PETROLOGY AND DIAGENESIS
OF THE PETTET INTERVAL, SLIGO FORMATION
(LOWER CRETACEOUS)
BOSSIER PARISH, LOUISIANA

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Presented to
the faculty of the Department of Geology
East Carolina University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science in Geology

by

Alan D. Hartsook

April, 1983

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ABSTRACT

Alan D. Hartsook, PETROLOGY AND DIAGENESIS OF THE PETTET INTERVAL, SLIGO FORMATION (LOWER CRETACEOUS), BOSSIER PARISH, LOUISIANA, (Supervising Professor, Dr. Donald W. Neal), Department of Geology, April, 1983.

The Lower Cretaceous Sligo Formation is the limestone half of a limestone-clastic couplet which was deposited in the Gulf Coast area during a major transgression. The Pettet interval is a porous limestone lentil within the Sligo. It is approximately 90 feet thick and lies approximately 50 feet below the top of the Sligo in the study area, which is located in a portion of northern Bossier Parish, Louisiana. Here, an anticline with an east-west axis and westerly plunge constitutes the local structure.

In the study area, five microfacies, named for their dominant lithologies, were recognized in the Pettet interval. They are: 1) oosparite, 2) oomicrite, 3) oobiosparite, 4) poorly washed oobiosparite and 5) biomicrite. These microfacies were deposited on a shallow, warm water shelf approximately 100 miles from the shelf edge. The rate of Pettet deposition exceeded sea level rise and subsidence; therefore, a shoaling sequence evolved. Several individual shoaling upwards oolite cycles within the Pettet possibly formed as a result of several relatively rapid sea level rises, each followed by sedimentary in-filling.

Diagenesis began in the marine environment immediately after deposition and continued through deep burial. Porosity and permeability increased with the leaching of aragonitic allochems and dolomite, and

decreased with the precipitation of various calcite cements and pressure solution. Meniscus and gravitational cements indicate at least one episode of subaerial exposure. This subaerial exposure may have created a relatively large meteoric-phreatic environment in which syntaxial calcite cement, equant sparry calcite cement and microspar were formed. An adjacent marine-fresh water mixing zone was a site for dolomite formation and possibly for formation of an isopachous calcite cement.

There is no statistical correlation between abundance of allochems and porosity and permeability. With the exception of the oomicrite microfacies, the porous and permeable zones occur in all the microfacies, making prediction of trends difficult. Porosity is predominantly secondary moldic, and localized differences in diagenetic alteration seem to control porosity and permeability. Though permeable zones in the Sligo commonly produce oil regardless of structure, production in the study area corresponds with the crest of an anticline. The best potential for expanding production here seems to be along the anticlinal crest in both updip and downdip directions.

ACKOWLEDGEMENTS

I would like to thank Dr. Donald Neal for all the time and energy he spent in guiding this thesis. Thanks also to Dr. Scott Snyder and Dr. Lee Otte for their invaluable assistance as members of my thesis committee. I am very grateful to Jack Moody of Western Reserves Oil Co. for serving as outside consultant and for providing the samples for the thesis, financial aid and advice. I would also like to thank the rest of the faculty in the Geology Department at East Carolina University for making my stay and studies most enjoyable.

TABLE OF CONTENTS

TABLE OF ILLUSTRATIONS

INTRODUCTION

GENERAL STATEMENT

The Sligo Formation (Lower Cretaceous) is primarily a subsurface unit that is found in all of the Gulf Coast states. The type locality is the Sligo Field in Townships 17 and 18 North, Ranges 11 and 12 West in Bossier Parish, Louisiana. Here, the Sligo Formation consists of dense limestones, shales, calcareous shales, shaley limestones and oolitic and pseudo-oolitic limestones (Nichols, 1958). The Pettet interval is a porous limestone with occasional shales; it occurs at various stratigraphic levels within the Sligo Formation.

The study area encompasses part of the oil producing North Carterville Field in the northeast corner of Bossier Parish, Louisiana (Figure 1). The Sligo Formation is found at a depth of approximately 6,000 feet in the study area. The Pettet interval has been drilled for oil since the early 1940's and drilling was still in progress as of January 1983.

