FAUNA, STRATIGRAPHY, AND PALEOECOLOGY OF THE FORAKER LIMESTONE: OSAGE, PAWNEE, PAYNE AND LINCOLN COUNTIES, OKLAHOMA

By

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PREFACE

The objectives of this study were to obtain a detailed account of fauna of the Foraker Limestone and study its stratigraphy over the whole length of its outcrop in Oklahoma. The major objective was to then combine all this information and produce a model of the paleoecology and depositional environment of this formation. Other objectives were to produce a map of the Foraker's outcrop and determine the southernmost extent to which the Foraker maintains its integrity as a formation. As the study was being made, it became apparent that some statement about the carbonate petrology would have to be included.

Many people have been of great help to me in the preparation of this thesis. I would especially like to express my appreciation to my adviser, Dr. John D. Naff, for suggesting this thesis and his assistance throughout the study. I also want to thank the other members of my committee, Dr. Gary Stewart, for so often being available for suggestions about format, references, and preparation of the maps, and Dr. Nowell Donovan, for his encouragement and advice on carbonate petrology.

I would also like to thank the Oklahoma Geological Survey and its director, Dr. Charles Mankin, for lending me most of the aerial photographs which were indispensible for the preparation of the maps. A note of thanks is also given to Drs. Laurel Babcock and Robert Scott of Amoco Production Company for furnishing me with some very valuable references on paleoecology. Special thanks go to several Oklahoma State University alumni, Gary Hart, Greg Cook, Robert Owen, Calvin Bennett, and Paul Pipes, for their financial contributions which helped defray my field expenses. I also wish to thank my friend Steve Shirck for his help in drafting the maps. I would also like to thank Jeanne Vale for doing such a fine job of typing the manuscript. Finally I want to thank my parents for their unending support and encouragement throughout my college career.

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CHAPTER I

INTRODUCTION

The Foraker Limestone crops out in the western part of northeastern Oklahoma. It is basically a sequence of limestones and shales in the northernmost part of the state, but as one passes southward sandstones become increasingly prevalent. It is quite fossiliferous and the assemblages present suggest that a variety of communities were present during deposition of the Foraker. The lateral lithologic variations plus the vertical and lateral variations in the fauna make study of the Foraker Limestone an interesting problem in paleoecological interpretation.

Objectives and Methods

The purpose of this study was to examine the stratigraphic trends of the Foraker on a regional scale and attempt to correlate the lithologic units across the entire extent of the Foraker's outcrop in Oklahoma; involved with this problem was to determine as accurately as possible the southernmost extent to which the Foraker maintains its integrity as a formation. Also, a map of the Foraker Limestone outcrop was to be made. The other major part of the problem was to identify as many of the invertebrate fossils as possible and note any trends present relative to environmental and paleoecological situations. The final objective was to integrate the paleontological and stratigraphic data in order to form a composite picture of the depositional environment and paleoecology of the Foraker Limestone.

The field work consisted mainly of travelling to the outcrop and measuring sections using a Jacob's Staff and Brunton compass. At these localities, fossils were either simply noted, photographed, or sometimes collected for further study. Fossils were also collected from a number of other exposures throughout the area. A few shale samples were also collected and brought back to the lab where they were wet-sieved and the residue examined for microfossils.

All mapping was done with the aid of stereoscopic aerial photographs. USGS topographic maps and geologic maps prepared by other investigators served as controls and as field guides. Wherever possible, the map was checked against field observations.

The principle problem encountered in both the field work and with the mapping was the poor quality of the outcrops in the area. Although the Foraker Limestone forms a prominent scarp over most of the length of its outcrop, the beds themselves are covered with colluvium and vegetation almost everywhere. Exposures of the formation which show all three members, most desirable for this type of study, were few and far between. However, an attempt was made to keep measured section localities as evenly spaced as possible.

Another problem was the fact that many fossils were so firmly imbedded in limestone that collection of them was impossible, so a photograph or notation in the field book had to suffice. A great many fossils were also highly fragmented, making identification difficult, but these were sometimes useful in paleoecological interpretation.

Location

The outcrop of the Foraker Limestone spans four counties in northeast Oklahoma (Fig. 1) along a general NNE trend. Specifically, the area of interest extends from T. 16 N. to T. 29 N. and from R. 4 E. to R. 8 E.

Previous Investigations

The Foraker Limestone was first named by Heald (1916) for limestone outcrops near the town of Foraker in northwestern Osage County, Oklahoma. Twenhofel (1919) studied chert in the Wreford and Foraker limestones where they crop out along the Oklahoma-Kansas state line. Garber (1962) dealt with the stratigraphy of the Foraker Limestone in east-central Kansas and Mogharabi (1966) did his doctoral dissertation at the University of Oklahoma on the carbonate petrology of the Foraker in Osage and Pawnee Counties, Oklahoma. Yarrow (1974) did a Kansas State University Master's thesis on the paleoecology of the Hughes Creek Member of the Foraker in north-central Kansas. The following year Schmidt (1975) wrote his thesis dealing with the paleobiology and carbonate petrology of certain parts of the Hughes Creek Shale in northeastern Kansas.

Most studies dealing with the Foraker in Oklahoma have treated it as a part of a broader, more regional study. Most of the following references are unpublished Master's theses done at the University of Oklahoma. Taylor (1953) did his thesis on the geology of the Foraker area in Osage County. Carter (1954) briefly dealt with the Foraker Limestone in his thesis area near Pearsonia, situated immediately to the east of Taylor's study. Also, Vosburg (1954) included the Foraker Limestone in his thesis on the Burbank-Shidler area. Similar studies also include

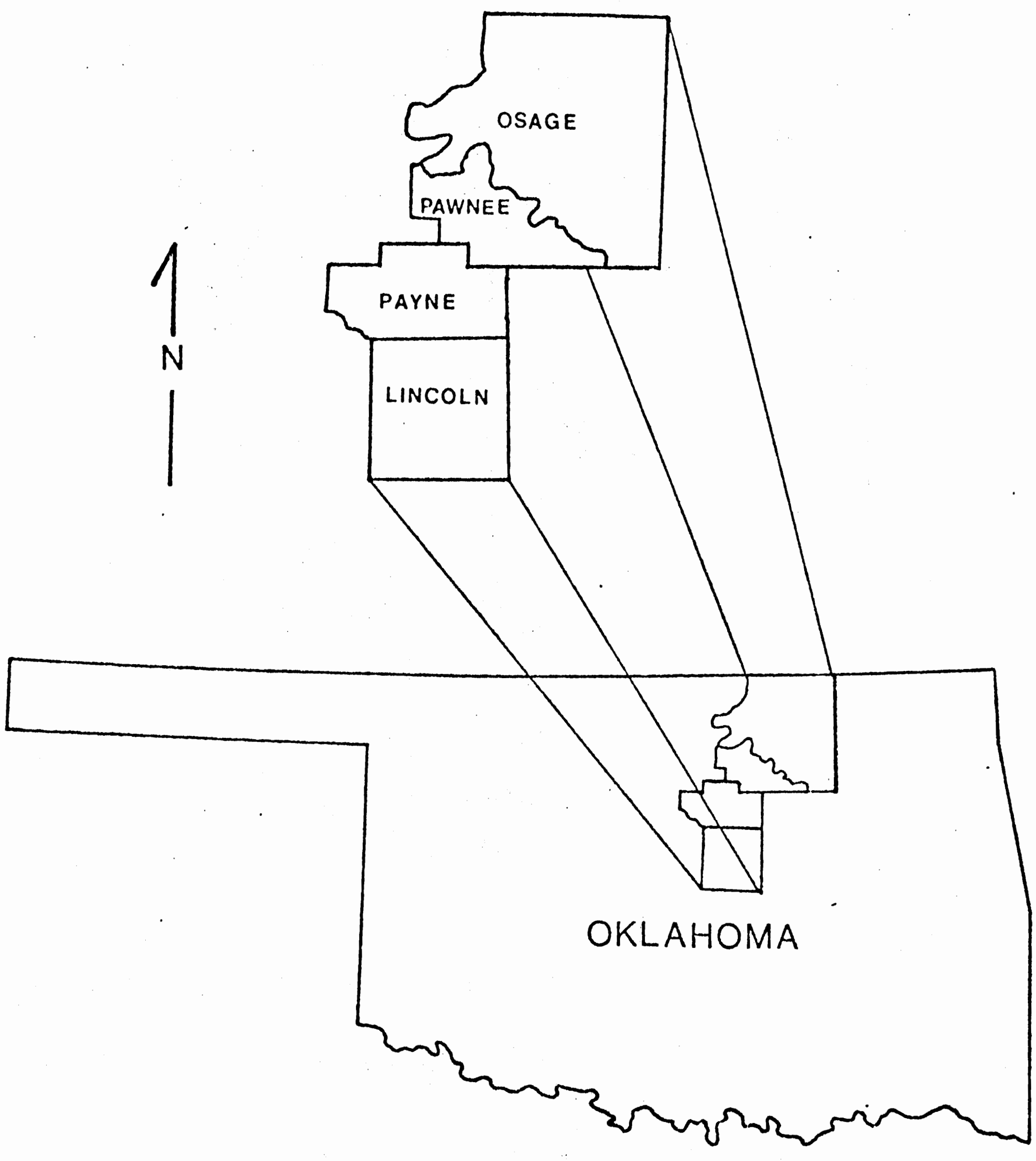


Figure 1.--Location of study area.

Fisher's (1956) thesis on the Belford area and Bryant's (1957) study of the Gray Horse area, all in Osage County. Bellis and Rowland (1976) briefly discussed the Foraker in their evaluation of the carbonate rock resources of Osage County. In their report the Foraker is assigned to the Pennsylvanian System. The dispute concerning the Pennsylvanian-Permian boundary will be discussed later (App. A). Greig's (1959) report on the geology of Pawnee County also describes the Foraker Limestone in their theses dealing with the geology of southeastern and northeastern Payne County, respectively. West (1955), in his thesis on northeastern Lincoln County, mapped the Americus Limestone Member and the Long Creek Limestone Member in the area, but assigned them both to the Konawa Formation having determined that the Foraker had lost its identity as a formation in his area. Masters (1955), who mapped the Prague area of Lincoln and Pottawatomie Counties south of West's study area, was able to identify only the Long Creek Limestone, which he also assigned to the Konawa Formation. Difficulty of precise identification of the Foraker Limestone as far south as in West's (1955) study area seems to make acceptable these differences in nomenclature from those farther to the north near the type area.

CHAPTER II

STRATIGRAPHIC SETTING

The Foraker Limestone is the basal formation of the Council Grove Group in the Gearyan Stage of the Permian System (Fig. 2). The Foraker is composed of three members, in ascending order they are: the Americus Limestone Member, the Hughes Creek Shale Member, and the Long Creek Limestone Member. Some workers dealing with the geology of northern Osage County use the terms Hughes Creek Limestone Member and Long Creek Shale Member, reflecting the local lithology of that area (Taylor, 1953; Bryant, 1957; and Vosburg, 1954). This report will use the names given at the type localities by the original investigators. The names given in Figure 2 do not apply throughout the entire study area. Figure 2 is meant only to be a representative example utilizing the units which are found in Pawnee County. In Osage County the Council Grove Group contains several more formations. Also, the name "Admire Formation" is used following the recommendation of Branson (1956), which states that where the Admire Group cannot be differentiated, then the name of Admire Formation may be applied to the entire group. This is the situation over most of the study area, especially Pawnee County (Greig, 1959).

Permian System

Rocks of Permian age crop out over much of Oklahoma. A major problem in dealing with this system is that nowhere in Oklahoma is there

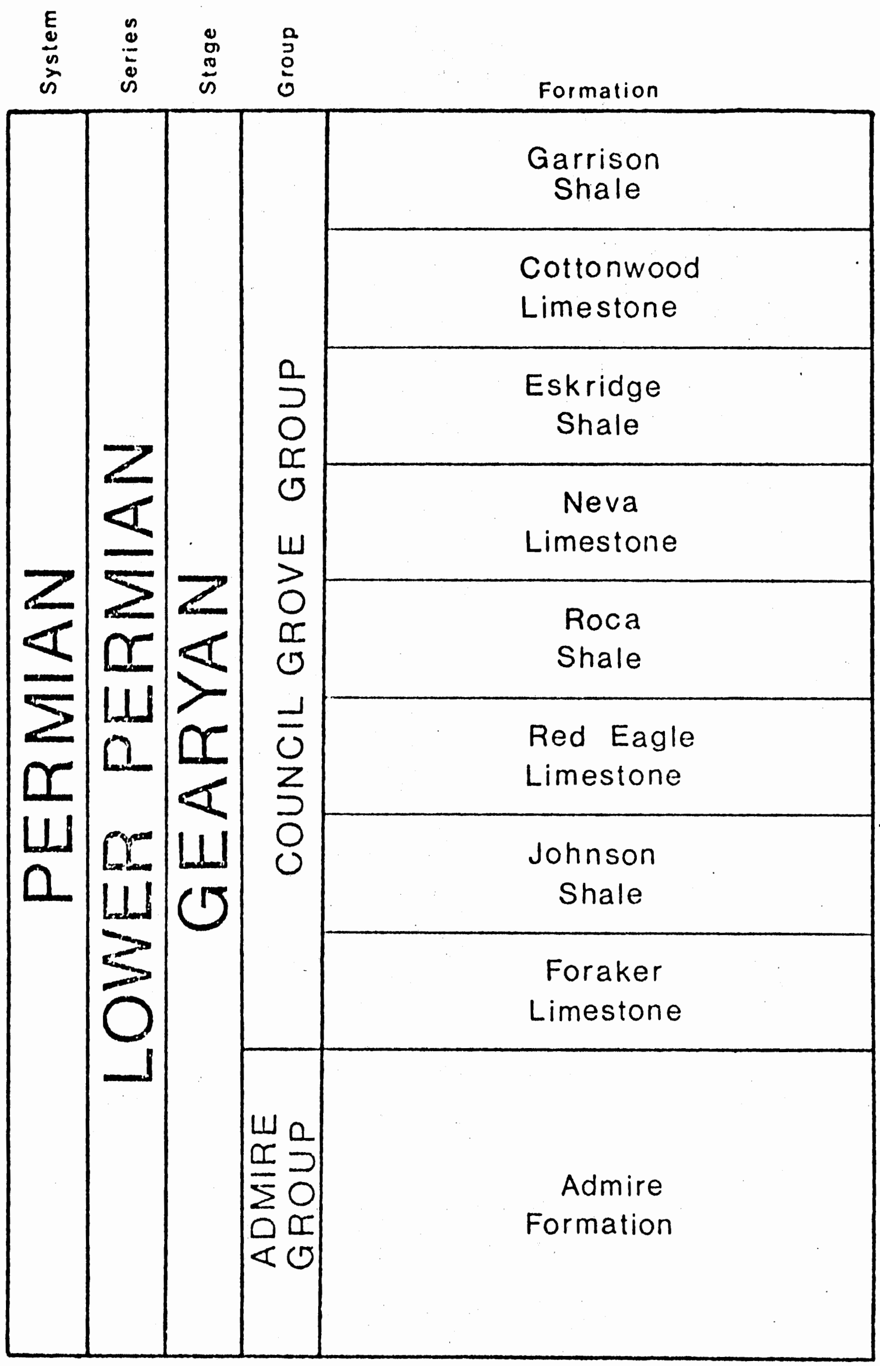


Figure 2.--Stratigraphic setting of the Foraker Limestone.

a distinct unconformity to mark the boundary between the Pennsylvanian and Permian Systems. The position of this boundary is still not fully agreed upon (App. A); evidence based on fusulinids indicates placing the boundary one place while palynological evidence indicates a different placement of the boundary. Moore and Moss (1934) placed the base of the Permian System at the top of the Brownville Limestone; this placement was later endorsed by the American Association of Petroleum Geologists Committee on the Permian (Tomlinson et al., 1940), and is the boundary utilized by this report.

Gearyan Stage

The author has chosen to accept the terminology of O'Connor (1963) and substitute the name "Gearyan" rather than the traditional, and perhaps more familiar, "Wolfcampian". Lower Permian strata in the northern mid-continent region bear little resemblance to rocks designated as the American standard section of the Permian, located in west Texas (Tomlinson et al., 1940). It is for this reason that O'Connor proposed adopting the name "Gearyan", named for Geary County, Kansas to refer to strata correlative with the Wolfcampian in the mid-continent region.

Council Grove Group

The name Council Grove was first applied as a stage name by Prosser (1902) to the interval including the Cottonwood Limestone and Garrison Shale at an exposure near the town of Council Grove in Morris County, Kansas. Moore (1932) changed the name to Council Grove Group and defined the Americus Limestone as its base. At present, the Council Grove includes all beds from the base of the Americus Limestone to the base of the Wreford Limestone of the overlying Chase Group. The Council Grove conformably overlies the Admire Group and is in turn conformably overlain by the Chase Group (Greig, 1959). In general, the thickness increases from north to south with a total thickness of 321 ft. in Kansas (Moore, 1951) to about 480 ft. in northwestern Pawnee County (Greig, 1959).

The Council Grove is mostly shale containing several persistent limestones. A few thick, lenticular sandstones appear in southern Osage and Pawnee Counties and become more abundant towards the south. In Osage County, the Council Grove Group is composed of 14 formations (Fisher, 1965) as compared to only 8 in Pawnee County (Greig, 1959); some of the formations having either pinched out or merged with others in the intervening distance. According to Greig (1959), the Wreford Limestone, whose base defines the upper limit of the Council Grove Group, loses its identity in the southwest part of T. 22 N., R. 4 E. in Pawnee County, which makes it impossible to differentiate the Chase and Council Grove Groups. However, Fenoglio (1957) and Nakayama (1953) both used the name Council Grove for the formations within it that they were able to identify in their respective areas of Payne County. Still further south, all of the formations of the Council Grove and Chase Groups grade into the Konawa and Asher Formations in central Oklahoma (Greig, 1959). Neither West (1955) nor Masters (1955) used the name Council Grove in their studies in Lincoln County; even though some of its members did persist that far south, they were included as members of the Konawa Formation.

CHAPTER III

STRUCTURAL SETTING

The principle structural feature which involves the Foraker Limestone is the Prairie Plains Homocline, the gentle westward-dipping flank of the Ozark Plateau. It is bounded on the south by the McAlester Basin, the Ouachita and Arbuckle Mountain systems, and on the west by the Nemaha Ridge and Anadarko Basin (Bryant, 1957). This approximate westward dip of the homocline ranges between 30 and 65 ft. per mile (Greig, 1959). Two other significant structural features are superimposed upon the homocline; one is a series of north-trending belts of en-echelon normal faults, and the other structure consists of numerous gentle folds mostly anticlines and noses which are referred to as "plains-type" folds (Powers, 1931).

En-Echelon Faults

While none of the belts of en-echelon faults crosses the Foraker, the faults which do occur in that vicinity are probably contemporaneous with, and therefore caused by, the same stresses which formed the en-echelon faults. Bryant (1957) believed that these faults represented the western limit of effectiveness of the forces which caused the en-echelon faults. There have been numerous explanations dealing with the origin of these faults. The first proposal was made by Fath (1920). He concluded that both the folding and faulting of the region could be attributed to strike-slip movement along pre-existing planes of weakness in the basement rocks. Sherril (1929) noted that the dip of the homocline increases southward and said that the resulting torsional stress produced the faults. There have been several other explanations which need not be mentioned here. More recent structural geology literature does support the theory that these and other similar fault belts are produced by strike-slip movement in the basement (de Sitter, 1956; Badgley, 1965).

Plains-Type Folds

The plains-type folds consist of gentle anticlines and noses with, interestingly, no true downwarping (Clark, 1932). A striking feature of these structures is that most of them become more pronounced with depth, forming traps for oil and gas. Clark (1932) studied these folds and determined that they are caused by vertically acting forces rather than horizontal compression. He suggested movements along ancient fault planes in the basement as the cause of these stresses.

In conclusion it can be said that all of the structural features affecting the Foraker Limestone can be attributed to some set of movements in the Precambrian basement.

CHAPTER IV

GENERAL CARBONATE PETROLOGY

Introduction

The profound facies changes which occur in the Foraker Limestone, particularly in the Hughes Creek Member, plus several types of diagenetic changes, make study of the petrology of the Foraker quite interesting. Mogharabi did his doctoral dissertation on the carbonate petrology of the Foraker Limestone in 1966. He made use of such investigative techniques as thin-section examination, X-ray diffraction, staining methods, insoluble residue analysis, and spectrographic, semi-quantitative analysis.

Facies and Constituents

Mogharabi (1966) divided the limestone beds of the Foraker into two general facies, a "biomicrudite facies" and a "biosparrudite facies", naming them according to the classification system of Folk. It was observed that the Americus Limestone consisted entirely of the biomicrudite facies, while the Hughes Creek and Long Creek members contained both types of facies with no consistency in their distributions.

The most abundant allochems occurring in the Foraker were fossils; pellets were also present in a few samples. Of these, fusulinids were found to be the most abundant and were associated with the micrite facies (Mogharabi, 1966). Also associated with the biomicrudite facies were bryozoans, mollusks, sponge spicules, and forams. Mogharabi found that the organisms associated with the biosparrudite facies were the algal genus *Osagia* and, to some extent, brachiopods of several species. The present author is a bit skeptical about this last observation since numerous brachiopod fragments have been collected from the Americus Limestone, which is micritic. Apparently, echinoderms do not indicate any facies preference. A few ostracodes were also observed by Mogharabi.

The most abundant terrigenous constituent of the Foraker Limestone is quartz. It does not commonly exceed one or two percent, however, some samples from the biosparrudite facies contained as much as ten percent quartz grains of very fine sand-grain size. The carbonate mud facies contained no more than three percent silt-sized quartz. The relatively high percentage, and larger grain size in the biosparrudite facies, was interpreted as indicating a high energy environment of deposition, while the biomicrudite facies was interpreted as being deposited in an environment in which the energy was not sufficient to winnow out the carbonte mud and quartz silt (Mogharabi, 1966).

Insoluble residue analysis revealed other constituents of interest, and the following conclusions were reached: (1) the bulk of insoluble residue was composed of terrigenous quartz and clays, the only exception being silica formed by replacement, (2) there was a general increase of insoluble material from north to south, and (3) the biomicrudite facies generally has a higher total residue and is mostly composed of clay, while the residue from the biosparrudite facies is generally less and is composed mainly of quartz (Mogharabi, 1966).

The elements analyzed by X-ray diffraction included manganese, zirconium, strontium, vanadium, copper, and titanium. One of the more significant findings was in the manganese content, which apparently serves as a paleoclimatic indicator. The amount of manganese found in the analyzed samples indicated that the Foraker Limestone was deposited in an arid climate (Mogharabi, 1966). Most of the other elements analyzed showed no significant variation.

Diagenetic Features

According to the American Geological Institute's Dictionary of Geological Terms (1957, p. 192), the definition of the word "diagenesis" is:

> Processes involving physical and chemical changes in sediment after deposition that converts it to a consolidated rock; includes compaction, cementation, recrystallization, and perhaps replacement as in the development of dolomite.

The diagenesis of the Foraker Limestone is quite interesting in that there has been a long history of diagenetic changes involving nearly all of the processes mentioned in the above definition.

Silicification is locally important but is mainly developed in the limestone beds of the Hughes Creek Shale in northern Osage County. Minor silicification was also observed in the Americus and Long Creek members. Replacement by silica is so pervasive in the Hughes Creek that it forms large nodules (Fig. 10) and discrete beds. It has also obliterated the internal structures of many fossils (Mogharabi, 1966). On the outcrop, the nodules are gray-blue, mottled gray-blue or yellowish-gray. The nodules show little or no internal structure. Examination of thin sections revealed that the chert is composed of microcrystalline quartz and chalcedonic quartz (Mogharabi, 1966). There is much evidence for the replacement origin of the silica, such as the silicification of fossils and the inclusion of carbonate mud. The source of the silica is possibly siliceous sponge spicules. The silification was found mostly to occur in the "micrite facies" with no appreciable replacement occurring in the sparry calcite facies (Mogharabi, 1966). This could be due to the fact that the same high energy environment which winnowed out the carbonate mud also washed away the sponge spicules. Mogharabi (1966) also noted that silicification was rare where there was a high Mg/Ca ratio. He thought this may be due to a higher pH and temperature such as those favoring the deposition of dolomitic limestone. This observation, however, is compatible with neither the replacement origin of the silica, nor the replacement origin of the dolomite in the Foraker, which will be discussed later.

In order for silica to replace calcite, the chemical conditions must be such that calcite is dissolved and silica precipitated simultaneously. Such conditions occur with a low pH value. Mogharabi (1966) went into considerable detail showing how bacterial action could first raise the pH, to mobilize the silica, then another type of activity would lower it, inducing the replacement reaction. He did not, however, eliminate the possibility of an inorganic process being responsible for the reaction. If such an inorganic process did produce the silicification, the necessary change in pH would require a rather drastic change in environment. Such a change could be brought about by a change from conditions dominated by marine waters to those of fresh water with a lower pH. This could be caused by a regression or a period of uplift, both of which imply that replacement by silica, caused by these conditions, would be a late-stage feature of diagenesis. Unfortunately, as the evidence presently available does not permit this author to assign the episode of silica replacement in the Foraker to any particular niche in the diagenetic scheme, all discussions must remain purely speculative.

Another diagenetic feature of the Foraker Limestone is dolomitization.

Mogharabi found that dolomite development is present in all members and in different localities, but was preferentially developed in the micrite facies. Where developed, the dolomite occurs in euhedral or subhedral crystals and replaces both carbonate mud and fossils, illustrating a replacement origin. Staining revealed that where dolomite is present, it occurs in an irregular pattern and the amount usually ranges between one and five percent, with the exception of one sample collected in southern Pawnee County from the Long Creek Limestone. This sample contains 80 percent dolomite (Mogharabi, 1966).

In Payne and Lincoln Counties, beyond Mogharabi's (1966) study area, the present author found dolomite to be very widespread if not pervasive. Spot checks at several localities in Payne County revealed that both the Americus Limestone and the Long Creek Limestone are largely or completely dolomitized throughout most of the county, no limestone is present in the Hughes Creek Shale this far south. A sample was collected from the Long Creek at the south line of Sec. 17, T. 19 N., R. 5 E., which was taken back to the lab, stained, and found (except for a few echinoderm fragments) to consist entirely of ferroan dolomite.

The distribution of dolomite, in particular its concentration in the southern part of the study area, may have a significant bearing on the diagenetic history of the Foraker alone, or it may reflect part of a regional process. The iron in ferroan dolomite is in the ferrous state, suggesting a reducing environment during its formation, so it is highly doubtful that the dolomite present could be penecontemporaneous in origin. Such indicators of a reducing environment usually suggest a later stage of diagenesis for their development. This observation concurs with textural evidence cited by Mogharabi (1966) for a secondary, or replacement origin for the dolomite. In order to change calcite to dolomite, water with a high Mg/Ca ratio is necessary. Such water can be produced in a region of high evaporation. Since continental rocks lie to the south of the study area, it is reasonable to assume that land was nearby, indicating that the sea could have been quite shallow in this region. These environmental parameters produce an ideal situation for high evaporation and the production of highly saline water necessary to bring about dolomitization. Although hypersaline water would have caused reducing conditions and could conceivably have caused penecontemporaneous ferroan dolomite to form, the textural evidence still dictates that the event would have to have occurred a considerable time after deposition. Furthermore, the fossils present are forms which could have lived only in water of normal salinity. Therefore, dolomitization by highly saline waters could have only occurred at a later period, perhaps during a regression. Of course, another explanation could be a late-stage event of regional proportions causing widespread dolomitization in all limestones in the area whose relationship to the paleogeography is purely coindidental. The sparsely distributed dolomite found further to the north could have been caused by autochthonous magnesium released by the dissolution of high magnesian calcite, which comprises the shells of many organisms.

Recrystallization is a diagenetic feature which is widespread throughout the Foraker. In many cases the original texture of the rock and the internal structures of fossils were obliterated. It was noted that the process was confined to the micritic facies, therefore it is best developed in the Americus Limestone. The recrystallization fabrics which were observed include: coarse mosaic calcite, microspar, and syntaxial recrystallized rims around many crinoid fragments (Mogharabi, 1966).

The Foraker Limestone has had a complex cementation history. Mogharabi (1966) noted widespread cavity filling in fossils plus sparry calcite cement in the Hughes Creek and Long Creek members, the biosparrudite facies. Mogharabi (1966) proposed that the Foraker Limestone was cemented by fresh water during a period of subareal exposure. Research done in places like Bermuda, the Bahamas, Florida, and the Faunafuti Atoll near New Guinea has proven that subareal or fresh water diagenesis is commonly a process to be taken under consideration for many limestones, and some have considered it to be the chief process responsible for the lithification of carbonate sediments (Bathurst, 1971). The carbonate minerals which form in the marine environment are high magnesian calcite and aragonite. High magnesian calcite occurs in various skeletal structures and in algae; aragonite is found in algae and in some shells. Ordinary calcite is not precipitated because the presence of magnesium ions in sea water inhibits calcite precipitation and aragonite precipitates instead (Bathurst, 1971). However, both of these minerals are transformed relatively quickly to low magnesian calcite upon subareal exposure and the influence of fresh water. The rapidness of this transformation is testified to by presence of Pleistocene limestones composed of low magnesian calcite at Bermuda and the Bahamas, to name a few. Since there is no aragonite or high magnesian calcite in the Foraker, nor is there any evidence of deep sea origin, Mogharabi (1966) concluded that the Foraker was cemented subareally. It must be borne in mind, however, that these minerals are metastable in the diagenetic environment and it is not at all surprising for them to be absent from a rock nearly 280 million years old. Even though aragonite has been found in Upper Devonian rocks (Bathurst, 1971), these cases must be considered as exceptions.

