4 microns) which occurs as (a) matrix of the microcrystalline calcite rocks, for example fusulinids in a micrite matrix; (b) as a combining term in the classification of carbonates, for example biomicrite; and (c) as the name for a rock made up entirely of carbonate mud. Micrite forms by chemical or biochemical precipitation in sea water, and is accumulated in low-energy environments.

III. Sparry calcite cement

The name sparry calcite refers to the calcite crystals commonly precipitated as a simple pore filling cement. The size of individual grains is 10 microns or more and their most distinguishing characteristic is that the grains are clear. Sparry calcite may be distinguished from micrite or carbonate mud on the basis of clarity and size. However, this term does not apply to recrystallized micrite.

Diagenetic Processes and Fabrics

The following discussions are primarily based on the work by Bathurst (1959) and Orme and Brown (1963).

1. Void filling: in this process open spaces were filled by chemical deposition of material from solution and the result is deposition of low Mg calcite in place of high Mg calcite. The crystals grow outward from free surfaces. If the host grain is a single crystal and the cement forms a rim in lattice continuity with it, the cement is termed rim cement. This feature is commonly observable on crinoid plates. The granular cement develops in the pore spaces among the multi-granular framework and other cavities are filled with a drusy mosaic. The small, initial crystals of the mosaic in contact with the cavity wall appear to protrude into the later-formed

grains in a direction normal to the wall. All cement fabrics are characterized by plane intergranular boundaries in the mosaics.

2. Recrystallization or grain growth refers to a process by which intergranular boundaries migrate, causing some grains to grow at the expense of their neighbors. Orme and Brown (1963) describe the two most commonly occurring fabrics in recrystallization; (a) coarse mosaic and (b) syntaxial replacement rim. Both fabrics interrupt the original fine mosaics, cutting across the boundaries of constituent particles. The grain size of the coarse mosaic varies irregularly. This mosaic may be sharply delimited or grade unobtrusively into the original fine mosaic. The syntaxial replacement rim forms commonly around a crinoid and extends into the enclosing fine carbonate with a highly irregular outer boundary. The writer prefers to use syntaxial recrystallized rim instead of the syntaxial replacement rim used by Orme (1963) to avoid any confusion of the concept of replacement in recrystallization processes. Replacement commonly refers to the process in which a new mineral of different composition replaces the space

formerly occupied by another mineral, such as replacement of calcite or aragonite by dolomite or chert.

STRATIGRAPHY

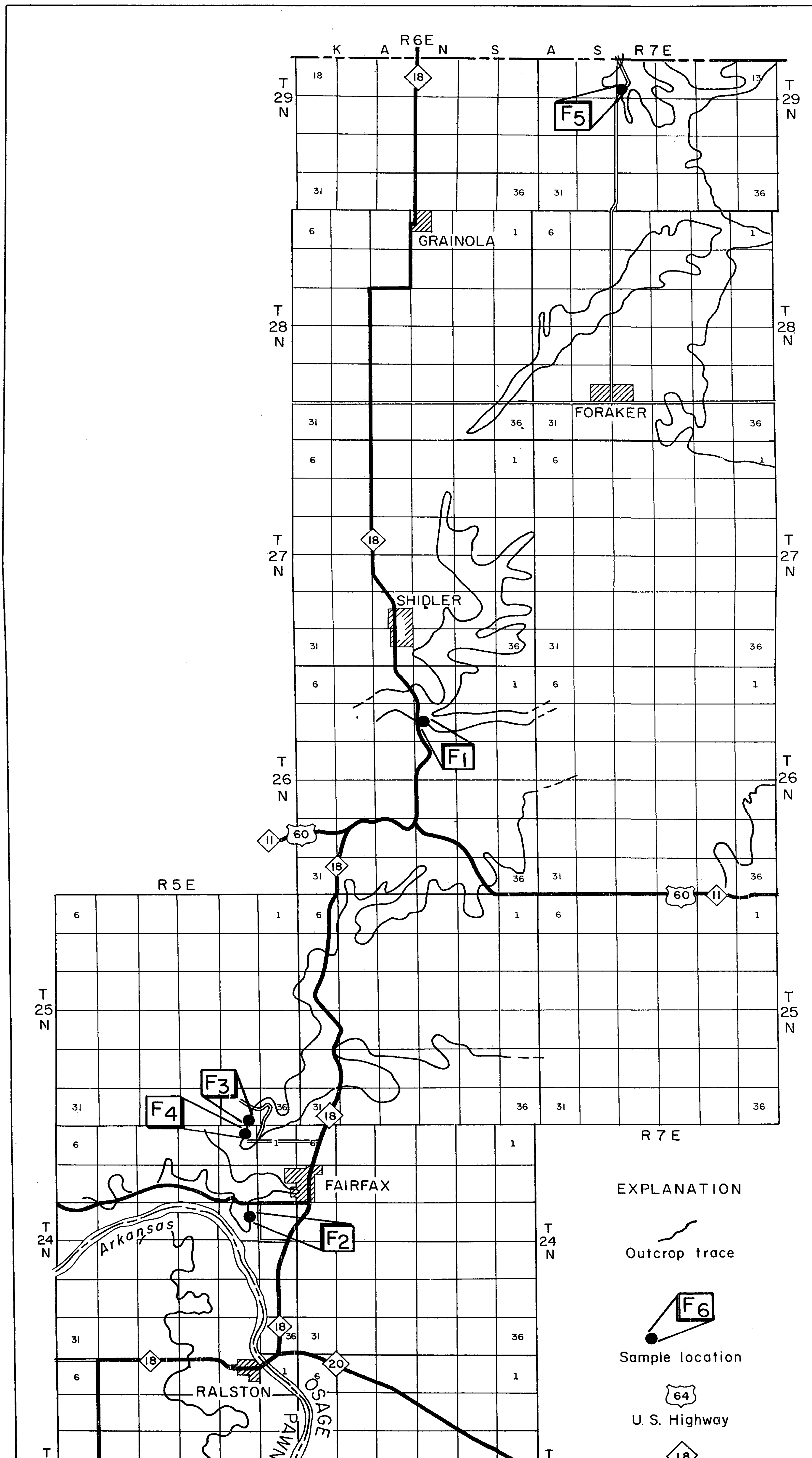
Foraker Formation

Regional Stratigraphic Setting

The Foraker Formation of the Council Grove Group in North-central Oklahoma consists of the strata which conformably overlie the Admire Shale and underlie Johnson Shale (Fig. 2).

The Foraker Formation was named originally by Heald (1916, p. 25) for outcrops near the town of Foraker in Osage County, Oklahoma. The upper and lower boundaries of this formation were redefined later by Condra (1935, p. 8). He also subdivided the formation into three members. These members in ascending order are: Americus Limestone, Hughes Creek Shale, and Long Creek Limestone. The Foraker Formation in North-central Oklahoma is composed mostly of carbonate and shale. To the south, in Osage County, the Hughes Creek member grades into calcareous sandstone, and finally, in Pawnee County, this member changes to thick beds of sandstone.

The Americus Limestone also shows a considerable



R6E
K A N S A S
R7E
T 29 N
F5
GRAINOLA
T 28 N
FORAKER
T 27 N
SHIDLER
F1
T 26 N
R5E
T 25 N
F3
F4
FAIRFAX
F2
Arkansas
T 24 N
RALSTON
OSAGE
R7E
EXPLANATION
Outcrop trace
F6
Sample location
64
U. S. Highway

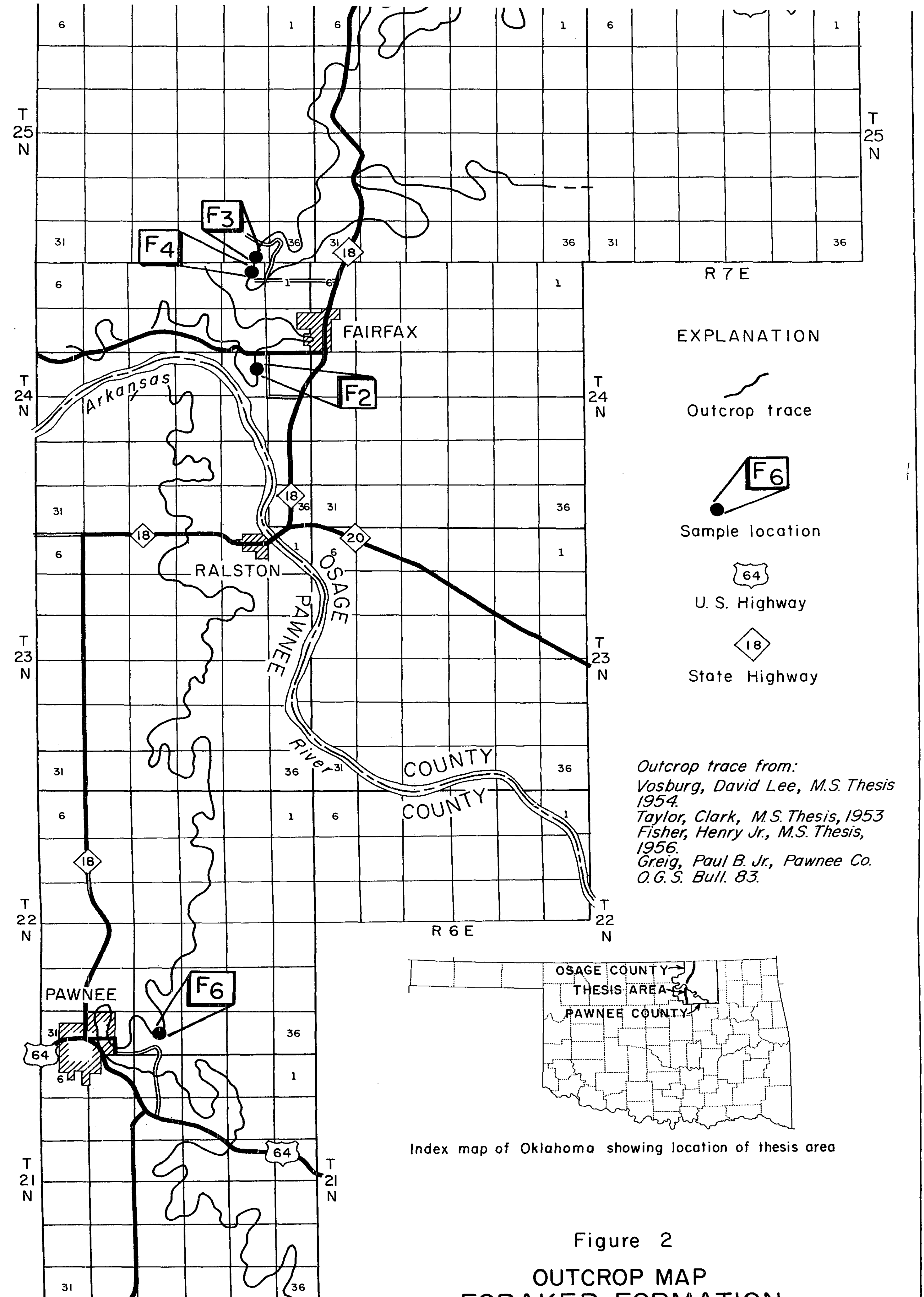


Figure 2

OUTCROP MAP
FORAKER FORMATION
OSAGE AND PAWNEE COUNTIES
OKLAHOMA

Ataolah Mogharabi — Ph. D., 1966

facies change throughout the area. In some measured sections the Americus Limestone consists of two beds of limestones, separated by a bed of shale, whereas locally it is composed of many limestone and thin-bedded shale units.

The members of the Foraker Formation in the area under study show a similarity in their faunal constituents and other field properties. On the basis of these observations in North-central Oklahoma, the following must be taken into consideration:

1. The applicability of tracing the Americus member as defined originally by Kirk (1896, p. 80) from Kansas to Oklahoma.
2. The lower boundary of the Hughes Creek, due to the facies changes of this member, must be redefined.

These aspects are discussed in detail in the following section.

Subdivision of the Foraker Formation

The Foraker Formation in Osage and Pawnee Counties consists of a series of limestones interbedded with shales, fine- to very fine-grained sandstones, and locally chert in the form of thin beds or nodules.

This formation includes the strata above the Admire Shale and below the Johnson Shale. It has been subdivided in ascending order into: Americus Limestone, Hughes Creek Shale, and Long Creek Limestone. The thickness of this formation increases southward. The thickest measured section is 65 feet in Pawnee County (sec. 23, T. 20 N., R. 5 E.). Considering that the Americus member of this section is not exposed, one may assume a greater thickness for the above section. Throughout the area under study most of the Foraker Formation outcrops are covered, or the formation is not exposed. The upper member of this formation, the Long Creek Limestone, is exposed only in a few localities. The Hughes Creek Shale member in most places is also either covered or weathered. The Americus Limestone, however, is more resistant to weathering, and forms an escarpment in many places throughout this area.

The general appearance of the carbonate rocks of the Foraker Formation in the field is a gray to tan rock that contains abundant fusulinids and some additional Foraminifera, algae, brachiopods, pelecypods, and gastropods. The shales are mostly gray to yellowish gray, thin-bedded, and contain (but in less abundance) the same type of fossils which are present in the limestone. The sandstones of the Hughes Creek

Shale are fine to very fine-grained, and increase in thickness southward in the southern part of the area, forming 90 per cent of this member. A prominent feature in the Hughes Creek member is the presence of chert which has replaced limestone in many localities.

On the basis of a detailed petrographic study, the general characteristic of the carbonate rocks in the Americus member is its homogeneity throughout the area. They are commonly biomicrudites that show extensive recrystallization.

The type locality (F_1) for this study, which was selected by Vosburg (1954, p. 35), is in sec. 10, T. 26 N., R. 6 E., Phillips Lake, Osage County, Oklahoma (Plate 1, 2, and 3). All three members of the Foraker are well exposed, and have a total thickness of 48.2 feet. The Americus Limestone consists of 5 thin beds of limestone with a total thickness of 8 feet. The most abundant fossils are fusulinids (Triticites rothi [Skinner, 1931] and Triticites eoextenta [Thompson, 1954]), algae, brachiopods, pelecypods, crinoid stems and plates, and some other Foraminifera. The limestones are gray to light gray and are classified as biomicrudites. The insoluble residue content of this member, with the exception of two samples, shows an increase of insoluble content upward. Dolomitization is minor; in only two samples

PLATE 1

1. Measured section F_1; Americus Limestone member. The outcrop is composed of many thin-bedded limestones which are separated by shale intervals.

2. Measured section F_1; another view of the Americus Limestone member.

PLATE 2

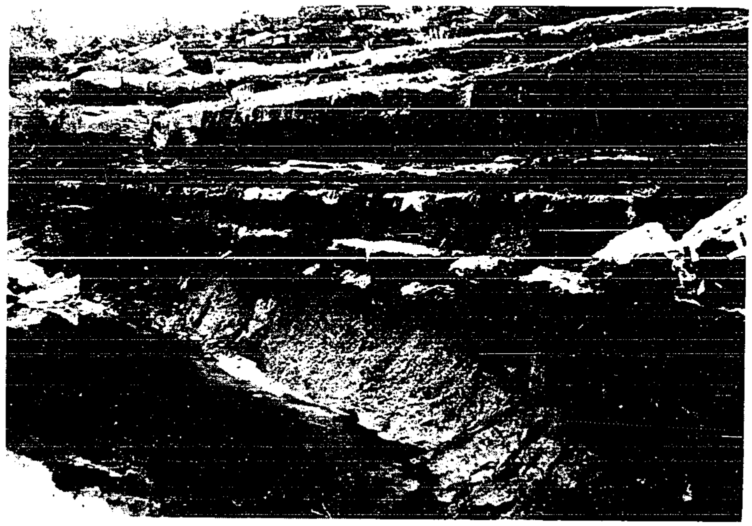
1. Measured section F_1; Hughes Creek member. This is a typical example of the limestone in this member. The solution of limestone has formed many of these holes.

2. Measured section F_1; Hughes Creek member. This is a view of the limestone which is partially replaced by chert. The holes have been formed by the solution of calcium carbonate.

PLATE 3

1. Measured section F_2; Hughes Creek member. The section is composed of sandstone and some shale.

2. Measured section F_1; Hughes Creek member. The ball point pen on top of the picture rests on a bed which shows a transition from limestone to calcareous sandstone.



1

2

PLATE I

1

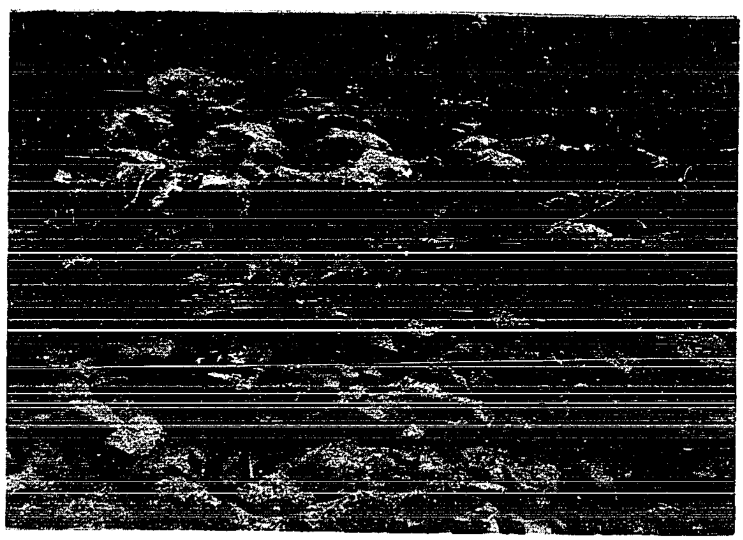


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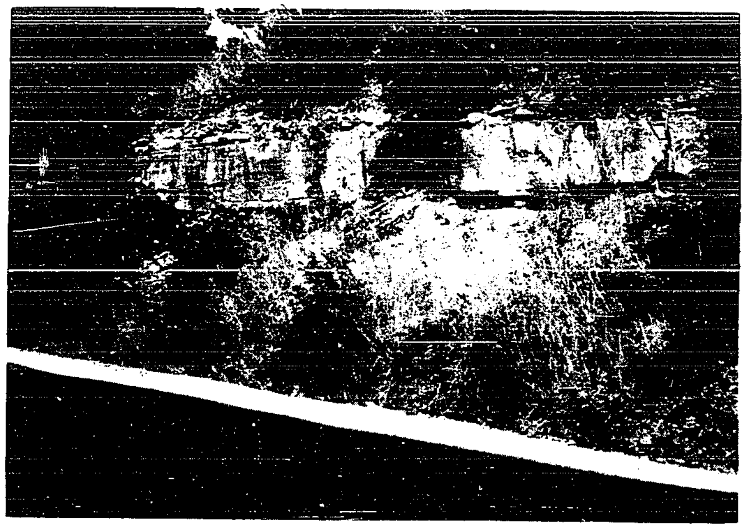
PLATE 2



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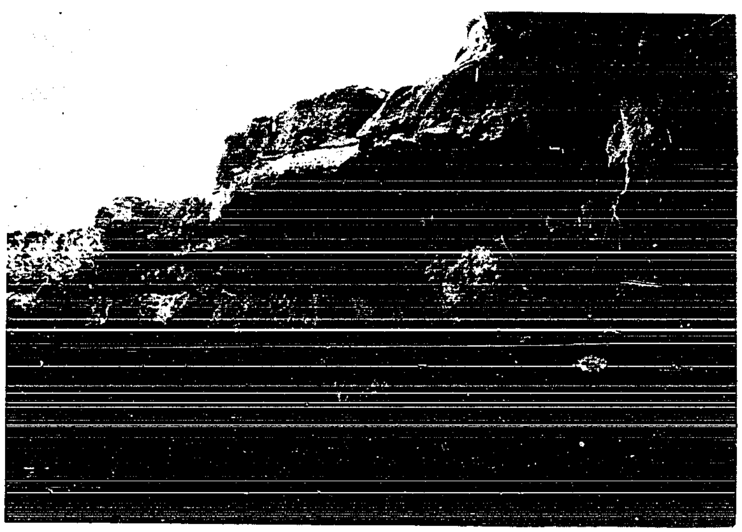

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PLATE 3

(note the appendix) was dolomite detected by X-ray diffraction. Evidence of burrowing is common in some of the thin sections; however, the amount and distribution is not consistent in all limestones of this member. Other diagenetic processes, such as recrystallization and cavity filling, may be observed in all thin sections. Silicification of carbonate was observed only in one sample (F_1-7), and in comparison with silicification in the Hughes Creek member, which will be discussed later, is insignificant. The shales of this member are very thin bedded, gray to tan in color, and contain fusulinids. The clay minerals such as montmorillonite, illite, and minor chlorite were identified by X-ray diffraction. Most of these shales are weathered on the surface throughout the area.

The Hughes Creek Shale in this locality has a thickness of 25.3 feet, and consists of limestone, shale, calcareous orthoquartzite, chert nodules, and extensive silicified limestone. The fossils of this member are fusulinids, algae, bryozoans, crinoids, and some brachiopods. The carbonate facies are mostly biomicrudites and essentially are the same as the Americus Limestone except for a thin bed of limestone with sparry calcite cement. This bed overlies a layer of calcareous sand which is in the lower part of the Hughes

Creek. The presence of calcareous sandstone in this locality is the first appearance as such in Osage County, and as will be seen later, the thickness of sandstone in the Hughes Creek member increases southward. In Pawnee County most of this member is composed of thick beds of sandstone. Another prominent feature in this member is the presence of chert nodules and extensive silicification in limestones. Solution of limestone at the surface and replacement by silica has produced two different and distinctive colors; dark gray chert and light gray to tan limestone. Dissolving of limestone has resulted in many vugs, which, in many cases, are partially filled by silica. Silicification of limestone has obliterated the shell structure of the fossils. This effect is shown in Plate 8, fig. 2, in which a silicified fusulinid shows no structural detail. Dolomitization of limestone is insignificant, and only in two samples was dolomite detected by X-ray diffraction methods (F_1-13, F_1-14). In both samples only 5 to 10 percent of the rock is dolomitized. Recrystallization and cavity filling in this member is similar to that of the Americus Limestone member. Evidence of burrowing has been detected in only one thin section (F_1-15).

The Long Creek Limestone in this area has a thickness of 10.7 feet, and is well exposed. Two beds of limestone which contain fusulinids, encrusing algae (Osagia sp.) crinoids, and some brachiopods are separated by a partially covered bed of gray shale. The carbonate facies are biosparrudite or biosparrite, and thus differ from the Hughes Creek and Americus members.

In the Foraker area near the Oklahoma-Kansas state line, a section was measured F5) in the SW¼ sec. 16, T. 29 N., R. 7 E. The Foraker Formation in this area is exposed in the road cut (Plate 4, fig. 1 and 2), and except for the uppermost part of the section and lowermost unit of the Hughes Creek, outcrops are well exposed. The total thickness of this section is 41.5 feet.

The Americus limestone has a thickness of 12 feet and consists of interbedded limestones and shales. Carbonate rocks are biosparrudites at the base, grading into biomicrudites upward. The distribution of fossils, regardless of the change of facies, shows no marked variation. In the lower part or biosparrudite facies, fossils are mostly fragmental and abraded, whereas in the micrite facies, fossils are far less fragmented and without indications of abrasion. There is evidence of burrowing in the micrite facies, which is undoubtedly responsible for the presence of unabraded fossil fragments. The conspicuous abrasion of fossil fragments in

PLATE 4

1. Measured section F5; Americus Limestone member. The outcrop is composed of limestone and shale.

2. Measured section F5; Hughes Creek member. This outcrop is composed of thin-bedded, interbedded chert and limestone, which is typical in the Hughes Creek member.

the biosparrudite facies may have been caused by wave action and currents.

The Hughes Creek member in this section is 19.5 feet thick, and consists of limestone and shale. Unlike the Hughes Creek at the Phillips Lake section (type locality), no sandstone is present. Silicification in the lower limestone of this member is common, very thin to laminated beds of chert being the most characteristic feature of this section. This locality contains more thin-bedded chert than any other measured section throughout the area. Dolomitization is locally common, but is not a consistent feature.

The Long Creek member is intensely weathered and partly covered so that no significant petrographic study could be made.

The next section measured (F3) was approximately 11 miles southwest of the type section (Phillips Lake) in sec. 35, T. 25 N., R. 5 E., at Fairfax Lake. Here, only the Americus Limestone and Hughes Creek Shale members are exposed. The Long Creek member or upper Foraker is eroded. The thickness of these two members is 47.5 feet, and consists of limestone, shale, and sandstone. The carbonate facies of the Americus Limestone is biomicrite and biomicrudite, and contains abundant fusulinids, large crinoid plates and stems, algae, and pellets. The color of the limestone is gray, and it is extensively weathered. The upper six feet is covered. Recrystallization and cavity filling is observable in all thin sections. Other diagenetic processes such as burrowing, silicification, and dolomitization are significant. Burrowing action by organisms is observable in most thin sections. Many fossils have been burrowed and infilled by micrite. The Hughes Creek consists of a thick unit of sandstone (29 feet) and a unit of limestone which is separated from the sandstone by a two-foot covered interval. The increase of sandstone in the section indicates a consistent increase of terrigenous material southward. The carbonates are burrowed algal crinoidal biomicrudites.

Another section was measured (F4) 2 miles south of Fairfax Lake in sec. 2, T. 24 N., R. 5 E. At this locality only the lower Foraker (Americus Limestone) is exposed, and the Hughes Creek and Long Creek members are weathered. This section has a 10-foot thickness that includes a one-foot basal unit of limestone. The limestone is a dark gray algal encrusting biomicrudite with some ostracods, gastropods, brachiopods, and Foraminifera. The overlying shale has a thickness of three feet, and is gray to yellowish gray, calcareous, and contains some fusulinids. Three limestone beds with a thickness of seven feet, of varying light colors and faunal characteristics comprise the uppermost part of the section. The lower limestone has abundant algae and some fusulinids; the middle limestone contains an abundance of crinoids, brachiopods, and fossil fragments; and the upper limestone is distinctive because 20 percent of the rock is composed of pink fusulinids. The carbonate facies, as elsewhere in Osage County, have a micrite matrix. Dolomitization is not persistent; it was found only in the middle unit of the upper limestone. Some micrites and fusulinids have been replaced. Silicification was found also in only one sample (the lower limestone) and not in significant quantity. The amount of silicification and also the number of nodules and thin beds of chert decrease gradually from the Kansas-Oklahoma state line southward. Burrowing is significant, and is observable in many thin sections. Recrystallization is common in every sample, and an appreciable percentage of the micrite has been changed to microspar and coarse mosaic calcite.

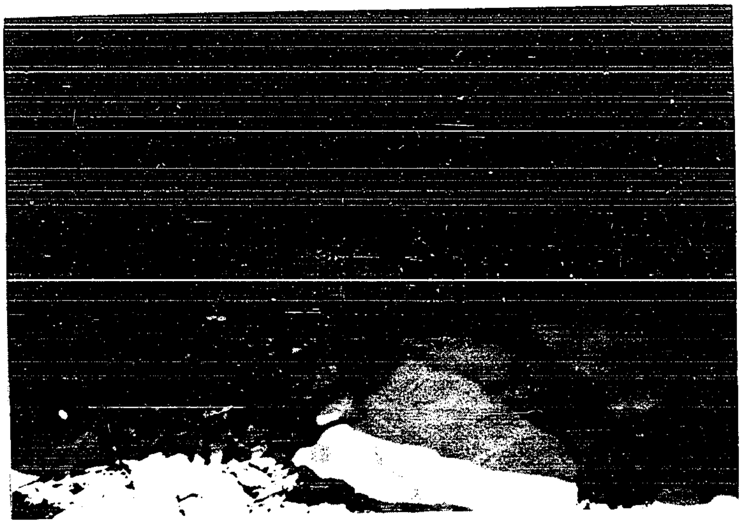
Section measured (F_2) is 2 miles south of F_4, in sec. 14, T. 24 N., R. 5 E. At this locality the Americus and Long Creek members are partly covered and partly weathered; hence for the purpose of this study, all thin sections were made from Hughes Creek member, which was well exposed and less weathered. The total thickness of the formation is approximately 55 feet. The Hughes Creek member has a thickness of 24.8 feet and consists of 14.3 feet of sandstone, 3 feet of shale, and 2.5 feet of limestone. The sandstones are yellowish brown, soft, and limonite stained, with an abundance of thin-bedded shale. The sieve analysis data of this sandstone are given in the appendix under the thin section description for (F_2-1). The thickness of sandstone is significantly high. On the contrary the thickness of limestone of this member has decreased considerably. The sandstone is very fine-grained, angular to sub-angular, and without carbonate cement. The carbonates are biomicrudites and contain an abundance of fusulinids, bryozoans, crinoids, and Foraminifera. Extensive recrystallization of micrite to microspar and coarse mosaic calcite may be observed in thin section. Dolomite has been detected in one sample in abundance by X-ray diffraction. In thin section the grains are euhedral, which is evidence of secondary dolomitization. Insoluble residue content of the limestones decreases upward.

The section in Pawnee County (F_6) was measured along the west side of Black Bear Creek, north of the bridge in the SW¼ sec. 33, T. 22 N., R. 5 E. At this locality the Hughes Creek and Long Creek members have been eroded and the Americus

PLATE 5

1. Measured section F_2; Hughes Creek member. A close look at the sandstone facies which is the dominant rock type. The sandstone beds commonly are homogeneous in the grain size and field properties.

2. Measured section F_2; Hughes Creek member. Another close look at the sandstone beds and thin-bedded shale.



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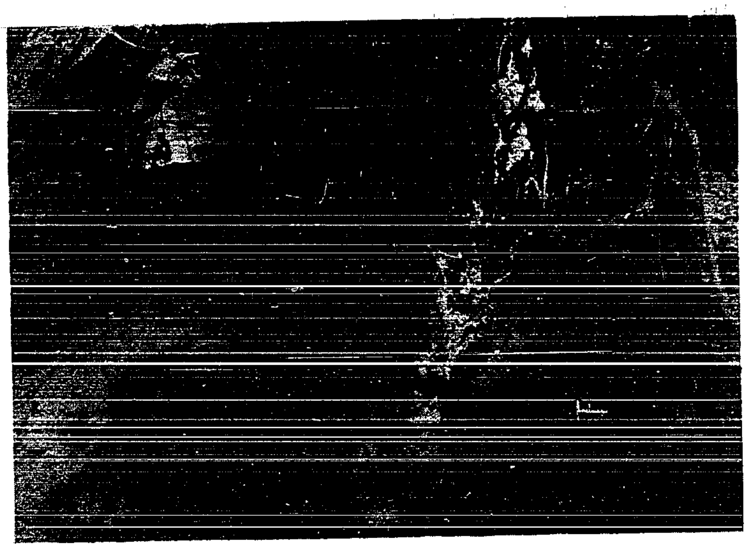


2

PLATE 5

Limestone is the only member which is well exposed and fresh on the surface. A 12-foot thickness was measured for this member, which consists of three limestone beds and a shale. The lower limestone is light gray, and no fossils are visible except for some traces of algae. The petrographic microscope reveals that 40 percent of the rock is composed of pellets, and evidence of burrowing is common. The next overlying limestone is gray, thin-bedded, and contains bryozoans, crinoids, and abundance of quartz grains. The carbonates are pelmicrites and biomicrudites and contain some sparry calcite cement. Recrystallization is significant, and cavity filling with drusy mosaic calcite may be observed in all thin sections. Burrowing is extensive and some of the brachiopods and gastropods have been partially destroyed by this process. A bed of shale (5 feet) separates these limestones from the upper limestone. The upper limestone is four feet thick, and is significantly different in fossil content and carbonate facies. All of the thin sections studied from this bed indicate a biosparrudite facies, and all contain abundant algae and significant amounts of crinoids, brachiopods, fusulinids, and bryozoans. The most significant features of this unit are the abundance of brachiopods and progressive recrystallization which is illustrated in Plate 6, fig. 1, 2, 3, and 4.