PREVIOUS INVESTIGATIONS

Until recently there have been relatively few reports on the Sligo Formation. Because it is a subsurface unit, the data concerning the

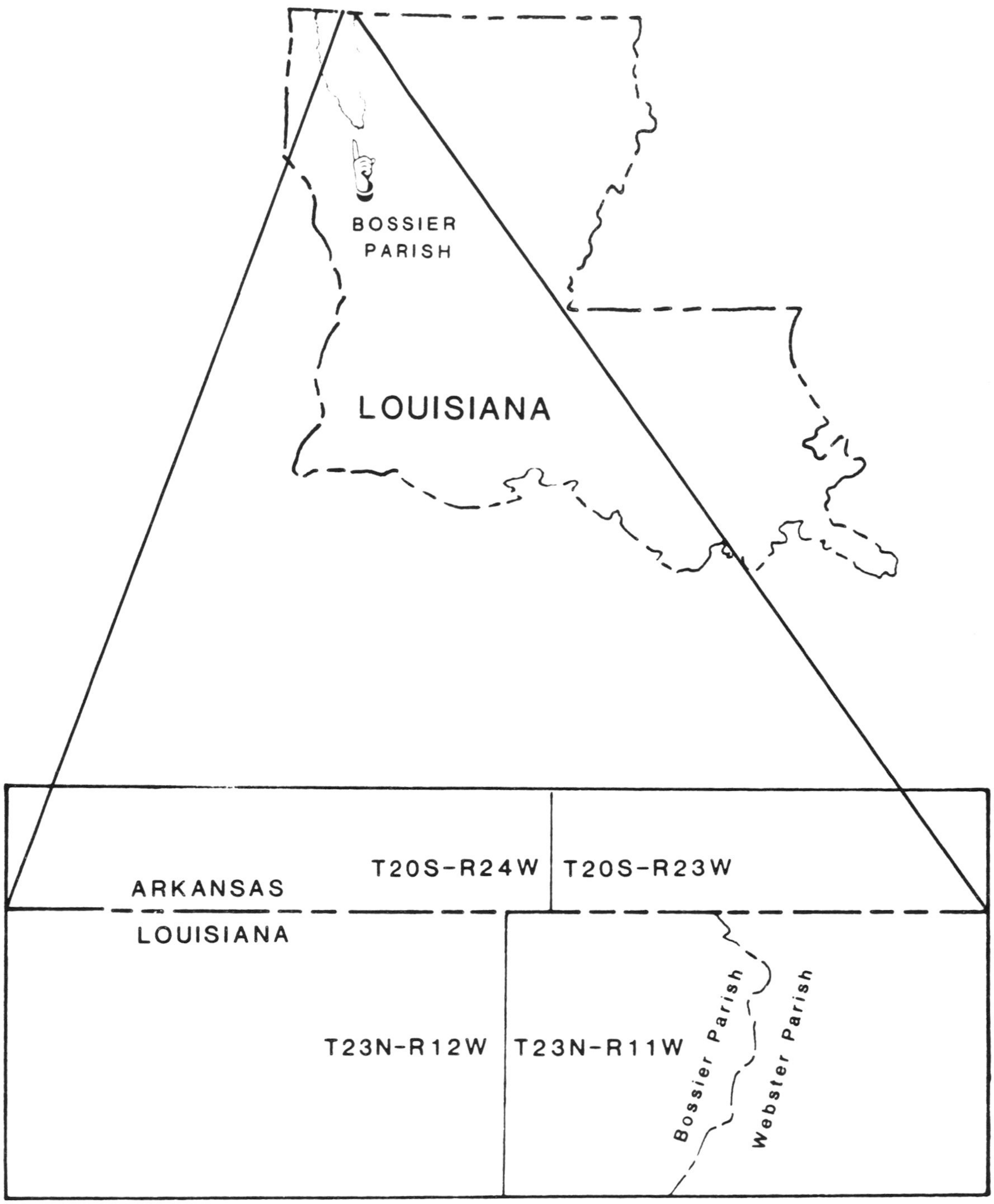

Figure 1. Study area.

Sligo Formation originates from oil company sources, and all studies are, at least in part, petroleum related.