While the evidence Mogharabi (1966) used to support his conclusions may have been invalid, his conclusions seem to be correct. Submarine cementation produces hardgrounds which become extensively bored by organisms; no evidence of this was found, nor was any evidence found of deep crustal cementation, such as styolites or crushing. So, by process of elimination, the only alternative remaining is fresh water cementation either at the surface or in the shallow subsurface during a period of regression.

The cementation of the Foraker appears to have occurred in at least two stages. This conclusion was reached by the author from the examination of acetate peels made from a stained sample of the basal bed of the Americus Limestone collected from a locality south of the town of Foraker. The rock consists of recrystallized carbonate mud and abundant fossils, mostly of the genus *Aviculopecten*, a scallop, and numerous small gastropods. The micrite was non-ferroan calcite while the fossils were made of ferroan calcite. Upon closer examination, the fossils were seen to be made up of a drusy calcite mosaic which had obliterated the original shell structure. The drusy texture of the calcite spar indicates growth in a void rather than gradual replacement. Since the fossils were not crushed, it is probable that the micrite was cemented before the original shell material was dissolved. There were other isolated patches of coarsely crystalline ferroan calcite cement scattered throughout the sample; similar patches of this kind were also found in a stained peel made from a sample of the Long Creek Limestone from the Phillips Lake spillway.

The sequence of events appears to have run as follows: The carbonate mud of the recently deposited sediment was cemented at an early stage (as evidenced by its non-ferroan composition) in a subareal, or shallow subsurface, fresh-water environment. This was followed by dissolution of the fossils, which in this sample were all molluscs which are composed at least partly of aragonite (Bathurst, 1971), leaving moldic porosity. The dissolved aragonite was then probably reprecipitated in the fossil molds and in the surrounding micrite as ferroan calcite cement. Since calcite is less dense than aragonite, it takes up more space, so after the fossil voids were filled there was still some calcite in solution left, which was precipitated in the micrite. The precipitation of this ferroan calcite probably occurred in the subsurface in a reducing environment necessary for its formation. Also, work done by other researchers has shown that ferroan calcite usually occurs as a second generation cement superimposed upon a non-ferroan first generation (Bathurst, 1971). Such a sequence of events as the one described has been found in studies of Bermudan carbonates and is summarized in Figure 3 from Bathurst. The events described here represent stages I through IV. Stage V is inferred also to have occurred because the rock at the end of stage IV is still quite porous, and it is necessary to bring in allochthonous cement from the dissolution of other limestones in order to bring about the complete porosity reduction observed (Bathurst, 1971). The silicification and dolomitization also occurred during this later stage.

This discussion has shown that the cementation history of the Foraker Limestone is more complex than had previously been suspected. This author did not do an in-depth petrologic study; if such a study is done in the future, an even more interesting story may be revealed. Bathurst (1971, p. 435) probably expressed it best when he said:

> . . . that cementation can have a long, drawn out history, and that both eogenetic (subareal or submarine) cementation and deep subsurface, mesogenetic cementation can each play volumetrically significant roles in the lithification of a single limestone.

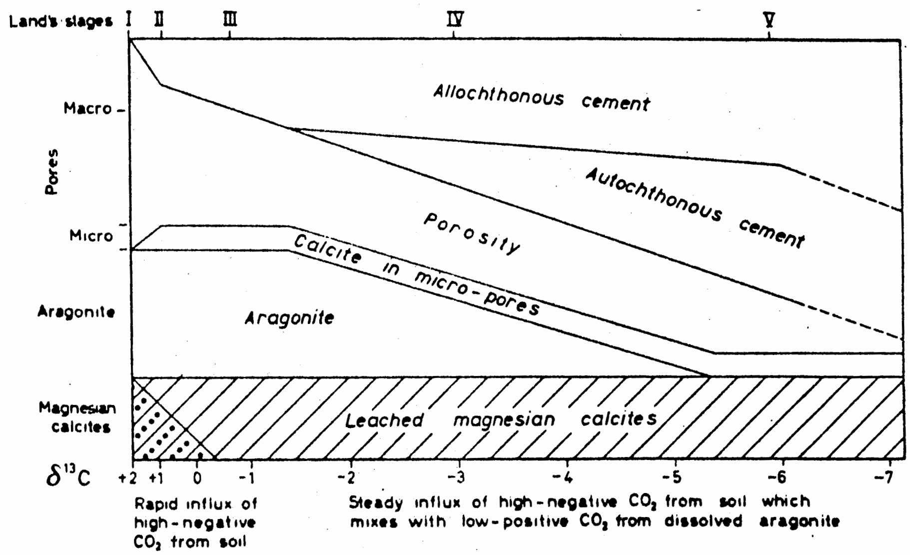


Figure 3.--Idealized sequence of events in the diagenesis of Bermudan carbonates (from Bathurst, 1971).

CHAPTER V

STRATIGRAPHY OF THE FORAKER LIMESTONE

The Foraker Limestone was named by Heald (1916) for exposures near the town of Foraker in Osage County, Oklahoma. It is composed of three members: the Americus Limestone Member, the Hughes Creek Shale Member, and the Long Creek Limestone Member, in ascending order. The name Foraker Limestone was introduced into Kansas terminology by Bass (1929) when he was able to correlate the Foraker Limestone of Osage County into Cowley County, Kansas. Condra (1935) introduced the name into the stratigraphic classification of northwestern Missouri and southeastern Nebraska and called it a limestone formation. He defined it as underlying the Johnson Shale and overlying the Hamlin Shale. This interval is a stratigraphic sequence composed of the Americus Limestone, the Hughes Creek Shale, and the Long Creek Limestone, which Condra designated as lower, middle, and upper members, respectively, of the Foraker Limestone. At this time he also abandoned the old name Elmdale Shale, the unit in which the members of the Foraker had been included.

The Foraker Limestone in Kansas has an average thickness of 50 feet. Heald (1916) originally described the Foraker as being 74 feet thick, but this section undoubtedly included the Admire Group and Brownville Limestone as well as the Foraker (Taylor, 1953). The present author and other workers (Taylor, 1953; Vosburg, 1954; Fisher, 1952; Bryan, 1957) all give an average thickness of 50 feet for the Foraker Limestone in

Osage County. In Pawnee County, Greig (1959) said that the Foraker ranges between 60 and 70 feet and thickens southward. The present author has not found thicknesses as great, but did observe a southward increase in thickness (App. C). In Payne County, Fenoglio (1957) and Nakayama (1955) gave average thicknesses of 67 and 65 feet, respectively. This author got similar values. West (1955) did not use the name Foraker in his area in northeastern Lincoln County, so no thickness was given in his report. In addition, the very poor quality of exposures there makes measuring a section a difficult task. The average thickness for the Foraker Limestone, taken over the whole study area, is 54 feet. The thicknesses of the individual members range over a wider range than the aggregate thickness of the entire formation.

In the type area, the Foraker Limestone is a sequence of limestone, cherty limestone, and shale (see Measured Section I, App. C). Southward, sandstones gradually become increasingly dominant, eventually forming the major part of the formation. In northern Payne County, the limestone mostly has been altered to dolomite. The limestone beds are also somewhat thinner than what is to be observed further to the north. Also, the shale intervals become more silty and commonly are red. In Lincoln County, the Foraker Limestone is little more than a few thin dolomite beds scattered throughout a series of red silty shales and thick lenticular sandstones.

The Foraker Limestone forms a prominent scarp over most of the study area. The Americus Limestone was usually found, when present, at or near the base of this scarp. The Long Creek Limestone could be found either near the rim of the scarp or on the gentle backslope of the cuesta. The Foraker Limestone is not always distinguished by the presence of its scarp; places such as these made the mapping quite difficult. One such place occurs northeast of the town of Foraker. Heald (1916) mapped a small anticlinal fold in this area and the slight reversal of dip on the east flank of this structure may account for the reduction of the scarp to a gentle, grass-covered slope (Taylor, 1955).

Americus Limestone Member

This unit was named by Kirk (1896) for a sequence of two thin limestones separated by shale at an exposure near the town of Americus in Lyon County, Kansas. Bass (1929) correlated the lower part of the Foraker Limestone in Cowley County, Kansas, with the type section of the Americus Limestone back in Lyon County. The Americus can be traced from southeastern Nebraska through eastern Kansas (Greig, 1959), and as far south as T. 16 N. in Lincoln County, Oklahoma.

In Kansas, the Americus Limestone generally consists of two bluish-gray limestone beds separated by about 3 to 13 feet of shale. The upper bed often contains nodules of flint, in southern Kansas, and many fusulinids and brachiopods make up the fauna (Moore, 1951).

In Oklahoma, the Americus Limestone generally consists of at least two limestone beds; there may be as many as five (Measured Section II, Fig. 4) or as few as one, which is the case in Lincoln County (Fig. 5). The overall thickness of the Americus is less than in Kansas, reaching a maximum of just over 12 feet in northern Osage County and generally decreasing southward to as little as three inches near the town of Avery in Lincoln County. Some of the thickness values presented in the measured sections in Appendix C are not accurate due to the lower part of the member being covered. The total thickness of the Americus in

Figure 4.--All five major limestone beds of the Americus Limestone are visible in this exposure at the Phillips Lake spillway near Shidler, Osage County; W½, Sec. 10, T. 26 N., R. 6 E.

Figure 5.--A single bed of sandy limestone composes the Americus member at this locality in Lincoln County; E. line, Sec. 20, T. 17 N., R. 5 E.

Measured Section I, located less than one mile from the Kansas state line, is surely greater than the 8.4 feet which were exposed. Greig (1959) measured one section in Pawnee County with 32 feet of Americus Limestone, however, no such exposure was seen by the present author.

The limestone of the Americus is dark gray, on a fresh surface, which weathers to a lighter gray or buff. It has a fine, recrystallized texture and locally is argillaceous. Beds range from less than 2 inches to more than 2 feet in thickness, the more thickly stratified beds usually occurring at or near the top of the member. While the upper part of the Americus is described as containing flint nodules in Kansas (Moore, 1951), glauconite was also found in this part of the member by Garber (1962); however, neither of these two minerals was observed in Oklahoma. A distinctive feature of the basal bed of the Americus in Oklahoma is that the fossil assemblage is characterized by an abundance of *Aviculopecten* (Fig. 30) and/or *Myalina*. Over most of the study area there is only patchy dolomitization of the Americus Limestone. However, in northern Payne County (T. 19 N.), whereas still patchy, the dolomite is widespread and is detected easily in the field (Fig. 6).

Further south in the vicinity of Cushing, the Americus has become completely dolomitized. Briefly, the process of dolomitization in shallow, nearshore waters goes as follows: intense evaporation leads to hypersalinity which brings about precipitation of gypsum and anhydrite. This causes the Mg/Ca ratio to rise and dolomitization of $CaCO_3$ occurs. This is the process that occurs in the sabkhas of the Persian Gulf, but the same principle may apply to other environments. The Foraker Limestone does not show any signs of having ever been a sabkha, but the general process could still apply in shallow, hypersaline water. In

Figure 6.--Exposures of the Americus Limestone in Payne County, near Twin Mounds; W. line, Sec. 16, T. 19 N., R. 5 E.

Lincoln County, nearly all that can bee seen of this member is a bed of maroon dolomite a few inches thick. The one exception to this is an exposure along the side of a section-line road in the NE ¼ of Sec. 20, T. 17 N., R. 5 E. There the Americus is about one foot thick and consists of a bed of limonite-stained, sandy limestone (Fig. 5).

In northern Osage County, the upper bed of the Americus appears to have split in half. Two beds of limestone are separated by a thin layer of shale or marl. This marly layer commonly is very fossiliferous, as in the case of Measured Section I, unit G (App. C; Fig. 7). This kind of layer may be evidence of a sort of diastem, a condition in which a period of sediment starvation caused a buildup of fossils in a thin layer. This layer could also have been formed by a transgression. This same bed may also be represented in Measured Section II, unit H.

The shales of the Americus Limestone are quite consistent in their character. Nearly all are gray, fissile, and calcareous. Fossils in the shale are much less abundant than in the limestone beds, although microscopic examination does reveal numerous ostracodes. One reason for the general absence of fossils in the shale may have been that there was a higher rate of sedimentation, such as that which occurs in prodeltaic environments (Heckel, 1972). The high rate of deposition, the accompanying increased turbidity, plus the fluctuations in salinity that would have occurred, could all reduce the fauna. Since nearly all of the shales are calcareous, this may be interpreted to mean that carbonate mud was being deposited at all times but became masked by clays and silts that formed the shales. When deposition of the shale ceased, perhaps when the depocenter of a delta had shifted position such as what has happened several times in the Mississippi Delta. When this occurs only the carbonate

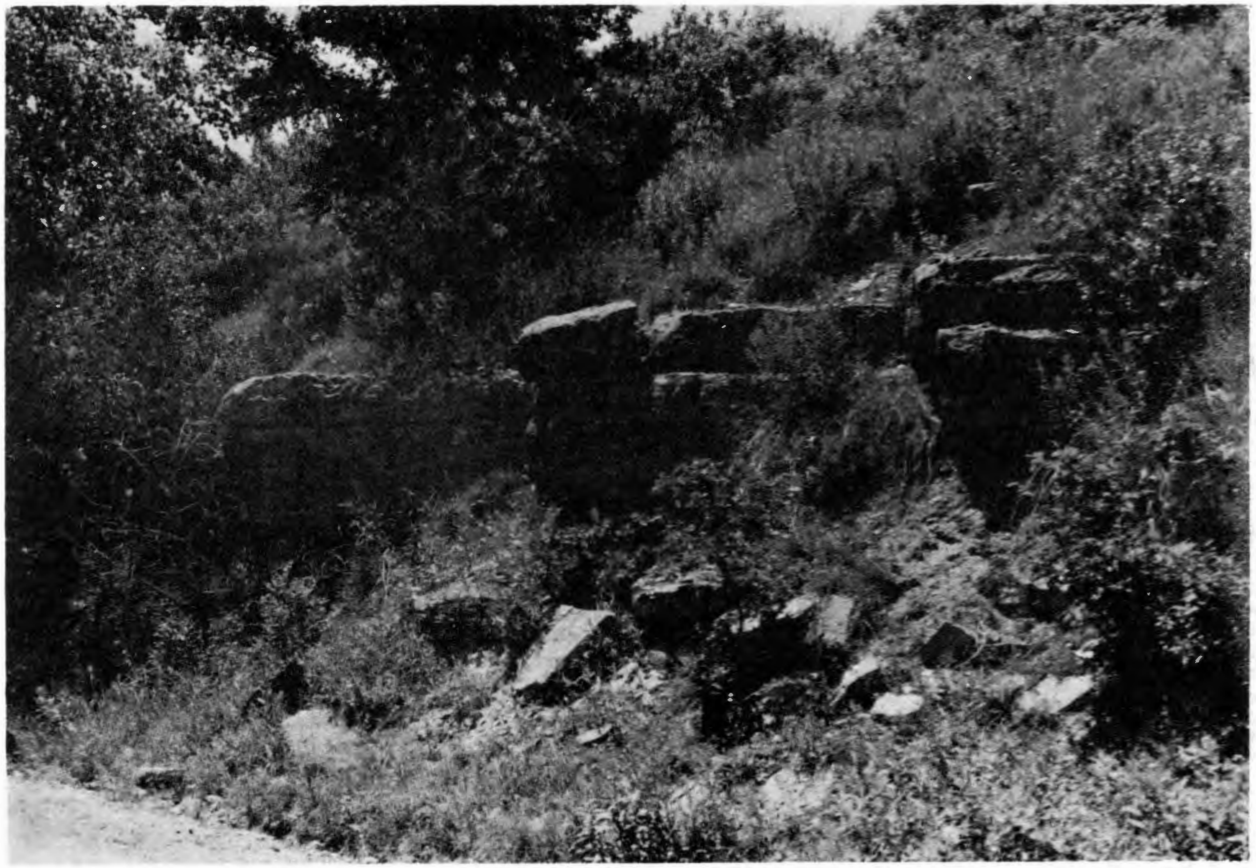


Figure 7.--This massive limestone is characteristic of the Americus Limestone in northern Osage County; SW¼, Sec. 16, T. 29 N., R. 7 E. Note the thin "diastem" about one-third down from the top.

mud is deposited, the water is less turbid and more normally marine so the fauna can flourish. The most extreme case of this sort is when even the carbonate deposition nearly ceases. Then a diastem, of the kind mentioned above, may develop. While at any one time there are no more organisms alive during this period of non-deposition than when carbonate was being deposited since the fossils are not "diluted" by sediment, it gives the impression of a very abundant fauna.

In general, the Americus Limestone has the least variation in facies of all the members of the Foraker Limestone. The fossil assemblage changes but, for the most part, a sample of the Americus from one locality looks like a sample from almost anyplace else, except where dolomitization becomes important in Payne and Lincoln Counties. The faunal assemblage is the most diverse of all the members of the Foraker (Chapt. VI); the implications of this will be discussed in Chapter VII.

The Americus Limestone defines the base of the Foraker Limestone. Since the Americus can be traced southward only to Sec. 11, T. 16 N., R. 5 E., about three quarters of a mile south of the town of Avery in Lincoln County, the author proposes that this location be considered as the southernmost extent of the Foraker Limestone.

Hughes Creek Shale Member

The Hughes Creek Shale originally was described by Condra (1927). The name was given to a section of bluish gray to black, fossiliferous shales exposed along Hughes Creek in Nemaha County, Nebraska. Moore (1932) revised the boundaries to their present form as being all rocks between the Americus Limestone and the Long Creek Limestone. The Hughes Creek was designated as the middle member of the Foraker Limestone by Condra (1935).

Generally speaking, the Hughes Creek thickens southward, in contrast with the Americus. The unusually thick section of the Hughes Creek at Measured Section I (App. C) may be spurious due to the large amount of covered section. Excluding that value and the incomplete section at Measured section VI, the Hughes Creek has an average thickness of about 29 feet in the study area.

Lithologically, the Hughes Creek Shale is in direct contrast with the Americus. Its fauna is the most poorly developed of all three members, consisting of sparsely distributed fossils, except in Osage County, and even there it is the least diverse of all the faunal assemblages. However, the Hughes Creek shows the most variation in facies making it a very interesting unit to work with stratigraphically.

In northernmost Osage County, the Hughes Creek Shale is made up mostly of cherty limestone and contains abundant fusulinids (Measured Section I). This limestone is light gray and the wavy bedding is a distinctive characteristic (Fig. 8). A few miles to the south at Phillips Lake (Measured Section II) there is less limestone and more shale plus a bed of sandstone. At this locality the limestone also is wavy bedded; it also has a cavernous appearance and contains large chert nodules (Figs. 9 and 10). The sandstone is thin and blanket-like (Fig. 11), bioturbated, and fossiliferous. Farther south, at a locality in the NE corner of Sec. 31, T. 25 N., R. 6 E. on Highway 18 north of Fairfax, the limestone has all but completely disappeared from the Hughes Creek. All that remains of it is a thin, fossiliferous, very sandy limestone bed. West of Fairfax at the locality of Measured Section III, there is no limestone in the Hughes Creek and the position of the thin, fossiliferous, blanket sandstone is occupied by a thicker, lenticular sandstone (Fig. 12).

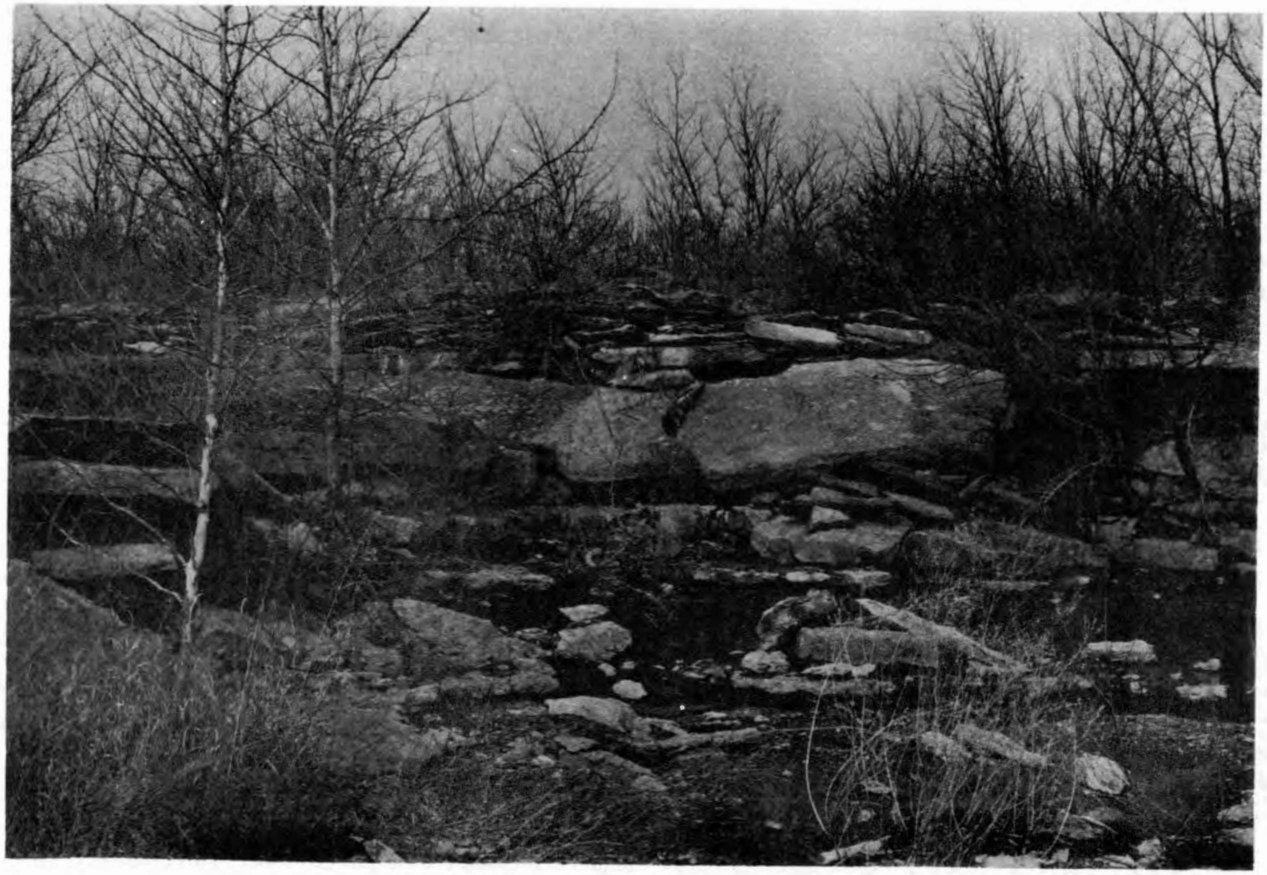


Figure 8.--Notice the characteristic wavy bedding, which distinguishes the limestone of the Hughes Creek in northern Osage County. The rock contains abundant fusulinids and chert nodules. This exposure is in the Phillips Lake spillway, Sec. 10, T. 26 N., R. 6 E.

Figure 9.--Cavernous weathering of limestone in the Hughes Creek Shale at Phillips Lake spillway.

Figure 10.--Large chert nodule in limestone of the Hughes Creek Shale at Phillips Lake spillway.

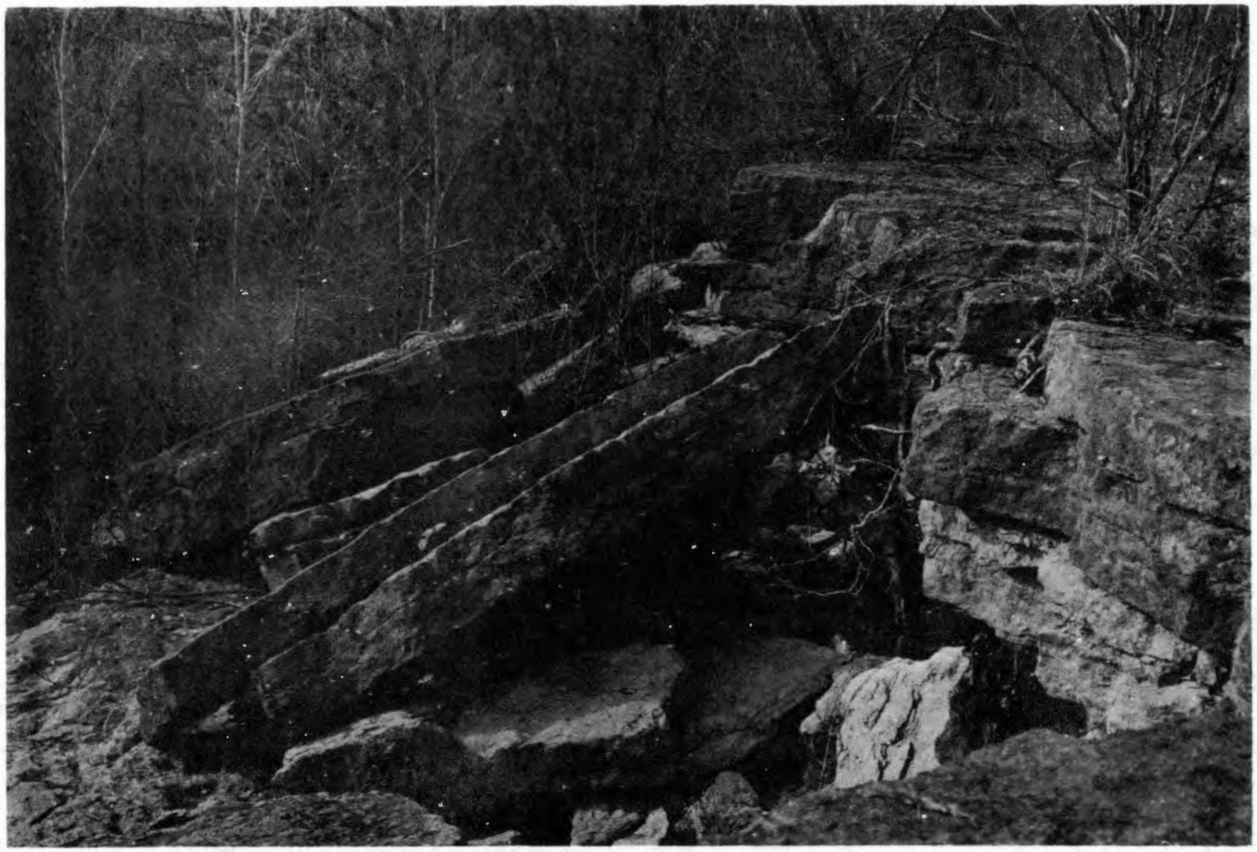


Figure 11.--Thin blanket-like sandstone bed in the Hughes Creek Shale at Phillips Lake spillway.

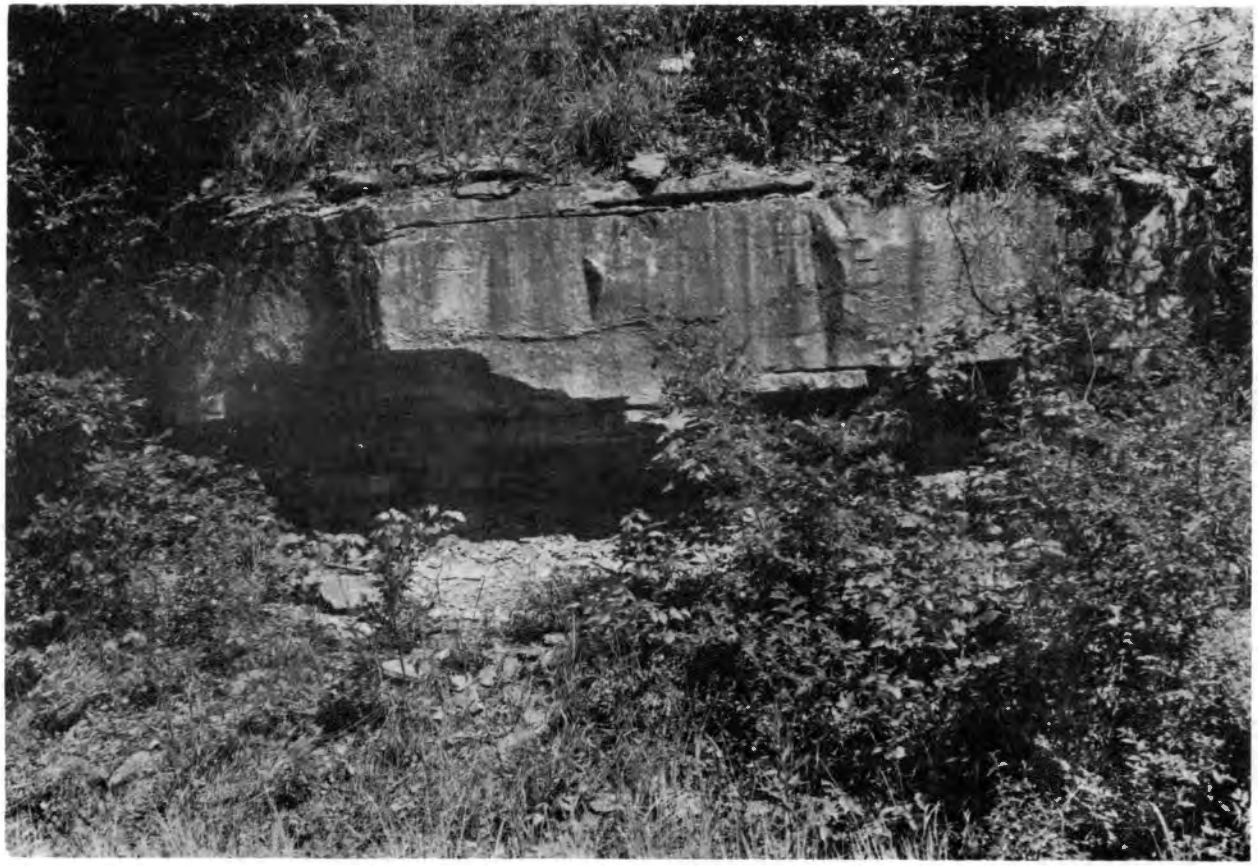


Figure 12.--Thick, channel-fill sandstone in the Hughes Creek Shale west of Fairfax, Osage County; SW¼, Sec. 11, T. 24 N., R. 5 E.