Figure 3

STRATIGRAPHIC POSITION OF THE FORAKER FORMATION IN NORTH-CENTRAL OKLAHOMA

SYSTEM	SERIES	GROUP	FORMATION	MEMBER
PERMIAN	GEARYAN*	COUNCIL GROVE GROUP	JOHNSON SHALE	
			FORAKER LIMESTONE	LONG CREEK LIMESTONE HUGHES CREEK SHALE AMERICUS LIMESTONE
		ADMIRE	ADMIRE SHALE	

* Gearyan is the new nomenclature which has replaced the older term Wolfcampian. (O'connor, 1963)

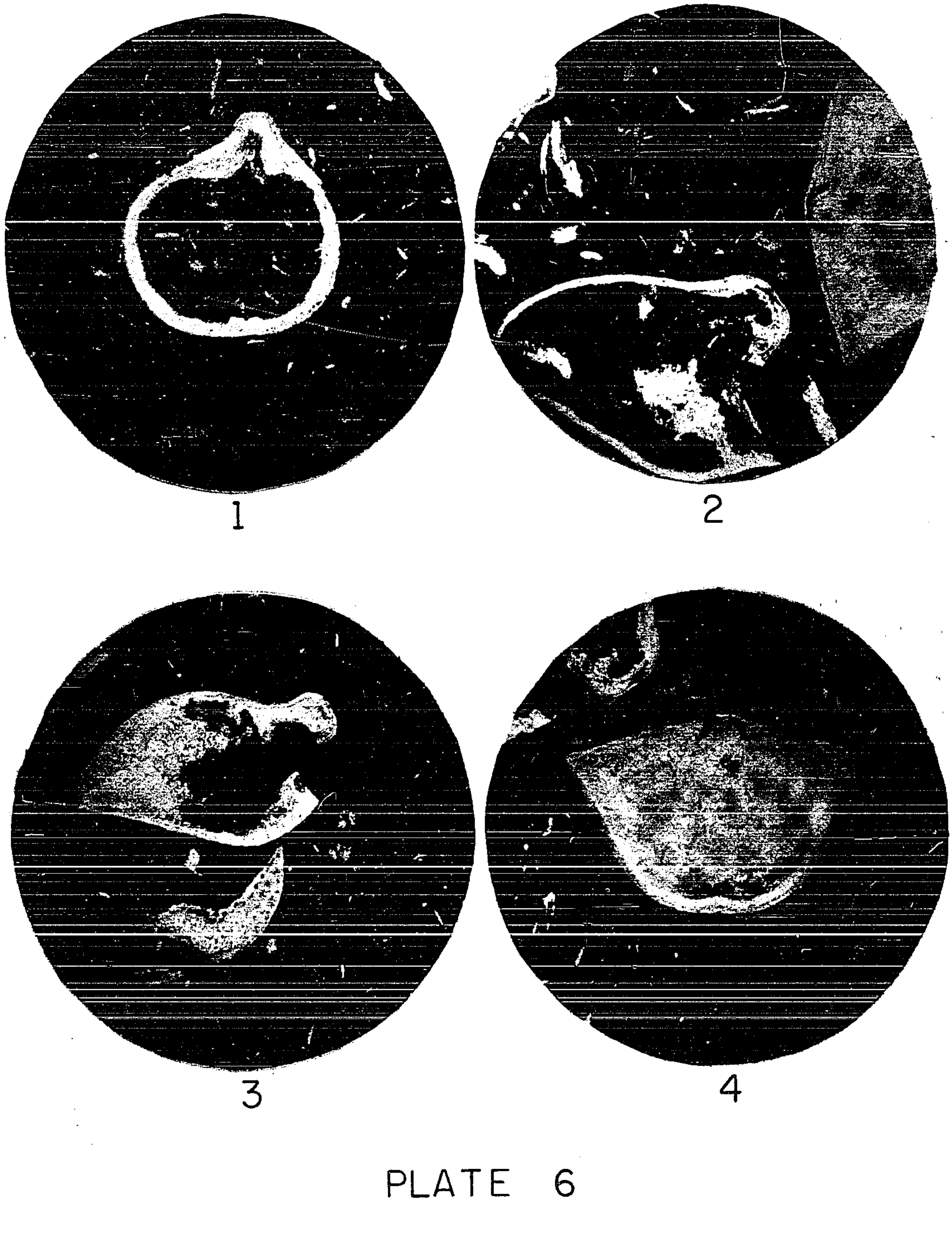
PLATE 6

1. Partially-recrystallized burrowed biomicrudite. A brachiopod shell is filled with micrite, plain light X10. Americus Limestone (F_6-4).

2. Same thin section. Note some recrystallization of micrite to drusy mosaic calcite in the brachiopod. Plain light X10.

3. Same thin section. More recrystallization of micrite to coarse mosaic calcite in the brachiopod. Note the effect of burrowing in the brachiopod shell. Plain light X10.

4. Same thin section. A brachiopod is completely filled with coarse mosaic calcite. The micrite relict is evidence of recrystallization. These photomicrographs show a sequence of recrystallization in the brachiopods. Plain light X10.



1 2 3 4

PLATE 6

Here, progressive recrystallization may be observed in different brachiopods (in different stages of development). No dolomite is observed either with the petrographic microscope or detected by X-ray diffraction. It is also significant to mention the absence of silicification.

The section measured in Pawnee County (F7), 10 miles south of Section F6, is located in sec. 23, T. 20 N., R. 5 E. The rocks are exposed along the section line along a small creek draining flattened topography. The Americus Limestone member is completely covered, but the Hughes Creek and Long Creek members are well exposed. In this section, the most significant feature is the absence of limestone in the Hughes Creek member. A thick bed of sandstone and some shale is present in place of the limestone. The unit has a thickness of 41 feet. On the basis of sieve analysis data the sandstone is very fine-grained, moderately sorted, and has a near-symmetrical skewness.

The Long Creek member has a thickness of 17.5 feet with a 10-foot covered interval, probably shale. The lower limestone is gray, intensely weathered and abundantly fossiliferous. The overlying limestone, which is separated by a shale interval from the lower limestone, is purplish gray, and contains abundant crinoids, some brachiopods, and bryozoans. These two limestone beds are biosparrudites and partially dolomitized. Recrystallization is extensive and has obliterated many fossils. The quartz content of these carbonates is three to four percent. Insoluble residue content decreases upward. Overlying this limestone is a 10-foot covered interval, and then on top, two feet of dolomitic limestone forms the uppermost part of the Long Creek. The degree of dolomitization in this limestone is so extensive that only a few relict crinoids have been preserved (Plate 7, fig. 2).

The subdivision of the Foraker Limestone into three members, and the correlation of these members in Oklahoma, due to significant facies changes, should be taken into consideration in the study of this formation. The original Americus member was restricted to two limestones and a shale interval in Lyon County, Kansas by Kirk (1896, p. 80). In most of the measured sections in Pawnee and Osage Counties the thickness of limestone in this member decreases and grades into shale of variable thickness southward. For example, in the type locality (Phillips Lake, measured section F_1), five thin beds of limestone interbedded with shale are defined as the Americus member. In measured section F_5, which is near the Oklahoma-Kansas state line, the Americus consists of three

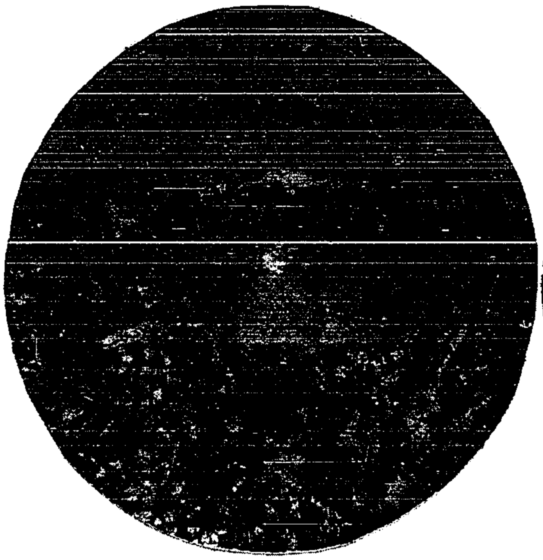
PLATE 7

1. Dolomitized crinoidal biosparrudite. The rock is partially dolomitized. Note the replacement of the center part of the crinoid by dolomite. Plain light X25, Long Creek member (F_7-5).

2. Dolomitized biosparrudite. This sample is composed of more than 80% dolomite, some calcite and a few relict of crinoid plates. Note the presence of euhedral dolomite. The irregular boundary of the crinoid fragment has been formed by dolomitization. Plain light X75. Long Creek member (F_7-6).

3. Encrusting-algae crinoidal biosparrudite. This is a typical example of *Osagia* which encrusting fossils and grains in the Foraker Formation. In central part of the picture a large crinoid fragment has been coated by the *Osagia*. Plain light X25. Long Creek member (F_1-24).

4. Encrusting-algae biosparrudite. This is another example of encrusting algae. Note the presence of some microfractures which have been filled by sparry calcite. Plain light X25. Long Creek member (F_1-23).



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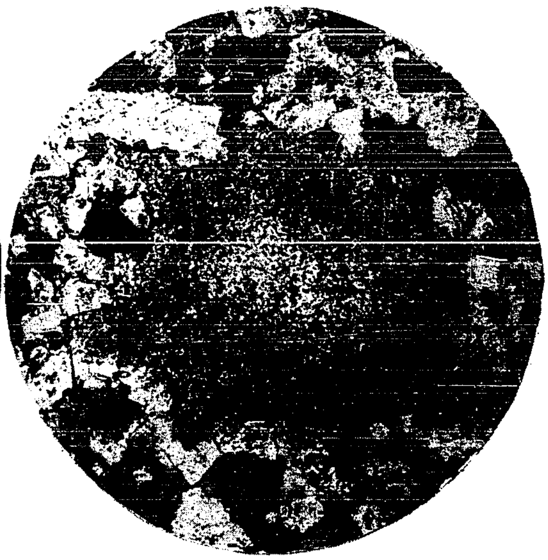

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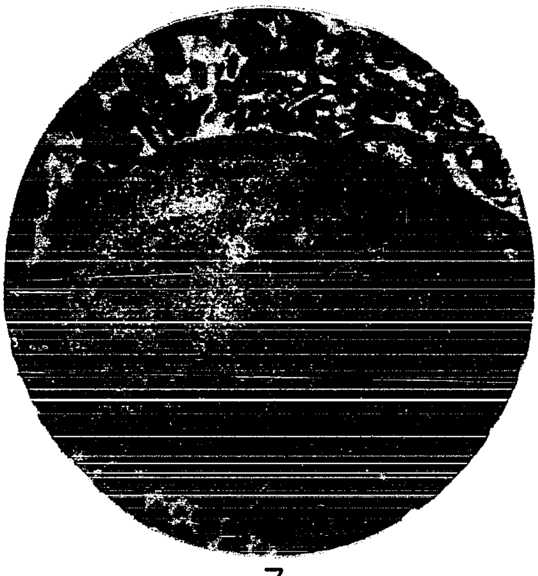

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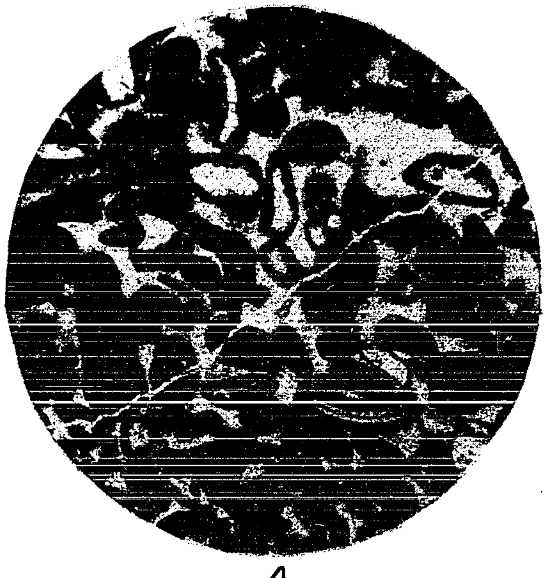

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PLATE 7

limestone and two shale units. Farther south in measured section F_3, the Americus Limestone consists of two thin beds of limestone at the base and a third thick bed at the top. The assigning of a definite number of limestones to this member makes the resulting correlation invalid. The faunal content and the color of these limestones are of little assistance in correlation because the limestones closely resemble each other, as well as overlying limestones in the Hughes Creek. The base of the Americus member as described by Mudge and Burton (1959, p. 53-54) is defined as the limestone that contains an abundance of stromatolite algae that is traceable in all measured sections. The Hughes Creek in Pawnee and Osage Counties shows a significant facies change from silicified limestone or cherty limestone in northern Oklahoma to calcareous sandstone and finally to sandstone farther south. Thus, it is suggested herein that the base of the Hughes Creek in Osage and Pawnee Counties be defined by the shale which is directly beneath the silicified or cherty limestone in northern Osage County, where no sandstone is present. It is defined by the first shale which is directly beneath either calcareous sandstone or sandstone in southern Osage and Pawnee Counties.

The base of the Long Creek is tan to gray-orange and is commonly soft and massive. Dolomitization is locally present, and in many measured sections extensive weathering has occurred. This alteration is so extensive that in many places the Long Creek has been completely removed. In those places where the Long Creek is present, it may be distinguished from the Hughes Creek member by the texture and fossil content.

PETROLOGY OF THE FORAKER LIMESTONE

General Statement

The Foraker Limestone, unlike the implication of its name, is a sequence of rocks consisting of limestone, sandstone, shale, and chert. Although all of these facies have been studied in this work, more emphasis has been placed on the petrology of its carbonate rocks. For this reason, many techniques were used to identify the mineral constituents, the percentage of terrigenous content, and the amounts of trace elements in the carbonate rocks.

Thin sections were made from 60 samples (including both carbonates and sandstones) representing all the measured sections. A detailed study of the thin sections was made with a petrographic microscope. Most of the carbonate samples contain as much as 90 percent calcium carbonate, but a few contain as low as 75 percent. The noncarbonate constituents are chert, finely disseminated silica, fine- to very fine-grained quartz, minor glauconite, limonite, and phosphate particles. Dolomite was detected in many samples by X-ray diffraction, staining methods, and petrographic microscope techniques. The presence of dolomite, mostly in small quantities, was determined in at least one or two samples in each measured section. The origin of the dolomite and the distribution pattern of this mineral is discussed under "diagenesis of carbonate."

The presence of chert in the form of thin layers or nodules and also silicification of many fossils and grains is specially significant in the Hughes Creek member, and is duscussed in more detail regarding its occurrence, origin, and the possibility of using it as a marker bed in northern Oklahoma.

Recrystallization, cementation, and cavity filling in the Foraker Limestone is significantly abundant, and in many cases the structure of the fossils has been obliterated to an extent that only a ghost structure may be recognized. Photomicrographs have been used to demonstrate progressive stages of recrystallization in some brachiopods. The fabrics of the above diagenetic processes also have been shown in many photomicrographs.

Although the primary purpose of this study was the carbonate petrology, because of the abundance and significance of sandstone, a detailed petrographic and statistical analysis of this latter material proved to be important for a fuller understanding of depositional environment and paleogeography of the Foraker Formation.

Carbonate Petrology

The basic step in petrology of carbonate rocks is to select a classification which facilitates communication of the descriptive data, and provides benefits derived from the organization of those data. The writer selected a descriptive classification by which the origin of the rock could be interpreted. The carbonate rock classification by Folk (1962, p. 62) is used in this study and proved to be applicable for all samples.

The petrographic study of the Foraker Limestone reveals some variation vertically and to lesser extent horizontally in individual beds. However, the components of an individual limestone in some places may vary within a few inches. The characteristics of the constituents commonly show a general consistency throughout the Foraker Formation.

The carbonate components in the Americus member are consistent, and are all biomicrite and biomicrudite, and are herein referred to as the "biomicrudite facies." The grains of the micrite do not exceed 10 microns, except where they have been recrystallized. Allochemical constituents are algae, fusulinids, bryozoans, gastropods, brachiopods, ostracods, pellets, and some Foraminifera. In the Hughes Creek member, the limestones are biomicrudite and biosparrudite, and no consistency in facies distribution can be demonstrated for this member because the variation of different carbonate types is irregular in all measured sections. Sparry calcite cement varies in size from 10 to 50 microns; however, in most of these sparry calcite samples the remnant of micrite is preserved, thus indicating that the energy of the environment was insufficient to winnow out all the carbonate mud. The presence of sparry calcite limestone generally occurs in the sections in which either the percentage of quartz is high or the section contains some sandstone beds. In the Hughes Creek member, in addition to sandstone beds, chert beds or nodules and extensive silicification are significant. Limestones of the Long Creek show extensive weathering, and have no definite facies consistency. The carbonate facies are generally biomicrudite, biosparrudite, and in some places, pelmicrite. Dolomitization in the Long Creek member is more pronounced than in the American and Hughes Creek members.

Distribution of Allochems

The most important allochems in this formation are fossils; in many thin sections they form more than 30 percent of the rock. Pellets also are present in a few samples.

Fusulinids

Fusulinids are the most abundant faunal element in this formation. The fusulinids have a random distribution in different members of the Foraker Formation and show no consistency even in a specific bed throughout the area. The highest percentage of fusulinids occurs in the Hughes Creek member (thin section F2-4). In this member fusulinids comprise 40 percent of the rock. The size variation among these faunal elements may be observed in different beds, but without an established consistency. In the Phillips Lake area (measured section F_1) the Hughes Creek member contains much larger fusulinids than in the Americus or Long Creek members. At this locality fusulinids are exceptionally abundant and have been observed in most thin sections. A significant feature of the fusulinids throughout the area is their susceptibility to post-depositional changes, especially silicification and cavity filling. Partially silicified fusulinids are present in some thin sections (Plate 8, fig. 4), but in

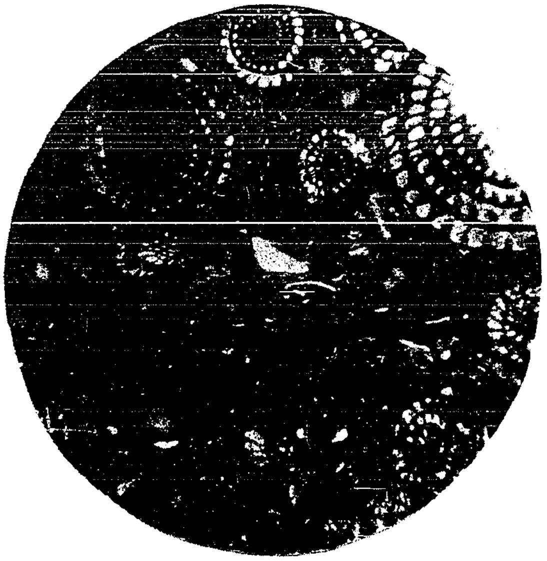
PLATE 8

1. Fusulinid biomicrudite. A preferred orientation of fusulinids exists in this picture. Plain light X10, Americus Limestone (F_2-5).

2. Silicified fusulinid biomicrudite. Silicification has completely obliterated the structure of the fusulinid. Plain light X25. Hughes Creek (F_1-22).

3. Fusulinid biomicrudite. Note the random orientation of fusulinids in micrite matrix. Plain light X10, Americus Limestone (F_2-4).

4. Partially-silicified fusulinid biomicrudite. A partial silicification has affected the fusulinid. The fossil fragments are formed by the burrowing action of the organisms. Plain light X25, Americus Limestone (F_1-7).



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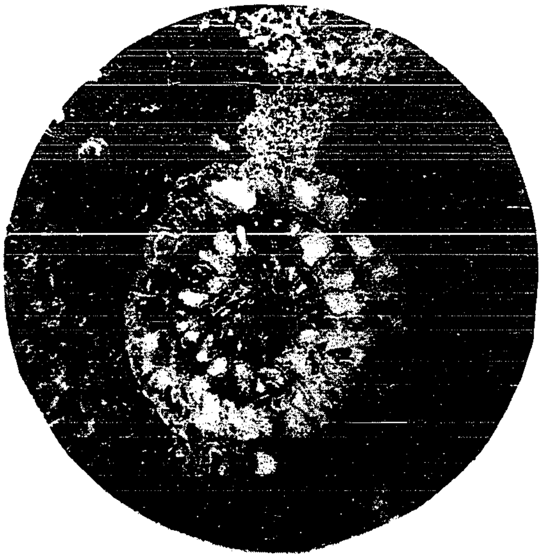

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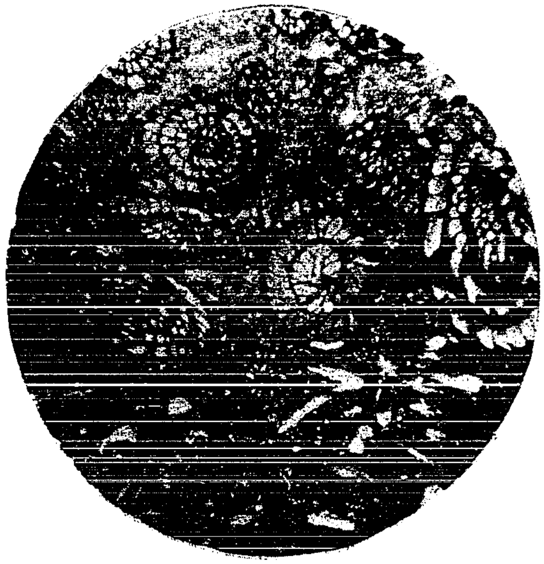

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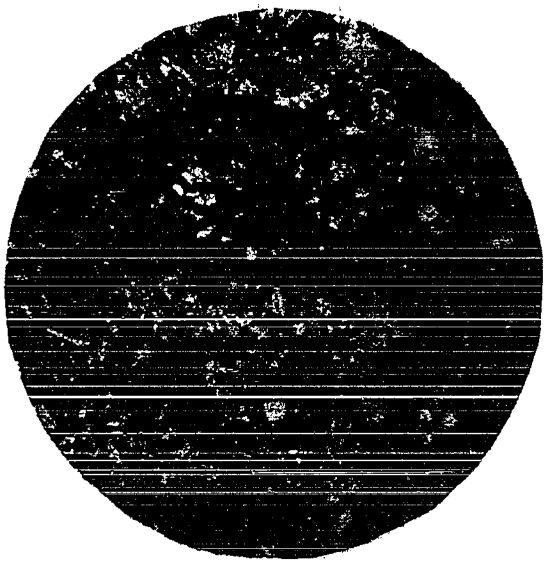

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PLATE 8

the northern part of Osage County abundant silicification in the Hughes Creek member has obliterated the structure of the fusulinids. An example of this process in the Phillips Lake area is shown in Plate 8, fig. 2.

Cavity filling in fusulinids is common, and in many cases the septal pores are filled with drusy mosaic calcite. The process of cavity filling in fusulinids according to Bathurst (1958, p. 14) forms by deposition of calcium carbonate from solution on free surfaces and grows outward. The distinguishing feature of this process is the elongated crystals of calcite which are normal to the wall of the openings.

The fusulinids in the Foraker Formation are associated with the micrite facies, and rarely have they been extensively abraded, except in rare cases, in which the fusulinids are fragmented due to the burrowing action of organisms. Commonly, fusulinids are randomly oriented (Plate 8, fig. 3), except in one thin section which shows a preferred orientation (Plate 8, fig. 1). The significance of preferred orientation locally in fusulinids is not well known and may be of no importance. Were preferred orientation observable on a larger scale, it could possibly be related to current direction.

Many species of fusulinids have been described from the members of the Foraker Formation in Kansas and Oklahoma but the most abundant species in samples of this research (R. W. Harris, personal communication, 1966) are Triticites rothi Skinner, n. sp. (1931, p. 18) and Triticites eoextenta Thompson (1954) (Plate 9, fig. 2).

The presence of unabraded fusulinids in the biomicrudite facies is reliable indication of a low energy environment.

Bryozoa

Bryozoa are present in most of the thin sections and comprising as much as 10 percent of some samples (F_1-18, F_1-9). The most abundant bryozoa are fenestrate forms which are normally fragmented even when they are associated with the biomicrite facies. The largest colony of this fenestrate group was found in thin section F_1-9, which shows no signs of abrasion. It has a length of 15 mm and width of 2 mm (Plate 9, fig. 4). Encrusting bryozoa are not common. However, in thin section F_6-1 there is shown a fragment of a bryozoan encrusting a large grain of fibrous calcite (Plate 9, fig. 3). In many thin sections the bryozoan colonies are single rows of cells probably of the genus Stromatopora. These bryozoans

PLATE 9

1. Cavity-filling fusulinid biomicrudite. A longitudinal section of a *Triticites rothi*. Note the infilling of the septal pores with drusy mosaic calcite. Plain light X50. Americus Limestone (F_4-4).

2. Fusulinid algal foraminiferal sparry calcite-bearing biomicrudite. Another view of a *Triticites rothi*. Plain light X50. Hughes Creek (F_2-5).

3. Fusulinid bryozoan biomicrudite. At the top, a bryozoan fragment is coating the fibrous calcite. Note the fibrous calcite which is replaced by silica in many places. At the bottom, fusulinids are observed. Plain light X25. Americus Limestone (F_6-1).

4. Bryozoan biomicrudite. A portion of a large fenestrate form bryozoan (15x2 mm) shows the structural detail. Although the matrix is micrite, many autopors of the bryozoan are filled with larger calcite crystals. Plain light X50. Americus Limestone (F_1-9).

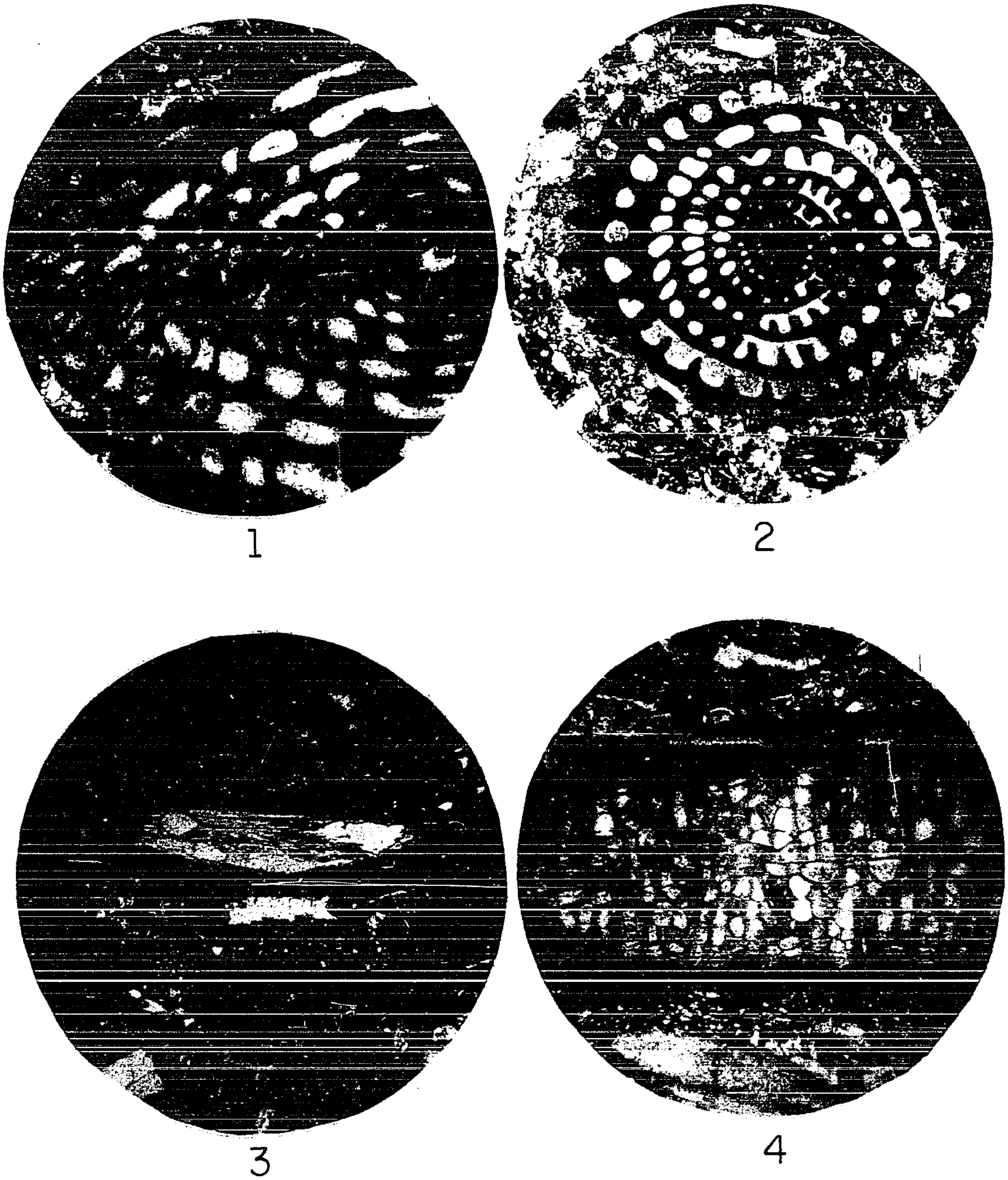

PLATE 9

are locally abundant. In thin section F_1-18 this genus forms 10 percent of the rock. In most bryozoa the autopores are susceptible to cavity filling processes similar to the cavity filling in fusulinid septal pores. Most of the bryozoa autopores have been filled with drusy mosaic calcite, and in a few samples, with hematite and limonite. The bryozoa found in this study are commonly associated with the biomicrudite facies; however, in a number of samples, such as F_1-18, which is a biosparrudite, they occur in a highly fragmented form. Therefore, the bryozoa in the Foraker Limestone are not restricted to a certain limestone type, but are more abundant in the biomicrudite facies. This indicates a low-energy environment.

Echinoderms

Echinoderm fragments form a high percentage of the faunal assemblage of the Foraker Formation. They range from less than one to as much as 30 percent. They are well preserved in many samples, some showing the detailed structure of the canals (F_4-4). In some samples they have been destroyed by diagenetic processes. The susceptibility of the echinoderms to dolomitization and recrystallization is lower than that of other fossils observed throughout this formation.

In many thin sections in which all the fossils have been recrystallized, these faunal elements show no or only minor signs of recrystallization. In many samples which are partially dolomitized, echinoderms commonly have not been subjected to this process, except when extensive dolomitization has affected the entire rock. In Plate 7, fig. 1, it may be observed that although the rock is completely dolomitized, a crinoid fragment shows only minor dolomitization. The irregular boundary of this fragment, which is the result of dolomitization, is completely surrounded by dolomite rhombs. This example is especially interesting because it demonstrates that the dolomitization in this sample is secondary, and the same is true for the entire Foraker Formation. Burrowing effects of the organisms on echinoderms are extensive in many samples, such as F5-3 and F1-26 (Plate 10, fig. 1). In one photomicrograph a crinoid plate has been partially burrowed and filled with micrite which is not in optical continuity, and in another photomicrograph which shows extensive burrowing of all the fossils, a crinoid fragment is also burrowed. Encrusting algae, which are commonly associated with sparry calcite cement, have coated echinoderms in many thin sections (Plate 7, fig. 3, 4).

PLATE 10

1. Burrowed recrystallized biomicrudite. The burrowing action of the organism can be observed in the echinoderm fragment. The burrowing is followed by the infilling of micrite. Plain light X75. Long Creek member (F_1-26).