Despot (1956) studied the Sligo Formation in several oil fields in east Texas. She divided it into upper, middle, and lower units and described the porous Page and Crane trends. This threefold division is useful only locally and it has not been used in other reports. Nichols (1958) used electric logs to show regional Lower Cretaceous structure and stratigraphy. He also reported on hydrocarbon production from the Sligo. The discovery of the Black Lake Field in central Louisiana prompted a paper by Herrmann (1971) describing the Sligo rudist reef trend. Boland (1980) concentrated on the Pettet "A" zone in Kerlin Field in south Arkansas. He described the lithology, diagenesis and depositional environment of this narrow producing zone.

During the past decade, hydrocarbon exploration in the Lower Cretaceous of south Texas has resulted in several detailed studies of the Sligo and Hosston Formations. Most notable are those by Bebout (1977), Bebout and Schatzinger (1978) and Bebout and others (1981). These broad studies discuss lithology, diagenesis and depositional environments.

OBJECTIVES

The objectives of this thesis are: 1) to determine the lithology of the Pettet interval and delineate sedimentary microfacies; 2) to correlate microfacies between cores; 3) to determine the nature and extent of diagenetic alteration; 4) to construct a depositional model based on microfacies analysis; 5) to explore possible relationships between microfacies, porosity, permeability and hydrocarbon production.

METHODS

Core chips from the Pettet interval in North Carterville Field were supplied by Western Reserves Oil Company. The samples represent one foot intervals from four wells. Total length of core is approximately 400 feet. Core Laboratory reports on porosity and permeability of the samples were made available. Electric logs for approximately 35 wells in the area were supplied.

Thin sections from each sample were stained with a solution of alizarin red S and potassium ferrocyanide in dilute HCl. By this method, calcite stains red, ferroan calcite stains purple, dolomite does not stain and ferroan dolomite and ankerite stain blue (Evamy, 1969; Friedman, 1971). The thin sections were studied petrographically and 150 were point counted using 300 points per slide. Voids and cement-filled voids within allochems were counted as constituents of the allochems. This method gives the grain volume percent (Dunham, 1962). The data was analyzed with the help of SPSS (Statistical Package for Social

Science) programs. The nature and strengths of relationships between all the variables were studied.

Scanning electron microscopy aided in the study of rock characteristics that are difficult to detect with the light microscope. Approximately 20 samples were studied for cement crystal morphology and dolomite habit.

Cements and dolomite were studied under cathodoluminescence. This method can reveal crystal zonations which are not visible under a light microscope. It can also help to determine the environment of cement precipitation and the relative abundance of Fe and Mn ions.

Paleontological observations, textural classes, sedimentary structures and diagenetic features were used to delineate the various microfacies present. These microfacies were then compared to the standard microfacies of Wilson (1975) to aid in determining a depositional model.

STRATIGRAPHY

The regional stratigraphic nomenclature of the Lower Cretaceous in the Gulf Coast was introduced, then amended, by R. T. Hill (1888, 1889, 1891). Hill recognized the Trinity "division" as the lowermost unit in the Comanchean Series. The term Trinity became preferred over the Bosque "division" of Taff (1891). The Trinity was assigned group status and was divided into three formations by Hamill (1921). The formations were, in ascending order, the Trinity, Glen Rose and Paluxy.

In the mid to late 1920's the first wells penetrated the Trinity Formation and underlying units (Vanderpool, 1928). A number of different drillers' terms were applied to the strata encountered. Bingham (1937) reported on the successful completion of three wells in the "so called 'Pettet' zone" at the base of the Glen Rose Formation in the Sligo Field, Bossier Parish, Louisiana. Weeks (1938) noted that in subsurface terminology the term Travis Peak had come to be used for the Trinity Formation. Weeks also divided the lower Glen Rose Formation into the basal Pine Island Member and the Rodessa Member. He placed the Pettet limestone at the base of the Pine Island Member.

According to Forgotson (1957) the term "Sligo Formation" was proposed by the Shreveport Geological Society based on the description by Imlay (1940) of 100-300 feet of gray to brown shale containing lenses of sandstone and limestone representing the base of the lower Glen Rose Formation. The term "Pettet" was used as an informal name for local porous limestone lentils within the Sligo Formation. Imlay (1944) proposed the Neuvo Leon and Durango Groups into which he placed the

Sligo and Hosston Formations, respectively. He also revised the nomenclature by naming the Cretaceous strata below the Comanchean Series the Coahuilan Series. Imlay's terminology has been adopted in reports on Louisiana and Arkansas (Despot, 1956; Herrmann, 1971; Boland, 1980) but it is not always used in other areas (Loucks, 1977; Bebout, 1977). In the study area, the Sligo Formation is placed in the Neuvo Leon Group of the Coahuilan Series (Figure 2) and is considered to be of Aptian age.