This sandstone, like the ones farther south, is a channel-fill deposit devoid of fossils, containing groove casts on the base as well as other current indicators. This sandstone probably was deposited in a deltaic distributary. Further south, in Pawnee County, sandstone continues to be a dominant constituent of the Hughes Creek Shale. While its development is mostly localized, there is a definite trend for the sandstone to increase towards the south. Greig (1959) reported a sandstone lens 40 feet thick in southern Pawnee County. Also in southern Pawnee County, red beds make their first appearance, both as shales and sandstones. The sandstone described in Measured Section V, on the Pawnee-Payne County line, is just such a unit. This bed is lenticular, has a gradational basal contact and is also bioturbated. It may be some form of tidal or shallow marine deposit (Fig. 13). Still farther south, in southern Payne and Lincoln Counties, the Hughes Creek is deep red, silty shale including, from place to place, cross-bedded, lenticular sandstone, possibly of continental origin. In Lincoln County the Hughes Creek Shale grades imperceptibly into the continental deposits of the Konawa Formation. In short, the Hughes Creek Shale is an excellent documentation of transition from offshore marine, coastal, and finally, to continental environments.

Long Creek Limestone Member

Like the Hughes Creek, the Long Creek Limestone was described originally by Condra in 1927, and in 1935, he defined the unit to be the upper member of the Foraker Limestone. The type locality for this unit is an exposure along Longs Creek in Auburn, Nemaha County, Nebraska.

In Kansas, the Long Creek is described as ranging from 4.5 to

Figure 13.--Red sandstone unit in the Hughes Creek Shale along Pawnee-Payne County line; SW¼, Sec. 34, T. 20 N., R. 5 E.

possibly 17 feet in thickness and consisting of beds of yellow limestone or dolomite alternating with shale. Toward the southern part of the state it becomes a somewhat more massive, light gray limestone (Moore, 1951).

The thickness of this unit is difficult to determine in Oklahoma. The Long Creek does not have the tendency to form prominent scarps like the Americus does, or the Hughes Creek does in northern Osage County. The top of the Long Creek commonly may be eroded away or covered. However, as with the Americus, a general tendency to thin southward can be observed (App. C). If one does not take into account the very poor exposure at Measured Section I, the Long Creek Limestone has an average thickness of slightly more than 13 feet in Oklahoma. Fenoglio (1957) recorded a thickness of 60 feet for the Long Creek in northeastern Payne County. The present author believes that units other than the Long Creek must have been included in this measurement. No measurement of the Long Creek made anywhere else is half as large as this one. If such a measurement were correct, it would double the thickness of the entire formation.

The Long Creek Limestone can be traced from southeastern Nebraska across Kansas. Masters (1955) was able to trace the Long Creek as far south as the Deep Fork River in T. 14 N. in Lincoln County, Oklahoma. However, since this report is concerned with the members of the Foraker Limestone, this author did not investigate south of Sec. 10 and 11, T. 16 N., R. 5 E., since that has been chosen as the southern limit of the Foraker. Beyond that point the Long Creek may be considered as a member of the Konawa Formation as West (1955) and Masters (1955) did.

Over much of the study area, the Long Creek Limestone consists of beds of light gray or tan limestone on a fresh surface separated by calcareous, buff shales. The Long Creek is not as thick-bedded as the Americus, so it tends to be eroded more. Also, the Long Creek has a coarser, more crystalline texture (the biosparrudite facies of Mogharabi (1966), as explained in Chapter IV). In southern Pawnee County, dolomite is locally developed. Proceeding a few more miles to the south in northern Payne County (T. 19 N.), the Long Creek is altered to dolomite. Throughout the remainder of Payne County and that part of Lincoln County that was studied, every sample collected was dolomite and locally cavernous (Fig. 14). The Long Creek Limestone in northern Lincoln County consists of only two thin beds of dolomite (Fig. 15) separated by several feet of shale. In this area, the Long Creek is no longer light colored but is gray or dark gray (with a few crystals of pink dolomite) with a dense, crystalline texture. Masters (1955) reported a 4.5 feet of Long Creek at an exposure along the Turner Turnpike and noted the presence of a one-inch coal bed under the unit. However, no mention of dolomite was made.

Many features serve to distinguish the Long Creek Limestone as well as make it an interesting object of study. Over all of the study area, except for the extreme northern and southern limits, the Long Creek is distinguished by abundant fusulinids. This is perhaps the most striking feature of the member. Usually these fossils are found in the limestone beds, but there is one notable exception. In Payne County (Measured Section VI), a layer of calcareous shale contains an extreme abundance of fusulinids. It is possible that this is another diastem of the sort discussed in the section on the Americus. Figure 16 is a closeup of this layer showing the great abundance of these fossils. However,

Figure 14.--Cavernous characteristic of the Long Creek Limestone in northern Payne County; SW¼, Sec. 24, T. 19 N., R. 4 E. Here the rock is completely altered to dolomite.

Figure 15.--In northern Lincoln County, all that remains of the Long Creek Limestone are two thin beds of dolomite, such as this one, separated by a few feet of shale. The location of the exposure is in the bar ditch, W. line of Sec. 4, T. 16 N., R. 5 E.

Figure 16.--Closeup of "diastem" layer in the Long Creek Limestone, in Payne County showing extreme abundance of fusulinids. Location is SW¼, Sec. 24, T. 19 N., R. 4 E. See Measured Section VI, Appendix C.

despite such profuse accumulations of fossils such as this one, the faunal assemblage of the Long Creek is not as diverse as that in the Americus. Another distinct feature of the Long Creek that may be found from Payne to Osage County is the presence of very large burrow-casts on the bases of some of the limestone beds. Figure 17 is one example from Payne County. These burrows commonly give the appearance of an undulose contact between a limestone and underlying shale bed (Fig. 18). Throughout much of Pawnee County and part of Osage County, the basal bed of the Long Creek Limestone is recognized by abundant broken crinoid columnals (Measured Section IV, unit I). Figure 19 is a closeup of this bed as it appears in northern Pawnee County a short distance west of Ralston. Locally, the Long Creek is additionally distinctive in that it contains *Osagia*; more will be said about this interesting and paleoecologically important fossil in Chapter VII. This was observed in Osage County (Measured Section II); furthermore, an exposure near Cushing in southern Payne County appeared to contain this fossil. Mogharabi (1966) reported in several instances the presence of *Osagia* in the thin sections he examined.

While the facies of the Long Creek Limestone do not vary as much as the Hughes Creek, there is very little lateral continuity within the member. One cannot trace a single bed or sequence of beds over distances comparable to those which can be traced within the Americus Limestone.

Figure 17.--Network of large burrow casts on a slab of Long Creek Limestone in southern Payne County; NE¼, Sec. 27, T. 18 N., R. 4 E.

Figure 18.--Underside of basal bed of the Long Creek near Ralson, Pawnee County, showing the typical undulose contact caused by large burrow casts; SW¼, Sec. 34, T. 24 N., R. 5 E.

Figure 19.--Same bed as Figure 18 showing the abundant broken crinoids that distinguish this bed over much of its outcrop.

CHAPTER VI

FAUNA OF THE FORAKER LIMESTONE

The Foraker Limestone is quite fossiliferous, containing a diverse assemblage of fossils with representatives from eight invertebrate phyla. The distribution of the fossils is not at all uniform. The Hughes Creek Shale Member is almost completely devoid of fossils except in Osage County. In all members the limestone beds yielded a much more diverse assemblage than the shale or sandstone beds.

Only two samples were examined for microfossils. In each case the microfauna was dominated by ostracodes. As these samples were taken several miles apart, it is likely that they can be considered as representative of the microfauna as a whole in the Foraker. The remainder of the fossil lists are devoted to larger fossils. The lists are grouped according to county, township, and each member sampled. Most of the variations among the lists can be explained by sampling error. For example: The meager list of fossils from T. 22 N. in Pawnee County is due to the fact that only one poor exposure was sampled, while T. 23 N. had a number of good exposures which were very thoroughly sampled to give the most complete list of the entire study area. Other variations among the lists are caused by actual changes in the faunal assemblage, such as a brachiopod-bryozoan dominated assemblage changing to one consisting mainly of fusulinids. The interpretation of such trends will be discussed in the following chapter. Following these fossil lists is another list made up of fossils which were reported by other workers to be in the Foraker Limestone, but the present author did not find any of them in the areas given. Note: The fusulinid genus *Triticites* is reported in most of the fossil lists. The fusulinids from every township could not be prepared for microscopic examination and identification, so only a few spot checks were made and the results applied to the whole area. The two genera *Triticites* and *Schwagerina* are the only fusulinids that have been reported from the Foraker (Greig, 1959; Vosburg, 1954), and the presence of *Schwagerina* is noted where it was found by the author of this paper.

Microfossils

The following microfossils were identified in Osage and Pawnee Counties:

SW¼, Sec. 16, T. 29 N., R. 7 E.
Americus Limestone

Ostracoda
Bairdia sp.
Primitia sp.

SE¼, Sec. 34, T. 24 N., R. 5 E.
Americus Limestone

Foraminiferida
Tetrataxis sp.
Ostracoda
Cavellina sp.
Also found were a small fish tooth, a small gastropod, fragments of echinoid spines, and innumerable shell fragments.

Macrofossils

The following forms were identified from Lincoln county:

T. 17 N.
Americus Limestone

Gastropoda
Pseudozygopleura(?) sp.
Crinoidea
Miscellaneous fragments

Long Creek Limestone

Fusulinacea
Triticites sp. (uncommon)
Crinoidea
Miscellaneous fragments

The following forms were identified from Payne County:

T. 18 N.
Long Creek Limestone

Algae
Osagia sp.
Bryozoa
Fenestrate and encrusting forms
Brachiopoda
Composita subtilita (Hall)
Neochonetes granulifer (Owen)
Neospirifer sp.
Reticulatia americana (Dunbar and Condra)
Crinoidea
Miscellaneous fragments

T. 19 N.
Americus Limestone

Fusulinaece
Triticites sp.
Bryozoa
Fenestrate forms
Fistulipora sp.
Meekopora sp.
Rhombopora sp.
Brachiopoda
Composita subtilita (Hall)
Crurithyris planoconvexa (Shumard)
Derbyia sp.
Hustedia mormoni (Marcou)
Hystriculina texana Muir-Wood and Cooper

Juresania nebrascensis (Owen)
Linoproductus sp.
Neochonetes granulifer (Owen)
Neospirifer dunbari King
Reticulatia americana (Dunbar and Condra)
Bivalvia
Aviculopecten sp.
Wilkingia sp.
Crinoidea
Columnals and plates

Long Creek Limestone

Fusulinacea
Triticites sp.
Bryozoa
Fenestrate forms
Rhombopora lepidodendroides Meek
Brachiopoda
Composita subtilita (Hall)
Derbyia sp.
Linoproductus sp.
Neospirifer dunbari King
Reticulatia americana (Dunbar and Condra)
Wellerella truncata Dunbar and Condra
Gastropoda
Unidentified gastropod
Crinoidea
Columnals and plates

The following forms were identified from Pawnee County:

T. 20 N.
Americus Limestone

Fusulinacea
Triticites sp.
Bryozoa
Fenestrate forms
Meekopora sp.
Rhombopora sp.
Brachiopoda
Composita subtilita (Hall)
Crurithyris planoconvexa (Shumard)
Derbyia sp.
Hustedia mormoni (Marcou)
Juresania nebrascensis (Owen)
Linoproductus sp.
Neochonetes granulifer (Owen)
Neospirifer dunbari King
Reticulatia americana (Dunbar and Condra)
Bivalvia
Aviculopecten sp.
Crinoidea
Columnals, plates, and spines

Long Creek Limestone

- Fusulinacea
  - *Triticites* sp.
- Bryozoa
  - Fenestrate forms
  - *Rhombopora lepidodendroides* Meek
- Brachiopoda
  - *Composita subtilita* (Hall)
  - *Derbyia* sp.
  - *Linoproductus* sp.
  - *Neospirifer dunbari* King
  - *Reticulatia americana* (Dunbar and Condra)
- Crinoidea
  - Columnals and plates

T. 21 N.
Americus Limestone

- Fusulinacea
  - *Triticites* sp.
- Anthozoa
  - *Lophophyllidium* sp.
- Bryozoa
  - Fenestrate forms
  - *Fistulipora* sp.
  - *Rhombopora* sp.
- Brachiopoda
  - *Chonetinella* sp.
  - *Composita subtilita* (Hall)
  - *Crurithyris planoconvexa* (Shumard)
  - *Derbyia* sp.
  - *Dielasma* sp.
  - *Echinaria* sp.
  - *Enteletes hemiplicatus* (Hall)
  - *Hustedia mormoni* (Marcou)
  - *Hystriculina texana* Muir-Wood and Cooper
  - *Juresania nebrascensis* (Owen)
  - *Linoproductus* sp.
  - *Meekella striatocostata* (Cox)
  - *Neochonetes granulifer* (Owen)
  - *Neospirifer dunbari* King
  - *Reticulatia americana* (Dunbar and Condra)
  - *Rhipidomella* sp.
  - *Wellerella truncata* Dunbar and Condra
- Bivalvia
  - *Wilkingia* sp.
- Crinoidea
  - Columnals, plates and spines

Long Creek Limestone

- Fusulinacea
  - *Triticites* sp.

Bryozoa
- Fenestrate forms
- *Fistulipora* sp.
- *Rhombopora* sp.
- *Rhombopora lepidodendroides* Meek

Brachiopoda
- *Composita subtilita* (Hall)
- *Crurithyris planoconvexa* (Shumard)
- *Derbyia* sp.
- *Hystriculina texana* Muir-Wood and Cooper
- *Juresania nebrascensis* (Owen)
- *Linoproductus* sp.
- *Meekella striatocostata* (Cox)
- *Neochonetes granulifer* (Owen)
- *Neospirifer dunbari* King
- *Reticulatia americana* (Dunbar and Condra)
- *Rhipidomella* sp.
- *Wellerella truncata* Dunbar and Condra

Mollusca
- Gastropoda
  - *Straparolus (Amphiscapha) muricatus* Knight
- Bivalvia
  - *Aviculopecten* sp.

Crinoidea
- Columnals, plates, and spines

Trilobita
- *Ditomopyge* sp.

T. 22 N.
Americus Limestone

Bryozoa
- Fenestrate forms

Brachiopoda
- *Derbyia* sp.
- *Hystriculina texana* Muir-Wood and Cooper
- *Neospirifer* sp.

Bivalvia
- *Aviculopecten*
- *Myalina (Orthomyalina)* sp.

Crinoidea
- Columnals and plates

T. 23 N.
Americus Limestone

Fusulinacea
- *Triticites* sp.

Anthozoa
- *Lophophyllidium* sp.

Bryozoa
- *Fenestrellina* sp.
- *Fistulipora* sp.
- *Meekopora* sp.

Polypora(?) sp.
Rhombopora lepidodendroides Meek
Tabulipora(?) sp.

Brachiopoda

Chonetinella sp.
Composita subtilita (Hall)
Crurithyris planoconvexa (Shumard)
Derbyia sp.
Derbyia crassa (Meek and Hayden)
Hustedia mormoni (Marcou)
Hystriculina texana Muir-Wood and Cooper
Juresania nebrascensis (Owen)
Linoproductus sp.
Meekella striatocostata (Cox)
Neochonetes granulifer (Owen)
Neospirifer dunbari King
Punctospirifer sp.
Reticulatia americana (Dunbar and Condra)
Rhipidomella sp.
Wellerella truncata Dunbar and Condra

Mollusca

Gastropoda

Bellerophontid gastropod
Straparolus (Amphiscapha) muricatus

Bivalvia

Acanthopecten sp.
Aviculopecten sp.
Aviculopinna sp.
Edmondia(?) sp.
Myalina (Orthomyalina) sp.

Echinodermata

Crinoidea

Delocrinus sp.
Columnals, plates, and spines

Echinoidea

Spine fragments

Long Creek Limestone

Fusulinacea

Triticites sp.

Anthozoa

Lophophyllidium sp.

Bryozoa

Fistulipora sp.
Meekopora sp.
Polypora sp., and other fenestrate forms
Rhombopora lepidodendroides Meek

Brachiopoda

Chonetinella sp.
Composita subtilita (Hall)
Derbyia sp.
Hustedia mormoni (Marcou)
Hystriculina texana Muir-Wood and Cooper

Linoproductus sp.
Neochonetes granulifer (Owen)
Neospirifer dunbari King
Reticulatia americana (Dunbar and Condra)
Wellerella truncata Dunbar and Condra

Gastropoda
Bellerophon (Pharkidonotus) sp.
Straparolus (Amphiscapha) muricatus Knight

Crinoidea
Columnals and plates

T. 24 N.
Americus Limestone

Fusulinacea
Triticites sp.

Bryozoa
Fenestrate forms
Fistulipora sp.
Meekopora sp.
Rhombopora sp.
Rhombopora lepidodendroides Meek

Brachiopoda
Chonetinella sp.
Composits subtilita (Hall)
Crurithyris planoconvexa (Shumard)
Derbyia sp.
Hustedia mormoni (Marcou)
Hystriculina texana Muir-Wood and Cooper
Juresania nebrascensis (Owen)
Linoproductus sp.
Neochonetes granulifer (Owen)
Neospirifer dunbari King
Reticulatia americana (Dunbar and Condra)
Wellerella truncata Dunbar and Condra

Bivalvia
Aviculopecten sp.
Myalina (Orthomyalina) sp.

Crinoidea
Columnals, plates, and spines

Long Creek Limestone

Fusulinacea
Triticites sp.

Anthozoa
Lophophyllidium sp.

Bryozoa
Fistulipora sp.
Meekopora sp.
Rhombopora lepidodendroides Meek

Brachiopoda
Cancrinella(?) sp.
Composita subtilita (Hall)

Hustedia mormoni (Marcou)
Hystriculina texana Muir-Wood and Cooper
Linoproductus sp.
Neochonetes granulifer (Owen)
Neospirifer dunbari King
Reticulatia americana (Dunbar and Condra)
Bivalvia
Myalina sp.
Crinoidea
Columnals and plates

The following forms were identified from Osage County:

T. 24 N.
Americus Limestone

Fusulinacea
Triticites
Bryozoa
Fenestrate forms
Rhombopora sp.
Brachiopoda
Chonetinella sp.
Composits subtilita (Hall)
Derbyia sp.
Hustedia mormoni (Marcou)
Juresania nebrascensis (Owen)
Linoproductus sp.
Neospirifer dunbari King
Punctospirifer sp.
Bivalvia
Aviculopecten sp.
Onychophora(?)
Unidentified specimen possibly from this subphylum of the arthropods.
Crinoidea
Plates and columnals

Hughes Creek Shale

Bryozoa sp.
Rhombopora sp.
Brachiopoda
Unidentifiable productoid fragments
Mollusca
Gastropoda
Unidentified gastropod
Bivalvia
Aviculopecten sp.
Crinoidea
Columnals and plates

Long Creek Limestone

- Fusulinacea
  - *Triticites* sp.
- Bryozoa
  - Fenestrate forms
  - *Fistulipora* sp.
  - *Meekopora* sp.
  - *Rhombopora* sp.
- Brachiopoda
  - *Composita subtilita* (Hall)
  - *Isogramma* sp.
  - *Linoproductus* sp.
  - *Neospirifer dunbari* King
- Crinoidea
  - Columnals and plates

T. 25 N.
Hughes Creek Shale

- Bryozoa
  - Fenestrate forms
  - *Rhombopora* sp.
- Brachiopoda
  - *Crurithyris planoconvexa* (Shumard)
  - *Derbyia* sp.
  - *Hystriculina texana* Muir-Wood and Cooper
  - *Neospirifer dunbari* King
  - *Reticulatia americana* (Dunbar and Condra)
- Mollusca
  - Gastropoda
    - Unidentified gastropod
  - Bivalvia
    - *Aviculopecten(?)* sp.
    - *Myalina* sp.
- Echinodermata
  - Crinoidea
    - Columnals and plates
  - Echinoidea
    - Spine fragments

T. 26 N.
Americus Limestone

- Fusulinacea
  - *Triticites* sp.
- Anthozoa
  - *Lophophyllidium* sp.
- Bryozoa
  - Fenestrate forms
  - *Fistulopora* sp.
  - *Meekopora* sp.

Brachiopoda
- Inarticulata
  - *Lingula* sp.
- Articulata
  - *Composita subtilita* (Hall)
  - *Dielasma* sp.
  - *Hystriculina texana* Muir-Wood and Cooper
  - *Linoproductus* sp.
  - *Meekella striatocostata* (Cox)
  - *Neochonetes granulifer* (Owen)
  - *Neospirifer dunbari* King
  - *Reticulatia americana* (Dunbar and Condra)
  - *Wellerella truncata* Dunbar and Condra

Mollusca
- Gastropoda
  - Bellerophontid gastropod
  - *Pseudozygopleura* (?) sp.
- Bivalvia
  - *Aviculopecten* sp.
  - *Aviculopinna* sp.
  - *Myalina (Orthomyalina)* sp.

Crinoidea
- Columnals and plates

Hughes Creek Shale

Fusulinacea
- *Triticites* sp.

Bryozoa
- Fenestrate forms
- *Fistulipora* sp.

Brachiopoda
- *Composita subtilita* (Hall)
- *Derbyia* sp.
- *Hustedia mormoni* (Marcou)
- *Hystriculina texana* Muir-Wood and Cooper
- *Linoproductus* sp.
- *Meekella striatocostata* (Cox)
- *Neospirifer dunbari* King

Mollusca
- Gastropoda
  - *Pseudozygopleura(?)* sp.
- Bivalvia
  - *Aviculopecten* sp.

Crinoidea
- Columnals and paltes

Long Creek Limestone

Algae
- *Osagia* sp.

Fusulinacea
- *Triticites* sp.

Bryozoa
Meekopora sp.
Rhombopora sp.
Brachiopoda
Chonetinella sp.
Composita subtilita (Hall)
Crurithyris planoconvexa (Shumard)
Linoproductus sp.
Neospirifer dunbari King
Echinodermata
Crinoidea
Columnals
Echinoidea
Spine fragments

T. 27 N.
Americus Limestone

Brachiopoda
Inarticulata
Trigonoglossa sp.
Articulata
Composita subtilita (Hall)
Derbyia sp.
Linoproductus sp.
Mollusca
Gastropoda
Belloerphontid gastropod
Pseudozygopleura(?) sp.
Bivalvia
Aviculopecten sp.
Aviculopinna sp.

T. 29 N.
Americus Limestone

Fusulinacea
Triticites sp.
Brachiopoda
Inarticulata
Lingula sp.
Articulata
Composita subtilita (Hall)
Crurithyris planoconvexa (Shumard)
Neochonetes granulifer (Owen)
Neospirifer dunbari King
Crinoidea
Columnals

Hughes Creek Shale

Fusulinacea
Schwagerina sp.
Triticites sp.

Brachiopoda
Hustedia mormoni (Marcou)
Linoproductus cora (d'Orbigny)
Crinoidea
Columnals and plates

Long Creek Limestone

Algae
Osagia(?) sp.

The following forms were not identified by the present author, but were reported by other workers:

Lincoln County (West, 1955)
Americus Limestone

Brachiopoda
Fragments

Payne County (Fenoglio, 1957)
Americus Limestone

Brachiopoda
Meekella striatocostata (Cox)
Bivalvia
Aviculopinna americana Meek
Trilobita
Ameura sp.

Long Creek Limestone

Brachiopoda
*Chonetes (*now *Neochonetes) granulifer* (Owen)

Payne County (Nakayama, 1955)
Americus Limestone

Bivalvia
Astartella vera Hall
Myalina sp.
Chondrichthyes
Deltodus sp.
Petalodus destructor (Newberry and Worthen)

Long Creek Limestone

Bivalvia
Myalina sp.
Wilkingia sp.

Pawnee County (Greig, 1959)
Americus Limestone

Bryozoa
Bascomella fusiformis Condra and Elias
Brachiopoda
Teguliferina(?) sp.
Trilobita
Ditomopyge decurtata (Gheyselinck)

Long Creek Limestone

Fusulinacea
Schwagerina sp.

Osage County (Vosburg, 1954)
Americus Limestone

Mollusca
Gastropoda
Straparolus (Amphiscapha) catilloides (Conrad)
Bivalvia
Pleurophorus sp.

Several changes have been made in the nomenclature of the brachiopods of this period, particularly with the productoids. If some of the names in this chapter seem unfamiliar, Appendix B is a listing of many of these changes.

The remaining pages of this chapter contain photographs of some of the fossils found throughout the area. In all the photographs the scale is graduated in millimeters and numbered every centimeter.

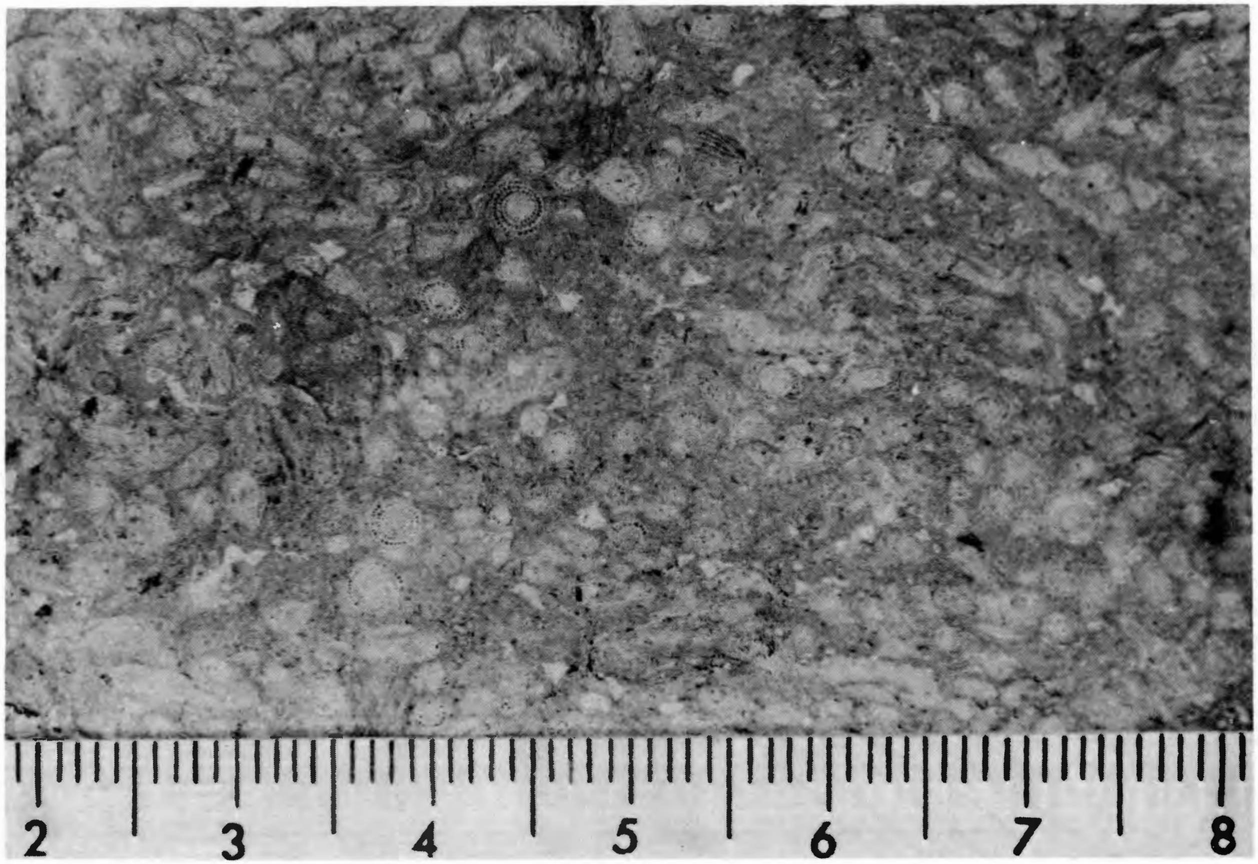


Figure 20.--Cherty limestone from the Hughes Creek containing abundant fusulinids. Both *Triticites* and *Schwagerina* have been found. This sample is from SW¼, Sec. 16, T. 29 N., R. 7 E., in Osage County near the Kansas state line.