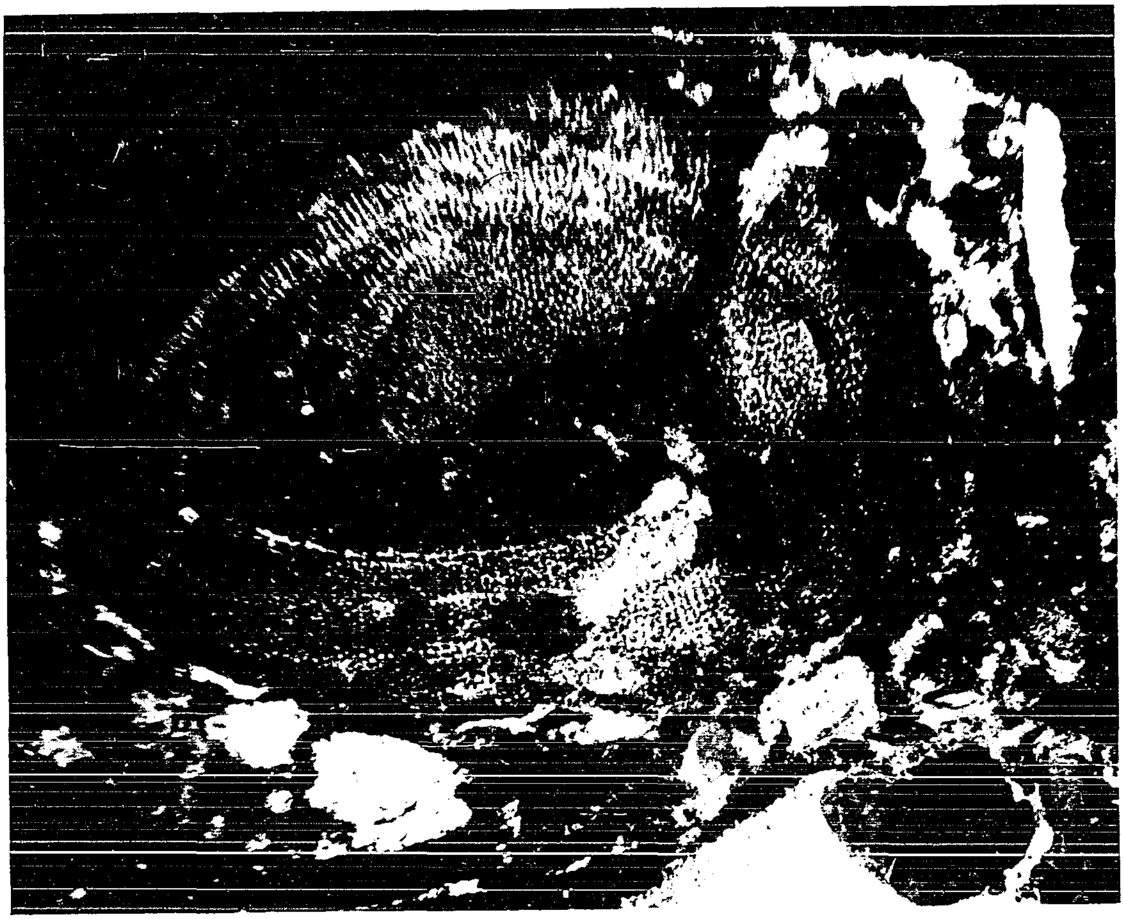

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PLATE 10

Brachiopods

Brachiopods are not abundant in the Foraker Formation, occurring in many samples as only minor to trace constituents. Only a few thin sections contain more than two percent brachiopods in the form of small fragments. However, in thin section F7-4 the brachiopods which are not abraded, have been partially to extensively recrystallized and are, therefore, not identifiable. Most of these brachiopod shell fragments are pseudopunctate and susceptible to recrystallization. Many genera of brachiopods have been described from the Foraker Formation in Oklahoma and Kansas (Vosburg, 1954; Fisher, 1956, p. 27; Fenoglia, 1957, p. 48-55; Mudge and Yocheslan, 1963, plates 13, 14, 15). Brachiopod fragments are commonly associated with the biosparrudite carbonate facies, and where they are present in the biomicrudite facies, show evidence of burrowing. In a few thin sections which show no abrasion, shells are well preserved and are associated with the biomicrudite facies, which indicates a low energy depositional environment.

Algae

Algae are one of the major constituents of the Foraker Formation, thus their mode of occurrence is significant to the understanding of the depositional environment. The most common type of algae is Osagia sp. which is identified in thin section by the writer. This algae is quite similar to the genus Osagia Twenhofel (Johnson, 1946, p. 1102), which was first described by Twenhofel in 1919. The colony of this algae was found in the Long Creek member at Phillips Lake (measured section F1). This algae is so abundant at this locality that approximately 80 percent of the organic and inorganic constituents of the rock have been coated. The characteristic feature of the colony of Osagia is that they develop a fusiform shape around a nucleus, regardless of the shape of the nucleus. The dominant nuclei found here are crinoid ossicles, coarse mosaic calcite, small brachiopod fragments, mollusk shells, some bryozoan zoaria, and a few Foraminifera. The original color of the Osagia colony is not retained in thin section because it has been discolored by an abundance of limonite. The surrounding sparry calcite is free from any limonite staining. The presence of limonite which is confined to the Osagia colony may have some depositional significance. Osagia has been classified as a genus of the Porostromata family and Cyanophyta class. Johnson (1946, p. 1094) believes that they may belong to Chlorophyta class. The compositional analyses of some chlorophyceae and cyanophyceae algae indicate the presence of iron compounds (Johnson, 1961, p. 19-21). In such analyses of Clark and Wheeler (1921), as much as 0.37 to 1.90 percent Fe_2O_3 was discovered in dry matter of Chlorophyceae and 0.05 percent Fe in Cyanophycea, but in the Osagia colony throughout this formation the percentage of iron seems to be far greater than those amounts. The origin of iron in marine invertebrates has been subjected to extensive study by many workers. Lowenstam (1962, p. 279) in a disucssion concerning the origin of goethite in some recent gastropods, contends that algae represent the main source of supply of iron for gastropod teeth. He stated that, because gastropods feed upon iron-rich filamentous algae, they obtain the necessary iron through the interaction with the algae.

The origin of iron in algae, however, is not fully understood, but many ideas have been published. One of the most plausible ideas is the suggestion of contribution from iron bacteria. J. M. Schopf et al. (1965) through a series of electron micrographs have shown the association of some iron bacteria with pyrite. They postulated that the iron bacteria probably derive most of their metabolic energy through oxidation of soluble ferrous iron, and, consequently, precipitate ferric hydroxide. This ferric hydroxide, then, could be converted directly into pyrite after being covered by a thin layer of organic debris. Although it is not possible in this study to prove the association of these iron bacteria with <u>Osagia</u>, a further investigation through the use of electron micrographs may provide some useful observations.

A distinguishing feature of these encrusting algae in the Foraker Formation is that they are associated with the biosparrudite facies. In F_1-23 and F_1-24, which illustrate superbe examples of encrusting algae (Plate 7, fig. 3, 4), the fossils and grains have been completely encrusted with <u>Osagia</u> sp. The presence of clear sparry calcite cement and the complete encrusting of the nucleus imply a high energy environment for <u>Osagia</u> sp.

Ostracodes

Ostracodes are rare in most of the measured sections; in only two cases, F_6-2 and F_6-3, do ostracodes form approximately 20 percent of the rock. Here they are extensively recrystallized and show only ghost structures (Plate 11, fig. 4). The type of carbonate facies associated with the ostracodes are biomicrodite and sparry calcite-bearing biomicrudite. However, due to the absence of ostracodes in most thin

PLATE 11

1. Spiculitic biomicrudite. This rock is composed of abundant spicules with different shapes and sizes. In the lower left corner of the picture a crinoid fragment is present. Plain light X25. Hughes Creek (F_1-14).

2. Intraclast-bearing foraminiferal biosparrudite. The fossil fragments mostly show some abrasion. Foraminiferas are the most abundant fossils. Note some ostracodes and minor crinoid plates. Plain light X25. Americus Limestone (F_5-1).

3. Gastropod crinoidal biomicrudite. Note the abundance of gastropods, crinoids and ostracodes in the micrite matrix. The dark-subrounded grains are pellets. Plain light X25. Americus Limestone (F_1-1).

4. Partially-recrystallized ostracodes biomicrudite. Recrystallization has obliterated the structure of the fossils. Ostracodes are completely recrystallized. Note the abundance of microspar which has been formed by recrystallization of the micrite. The dark-subrounded grains are pellets. The irregular dark spots are micrite. Plain light X25. Americus Limestone (F_6-2).

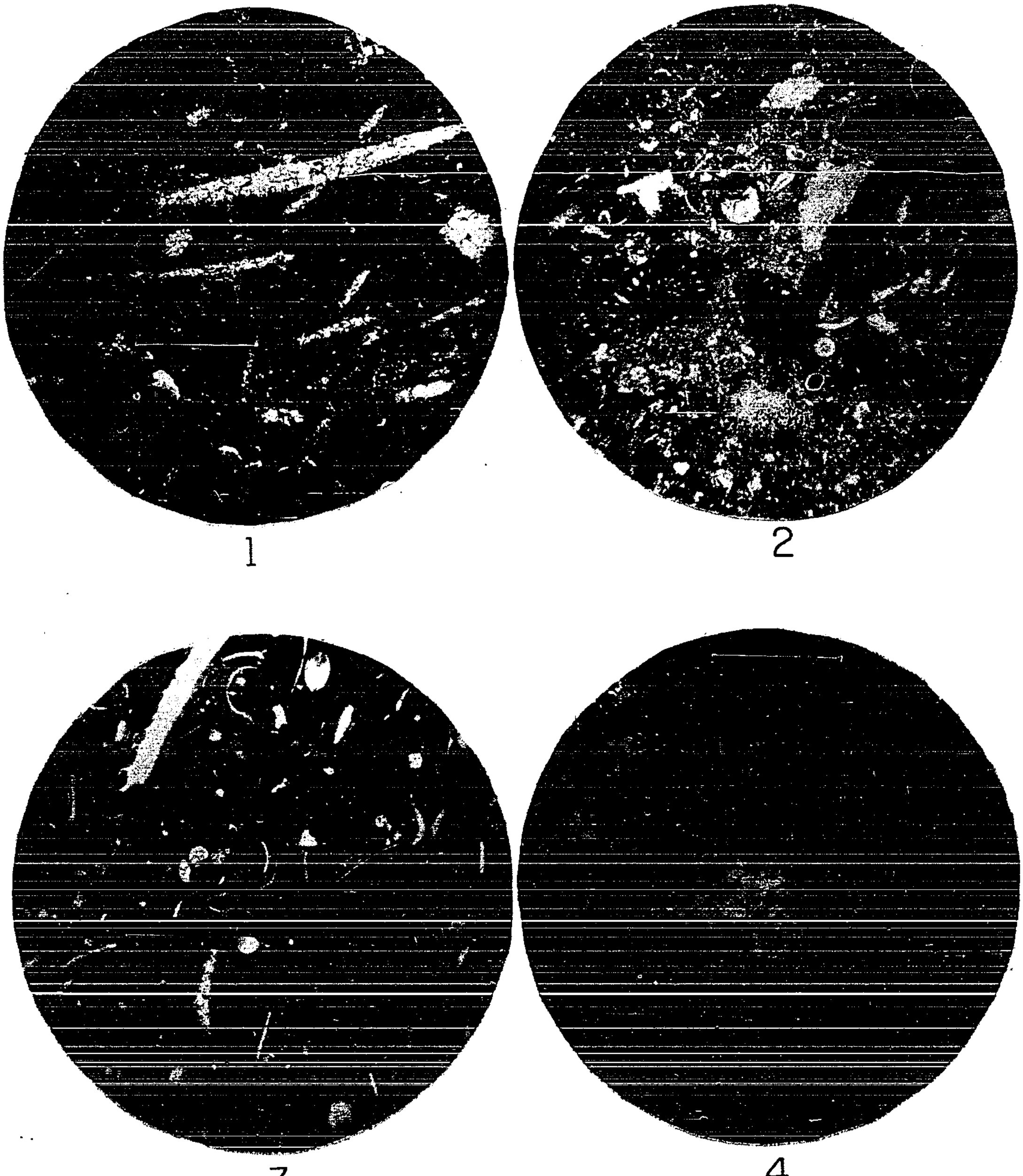

PLATE II

sections, it would involve considerable speculation to confine these faunal elements to a specific carbonate facies.

Mollusks

Mollusk fragments are locally abundant, especially in the lower part of the Foraker Formation (Americus Limestone). In the Phillips Lake area the lower part of the Americus (thin sections F_1-1 and F_1-5) contains abundant pelecypods and gastropods, especially of the superfamily Pectinacea. At this locality the pelecypods have been washed out by rain and are scattered throughout the spillway area.

In a few thin sections mollusks constitute as much as 25 percent of the total rock (Plate 11, fig. 3), but in most thin sections they represent less than two percent. They show a high degree of susceptibility to recrystallization and in many samples their structures have been obliterated due to this process. The mollusks in most cases are associated with biomicrudite facies.

Other faunal elements

Other faunal elements are Foraminifera and spicules which are rather scarce throughout this area. Some thin sections reveal these elements constituting two to five percent of the rock (Plate 11, fig. 1, 2). They are commonly associated with the biomicrudite facies, and in many cases they have been recrystallized. The Foraminifera are mostly fragmented and unidentifiable. Spicules are susceptible to recrystallization.

Pellets

Pellets are one of the nonskeletal allochems which constitute from 5 to 25 percent of the rock in a few samples (F5-6, F6-1, and F6-2). The size of these pellets varies from 80 to 250 microns, varying in shape from rounded or spherical to elliptical or ovoid. In F6-1 these aggregates are mostly of the same size, and are commonly rounded to angular, and brownish in convergent light (Plate 12, fig. 2). This brownish color is possibly due to the enrichment of organic matter in the pellets (Folk, 1962, p. 65). In other samples these aggregates are much larger and are more elongated than in the previous example (Plate 12, fig. 4). They are much larger (100-250 microns) and constitute as much as 10 percent of the rock. The writer consideres these pellets as representative of various origins. In one case (F6-1), these aggregates show a consistency in their shape and size, whereas in another case (F6-2), they vary in shapes and sizes. Some of the elongated forms are similar to some small algal

PLATE 12

1. Crinoidal algal biosparrudite. Note the abundance of abraded fossil fragments in the sparry calcite cement. Plain light X25. Americus Limestone (F_5-3).

2. Partially-recrystallized pelmicrite. A typical example of pellets in a micrite matrix. Plain light X25. Americus Limestone (F_6-1).

3. Spiculitic micrite. Spicules are the only allochemical constituent of the rock. Plain light X25. Americus Limestone (F_1-9).

4. Pellet-bearing algal biosparrudite. The dark, rod-shaped particles are probably pellets. Abundant algae and some bryozoan are observed in the photomicrograph. All allochems are set in sparry calcite cement. Plain light X25. Americus Limestone (F_6-2).

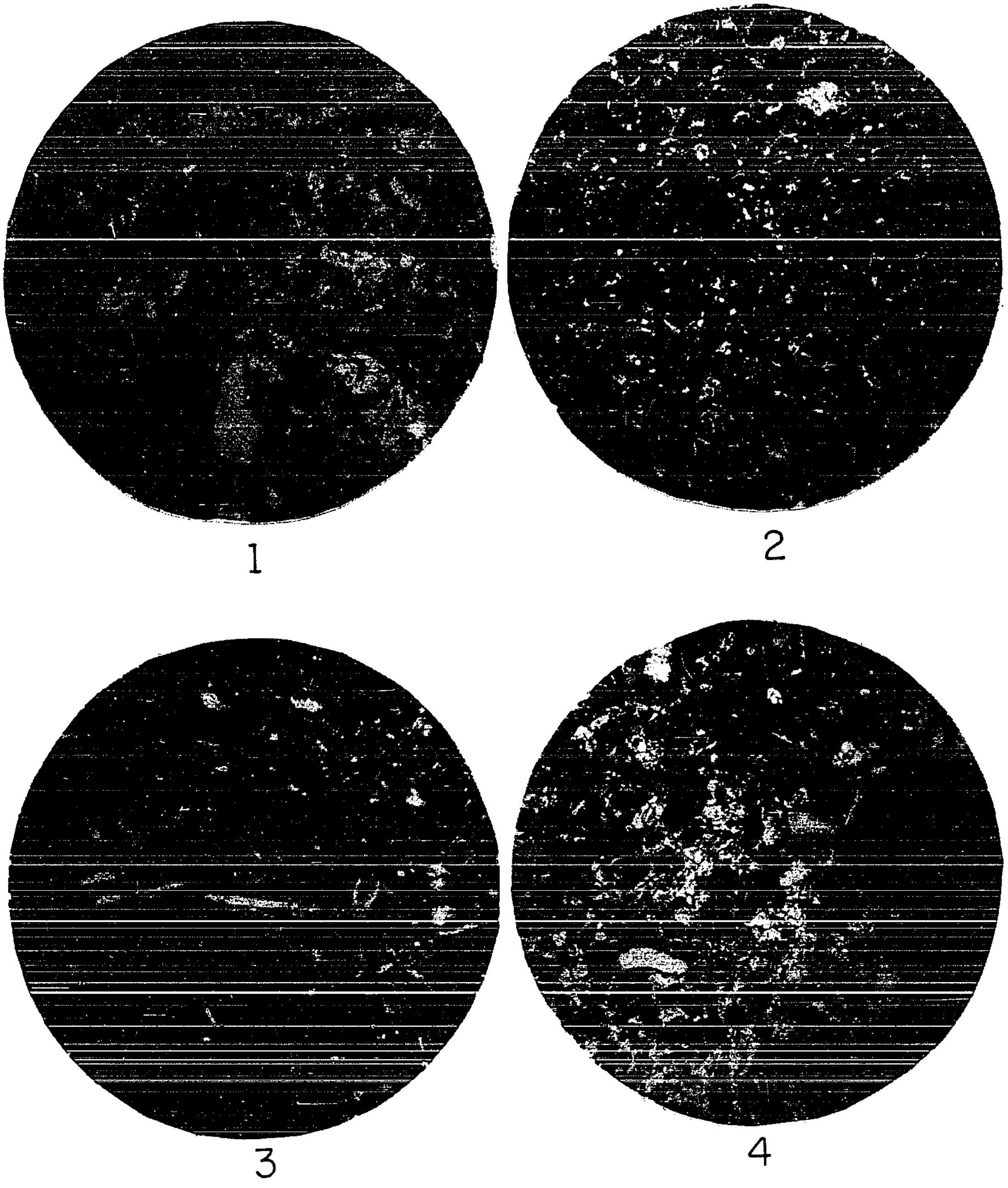

PLATE 12

fragments, except that they have no internal structure. According to Hatch and Rastall (in Folk, 1962, p. 65), those pellets which have a similar shape and size may be invertebrate fecal pellets. The origin of the larger pellets is doubtful. The size of these aggregates, according to Folk (1962, p. 65), exceeds the upper boundary for pellets (150 micron), so they would be assigned to the intraclast category. However, they do not display the complexity of internal structure if intraclasts. Powers (1962, p. 135) stated that these features may be formed from partially consolidated carbonate mud that has been broken up and abraded to some degree and then redeposited. Illing (1954, p. 24) reported that these aggregates have been formed in situ by cementation of smaller aragonite particles to sand size. Eardley (1938, p. 1401) in a discussion of the origin of these pellets has shown that the rod-shaped aggregates in Great Salt Lake, Utah, are fecal pellets of the brine shrimp, Artemia gracilis. The small and rounded pellets are commonly confined to the carbonate mud facies, whereas the rod-shaped pellets are associated with the sparry calcite-bearing carbonate mud facies, which indicates a higher energy environment.

Terrigenous constituents

Quartz is the most abundant terrigenous constituent in the Foraker Formation. The grain size ranges from 20 to 100 microns in different carbonate facies, and constitutes up to 10 percent of the rock. The grains are commonly angular to subangular and rarely rounded. Under the petrographic microscope they show straight extinction. Microlites form the most abundant inclusions in the quartz grains. The abundance of quartz, with some exception, corresponds to the carbonate facies. In most of the carbonate mud facies (micrite facies) the silt-size quartz does not exceed three percent of the rock. In the biosparrudite facies some samples contain as much as 10 percent quartz grains, with a larger grain size. In thin section F5-6 the subrounded, very fine quartz sand forms 10 percent of the rock and in association with a sparry calcite cemented rock indicates a high energy environment. However, a majority of the samples contain one to two percent angular quartz with a maximum diameter of 50 microns. The association of quartz with a micrite facies indicates a depositional environment in which the energy was not sufficient to wash out the carbonate mud and quartz silt. At the type section (F_1), the transition from sandy limestone to calcareous sandstone in Hughes Creek member may be observed both on the outcrop and in thin section. In thin sections F_1-10, F_1-11, F_1-12 (Appendix B) it has been shown that very fine quartz sand forms more than 60 percent of the rock, which is cemented by poikilitic calcite (40 percent). Higher in the section the percentage of quartz decreases. A thin section of a limestone bed overlying the calcareous sandstone contains only three percent quartz, and a bed overlying this limestone contains no appreciable amount of quartz. The decrease in quartz content of the carbonate rocks is possibly a reflection of the decrease in the energy of the environment of deposition.

Diagenesis of Carbonate Rocks

The word diagenesis has been defined by many authors, yet there is no universal agreement of a definition. Twenhofel (1939, p. 254) defined diagenesis:

> . . . Diagenesis includes all modifications that sediments undergo between deposition and lithification under conditions of pressure and temperature that are normal to the surface or outer part of the crust, and in addition, those changes that take place after lithification under the same condition of temperature and pressure, which are not katamorphic in character, so that the effect is delithification. . . .

Krumbien (1942, p. 111) uses the same definition. Pettijohn (1957, p. 648) follows the definition by Deverin (1924), contending that no distinction between diagenesis and metamorphism is possible. In his opinion, diagenesis is the beginning of metamorphism because it leads to modification of the texture, structure, and mineral composition of a sediment. Others, recognizing that there is no sharply defined stage, or time, at which cementation is initiated, consider cementation as a part of diagenesis. Among the followers of this definition is Correns (1950), who suggests that the term be reserved to indicate the transformation which a sediment may undergo between the time of deposition and its metamorphism. The writer prefers the definition of Correns. Silicification, dolomitization, recrystallization, cementation, and cavity-filling which are the most prominent diagenetic features in the Foraker Formation, will be discussed to show the significance of each process in the history of this formation.

Silicification

Silicification of carbonate rocks in the Foraker Formation is a significant feature, especially in the Hughes Creek member. Minor silicification of fossils and carbonate mud has been observed in many samples of the Americus Limestone and Long Creek members. In these units silicification does not exceed one percent of the rock. Among the fossils, fusulinids are more susceptible to this process than any other faunal element, followed by echinoderms and mollusks. The silica is in the form of chalcedonic quartz, which is composed of radiating fibers and is brownish under transmitted light. Folk and Weaver (1952) have shown by electron micrographs that the brownish color is due to the presence of liquid-filled cavities.

Extensive silicification in the Hughes Creek member has obliterated the internal structures of many fossils (Plate 8, fig. 4). In thin sections F_1-22, F_5-7, and F_2-5 nearly 50 percent of the rock has been silicified, resulting in extensively altered fusulinids and echinoderms. Fine chalcedonic quartz (approximately 40 microns) has filled all the septal pores of the fusulinids (Plate 8, fig. 2).

Silicification of crinoids in all samples is less extensive, and in most instances only a few parts of the fossils have been affected by this process.

Silica in the form of chert nodules and layers is abundant in the Hughes Creek member in Osage County (measured section F1 and F5). Most of the nodules are flattened lenses, but some are irregular bodies. They vary in size from several inches to as much as one foot in maximum length. They are commonly porous, apparently because of the removal of organic material. The color of the silica is normally gray blue, mottled gray blue, or yellowish-gray on fresh surfaces. The exterior of the nodules when weathered is white and spongy. The nodules show little to no concentric arrangement. Fusulinids, the most abundant faunal elements, are scattered throughout the chert. No preferred orientation exists among the fossils either in hand specimen or in thin section. Although the fusulinids have been preserved in chert, no detail of the structure is observable in thin section. Under crossed nicols, the chert is light gray, and consists of microcrystalline quartz and chalcedonic quartz. There are some needle-like structures that are colorless to light brown, and are composed of chalcedonic quartz. They are believed to be sponge monaxons.

The bedded chert in the Foraker Formation is commonly parallel to the bedding, but in many places it cuts across the limestone beds. Weathering normally has formed a distinctive plane of separation between the chert and carbonate components. This phenomenon is due to the differential permeability of carbonate and chert. Because the chert is less permeable, the work of solution has been concentrated at the carbonate-chert contact. However, in thin section, the contact of the carbonate and the chert is much less sharp and in many places relicts of calcium carbonate have been preserved in the chert masses. Silicification in the Foraker Formation commonly occurs in the "micrite facies"; no appreciable silicification has been found in the coarse-grained carbonates (sparry calcite facies). Also, where the Mg/Ca ratio is high, silicification is rare. This may be due to a higher pH and temperature which favors the deposition of dolomitic limestone and is not favorable for the precipitation of silica (Chillingar, 1956, p. 1561).

The source of silica, the processes and agents responsible for its concentration and precipitation, and the environment in which deposition occurred has been a controversial problem for a long time. There are two basic theories concerning the origin of chert in sediments: organic and inorganic precipitation. The inorganic theory was advanced by Tarr (1926), and Tarr and Twenhofel (1932). They postulated that silica is transported to the sea by streams in the form of hydrophilic colloids, which is then flocculated by strong electrolitic action of sea water, and precipitated.

More recent studies have shown (Bruevich, 1953, p. 68) that most of the silica in sea water is in the form of H_2SiO_3 (monomolecular form), and the concentration of dissolved silica is six times higher than the colloidal silica. Yet the concentration of silica in the sea water is 0.01 to

7 grams per ton (Rankama and Sahama, 1950, p. 290), which indicates that sea water is undersaturated with respect to silica (approximately 1/3). Therefore, enormous amounts of sea water would be required to furnish sufficient silica for even small amounts of chert.

In another theory, the assumption is that amorphous silica is extracted from the sea water by organisms such as radiolarians, sponges, and diatoms, which upon death are no longer protected and may dissolve as their siliceous skeletons sink to the sea floor (Lewin, 1961; Iler, 1955).

There is much evidence for the replacement origin of chert in the Foraker Formation; partial silicification of fossils and other carbonate fragments, relicts of carbonate mud in many thin sections, and destruction of the internal structure of the fossils. Because the silica in sea water from such a dilute solution (with respect to silica) is difficult to precipitate inorganically, the writer suggests that organisms, especially sponges, provided the main supply of silica for the formation of chert in the Foraker Formation. The mechanism of replacement of the carbonate and formation of chert nodules could be attributed to changes in pH. An increase in pH will cause more silica to be dissolved, and a decrease in pH will cause the precipitation of silica

(Rankama and Sahama, 1950, p. 555-556). The solubility of calcite is affected in a reverse manner, so that pH changes which tend to precipitate silica also tend to dissolve calcite. The change in pH may be caused by bacterial activity, which results in the liberation of ammonia, thus raising the pH of the solution. The lowering of pH also may be attributed to the activity of another group of bacteria which results in the liberation of carbon dioxide or hydrogen sulphide. The presence of different types of bacteria in the sediments will result in differential lowering and raising of the pH. Pittman (1959, p. 132) stated that through this mechanism, while silica is being dissolved at one place in the sediment, it would be precipitated at another place. He suggested that as silica is deposited, a silica deficiency would be created in that local volume of the sediment, so fresh silica could diffuse in for replenishment. Therefore, a silica diffusion gradient would be set up which would continue as long as the pH differentials last or until all available silica had been concentrated in the chert nodules or beds. The presence of sponge spicules in the chert of the Foraker Carbonates, although not abundant, may have acted as nuclei for silicification; however, the writer does not completely eliminate inorganic mechanisms for possible concentration and precipitation of Foraker silica.

Dolomitization

Dolomitization in the Foraker Formation is observed under petrographic microscope as euhedral or subhedral crystals in several thin sections. However, in several thin sections in which no dolomite was observed, the use of X-ray diffraction revealed a small quantity. The distribution of dolomite in the Foraker Formation is not confined to a certain member; it has been observed randomly in all members and in different localities. In measured section F7 (Appendix A) in the Long Creek member, one sample is almost pure dolomite with a few relict structures of some crinoid plates (Plate 7, fig. 2).

Dolomite in the Foraker Formation occurs mostly in the micrite facies, in a few cases being associated with the sparry calcite facies. The identification of dolomite was made by X-ray analysis (for the procedure see the discussion on X-ray), the petrographic microscope, and staining methods.

A total of 60 polished hand specimens were treated with the staining method to determine the occurrence and distribution patterns of dolomite in carbonate rocks. Prior to staining, the hand specimens were etched in a 10 percent hydrochloric acid solution for three minutes and washed in running water for about one minute. For the staining procedure, Alizarine Red S was used. A 0.1 gram of Alizarine Red was dissolved in 100 cc. of 0.2 percent hydrochloric acid. The etched samples were then dipped into the stain. By using this procedure, calcite is stained deep red within one to two minutes, and dolomite is not stained, excepting after excessive exposure (Friedman, 1959, p. 93).

The staining of carbonate rocks in the Foraker Formation showed that dolomite occurs in an irregular pattern, no sharp calcite-dolomite contacts having been observed in any sample. The percentage of dolomite varies from 1 to 5 in most of the samples, except in one sample (F7-6), where dolomite exceeds 80 percent of the rock.

In thin section, different fossils show varying degrees of susceptibility to dolomitization. Algae were the most susceptible to dolomitization, followed by fusulinids, and then echinoderms.

The origin of penecontemporaneous dolomite has been a controversial subject for a long time. The recent finding of dolomite in the Persian Gulf (Illing, Wells and Taylor, 1965), Andros Island, Bahama Bank (Shinn, Ginsburg, and Lloyd, 1965) and Bonaire, Netherland Antilles (Deffeyes, Lucia, and Weyl, 1965) has shed much light on the subject. In all of these localities, evaporation of sea water precipitates calcium carbonate and evaporites which produce dense brines with high Mg/Ca ratios. These magnesium-rich brines cause diagenetic changes in the calcium carbonate. The dolomite which forms in this manner replaces the pre-existing calcium carbonate. Carbon 14 determinations on all of these dolomite samples indicated ages less than 3,000 years, indicating that the dolomitization is a penecontemporaneous phenomenon related to the present sedimentary environment. These new findings shed additional light on the origin of at least some ancient dolomites. However, it has been shown that many ancient dolomites have been formed by different mechanisms and are, therefore, not necessarily penecontemporaneous phenomena.

The petrographic examination of the dolomite which is associated with the Foraker Formation shows that it was formed after deposition. The perfect euhedral crystals in nearly all samples, partially dolomitized fossils and matrix, and the relicts of calcium carbonate in dolomite show that replacement of pre-existing calcium carbonate has occurred in the Foraker Formation and, therefore, may be considered secondary or replacement dolomite. Hall and Ritter (*in*

Deffeyes *et al*., 1965, p. 71) suggest that the necessary condition for dolomitization is a water having a Mg/Ca ratio larger than the ratio that would be in equilibrium with both calcite and dolomite. This water must be produced and flow through the limestone, because magnesium transport by diffusion is inadequate to explain most dolomite occurrences. This phenomenon may well explain in one of the samples which has more than 80 percent dolomite. However, in many samples in which minor amounts of dolomite are present, the dolomite could have been formed by diffusion of magnesium ions.

Recrystallization

Recrystallization in the Foraker Formation was observed in nearly all thin sections. In many cases the original texture of the rock has been obliterated due to this process (Plate 13, fig. 1-4). In the Americus Limestone, a biomicrudite facies, recrystallization occurs more extensively. It has been observed that this process is confined to the carbonate mud. Although recrystallization may have affected some of the sparry calcite facies, no positive evidence was recognized. Among the fossils, bryozoa show the highest susceptibility to recrystallization, followed by ostracodes, algae, brachiopods, and mollusks. Echinoderms

PLATE 13

1. Recrystallized biosparrite. This is a typical example of recrystallization. Most of the fossils show only a ghost. Plain light X25. Americus Limestone (F7-2).

2. Recrystallized pellet-bearing biosparrite. Note the extensive recrystallization of the fossils. Plain light X25. Americus Limestone (F7-2).

3. Partially-recrystallized biomicrudite. Recrystallization has obliterated the structure of the fossil. Note the relict of micrite in center of the fossil which is indicative of recrystallization. Plain light X25. Americus Limestone (F4-1).