The Sligo Formation is overlain by the Pine Island Shale. The contact is conformable in the northward, updip direction (Stricklin and others, 1971). This contact is recognized on electric log resistivity curves as the top of three limestone "kicks" which are known by oil company geologists as the Three Fingered Limestone. The lower contact with the Hosston Formation is placed at the first appearance of red beds.

The Sligo and Hosston Formations are, for the most part, a single time stratigraphic unit. The Sligo Formation is a marine unit composed of fossiliferous and oolitic limestones, shales and minor sandstones. It interfingers with and overlies the Hosston Formation, which is composed of alluvial and marginal marine deposits. Together they form a limestone-terrigenous clastic couplet, the lowermost of three such couplets recognized by Stricklin and others (1971) in central Texas. Each couplet represents a major transgressive cycle. Contacts between couplets are unconformable in the updip area.

The Sligo Formation is a wedge-shaped unit that is known only in the subsurface. It is less than 100 feet thick in southern Arkansas (Imlay, 1940) where it pinches out or becomes unrecognizable due to

SYSTEM	SERIES	GROUP	FORMATION
LOWER CRETACEOUS	COMANCHEAN	WASHITA	MANESS
			BUDA
			GRAYSON
			MAINSTREET
			PAW PAW
			DENTON
			FORT WORTH
			DUCK CREEK
		FREDERICKSBURG	KIAMICHI
			GOODLAND
			WALNUT
		TRINITY	PALUXY
			MOORINGSPORT
			FERRY LAKE
			RODESSA
			BEXAR
			JAMES
			PINE ISLAND
	COAHUILAN	NUEVO LEON	SLIGO
		DURANGO	HOSSTON
UPPER JURASSIC		COTTON VALLEY	SCHULER
			BOSSIER

Figure 2. Lower Cretaceous stratigraphy of north Louisiana.

facies change. To the south the wedge thickens to over 2,000 feet in south Texas (Achauer, 1977). From the junction of the western Bossier Parish boundary line and the Louisiana-Arkansas state line downdip to the Sligo shelf edge, the Sligo wedge increases in thickness at an average rate of approximately 7 feet per mile (Figure 3). The rate of increase is much greater downdip than near the northern limits of the formation. Despot (1957) reported that in east Texas near the center of the north-south formation limits, the rate of thickening is approximately 3.4 feet per mile. An isopach map by Nichols (1958) shows that the rate increases to approximately 10 feet per mile between Despot's area and the shelf edge.

The paleogeography of the Lower Cretaceous shelf was similar over a very wide area. Because of this the Sligo Formation and its equivalents now exist in the subsurface from Florida through Alabama, Mississippi, Louisiana, Texas and into northern Mexico (Forgotson, 1957). In Coahuila, Mexico, the Cupido Limestone and underlying Taraises Formation are the time stratigraphic equivalents of the Sligo and Hosston Formations (Ekdale and others, 1976).

The term "Pettet" originated in 1936 upon the successful completion of Producers Oil and Gas Company's No. 1 Mrs. G. F. Pettet in a porous limestone lentil (Herrmann, 1971). Despite the previously mentioned work of Imlay (1940) the term Pettet was used for many years as equivalent to or instead of the Sligo Formation. Pettet was also commonly misspelled Pettit in the early literature. The Pettet is now properly identified as a porous oolitic limestone lentil, containing zones of fossiliferous micrite and shales, occurring at different stratigraphic levels within the Sligo Formation.