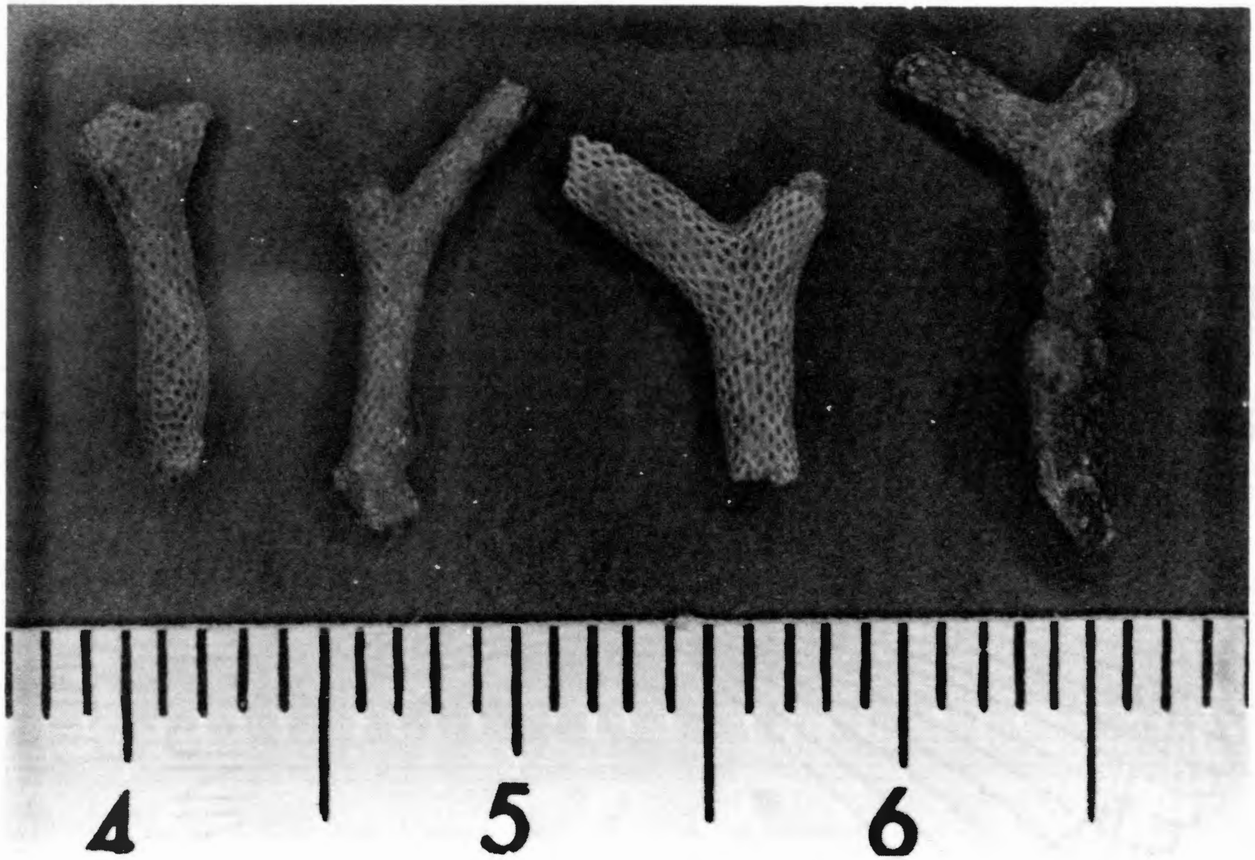


Figure 21.--These specimens of the bryozoan *Rhombopora* were collected from the Americus Limestone from various localities in Pawnee County.

Figure 22.--These two specimens of the bryozoan genus *Meekopora* were collected from the Long Creek Limestone in Pawnee County.

Figure 23.--Note the borings made in this specimen of *Fistulipora* from the Americus in the SW¼, Sec. 22, T. 23 N., R. 5 E., in Pawnee County.

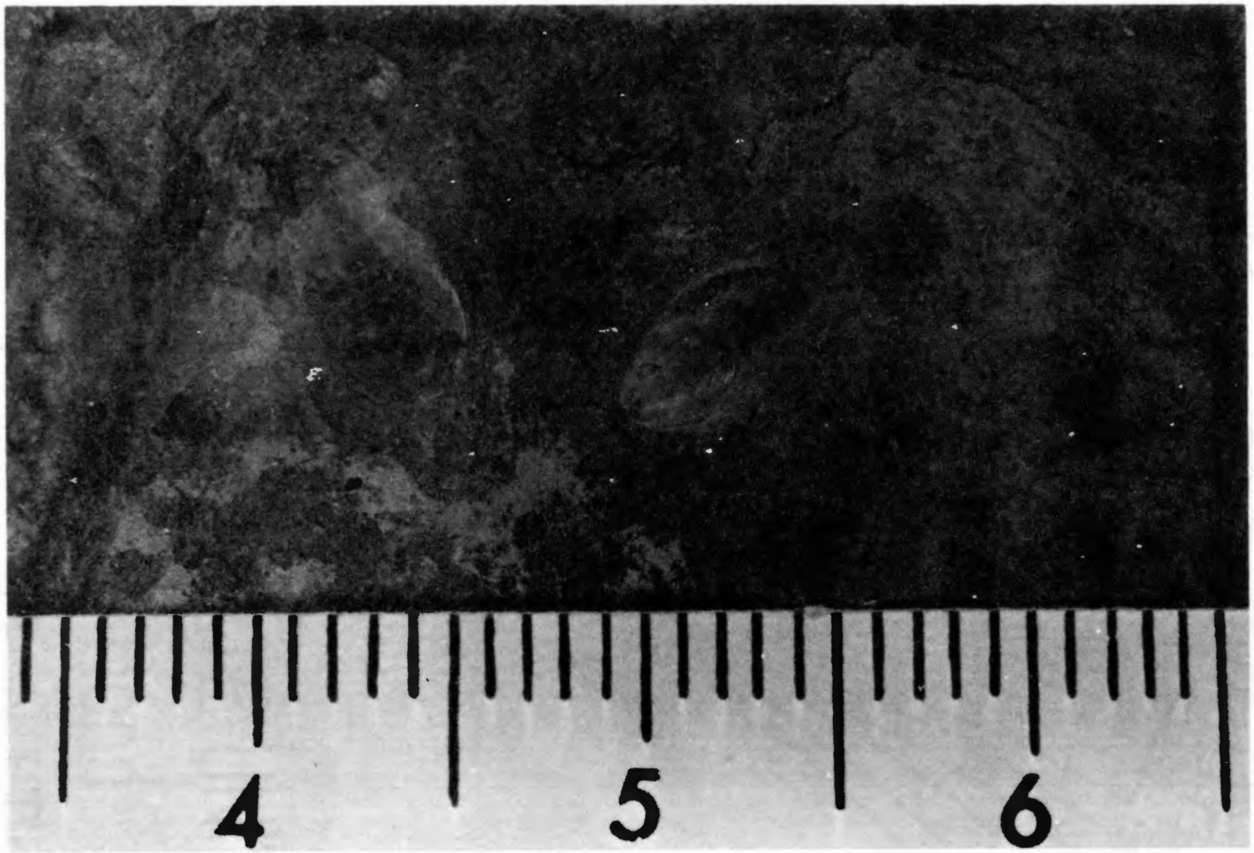


Figure 24.--Two specimens of *Lingula* from the Americus Limestone near the Kansas state line near the same spot as the sample in Figure 20.

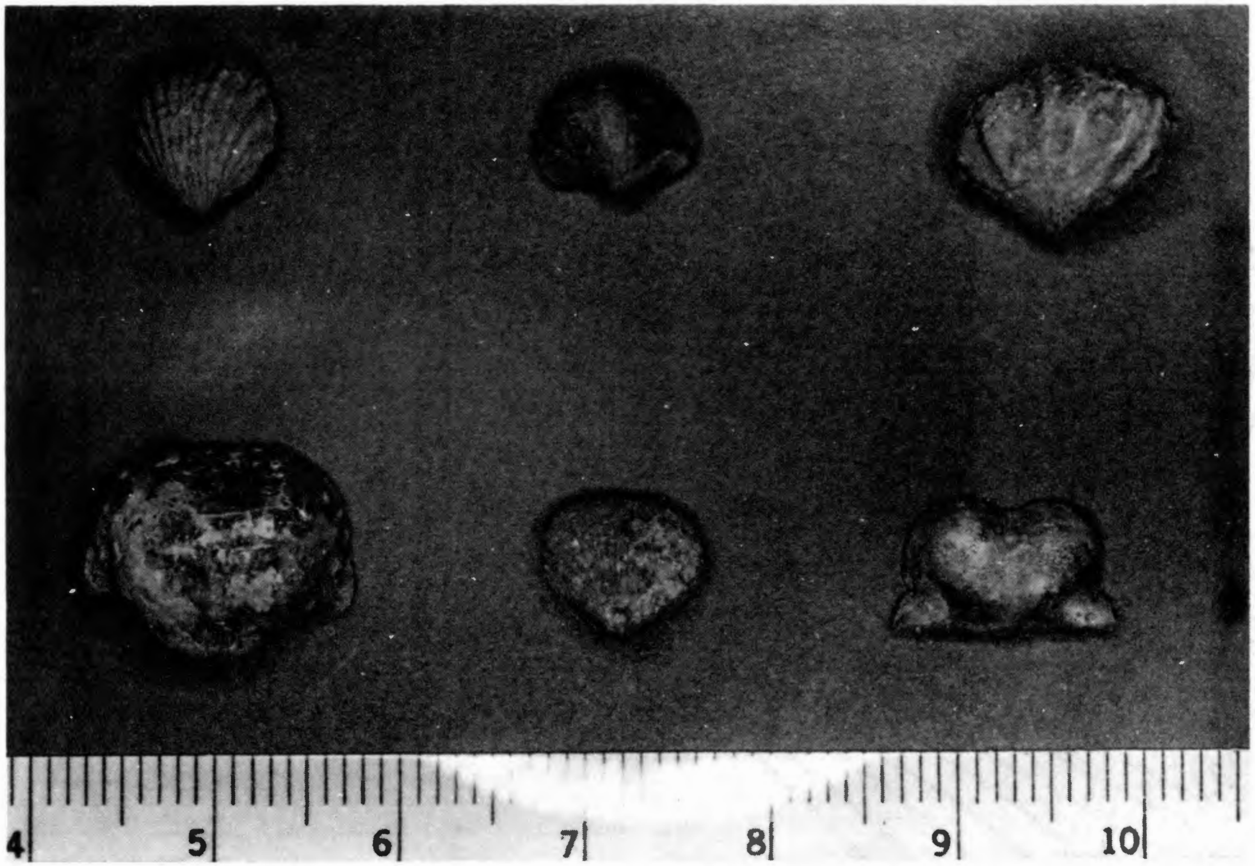


Figure 25.--Six small brachiopods from the Americus of Pawnee County. Clockwise from top left: *Hustedia mormoni*, *Crurithyris planoconvexa*, *Wellerella* sp., *Chonetinella* sp., *Rhipodomella* sp., and *Hystriculina texana*.

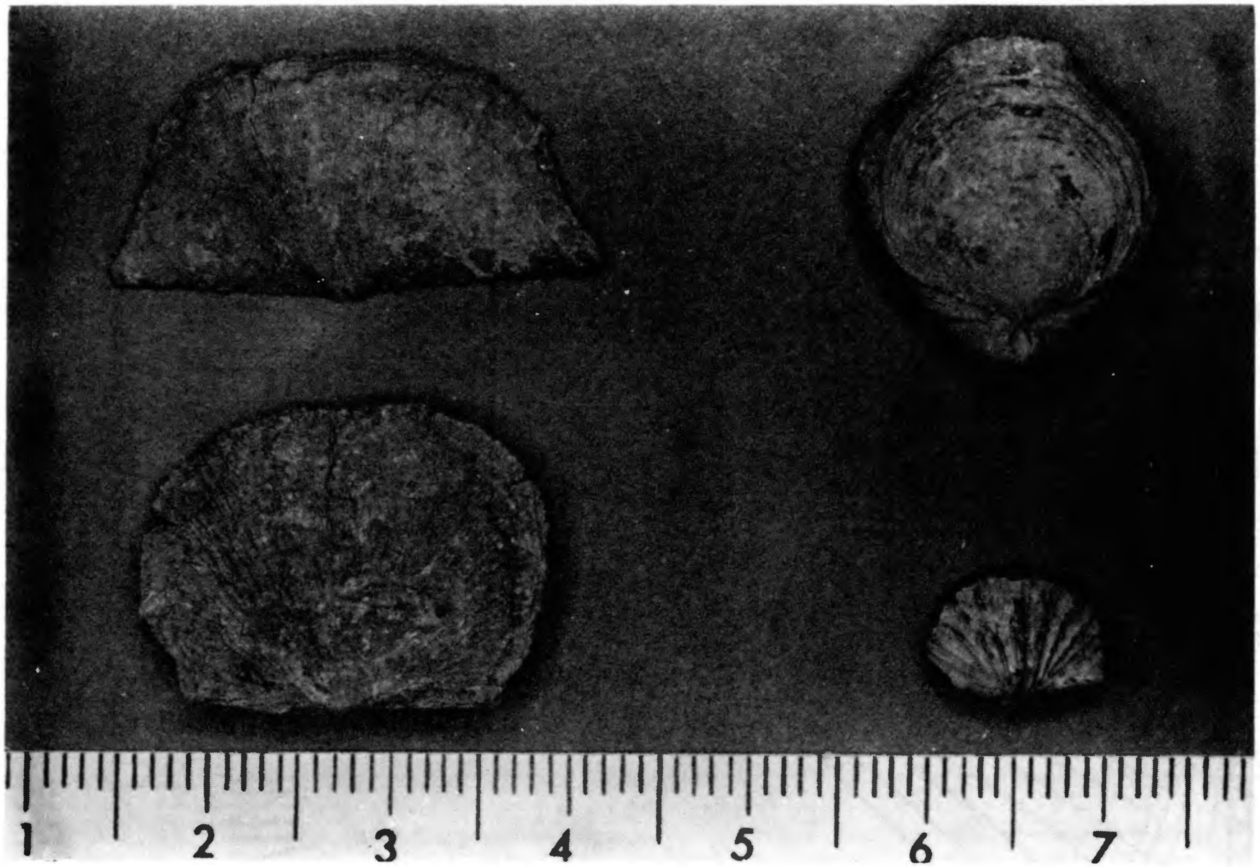


Figure 26.--Brachiopods, clockwise from top left: *Neochonetes granulifer*, *Composita subtilita*, *Punctospirifer* sp., and *Derbyia* sp. Localities vary.

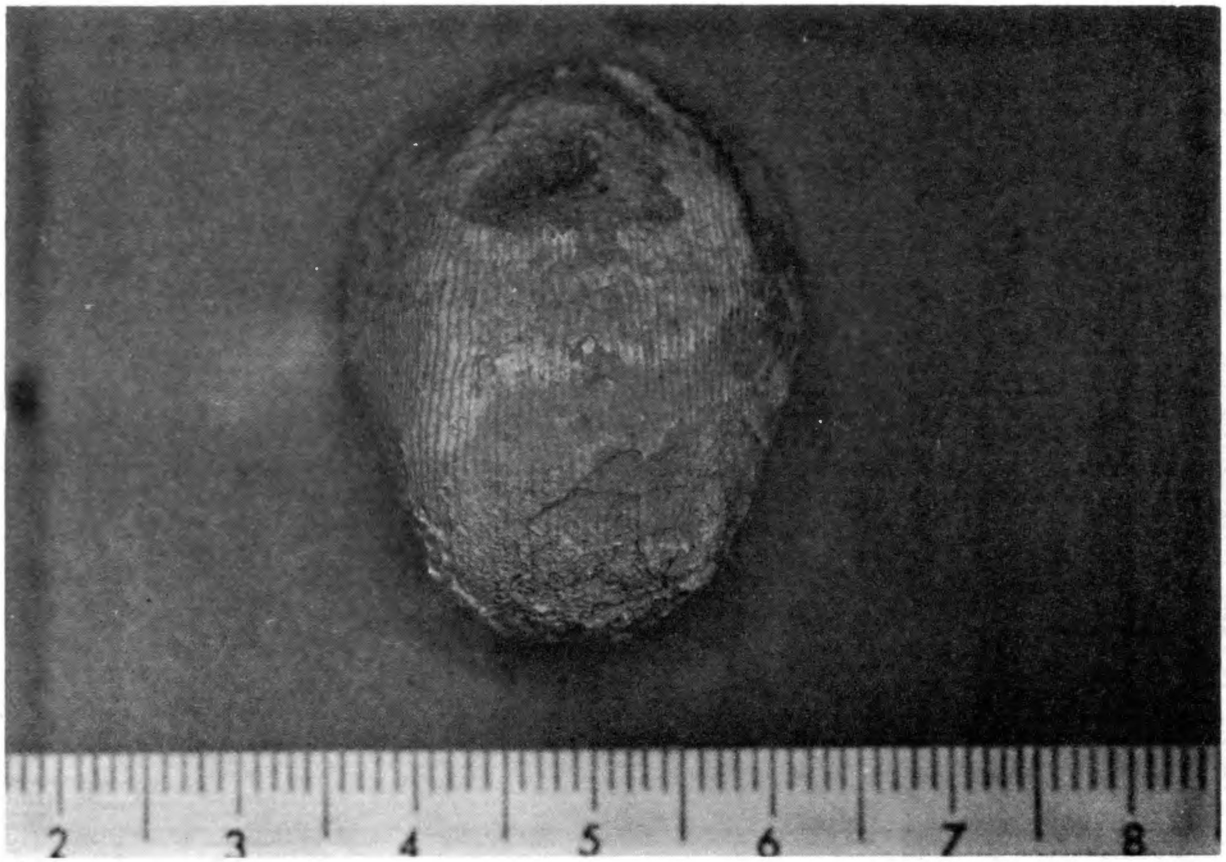


Figure 27.--*Linoproductus cora* from the Hughes Creek near the Kansas state line.

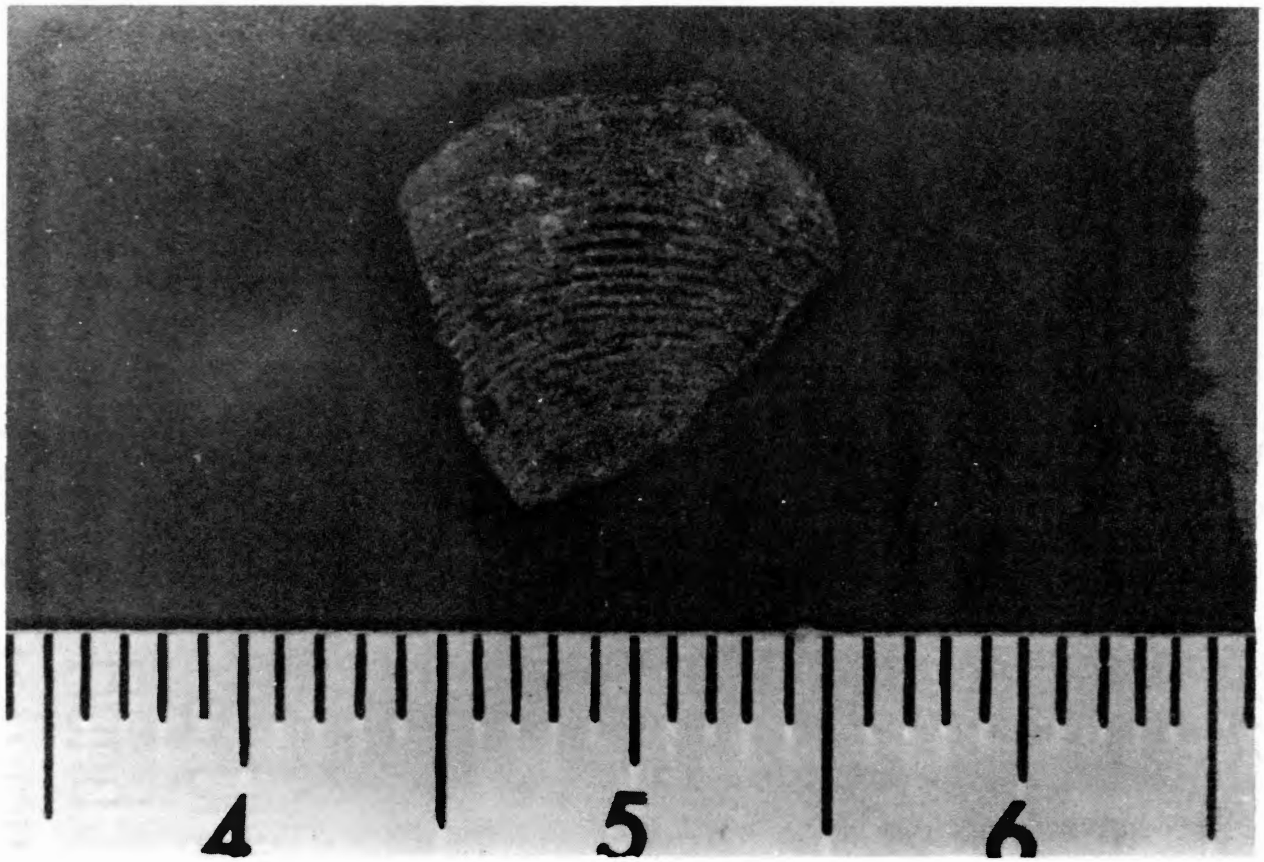


Figure 28.--Fragment of the rare brachiopod genus *Isogramma* collected from the Long Creek Limestone west of Fairfax, Osage County; SW¼, Sec. 11, T. 24 N., R. 5 E.

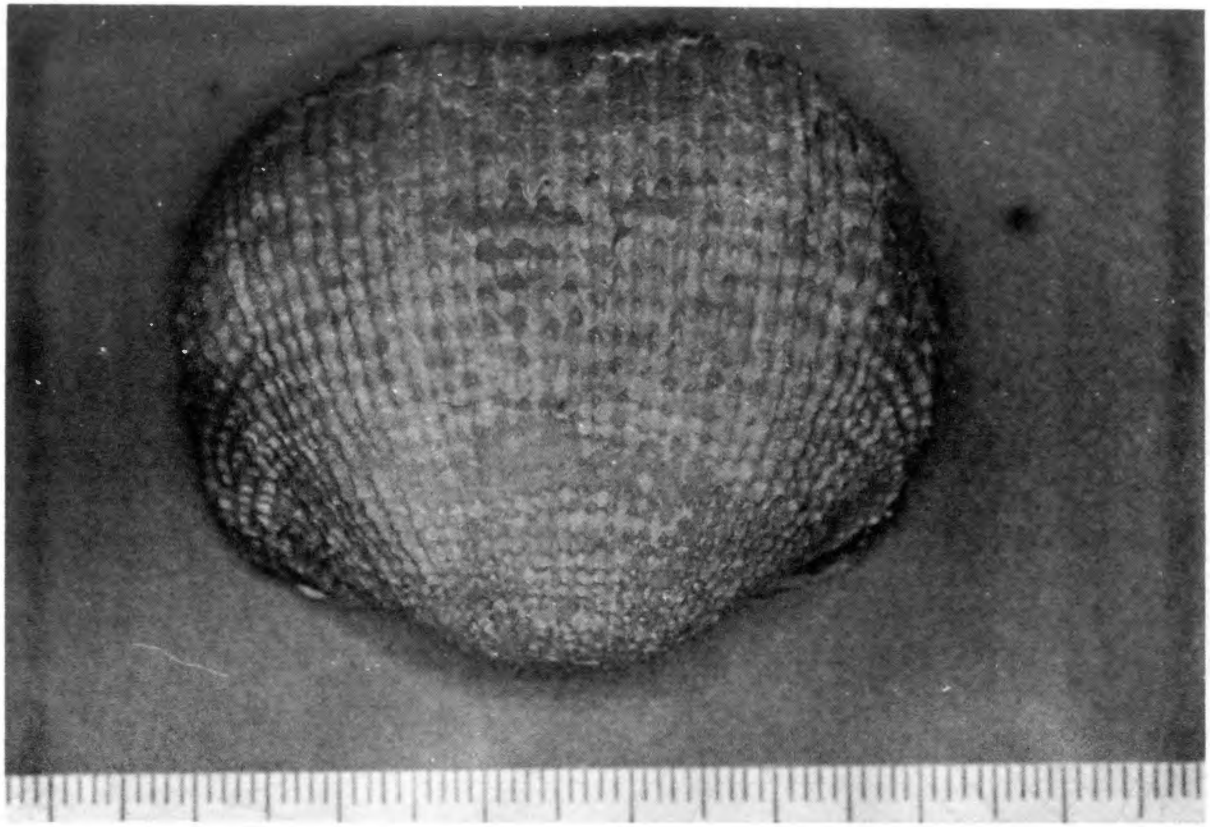


Figure 29.--Well preserved *Reticulatia americana* from the Americus Limestone at Phillips Lake spillway, Osage County.

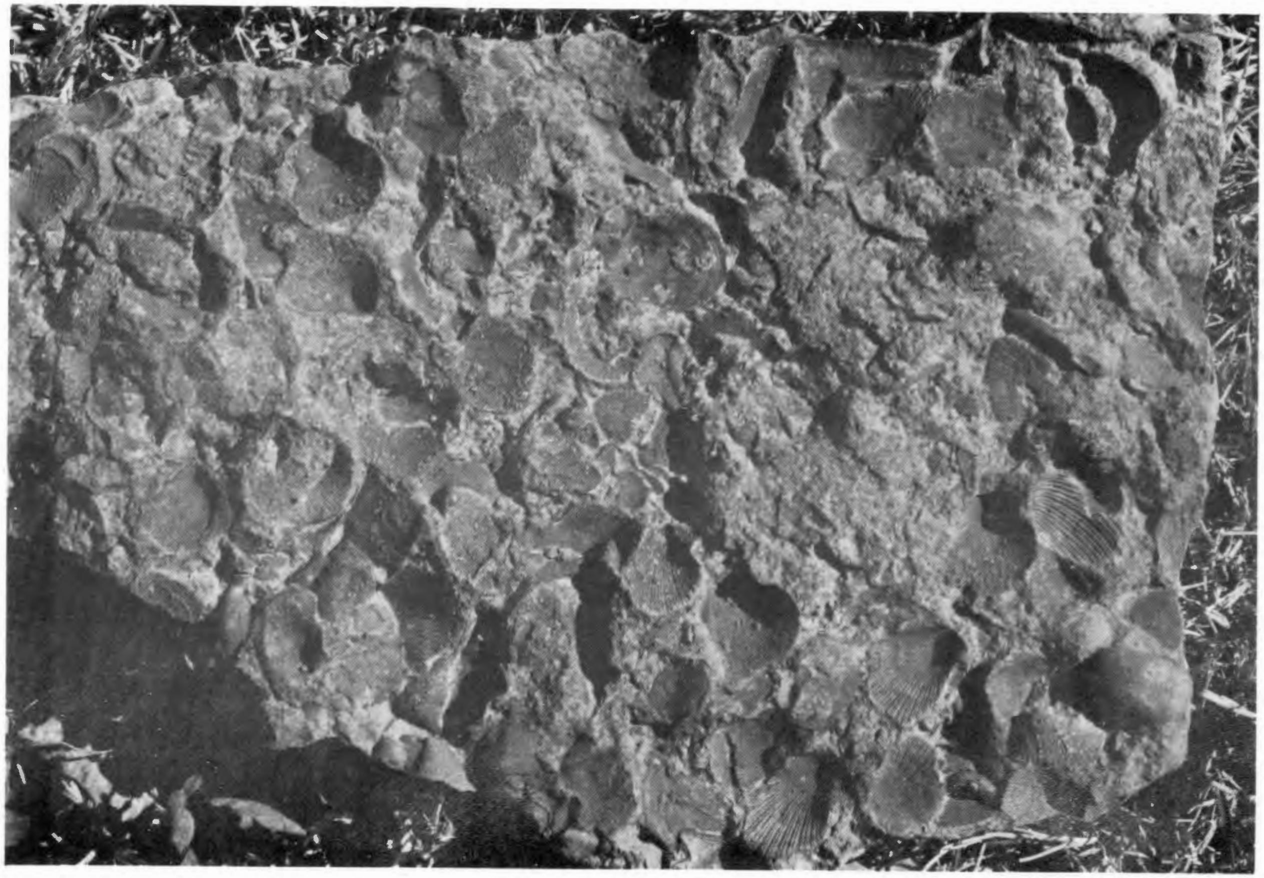


Figure 30.--Underside of slab from basal bed of the Americus Limestone collected from Phillips Lake spillway. Contains abundant *Aviculopecten*, a bellorophontid gastropod, *Aviculopinna*, and possibly *Orthomyalina*.