4. Partially recrystallized ostracode biomicrudite. This is another example of recrystallization. Some of the fossils such as the ostracode (in the center) still show some structures. Plain light X25. Americus Limestone (F4-1).

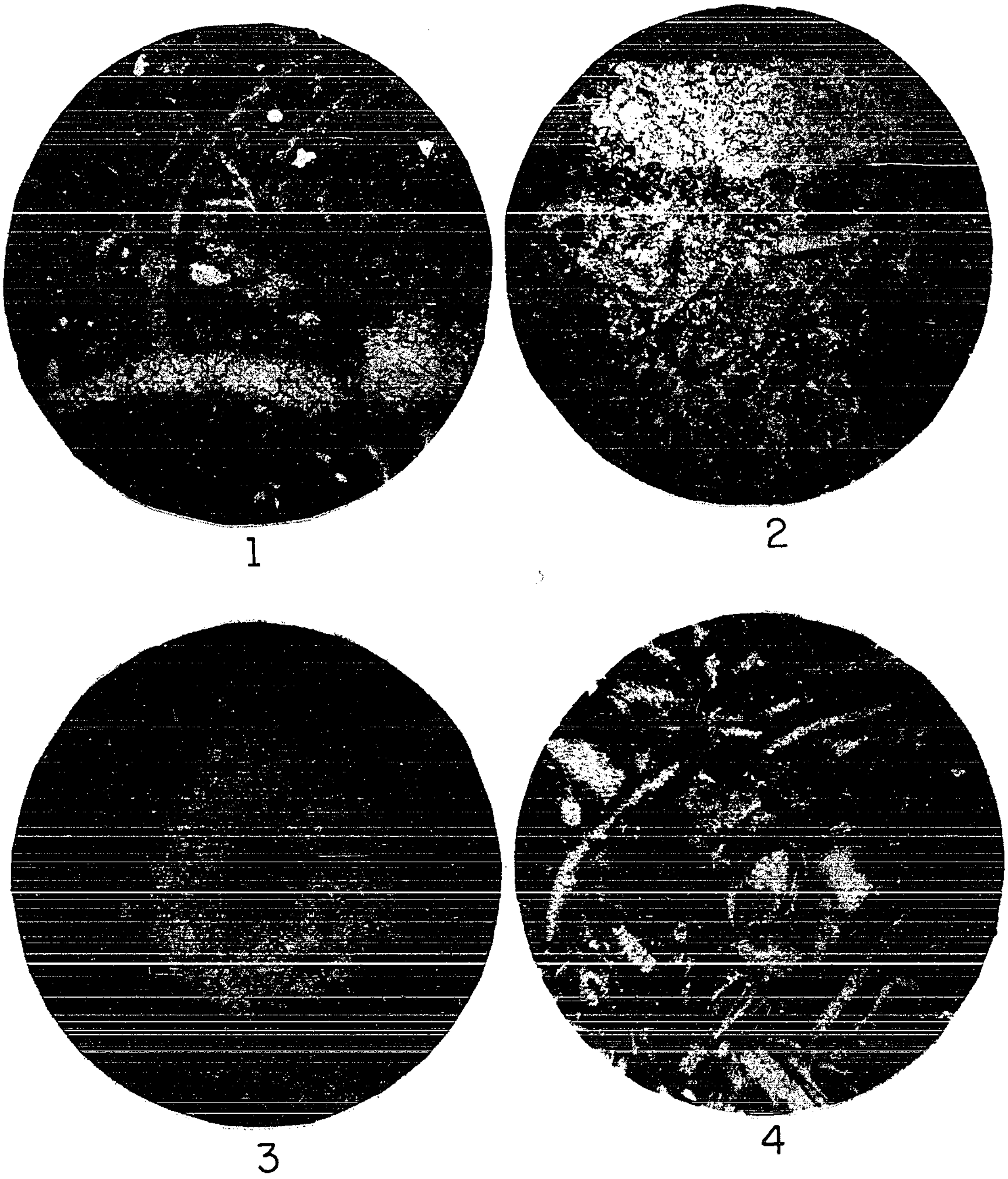

PLATE 13

in all thin sections show the least susceptibility to recrystallization, and in many thin sections in which all of the fossils have been obliterated due to recrystallization, the echinoderms are well preserved.

The criteria for recognition of recrystallization or grain growth as Bathurst suggests (1958) was based on the work by Orme and Brown (1963), and Bathurst (1959, p. 24-27). These criteria are:

a. Fine-grained carbonate mud interrupted by coarse mosaic calcite.
b. The grain size of the coarse mosaic varies irregularly.
c. The boundaries of the grains are commonly curved.
d. The syntaxial recrystallized rim develops commonly around crinoid fragments.

The common fabrics of recrystallization in the Foraker Formation are: coarse mosaic calcite, microspar, and syntaxial recrystallized rim around many crinoids (F_1-23). A series of photomicrographs (Plate 6, fig. 1-4) shows the different stages of recrystallization in some brachiopods, and formation of coarse mosaic calcite at the expense of carbonate mud.

1. Figure 1 shows a brachiopod shell which is well preserved and without evidence of recrystallization.

2. Figure 2 is another brachiopod shell which is filled with micrite. Minor recrystallization

has changed the micrite to coarse mosaic calcite.

3. Figure 3 demonstrates a brachiopod with more recrystallization. Nearly two thirds of the micrite has been recrystallized to coarse mosaic calcite. The presence of relict micrite in the coarse mosaic calcite, and the irregular boundary of micrite and coarse mosaic calcite is a positive indication of recrystallization.

4. Figure 4 is a brachiopod shell which is filled completely with coarse mosaic calcite. The presence of some relict micrite in the coarse mosaic calcite is an indication of recrystallization. Although this phenomenon may be interpreted as cavity filling, the presence of micrite relicts (more micrite may be observed in the thin section) suggests that this stage is the end product of recrystallization.

Another recrystallization fabric which is common in carbonates is microspar. Microspar grains vary from five to 20 microns in diameter and are exceedingly uniform in size.

The criteria for recognition of microspar have been discussed in detail by Folk (1965, p. 37-42), who suggests some environmental causes such as salinity and clay content as being responsible for the occurrence of microspar. The evidence for this is the association of microspar in limestones that change facies to adjacent clay beds or are interbedded with shale. In addition, the absence of microspar in dolomitic rock, in Folk's opinion, may indicate a relation between the salinity and occurrence of microspar. Although in many Foraker carbonate rocks such a relation was observed, nevertheless, in some pure limestones and dolomitized limestones, microspar was found in appreciable quantity.

Another type of calcite which has been found in many thin sections is fibrous calcite. These fibrous calcite grains commonly do not have a sharp contact with the enclosing fine mosaic and have developed indiscriminately with no preferred orientation through the rock. There is evidence in many thin sections (F_7-5, F_3-3, F_1-16) that the fibrous calcite may have been formed by the diagenesis of fine mosaic calcite. Orme and Brown (1963, p. 55) have shown that in many cases fibrous calcite has been formed by grain growth.

Cavity filling and cementation

In many thin sections the process of cavity-filling was observed in fossils. Nearly all fusulinids, brachiopods, and mollusks show the infilling of the septal pores and shell chambers with drusy mosaic calcite. Micro-fractures and veins in places are filled with fine mosaic calcite (Plate 14, fig. 1, 2).

Sparry calcite cement or granular cement (Bathurst, 1956, p. 14) has been observed in many thin sections of the Hughes Creek and Long Creek members. In this paper these units are placed in the sparry calcite facies (Plate 7, fig. 3, 4). The criteria which was used for recognition of the drusy mosaic calcite is based on the work of Bathurst (1958, p. 20) and are as follows:

1. Calcite mosaics show an increase in grain size away from the wall of the cavity.
2. The longest axis of the mosaics are normal to the wall of the cavity.
3. All mosaics are characterized by plane intergranular boundaries.

Granular cement grows in the pore spaces between multigranular particles and, except for the site of deposition, their mode of formation is similar to that of the

PLATE 14

1. Vein-filling partially recrystallized biomicrudite. Algae and recrystallized ostracodes are abundant. Note the infilling of veins by calcite. The micrite matrix has been recrystallized to microspars and coarse mosaic calcite. Plain light X25. Americus Limestone (F_1-2).

2. Fusulinid crinoidal biomicrudite. All the fossils have been burrowed. Note vein-filling with calcite which cut across the fusulinid. Plain light X25. Americus Limestone (F_5-5).

3. Void-filling micrite. Drusy mosaic calcite has filled the cavities. Plain light X25. Americus Limestone (F_1-4).

4. Partially recrystallized biomicrudite. Recrystallization has affected the brachiopod and some part of the matrix. Plain light X25. Hughes Creek member (F_5-7).

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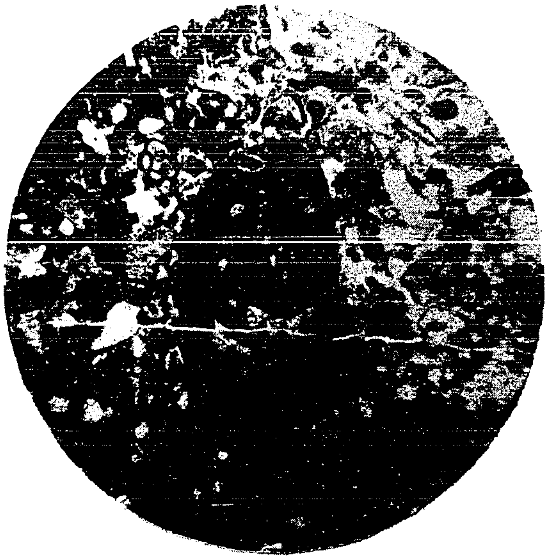

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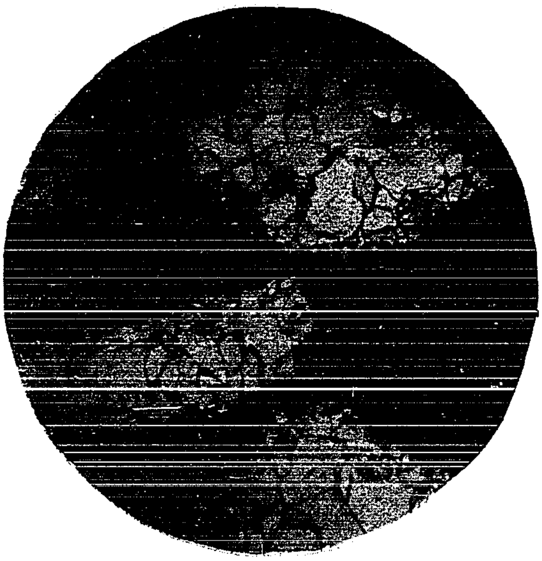

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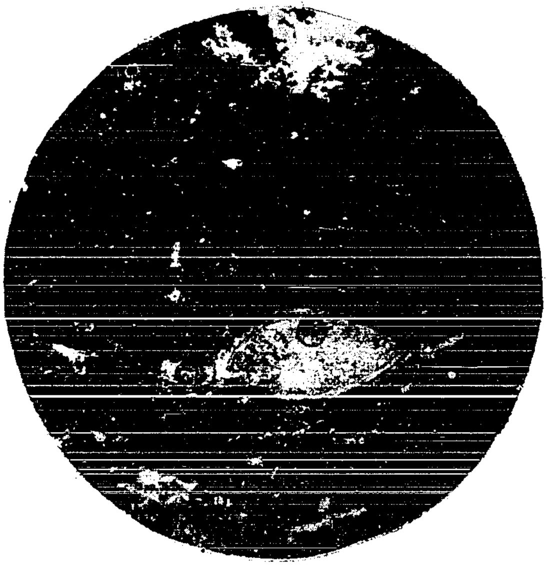

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PLATE 14

coarse mosaic calcite. Both granular cement and coarse calcite mosaics are chemically precipitated from calcium carbonate in solution in free space.

Friedman (1964) has shown that the dominant carbonate minerals are deposited originally in the form of aragonite and high-magnesian calcite, and during lithification in subaerial exposure they undergo mineralogical and textural changes. Aragonite grains will be dissolved to form moldic porosity, and, consequently, molds are infilled by a drusy low-magnesian calcite. In the process of change from high-magnesian calcite to low-magnesian calcite, no textural change occurs, and by removing high-magnesian calcite, low-magnesian calcite will be formed on a microscale by a solution-deposition process. If the carbonate rocks which have been formed in a high energy environment in which micrite either has been washed away or is not abundant, are exposed to subaerial processes or vadose water (W. E. Ham, personal communication, 1965), low-magnesian calcite will be precipitated as a granular cement to bind the grains together. The stability of aragonite and high-magnesian calcite would remain unchanged if these minerals continue to be exposed to sea water. This would result in resistance to lithification. The study of the Funafuti reef has shown no evidence of a significant amount of inversion of aragonite to calcite during early diagenesis (Cullis, 1904; and Judd, 1904, in Fairbridge, 1950, p. 384). On the other hand, in the Pleistocene limestones which are subaerially exposed or in the zone of meteoric water, the inversion of aragonite to low-magnesian calcite is common.

Carbon isotope studies have proved to be a significant paleo-environment indicator. According to Craig (1953, p. 61) the enrichment in C^{12} (more negative value for $\delta C^{13/12}$) indicates exposure to a post-depositional subaerial environment. Vogel (1959, p. 283 in Friedman, 1964, p. 784) has shown that marine carbonates which undergo solution by rain water are enriched in the lighter carbon isotopes, because the $\delta C^{13/12}$ of the fresh water has been greatly influenced by the CO_2 of humus which has a $\delta C^{13/12}$ ratio of approximately -25.0 parts per thousand. Conversely, carbonates which are not exposed to subaerial environments show no enrichment of C^{12}, and, hence, the $\delta C^{13/12}$ has a positive value.

In more recent work by Gevirtz and Friedman (1966) with carbonate sediments of the Red Sea, it has been shown that aragonite under high temperature and hypersaline water precipitates and cements together carbonate grains which leads to lithification in a marine environment. The textures of these aragonites are diagnostic because they grow around the center of accretion, form the matrix between grains, and commonly provide syntaxial fibrous rims around the fossils. High-magnesian calcite also has been observed as a cement in lithification in deep sea carbonates under more normal marine salinity, but little is known regarding the temperature required for the precipitation of high-magnesian calcite.

On the basis of these data, the lack of aragonite and high-magnesian calcite with diagnostic textures of deep sea origin, and the presence of granular cement and drusy mosaic calcite, it is a probable speculation to propose a period of subaerial exposure for the Foraker carbonate sediments before lithification. It is also probable that some unknown biochemical and physico-chemical processes active in the sediments would cause a change in the environment and the inversion of aragonite and high-magnesian calcite to low-magnesian calcite could have occurred in the depth of burial without the necessity of subaerial exposure.

Geopetal structures

Many examples of these structures have been observed in the fossils (Plate 15, fig. 1, 2). Upon the death of the organism and digestion of the soft parts, the shell chamber is infilled with carbonate mud. Being metastable, aragonite or high-magnesian calcite after subaerial exposure will be dissolved. The floor of the cavity will then be filled with the mechanical precipitation of the suspended material, which is called a basal sediment (Orme, 1963, p. 57).

The top of the cavity is filled with drusy mosaic calcite. The presence of the geopetal structure is significant because it reveals the depositional history of the rock and, furthermore, such cavities have been used to determine the trend of the bedding.

Burrowing

The burrowing effect of organisms is evident in the "biomicrudite facies" of virtually all thin sections examined. Evidence of burrowing is especially common in the Americus Limestone, which is a unique biomicrudite lithofacies that contains varying amounts of benthonic faunal debris in the carbonate mud (micrite), and shows no evidence of lamination. The presence of highly fragmented and unabraded faunal elements (Plate 12, fig. 2, 4) in a carbonate mud (low energy environment) indicates burrowing action.

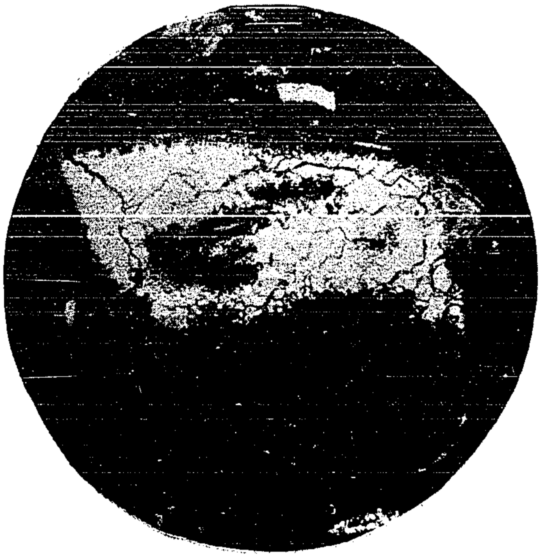
PLATE 15

1. Cavity-filling brachiopod biomicrudite. A typical geopetal structure has formed in the brachiopod. Note the sharp boundary between the internal sediment and drusy mosaic calcite. Plain light X25. Long Creek (F_1-26).

2. Cavity-filling gastropod biomicrudite. This is another example of a typical geopetal structure. Other fossil fragments are probably burrowed. Plain light X25. Americus Limestone (F_1-5).

3. Vein-filling algal biomicrite. This is typical example of vein-filling with drusy mosaic calcite. Note the encrusting algae around the cavity. Plain light X25. Americus Limestone (F_4-2).

4. Partially dolomitized biomicrudite. Note a transition from calcite micrite (top) to partially dolomitized micrite (bottom). A significant feature is the presence of fossils in the upper part and its absence in the lower part. Plain light X25. Americus Limestone (F_1-5).



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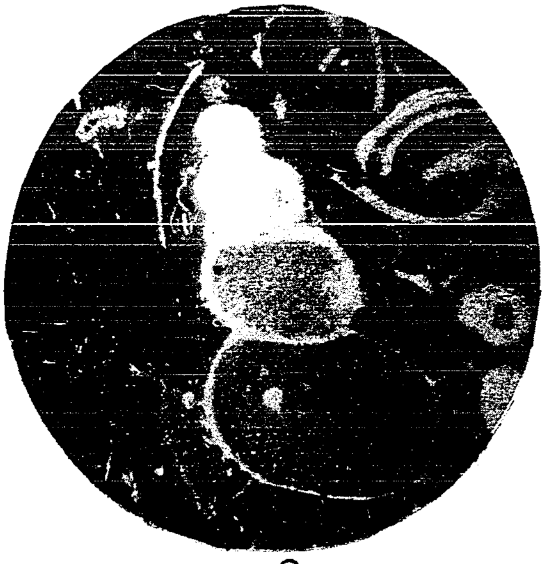

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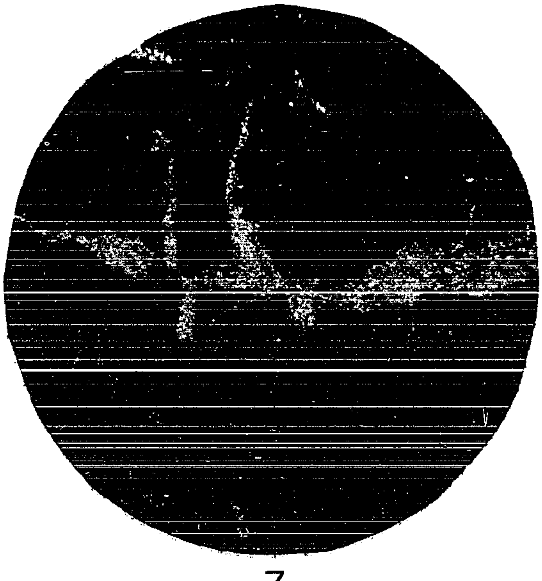

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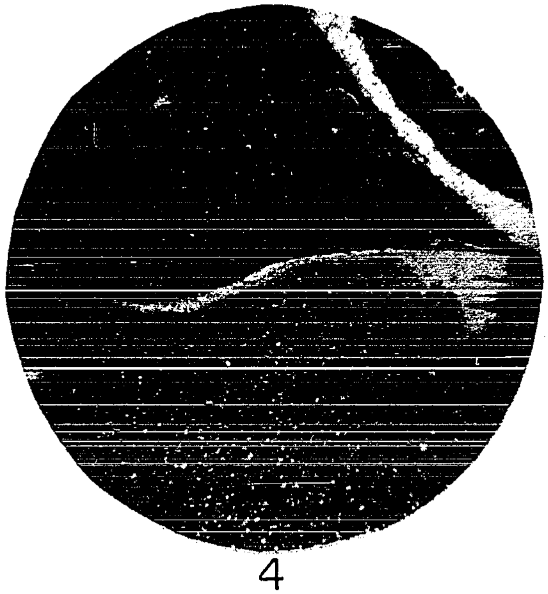

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PLATE 15

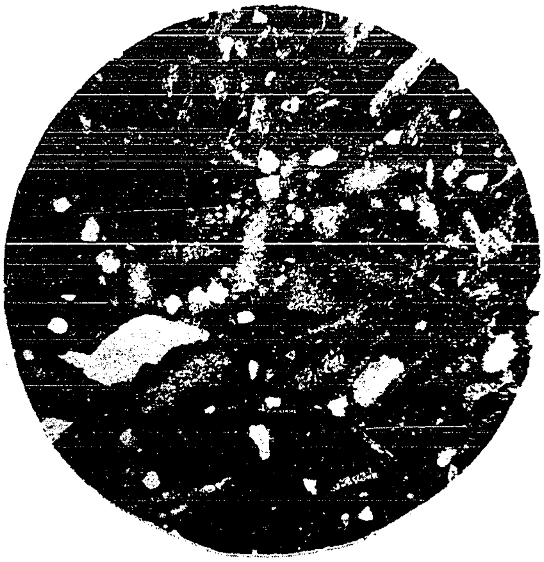
PLATE 16

1. Sandy encrusting-algae biosparrudite. Encrusting algae can be observed around the fossils and grains. Note the abundance of quartz in varying size and shape. Plain light X25. Hughes Creek member (F_1-13).

2. Encrusting-algae sandy biosparrudite. This is the same thin section as above. Note the bryozoan which is coated by algae. Some spicules are also present. Plain light X25. Hughes Creek member (F_1-13).

3. Encrusting-algae sandy biosparrudite. The significant feature in this photomicrograph is the silicification of limestone (in the elongated calcite grain). Note also the encrusting algae, quartz grains, and minor spicules. Plain light X25. Hughes Creek member (F_1-13).

4. Algal biosparrudite. The algal fragments and minor bryozoa are set in microspar and sparry calcite cement. Plain light X25. Americus Limestone (F_6-5).



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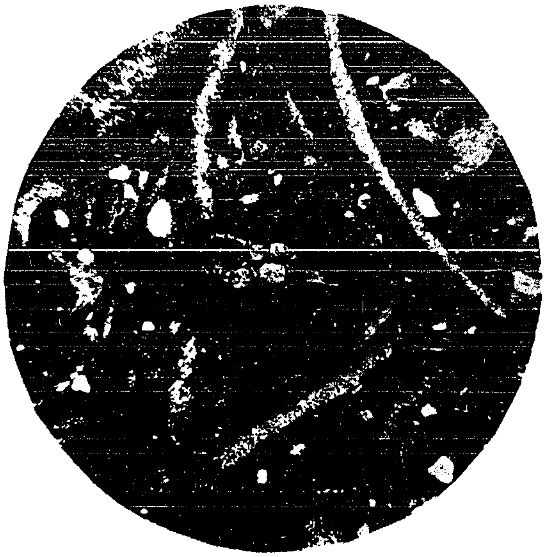

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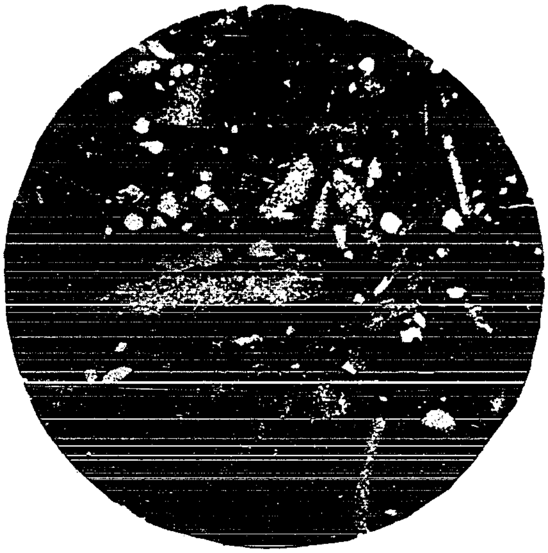
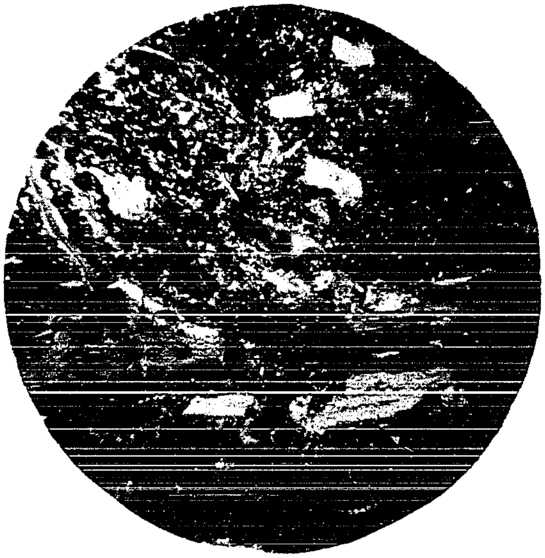


3



4

PLATE 16

A rational deduction visualizes many Foraker invertebrates, with numerous scavengers likewise abundant; and where Foraker invertebrates were scanty, scavengers were correspondingly reduced in number. Where Foraker fossils are well preserved, it may indicate that the rate of sedimentation was so rapid the scavengers were unable to keep the bottom clean from organic debris before burial. A detailed analysis of the effect of burrowing organisms has been reported by Emery (1953), Ginsburg (1957), Shepard and Emery (1946), and Northrup (1951).

Chemical Analyses

Although the essential petrographic study in this work was based on the use of a petrographic microscope, positive identification of the carbonate minerals, clay minerals, and trace element content of the Foraker Formation involved the application of other methods. These methods include: X-ray diffraction, spectrographic semi-quantitative analysis, and insoluble residue analysis.

Insoluble Residue Analysis

Insoluble residue analysis was used to determine the weight percentage of the terrigenous content of carbonate rocks. Forty-seven carbonate samples were selected, and after breaking, 20 grams of each sample were weighed and poured into a 500 ml beaker. Approximately 50 ml of cold hydrochloric acid (10 percent concentration) was used to dissolve each sample. For the complete digestion of the calcium carbonate, two applications of acid were used. For digestion of dolomite, the samples were boiled for five minutes in the HCl solution. After five hours, which is a sufficient time for digestion of dolomite and calcite, the samples were filtered through filter paper (no. 30). The filter paper was then dried in a low temperature oven in order to prevent ashing. The insoluble residue was then weighed and a weight percentage of each sample was calculated (Table 1 and 2). The clay content of the insoluble residue was separated by decantation. The remaining coarse fraction was examined with a binocular microscope. Very fine-grained quartz and sponge spicules were the most abundant constituents in the insoluble residues. In a few samples of the Hughes Creek member some microcrystalline silica was observed.

With some exceptions, the percentage of the insoluble residue content of all samples shows an increase from the Kansas-Oklahoma State Line southward to Pawnee County. The average percentage of the insoluble residue content of the "biomicrudite facies" is much greater than in the

TABLE 1

Weight Percentage of the Insoluble Residues

Americus Limestone

Sample	Percent	Sample	Percent
F_5-1	12	F_3-1	15.3
F_5-2	3	F_3-2	10.2
F_5-3	4.5	F_3-3	13.2
F_5-4	3	F_4-1	0.5
F_5-5	3	F_4-2	6.0
F_1-1	8.9	F_4-3	4.8
F_1-2	0.7	F_4-4	9.2
F_1-3	0.1	F_6-1	2.0
F_1-4	4.0	F_6-2	5.0
F_1-5	12.5	F_6-3	7.0
F_1-6	29.7	F_6-4	17.0
F_1-7	1.6	F_6-5	8.0
F_1-8	8.5	F_6-6	8.8
F_1-9	14.0		

TABLE 2

Weight Percentage of the Insoluble Residues

A. Hughes Creek

B. Long Creek

	Sample	Percent	Sample	Percent
A.	F_1-13	1.6	F_1-20	0.4
	F_1-14	52.6	F_1-21	28.0
	F_1-15	1.0	F_2-4	22.0
	F_1-16	0.6	F_2-5	10.4
	F_1-17	0.2		
	F_1-18	1.0		
	F_1-19	7.5		
B.	F_1-23	0.8	F_1-27	1.1
	F_1-24	3.5	F_7-4	5.5
	F_1-25	0.4	F_7-5	3.0
	F_1-26	1.5		

"biosparrudite facies." In the "biosparrudite facies" of measured section F_1 the highest percentage of the insoluble material is 3.5, whereas at the same locality, the biomicrudite contains up to 29 percent. The percentage of acid insoluble components of Foraker biosparrudite facies, with few exceptions, increases southward. In measured section F_1 (Osage County) the biosparrudite facies contains 0.1 to 3.5 percent, whereas southward in Pawnee County, it is as much as eight percent. The size of the quartz grains maintains a linear relationship with the type of carbonate rocks; in the sparry calcite carbonate, the quartz grains vary in diameter from 40 to 80 microns, whereas in all biomicrudite samples the quartz grains are less than 40 microns. The clay content of the biomicrudite facies in some samples, such as F_1-5, F_1-6, and F_1-9, comprises more than 95 percent of the acid insoluble content. In sparry calcite carbonates, however, the clay content is insignificant in many samples, and did not exceed 20 percent of the insoluble residue in other samples.

The highest percentage (52.6 percent) of acid insoluble material was obtained from F_1-14 in measured section F_1 (Phillips Lake). This sample is an extensively silicified biomicrudite and the insoluble residue was primarily silicified material, with a small quantity of clay. Many X-ray diffraction patterns were run on the insoluble residues and the most prominent mineral constituents were quartz, montmorillonite, illite, and some chlorite. The clay mineral content of the carbonate rocks is discussed in the section on "X-ray analysis." The study of the quartz grains reveals that they are land derived. In a few samples, however, there are many sponge spicules, some microcrystalline quartz, and some chalcedonic quartz which has replaced other material.

On the basis of acid insoluble data, the following conclusions may be drawn:

1. Insoluble residues are land derived, except in a few cases involving replacement silica.
2. The percentage of the acid insoluble content in many samples indicates an increase from north to south in the area.
3. The biomicrudite facies contains more insoluble residue than the biosparrudite carbonate. The residue is composed primarily of clay minerals and minor amounts of quartz.
4. The biosparrudite samples have a lower acid insoluble content, which is composed mostly of

quartz and a minor amount of clay.

5. The grain size of the quartz is considerably larger in the biosparrudite rocks than in the biomicrudite facies.

6. The most abundant insoluble residue in the Foraker Limestone is quartz, clay minerals, and a minor amount of silica in the form of microcrystalline quartz and chalcedonic quartz.

X-ray analysis

X-ray diffraction techniques were used in this study to make positive identifications of the mineral constituents of the carbonate rocks and shale samples. In many carbonate samples the dolomite content was so minor that it was not identifiable by petrographic microscope and staining methods. By using X-ray diffraction techniques small amounts could be detected.

More than 55 X-ray diffraction patterns were run on carbonate samples, using a Norelco X-ray diffraction unit with Cu K alpha radiation, (Ni filtered) at a setting of 35 Kv and 18 ma. The samples were crushed, powdered, and passed through an 80 mesh screen. The powder was then placed in a powder-pack sample holder and analyzed. The series of diffraction patterns that are illustrated in Figure 4 and 5 show

Figure 4 and 5

X-RAY DIFFRACTION PATTERNS OF SOME CARBONATE SAMPLES

FROM THE FORAKER FORMATION

Powdered samples illustrating diffraction maxima of quartz, calcite, and dolomite. The intensity of dolomite and calcite peaks varied in different samples. Note the intensity of dolomite peak in sample F7-6 (Figure 5). This sample is a completely dolomitized calcite. Cu K alpha radiation, (Ni filtered) at a setting of 35 Kv and 18 ma.