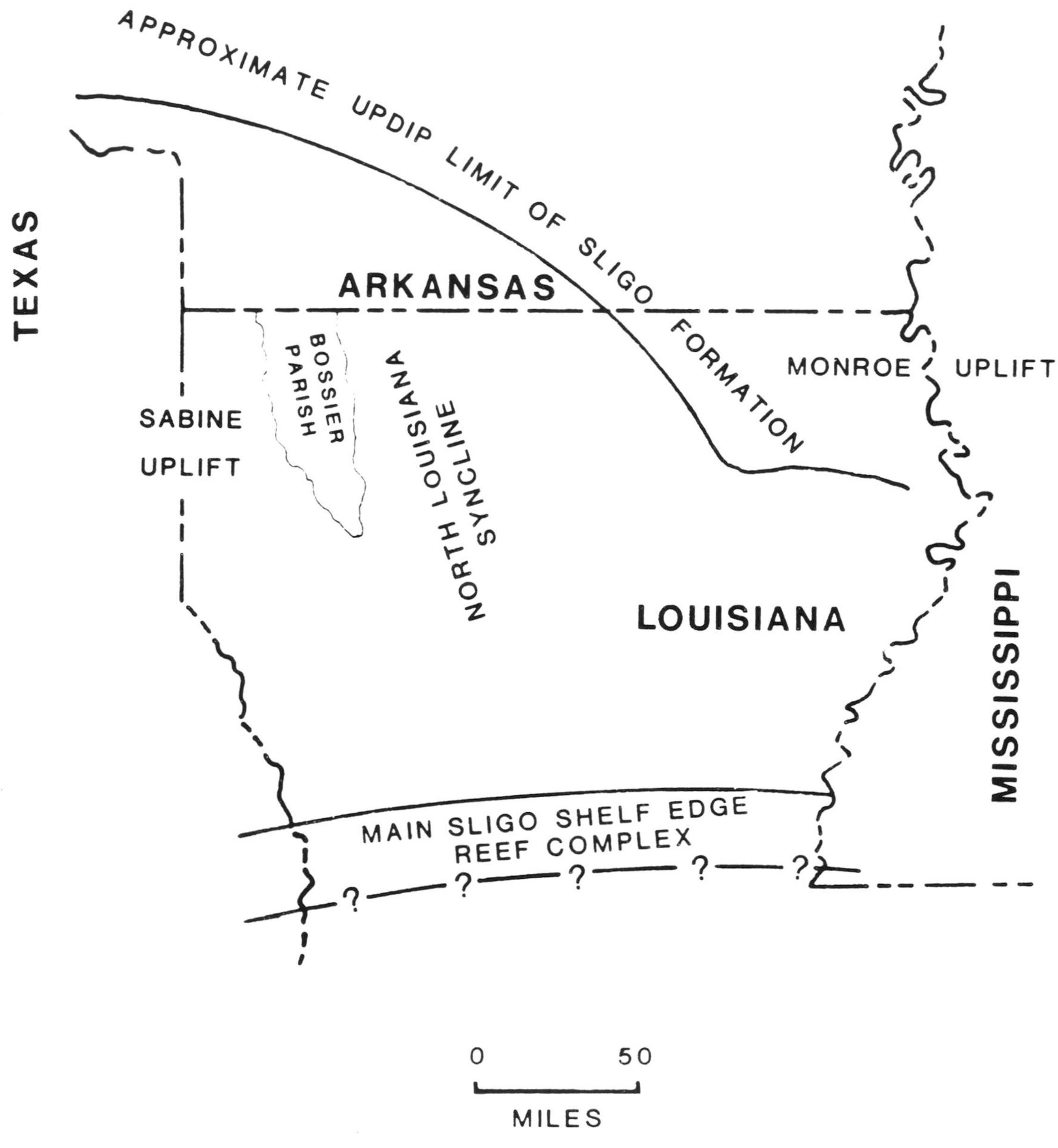

Figure 3. Regional structures and approximate limits of the Sligo Formation.

The terms Pettet porosity, Pettet zone and Pettet lentil have all been used in the past to describe the same unit. The American Commission on Stratigraphic Nomenclature (1961) describes a lentil as a geographically restricted member which terminates on all sides within a formation. Therefore, a lentil is a special type of member. Though the Pettet fulfills the requirements for classification as a member, it has not been so defined in previous literature. Therefore, to avoid improper usage of the term member, the informal term Pettet interval is used in this study.

For this study, the top of the Pettet is recognized by a large "kick" on the electric log measuring spontaneous potential (SP curve). The lower boundary is less distinct and is placed at the point where the SP curve returns to the shale baseline. The Pettet is approximately 90 feet thick and its upper surface lies approximately 50 feet below the contact of the Sligo Formation and the Pine Island Shale. Stratigraphic columns for the four study wells are given in Figures 4 to 7.