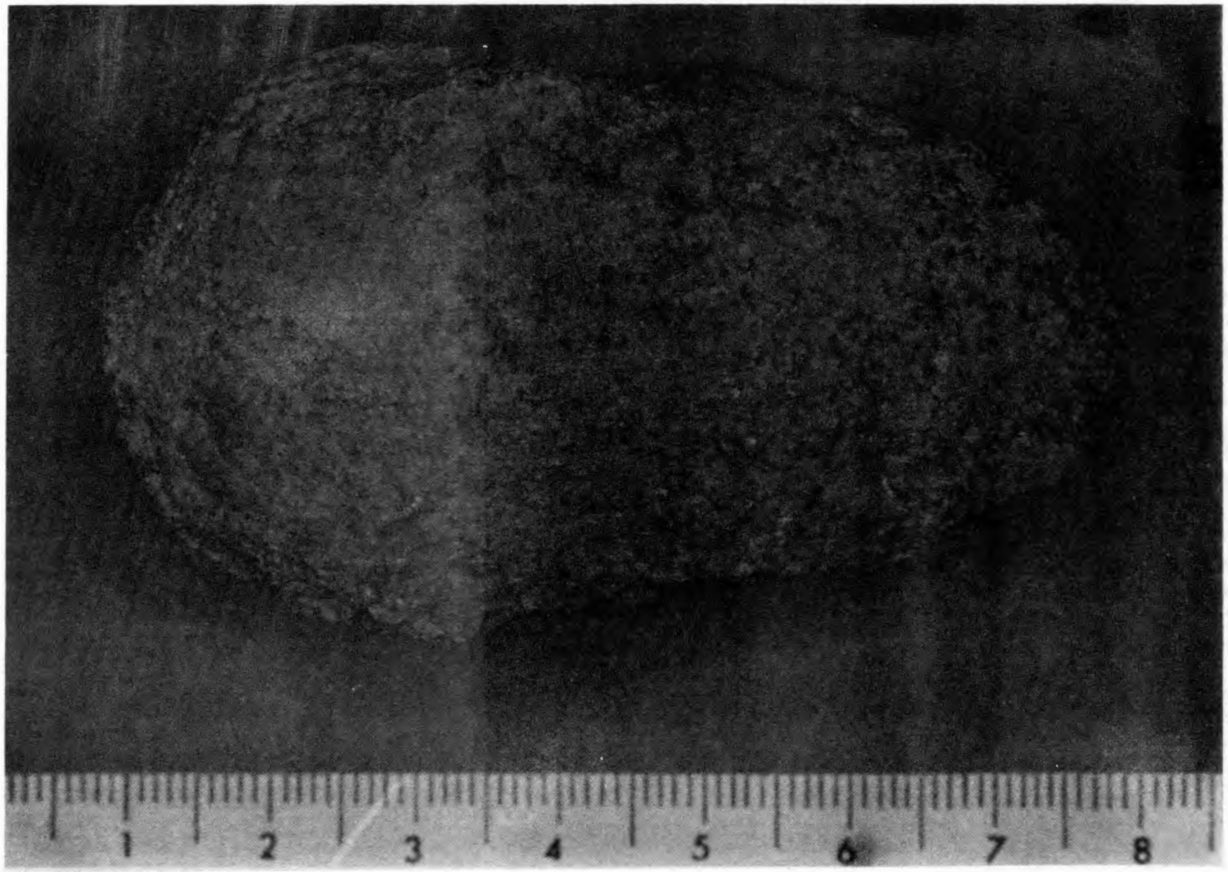


Figure 31.--Poorly preserved *Wilkingia* from the Americus Limestone along the section line between Secs. 16 and 17, T. 19 N., R. 5 E., in Payne County.

Figure 32.--Calyx of *Delocrinus* from near the base of the Americus Limestone; SW¼, Sec. 22, T. 23 N., R. 5 E., in Pawnee County.

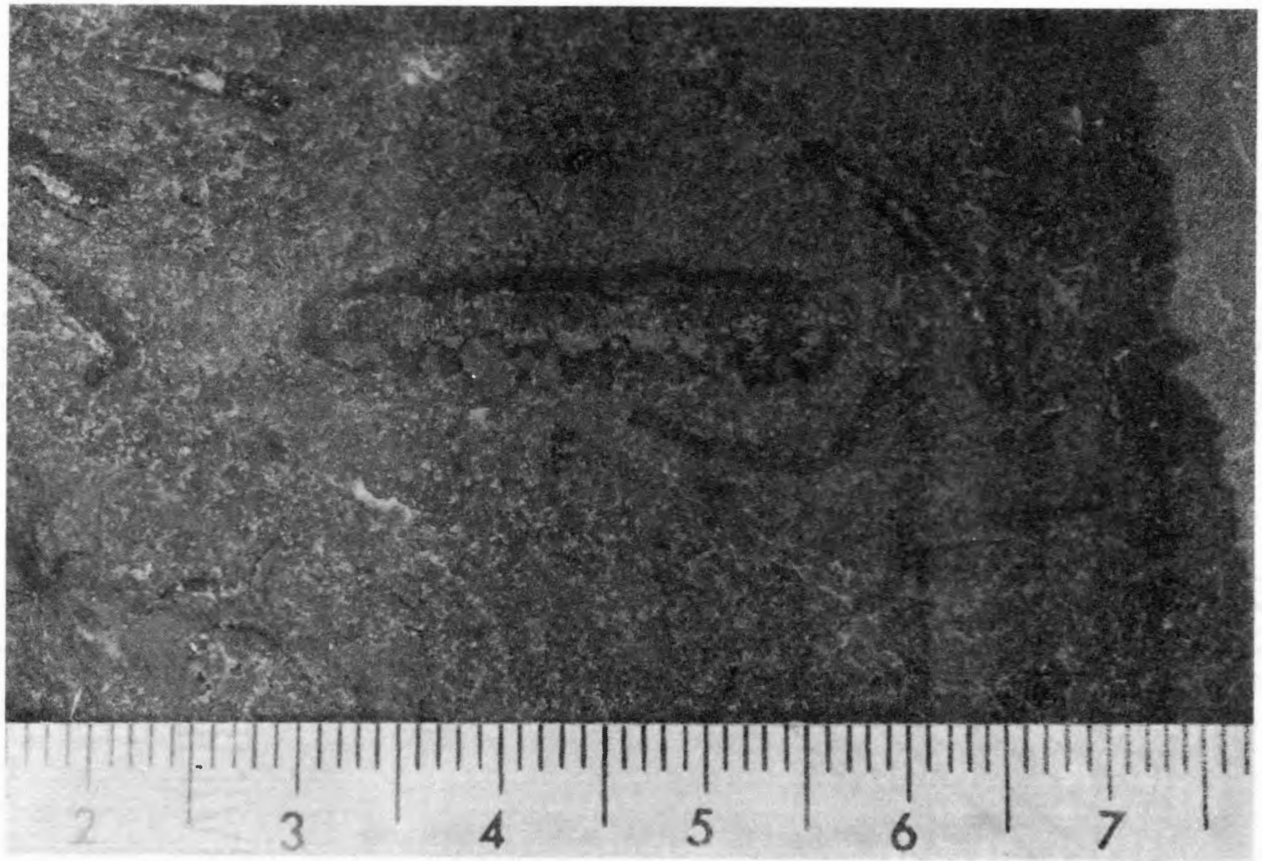


Figure 33.--Pyritized specimen of what appears to be an onychophoran from the Americus at the same locality as the specimen in Figure 28 near Fairfax, Osage County.

CHAPTER VII

PALEOECOLOGY AND DEPOSITIONAL ENVIRONMENT OF THE FORAKER LIMESTONE

Introduction

The topic of this chapter is very broad and diverse. There are many ways to approach the study of paleoecology. Some make general judgements about a fossil assemblage's relationship to its immediate surroundings. Others try to relate fossils to such physical parameters as water depth, salinity, distance from shore, etc. Still other approaches make very meticulous measurements of fossil orientation, relationships to bedding and relative abundances of faunules. This last method is often used to make deductions relating to population dynamics of an ancient community, predator-prey relationships, and the general flow of energy throughout the community. Each approach has developed its own set of terms and classification scheme.

Since the area of study was quite large, it is impractical to apply any detailed methods to learn the paleoecology of the Foraker Limestone. Likewise, with the depositional environment, the large extent of the study area offers ample room for many sedimentary environments, so this subject will also be dealt with in a rather general sense.

The best way to begin is to set down definitions of some of the terms that will be in common use throughout this chapter; other definitions will be added later. Paleoecology is the study of all aspects of relationships between ancient organisms and their environment (Moore, 1964). Paleo-ecology has two broad divisions which are generally agreed upon. Paleoautecology is the study of individual fossil organisms, or small groups of taxonomically similar organisms (Moore, 1964). This division makes use of such tools as functional morphology and studying the life habits of modern organisms believed to be similar to their ancient counterparts. The other major division is paleosynecology which is devoted to the study of ancient organic communities (Moore, 1964). Measurements of numbers of different species, their orientations and degrees of fragmentation are some of the methods employed here. Also, the sizes of individuals of one species may be measured in an effort to learn the relative numbers of adults to juveniles, and thus to learn something about the population dynamics of that species. Paleosyncecological data commonly is treated statistically as data collection usually involves some measureable quantity.

Aside from this very general, twofold classification of paleoecology, there are many different ways of classifying individual fossils and fossil communities. Some authors take the approach of relating the fossils only to the physical environment, such as determining where a fossil community existed relative to the shore, or if a fossil assemblage was buried *in situ*, or if it had been transported some distance. The other extreme is examining only the interactions of the organisms with each other to the exclusion of the physical environment. Such studies are those dealing with population dynamics, predator-prey relationships, etc. There are also approaches which utilize elements of both of the above-mentioned methods. Another popular method which does a successful job of mating physical environmental relationships with community interaction is the concept of trophic analysis. It ranks the various members of the community according to their position in the feeding hierarchy. However, since the physical environment can have considerable influence on the types of food available and the feeding mechanisms best suited to exist there, the physical environment plays an important part. Trophic analysis will be discussed in greater detail later.

Paleoautecology

Algae

While this report is mostly concerned with fauna, certain algae have important paleoecological implications. The algae which are found in the Foraker Limestone are of the genus *Osagia*. This author observed it in outcrop in only a few places in the Long Creek Limestone Member; however, Mogharabi (1966), through microscopic examination of thin sections, noted that this fossil is more universally distributed than what is apparent at the outcrop. These algae are distinguished by a tendency to form a fusiform-shaped coating around some nucleus, regardless of its shape. Crinoid fragments were found to be the nuclei of many *Osagia* colonies in the Long Creek (Mogharabi, 1966). Actually, *Osagia* is not just an algae, but an intergrowth of both algae and a foraminiferid. In his study of the Hughes Creek Shale in Kansas, Schmidt (1975) reported that *Osagia* was an algal-foraminiferid consortium made up of the algal genus *Girvanella* and the opthalmid foraminiferid genus *Hedraites*. The algae are usually the dominant members of the colony. Since it cannot be proved that any mutual benefit was derived from this association, the term symbiont is not applied to these organisms.

The single most important factor controlling the distribution of algae is sunlight, which is necessary for the algae to carry on photosynthesis. Therefore, algae can only live in shallow water that is quite clear (Heckel, 1972). A peculiar item concerning the environment of algae was noted by Moore (1964). He said that abundant *Osagia* typically occur at or near the top of cyclothems, indicating that *Osagia* had a preference for regressive environments.

Fusulinids

While the fusulinids are not distributed evenly throughout the Foraker, their large numbers make them the most abundant form in the whole formation. Since they obviously make up a significant part of the Foraker fauna, careful attention must be given to their paleoecological interpretation.

For some time, paleontologists have noticed that fusulinids commonly are abundant in the strata which indicate the culmination of a marine transgressive phase in a cyclothem. This implies that the sea was at its deepest during this phase, and Elias (1937) reached the conclusion that the fusulinids lived at depths of about 160 to 180 feet based on comparisons with some modern foraminiferids. There is, however, considerable evidence to dispute this. Heckel (1972) has observed that fusulinids occur locally with abundant phylloid red or green algae in certain Upper Pennsylvanian Midcontinent algal mound complexes. Fusulinids were also observed to be common in small channels in the tops of these mounds. Since algae are positive indicators of shallow water, this evidence clearly suggests a very shallow water environment for these particular fusulinids. Laporte (1962), in his study of the Cottonwood Limestone, said that there is strong evidence that fusulinids inhabited shallow waters, around 50 feet deep. In the present study, the concentration of many fusulinids in the sparry facies of the Long Creek Limestone suggests that these organisms inhabited waters shallow enough to be above normal wave base so that wave energy was sufficient to winnow out most of the carbonate mud. Ideally, the strata containing fusulinids are in the middle of the marine parts of cyclothem, representing the culmination of a transgression. Stratigraphic evidence indicates that fusulinids penetrated continental basins farthest when epeiric seas were most extensive (Thompson, 1964). However, this does not necessarily imply that a fusulinid-dominated assemblage is an indicator for the deepest part of an invading sea, but rather indicates intermediate to greatest distances from sea margins (Moore, 1964).

Fusulinids were unusually sensitive to their physical surroundings. They are associated with neither coarse clastics nor evaporites but are found mostly in limestones and clacareous shales. Also, fusulinids are not found in association with fossils whose modern counterparts are characteristic of brackish-water or nearshore environments (Thompson, 1964). All of these factors point to an open environment with full marine salinity. In the Foraker, and in other formations, it has been observed that where fusulinids are abundant, other types of fossils are sparse or lacking. Fusulinids probably avoided areas colonized by larger organisms because these animals preyed on them, or they gave the fusulinids too much competition for dissolved calcium carbonate (Schmidt, 1975).

Corals

The only coelenterate found by the writer in the Foraker is the solitary, rugose coral *Lophophyllidium*. According to Heckel (1972), corals are quite sensitive to their environment and cannot tolerate influxes of fresh water for even short periods of time. Also, because of their nature of feeding on small nektonic or suspended organisms, corals need water which is constantly circulating and quite clear.

Colonial corals require a firm substrate for attachment; however, solitary corals, like *Lophophyllidium*, may have lived on soft substrates. These corals could tolerate a wide range of temperatures and could live at diverse depths, being best developed at depths slightly deeper than the neritic zone (Heckel, 1972). The occurrence of *Lophophyllidium* in the Foraker agrees with the conditions just mentioned. It has only been found associated with the biomicrite facies of the Americus and Long Creek limestones.

Bryozoans

Bryozoans can be found in all members of the Foraker Limestone. Fenestrate, ramose, ribbon, and a few encrusting forms are all represented. They are associated with the limestone beds of the formation and possibly some of the interbedded shales.

Bryozoans prefer water which is clear and constantly agitated by waves or strong currents to assure maximum food supply. Also, they need a firm substrate for attachment. This may be afforded by a rocky habitat, a hardground, or shells and other hard objects resting on a soft surface (Schmidt, 1975). The above statements are an oversimplification. The general forms of the bryozoans are a reflection of the conditions in which the organisms lived. The massive or laminar encrusting forms tend to grow mainly in rough water, whereas the more delicate branching forms tend to grow only in quiet water (Heckel, 1972). Simonsen (1977) concluded that the fenestrate and pinnate bryozoans of the Wreford Megacyclothem preferred fairly deep water, offshore with normal marine salinity, and a mixed clay and lime mud bottom (Note: For Simonsen "deep" water is around 50 feet, which is considered shallow by most other authors). Simonsen (1977) added that a few species were tolerant of more sandy, shallow, and even brackish environments. The observations made on the Foraker Limestone concur with these generalizations. The micritic facies of the Americus Limestone contain fenestrate forms and the delicate, branching *Rhombopora*. The more sparry, higher energy facies of the Long Creek Limestone Member yield the more durable ribbon forms like *Meekopora* and a few encrusting forms.

Brachiopods

Brachiopods are probably the second most abundant fossil phylum represented in the Foraker. They are the most conspicuous fossils, visible on nearly any given outcrop and they are certainly the most diverse phylum represented as a brief examination of the fossil lists of the preceding chapter will show. Because of their diversity, it will be necessary to give more than the general environmental preferences listed for the preceding groups. However, there are several characteristics that do apply to brachiopods as a whole.

All living brachiopods require well oxygenated water with fully marine salinity (Ager, 1967). Brachiopods are intolerant of any freshening of their water and none are adapted to brackish or fresh-water environments. The lingulids can tolerate brief periods of freshening of their water, but they do so by closing their shells tightly and retreating into their burrows; they are the only living brachiopods so adapted (Rudwick, 1965).

The great majority of living brachiopods are confined to the shallower waters of the continental shelves; a few species are able to live at abyssal depth. Likewise, only a very few species range into the littoral zone and none of them are anything but marginally littoral and these are all most abundant below low-tide level (Rudwick, 1965).

Some myths have sprung up concerning brachiopods' relationships with their environments; Rudwick (1965) has exposed some of them. It has been said that brachiopods have generally migrated into deeper waters through time. While it is true that brachiopods have become less dominant members of the shallower water communities, this observation is probably not accurate. Few fossil brachiopods can be used as depth indicators. When lingulids are found alone and with no indicators of toxic conditions, it can be taken to reflect the possiblity of littoral conditions.

Another myth is that brachiopods were quite intolerant of turbidity. While this may be true of some species, it is not true of all; *Lingula* is such an exception. A tolerance of turbidity is evidenced by the fact that fossil brachiopods are commonly found in muddy or silty sediments or in fine-grained limestones. It is possible that the sediments accumulated discontinuously with long periods of non-deposition interrupted by episodes of turbidity with some sedimentation (Rudwick, 1965). Those brachiopods which can tolerate turbidity are able to do so because their feeding mechanisms are able to reject unwanted matter. However, because they are sessile benthos, they cannot live in areas of rapid sedimentation. In addition, few brachiopods can tolerate intense water turbulence (Heckel, 1972).

Fossil evidence shows that brachiopods have tried many methods of attaching or anchoring themselves to some substrate. Most living species either prefer or require a hard material for attachment, such as a rock, shell, or coral. On fine-grained substrates, these brachiopods have to use shells or other isolated patches of hard material. Such may have been the case with many fossil brachiopods which lived attached to objects which would not normally be preserved in the fossil record, such as algal stems or worm tubes. This probably accounts for the abundance of brachiopods in fine-grained sediments. Another possibility is that the pedicles of these brachiopods were so modified that they could anchor their shells in soft sediment. This adaption is found in a few living species and could have been more common in the past (Rudwick, 1965). An anchoring adaption found in the fossil record is for some brachiopods to use the shell material itself to weigh down the posterior end of the shell. This is accomplished by thickening the interior of the umbonal region. In this way the shell maintains its orientation relative to the substrate, even if the pedicle attachment is cut. During the ontogeny of many fossil brachiopods (e.g., the productoids), the pedicle atrophied or has even completely disappeared. Thereafter, the extra weight in the thickened part of the shell served to keep the shell properly positioned on the sea bottom with the umbonal region partly buried. This kept the commissure of the shell clear of the surface, held at an oblique or evan a vertical angle (Rudwick, 19-5). With the Strophomenida, the pedicle atrophied at a very early stage in life so the shell became free while still quite small. This was accomplished by the development of a concavo-convex shell which allowed the shell to rest on soft sediment with the commissure held slightly above the substrate. If the shell happened to get turned over or covered with sediment, a vigorous snapping action would restore everything to its proper state. Possibly some of the strophomenids with gently concavo-convex shells (the chonetids) could swim for short distances as a pectinid does in order to escape from predators (Rudwick, 1965). However, most strophemnids developed strongly concavo-convex shells, which were sufficiently large and heavy enough to prevent it from being overturned by currents. The convex valve was sunk deeply into the sediment and the commissure was held slightly above the bottom. Some may have carried this adaption so far as to assume a "quasi-infaunal" mode of life. These brachiopods would have been well protected from predators with only the shell margin projecting above the surface and the concave brachial valve possibly filled with sediment (Rudwick, 1965).

Other brachiopods had other adaptions to life on a soft substrate; *Neospirifer* may have been one example. *Neospirifer* is a common fossil throughout the Foraker Limestone, especially so in the Americus Limestone. Ager (1963) showed that *Neospirifer* was probably oriented with the hinge line downward. In order to bear the weight of the whole animal and shell, *Neospirifer* would have to have been equipped with a stout pedicle. Evidence for this can be seen in the form of the unusually large delthyrium found in many spiriferid brachiopods. Also, the extended hinge line of *Neospirifer* probably helped stabilize and distribute the weight of the animal on a soft substrate (Schmidt, 1975). Furthermore, flume experiments indicate that spiriferid brachiopods were probably oriented normal to the prevailing currents. This orientation helped to set up currents within the shell in order to carry food particles in at the fold and waste products out at the lateral margins (Schmidt, 1975). Note: Other authors, Muir-Wood and Cooper (1960) for example, state that intake occured at the lateral margins and expulsion at the anterior margin.

Some rhynchonellid brachiopods may have lived attached to floating seaweed, an epiplanktonic mode of life. *Wellerella* may have had this habit (Schmidt, 1975).

Another adaption may have been flattened brachiopods with wide hinge lines. These modifications may have been well suited for life on a soft substrate. Since these kinds of substrates are poor in oxygen, forms with a larger mantle area would be favored, such as *Derbyia, Neochonetes,* and *Isogramma,* which are present in the Foraker.

The lingulids are another brachiopod group with certain distinguishing habits. *Lingula* is quite common in the lower Americus Limestone in northern Osage County. The fossils are found oriented parallel to bedding in a silty limestone bed. No other fossils were found in that bed with *Lingula*. It was mentioned earlier that brachiopods must have water of full marine salinity to survive. However, fossil lingulids found unaccompanied by other brachiopods may indicate an environment that was normally marine but interrupted by occasional influxes of brackish water. But since lingulids are ecologically aberrant in several other ways, other environmental models could explain these assemblages (Rudwick, 1965). One obvious inference that can be drawn from lingulids is that their burrowing habit usually indicates a soft substrate (Heckel, 1972). However, one cannot always strictly apply the principle of uniformitarianism to the distant past, especially since organisms, unlike physical processes, evolve through time.

> It is not certain that all lingulids were infaunal burrowers; this mode of life is not reflected in any distinctive feature of the shell itself, and many fossil lingulids may have been epifaunal (Rudwick, 1965, p. 203).

The orientation of lingulids parallel to bedding in the Foraker may be evidence supporting that mode of life.

Another important group of brachiopods that deserves special mention is the productoid assemblage. Being strophomenids, the pedicle is absent and the shell is weighted so that it naturally rests on the umbonal region.

But the picture is a bit more complicated. Some brachiopods lived free on the surface while others lived all or part of their lives attached in some manner.

Juresania is a common productoid genus in the limestone members of the Foraker. In early life *Juresania* was attached by cementation of the umbo to a supportive surface and later broke free. When this happened the shell depended on its spines for support. Additionally, the shell was weighted being thickest and heaviest at the posterior margin of the pedicle valve so that it would always come to rest on the pedicle umbo while the spines kept the anterior margin directed upward. This was the animal's normal living position. The weighting of the shell and the arrangement of the spines were so that if the shell was disturbed and rolled about by bottom currents, it would land in its normal upright position (Muir-Wood and Cooper, 1960).

Other productoid brachiopods in the Foraker spent their whole lives unattached. The families Marginiferidae, Echinoconchidae, Dictyoclostidae, and many of the Linoproductidae, all of which have representatives in the Foraker Limestone, probably lived out their entire lives free on the sea floor. All of these groups had specially arranged spines permitting each genus to live efficiently on or near the bottom. The Dictyoclostidae, for example, are generally distinguished by massive and extremely long spines, apparently functioning to steady the animal (Muir-Wood and Cooper, 1960).

Probably the most distinguishing features of the productoids are their spines. So far they have been mentioned only as serving to anchor or support the shell. However, according to Rudwick (1965), not all forms of tubular spines found on brachiopods were used for attachment; some may have functioned as sensitive "antennae" with a bit of sensitive mantle tissue protruding from the open distal end of such spines. Some examples of this type may include the fine prostrate spines of many productoids and the posterior spines of most chonetids.

There are a few more observations that can be made about brachiopods as a whole. Rudwick (1965) has noted that generally no large numbers of young brachiopods are ever found. Indeed, only a small handful were collected from the Foraker. This implies that if a high rate of juvenile mortality occurs, it would have to happen during the free swimming larval stage. Apparently, once an individual survived the larval stage and settled on the bottom, its chances for surviving to maturity were fairly good.

Ager (1967) has outlined two ecological factors which have exerted much influence on brachiopod evolution. First is their tendency for a gregarious mode of life, giving rise to much intra-specific competition and high selective pressures resulting in few novelties and commonplace homeomorphy. The second factor is that brachiopods were very sensitive to their environments; so much so that local brachiopod successions reflect changes in the sediments containing them and other ecological factors rather than the passage of time. A fine example of this can be seen in the lower Americus Limestone of northern Osage County in which the bed dominated by specimens of *Lingula* is succeeded by a much more diverse productoid-spiriferid assemblage of brachiopods and other fossils.

Molluscs

Two classes of molluscs are represented in the Foraker Limestone; the Gastropoda and the Bivalvia (also known as Pelycepoda or Lammellibranchiata). Molluscs are not common at many localities in the Foraker; they are present in all three members but abundant only locally in the Americus Limestone. These molluscan assemblages are not diverse, consisting mainly of the pectinid genus *Aviculopecten* and numerous minute pseudozygopleurid gastropods. The only other widespread mollusc to be found is the bivalve genus *Myalina*, commonly occurring as its subgenus *Orthomyalina*. The gastropod subgenus *Amphiscapha* can be frequently, but not commonly, found.

So diverse are the molluscs that an adequate treatment of their autecology cannot be presented in this paper. Only a few broad generalizations will be given along with some specifics relating just to the forms found to occur in the Foraker.

Generally, gastropods form a minor part of a brachiopod-dominated assemblage in the Foraker. This indicates that they lived under the same conditions as the brachiopods; clear, shallow, marine water with good circulation. Some general statements made by Moore, Laliker, and Fisher (1952) concerning living gastropods include such comments as: They live chiefly on shallow sea bottoms, but range from deep marine to fresh water and even to dry land far above sea level. As a whole they show great variety in their feeding habits which range from scavenger, to parasite, to browsing herbivores, and even to some carnivorous predators. The members belonging to this last category usually accomplish their purpose by boring a hole through the shell of their victim in order to get at the soft parts within. Most snails are able to crawl about on the sea floor; many types are capable of burrowing into sand or mud; some are sessile, and one group is pelagic.

The only gastropods which occur in any abundance in the Foraker

Limestone is a very small form resembling the genus *Pseudozygopleura*. It is found locally in the lower Americus Limestone in northern Osage County in association with the bivalve *Aviculopecten*. It was also observed in much less abundance in Lincoln County in the Americus Limestone.

Like the gastropods, the bivalves have become incredibly diverse, enabling them to adopt many environments, substrates, foods, and life habits. Two bivalve genera occur more frequently than the others in the Foraker Limestone; they are: *Aviculopecten* and *Orthomyalina*.

Aviculopecten can be found in all three members of the Foraker, but only occurs in large numbers in a single bed at or near the base of the Americus Limestone. Some of the other fossils occurring in this assemblage are *Aviculopinna*, some bellerophontid gastropods, *Orthomyalina,* and the pseudozygopleurid gastropod mentioned above. Since such animals as brachiopods and crinoids, which required normal marine conditions, are absent, the environment inhabited by this pectenid assemblage was something other than normal marine. Perhaps there was some fresh water influx which the molluscs could tolerate. According to Heckel (1972), pectinids have a wide salinity tolerance which reinforces this possibility. Moore (1964) further supported this explanation by noting that *Myalina* and pectinids are considered nearshore animals. According to Kauffman (1969), it is possible that *Aviculopecten* and related genera may have been free-swinging bivalves attached by a byssus to some firm, raised object. However, the species of *Aviculopecten* collected from the Foraker does not have the pronounced auricles, nor the distinct re-entrants to afford passage of the byssus. Furthermore, it does not have the prosocline orientation that such bivalves have for the purpose of streamlining themselves in the presence of strong currents and wave action. The absence of these features would seem to indicate that the *Aviculopecten* specimens found in the Foraker were of the unattached type. Modern pectinids are attached byssally during their early lives; later on they become a free-dwelling form. These fossils were capable of swimming, like their modern counterparts, but were basically bottom dwellers. They generally lay on their sides on the bottom (Moore, Laliker, and Fisher, 1952).

Orthomyalina is fairly common and widely distributed throughout the Foraker. Comparison with modern counterparts suggests that the myalinids inhabited shallow seas down to a depth of a few fathoms. They were attached by a byssus and may have been quite gregarious. They can tolerate great variations in salinity, and modern analogy suggests that by tightly closing their shells they could survive a few hours exposure to the air (Moore, Laliker, and Fisher, 1952).

A few specimens of the genus *Aviculopinna* were also observed in the Foraker Limestone. This genus also was attached by a byssus and lived partly buried in the sediment of the sea bottom (Moore, Laliker, and Fisher, 1952).

Finally, a few specimens of *Wilkingia* were observed. *Wilkingia* live unattached in a semi-faunal mode of existence (Schmidt, 1975).

Echinoderms

Crinoid fragments are so widespread and common in the Foraker that, after awhile, they can almost go unnoticed. While fragments are quite common, only one calyx was found (Fig. 32); it was identified as belonging to the genus *Delocrinus*. Crinoids are exclusively marine creatures

(Heckel, 1972). They are filter feeders subsisting on phytoplankton and zooplankton (Tasch, 1973). For this reason, they require clear water so as not to foul their feeding mechanisms. Modern crinoids usually have a system of holdfast organs called the radix to anchor themselves in soft sediment, but many existing and extinct forms were moored to firmer substrates by means of an attachment disk (Tasch, 1973). Most living crinoids prefer shallower water (Tasch, 1973).

The other representative group of the echinoderms in the Foraker consists of echinoids. Their remains are very rare and the only record of their presence is the occurrence of a few fragments of their spines.

Like other echinoderms, echinoids are exclusively marine. Modern forms range from the intertidal zone down to abyssal depths. Most echinoids are vagile benthos, able to wander about on the sea floor either on their spines or by the use of prehensile tube feet. Some have powerful suckers on their tube feet enabling them to cling to rocks and cliffs in the presence of strong wave action, whereas some live in cavities in cliffs. They have a varied diet; some being vegetarians, others are predators which prey upon bryozoans, worms, coelenterates, or sometimes larger creatures such as clams and crustaceans (Moore, Laliker, and Fisher, 1952); still others are deposit feeders.

Summary

In terms of autecology, the fauna of the Foraker Limestone shows, in some respects, much variety as in feeding and substrate relationships. There are a great many different adaptive modifications, both among and within the various phyla represented. The different groups also show considerable consistency in certain respects; for example, most of the genera were adapted to a shallow marine environment. The few exceptions to this rule are usually found apart from the marine forms and can be treated separately. It should be stressed that all of the fossils observed were adapted to marine waters, and the only factor which suggests any fresh water influx is the presence of low salinity-tolerant forms apart from the strictly marine species.