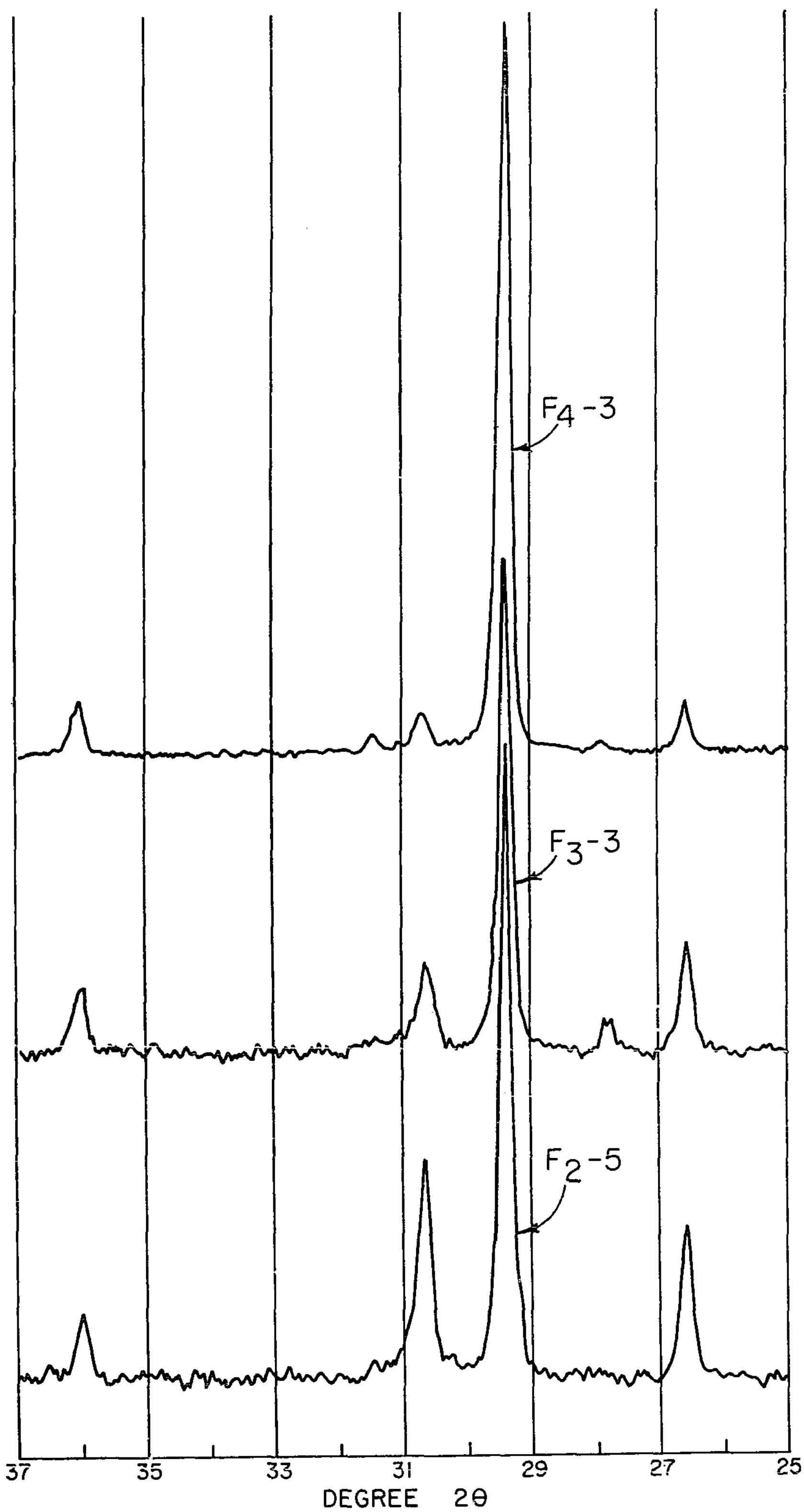


Figure 4

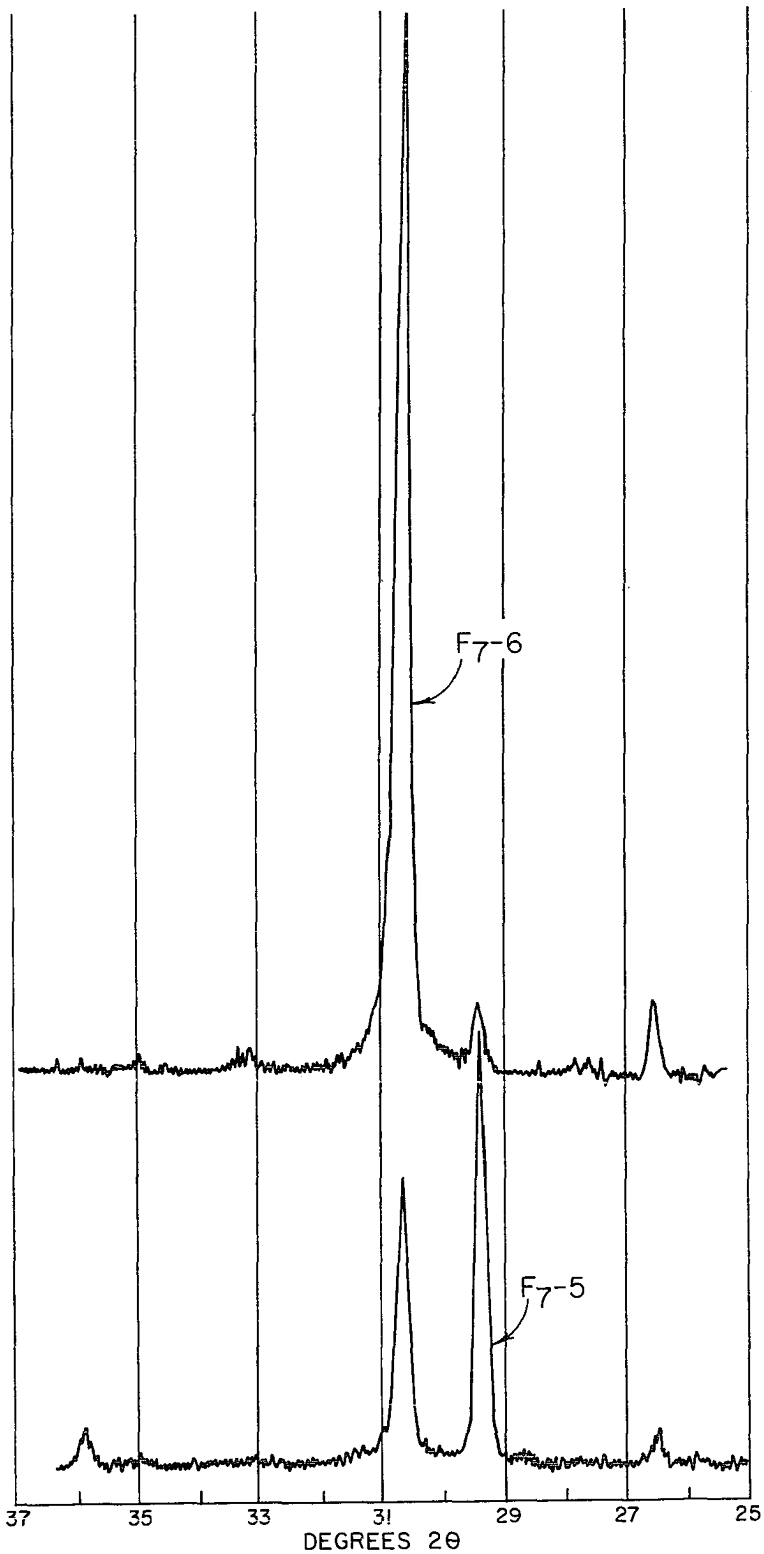


Figure 5

the mineral content of carbonate rocks from different localities throughout the area. The pattern in Figure 4 shows the first order reflection in the vicinity of 3.0 Å for calcite, 2.89Å for dolomite, and 3.34Å for quartz.

The highest percentage of dolomite was detected in F7-6, where it comprises approximately 90 percent of the rock, with minor amounts of calcite and quartz.

For identification of the clay minerals, X-ray patterns were run on 20 shale samples. For the preparation of sedimented slides, shale samples were dispersed in distilled water in an ultrasonic transducer tank for approximately 15 minutes. Two sedimented slides were prepared from each sample. One sample was X-rayed and the other was treated in an ethylene glycol bath at 60° C for approximately 10 hours. This treatment was done to determine the expansion of some specific clay minerals. The most abundant clay minerals associated with the Foraker Formation are montmorillonite, illite, and minor amounts of chlorite.

Montmorillonite

Montmorillonite is the most abundant clay mineral found throughout the area. The first, second, and third order basal reflections were observed in many samples. The

(001) d-spacing of untreated samples was observed between 14.2 to 14.75 Å. The first order reflection (001) after treatment with ethylene glycol expanded to approximately 17 Å (Fig. 7).

Illite

Illite was found in many samples of the Foraker Formation, no consistency having been observed in the distribution pattern of this clay mineral. Observed d-spacings for the first order basal reflection (001) is approximately 10 Å. Second and third order basal reflections were observed at approximately 5 and 3.33 Å, respectively. The (001) peak of all observed illite samples is asymmetrical. Weaver (1956) and others contend that the asymmetry may be due to the random interstratification of illite and montmorillonite or illite and vermiculite.

Other clay minerals, such as chlorite, were present in minor amounts in some samples.

<u>Trace element geochemistry</u>

Trace element analyses were run on 30 carbonate samples according to the semi-quantitative spectrochemical methods outlined by A. J. Mitteldorf (1957). The analyses were performed by Mr. Kenneth Sargent, graduate student at

Figure 6

X-RAY DIFFRACTION PATTERNS SHOWING CLAY

MINERALOGY OF THE FORAKER FORMATION

Sedimented slides illustrating diffraction maxima of montmorillonite and illite. Cu K alpha radiation, (Ni filtered) at a setting of 35 K_v and 18 ma.

A. Measured section F_1, 3.5 feet above the base of the Americus Limestone.

B. Measured section F_1, 7 feet above the base of the Americus Limestone.

C. Measured section F_1, 13 feet above the base of the Hughes Creek member.

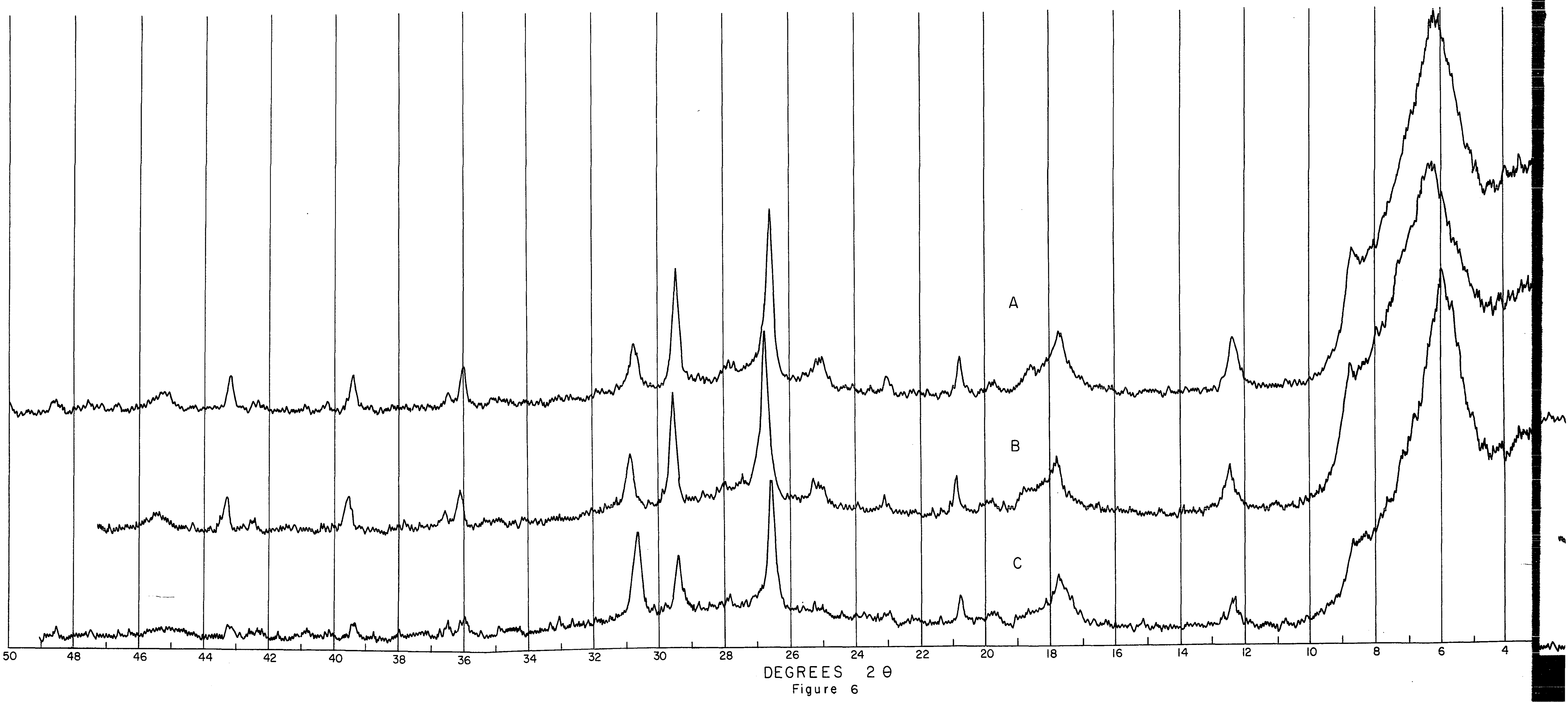

A
B
C
50
48
46
44
42
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
DEGREES 2 θ

Figure 6

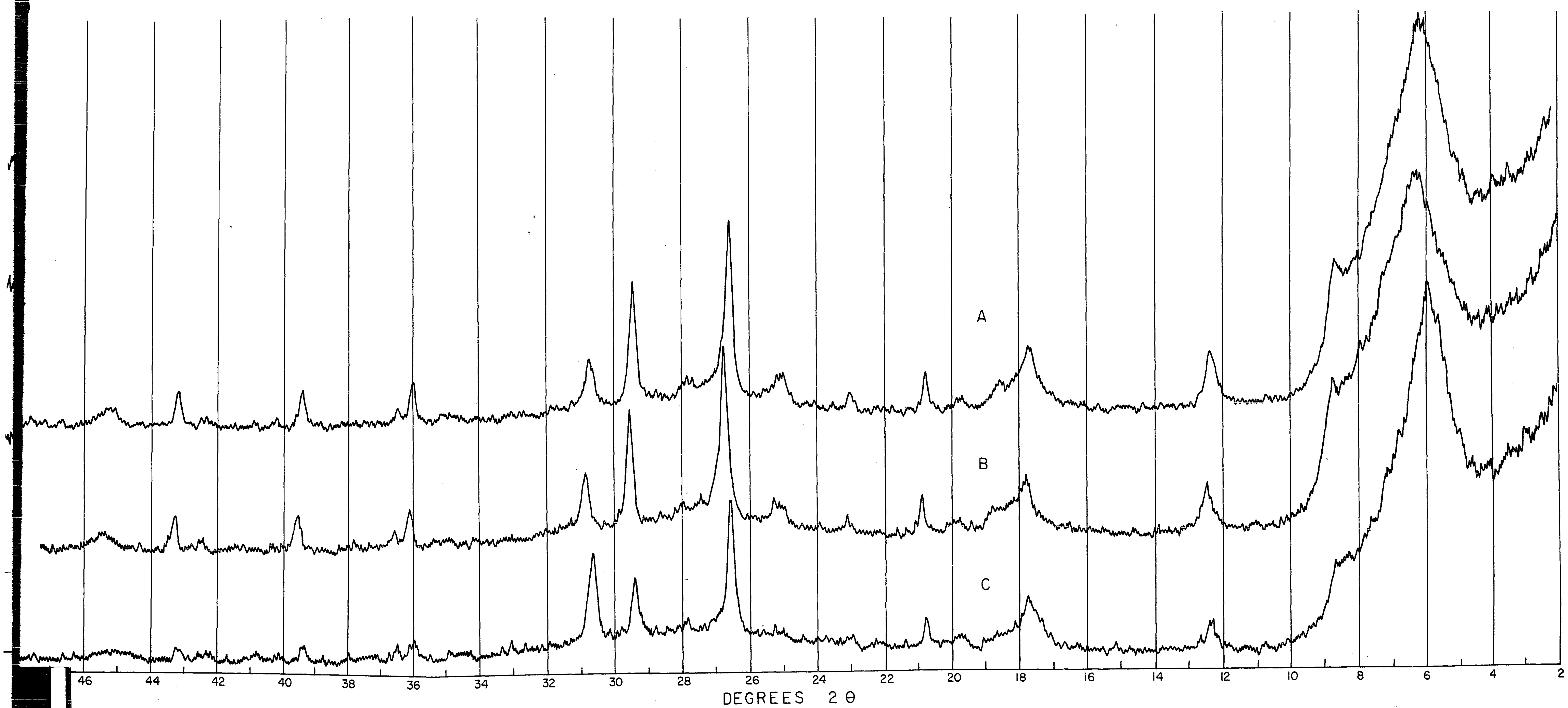

A
B
C
46
44
42
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
DEGREES 2 Θ

Figure 6

Figure 7

X-RAY DIFFRACTION PATTERNS SHOWING EFFECT OF

ETHYLENE GLYCOL BATH ON MONTMORILLONITE

Samples A and C of Figure 6 were treated in an ethylene glycol bath at 60°C for approximately 10 hours. Figure 7 shows that both A and C were expanded from 14 Å to approximately 17 Å. Cu K alpha radiation, (Ni filtered) at a setting of 35 Kv and 18 ma.

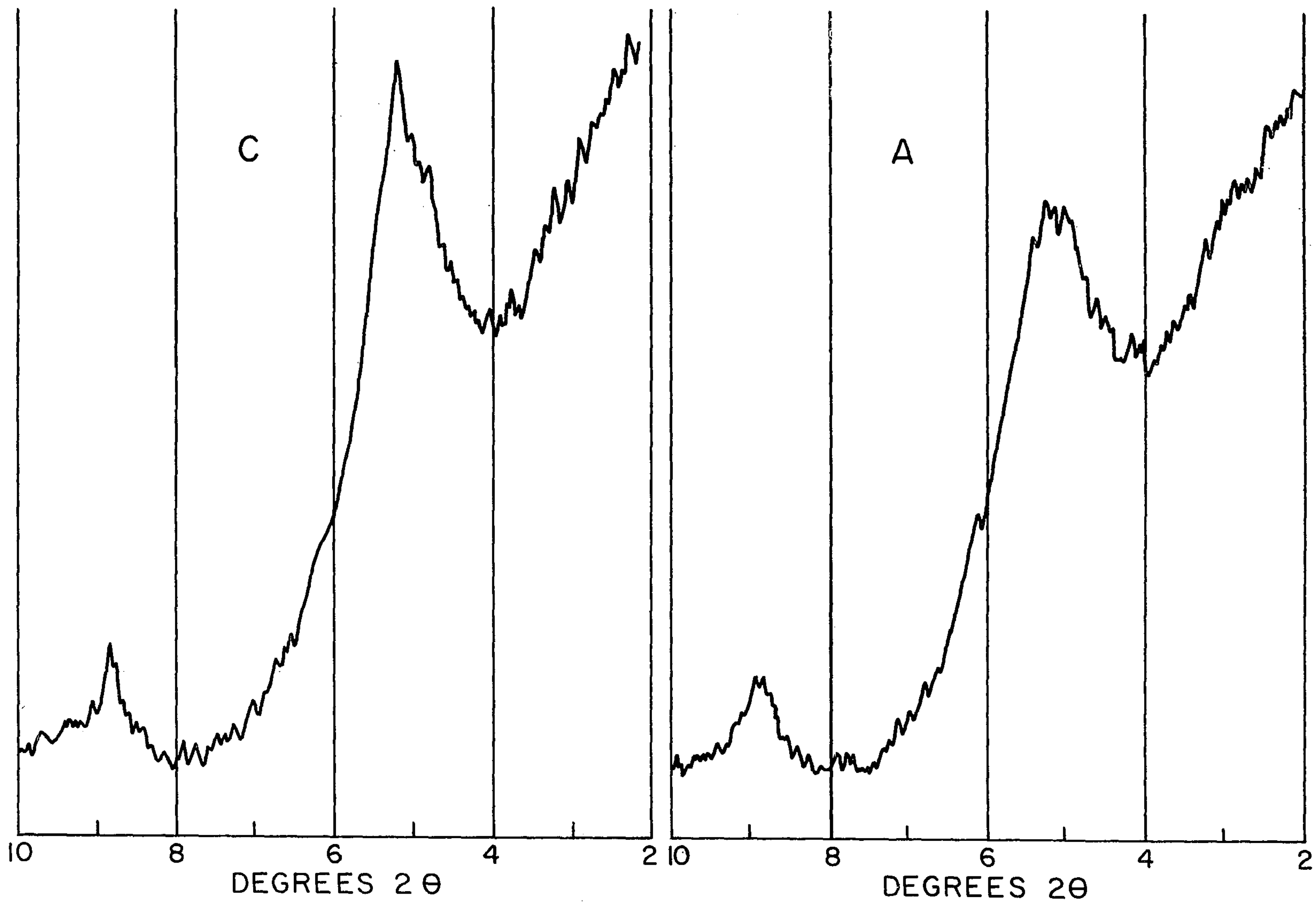


Figure 7

Figure 8

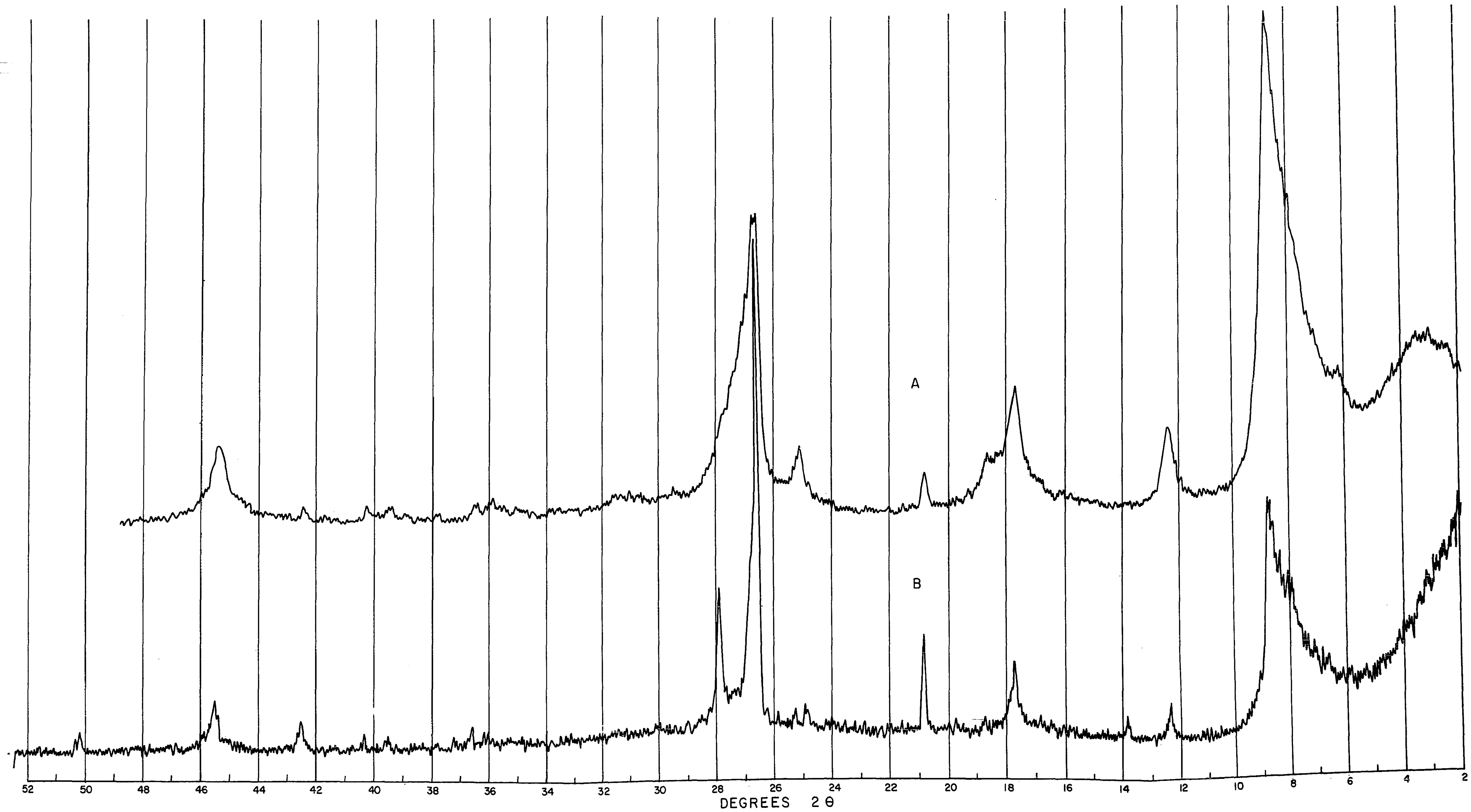
X-RAY DIFFRACTION PATTERNS SHOWING CLAY MINERALOGY

OF THE FORAKER FORMATION

Sedimented and powdered slides illustrating diffraction maxima of illite. Cu K alpha radiation, (Ni filtered) at a setting of 35 Kv and 18 ma.

A. Measured section F_1, 9 feet above the base of the Americus Limestone.

B. Measured section F_6, 9 feet above the base of the Americus Limestone. The X-Ray Pattern was run on the insoluble residue.


A
B
52 50 48 46 44 42 40 38 36 34 32 30 28 26 24 22 20 18 16 14 12 10 8 6 4 2
DEGREES 2 θ
Figure 8

the University of Oklahoma.

The rock samples (less than 80 mesh) were diluted with spectrographic grade graphite at a ratio of 1:9. The sample was then mixed and 5 milligrams were loaded into a graphite electrode and burned to completion in a DC arc of 5 amperes. The standards used were G standards and were diluted with spectrographic grade graphite and burned in the same manner as the samples. The instrument used was a Jarrell-Ash, 1.5 Ebert mount spectrograph. The spectra was recorded on 35 millimeter film and compared on a Jarrell-Ash micro-photometer.

The purpose of trace element analyses of the carbonate rocks was 1) to determine the abundance of some commonly occurring trace elements, 2) on the basis of obtained data to determine if these elements provide any information for a fuller understanding of the depositional environment, and 3) to determine the relationship of selected trace elements, especially strontium, with respect to the diagenesis of the carbonates.

The trace elements which were selected for semiquantitative analyses were: strontium, zirconium, copper, manganese, vanadium, and titanium. Table 3 illustrates the result of the analyses in parts per million.

TABLE 3

Trace Element Analysis of Carbonates (Foraker Formation)

Sample number	Concentration of Elements (parts per million)					
	Ti	V	Mn	Cu	Zr	Sr
F_1-1	75	50	200	75	ND	200
F_1-2	50	ND	200	1		400
F_1-3	50		75	75		400
F_1-4	100		350	75		600
F_1-5*	200	<5	300	75		900
F_1-6*	25	ND	75	<1		200
F_1-7	25	25	75	1		300
F_1-9	100	<5	250	50		300
F_1-10	100	ND	75	1	200	100
F_1-13*	75	<5	150	1	ND	200
F_1-14*	25	<5	75	<1		200
F_1-17	10	ND	50	10		300
F_1-18	75	<5	100	50		700
F_1-19	100	<5	75	1		400
F_1-24	50	ND	75	<1		400
F_1-26	25	10	50	<1		200
F_1-27	25	25	75	1		300
F_2-4	100	ND	300	50	100	400
F_2-5*	75		350	<1	ND	200
F_3-2	75		100	<1	10	300
F_3-3*	75		350	1	10	200
F_4-1	50		200	<1	ND	500
F_4-3*	50		100	<1		400
F_5-2	50		75	<1		200
F_5-5	75		350	1		500
F_6-1	75		700	1	10	100
F_6-4*	100		400	<1	ND	100
F_7-4	50		400	10		100
F_7-5	50	10	800	<1		400
F_7-6	75	25	800	1		50

* samples contain some solomite.

ND indicates not detected.

Manganese

The manganese content of the 30 carbonate samples varies from 50 to 800 parts per million, with an average of 245 parts per million. An extensive study by Ronov and Ermishkina (1959) regarding the manganese content of sedimentary rocks demonstrates the significance of this element as an indicator of paleo-climate. They reported that the manganese content of carbonate rocks formed in humid climates exceeds that formed in arid climates. The average Mn content of 3,967 carbonate rock samples which were regarded as having been formed in humid climates is 810 parts per million, and the average for more than 6,000 samples from arid climates is 320 parts per million. They concluded that the humid climate is characterized by having acid solutions rich in organic matter, and, consequently, the migration of manganese in such a solution could have traveled a greater distance and lasted for a longer period of time. The extensive erosion of fresh manganese from source rocks could have resulted in the migration of great amounts of bivalent manganese, which would precipitate as it came in contact with the higher pH of sea water. The presence of abundant inflowing fresh water would change the pH of sea water for quite a distance from the shore, and, consequently, the precipitation of manganese in the sediment would extend a great distance from the shore. In an arid climate, however, the sparse development of vegetation, low discharge of streams, and the slow process of weathering would result in oxidation of bivalent manganese and conversion to an immobile manganese of a higher valence (Mn^{+3}). Consequently, the migration of manganese in an arid climate is less, and its precipitation would occur near the shore.

The average manganese content of the 30 samples is 245 parts per million, which is slightly below the average value obtained by Ronov and Ermishkina for carbonate rocks of an arid climate. Considering the limited number of samples analyzed, the writer considers this average very near the average for arid-climate carbonates, and it is thus probable that the paleo-climate during the deposition of the Foraker Formation was arid.

The maximum manganese content in all the samples studied is associated with two samples which are rich in dolomite. Both samples contain 800 parts per million of manganese. A relevant question involves whether the manganese is an impurity in the rock or whether it is incorporated into the calcite or dolomite structures. The solid solution in the system $CaCO_3$-$MnCO_3$ is extensive, and many examples of manganoan calcites and calcian rhodochrosites are known (Goldsmith, 1959). Goldsmigh has shown a complete solid solution between zero and 50 mole percent $MnCO_3$ at temperatures down to approximately 400°C, and as a result he demonstrates that manganoan calcites may thus be formed at moderately low temperatures (Goldsmith, 1959, p. 340).

In the binary system of $MgCO_3$-$MnCO_3$, although the Mg^{++} and Mn^{++} cations differ in radius, the solid solution is extensive with the tendency for $MnCO_3$ to take up more $MgCO_3$ than vice versa (Palache, et al., 1951). The reason involves the fact that the radius of Mn^{++} (0.92 Å) is larger than Mg^{++} (0.78 Å) and, therefore, the smaller ion substitutes more readily in the site of the larger ion.

Frondel and Bauer (1955, p. 758) reported that an ordered compound of the dolomite-type between Mg and Mn appears to be as likely as that between Ca and Mn, because the difference in ionic radius in the two situations is identical.

Although it is not within the scope of this study to determine positively the nature of occurrence of Mn in the dolomitic sample, it is probable that the manganese is at least partly incorporated in the system of $MgCO_3$-$MnCO_3$ and $MnCO_3$-$CaCO_3$ and partly is associated with impurities in the carbonate rock.