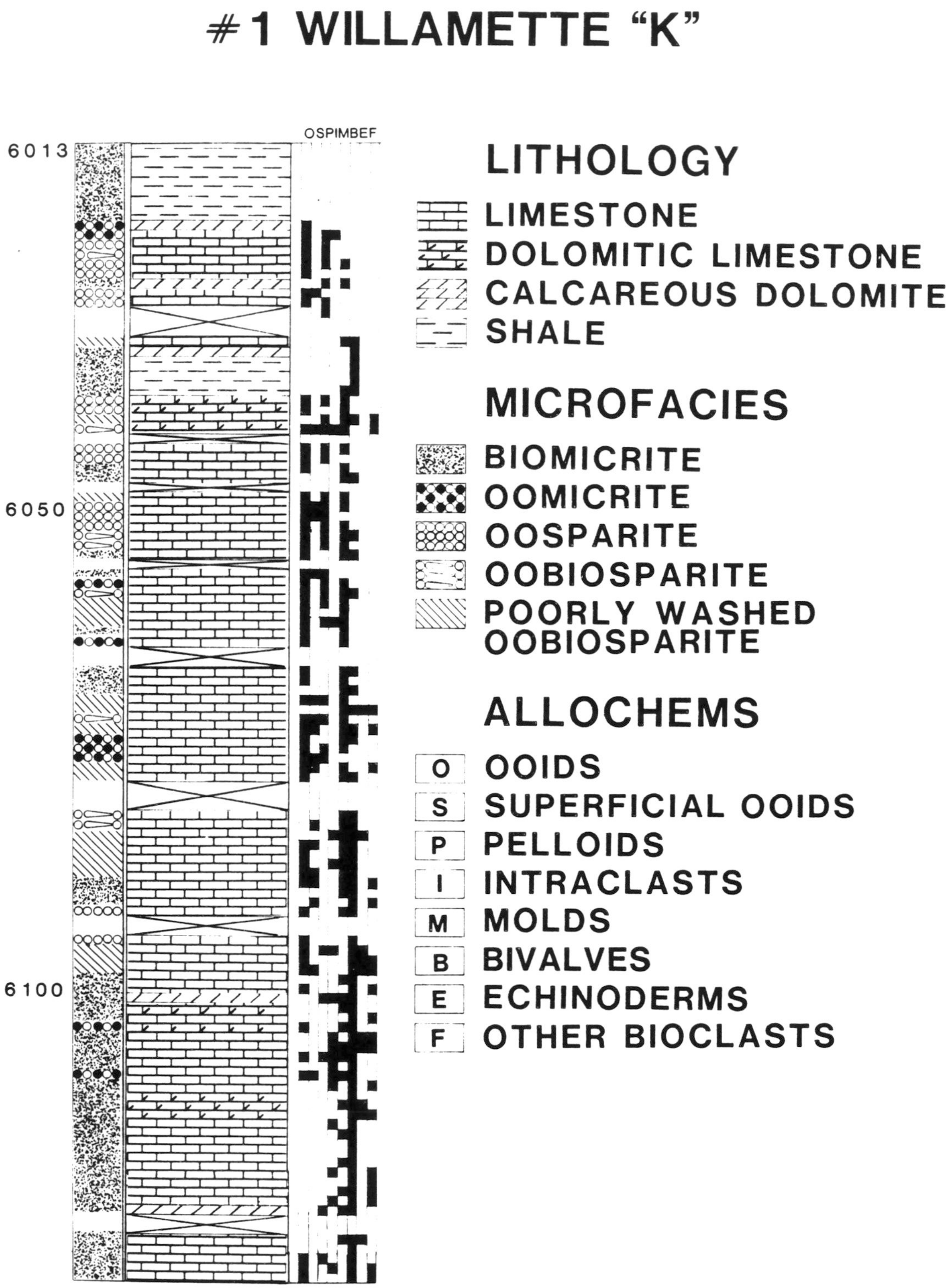

Figure 4. Stratigraphic column for the #1 Willamette "K" well. Depths are in feet below the surface. The top of the Pettet is at the base of the uppermost shale and the Pettet base is approximately at the bottom of the column. Dark blocks represent an allochem abundance of greater than 10%.