Paleogeography

Before addressing the problem of paleosynecology, it might be appropriate to consider the paleogeography of the region which includes the Foraker Limestone. This is an important subject to consider because it provides the context into which all paleocommunities must fit. It also exerts a controlling factor on the distribution, both laterally and vertically, of different kinds of sedimentary rocks.

The outcrop of the Foraker, being a comparatively narrow band, offers little insight into the paleogeographic conditions which existed either to the east or the west of this north-northeast trending band. Virtually the only information which can be gleaned is that toward the south, the Hughes Creek Shale Member becomes increasingly sandy, implying increased proximity to some landmass which contained areas of sufficient relief to shed a large volume of sand-size sediment. As one proceeds to the north, the Hughes Creek becomes chiefly limestone containing chert nodules and abundant fusulinids suggesting farther offshore, marine conditions. This is an oversimplification at best. The presence of fusulinids in the Americus Limestone at Twin Mounds (T. 19 N., Payne County), farther south than any other large accumulation of fusulinids, suggests a more complicated picture than simple northward progression from continental environments to offshore marine conditions. Since the Foraker itself does not offer much revealing information on paleogeography, studies made by other authors on formations close in age to the Foraker have been most informative.

One very important aspect to keep in mind is that the sea in this region during Late Pennsylvanian and Early Permian time was epeiric or epicontinental. Many conditions which apply to continental margin seas do not apply here.

Perhaps the most important parameter needed is water depth. Water depth controls light penetration and so has a profound effect on the distribution of living organisms. Elias (1937), in his study of the Big Blue Series, stated that the sea which covered Kansas and surrounding area in Late Paleozoic time was no deeper than 200 feet. Moore (1964) put a maximum depth of 100 meters for the Pennsylvanian sea which covered the Kansas stable platform. According to Heckel (1972), epeiric seas probably only rarely exceeded 600 feet and may have ususally been no deeper than 100 feet.

Besides their shallow depth, another distinctive characteristic of epeiric seas was their great lateral extent (up to 1,000 or perhaps 2,000 miles wide)(Heckel, 1972).

An important consequence to the shallow depth and broad extent of epeiric seas is that they had very gentle subsea slopes. Because of this, only a relatively small amount of subsidence would have been sufficient to inundate vast tracts of land (Heckel, 1972). Likewise, a small drop in sea level would expose a very large area; an important idea to keep in mind when considering fresh water cementation of limestones (Chapter IV). In stable conditions with no subsidence to accompany sedimentation, a large part of the sea could be completely filled in. With this in mind, it is easy to see how an area could fluctuate rapidly from marine to non-marine and back again over a fairly brief period of geologic time (Heckel, 1972). In Chapter V it was mentioned that the transgressive-regressive relationships were probably not due so much to eustatic sea-level fluctuations, but that alternating phases of deltaic progradation and destruction were a more likely cause. Fusulinids in the Foraker Limestone also may point up this situation. Garber (1962) stated that the Hughes Creek Shale is distinguished by its abundant fusulinids. This is the situation in north-central Kansas (Garber's study area) and in northern Osage County in Oklahoma. It is definitely not the case in the southern part of the present study area; to the contrary, it is the overlying Long Creek Limestone Member that has characteristically abundant fusulinids. Assuming that fusulinids represent the culmination of a marine advance and that each member of the Foraker is isochronous over its length, then this implies that there were culminations of marine advances at different times. This does not suggest eustatic sea level changes. This is not to say that there were no eustatic sea level changes at all, but that the major transgressive-regressive relationships were due to changes in the dynamic equilibrium of progradation versus destruction.

The Beattie Limestone is a formation in the Upper Council Grove Group in Kansas and Nebraska; in Oklahoma it appears in the form of one of its members, the Cottonwood Limestone. Laporte (1962) did a study of the paleoecology of the Cottonwood and, since it is stratigraphically fairly close to the Foraker, some of Laporte's observations, may have application here.

During deposition of the Beattie Limestone Formation an elongate seaway extended from northeastern Wyoming southeastward across Kansas, northeastern Oklahoma, and into Arkansas. This seaway is known as the Kansas Strait and it was about 400 miles wide. Its main connection to the ocean was to the southeast through what is known as the Arkansas Embayment; a lesser connection may have existed to the southwest (Tanner, 1959). The Kansas Strait was bounded on the north and east by a low-lying continental land mass, and on the west and south by tectonic lands (Laporte, 1962; Fig. 34). This sea existed intermittently through the Lower Permian (Moore, 1964). Moore (1964) has noted that the great areal extent of many paleobiotopes (areas of uniform ecology) in the Pennsylvanian and Permian of Kansas is an indicator of exceptionally widespread, nearly uniform environments. It also appears that any changes that took place occurred everywhere almost simultaneously. An implication of such uniform environments over such an enormous area is that the underlying crust was relatively stable. Moore (1964) went on to say that since marine and non-marine sediments may be separated by only a few feet, it is unreasonable to postulate vertical movements of the earth's crust or sea level measured in tens of meters. He also said that the rates of sedimentation and subsidence were almost in equilibrium in the Kansas region during Pennsylvanian and Permian time; however, it appears that subsidence was greater in Oklahoma and southern Kansas than elsewhere. This may have been due to the effect of isostatic loading from a prograding delta.

Not only does the paleogeography control the distribution of the fauna of the period, but the kinds of sediments themselves were governed by this configuration, which cannot be accurately modeled by any known modern environment. Heckel (1972) believed that the shallowness and great width of epeiric seas would tend to hamper the development of great

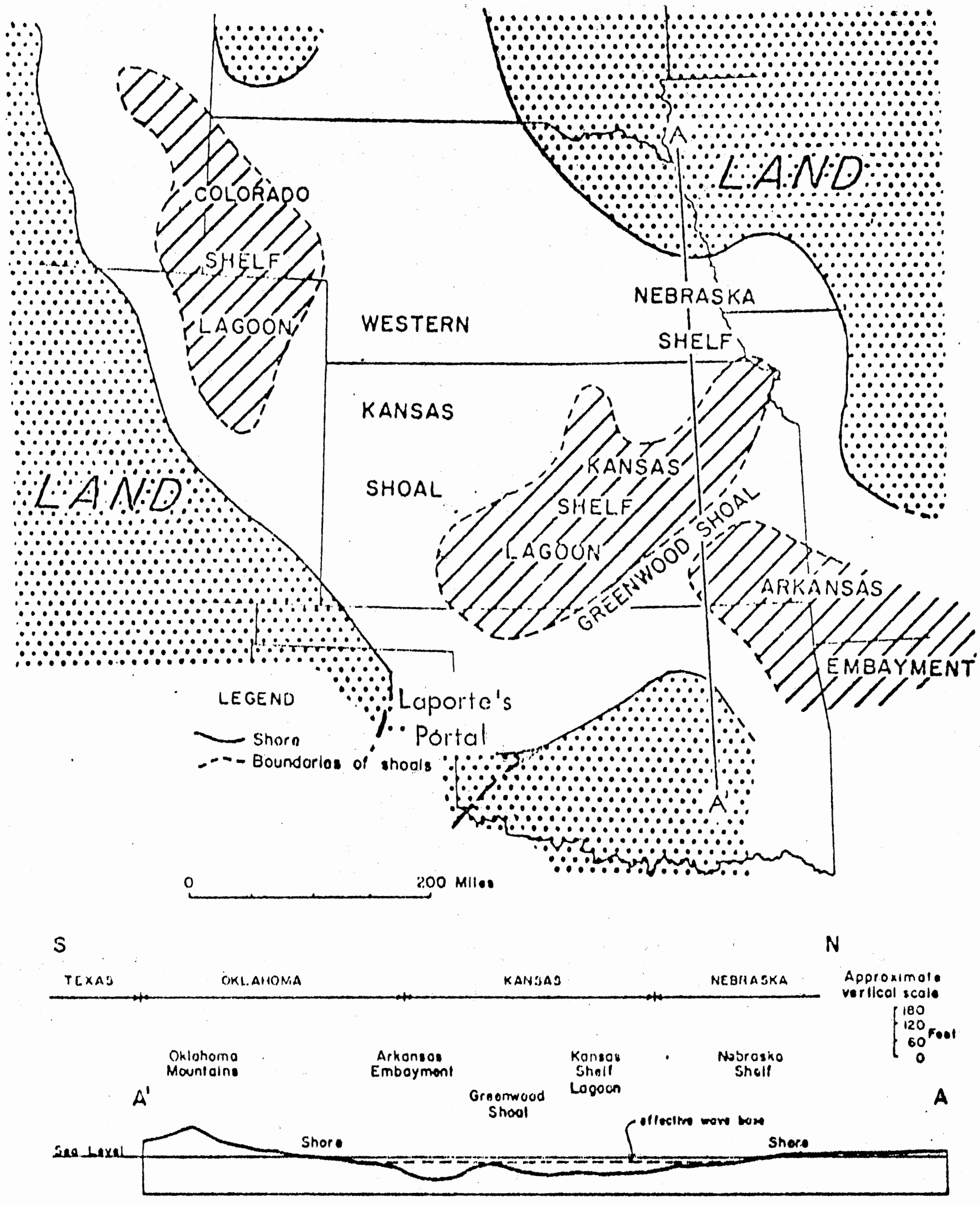


Figure 34.--Paleogeography of the northern midcontinent during deposition of the Beattie Limestone, and a diagrammatic north-south profile across the "Kansas Strait" as interpreted by Imbrie, Laporte, and Merriam (1959) (from Moore, 1964).

currents, such as those which now occur in the oceans. He also said that bottom friction would have had a damping effect on tides. This reduction of water circulation would give rise to hypersaline conditions around the margin of the sea in arid climates. In an unrestricted environment, it could lead to the formation of evaporites. While no evidence of this can be seen now, that does not preclude the possibility that there once were some evaporite deposits associated with the Foraker. It is important to remember that hypersalinity was suggested as a possible cause for the development of dolomite in Payne and Lincoln Counties.

Another geographic control of sediment was noted by Laporte (1962) concerning the Cottonwood Limestone. Since the northern facies contain so little clay and quartz, Laporte reasoned that the land to the north was relatively low-lying and shed little detrital material. The sediment that was derived from erosion of the tectonic lands to the south became trapped in the so-called Arkansas Embayment. A similar relationship has already been noted for the Foraker Limestone in Oklahoma with carbonte rocks becoming more prevalent over terrigenous rocks in the northernmost parts of the study area, accompanied by an increase in the abundance of fusulinids which are indicators of far offshore conditions.

Depositional Environment and Provenance

Before resuming discussion of paleoecology, another physical aspect, the depositional environment will be mentioned.

The environment of deposition of the Foraker Limestone was another topic discussed by Mogharabi (1966) in his study of the carbonate petrology of the Foraker. He stated that the presence of abundant micrite in the Americus Limestone indicates a low energy environment.

Mogharabi (1966) visualized the depositional environment of the Americus to have been a broad shelf which fluctuated between terrigenous influx and carbonate deposition.

The onset of Hughes Creek deposition is marked by a more pronounced influx of terrigenous material resulting in deposition of thick layers of sandstone. Through petrographic examination, Mogharabi (1966) determined that the quartz that went into the Hughes Creek Shale sandstones was derived from reworked sedimentary rocks to the east. Since the Ozark Dome was not a high-standing area at this time it could not have been the source. Mogharabi concluded, therefore, that the Ouachita Mountains were the only high-relief area capable of shedding enough sand-size sediment to form the thick sandstone beds of the Foraker. Mogharabi (1966) also noted that there was a similarity between the quartz grains of the Foraker and those which have been described in the Ouachitas.

Following the regression which deposited the sandstones of the Hughes Creek, there was a transgression and deposition of limestone and shale resumed (Mogharabi, 1966). These limestones are neither consistantly sparry calcite-cemented nor micritic; there is evidence of both high and low energy environments, and no facies consistency was observed (Mogharabi, 1966).

In contrast, the limestone of the Long Creek Limestone is almost wholly cemented by sparry calcite. This and the presence of the encrusting algae *Osagia* combine to suggest that the Long Creek was deposited in a shallow, high energy environment (Mogharabi, 1966).

Paleosynecology

If paleoautecology is the study of ancient individual organisms, then it follows that paleosynecology is concerned with the study of ancient organic communities (Moore, 1964). Paleoautecology makes much use of functional morphology of fossil shells; paleosynecology is not as tangible so there is great variety of opinions among different authors who have written on the subject. Much published material on this subject has dealt with observing modern invertebrate communities and attempting to extrapolate these observations into the geologic record. This approach encounters two serious problems when considering the Foraker Limestone. The first is that most of the fossil genera which dominate the Foraker assemblage are now extinct. The second problem is that these modern studies all study invertebrates in a continental margin sea environment, while the organisms of the Foraker lived in an epeiric sea setting. From the discussion above, it is evident that the configuration of an epeiric sea and its physical processes were so foreign to anything in the modern world, that is is unreasonable to try to apply many modern analogies to such a different setting. It is necessary then to rely on models, and there are may. Another pitfall which must be borne in mind when interpreting paleosynecology is that the taxonomic composition of a fossil assemblage is nothing more than the residue of some unknown community of living organisms (Scott, 1978). During the processes of preservation the relative abundances of the living organisms in an ancient community are subject to much modification. Some of the factors which affect the relative abundance of a particular fossil are shell durability, predation, sedimentation rates, rates of reproduction and growth, and the duration of transportation. The implication of all these factors is that the abundance pattern of fossil assemblages represent the patterns of ancient, living communities only under special conditions and are generally unreliable (Scott, 1978).

The most basic attempts at understanding ancient communities involved looking at the fossils as though they were ordinary sedimentary particles. The fossils are not even identified so these methods can be applied equally well to any fossil assemblage.

One such method was suggested by Johnson (1960). He proposed three models for the formation of fossil assemblages taking into account modes of accumulation and exposure effects. He acknowledged the fact that these models are only approximations of actual conditions in modern environments. The models represent a death assemblage buried at the site of life with only a minimum of preburial disturbance; another of Johnson's models represents the other extreme, i.e., an assemblage made up entirely of transported remains. Johnson's third model represents a category intermediate between the first two with regard to exposure and introduction of foreign elements and is the most commonly occurring of the three. This approach is a little too simplistic. Fagerstrom (1964) proposed a classification similar to Johnson's; however, he added a fourth type of assemblage. This assemblage was called a residual or winnowed fossil community. This community is one in which nearly all the specimens found belonged to the same ecological community but are not present in the same numbers or sizes as when they were alive. They have been subjected to a moderate amount of preburial alteration which has selectively removed a part of the original community. This is surely a very common type of assemblage, considering that a sizeable number of organisms in an ecological community may not have fossilizeable parts. This is the most likely category in which to place most, if not all, of the assemblages of the Foraker Limestone. Fagerstrom (1964) also acknowledged the highly theoretical aspect of these models and stressed that they should be considered as only end members.

A central point to the classification schemes of Johnson (1960) and Fagerstrom (1964) is that they both place great importance on the relative number of fossils that were actually indigenous to the place where they finally came to rest and became preserved. While these classifications are a bit simplistic, the question of a transported assemblage is actually quite critical because all other classifications examined in this paper will assume an indigenous fauna; if such is not the case, then all conclusions drawn may have to be negated. When this author first began to examine the exposures of the Foraker Limestone, it appeared as though many of the fossil assemblages had been transported. The fossils were highly fragmented and obviously not in positions of growth. The overall impression was that the fossils were just "jumbled" together. Many fossils, such as some brachiopods, although they may not have been fragmented, were disarticulated. The basal bed of the Americus Limestone in northern Osage County and partly in Shawnee County is characterized by abundant *Aviculopecten* valves which are oriented convex side up, suggesting the activity of a current (Fig. 30). The Long Creek Limestone has some beds in which the dominant fossils consist of thoroughly communited crinoid ossicles (Fig. 19).

Closer examination of the evidence suggests that this first impression was in error. One fact arguing against the fossils having been transported is that while the fossils are quite fragmented and disarticulated, they are not sorted or abraded. Fagerstrom (1964) does cast some doubt on the reliability of those criteria when he said that neither the surface condition of the fossils nor the ratio of whole to fragmented shells can be taken as a reliable indicator of the mode of formation of fossil assemblages. However, there is other evidence arguing against transportation. Transported fossil assemblages commonly occur in coarse grained, well-sorted clastic rocks with sedimentary structures, such as ripple marks and cross-bedding, indicating deposition from moving water (Fagerstrom, 1964). Also, Ager (1967) stated that the articulation or disarticulation of brachiopod valves does not appear to be a good criteria of post-mortem transport as it is with the bivalves which required muscular effort to hold the valves together. Heckel (1972) also noted that disarticulation of jointed forms such as certain algae, echinoderms, and arthropods is not evidence of transport because such disarticulation can take place in quiet environments due to the decay of soft connecting tissue and the activity of burrowing organisms. Mogharabi (1966) attributed fragmentation of the fossils of the Foraker to burrowing activity. Some of the evidence he cited is that some fossil fragments actually have burrows in them that can be seen microscopically (Mogharabi, 1966; Plate 10; Fig. 1). One last bit of evidence against a transported assemblage is that shelly benthonic organisms become so severely comminuted that they are unrecognizeable after only a relatively short distance of transport (Ager, 1967). Two bits of evidence remain that favor transportation as being the process responsible for the origin of the fossil assemblages in the Foraker. One is the convex upward orientation of the pectinids in the Americus. These fossils occur in a fine-grained limestone which was once a carbonate mud. This mud would have been winnowed out had the current been strong enough to transport the shells. It would seem that the current was just strong enough to orient the shells into the position where they now occur. The other remaining piece of evidence is the presence of the highly comminuted crinoid ossicles in the Long Creek Limestone. These fragments occur in a sparry calcite-cemented rock containing little fine-grained material. However, it is quite possible that this unit was deposited on a shallow shelf above wave base, and the winnowing of carbonate mud and fragmentation of the crinoids could have been accomplished by oscillatory wave action rather than a steady current.

Reworking by waves, currents, and burrowing organisms are not the only agents which can severely alter the nature of a fossil assemblage. A community may be altered either before or after burial; the postburial effects operating to obscure any preburial effects (Fagerstrom, 1964). Leaching and replacement of fossils by intrastratal solution and crushing of shells by compaction are the most important diagenetic processes which act to alter or destroy fossil assemblages. Both of these processes can be quite selective with respect to shell size or structure, and can alter the size distribution (if such a study is being done) and give an erroneous picture of the population structure of an assemblage (Fagerstrom, 1964). Crushing can also act selectively on shell shape. Fagerstrom (1964) noted that in a study of the Bonner Springs Formation (Upper Pennsylvanian) of Nebraska, the larger, flat thickened brachial valves of productoid brachiopods were much more common than the highly convex pedicle valves. The crushing of the pedicle valves undoubtedly took place when the lime and clay muds were compacted into limestone and shale. A similar type of selective crushing, although not as well developed, was observed in the Americus Limestone in the present study. The genus *Juresania* was most affected with *Reticulatia* less so. Leaching and crushing also can alter the whole-to-fragmented fossil ratio, causing an indigenous assemblage to appear as a transported or mixed assemblage (Fagerstrom, 1964).

Some other less important diagenetic effects include infaunal scavengers and microorganisms as well as bacteria which can lower the pH and promote leaching (Fagerstrom, 1964). Some organisms are more prone to alteration than others. Productoid brachiopods, for example, are especially vulnerable to disarticulation because they had no hinge teeth and sockets (Fagerstrom, 1964). Very few whole productoid brachiopods were found in the Foraker Limestone, and this fact probably contributed to this author's erroneous first assumption that the fossils in the Foraker had been transported.

In summary, it can be said that postburial alteration or "diagenetic overprint" can severely alter the picture one perceives of a fossil assemblage. Diagenetic overprint is very difficult to remove from the fossil record (Herm, 1972); however, if its effects can be recognized, it can enhance one's understanding of what he observes.

The rest of the approaches to paleosynecology that will be discussed actually take into account the taxonomic composition of a fossil assemblage, and try to relate the life habits of the individual members of the community into the functioning of the community as a whole.

Moore (1964) used a very interesting and easy-to-apply approach. He related the taxonomic composition of a fossil assemblage to its position in several Pennsylvanian and Permian cyclothems of Kansas. Environmental interpretation of the rocks making up a given cyclothem provided the link between the physical environment and a distinctive suite of fossils. The nomenclature for the fossil assemblages used by Moore conform to the standard practices of biostratigraphy: An assemblage is named for a certain genus which is characteristic of the assemblage as a whole. This genus need not be present in order for an assemblage to be named for it.

Conversely, this genus may occur in other assemblages named for some other fossil. Moore (1964) went one step further and also named his assemblages for some rock unit in which a particular assemblage was especially well developed. Some of the assemblages and their paleo-environmental associations recognized by Moore also appear to have applicability to the Foraker, especially the Americus Limestone.

One type of assemblage that Moore (1964) described was called the Beil-type or *Pulcratia* assemblage. This assemblage is characterized not so much by the presence of that genus, but more by an unusually large and diverse invertebrate fauna. The specimens are exceptionally well preserved showing almost no abrasion or other effects of current activity. Brachiopods, bryozoans, corals, and crinoid remains are the chief constituents of this assemblage,while molluscs tend to be varied but not prominent. Fusulinids may be found in great numbers and trilobite remains may also be found (Moore, 1964). This assemblage aptly describes most of the limestone beds of the Americus Limestone over most of its outcrop. It may also be characteristic of parts of the Long Creek Limestone. The *Pulcratia* assemblage is interpreted to have inhabited clear, sunlit water estimated to be an average of less than 20 meters deep (Moore, 1964). It also lived very far from shore, possibly as many as 50 to 100 miles away. Since Moore has noted the presence of this assemblage in the middle of cyclothems in Kansas, it is interpreted to represent the culminating marine phase of a cyclothem.

Another assemblage mentioned by Moore (1964) which may have application to the Foraker is the Tarkio-type or *Triticites* assemblage. It is very similar to, and sometimes indistinguishable from, the *Pulcratia* assemblage. It is characterized by a great abundance of fusulinids; so many that sometimes the rock may be so crowded with fusulinids that not only is there no room for other fossils, but there is not much space occupied by rock matrix (Moore, 1964). This assemblage may indeed describe the fusulinid-rich beds of the Long Creek Limestone, especially the "diastems" described in Chapter V, and the fusulinid-rich, cherty limestone beds of the Hughes Creek Shale in northernmost Osage County. The other possibility is that these rocks represent the fusulinid-rich manifestation of the *Pulcratia* assemblage.

The *Triticites* and *Pulcratia* assemblages are closely akin. Since fusulinids are by no means restricted to the *Triticites* assemblage; this indicates that the environments which produced profuse numbers of fusulinids were not radically different from shallow sea environments in which fusulinids were present in much smaller numbers (Moore, 1964). Apparently the *Triticites* assemblage represents the maximum development of offshore conditions. It must be remembered that fusulinids often do not mark the deepest water, but only the development of greatest distances from any shoreline. However, since the Long Creek Limestone persists much farther south than any other member of the Foraker (the southern limit of the Foraker being rather arbitrarily chosen in Chapter V), it could imply that the water was deeper at this time than during any other stage of deposition of the Foraker. One must recall from the section of paleogeography that it would take only a small rise in sea level to submerge a large area of land.

The *Pulcratia* and *Triticites* assemblages represent the normal state of affairs during the deposition of the Foraker, and most of the fossil assemblages in the Foraker fit into one or both of these types. It is the beds containing assemblages that deviate from this norm that make the Foraker such an interesting formation to study.

One of these assemblages is what Moore (1964) called the Speiser-type or *Derbyia* assemblage. This assemblage is invariably found in the initial marine phases of cyclothems (Moore, 1964). It is interpreted to have inhabited an offshore zone of nearly normal marine salinity in which there was little turbulence from wave activity. The genera *Myalina* and *Aviculopecten* are common members of this assemblage; also present are well preserved crinoid cups and common stem fragments along with numerous ramose bryozoans (Moore, 1964). This describes very well the assemblage found in the basal Americus in Pawnee and Osage Counties.

One of the more paleoecologically interesting beds of the Americus Limestone is the one found in northern Osage County which contains only lingulid brachiopods (Fig. 24). Moore (1964) calls this assemblage the Red Eagle-type or *Orbiculoidea-Lingula* assemblage. It is believed that this assemblage represents a poorly oxygenated shallow sea bottom, perhaps less than ten feet deep. The environment may have also been restricted (Moore, 1964).

Locally, such as near the town of Pawnee, the Long Creek Limestone appears to be characterized more by the genus *Neochonetes* than by fusulinids. Moore (1964) describes a Florena-type or *Neochonetes-Derbyia* assemblage which occurs in the same general environment as the *Triticites* assemblage, but the dissimilarity between them appears to be caused by the influx of terrigenous clay and silt (Moore, 1964).

Heckel (1972) had several useful comments of a more general nature. He noted that both calcilutite (micrite) and shale indicate a quiet environment. This setting may have been in shallow water but having the energy level kept low by some physical barrier, or the water could have been deeper and below wave base. Which of these conditions existed can be determined by the use of fossils; a restricted environment will have a restricted fauna (Heckel, 1972).

The concept of diversity is very important. It is mentioned by many authors (Heckel, 1972; Fagerstrom, 1964; Laporte, 1962; Scott, 1976 and 1978). In general, waters with normal marine salinity have an increased number of individuals among a decreased number of taxa, i.e., low diversity. This condition is brought about by reduced competition from similar taxa (Heckel, 1972). Heckel warns that while faunal diversity can denote environmental stability, it cannot be used as readily to differentiate shallow from deep water environments. However, deeper environments are generally more stable, and therefore have a more diverse fauna.

The findings of Laporte (1962) in his study of the Cottonwood Limestone concur with what has just been said. Laporte called the most taxonomically diverse assemblage he found the "shelly facies". He interpreted this facies to have had the most nearly normal marine environment, which he attributed to the proximity of the Arkansas Embayment. This embayment provided communication with the open ocean which gave enough circulation to prevent any unusual environments from developing in this region. More specifically, the shelly facies was deposited in a low turbulence, offshore environment having good circulation (Laporte, 1962). This assemblage bears a close resemblance to the well-preserved, diverse fauna of most of the Americus Limestone. Laporte also noted that depth was not an important factor in the generation of the various Cottonwood biofacies. The most important factors were the rate and amount of terrigenous influx, which is somewhat related to the proximity and releif of the source area; turbulence, which is usually inversely proportional to water depth, and water circulation, which is a function of basin geometry (Laporte, 1962).

In their study of the Upper Pennsylvanian and Lower Permian sections in Kansas, Mudge and Yochelson (1962) reached several conclusions, including the fact that with few exceptions the animals in their study lived under essentially normal marine conditions. Most of the organisms lived on a fairly firm mud bottom with the calcareous shales representing somewhat softer conditions than the argillaceous limestone beds. The water was generally quiet with a slow rate of sedimentation. However, certain myalinid and pectinid assemblages may represent a community which was overwhelmed by a rapid influx of mud; such may be the case in the basal Americus. The water depth increased in a southerly direction (the Arkansas Embayment). They also state that none of the genera or species they studied can be considered as a reliable indicator of depth, except certain inarticulate brachiopod assemblages may indicate a water depth of less than 30 feet. Otherwise water depth was probably not a controlling factor in the distribution of the various organisms (Mudge and Yochelson, 1962). They also noticed that in southern Kansas the Lowermost bed of the Americus Limestone is composed mainly of stromatolites; this phenomenon was not observed in Oklahoma. The stromatolites represent very shallow or even intertidal conditions, possibly hypersaline. This suggests that the base of the Americus marks the beginning of a marine transgression.

From the preceding pages it can be seen that much can be learned about ancient communities by simply applying common sense. Sophisticated statistical methods are simply not always necessary; however, there are pitfalls. One of the most serious problems in attempting paleoecologic interpretation of this formation is that so many of the major fossil taxonomic divisions are now either extinct or through competition have been forced into niches that may greatly differ from those they occupied in the Paleozoic. The principle of uniformitarianism must be applied with caution when dealing with organisms that continually evolve through time.

A very interesting approach to the study of ancient communities, and one which appears to be gaining popularity, is the concept of trophic anlaysis. This method does not examine the taxonomic composition of a fossil assemblage, nor does it treat the fossils as purely physical particles as do the methods of Johnson (1960). Instead, the feeding mechanisms of the various members of the assemblage are considered. Trophic analysis is the study of stratification of feeding types. A community as a whole may be classified on the basis of dominant feeding habits (Walker, 1972). The concept of trophic group analysis was first suggested by Turpaeva (1948, 1949). The advantage in applying these methods to ancient communities is that it emphasized dominant taxa which are the ones most likely to be preserved (Walker, 1972).

According to Scott (1976, p. 38):

> Trophic relations deal with the nourishment of the community. The trophic structure of a community consists of the pattern of feeding habits of the species which transmits energy through the community and results in the metabolism and growth of species populations.

The way the system works is to classify animals according to how they feed. Organisms which feed in the same general fashion can be put into a group which is referred to as a trophic category (Walker and Bambach, 1974). What enables this classification to be useful is the fact that the distribution of food is not random; there is a high concentration of organic matter at the sediment-water interface with lesser amounts above and below it. Therefore, the feeding activities of benthic invertebrates are usually directed toward utilizing the food resources at one of three general levels; in the sediment, at the sediment-water interface, or in the water just above the sediment (Walker and Bambach, 1974).