Zirconium

Zirconium was detected in only five samples, varying in amounts from 10 to 200 parts per million. It is obvious from the obtained data that there are positive correlations between the insoluble residue of the carbonate rocks and the zirconium content; the percentage of zirconium increases with an increase in the insoluble residue content. The composition of the insoluble residue in these samples is quite similar. It is composed essentially of quartz, clay minerals (montmorillonite, illite, chlorite), and minor amounts of feldspars. Figure 9 shows the relationship between the insoluble residue content and zirconium concentration. Adams and Weaver (1958) also have shown, by analyses of many carbonate samples, that there is a linear relationship between zirconium and insoluble residue content. Degenhardt (1957, in Graf, 1960, p. 39) suggests that the entire zirconium content of carbonate rocks commonly is found in the insoluble residues.

The zirconium in the Foraker carbonates is possibly associated with clay minerals as a minor lattice component and with the heavy minerals as a trace amount of zircon.

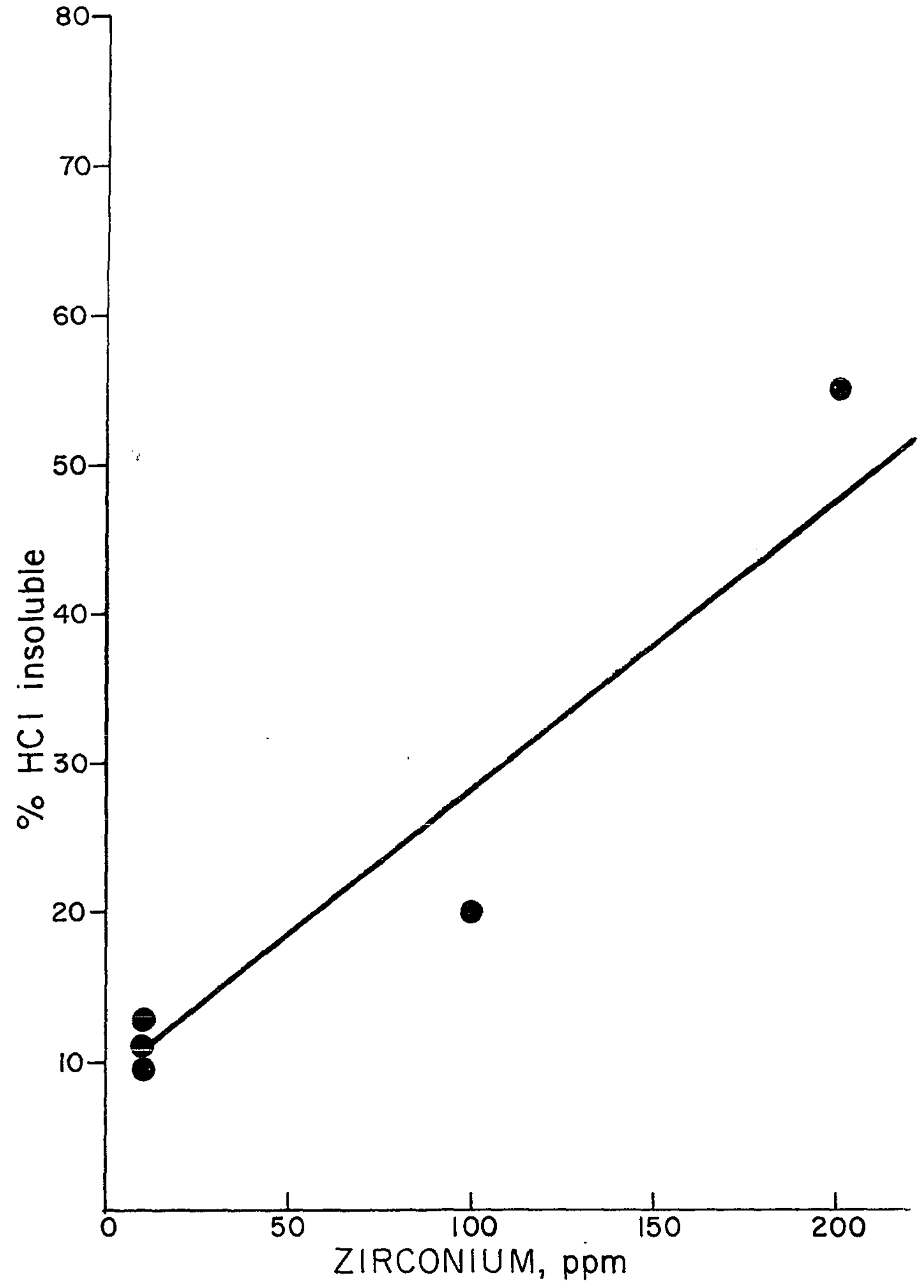
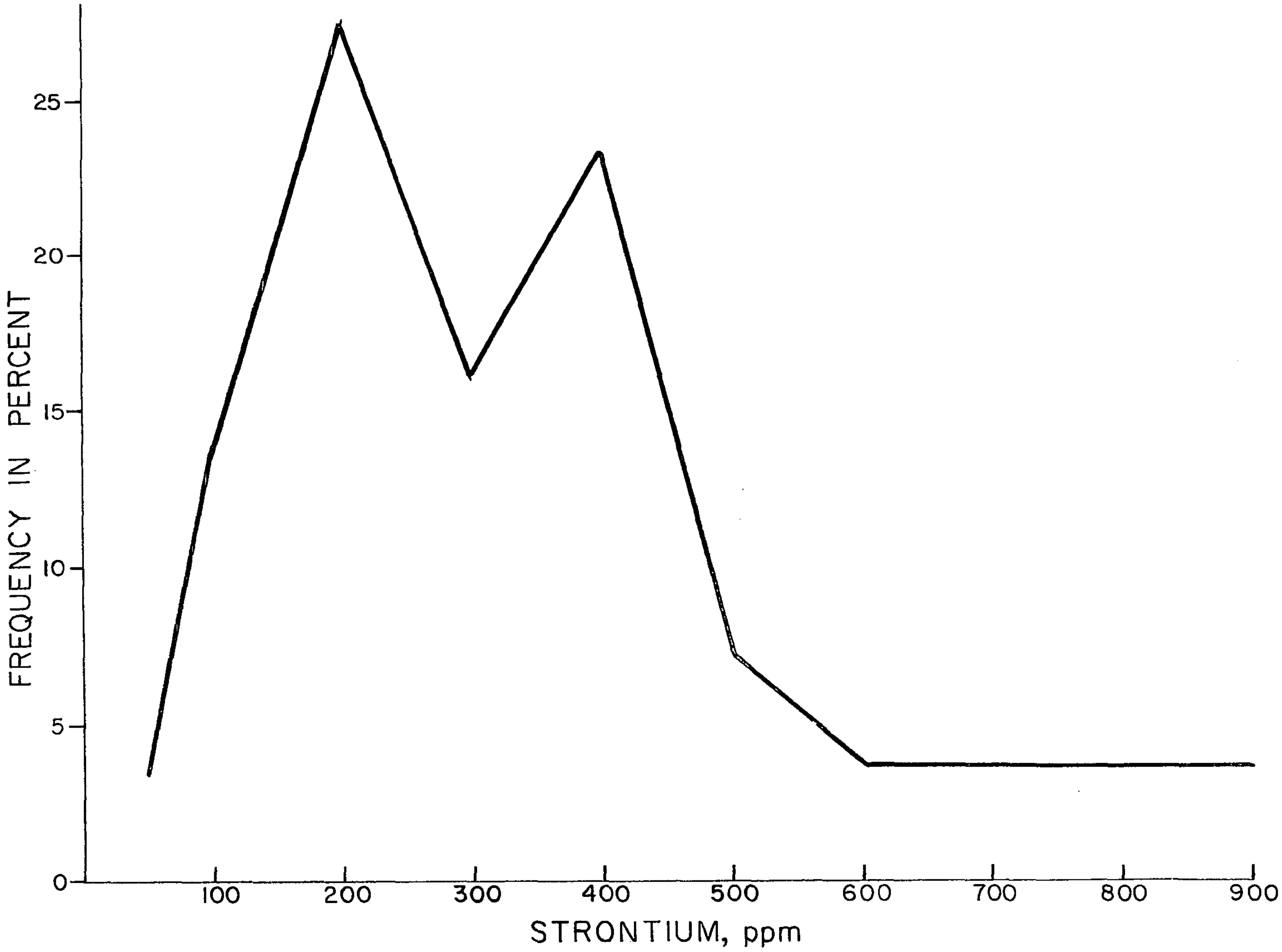

80
70
60
50
40
30
20
10
% HCl insoluble
0
50
100
150
200
ZIRCONIUM, ppm

Figure 9

Strontium

The strontium content of 30 carbonate samples was found to vary from 50 to 900 parts per million. A significant correlation exists between the strontium and the dolomite content of the samples. Twelve samples (Table 3) contain varying amounts of dolomite (determined by X-ray diffraction). Eight of the twelve dolomitized samples contain 50 to 200 parts per million strontium, which is less than the average strontium content of the "non-dolomitized" samples (350 parts per million). The lowest strontium content was found in F_7-6, which contains approximately 90 percent dolomite. This observation positively indicates a loss of strontium during the calcite-dolomite transformation. This conclusion is in agreement with Stout's analysis of Ohio dolomites (1941) which show a bimodal strontium distribution. He found that the low-strontium dolomites have no celestite, but the high-strontium samples contain measurable percentages. Graf (1960) also suggests that dolomite may contain either less or more strontium than limestone, depending upon whether celestite is present. In the dolomitized carbonate samples of the Foraker Formation no celestite was found.

Most of the strontium introduced in the carbonate


FREQUENCY IN PERCENT
25
20
15
10
5
0
100
200
300
400
500
600
700
800
900
STRONTIUM, ppm
Figure 10

sediments is substituted for Ca in the aragonite structure and to lesser extent in calcite. There is a tendency in the aragonite structure (orthorhombic) to accept larger cations than calcite (rhombohedral), and this tendency may be observed in a higher Sr content of aragonite than calcite. Cork and Gerhard (1931) have shown a complete miscibility of strontium in the orthorhombic structure.

On the basis of evidence from Recent carbonate sediments in which aragonite is always precipitated in preference to calcite (Cloud, 1960, in Kahle, 1965), many investigators (Cloud and Barnes, 1957; Ross and Dana, 1961; Brown, 1959, p. 265; Campbell; 1962, p. 495; Bergenback and Terriere, 1953, p. 1022) contend that aragonite is the primary precipitate, and during diagenesis is transformed to calcite or dolomite. This implies that the original carbonate sediment may have a higher strontium content and in the course of aragonite to calcite transformation, some strontium may be liberated from the carbonate sediments (Stehli and Hower, 1961; Turekian and Armstrong, 1961, p. 1818).

The average strontium content of many aragonite and calcite samples shows a positive indication for the tendency of larger amounts of strontium to be associated with aragonitic materials (Kahle, 1965, p. 847).

The strontium content of the Foraker Formation did not show a systematic relationship with the degree of recrystallization. Sternberg and others (1959) state that there is a systematic variation between the amount of strontium and degree of recrystallization; however, Kahle (1965, p. 854) from the analysis of 200 samples did not find such a relationship. The loss of strontium and other trace elements associated with carbonate sediments during recrystallization is well known, but this loss may be a transformation of strontium from allochem to interstitial fluids or cement. Therefore, the absence of any systematic variation in strontium content in the samples under study may mean that in the process of recrystallization the strontium is merely transferred from allochem to cement.

Vanadium

Vanadium was detected in only 11 samples, varying from less than 5 to a maximum of 50 parts per million. The highest amount of vanadium (50 ppm) was found in a sample which contains an abundance of pelecypods. However, no significant variation of vanadium is observed in these samples. Commonly the carbonate rock is low in vanadium content and according to Jost (1932, in Rankama and Sahama, 1949, p. 601) the average vanadium content of limestone and dolomite is less than 10 parts per million. Jost has established the presence of regional differences in the vanadium content of carbonate rocks. Bituminous limestones have the highest vanadium content of any carbonate. The apparent reason is that porphyrins in bituminous materials are preferentially complexed with either vanadium or nickel (Degen, 1965, p. 242).

Copper

The copper content of 70 percent of the samples varies from one to less than one part per million. The maximum amount of copper is 75 parts per million, which was found in four samples (Table 3). On the basis of the data obtained no significant variations exist in the distribution of copper in these samples. However, three of the four samples which have the highest amount of copper, contain abundant pelecypods, gastropods, and algae.

Rankama and Sahama (1949, p. 701) reported that copper is an essential element in hemocyanins, a respiratory pigment in the blood of many invertebrates, such as mollusks, crustaceans, and corals. Although this copper is in organic form, a portion would be deposited in the sediment and concentrated in the organic matter.

Although copper is disseminated widely, it seldom shows any enrichment in sedimentary rock, especially in carbonate rocks (Krauskopf, 1955), because it readily goes into solution or is adsorbed by clay minerals or organic matter.

Titanium

The titanium content for 30 analyzed samples varies from less than 10 to 200 parts per million. In this range, a characteristic feature is the tendency for some correlation between the insoluble residue content and titanium concentration. The percentage of HCl insoluble material increases with an increase of titanium for a majority of the samples. Degens (1965, p. 90) has shown that in sedimentary rocks, titanium is incorporated in the clay minerals as a lattice constituent or occurs in the form of finely disseminated cryptocrystalline TiO_2 needles in rutile, anatase, and brookite. Therefore, it is possible for the enrighment of titanium in these samples to be associated with either the clay minerals and/or accessory mineral fractions.

Other trace elements, such as boron, were detected only in one sample (10 parts per million) and, therefore, are not significant for the carbonate rocks in this area.

Sandstone Petrology

General Statement

The distribution of sandstone in the Foraker Formation is restricted to the Hughes Creek member. The thickness of sandstone shows a significant increase from north to south in the study area. The northernmost sandstone is exposed at Phillips Lake (type section, see outcrop map), where it is a well-cemented calcareous sandstone that has a thickness of approximately four feet. To the south of this outcrop, in measured sections F_3, F_2, and F_7, where the Hughes Creek member is exposed, the thickness of sandstone increases up to 40 feet (in F_7), and no carbonate cement is observed.

The sandstone shows even bedding planes, and the color varies from yellowish brown in the Phillips Lake area to pale orange in the southern part of the area.

Under the petrographic microscope as much as 90 percent of the quartz grains are single grains with straight to slightly undulose extinction. But in many samples a substantial amount of composite quartz with undulose extinction is observable. Inclusions are mostly microlites, which are present in most of the quartz grains. Feldspars, which form a minor constituent, are mostly weathered plagioclase and form up to two percent of the rock in some samples. Metamorphic rock fragments are present in some samples and commonly form less than three percent of the rock. The sandstones are mostly bonded with clay minerals and only in measured section F_1 is carbonate the dominant cement.

Statistical Analysis of Grain Size

Only four samples were analyzed by sieve analysis techniques because the sandstones in all measured sections are composed of a single lithic type and no significant variation in grain size or other field properties were observed. The samples were tested with hydrochloric acid to determine the presence of carbonate cement. Only one sample (F_1-12) had carbonate cement; a treatment with 10 percent hydrochloric acid was used to dissolve the carbonate cement. The samples were crushed with a mortar and pestle, then sieved at one-half phi intervals from 2 to 4.5 phi, using the mechanical Ro-tap for 20 minutes. Each size fraction was checked with a binocular microscope for aggregates, and then weighed. The weight percent and cumulative percent were calculated (Appendix C) and a cumulative curve plotted for statistical analysis. Graphic Mean (M_Z), Inclusive Graphic Standard Deviation (σ_I), Inclusive Graphic Skewness (SK_I), and Graphic Kurtosis (K_G) were calculated, using the formulae given by Folk (1959, p. 44-47).

Mean Grain Size (M_Z)

The mean size of the sandstone varies from 2.91 to 3.62 phi; fine sand to very fine sand, respectively.

Three sieved samples (F_2-1, F_3-4 and F_7-1) have a mean grain size between 3.50 and 3.62 phi, and only one sample has a value of 2.91 phi. A map (Fig. 11) was constructed to show the mean size vs. location of each sample. A characteristic feature of this map involves a decrease of grain size from north to south which does not correlate with the thickness of the sand. This observation suggests that the mean grain size is independent of the thickness and is related to the degree of transportation, but these results are based upon only four samples and their reliability is, therefore, open to question.

Inclusive Graphic Standard Deviation (σ_I)

Standard deviation, which is an inverse measure of sorting, varies from 0.36 to 0.68, and indicates a well sorted

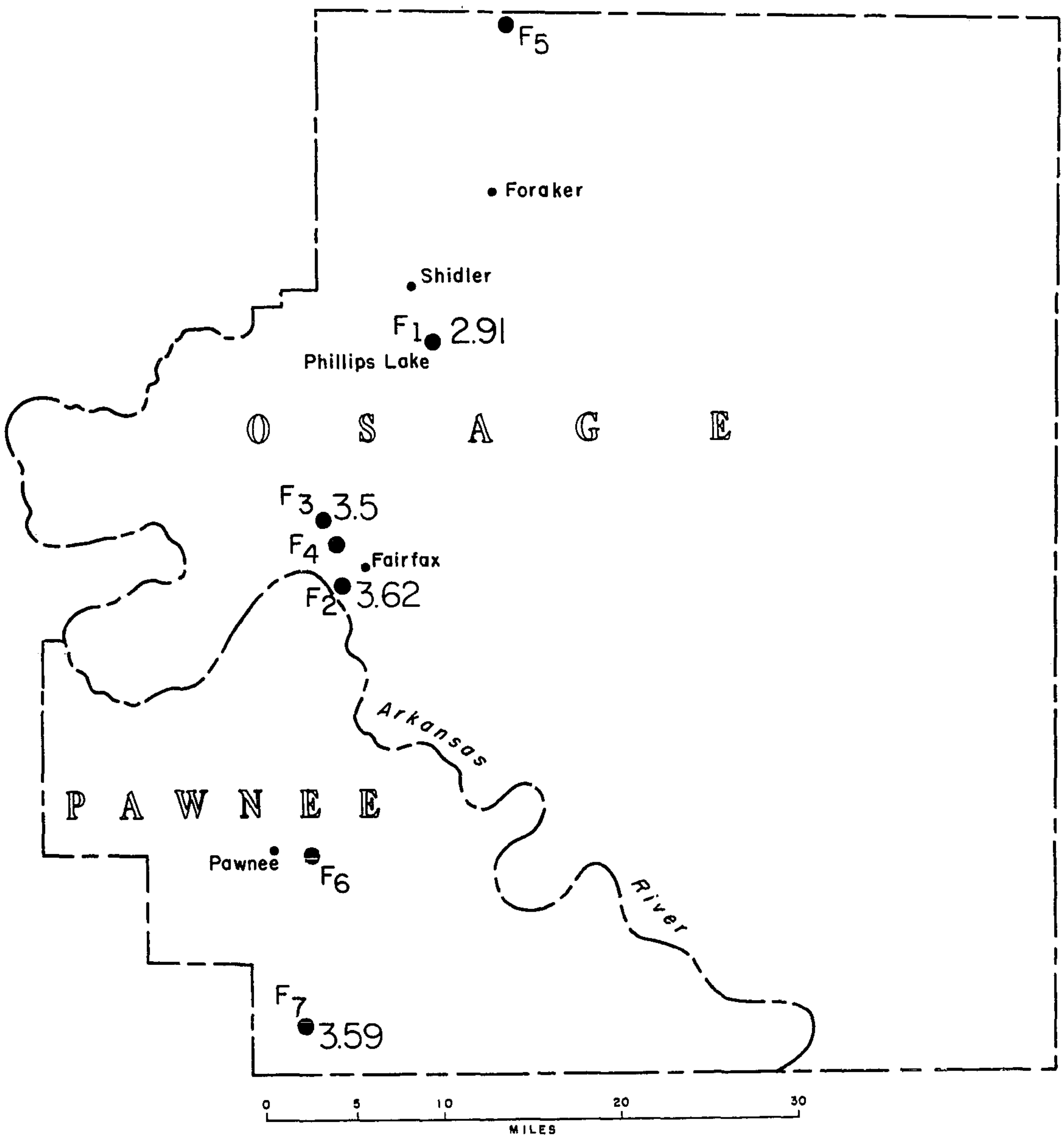


Figure 11. Mean Grain Size in Phi Units of the Hughes Creek Sandstone, North-central Oklahoma.

to moderately sorted distribution for these samples. Two of the samples, F_1-12 and F_7-1, have the standard deviation of 0.36 and 0.46, or within the range of well sorted sand. The other two samples, F_2-1 and F_3-4, have the same coefficient of 0.68, which indicates a moderately sorted sandstone. No significant trend exists in the sorting of the sandstones.

Inclusive Graphic Skewness (SK_I)

This coefficient which measures the symmetry of the frequency curve varies from -0.01 to 0.35. Two of the samples have the coefficient of -0.01, and thus fall in the class of near-symmetrical. The other two samples have a skewness of 0.23 and 0.35, or fine and strongly fine skewed. No significant pattern exists between the skewness of these samples and their locations. According to Friedman (1961), beach deposits have a negative skewness. The variation in the skewness of the samples may be an indication of different source areas or the mixing of different sedimentary fractions. Again the results are based upon too few observations.

Graphic Kurtosis (K_G)

Kurtosis, which measures the sorting of the central part of a curve in comparison to the sorting of the tails, varies from 0.821 to 1.3, platykurtic to leptokurtic. This deviation from a normal "Gaussian" curve may have been caused by introducing sediments from different sources. This observation is not supported, however, by the petrographic analysis of the sandstone.

Environment of Deposition

An interpretation of the depositional environment for the Foraker Formation was based largely on a detailed study of the carbonate rocks in conjunction with the terrigenous constituents.

Although the carbonate rocks form the main lithic type of this formation, in three measured sections a thick unit of sandstone is the dominant rock unit in the middle Foraker (Hughes Creek member).

The Americus Limestone contains an abundant fossil assemblage; mainly fusulinids, algae (*Osagia* sp. and *Stromatopora*), echinoderms, mollusks, and bryozoans (fenestrate forms), which are associated with a micrite matrix. The most distinguishing feature of this rock unit is the consistency in the faunal assemblage, matrix, and the textural features throughout the area under study. Recrystallization has been observed in nearly all samples. Dolomitization is relatively minor and only in a few samples was some dolomite identified by the petrographic microscope or X-ray diffraction methods.

Faunal constituents in the Americus member are commonly well preserved in most of the samples and in others, where they are fragmented, show no evidence of abrasion. Burrowing action by organisms, which is observed in many samples, seems to be the primary mechanism for fragmentation of the fossils. It is, therefore, the opinion of the writer that all the observations confirm the concept that the depositional environment of the Americus Limestone was a low energy area in which the carbonate mud (micrite) was precipitated. It is further believed that current or wave action was insufficient to winnow out the micrite.

An interesting observation in the carbonate rocks is the association of different faunal elements with a micrite matrix. Wade (1926, p. 21) suggests that pelecypods are primarily present in a high energy environment. Newell *et al*. (1951, p. 18, and 1959, p. 221-222) contend that gastropods are more abundant in high energy, near shore environments. Elias (1937, p. 410) indicated that an assemblage dominated by mollusks is indicative of a shallow marine environment. The writer, in the study of this unit, was unable to find any indication of a high energy environment, yet mollusks in many samples are abundant (F_1-1). Also, no indication was found of baffling effects by grass (Ginsberg and Lowenstam, 1958, p. 312-314) to confirm a local low-energy environment in a shallow water zone. However, in many samples where the dominant faunal elements are fusulinids, pelecypods, gastropods, and brachiopods are rare and algae are relatively abundant. This observation has also been confirmed by Kahler and Kahler (in Dunbar, 1957, p. 754) who have shown the same relationship between fusulinids and other faunal elements. They suggest that fusulinids avoided areas that were strongly colonized by larger organisms that utilized great amounts of calcium carbonate for shell construction. According to Dunbar (1957, p. 754), where different species of fusulinids are abundant and unabraded, they must have lived and accumulated on a quiet sea floor free from wave action and bottom currents capable of transporting and size grading the shells. The presence of preferred orientation in fusulinids (Plate 8, fig. 1) may, however, indicate a gentle bottom current.

On the basis of all data obtained for the Americus Limestone, the environment of deposition is interpreted to have been a broad shelf which fluctuated between terrigenous influx and carbonate deposition. It is, therefore, proposed that the carbonate facies of the Americus Limestone member which is distinguished by the general consistency of its faunal assemblage and micrite matrix be referred to as the "biomicrudite facies."

The beginning of deposition of the Hughes Creek member is marked with a more pronounced influx of terrigenous material, resulting in deposition of thick layers of sandstone. The sea apparently consistently regressed, especially in southern Osage and all of Pawnee County. The petrographic study and statistical analyses of the sandstone units reveal that, although the most abundant quartz type is single grains with straight extinction, composite and stretched quartz are also present. This may indicate that the quartz could have been derived from reworked sedimentary rocks to the east (C. J. Mankin, Oral Communication, 1966).

The presence of single-grained quartz with straight to slightly undulose and strongly undulose composite quartz grains may indicate plutonic and metamorphic rocks as ultimate source materials for the sandstone. Because the sandstone grades into shale to the west, it is inferred that the source must have been to the south and east of the are. This suggests the Ozark dome, Ouachita, and Arbuckle Mountains.

The mean grain size of quartz vs. location (Fig. 11) indicates a minor increase from northward in three samples (F_7, F_2, F_3), and a sharp increase in F_1, the northernmost sandstone outcrop. Two possible explanations are presented for this phenomenon. First, the source of all sandstone throughout the area was to the east, and the transportation within the depositional environment decreased the grain size from north to south. If this be true, the immediate source was the Ozark uplift, but according to Eardley (1962, p. 52), the Ozark dome was covered by Pennsylvanian transgression and thus would be eliminated as a possible source area. A second possible explanation is that all terrigenous material may have been supplied from source areas to the south. The Arbuckle Mountains and Ouachita Mountains are possible source areas in this direction. The lack of significant amount of feldspar and carbonate material in the sandstones of the Foraker Formation indicates that the Arbuckle Mountains, which are composed of thick carbonate units and igneous rocks, was not a major source area. The Ouachita Mountains, therefore, are the only possible source which could have supplied the thick beds of terrigenous material in the Foraker Formation. This explanation is substantiated by the similarity between the quartz types in rock units in the Ouachita Mountains, which have been described by Seely (1962, p. 117-118), and the Foraker Formation.

The regression of the sea during the deposition of the sandstone in the Hughes Creek member was followed by a transgression and deposition of shale and carbonate sediments. The petrographic study of the carbonate rocks show that some samples are micritic and others vary from micrite-bearing sparry calcite cement to a well washed sparry calcite rock type. Unlike the Americus Limestone, which is a biomicrudite throughout the area, the Hughes Creek is not a consistent sparry calcite-cemented facies; it changes vertically and horizontally locally to a micritic rock. Therefore, a single facies is not proposed for the Hughes Creek Limestone.

The faunal distribution in this member is similar to that of the Americus member, except that fusulinids are not so abundant throughout the area, but locally they are significant. The environment of deposition with respect to the Hughes Creek carbonate rocks shows a fluctuation in energy. A high energy environment is indicated by sparry calcite cement and highly abraded fossils. The low to moderate energy environment is suggested by the presence of micritic to micrite-bearing and unabraded to partially abraded fossils. In this environment, the energy was not sufficiently strong to winnow out all the micrite.

The Long Creek member is present in a few measured section, but absent in others due to weathering. The petrographic study of the Long Creek carbonate rocks revealed that they are, except in rare cases, a sparry calcite-cemented carbonate. A distinctive feature of the carbonate is that encrusting algae have coated most fossil fragments and grains. All the samples containing encrusting algae are cemented with sparry calcite (Plate 7, fig. 3, 4). Johnson (1942, p. 216, and 1945, p. 842) reported that encrusting algae form in shallow water. This interpretation is positively confirmed in the samples from the Long Creek member, where the encrusting algae (Osagia sp.) is associated with sparry calcite cement. All of the data obtained here suggest that the carbonate sediments composing the Long Creek member were deposited in a shallow, high energy, marine environment. Therefore, the writer wishes to propose that the carbonate rocks of the Long Creek member be referred to a "biosparrudite facies."

The trace element study of the Foraker Formation showed that in some cases it may have significance for a better understanding of the depositional environment. The distribution of manganese in the Foraker Formation suggests that the paleo-climate was arid (see the discussion regarding manganese). The strontium content of many dolomite samples suggests that in the process of dolomitization, some strontium was liberated.

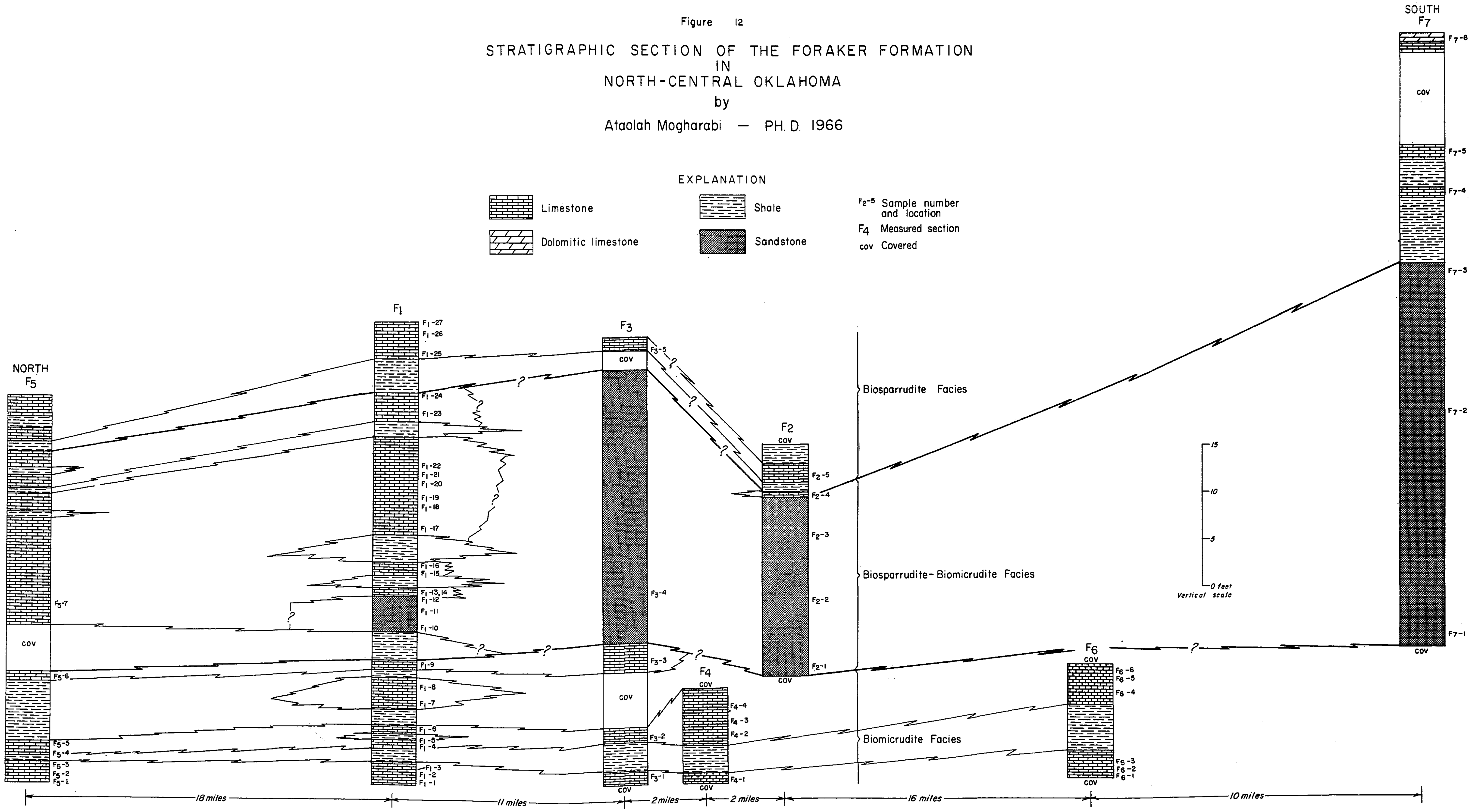
The early diagenesis of carbonate sediments has resulted in silicification, dolomitization, and recrystallization of the rocks. In the process of these changes, the carbonate rocks have undergone a substantial modification. Cementation of many carbonate samples indicates a possible period of subaerial exposure (Friedman, 1964) or an exposure to vadose water (see the discussion regarding cementation and cavity-filling).

Figure 12

STRATIGRAPHIC SECTION OF THE FORAKER FORMATION IN NORTH-CENTRAL OKLAHOMA

by

Ataolah Mogharabi — PH. D. 1966



CONCLUSION

The Foraker Formation in North-Central Oklahoma is composed mainly of a carbonate facies and lesser amounts of terrigenous material. The carbonates of the Americus member are a consistent "biomicrudite facies" throughout the area, and contain fusulinids as the dominant faunal element. Other fossils, such as mollusks, algae, brachiopods, echinoderms, and bryozoa are locally abundant. No significant correlation exists between the type of fauna and the rock type in the Americus member. However, it was observed that fusulinids avoided areas that were strongly colonized by larger fossils, and it is suggested that they lived in a quiet water environment.

The middle Foraker Formation is composed of carbonates in the northern part of the area and sandstone in the southern part. The petrographic and statistical analyses of the sandstone suggest that they are a beach type deposit that was derived from the Ouachita, Arbuckle, and/or Ozark Mountains.

The carbonate rocks of the Hughes Creek did not show a consistent lithology, and thus are postulated to have been deposited in a low to moderate energy environment, with minor high energy fluctuations.

The presence of chert in the form of nodules and beds in the Hughes Creek is significant, and occurs mostly in the northern parts of the area. The evidence suggests that the chert is of replacement origin.

The upper member of the Foraker Formation, the Long Creek, is composed mainly of carbonate and shale. The carbonate facies is predominantly homogeneous in fossil content and textural features and thus is here referred to as the "biosparrudite facies," which indicates a high energy and shallow water environment.

The trace element content of the carbonate rocks did not show a consistent pattern, but some elements, such as manganese and strontium, provide some information regarding the paleo-climate and diagenetic history. The average manganese content of the carbonate rocks is in the range of the average value obtained by Ronov and Ermishkina (1959) for carbonate rocks of an arid climate. It is thus probable that the paleo-climate during the deposition of the Foraker Formation was arid.

The strontium content of the dolomitized samples was commonly lower than the "non-dolomitized" samples. This indicates a loss of strontium during calcite-dolomite transformation. No systematic relationship was found between the strontium content of the rocks and the degree of recrystallization.

The clay mineral content of the shale was mostly montmorillonite, with some illite and minor amounts of chlorite.

The clay mineralogy of the Foraker Formation did not show any significant variation throughout the area. No environmental significance is therefore suggested for the clay minerals of this formation.

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APPENDIX A

MEASURED STRATIGRAPHIC SECTIONS

The Foraker Formation in North-Central Oklahoma has complete exposures in some areas and poor exposures in many others. Seven stratigraphic sections were measured by use of a tape. Columnar sections have been made for all measured sections and different units of the Foraker Formation have been correlated (Fig. 12). The vertical location of a sample in each stratigraphis section has been shown by a number, such as "5" and a prefix such as F_1. The "5" indicates the fifth sample from the base, and F_1 refers to the particular stratigraphic section.

Rock colors and their codes are those of the Rock Color Chart, 1948, distributed by the National Research Council, Washington, D. C.

Terminology for bedding thickness was used according to the classification by Ingmar (1954).

Section F_1: NW¼ sec. 10, T. 26 N., R. 6 E., Phillips Lake, Osage County, Oklahoma, measured from top of the hill south of the small wooden dam to the lower part of the spillway. Phillips Lake is located to the east of highway 18.

	Thickness (feet)
Americus Limestone	
Limestone, medium gray (N5), partially recrystallized, fossiliferous (algae, gastropods, brachiopods), thin bedded, dip 2-3 degrees W.	2.5
Shale, light gray (N7), platy, weathered	0.5
Limestone, shaly, light gray (N7), contains some brachiopods, crinoids, and some bryozoans	0.8
Shale, very platy, light gray (N7), thin bedded	0.6
Limestone, light gray (N7), shaly, compact, contains brachiopods, gastropods, and some bryozoans	0.8
Shale, medium gray (N5), calcareous, thin bedded	1.8
Limestone, light gray (N7), massive, contains fusulinids, bryozoans, and fragments of algae, crinoids, and brachiopods	3.2
Shaly limestone, light brownish gray (5 YR 6/1), abundant fusulinids	1.0
Limestone, yellowish gray (5 Y 7/2), massive, contains abundant fusulinids	1.0
Total unit thickness	12.2

	Thickness (feet)
Hughes Creek	
Shaly limestone to calcareous shale, yellowish gray (5 Y 7/2), partially compact and partially platy, abundant bryozoans and rare fusulinids	3.2
Sandstone, yellowish gray (5 Y 8/1), calcareous, no visible fossils or fossil fragments, excessive recrystallization	2.4
Sandstone, yellowish gray (5 Y 8/1), fine-grained, calcareous cement	1.4
Limestone, light olive gray (5 Y 5/2), contains some shale, brachiopod fragments, algae	0.8
Shale, medium gray (N5), very platy, no fossils	1.2
Limestone, light gray (N7), abundant fusulinids, massive, jointed, rough surface indications of solution activity	1.6
Shale, light gray (N7), exceptionally thin-bedded	2.8
Limestone, light brownish gray (5 YR 6/1), trace of fusulinids, recrystallized, abundant echinoderm fragments	1.2
Limestone, light olive gray (5 Y 6/1), large brachiopods, gastropods, algae, trace of fusulinids, partially recrystallized	3.0
Limestone, yellowish gray (5 Y 8/1), abundant fusulinids, replacement of limestone by chert nodules is extensive, cavities in the limestone, some of these vugs have been filled with dark gray chert, fusulinids have been completely replaced by chert	6.2

	Thickness (feet)
Shale, light brownish gray (5 YR 6/1), noticeably thin-bedded	1.5
Total unit thickness	25.3

Long Creek

Limestone, medium gray (N5), contains brachiopods, trace of fusulinids, abundant algae and echinoderms	3.2
Shale, medium gray (N5), partially covered ...	3.4
Limestone, yellowish gray (5 Y 6/1), contains fusulinids, echinoderms, and brachiopods	4.1
Total unit thickness	10.7
Total Formation thickness	48.2

Section F_2: NE¼ NE¼ sec. 14, T. 24 N., R. 5 E., Osage County, Oklahoma; measured section located in roadcut on south side of highway.

Americus Limestone

Limestone, medium gray (N5), weathered	1.5
Covered interval	5.5
Limestone, blue-gray, iron oxide stained, weathered	2.5
Shale, dark greenish gray (5 GY 4/1), platy ..	3.0
Total unit thickness	12.5

	Thickness (feet)
Hughes Creek	
Sandstone, yellowish gray (5 Y 7/2), exceedingly fine-grained, iron oxide stained	1.8
Covered interval (probably shale)	5.0
Sandstone, interbedded with shale, yellowish gray (5 Y 7/2), in places the sandstone contains shale specks, much limonite stain, massive, no variation in color or grain size .	12.5
Limestone, medium gray (N5), abundant pink fusulinids and small gray fusulinids, partially covered	0.5
Shale, light gray (N7), weathered	1.0
Limestone, light gray (N7), weathered, large fusulinids, no pink fusulinids similar to the lower limestone, large brachiopods, crinoid stems	2.0
Shale, greenish-gray (5 GY 6/1), weathered ...	2.0
Total unit thickness	24.8
Long Creek	
Limestone, light gray (N7), weathered, contains fusulinids, crinoid fragments, iron oxide stain	2.5
Covered interval	8.0
Shale, tan to light gray (N7)	2.5
Limestone, light brownish gray (5 YR 6/1), weathered, contains some fusulinids, crinoid stems, brachiopods, pelecypod fragments	2.0

	Thickness (feet)
Limestone, light gray (N7), locally contains some shale, some pink fusulinids, crinoid plates, extensively weathered	2.3
Total unit thickness	17.3
Total Formation thickness	54.6

Section F3: SE¼ sec. 35, T. 25 N., R. 5 E., Osage County, Oklahoma; measured section located at Fairfax Lake, on south side of spillway.

Americus Limestone

Limestone, light gray (N7), noticeable silicification, contains gastropods, crinoid stems, algae, and fusulinids. This exposure is extensively weathered	1.5
Shale, light gray (N7), calcareous	3.0
Limestone, yellowish gray (5 Y 8/1), abundant fusulinids, crinoid stems, bryozoans, extensive recrystallization	1.5
Covered interval	6.0
Limestone, yellowish gray (5 Y 7/2), contains some shale, fossil fragments, extensively weathered, partially covered	3.0
Total unit thickness	15.0

	Thickness (feet)
Hughes Creek	
Sandstone, light olive gray (5 Y 6/1), exceptionally fine-grained, soft, much limonite stain, no significant changes in color or grain size in total section	29.0
Covered interval	2.0
Limestone, yellowish gray (5 Y 8/1), weathered, abundant fusulinids, large brachiopods, extensive recrystallization	1.5
Total unit thickness	32.5
Total Formation thickness	47.5

Section F_4: NE¼ sec. 2, T. 24 N., R. 5 E., Osage County, Oklahoma; this section is measured near the railroad.

Americus Limestone	
Limestone, medium gray (N5), contains large brachiopods, algae, crinoid stems	1.0
Shale, light gray (N7), calcareous, abundant fossil fragments	3.0
Limestone, light gray (N7), abundant algae and fusulinids	2.0
Limestone, medium gray (N5), contains fossil fragments, especially brachiopods and crinoid stems	1.0
Limestone, light gray (N7), abundant pink fusulinids, large crinoid plates, algae	3.0
Total unit thickness	10.0

Section F_5: SW¼ sec. 16, T. 29 N., R. 7 E., Osage County, Oklahoma; this section is measured in the roadcut.

	Thickness (feet)
Americus Limestone	
Limestone, light gray (N7), contains abundant fusulinids in the upper part, crinoids, trace of gastropods and brachiopods	2.5
Shale, medium gray (N5), thin-bedded, calcareous	0.5
Limestone, light brownish gray (5 YR 6/1), abundant fusulinids, large crinoid plates, bryozoans, algae	1.5
Shale, greenish gray (5 GY 6/1), calcareous, laminated	6.5
Limestone, light gray (N7), fossil fragments, sandy, recrystallized	1.0
Total unit thickness	12.0
Hughes Creek	
Covered interval	5.0
Limestone, light gray (N7), partially silicified, abundant chert nodules, fusulinids and crinoids are mostly silicified and their structures are obliterated	4.0
Chert, yellowish gray (5 Y 8/1), weathered, thin bedded, some fusulinids have been completely silicified	0.5
Limestone, medium gray (N5), cherty, contains fusulinids, crinoids, gastropods	7.0

	Thickness (feet)
Shale, light gray (N7), weathered	0.5
Limestone, light gray (N7), massive, partly weathered, abundant fusulinids	2.0
Shale, light gray (N7), soft, thin-bedded	0.5
Total unit thickness	19.5

Long Creek

Limestone, light brownish gray (5 YR 6/1), extensively weathered, interbedded with shale ..	10.0
Total unit thickness	10.0
Total Formation thickness	41.5

Section F_6: SW¼ sec. 33, T. 22 N., R. 5 E., Pawnee County, Oklahoma; this section was measured along west side of Black Bear Creek, north of car-bridge. In this locality only the Americus Limestone of the Foraker Formation is exposed.

Americus Limestone

Limestone, light gray (N7), compact, partially recrystallized, fossils are rare, except for some algae	1.0
Limestone, medium gray (N5), thin-bedded, contains some very fine sandstone	2.0
Shale, light gray (N7), fossiliferous, thin-bedded	5.0

	Thickness (feet)
Limestone, light gray (N7), contains brachiopods, crinoids, bryozoans, trace of fusulinids, and some glauconite	4.0
Total unit thickness	12.0

Section F7: SE¼ sec. 23, T. 29 N., R. 5 E., Pawnee County, Oklahoma; measured section located along south section line. Americus member is covered at this section.

Hughes Creek

Sandstone, light brownish gray (5 YR 6/1), massive, in places contains some shale specks, some biotite; no significant change in color or other characteristics of this massive sandstone is observed throughout the section .	41.0
Shale, light gray (N7), exceptionally platy, weathered	7.0
Total unit thickness	48.0

Long Creek

Limestone, light gray (N7), fossiliferous, weathered	1.0
Shale, light brownish gray (5 YR 6/1) and interbedded greenish gray, weathered	3.0
Limestone, pale red (5 R 6/2), contains crinoid plates, brachiopods, glauconite, partially recrystallized, weathered	1.5
Covered interval (probably shale)	10.0

	Thickness (feet)
Limestone, light gray (N7), dolomitic, trace of crinoid plates	2.0
Total unit thickness	17.5
Total Formation thickness	65.5

APPENDIX B

THIN SECTION DESCRIPTION

The following detailed carbonate and sandstone descriptions were obtained from:

1. Thin section study with the use of a petrographic microscope.
2. X-ray diffraction.
3. Insoluble residue analysis.
4. Semi-quantitative analysis of the trace elements.
5. Sieve analysis of sandstones.

The first part of each description refers to thin section information, which includes sample number, stratigraphic position above the base, rock name (underlined), percentage of the most significant constituents, observations regarding texture, diagenesis, diagenesis fabric, and generalized names of most abundant fossils. Other data were obtained with the following techniques:

X-ray diffraction analysis, which is designated by "X-Ray" and describes pertinent mineral constituents of the sample.

Insoluble residue analysis is shown by "IR" and describes the percentage of the insoluble content of the sample.

Some samples were selected for trace element study. If a trace element analysis was run on a particular sample, the letters "TE" will be shown, with the results in parts per million (ppm).

Section F_1 ("F" refers to the Foraker): sec. 10, T. 26 N., R. 6 E., Phillips Lake, Osage County, Oklahoma, east of Highway 18.

Americus Limestone

F_1-1, One foot above the base, burrowed, skeletal, dolomitic biomicrite; 15% gastropods, 20% spicules, 5% algae, 5% pellets, 1% quartz with 100 micron mean size, extensive burrowing evident, fossils mostly recrystallized, cavity filling abundant.
X-Ray: calcite, quartz, and trace of dolomite
IR: 8.9%
TE (ppm): 50 Ti, 250 Mn, 1 Cu, 300 Sr.

F_1-2, 2 feet above the base, partially recrystallized, sparry calcite-bearing, crinoidal, algal biomicrudite; 8% algae, 2% crinoid plates, 1% fusulinids, some recrystallized gastropods, trace of spicules, in many places micrite has been cut by veins which are later filled with a drusy mosaic of calcite, fossils are mostly fragments possibly due to burrowing action, no appreciable amount of quartz present.
X-Ray: Calcite, trace of quartz.
IR: 0.7%
TE (ppm): 800 Mg, 50 Ti, 200 Mn, 1 Cu, 400 Sr.

F_1-3, 2.5 feet above the base, excessively burrowed, partially recrystallized, void-filling, spiculitic, microspar-bearing biomicrite; 10% spicules, 1% algae, some recrystallized brachiopod fragments which show only an outline,

20% of the matrix is recrystallized to microspar and coarse mosaic calcite, some gastropods, extensive void-filling by drusy mosaic along fracture zones.
X-Ray: Calcite, trace of quartz.
IR: 0.1%
TE (ppm): 50 Ti, 75 Mn, 75 Cu, 400 Sr.

F_1-4, 4.5 feet above the base, void-filling dolomitized micrite. More than 20% of the rock is drusy mosaic calcite which fills the voids, no significant fossils or fossil fragments present, some dolomite rhombs, 1% quartz with mean size of 50 microns.
X-Ray: Calcite, trace of dolomite, quartz, montmorillonite, kaolinite, illite, chlorite.
IR: 4%
TE (ppm): 10 B, 100 Ti, 350 Mn, 75 Cu, 600 Sr.

F_1-5, 5 feet above the base, partially recrystallized, microspar-bearing, dolomitic, gastropod biomicrite; 20% gastropods, 10% crinoids, 10% pelecypods, 5% pellets, most of the fossils are recrystallized, dolomite rhombs are abundant (5%) and are present around some microfractures, many geopetal structures, 1% quartz with 100 micron mean grain size.
X-Ray: Calcite, dolomite, quartz.
IR: 12.5%
TE (ppm): 200 Ti, $<$5 V, 300 Mn, 75 Cu, 900 Sr.

F_1-6, 5.5 feet above the base, sandy, recrystallized, dolomitic, spiculitic micrite; due to dolomitization and recrystallization no significant fossil content is preserved except ghosts of spicules and traces of fusulinids, clay minerals abundant, some parts of the rock have been silicified, quartz content 1% with 50 micron mean grain size.
X-Ray: Calcite, dolomite, and quartz.
IR: 29.7%
TE (ppm): 25 Ti, 75 Mn, $<$1 Cu, 200 Sr.

F_1-7, 7.7 feet above the base, recrystallized, fusulinid, dolomitic biomicrudite; 25% fusulinid (Triticites), 2% algae, 2% crinoid plates, 1% Foraminifera, 1% bryozoan, trace of quartz, minor gastropods, dolomitization occurs in matrix and some of the fusulinid septal pores,

extensive recrystallization has formed abundant microspars, some fibrous calcite.
X-Ray: Calcite, dolomite, quartz.
IR: 1.6%
TE (ppm): 25 Ti, 25 V, 75 Mn, 1 Cu, 300 Sr.

F_1-8, 11 feet above the base, burrowed, microspar-bearing, bryozoan, skeletal biomicrite; 20% algae, 3% crinoid plates, 3% fusulinids, 2% bryozoans, 1% Foraminifera, void-filling with abundant drusy mosaic, matrix shows extensive recrystallization, burrowing organisms caused the fossils to be highly fragmented, crinoids show some degree of abrasion, recrystallization fabrics such as coarse mosaic and syntaxial recrystallized rim around the crinoids are common, trace of quartz and dolomite rhombs.
X-Ray: Calcite, trace of dolomite, quartz.
IR: 8.5%

F_1-9, 13 feet above the case, brachiopod, bryozoan, molluscan, spiculitic, dolomitic biomicrudite; 10% bryozoans, 4% algae, 1% brachiopods, 1% crinoid plates, the largest bryozoan colony measured is 1.5 centimeters in length and 1.6 millimeters in width, silicification in some algae, some fibrous calcite, evidence of recrystallization of micrite to microspar, algae encrusting around bryozoans, minor dolomite.
X-Ray: Calcite, quartz, minor feldspar, and dolomite.
IR: 14%
TE (ppm): 100 Ti, $<$5 V, 250 Mn, 50 Cu, 300 Sr.

Hughes Creek

F_1-10, 3.5 feet above the base; very fine sandstone: poikilitic, calcite cemented, submature feldspathic orthoquartzite. Mean grain size 120 microns. The grains are not well sorted, angular to subangular, 40% poikilitic calcite cement. Quartz; mostly single grain with straight extinction, some composite grains have undulose extinction, microlites occur in most of the grains. One percent orthoclase and some plagioclase feldspars. 1% Zircon, trace of magnetite, hematite, tourmaline, 1% biotite, some bryozoan.

F_1-11, 5 feet above the base; very fine sandstone: poikilitic calcite cemented, submature feldspathic orthoquartzite. Mean grain size 130 microns. The grains are not well sorted, angular to subangular, calcite cement is more than F_1-10 (45%). Quartz; 90% single grains, straight and undulose extinction, microlites occur in a majority of the grains, remainder are composite grains with straight to undulose extinction. One percent fresh and weathered plagioclase feldspars. 1% biotite, trace of tourmaline and zircon.

F_1-12, 7 feet above the base; fine sandstone: poikilitic calcite cemented, submature orthoquartzite.
Graphic mean (M_Z): 2.91 Ø, fine sand.
Inclusive Graphic Standard Deviation (σ_I): 0.369 Ø moderately sorted.
Inclusive Graphic Skewness (SK_I): +0.35, fine skewed.
Graphic Kurtosis (K_G): 1.28, Leptokurtic.
Sparry calcite cement 40%, some fibrous calcite.
Quartz; 90% single grains with straight extinction, remainder composite grains with straight undulose and strongly undulose extinction. One per cent plagioclase feldspar, trace of biotite, tourmaline, and zircon.

F_1-13, 7.3 feet above the base, sandy, dolomitic micrite-bearing, encrusting algal, biosparrudite; 20% algae, 2% bryozoans, 1% foraminifera, 3% subangular quartz with 100 micron mean grain size, dolomite rhombs aboudant that have replaced the matrix, recrystallization has formed coarse mosaic calcite in matrix and most bryozoan autopores and molluscan fragments, silicification common in matrix, some fibrous calcite.
X-Ray: Calcite, dolomite (high intensity peak), quartz.
IR: 1.6%
TE (ppm): 75 Ti, $<$5 V, 150 Mn, 1 Cu, 200 Sr.

F_1-14, 8.5 feet above the base, burrowed, spiculitic, silicified, fusulinid biomicrudite; 25% fusulinids, 10% spicules, 5% crinoid plates, syntaxial recrystallized rim around crinoid plates, silicification has obliterated some of the fossils, especially fusulinids, extensive fossil fragments indicate burrowing action, trace of quartz.
X-Ray: Calcite, trace of quartz.
IR: 52.6% mostly chert and clay minerals.
TE (ppm): 25 Ti, 5 V, 75 Mn, 1 Cu, 200 Sr.

F_1-15, 10 feet above the base, burrowed, fusulinid, molluscan, algal biomicrudite; 15% fusulinids, 3% algae, 2% mollusks, 2% spicules, 2% Foraminifera, 1% ostracodes, 1% bryozoans, 1% quartz with mean grain size of 50 microns, abundant silicification in micrite and fusulinid septal pores, cavity filling common, especially in fusulinids (with microspar), syntaxial recrystallized rim on some crinoid plates, fusulinids show no preferred orientation, many spherical particles filled with drusy mosaic, possibly proloculus of Foraminifera.
X-Ray: Calcite, trace of quartz.
IR: 1%

F_1-16, 10.5 feet above the base, partially recrystallized, fusulinid, crinoidal biomicrite; 25% fusulinids, 3% Foraminifera, 2% bryozoans, 3% crinoid plates, trace of Foraminifers, some fibrous calcite, recrystallization is common, forms abundant coarse mosaic calcite, cavity filling with drusy mosaic calcite occurs in septal pores of the fusulinids.
X-Ray: Calcite, minor quartz.
IR: 0.6%

F_1-17, 14 feet above the base, cavity filling, fusulinid biomicrudite; 5% fusulinids (Triticites), 3% algae, 1% crinoid plates, 1% brachiopod fragments, 1% bryozoans, 25% of the rock is filled with drusy mosaic and granular cement, trace of quartz, trace of gastropods.
X-Ray: Calcite, minor quartz.
IR: 0.2%
TE (ppm): 10 Ti, 50 Mn, 10 Cu, 300 Sr.

F_1-18, 15 feet above the base, bryozoan, algal, crinoidal biosparrudite; 30% bryozoans, 20% crinoid plates and stems, 10% algae, minor Foraminifera and molluscan fragments, recrystallization is common, especially in most of the bryozoans.
X-Ray: Calcite, trace of quartz.
IR: 1%
TE (ppm): 75 Ti, $<$5 V, 100 Mn, 50 Cu, 700 Sr.

F_1-19, 17 feet above the base, bryozoan, algal biomicrudite; 15% bryozoans, 5% algae, 1% gastropods, minor ostracodes and molluscan fragments, recrystallization is common in matrix, cavity filling with drusy mosaic calcite is abundant, specially in bryozoan autopores.

X-Ray: Calcite, quartz.

IR: 7.5%

TE (ppm): 100 Ti, $<$5 V, 75 Mn, 1 Cu, 400 Sr.

F_1-20, 18 feet from the base, bryozoan, algal, crinoidal biomicrudite; 5% bryozoans, 5% algae, 3% crinoid stems and plates, minor ostracodes and molluscan, some recrystallization occurs in matrix, cavity filling with drusy mosaic calcite is common, some of the bryozoan autopores have been silicified, some encrusting algae around bryozoans, trace of phosphate.

X-Ray: Calcite, trace of quartz.

IR: 0.4%

F_1-21, 21 feet above the base, bryozoan, encrusting algal biomicrudite; 15% bryozoans, 10% encrusting algae mostly around bryozoans, 5% crinoid stems and plates, cavity filling with drusy mosaic calcite, recrystallization of micrite has formed coarse mosaics, minor silicification in a few crinoids, trace of quartz.

X-Ray: Calcite and appreciable amount of quartz.

IR: 28%

F_1-22, 23 feet above the base, extensively silicified fusulinid biomicrudite; 35% fusulinids, some ghosts of brachiopods. The rock is so highly silicified that the structure of the fossils is completely obliterated, matrix has also been extensively replaced by silica.

X-Ray: Calcite and high percentage of quartz.

IR: 28%

Long Creek Limestone

F_1-23, one foot above the base, algal-encrusting, crinoidal, brachiopod, Foraminiferal biosparrudite; 20% crinoid plates, 5% brachiopods, 5% Foraminifera, 2% gastropods, 1% fusulinids, 1% bryozoans, 2% ostracodes, all the fossils have been encrusted by algae (Osagia, Johnson, 1946), algal-encrusting around some coarse calcite mosaics is common, vein filling with drusy mosaic calcite is abundant.

X-Ray: Calcite, trace of quartz.

IR: 0.8%

F_1-24, 3 feet above the base, algal-encrusting, crinoidal, brachiopodal, foraminiferal biosparrudite; this is almost the same as F_1-23, 20% crinoid plates, 5% Foraminifera, 5% brachiopods, 2% gastropods, 2% bryozoans, trace of quartz, algal-encrusting (Osagia, Johnson, 1946) have coated fossils, many micro-fractures have been filled with granular calcite cement, large openings have been filled with drusy mosaic and drusy fibrous calcite.
X-Ray: Calcite, trace of quartz.
IR: 3.5%
TE (ppm): 50 Ti, 75 Mn, $<$1 Cu, 400 Sr.

F_1-25, 7 feet above the base, fusulinid, crinoidal, bryozoan, micrite-bearing biosparrudite, 40% fusulinids, 15% crinoid plates and stems, 8% bryozoans, 5% algae, 3% Foraminifera, 1% gastropods, most of the fossils show some abrasion, especially fusulinids, minor silicification, extensive recrystallization of micrite to coarse calcite mosaic, some classic examples of syntaxial recrystallized rims around crinoid plates.
X-Ray: Calcite, trace of quartz.
IR: 0.4%

F_1-26, 9 feet above the base, burrowed, algal, crinoidal, micrite-bearing biosparrudite; 30% algae, 10% crinoid plates and stems, 5% brachiopods, 2% gastropods, abundant fibrous calcite, minor silicification of some algae, burrowing is the main mechanism for fossils to be highly fragmented, evidence of burrowing in some crinoid plates is distinctive because the burrowed structure are filled with micrite, some good examples of geopetal structure with clear internal sediments in the floor and mosaic calcite on top, abundant cavity filling.
X-Ray: Calcite, minor quartz.
IR: 1.5%
TE (ppm): 25 Ti, 10 V, 50 Mn, $<$1 Cu, 200 Sr.

F_1-27, 10.5 feet above the base, burrowed, fusulinid, crinoidal, bryozoan, micrite-bearing biosparrudite; 25% fusulinids, 10% crinoid plates and stems, 5% bryozoans, 3% algae, minor Foraminifera, burrowing very common, some silicification, recrystallization results in abundant coarse calcite mosaic and microspar cavity filling with drusy mosaic, calcite septal pores of fusulinids with microspar is common.

X-Ray: Calcite, trace of quartz.
IR: 1.1%
TE (ppm): 25 Ti, 25 V, 75 Mn, 1 Cu, 300 Sr.

Section F_2: NE¼ sec. 14, T. 24 N., R. 5 E. Belford area, Osage County, Oklahoma, south side of the highway.

Hughes Creek Member

F_2-1, one foot above the base, very fine sandstone; hematitic, submature orthoquartzite.
Graphic mean (z): 3.61Ø; very fine sandstone.
Inclusive Graphic Standard Deviation (σ_I): 0.681Ø; moderately poorly sorted.
Inclusive Graphic Skewness (SK_I): -0.016; near symmatrical.
Graphic Kurtosis (K_G): 0.821; platykurtic.
Quartz; 95% single grains displaying mostly straight extinction and some undulose, remainder composite and undulose extinction. Two percent fresh and some weathered feldspars, 3% phosphate, trace of biotite and magnetite, cement is mostly hematite and siliceous material.

F_2-2, 8 feet above the base, fine sandstone: hematitic, submature orthoquartzite, mean grain size 130 microns, extremes, 60-300 micron, moderately sorted, grains are angular to subangular, hematite-cemented. Quartz; 90% single grain with mostly straight extinction and some undulose, remainder composite grains with mostly undulose extinction. Trace of zircon, one percent fresh and weathered plagioclase, trace of biotite, 2% metamorphic rock fragments.

F_2-3, 15 feet above the base, clayey, very fine sandstone: immature feldspathic orthoquartzite. Mean grain size 65 microns, poorly sorted, grains are angular to subangular, cemented by clay and hematite. Quartz; 90% single grains with straight to slightly undulose extinction, remainder are composite with straight to slightly undulose extinction. One per cent weathered plagioclase feldspars, 3% metamorphic rock fragments, 1% zircon, some biotite.

F_2-4, 19.5 feet above the base, partially recrystallized, sandy, fusulinid, foraminiferal, bryozoan biomicrudite; 40% fusulinids, 5% bryozoans, 5% Foraminifera, 2%

crinoids, 3% algae, 1% gastropods, 1% ostracodes. Most of the fusulinids show some degree of abrasion, Triticites rothi is the most abundant species, with maximum length of 4.2 mm, minor silicification in some of fusulinids, cavity filling with drusy mosaic calcite especially in septal pores of fusulinids, 4% single grain quartz with straight extinction.

X-Ray: Calcite, quartz.

IR: 21%

TE (ppm): 100 Ti, 300 Mn, 50 Cu, 100 Zr, 400 Sr.

F_2-5, 21 feet above the base, fusulinid, crinoidal, bryozoan, algal, dolomitized biomicrite; 30% fusulinids, 10% fenestrate bryozoans, 8% crinoid plates and stems, 3% encrusting-algae, trace of quartz, dolomitization is the most distinctive diagenetic process which has affected 15% of the matrix and fossils, especially the septal pores of fusulinids, some crinoid plates and bryozoans are dolomitized, abundant fossil fragments possibly due to burrowing, minor silicification present in some crinoid plates, syntaxial cement rim present around many crinoid fragments.

X-Ray: Dolomite (very high intensity peak), calcite (less than dolomite), quartz.

IR: 10.4%

TE (ppm): 75 Ti, 350 Mn, $<$1 Cu, 200 Sr.

Section F_3: SE¼, sec. 35, T. 25 N., R. 5 E., Section measured at Fairfax Lake, south side of spillway.

Americus Limestone

F_3-1, one foot above the base, burrowed, algal, crinoidal biomicrudite; 20% algae, 10% crinoid fragments, 5% bryozoan debris, 2% fusulinid fragments, 1% gastropods, 2% Foraminifera, minor ostracodes, fossils are extremely fragmented, abundant cavity filling with drusy mosaic calcite, syntaxial cement rim around crinoid plates common, minor silicification, evidence of recrystallization, abundant fibrous calcite.

X-Ray: Calcite, quartz.

IR: 15.3%

F_3-2, 5 feet above the base, extensively recrystallized, burrowed, fusulinid, crinoidal, algal, bryozoan biomicrudite; 20% fusulinids, 10% crinoid plates and stems, 5%

bryozoans (fenestrate), 5% algae, 2% Foraminifera, 1% ostracodes, extensive recrystallization has formed abundant microspar, coarse calcite mosaic, and syntaxial recrystallized rim around the crinoids. Burrowing is common.