There are six major trophic categories: (1) Suspension feeders remove particles such as phytoplankton and zooplankton from the water. Fossil examples include sponges, smaller anthozoans, hydrozoans and stromatoporids, bryozoans, brachiopods, many bivalves, and some gastropods. Detritus feeders include (2) deposit feeders which take in smaller organic particles and organic-rich sediment grains from within the sediment, and (3) scavengers which eat larger particles and dead animals either on or within the sediment. Both serve to recycle organic matter. Fossil detritus feeders include some gastropods and bivalves, scaphopods, some annelids, ophiuroids, and holothurians. This category grades into the (4) predators or carnivores, some of which eat both living and dead animals, and the (5) browser category whose members feed upon both detritus and live plants. Some common fossil predators are the larger crustaceans, asteroids, ophiuroids, and some echinoids. The remaining category consists of (6) the parasites. Three of these groups (suspension feeders, detritus feeders, and predators) are useful in the classification of ancient communities (Scott, 1976). The examples given of the various trophic categories are not fixed. Many species can feed at more than one level (Scott, 1976). There is a difference between an organism's feeding habit and its trophic level. Feeding habit is what an organism does to obtain nourishment and trophic level is its position in the energy transfer system of the community. The trophic level of a species may change during ontogeny, possibly due to secular changes in the environment (Scott, 1976).

Turpaeva (1957) was a pioneer in this method, and she published some general conclusions: If there are several dominant species in a community, they generally feed at different trophic levels, thus reducing competition. Also, if the most dominant species in a community belongs to one group, the next most dominant species belongs to another and so on. Usually there is only one dominant species (Walker, 1972). The Foraker Limestone does not appear to conform to these conclusions because the fauna is made up mainly of suspension feeding brachiopods and bryozoans, but there are reasons for this apparent discrepancy. Scott (1976) cautions that one cannot assume that a fossil assemblage is representative of a community; it is even less likely that the preserved trophic structure accurately reflects the actual structure. One explanation is that the dominant species may have been soft bodied and thus not fossilized, and possibly fed at a different level than the brachiopods and bryozoans. Usually the most abundant taxa is preserved in some manner (Walker, 1972). The only clue to this possibility occurring in the Foraker is the presence of deposit feeders. However, it is difficult to say if the animals that made the burrows were indeed the dominant species, or if they occupied a subordinate position in the trophic structure of the community. It has been mentioned before that the rate of sedimentation was quite slow for the limestone beds of the Foraker. Therefore, it could be that only a few burrowing animals working over a long period of time were responsible for the extensive network of burrows visible in some of the limestone beds of the Foraker. The factors of evolution and time also enter the picture. Scott (1978) said that great care should be used when applying the methods of trophic analysis to the fossil record. Some niches may not have been filled because the organisms which fill them may not have evolved then. Also, the feeding habits of many organisms are still unknown. These are distinct possibilities when considering a Paleozoic community such as that which existed during the deposition of the Foraker. The dominance of suspension feeders is definitely not unique to the Foraker. In fact, Scott (1976) said that during the Paleozoic, lower shoreface and nearshore community structures were epifaunal, detritus-suspension feeder-dominated.

A modification of the trophic analysis concept is the addition of substrate relationships. Scott (1976, 1978) uses a system in which trophic categories are referred to a classification scheme based on feeding habits and substrate niches. Both of these categories are subdivided into three end members each (suspension, detritus, and predator feeders) and put on triangular diagrams (Fig. 35). These diagrams can be used to describe quantitatively the different types of communities (Scott, 1976).

In the Foraker Limestone, the lowest preserved member of the food chain is algae and it is referred to as a producer (Schmidt, 1975). The exact feeding mechanism of the fusulinids is uncertain but it is believed that they were deposit or suspension feeders which fed either on particulate organic matter or on nutrients dissolved in sea water. Their substrate relationship was epifaunal (Schmidt, 1975).

The suspension feeding category can be further subdivided into high- or low-level suspension feeders. Bryozoans are epifaunal, high-level suspension feeders, and brachiopods have a variety of feeding habits. *Lingula*, oriented parallel to bedding, is classified as an infaunal, low-level suspension feeder. *Reticulatia, Linoproductus, Juresania,* and *Hystriculina* were quasi-infaunal, low-level suspension feeders (Schmidt, 1975). Studies have shown that living brachiopods feed on phytoplankton

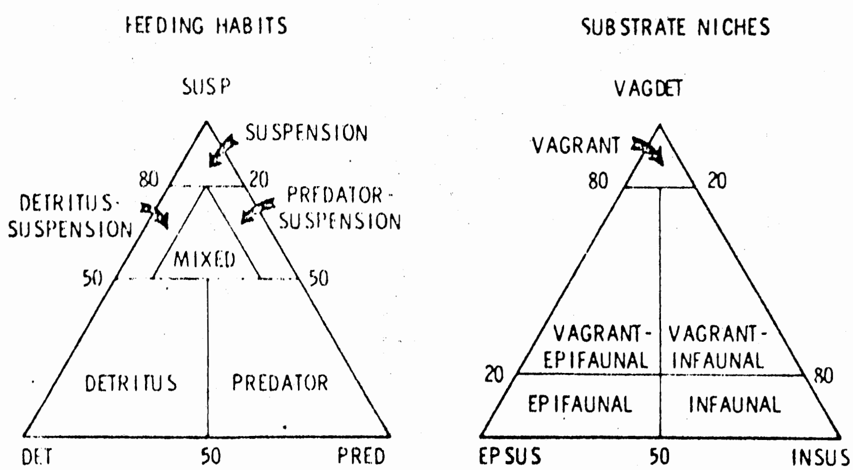


Figure 35.--Classification of trophic groups. End-members: SUSP = suspension feeders; DET = detritus feeders; ESPUS = epifaunal suspension feeders; INSUS = infaunal suspension feeders (from Scott, 1976).

at shallower depths and subsist mainly on the absorption of dissolved nutrients at greater depths (Scott, 1978). An important group of brachiopods in the Foraker are the productoids. Since they are now extinct, their feeding mechanism can only be conjectured. According to Muir-Wood and Cooper (1960), there is no reason to believe that the productoids fed in a manner that was any different than that of living brachiopods. They probably brought water and food particles in laterally and expelled the water carrying the waste products anteriorly. Rudwick (1965) has suggested that possibly most or all of the productoids utilized a feeding mechanism similar to that of the richthofenid brachiopods, which was a rhythmic opening and closing of a lid-like brachial valve which served to suck water-bearing food particles into the mantle cavity where the food particles were collected by the lophophore and transported to the mouth. The molluscs have more variety to their feeding habits. Most bivalves are shallow water benthonic animals which feed on particulate matter. *Aviculopecten* and *Myalina* were both epifaunal, high-level suspension feeders. *Wilkingia* was a semi-infaunal, high-level suspension feeder and the bellerophontid gastropds were epifaunal scavengers (Schmidt, 1975). Crinoids are also epifaunal, high-level suspension feeders while echinoids are epifaunal carnivores.

Some general deductions about community structures and their relationship to the physical environment have been made using trophic analysis as the method of investigation. Scott (1978) has made the connection between trophic structure and the physical environment by noting that several environmental factors influence the trophic structure of a community. These factors include water turbulence, diversity and abundance of food, sedimentation rate, bottom stability and turbidity, salinity, dissolved oxygen, and substrate type. The same principle of community diversity being related to environmental stability also applies to trophic structure. Stable environments, implying predictability of environmental fluctuations, have high species diversity, stable communities, and a complex trophic structure. Homogeneous environments ususally contain less diverse communities than heterogenous environments (Scott, 1976). Conversely, less stable communities have a more restricted trophic structure. Once again the Foraker Limestone does not seem to conform to the model. Most of the fossils from the Foraker are simply described as epifaunal high-level suspension feeders. However, this is an oversimplification; the trophic structure of the Foraker is more complex than what it seems. Walker (1972) cited a study he did of an Ordovician brachiopod-ectoproct (bryozoan) assemblage. He noted that such communities occurred mainly in open shelf environments some distance from shore; an environment very similar to that suggested for the Foraker. The community in Walker's (1972) study was dominated by filter feeders of several species. However, it still conforms to Turpaeva's (1957) generalizations, especially with respect to the alternation of trophic groups by dominance position, and to the principle of high diversity in stable environments. What probably happened was that the several dominant filter-feeding species actually fed at varying levels even though they all fell under the broad categories of either high-level or low-level filter (suspension) feeders. These broad categories are actually subdivided into finer divisions. This fine degree of subdivision of available food resources serves further to reduce competition. During the Paleozoic more diverse brachiopod faunas than the one in this study by Walker existed, and most of them were probably low-level filter feeders. Another study by Walker (1972) (in this case from the Silurian) further supports the idea of fine subdivision of suspension feeders. In this study, 12 of the 13 most abundant detritus-eating animals in the communities were brachiopods; an excellent example of the brachiopod-dominated, offshore communities of the Paleozoic. It would seem as though this situation would have to foster extreme competition; all of the brachiopods were low-level suspension feeders. Walker (1972) suggested three possible explanations: (1) The apparent competition may have actually existed, which would lead to rapid evolution of the taxa in the community. (2) Their food resource may have been intricately subdivided by partitioning of the general feeding niche. An example of this is a case where several species of brachiopods are strophomenids, which lay free on the bottom and fed very near the bottom, while the several other brachiopod species were supported by a pedicle and probably fed several millimeters above the sediment-water interface. (3) The filtrate food near the sediment-water interface may have been so abundant that a great number of species were all able to feed from this same resource without interfering with each other. According to Walker (1972), present knowledge does not allow a confident decision to be made as to which one, or combination of these three explanations was actually responsible for the data observed.

Most of the fauna of the Foraker appear to have been suspension feeders with detritus feeders occupying a secondary position; there is slight evidence that at least two more trophic categories were present in the Foraker. Other authors have collected sharks' teeth from the Foraker, and a microscopic-sized tooth from some unidentified fish was found by this author; these obviously represent some of the predators. No direct evidence of predation (i.e., tooth marks, gastropod borings in shells) was observed, so the exact extent of predation is uncertain. There is also some evidence of scavenging or parasitism preserved in the fossil record. The member of the bryozoan genus *Fistulipora* (Fig. 23) has several borings in it. These borings are present only in the side of the zooarium visible in the photograph. Perhaps the colony had already died, fallen over, and was lying on its side partially buried in the mud when the boring scavengers attacked it.

The study of trophic relationships has led various workers to reach some conclusions regarding suspension feeder-dominated communitites. According to Walker (1972), Paleozoic brachiopod-dominated communities of open marine shelf environments seem to have been quite unstable. The weakly competitive nature of the trophic relationships was cited as the cause of this unstability for this type of community. These brachiopod communities are nearly always composed of two trophic groups: high- and low-level suspension feeders. However, this tendency toward instability may have been circumvented by the process discussed above of subdividing the broad trophic categories into more specific niches. Heckel (1972) has observed that suspension feeders are most common in fairly clean sands; in muddy environments, the turbidity stirred up by deposit feeders would tend to keep the suspension feeder population down. In the Foraker Limestone there is a predominance of suspension feeders in fine-grained limestones. Possibly this layer of turbidity mentioned by Heckel (1972) was thin enough to not disturb the high-level suspension feeders. Furthermore, it was noted earlier in this chapter that brachiopods and certain bivalves can tolerate more turbidity than other benthonic invertebrates because their feeding mechanisms are quite sophisticated in their ability to reject and dispose of unwanted material (Heckel, 1972). It is also possible that this layer of turbidity did not exist at all. According to Scott (1978), communities dominated by suspension feeders usually lived on substrates in which there was an inadequate food supply or the substrate was hard. The burrows visible in several beds of the Foraker and through fragmentation of the shells by burrowing organisms indicate that there was adequate food supply in the sediment for these organisms. This would cause one to choose the alternative condition mentioned by Scott (1978), i.e., that the substrate was hard. Not too hard, however, to permit burrowers to move through the sediment. It would seem then that the description of the substrate as being a fairly firm mud bottom (Mudge and Yochelson, 1962) is the most accurate. Scott (1978) also mentioned that deposit feeders tend to thrive better in oxygen-poor environments suggesting that the waters of the Foraker communities were well oxygenated with good circulation. Walker (1972) summarized the type of environment inhabited by suspension feeder-dominated communities as being far off-shore, level bottom, normal marine communities.

To summarize, the conclusions regarding the Foraker Limestone reached by methods of trophic analysis, concur with the generalizations reached by various other means. In addition, trophic analysis provides some additional interesting information about how members of a community interacted with each other as well as with their physical environment.

While this last chapter appears to have much repetitive material, it is significant that the same conclusions can be reached by using different methods. Some of the interpretations are obvious, such as most of the assemblages having existed in a shallow off-shore marine setting. Other conclusions are less obvious, such as those concerning the myalind-pectinid assemblage of the Americus Limestone. It is these unusual assemblages that make the paleosynecology of the Foraker Limestone distinctive and interesting. The wide variety of organisms present make the paleo-autecology of the Foraker also quite interesting.

The typical diverse fauna of the Foraker Limestone is a good community to study from the standpoint that it is representative of many assemblages in nearby formations, so study of the Foraker can tell much about the conditions that prevailed during the Early Permian of the mid-continent region.

BIBLIOGRAPHY

Ager, D. V., 1963, Principles of Paleoecology: McGraw-Hill, New York, N.Y., 371 p.

________, 1967, Brachiopod Paleocology: Earth Science Review, v. 3, p. 157-179.

American Geological Institute, 1957, Dictonary of Geological Terms: Anchor Press/Doubleday, Garden City, N.Y., 545 p.

Badgley, P. C., 1965, Structural and Tectonic Principles: Harper and Row Publishers, New York, N.Y., 521 p.

Bass, N. W., 1929, Geology survey of Cowley County, Kansas: Kansas State Geological Survey, Bull. 12.

Bathurst, R. C. G., 1971, Carbonate Sediments and Their Diagenesis: Elsevier Scientific Publishing Co., Amsterdam, 658 p.

Branson, C. C., 1956, Cyclic formations or mappable units: Oklahoma Geology Notes, v. 16, p. 122-125.

________, 1962, Pennsylvanian System of the mid-continent, in C. C. Branson, (ed.), Pennsylvanian System in the United States, a symposium: Amer. Assoc. Petroleum Geologists, p. 431-460.

Bellis, W. H., and T. L. Rowland, 1976, Shale and carbonate rock resources of Osage County, Oklahoma: Oklahoma Geological Survey, Circular 76.

Bryant, D. G., 1957, Geology of the Grayhorse area, Osage County, Oklahoma: Univ. of Oklahoma, unpublished M.S. thesis.

Carter, J. A., 1954, Geology of the Pearsonia area, Osage County, Oklahoma: Univ. of Oklahoma, unpublished M.S. thesis.

Clark, S. K., 1932, The mechanics of plains-type folds of the mid-continent area: Jour. Geology, v. 40, p. 46-61.

Clendening, J. A., 1971, Palynological evidence for assignment of the Gearyan Stage of Kansas to the Pennsylvanian: Geol. Soc. America, Abs. with Prog., v. 3, p. 234-235.

Condra, G. E., 1927, The stratigraphy of the Pennsylvanian System in Nebraska: Nebraska Geol. Survey Bull. 1, 2nd ser.

________, 1935, Geologic cross section, Forest City, Missouri, to Du Bois, Nebraska: Nebraska Geol. Survey, Paper 8.

de Sitter, L. U., 1956, Structural Geology: McGraw-Hill Book Company, New York, N.Y. 551 p.

Elias, M. K., 1937, Depth of deposition of the Big Blue (Late Paleozoic) sediments in Kansas: Geol. Soc. America Bull., v. 48, p. 403-432.

Fagerstrom, J. A., 1964, Fossil communities in Paleoecology: Their recognition and significance: Geol. Soc. America Bull., v. 75, p. 1197-1216.

Fath, A. E., 1920, The origin of faults, anticlines, and buried granite ridge of the northern part of the mid-continent oil and gas fields: U.S. Geol. Survey, Prof. Paper 128, p. 78-84.

Fenoglio, A. F., 1957, Geology of northeastern Payne County, Oklahoma: Univ. of Oklahoma, unpublished M.S. thesis.

Fisher, H. C., Jr., 1956, Surface geology of the Belford area, Osage County, Oklahoma: Univ. of Oklahoma, unpublished M.S. thesis.

Garber, M. S., 1962, Stratigraphy of the Foraker Limestone in east-central Kansas: Kansas University, unpublished M.S. thesis.

Greig, P. B., 1959, Geology of Pawnee County, Oklahoma: Oklahoma Geol. Survey Bull. 83.

Heald, K. C., 1916, The oil and gas geology of the Foraker quadrangle, Osage County, Oklahoma: U.S. Geol. Survey Bull. 641b, p. 17-47.

Heckel, P. H., 1972, Recognition of ancient shallow marine environments, in J. K. Rigby and W. K. Hamblin (eds.), Recognition of Ancient Sedimentary Environments: Soc. Econ. Paleontologists and Mineralogists, Spec. Publ. No. 16, p. 226-286.

Herm, D., 1972, Pitfalls in paleoecologic interpretation - An integrated approach to avoid the major pits: 24th International Geological Congress, Sec. 7, Paleontology, p. 82-88.

Johnson, R. G., 1960, Models and methods for analysis of the mode of formation of fossil assemblages: Geol. Soc. America Bull., v. 71, p. 1075-1086.

Kauffman, E. G., 1969, Form, function, and evolution, in R. C. Moore and C. Teichert (eds.), Treatise on Invertebrate Paleontology, Part N, v. 1, Mollusca, Bivalvia: Geol. Soc. America and the University of Kansas Press, p. N130-N203.

Kirk, M. Z., 1896, A geologic section along the Neosho and Cottonwood rivers, Kansas: Kansas Univ. Geol. Survey, v. 1, p. 72-85.

Laporte, L. F., 1962, Paleoecology of the Cottonwood Limestone (Permian), northern mid-continent: Geol. Soc. America Bull., v. 73, p. 521-544.

Masters, K. E., 1955, Geology of the Prague area, Lincoln and Pottawatomie Counties, Oklahoma: Univ. of Oklahoma, unpublished M.S. thesis.

Mogharabi, A., 1966, Carbonate petrology of the Foraker Formation (Lower Permian), north-central Oklahoma: Univ. of Oklahoma, unpublished Ph.D. dissertation.

Moore, R. D., 1932, Revised classification of the Upper Paleozoic rocks of central Kansas: Kansas Geological Society Guidebook, 6th Annual Field Conference, p. 79-98.

________, 1940, Carboniferous-Permian boundary: Amer. Assoc. Petroleum Geologists Bull., v. 24, p. 282-336.

________, 1964, Paleontological aspects of Kansas Pennsylvanian and Permian cyclothems, in D. F. Merriam (ed.), Symposium on cyclic sedimentation: State Geological Survey of Kansas Bull. 169, p. 287-380.

________, 1951, The Kansas rock column: Kansas Geological Survey, Bull. 89.

________, C. G. Laliker, and A. G. Fisher, 1952, Invertebrate Fossils: McGraw-Hill Book Company, Inc., New York, N.Y. 766 p.

________, and R. G. Moss, 1934, Pennsylvanian-Permian boundary in the northern mid-continent area: Geol. Soc. America, Proc. 1933, p. 100.

Mudge, M. R., and E. L. Yochelson, 1962, Stratigraphy and paleontology of the uppermost Pennsylvanian and lowermost Permian rocks in Kansas: U.S. Geol. Survey, Prof. Paper 323, 207 p.

Muir-Wood, H. M., and G. A. Cooper, 1960, Morphology, classification and life habits of the Productoidea (Brachiopoda): Geol. Soc. America Mem. 81, 447 p.

Nakayama, E., 1955, Geology of southeastern Payne County, Oklahoma: Univ. of Oklahoma, unpublished M.S. thesis.

O'Connor, H. G., 1963, Changes in Kansas stratigraphic nomenclature: Amer. Assoc. Petroleum Geologists Bull., v. 47, p. 1873-1877.

Powers, S., 1931, Structural Geology of northeastern Oklahoma: Jour. Geol., v. 39, p. 117-132.

Prosser, C. S., 1902, Revised classification of the Upper Paleozoic rocks of Central Kansas: Jour. Geology, v. 10, p. 702-733.

Rudwick, M. J. S., 1965, Brachiopod and ecology and paleoecology, in R. C. Moore (ed.), Treatise on Invertebrate Paleontology, Part H, Brachiopoda: Geol. Soc. America and the University of Kansas Press, p. H199-H213.

Schmidt, W., 1975, Paleontology and carbonate petrology of part of the Hughes Creek Shale in northeastern Kansas: Kansas State Univ., unpublished M.S. thesis.

Scott, R. W., 1976, Trophic classification of benthic communities, in R. W. Scott and R. E. West (eds.), Structure and Classification of Paleocommunities: Dowden, Hutchinson & Ross, Inc., Stoudsburg, Penn., p. 29-65.

________, 1978, Approaches to trophic analysis of paleocommunities: Lethaia, v. 11, p. 1-14.

Sherril, R. E., 1929, Origin of the en echelon faults in north-central Oklahoma: Amer. Assoc. Petroleum Geologists Bull., v. 13, p. 31-37.

Shimer, H. W., and R. R. Shrock, 1944, Index Fossils of North America: The M.I.T. Press, Cambridge, Mass. 837 p.

Simonsen, A. H., 1977, Wreford fenestrates: Important bryozoans in a Lower Permian megacyclothem in Kansas, Oklahoma, and Nebraska: Pennsylvania State Univ., unpublished Ph.D. dissertation.

Tanner, W. F., 1959, Permo-Pennsylvanian paleogeography of part of Oklahoma: Jour. Sed. Pet., v. 29, p. 326-335.

Tasch, P., 1973, Paleobiology of the Invertebrates: John Wiley and Sons, Inc., New York, 946 p.

Taylor, R. C., 1953, Geology of the Foraker area, Osage County, Oklahoma: University of Oklahoma, unpublished M.S. thesis.

Thompson, M. L., 1964, Fusulinaecea, in R. C. Moore (ed.), Treatise on Invertebrate Paleontology, Part C, Protista 2, Sarcondina: Geol. Soc. America and the University of Kansas Press, p. C358-C394.

Tomlinson, C. W. et al., 1940, Classification of Permian rocks; Amer. Assoc. Petroleum Geologists Bull., v. 24, p. 337-358.

Turpaeva, E. P., 1957, Food interrelationships of dominant species in marine benthic biocoenoses, in B. N. Nikitin (ed.), Trans. Inst. Oceanol., Mar. Biol. USSR Acad. Sci. Press 20: Published in U.S. by Amer. Inst. Biol. Sci., Washington, D.C., p. 137-148.

Twenhofel, W. H., 1919, The chert of the Wreford and Foraker limestones along the state line of Kansas and Oklahoma: Amer. Jour. Science, v. 47, p. 407-429.

Vosburg, D. L., 1954, Geology of the Burbank-Shidler area, Osage County, Oklahoma: Univ. of Oklahoma, unpublished M.S. thesis.

Walker, K. R., 1972, Trophic analysis: A method for studying the function of ancient communities: Jour. Paleontology, v. 46, p. 82-93.

________, and R. K. Bambach, 1974, Feeding by benthic invertebrates: Classification and terminology for paleoecological analysis: Lethia, v. 7, p. 67-78.

West, A. E., 1955, Surface geology of northeastern Lincoln County, Oklahoma: Univ. of Oklahoma, unpublished M.S. thesis.

Yarrow, G. R., 1974, Paleoecologic study of part of the Hughes Creek Shale (Lower Permian) in north-central Kansas: Kansas State Univ., unpublished M.S. thesis.

APPENDICES

APPENDIX A

PENNSYLVANIAN-PERMIAN BOUNDARY

PENNSYLVANIAN-PERMIAN BOUNDARY

The Pennsylvanian-Permian boundary in the northern mid-continent has been greatly disputed and changed many times. Part of the problem stems from the fact that the boundary at the type section in Russia is not fully agreed upon. Furthermore, the North American mid-continent does not have any major widespread unconformities to mark this important boundary. In addition, this boundary has become the object of controversy as the Foraker Limestone actually falls within the disputed interval. Therefore, it was decided to include this appendix presenting the two main alternatives and giving the reasons for the choice that was made.

The root of the problem seems to be which criteria one accepts. Since physical stratigraphic evidence is lacking, one needs to resort to paleontology.

When fusulinids were recognized as important stratigraphic zone indicators, the zone of "*Schwagerina*" (now termed *Pseudoschwagerina* and *Paraschwagerina*) was said to be of such importance that it should be recognized as a major stratigraphic marker wherever it was found. Subsequently, this zone was recognized as the initial subdivision of the Permian rocks (Moore, 1940).

In 1934 Moore and Moss discovered an obscure, but possibly important unconformity, marked by large sandstone channel fillings about 100 feet beneath the Americus Limestone. Moore and Moss were able to trace this disconformity from Nebraska into Oklahoma (Moore, 1940). While only locally developed, this sandstone (called the Indian Cave Sandstone) is the only physical stratigraphic break in the area, and it forms the lower boundary of the Admire Group (Moore, 1940).

The Americus Limestone contains the fusulinid *Schwagerina* and an advanced type of *Triticites*, both of which are common members of the zone of *Pseudoschwagerina*. The Americus is the lowest horizon observed to contain *Schwagerina* (Moore, 1940). *Schwagerina* is quite abundant in the Cottonwood Limestone and *Pseudoschwagerina* occurs in the Florence flint (Moore, 1940). Moore stated that if one included all conformable beds below and above those that contain *Pseudoschwagerina*, then the Admire, Council Grove, and Chase Groups should all be considered as belonging to the *Pseudoschwagerina* zone and, therefore, are Permian (Moore, 1940).

This position, however, has been challenged. Branson (1962, p. 449) disputed placement of the Pennsylvanian-Permian boundary at the base of the Admire Group on the grounds that *Schwagerina* is part of an evolving phylogenetic series and that there ". . . is really no stage at which one can say what to call *Schwagerina*." He also said that the *Pseudoschwagerina* zone was accepted as Permian by only about half of the Russian geologists. Branson (1962) proposed including the Admire, Council Grove, and Chase Groups in a "Lyonian" series and calling them Pennsylvanian since they bore more similarity to the Virgilian rocks than to the overlying redbeds.

In addition, Clendening (1971) has done some palynological research and has advocated including the whole Gearyan Stage in the Pennsylvanian System. This would put the Permian boundary at the base of the Herrington Limestone.

The Oklahoma Geological Survey has adopted the position of Branson (1962) and Clendening (1971), and included the Foraker Limestone as part of the Pennsylvanian System. However, the state geological surveys of

Kansas, Nebraska, and Missouri have not taken this point of view and still place the Pennsylvanian-Permian boundary at the base of the Indian Cave Sandstone, or the top of the Brownville Limestone if this formation is absent, which is where Moore and Moss (1943) placed it (O'Connor, 1979, personal communication). There is still the evidence of the fusulinids to consider. The Treatise on Invertebrate Paleontology lists *Schwagerina* as a Permian fossil. *Schwagerina* has been described from the Americus; Greig (1959) noted the presence of *Schwagerina* in the Long Creek Limestone and this author has found it in the Hughes Creek Shale in Osage County.

It is for these reasons that this author has chosen the lower boundary as placed by Moore and Moss (1934), and thus includes the Foraker in the Permian System.

The question remains unanswered. The boundary one accepts depends on the criteria one chooses to believe in; whether it be fusulinids or palynology. This author chose to use the fusulinid scale because of its wide acceptance and worldwide distribution.

Mudge and Yochelson (1962) concluded that there is no apparent faunal evidence for placing the Pennsylvanian-Permian boundary at the top of the Brownville, but since this boundary is so commonly accepted by workers in the mid-continent, it may as well be continued as the boundary. However, there is very little actual evidence for placing the boundary at any one place in this general conformable sequence.