X-Ray: Calcite, quartz.
IR: 10.2%
TE (ppm): 75 Ti, 100 Mn, < 1 Cu, 10 Zr, 300 Sr.

F_3-3, 13 feet above the base, pelleted, encrusting-algal, extensively recrystallized, dolomitic biomicrudite; 5% encrusting algae, 3% bryozoans coated with algae, 2% pellet, 1% gastropods, 1% molluscan fragments, minor ostracodes, 2% quartz with 80 micron mean grain size, dolomitization has affected 20% of rock. Microspar and coarse calcite mosaic are common as a result of recrystallization.

X-Ray: Calcite, dolomite, quartz.
IR: 13.2%
TE (ppm): 75 Ti, 350 Mn, 1 Cu, 200 Sr.

Hughes Creek Member

F_3-4, 5 feet from the base, very fine sandstone: siliceous, submature orthoquartzite.

Graphic Mean (M_z): 3.50Ø; very fine sandstone.
Inclusive Graphic Standard Deviation (σ_I): 0.681Ø; moderately poorly sorted.
Inclusive Graphic Skewness (SK_G): 0.23; fine skewed.
Graphic Kurtosis (K_G): 0.821; platykurtic.
Quartz 85%; single grains with mostly straight extinction, some slightly to strongly undulose extinction, abundant quartz overgrowths, microlites are the most abundant inclusions in the quartz. Other minerals: one per cent weathered plagioclast feldspar, < 1% zircon, trace of apatite, 1% metamorphic rock fragments. Cement is clay and hematite.

F_3-5, 32 feet above the base, burrowed, algal, crinoidal, bryozoan biomicrudite; 20% algae, 15% crinoid plates and stems, 5% bryozoans, 1% gastropods, minor fusulinid fragments, silicification in some crinoids, extensive burrowing which has concentrated highly fragmented fossils, recrystallization of some micrite to microspar and

coarse mosaic calcite, some cavity filling with drusy mosaic calcite, some fibrous calcite.
X-Ray: Calcite, trace of quartz.
IR: 11% (abundance of clay)

Section F_4: NE¼ sec. 2, T. 24 N., R. 5 E., Belford area, Osage County, Oklahoma; section measured near the railroad.

Americus Limestone

F_4-1, 0.5 foot above the base, partially recrystallized, encrusting-algal, micrite-bearing biosparrudite; 20% encrusting algae, 5% crinoid plates. A distinctive feature of this rock is recrystallization that has completely obliterated the structure of the fossils, in some instances, only a ghost being present, at least 50% of the micrite and 95% of the fossils are recrystallized.
X-Ray: Calcite, trace of quartz.
IR: 0.5%
TE (ppm): 50 Ti, 200 Mn, $<$1 Cu, 500 Sr.

F_4-2, 5 feet above the base, pelleted, encrusting-algal, foraminiferal, partially recrystallized biomicrudite; 15% encrusting algae, 5% crinoid plates, 5% Foraminifera, 15% pellets, 1% gastropods, 2% ostracodes, 1% quartz with 100 micron mean grain size, some micrite recrystallized to microspar and coarse mosaic calcite, some evidence of cavity filling with drusy mosaic calcite, some evidence of burrowing.
X-Ray: Calcite, quartz.
IR: 6%

F_4-3, 6.5 feet above the base, burrowed, void-filling, dolomitic, crinoidal, bryozoan, algal biomicrudite; 20% algae, 8% crinoid plates and stems, 5% bryozoans, 1% gastropods, 2% fusulinids, 10% dolomitization, abundant void-filling with drusy mosaic calcite, trace of glauconite and phosphate, minor quartz with 30 micron mean grain size, the presence of highly fragmented fossils suggests the effect of burrowing organisms.
X-Ray: Calcite, dolomite, trace of quartz, and feldspar.
IR: 4.8%
TE (ppm): 50 Ti, 100 Mn, $<$1 Cu, 400 Sr.

F_4-4, 8 feet above the base, crinoidal, fusulinid biomicrudite, 30% crinoid plates, 20% fusulinids, 3% bryozoans, 1% gastropods, 1% Foraminifera, 3% spicules, 1% ostracodes, evidence of burrowing, extensive microfractures, many cavity-fillings with drusy mosaic calcite, some recrystallization. The fusulinids show some preferred orientation.
X-Ray: Calcite, quartz.
IR: 9.2% (abundance of clay).

Section F_5: SW¼ sec. 16, T. 29 N., R. 7 E., Foraker Area, Osage County, Oklahoma.

Americus Limestone

F_5-1, one foot above the base, partially recrystallized, micrite-bearing, fusulinid, encrusting-algal, foraminiferal biosparrudite; 20% fusulinids, 5% Foraminifera, 8% encrusting algae, 5% crinoid plates, 3% bryozoans, 1% ostracodes, 3% intraclasts, 3% quartz with 70 micron mean grain size. Many fossils, especially fusulinids, are abraded, matrix and fossils show rather extensive recrystallization, minor replacement of calcite by chert, minor burrowing.
X-Ray: Calcite, quartz.
IR: 12%

F_5-2, 1.5 feet above the base, partially recrystallized, algal, fusulinid, crinoidal, foraminiferal, bryozoan, micrite-bearing biosparrudite; 40% algae, mostly small fragments and some encrusting bryozoan and other fossils, 5% fusulinids, 10% crinoid plates, 5% Foraminifera, 1% gastropods, trace of glauconite, some pellets, many fossil fragments showing some abrasion, some micrite recrystallized to microspar and coarse mosaic calcite.
X-Ray: Calcite, quartz.
IR: 3%
TE (ppm): 50 Ti, 75 Mn, $<$1 Cu, 200 Sr.

F_5-3, 2 feet above the base; partially recrystallized, cavity filling, algal, fusulinid, crinoidal, foraminiferal, bryozoan, micrite-bearing biosparrudite; similar to F_5-2, 35% algae, 15% fusulinids, 15% crinoid stems and plates, 5% bryozoans, 3% Foraminifera, some brachiopod fragments, cavity filling with drusy mosaic calcite

is a distinctive feature of this rock, recrystallization of micrite to coarse calcite mosaic, minor silicification.
X-Ray: Calcite, quartz.
IR: 4.5%

F_5-4, 4 feet above the base, burrowed, fusulinid, algal, bryozoan, foraminiferal, crinoidal biomicrudite; 20% fusulinids, 15% algal fragments, 10% crinoid plates and stems, 5% bryozoans, 3% Foraminifera, 1% ostracodes, 1% quartz with 50 micron mean grain size, burrowing common which results in extensive fossil fragmentation, expecially in fusulinids, minor silicification in some fibrous calcite, evidence of cavity filling and also rim cementation around many crinoids.
X-Ray: Calcite, quartz.
IR: 3%

F_5-5, 4.5 feet above the base, burrowed, partially recrystallized fusulinid, algal, crinoidal, bryozoan, foraminiferal biomicrudite; 30% fusulinids, 10% algae, 5% crinoid stems, 3% bryozoans, 2% Foraminifera, 1% ostracodes, many fossils, especially fusulinids, are highly fragmented due to the effect of the burrowing organisms, abundant cavity filling with drusy mosaic, some crinoids show rim cementation and some show syntaxial recrystallized rims with minor replacement of calcite by chert, many veins are filled with drusy mosaic calcite.
X-Ray: Calcite, quartz.
IR: 3%
TE (ppm): 75 Ti, 350 Mn, 1 Cu, 500 Sr.

F_5-6, 11.5 feet above the base, sparry, calcite-bearing, dolomitized, foraminiferal pelmicrite; 30% pellets, 5% Foraminifera, 2% crinoid debris, 5% spicures, 1% ghosts of bryozoans, 10% quartz with 40 micron mean grain size, 3% ghosts of algae, the most distinctive diagenetic process is dolomitization, which has affected 30% of the rock, some microfractures have been filled with granular cement.
X-Ray: Calcite, dolomite, quartz.

Hughes Creek

F_5-7, 6 feet above the base, extensively silicified, fusulinid, crinoidal, spiculitic biomicrudite; 8% fusulinids,

5% crinoid fragments, 2% encrusting algae. The most prominent feature of this rock is extensive silicification which has obliterated the structure of the fossils and matrix, the wall of all fusulinids are composed of chert. Cavity fillings with typical examples of drusy mosaic normal to the wall of cavities are abundant.
X-Ray: Calcite, quartz.

Section F_6: SW¼ sec. 33, T. 22 N., R. 5 E.; section measured along west side of Bear Creek.

Americus Limestone

F_6-1, 0.5 foot above the base, burrowed, partially recrystallized, cavity-filled, sparry calcite-bearing, foraminiferal pelmicrite; 30% pellets with 40 micron mean grain size, abundant ghosts of fossil fragments is caused by recrystallization, extensive recrystallization has formed microspars and coarse calcite mosaic, cavity filling with drusy mosaic calcite in many fossils.
X-Ray: Calcite, quartz.
IR: 2% mostly quartz.
TE (ppm): 75 Ti, 700 Mn, 1 Cu, 10 Zr, 100 Sr.

F_6-2, one foot above the base, extensively recrystallized, ostracodal, pelletiferous biomicrite; 20% ostracode fragments, 5% pellets, trace of crinoid plates and bryozoans, 90% of the rock is recrystallized to microspars and coarse mosaic calcite and, as a result, no definite structure may be observed in the fossils, some cavity filling with drusy mosaic. 1% quartz with 60 micron mean grain size.
IR: 5%
TE (ppm): 50 Ti, 75 Mn, 1 Cu, 200 Sr.

F_6-3, 1.5 feet above the base, extensively recrystallized, sparry calcite-bearing, ostracodal biomicrite; very similar to F_6-2, 20% ostracodes, 5% pellets, 2% spicules, bryozoan fragments are abundant, 90% of the rock is completely recrystallized and all of the fossils have been obliterated, recrystallization fabrics are coarse mosaic calcite and microspars, cavity filling very common, 3% quartz with 50 micron mean grain size.
X-Ray: Calcite, quartz.
IR: 7%

F_6-4, 9 feet above the base, burrowed, partially recrystallized, sandy, brachiopodal biomicrite; 5% algal fragments, 3% bryozoans, 5% brachiopods, 1% ostracodes, 1% fusulinids, 2% crinoid plates, 5% quartz with 40 micron mean grain size, burrowing has resulted in abundant fossil fragments, recrystallization is very common, in four brachiopods the progress of this process may be observed, abundance of fibrous calcite.
X-Ray: Calcite, quartz.
IR: 17% with abundant clays.
TE (ppm): 100 Ti, 400 Mn, $<$1 Cu, 100 Sr.

F_6-5, 10 feet above the base, sandy, partially recrystallized, micrite-bearing, brachiopodal, algal biosparrudite; 5% brachiopod fragments, 5% algae, 2% bryozoans, 8% crinoid stems and plates, 1% gastropods, 6% quartz with 40 micron mean grain size, trace of glauconites, some evidence of burrowing, some micrite recrystallized to microspars and coarse calcite mosaics, abundance of micro-fracture filled by iron oxides, trace of fusulinids.
X-Ray: Calcite, quartz.
IR: 8% (mostly quartz).

F_6-6, 11 feet above the base, partially recrystallized, micrite-bearing, burrowed, crinoidal, algal biosparrudite; 10% crinoid stems and plates, 2% brachiopod fragments, 10% algae, 2% bryozoans, 2% fusulinids, trace of gastropods and Foaminifera, 3% quartz with 40 micron mean grain size, some micrite recrystallized to microspars, minor silification, some cavity filling with drusy mosaic calcite.
X-Ray: Calcite, quartz.
IR: 8.8% (abundance of quartz).

Section F_7: sec. 23, T. 20 N., R. 5 E.; section measured along south section line.

Hughes Creek Member

F_7-1, one foot above the base, very fine sandstone: immature orthoquartzite.
Graphic Mean (M_Z): 3.596Ø, very fine sand.
Inclusive Graphic Standard Deviation (σ_I): 0.468Ø, moderately sorted.

Inclusive Graphic Skewness (SK_I): -0.016, near symmetrical.
Graphic Kurtosis (K_G): 1.305, leptokurtic. Quartz 95% single grain, with mostly straight extinction, some slightly undulose extinction. One per cent weathered plagioclase feldspars, 4% metamorphic rock fragments, minor tourmaline, 8% clay material.

F_7-2, 25 feet above the base, very fine sandstone: immature orthoquartzite. This sample is very similar to F_7-1. Quartz; 80% single grain with mostly straight extinction, some slightly and strongly extinction, abundance of overgrowth quartz, many quartz grains have microlite inclusions. Three per cent weathered plagioclase and orthoclase feldspars, 5% metamorphic rock fragments, 1% biotite, trace of tourmaline, 10% clay which cemented the quartz.

F_7-3, 40 feet above the base, very fine sandstone: immature orthoquartzite. Mean grain size 90 micron, angular to subangular quartz; 80% single grain, 20% composite, most of the grains display strongly undulose extinction, 30% of the quartz are fractured, 5% metamorphic rock fragments, some biotite. Cement is mostly clay and some hematite.

Long Creek Limestone

F_7-4, 0.5 foot above the base, glauconitic, dolomitized, partially recrystallized, crinoidal, algal biosparrudite; 15% crinoid plates and stems, 10% algae, 3% bryozoans, 3% quartz with 40 micron mean size, 3% glauconite, dolomitization has obliterated the fossils, some micrite has been recrystallized to microspars and coarse calcite mosaic.
X-Ray: Calcite, dolomite, quartz.
IR: 5.5%
TE (ppm): 50 Ti, 400 Mn, 10 Cu, 100 Sr.

F_7-5, 5 feet above the base, sandy, dolomitized, partially recrystallized, crinoidal biosparrudite; 10% crinoid plates and stems, 2% bryozoans, 2% quartz with 50 micron mean grain size, 3% glauconite, 1% algae, abundance of siderite and limonite, cavity filling with drusy mosaic, granular cement very common, recrystallization has caused most of the fossils to be obscured, abundant micro-fractures are filled by limonite, dolomitization is a distinctive feature in this sample.

X-Ray: Dolomite, calcite, quartz.

IR: 3%

TE (ppm): 50 Ti, 10 V, 800 Mn, $<$1 Cu, 400 Sr.

F_7-6, 17 feet above the base, sandy, coarsely crystalline, biogenic dolomite, 80% of this rock is dolomitized and results in grains of 40 micron mean size. No fossil structure may be observed, except crinoid plates, which mostly show partial dolomitization, some show only a ghost. Many evidences show that this dolomite is not primary, having replaced micrites and fossils. Other minerals are: 3% quartz with 50 micron mean grain size, 3% glauconite.

APPENDIX C

STATISTICAL DATA - SIEVE ANALYSIS

APPENDIX C

STATISTICAL DATA - SIEVE ANALYSIS

F1-12

Size (Phi units)	Weight (Grams)	%	Cum. %
2.5Ø	2.36	3.815	3.815
3.0"	38.35	61.99	65.81
3.5"	15.53	25.10	90.92
4.0"	3.40	5.50	96.42
4.5"	1.49	2.40	98.83
<4.5"	0.72	1.16	99.99

Mean Grain Size = 2.91Ø, Standard Deviation = 0.369Ø, Skewness = +0.35, Kurtosis = 1.28.

F2-1

Size (Phi units)	Weight (Grams)	%	Cum. %
2.5Ø	1.37	2.03	2.03
3.0"	16.94	25.12	27.15
3.5"	7.55	11.20	38.35
4.0"	26.74	39.66	78.01
4.5"	5.23	7.75	85.76
<4.5"	9.59	14.22	99.98

Mean Grain Size = 3.61Ø, Standard Deviation = 0.681Ø, Skewness = -0.016, Kurtosis = 0.821.

F3-4

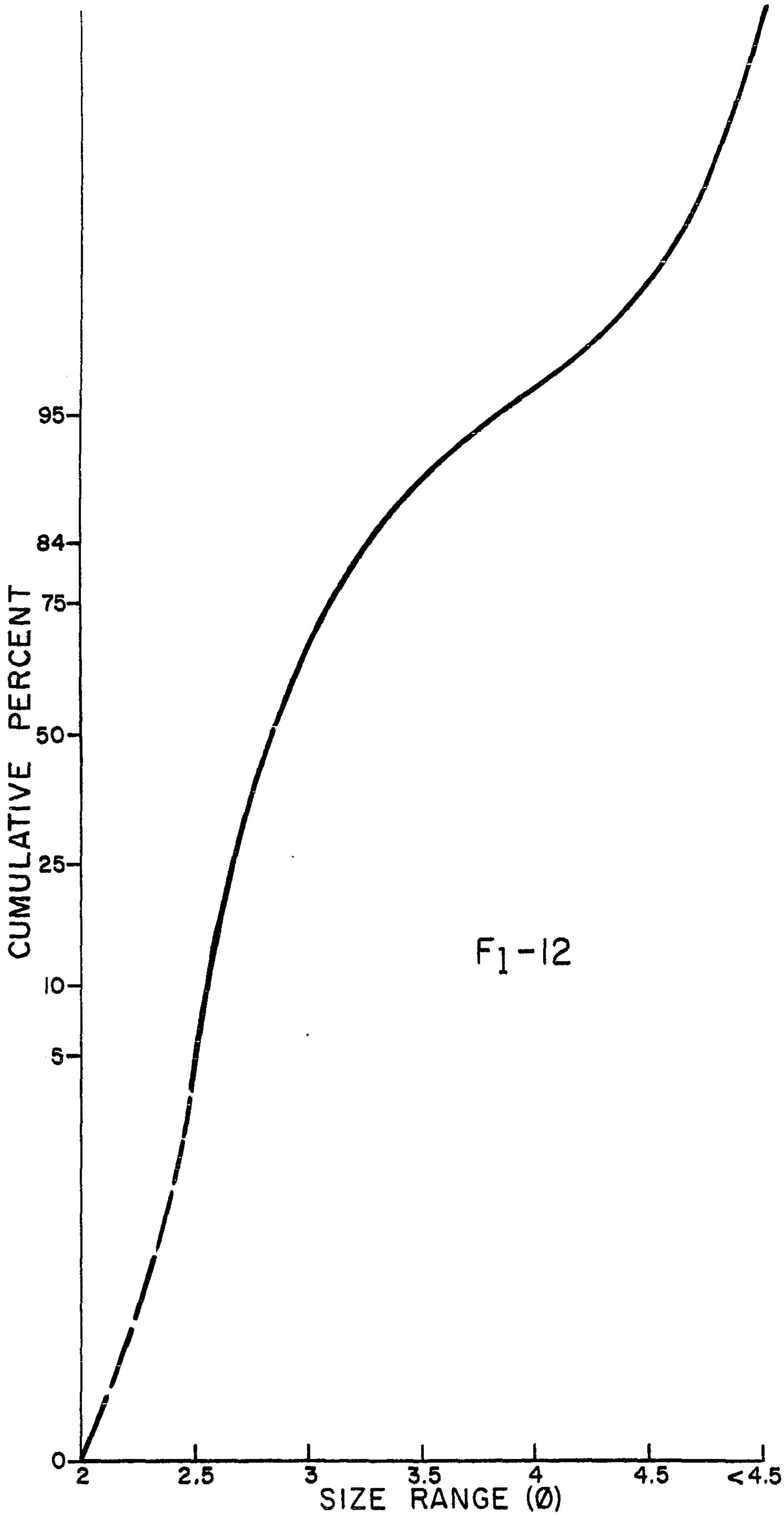
Size (Phi units)	Weight (Grams)	%	Cum. %
2.5Ø	1.27	1.91	1.91
3.0"	21.84	32.77	34.68
3.5"	13.08	19.62	54.30
4.0"	15.99	23.99	78.29
4.5"	5.38	8.07	86.36
< 4.5"	9.07	13.61	99.97

Mean Grain Size = 3.50Ø, Standard Deviation = 0.681Ø, Skewness = +0.23, Kurtosis = 0.821.

F7-1

Size (Phi units)	Weight (Grams)	%	Cum. %
2.5Ø	0.148	0.21	0.21
3.0"	6.91	10.02	10.23
3.5"	17.39	25.20	35.43
4.0"	34.01	49.29	84.72
4.5"	2.43	3.52	88.24
< 4.5"	8.09	11.73	99.97

Mean Grain Size = 3.59Ø, Standard Deviation = 0.468Ø, Skewness = -0.016, Kurtosis = 1.305.


CUMULATIVE PERCENT
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75
50
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2
2.5
3
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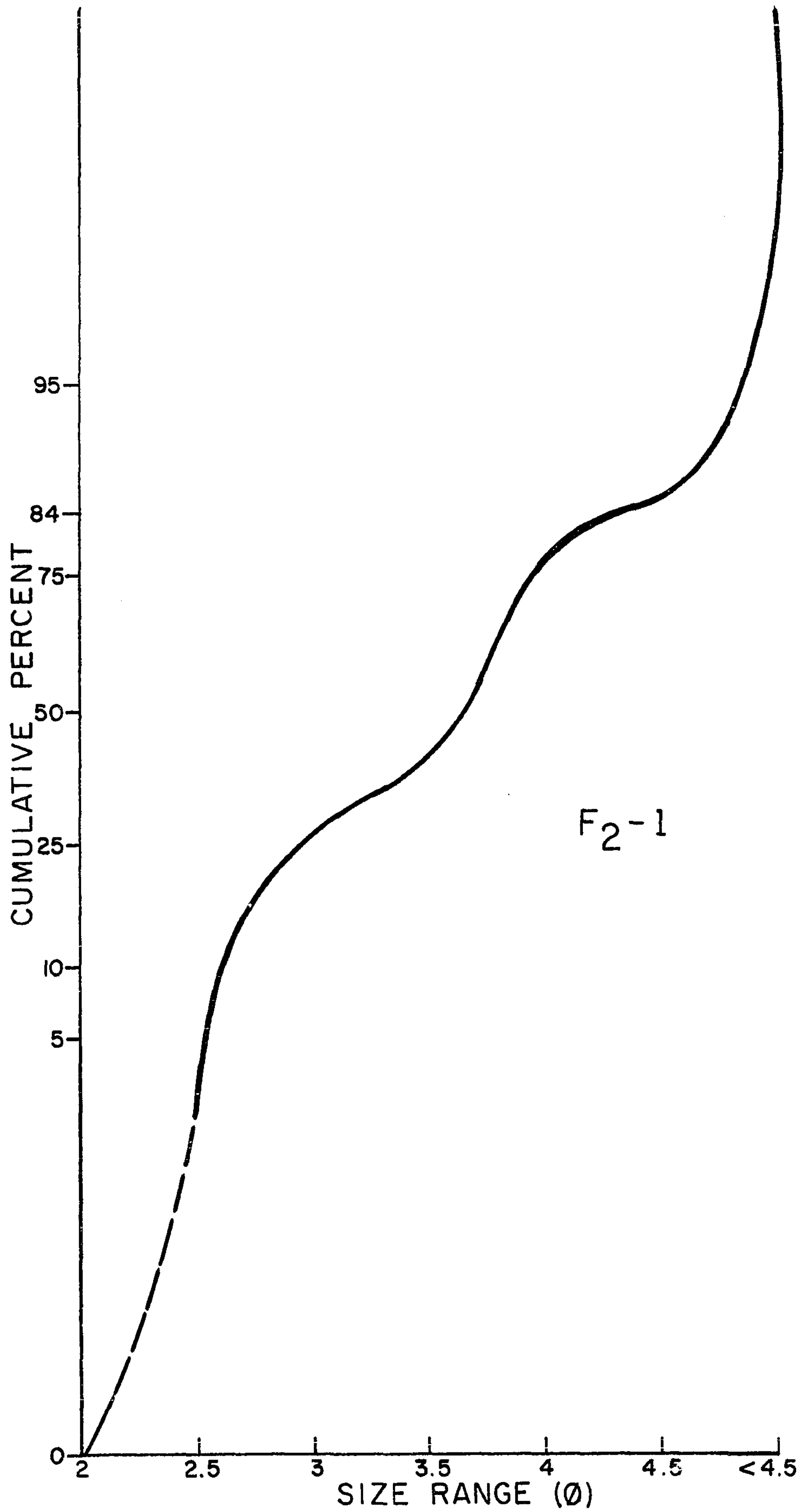
4
4.5
<4.5
SIZE RANGE (Ø)
F1-12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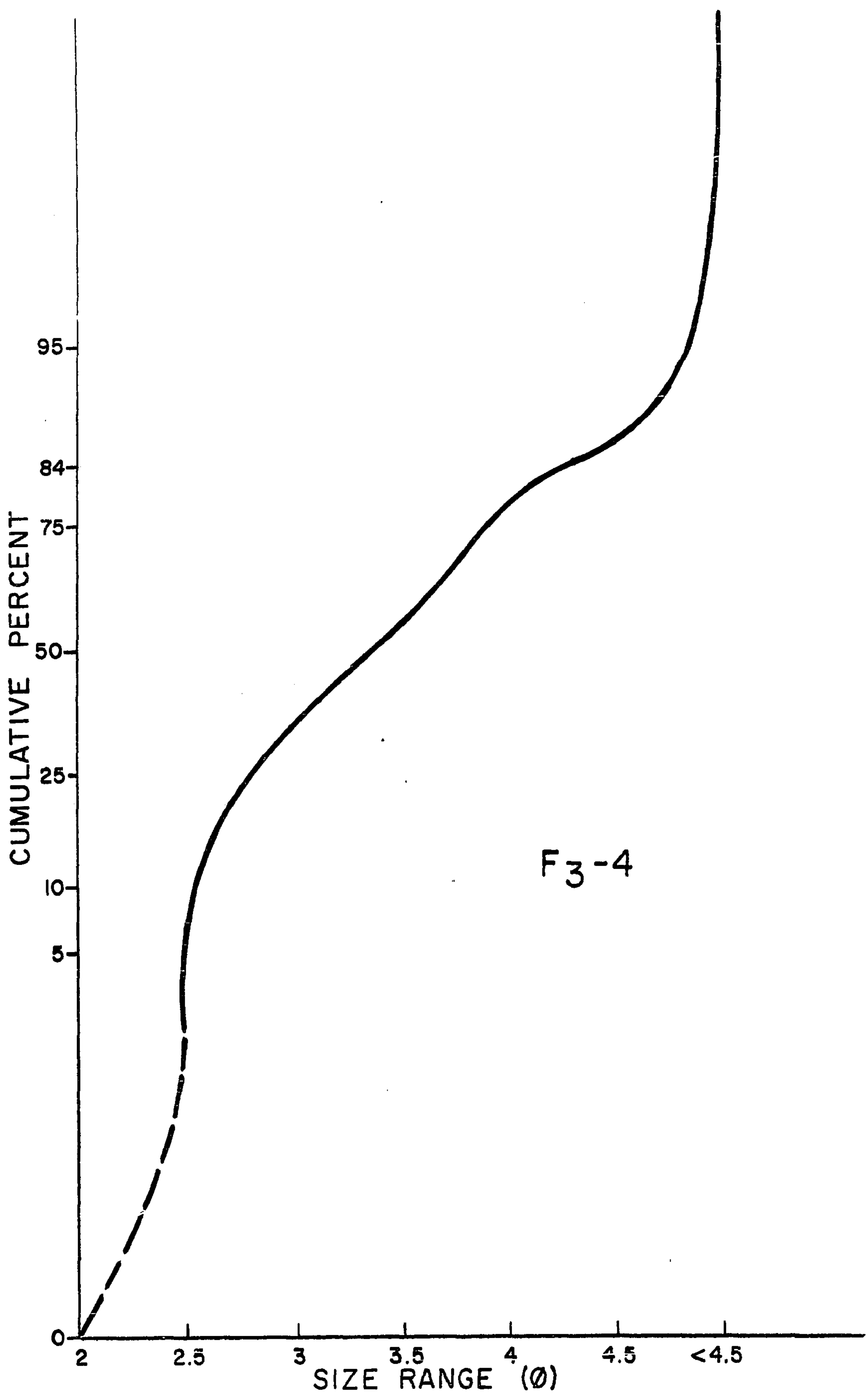
SIZE RANGE (Ø)
F2-1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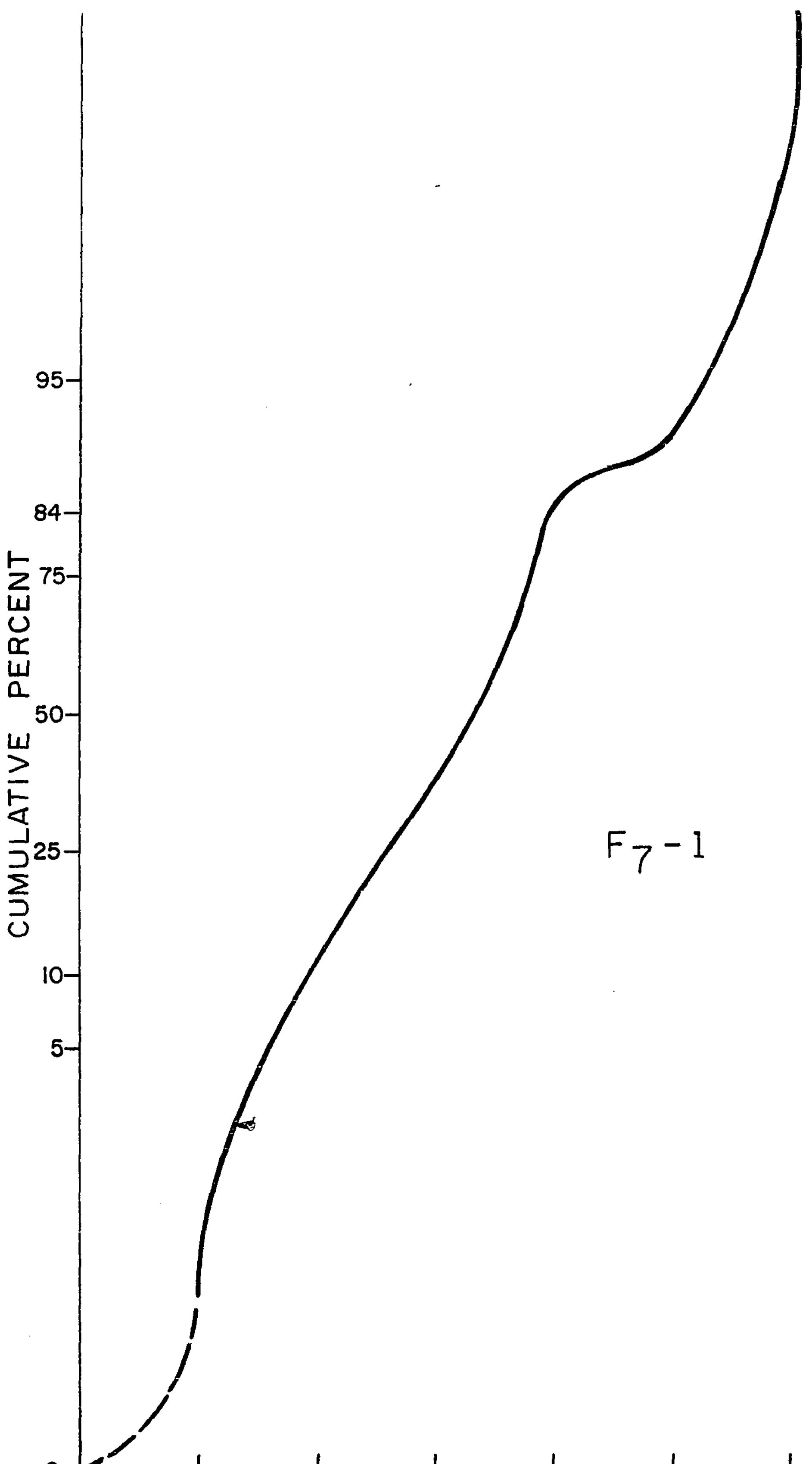
SIZE RANGE (Ø)
F3-4


CUMULATIVE PERCENT
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SIZE RANGE (Ø)
F7-1