APPENDIX B

NOMENCLATURE CHANGES OF SOME PENNSYLVANIAN-

PERMIAN BRACHIOPODS

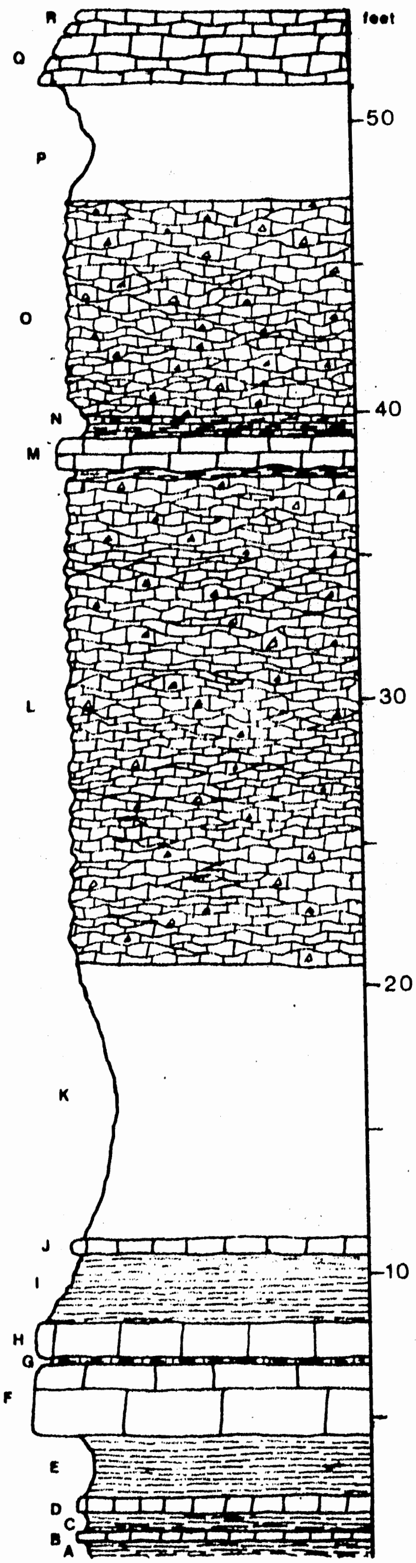
(FROM MOORE, 1964)

NOMENCLATURE CHANGES OF SOME PENNSYLVANIAN-PERMIAN BRACHIOPODS
(FROM MOORE, 1964)

Ambocoelia expansa Dunbar and Condra	*Crurithyris expansa* (D. & C.)
Ambocoelia lobata Girty	*Crurithyris lobata* (Girty)
Ambocoelia planoconvexa (Shumard)	*Crurithyris planoconvexa* (Shumard)
Chonetes granulifer Owen	*Neochonetes granulifer* (Owen)
Chonetes granulifer meekanus Girty	*Neochonetes meekanus* (Girty)
Chonetes granulifer transversalis D. & C.	*Neochonetes transversalis* (D. & C.)
Chonetes Granulifer armatus Girty	*Neochonetes armatus* (Girty)
Chonetina flemingi (Norwood & Pratten)	*Chonetinella flemingi* (N. & P.)
Chonetina flemingi alata D. & C.	*Chonetinella alata* (D. & C.)
Chonetina flemingi plebeia D. & C.	*Chonetinella plebeia* (D. & C.)
Chonetina verneuiliana (N. & P.)	*Chonetinella verneuiliana* (N. & P.)
Dictyoclostus portlockianus (N. & P.)	*Antiquatonia portlockiana* (N. & P.)
Dictyoclostus portlockianus crassicostata D. & C.	*Antiquatonia crassicostata* (D. & C.)
Dictyoclostus americanus D. & C.	*Reticulatia americana* (D. & C.)
Echinoconchus moorei D. & C.	*Echinaria moorei* (D. & C.)
Echinoconchus semipunctatus (Shepard)	*Echinaria semipunctata* (Shepard)
Echinochoncus semipunctatus knighti D. & C.	*Echinaria knighti* (D. & C.)
Juresania ovalis D. & C.	*Pulcratia ovalis* (D. & C.)
Juresania symmetrica (McChesney)	*Pulcratia symmetrica* (McChesney)
Krotovia meeki D. & C.	*Pulcratia meeki* (D. & C.)
Lissochonetes geinitzianus geronticus D. & C.	*Quadrochonetes geronticus* (D. & C.)
Lissochonetes geinitzianus plattsmouthensis D. & C.	*Quadrochonetes plattsmouthensis* (D. & C.)
Marginifera fragilis D. & C.	*Hystriculina fragilis* (D. & C.)
Marginifera haydensis Girty	*Kozlowskia haydensis* (Girty)
Marginifera hystricula D. & C.	*Hystriculina hystricula* (D. & C.)
Marginifera lasallensis (Worthen)	*Retaria lasallensis* (Worthen)
Marginifera missouriensis Girty	*Desmoinesia missouriensis* (Girty)
Marginifera muricatina D. & C.	*Desmoinesia muricatina* (D. & C.)
Marginifera spendens (N. & P.)	*Kozlowskia spendens* (N. & P.)
Marginifera wabashensis (N. & P.)	*Hystriculina wabashensis* (N. & P.)
Marginifera wabashensis armata D. & C.	*Hystriculina armata* (D. & C.)

APPENDIX C

MEASURED SECTIONS



R. Limestone, light brown weathering darker brown, flat, irregular bedding; thick stratification; contains few scattered fossil remains (crinoids and shell fragments), contacts covered..0.8'

Q. Limestone (Long Creek), mottled gray and rust brown, dense and hard, irregular bedding, thick stratification, mostly non-fossiliferous, may contain some algae, blotched with iron oxide stain, contacts covered.................1.6'

P. Covered..4.1'

O. Same as "L", the uppermost 2'(approx.), are stained yellow-brown and are cavernous. Fusulinids are abundant throughout but are not uniformly distributed............7.4'

N. Shaly limestone, buff.............................0.8'

M. Limestone, gray weathering to gray-brown, similiar to "L", but has a more crystalline texture and is more resistant, gradational contacts; smooth, massive appearance; it contains crinoidal debris and rare fusulinids, it is underlain by ca. 0.2' of buff shale.........................1.4'

L. Limestone, very light gray-brown weathering to gray, irregular bedding, thick stratification, very abundant fusulinids, crinoids rare, contacts covered, contains chert nodules and ironstone concretions.....................16.9'

K. Covered interval.................................9.6'

J. Limestone, light gray weathering dark gray, flat bedding, thick stratification; contains scattered crinoid debris and few fusulinids; contacts covered..............0.5'

I. Shale (Hughes Creek), light tan to yellow, calcareous, fissile; possibly contains Linoproductus; gradational upper contact (lower covered)................................2.3'

H. Limestone, same as "F", thick stratification, contains very abundant fusulinids and fewer Crurithyris, Neospirifer, crinoids, and Composita(?), upper contact covered.......1.3'

G. Shaly limestone, gray weathering to buff, irregular bedding, laminated, fissile; contains Neospirifer, inflated fusulinids, crinoid columnals, Neochonetes, burrows; has gradational contacts..................0.1-.2'

F. Limestone, gray weathering to dark gray-brown; flat, massive bedding; very thick stratification, abundant highly fragmented crinoid columnals, gradational contacts, covered by a mantle of caliche................................2.5'

E. Shale, same as "C"...............................2.2'

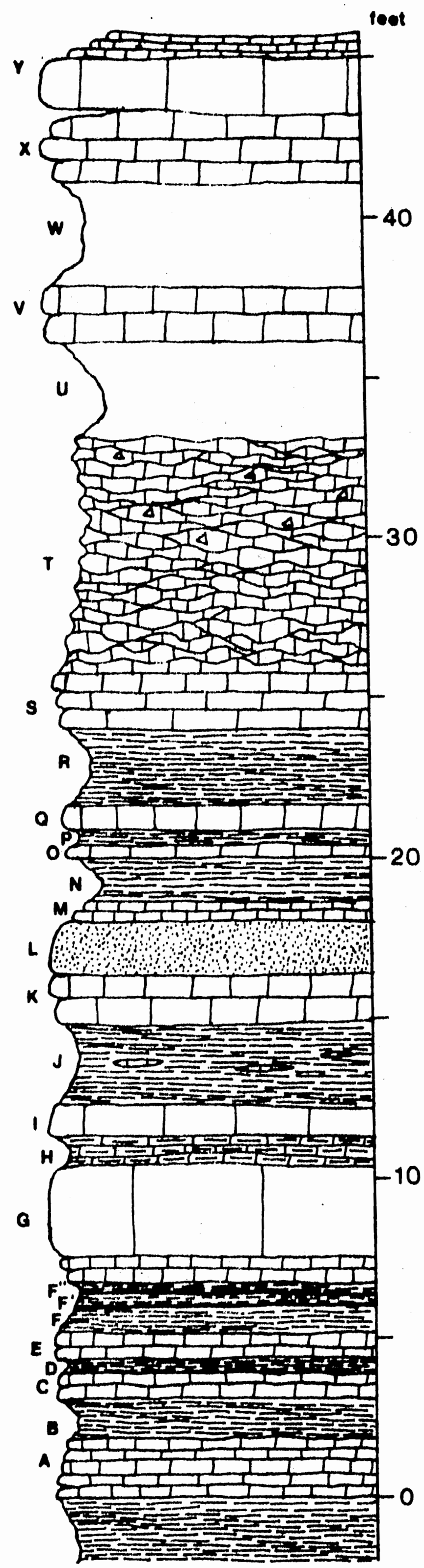
D. Limestone, same as "B", numerous Lingula, gradational upper contact...0.6'

C. Shale, gray weathering to buff, calcareous, fissile, possible sharp upper contact..........................0.6'

B. Limestone, gray weathering buff, irregular bedding, laminated, gradational contacts, no fossils............0.4'

A. Shale (Americus Limestone), gray weathering to buff, calcareous, fissiel; base covered......................0.6'

Measured Section I.--SW¼, Sec. 16, T. 29 N., R. 7 E., Osage County. Section measured is in the roadcut.



U. Covered..3'

T. Limestone, light gray and tan weathering darker gray, fine-grained; irregular, wavy bedding, thick stratification; crinoid hash abundant near base, fusulinids abundant further up; has cavernous weathering and upper part contains large gray-blue chert nodules, lower contact gradational, upper contact covered..7.5'

S. Limestone, light gray weathering dark gray, medium-grained, flat bedded, thick stratification; contains abundant, broken crinoids, *Hystriculina*, *Neospirifer*, and rugose coral; gradational contacts..1.7'

R. Shale, brown weathering buff, laminated, fissile, calcareous, gradational contacts..2.4'

Q. Limestone, gray, fine-grained, flat bedded, thick stratification; large, extensive burrows visible; contains abundant fusulinids and rare brachiopods, gradational contacts..0.8'

P. Shale, brown, calcareous, laminated, fissile, contains very abundant fusulinids..0.4'

O. Limestone, gray weathering buff, fine-grained, flat bedded, thick stratification; contains very abundant fusulinids, gradational contacts..0.4'

N. Shale, gray, calcareous, laminated, fissile, gradational contacts..1.3'

M. Limestone, gray weathering light gray, fine-grained with coarse allochems, flat bedded, thin stratification; contains rare brachiopod fragments, gradational contacts....0.7'

L. Sandstone, tan weathering gray to brown, medium to fine-grained (may be slightly coarsening upward), well sorted, calcareous cement, flat bedded, laminated, bioturbated; contains brachiopods *Hystriculina*(?), *Neospirifer*, and crinoids; gradational contacts..1.6'

K. Limestone, gray weathering light gray, fine-grained, flat bedded, thick stratification, contains small gastropods, *Derbyia*, *Hustedia*(?), *Composita*(?), *Aviculopecten*, fenestrate and other bryozoans, crinoids and shell fragments; gradational contacts..1.5'

J. Shale (Hughes Creek Shale), brown weathering buff, calcareous, fissile, laminated; contains small, scattered limestone lenses ca. 3" thick which contain *Linoproductus*; gradational, undulose contacts..2.6'

I. Limestone, gray weathering gray, fine to medium-grained, flat bedded, thick stratification, massive appearance; contains *Retulatia*, abundant fusulinids, crinoids, bryozoans, *Neochonetes*, *Neospirifer*, *Wellerella*, and *Dielasma*; has calcite filled vugs and fractures; gradational, undulose contacts..1.0'

H. Limy shale, same as "G", but is laminated, fissile, and a slope former; contains a 3" nodular limestone bed, fossils are not as abundant, gradational contacts..0.9'

G. Limestone, mottled gray and tan weathering light tan, granular texture, flat bedded, very thick stratification, massive appearance, contains abundant, abraded(?) fusulinids and crinoid columnals, common *Neospirifer*, rugose corals, common *Meekella*, *Aviculopecten*, *Hystriculina*, gradational contacts..3.7'

F''. Shale, same as "F"..0.3'

F'. Shale, calcareous, more massive appearing than "F", non-fissile, contains *Lingula*..0.4'

F. Shale, calcareous, gray, laminated, fissile........0.9'

E. Limestone, gray weathering dark gray, flat bedded, thick stratification except top 3" are laminated, gradational contacts..0.7'

D. Shale, calcareous, gray weathering light gray, flat bedded, laminated, fissile, contains *Orthomyalina*; gradational contacts..0.6'

C. Limestone, gray weathering light gray, fine-grained, flat bedding, thick stratification, gradational contacts, contains calcite fracture fillings..0.7'

B. Shale, calcareous, gray, laminated, fissile, gradational contacts..1.3'

A. Limestone (Americus Limestone), gray weathering lighter gray, mottled; medium sized, angular allochems suspended in very fine matrix, flat bedding, thick stratification; contains abundant *Aviculopecten*, abundant small, turreted gastropods, possibly a few brachiopods, *Orthomyalina*, possibly crinoids, plus a bellerophontid gastropod and *Aviculopinna*; most of the pectenids are convex upward on bedding planes, gradational contacts..1.8'

Calcareous gray shale (Admire Group).

(Continued on next page)

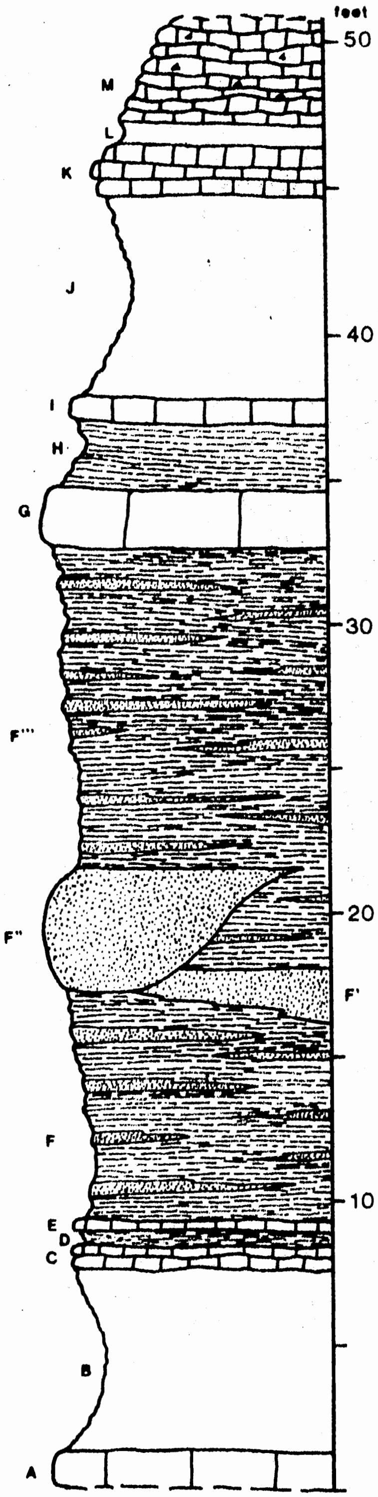
Y. Limestone, light gray weathering dark gray, fine-grained, flat bedding, thick stratification, massive appearance; contains abundant fusulinids and crinoids, also contains _Rhombopora_, productoid brachiopods, _Composita_, _Chonetinella_, echinoid spines, and _Crurithyris_; fusulinids are more abundant at base, scarce near top; gradational contacts 2.6'

X. Impure limestone, tan-yellow weathering brown, fine-grained, flat bedded, thick stratification; contains abundant fusulinids, _Meekopora_, brachiopods, echinoid spines, and crinoids; gradational contacts......................2.1'

W. Covered...3.2'

V. Limestone (Long Creek Limestone), light gray weathering brown-gray, fine-grained, flat bedded, thick stratification; contains abundant fusulinids, crinoids and few gastropods, also _Neospirifer_, _Linoproductus_, _Composita_, _Meekopora_ and _Osagia_ (algae), are present; basal contact covered, upper contact gradational and undulose........................1.7'

Measured Section II.--NW¼, Sec. 10, T. 26 N., R. 6 E. Phillips Lake, Osage County. Section is measured in the spillway from the pool up to the rim of the spillway.



M. Limestone, tan weathering gray, irregular bedding, thin to thick stratification, contains abundant fusulinids, with some crinoid debris, fenestrate bryozoans, Neospirifer, few chert nodules, contacts covered........................5'+

L. Covered..0.8'

K. Limestone, gray, flat bedded, thick stratification, contains crinoid debris and fusulinids, lower contact gradational, upper contact covered.........................1.8'

J. Covered, probably same as "H"......................6.8'

I. Limestone, light gray weathering darker gray; flat bedded, thick stratification, contains crinoid debris and shell fragments, contacts covered...........................0.9'

H. Light brown, calcareous shale.....................2.3'

G. Limestone (Long Creek Limestone), mottled gray and rust brown weathering dark gray, massive bedding and very thick stratification; fusulinids are abundant with bryozoans, brachiopods, and crinoids common; lower contact sharp and undulose, upper contact gradational....................2.1'

F'''. Same as " F "................................11.3'

F''. Sandstone, tan weathering brown, medium to fine grained, fining upwards, moderately well sorted; non-calcareous cement; massive, lenticular bedding; has lamination, parting lineation and groove casts on the base (both oriented N 70° E); sharp basal contact......................0-4'

F'. Sandstone (with minor amount of shale), tan weathering brown, fine grained, well sorted, non-calcareous cement; lenticular bedding, laminated and cross-bedded, also has burrows, sharp upper contact...........................2'

F. Shale (Hughes Creek Shale), light brown, calcareous, fissile; alternating with Sandstone, tan weathering gray, fine grained, well sorted, calcareous cement; lenticular bedding, laminated, low angle cross-bedding; contacts covered..6'

E. Limestone, same as "C"............................0.4'

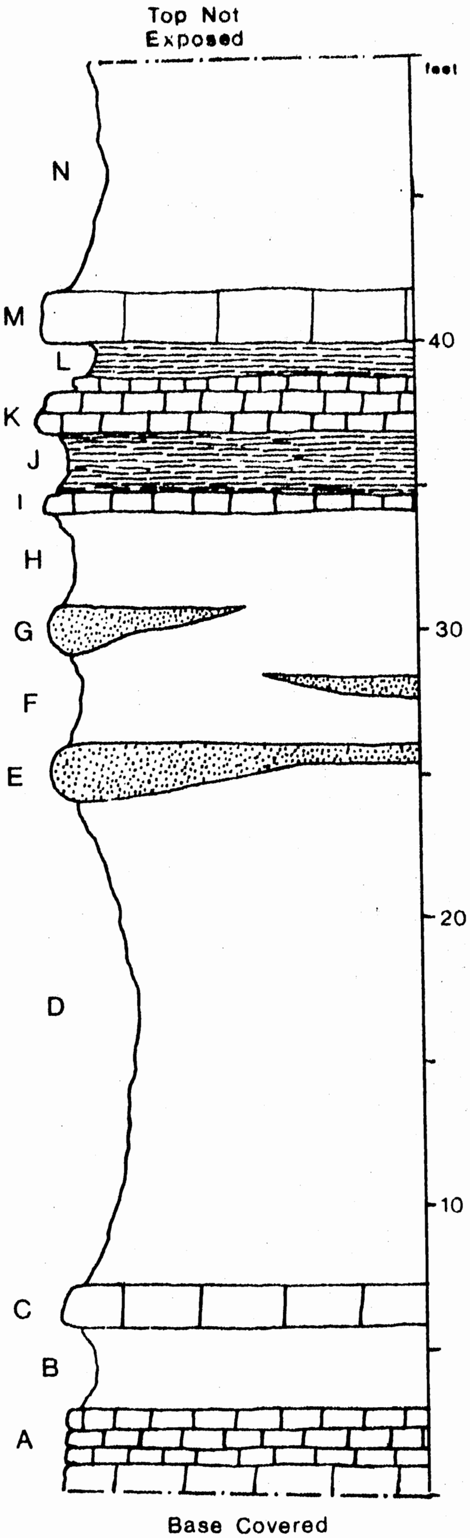
D. Gray, calcareous shale............................0.5'

C. Limestone, gray weathering tan, irregular bedding, thick stratification; contains Composita, Punctospirifer, Juresania plus shell fragments and crinoid debris, some fragments have been pyritized; gradational, undulose contacts...0.8'

B. Mostly covered, probably tan shale with thin, scattered sandstone stringers...................................6.3'

A. Limestone (Americus Limestone), gray-brown weathering light gray, dense crystalline texture; flat, massive bedding, thick stratification, common brachiopods incl: Neospirifer, Hustedia, Composita, Linoproductus, Derbyia, Chonetinella, also Rhombopora, Polypora(?), crinoid plates & columnals, fusulinids (uncommon), and Aviculopecten; contacts covered ....1.3'

Measured Section III.--SW¼, Sec. 11, T. 24 N., R. 5 E. About 2 miles west of Fairfax, Osage County. Section is measured in the roadcut from near the bottom of the hill to the top.



N. Covered........................10'

M. Limestone, gray weathering light tan, fine grained, thick stratification, dense; Linoproductus and fusulinids common; gradational contact......................1.7'

L. Covered, probably same as "J".....1.3'

K. Limestone, gray weathering tan, fine grained, thick stratification, very abundant fusulinids becoming scarcer in top bed, gradational contact...................1.9'

J. Shale, gray-brown weathering light tan, calcareous, fissile...............2.1'

I. Limestone (Long Creek), gray weathering to light tan, fine grained, thick stratification; contains abundant, broken crinoid stems, brachiopods (small ones intact), ribbon bryozoan colonies, & few rugose corals; sharp, undulose basal contact .5'

H. Covered..........................3.3'

G. Sandstone, similiar to "E" but has calcareous cement and is fining upward. 1.6'

F. Mostly covered, contains at least one discontinuous sandstone bed............3.2'

E. Sandstone (Hughes Creek), light tan weathering dark tan, fine grained, well sorted, siliceous cement, lenticular bedding, lamination, cross-bedding & parting lineation, no fossils, contacts covered......1.7'

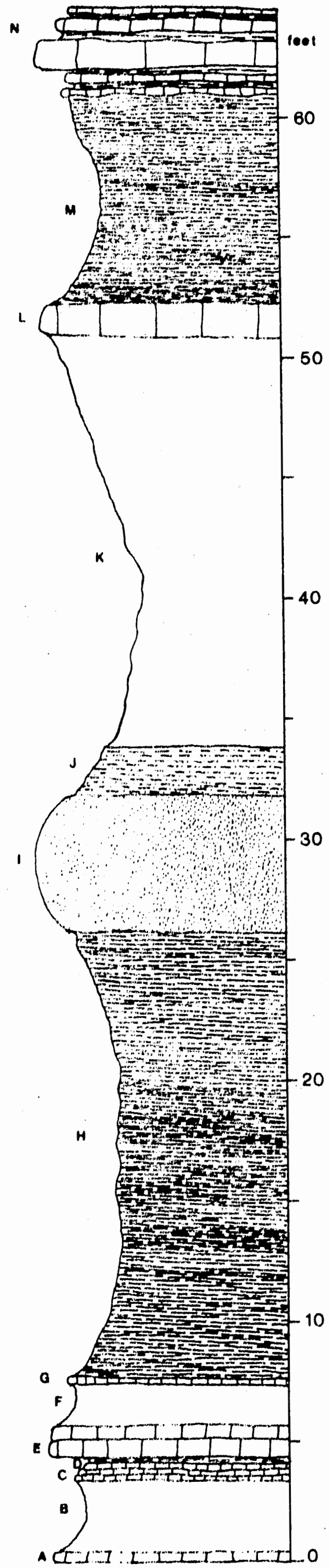
D. Covered..........................17'

C. Limestone, massive, gray weathering to gray-brown, dense, fine-grained, thickly stratified; contains abundant, broken crinoid stems, brachiopods & bryozoans; sharp, undulose basal contact.................1.4'

B. Covered, probably calcareous shale 2.9'

A. Limestone (Americus), gray weathering tan, fine grained, thickly stratified with thin shale beds; bottom 6" are densely fossiliferous containing crinoids, Aviculopecten, Jurenania, Orthomyalina, and Hystriculina; fossils are randomly oriented, some broken and some well preserved; contacts covered..............................3.0'

Measured Section IV.--SW¼, Sec. 22, T. 23 N., R. 5 E., Pawnee County. Section is measured in the roadcut.



N. Limestone, gray-brown weathering tan, medium grained crystalline texture; flat, irregular bedding, thickly stratified limestone beds separated by thin shale beds. Contains abundant crinoid debris, also brachiopod fragments, abundant fusulinids, Retulatia, Neospirifer, Derbyia, and gastropods; bioturbated, gradational contacts......................3.7'

M. Shale, gray weathering buff, calcareous, contains brachiopod fragments, including: Linoproductus, and Composita, fenestrate bryozoans, Rhombopora, crinoid fragments, Derbyia and Neospirifer; unit includes a thin bed of limestone (0.2') containing abundant crinoid debris.........8.5'

L. Limestone (Long Creek Limestone), buff weathering light gray, medium to fine crystalline texture, flat bedding, thick stratification, apparently nor fossiliferous; gradational, undulose contacts..............................1.5'

K. Mostly covered, but consists, at least in part, of maroon and green shale.................................17'

J. Sandy shale, maroon, heavily bioturbated, gradational contacts..ca. 2'

I. Sandstone, varigated light gray, purple, yellow, and maroon weathoring to brownish red; fine to very fine sand, well sorted, siliceous cement; multi-storied, lenticular bedding, laminated stratification, bioturbation, slump structures, cross-bedding; contains rare crinoid stems; gradational contacts with sharp internal contacts separating the lenses; lenses are ca. 1½' thick separated by .1-.2' thick sandy shale breaks; composed of quartz sand and some clay..5.7'

H. Shale (Hughes Creek Shale), gray weathering buff, fissile, laminated, non-calcareous, non-fossiliferous, gradational contacts, contains small ironstone concretions; approximately 10' from the base there is ca. 1½' of silty shale with well preserved burrow casts on soles of laminae.. 18.5'

G. Impure Limestone, dark gray, flat bedding, thin stratifaication; contains crinoid fragments, Aviculopecten, Hustedia, fenestrate bryozoans, and Neochonetes; gradational, undulose contacts.....................................0.2'

F. Covered (probably shale)..........................1.8'

E. Limestone, similiar to "C", but has thicker stratification; contains Juresania, Neochonetes, crinoid debris, fusulinids, Linoproductus, Composita, and Neospirifer; there is a small shale break present about half way up........1.3'

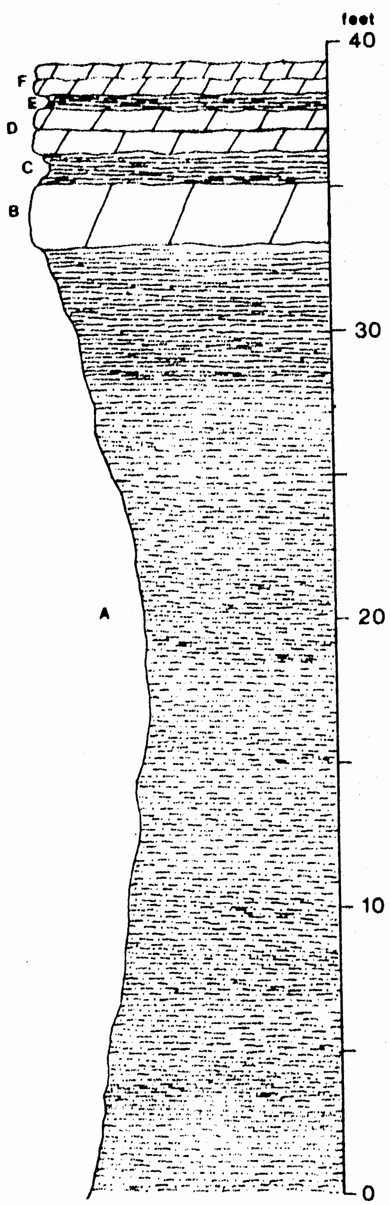
D. Shale...0.2'

C. Limestone, dark gray weathering lighter gray, fine-grained; flat, irregular bedding; thin stratification; fossils include: Retulatia, Composita, Crurithyris, Juresania, Linoproductus, and crinoid fragments; gradational contacts. 0.7'

B. Covered..3'

A. Limestone (Americus Limestone), gray weathering buff-gray; fine-grained, crystalline texture; flat bedding, thick stratification; abundant, fragmented fossils, including: Aviculopecten, fusulinids, crinoids, Crurithyris, Meekopora, Rhombopora and productoid brachiopods; contacts gradational..0.4'

Measured Section V.--South line, SW¼, Sec. 34, T. 20 N., R. 5 E., Pawnee-Payne County line. Section is measured in the bar ditch and roadcut.



F. Dolomite, similiar to "D", contains a few crinoids and Neospirifer, gradational, undulose contacts............1.2'

E. Shale, buff, calcareous, laminated, fissile........0.5'

D. Dolomite, gray weathering brown, medium-grained crystalline texture, flat bedding, thick stratification, somewhat cavernous appearance; contains few crinoids, Neospirifer, Retulatia, Composita, and Linoproductus, all scarce, plus a few fusulinids, becoming abundant in a thin layer at the top; gradational, undulose contacts................1.5'

C. Shale, buff, calcareous, laminated, fissile, fusulinids very abundant, also there is Reticulatia, Neospirifer, Linoproductus, Wellerella, crinoids, and Rhombopora; gradational, undulose contacts.....................................1.1'

B. Dolomite (Long Creek Limestone), mottled gray weathering buff, fine-grained, flat bedding, very thick stratification; contains few crinoids and possibly fusulinids, gradational, undulose contacts.............................2.1'

A. Silty shale (Hughes Creek Shale), red, calcareous, laminated, fissile; approximately the top 5' are gray and less silty...33'

Americus Limestone not exposed.

Measured Section VI.--SW¼, Sec. 24, T. 19 N., R. 4 E., Payne County. Section is measured up the hill in the roadcut.

VITA

John Raymond Fritts

Candidate for the Degree of

Master of Science

Thesis: FAUNA, STRATIGRAPHY, AND PALEOECOLOGY OF THE FORAKER LIMESTONE: OSAGE, PAWNEE, PAYNE, AND LINCOLN COUNTIES, OKLAHOMA

Major Field: Geology

Biographical:

Personal Data: Born in Kansas City, Missouri, September 4, 1954, the son of Mr. and Mrs. Raymond J. Fritts.

Education: Graduated from Charles Page High School, Sand Springs, Oklahoma, in May, 1972; received Bachelor of Science degree (cum laude) in Geology from Phillips University in May, 1976; completed requirements for Master of Science degree at Oklahoma State University in July, 1980, with a major in Geology.

Professional Experience: Junior Member of the American Association of Professional Geologists; member of the Society of Economic Paleontologists and Mineralogists; part-time computer programmer, Phillips University, 1973-1975; graduate teaching assistant, Oklahoma State University, 1976-1978; Geologist, Cities Service Company, 1979 to present.