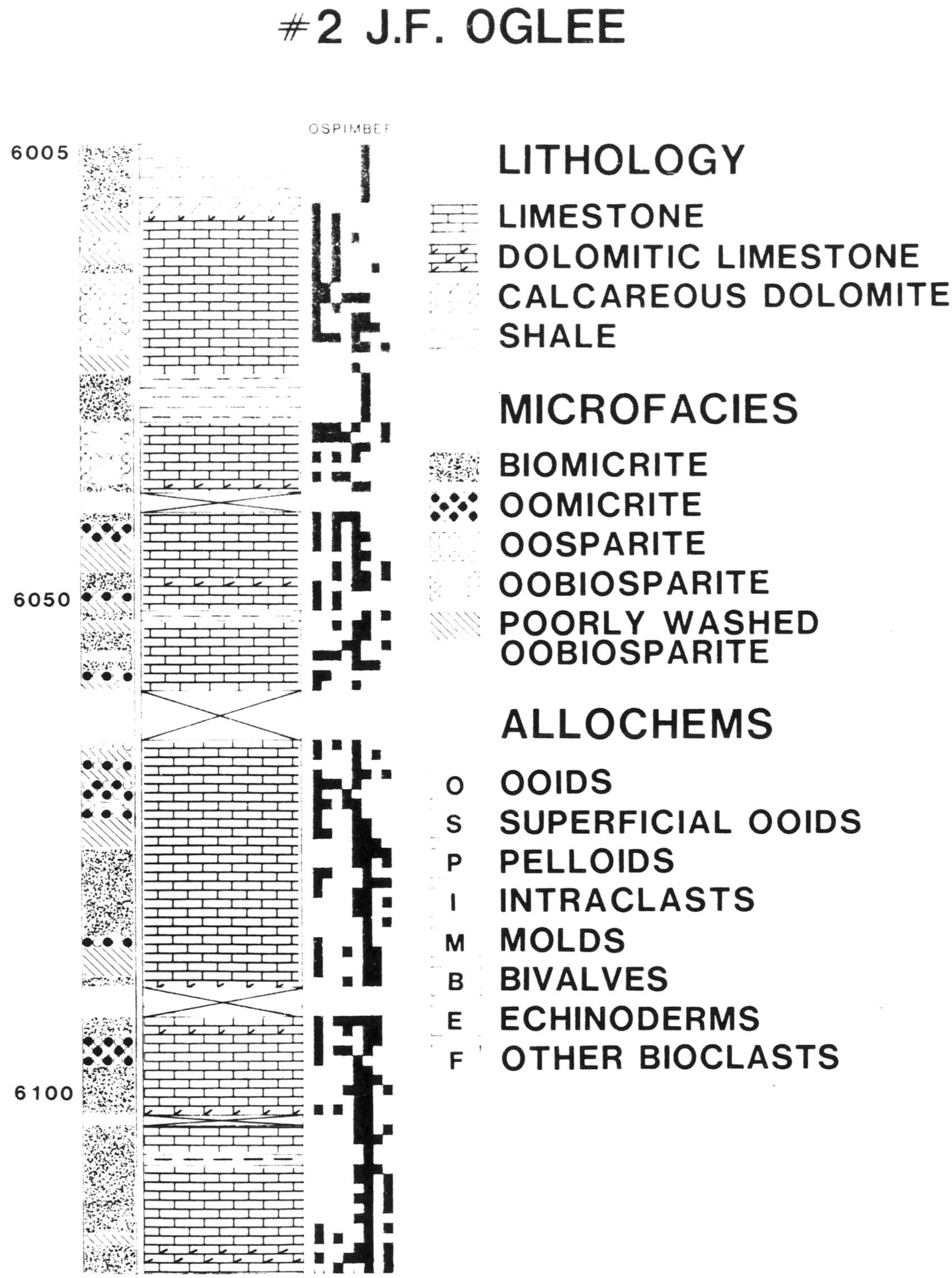

Figure 5. Stratigraphic column for the #2 J. F. Oglee well. Depths are in feet below the surface. The top of the Pettet is at the base of the uppermost shale and the Pettet base is approximately at the bottom of the column. Dark blocks represent an allochem abundance of greater than 10%.

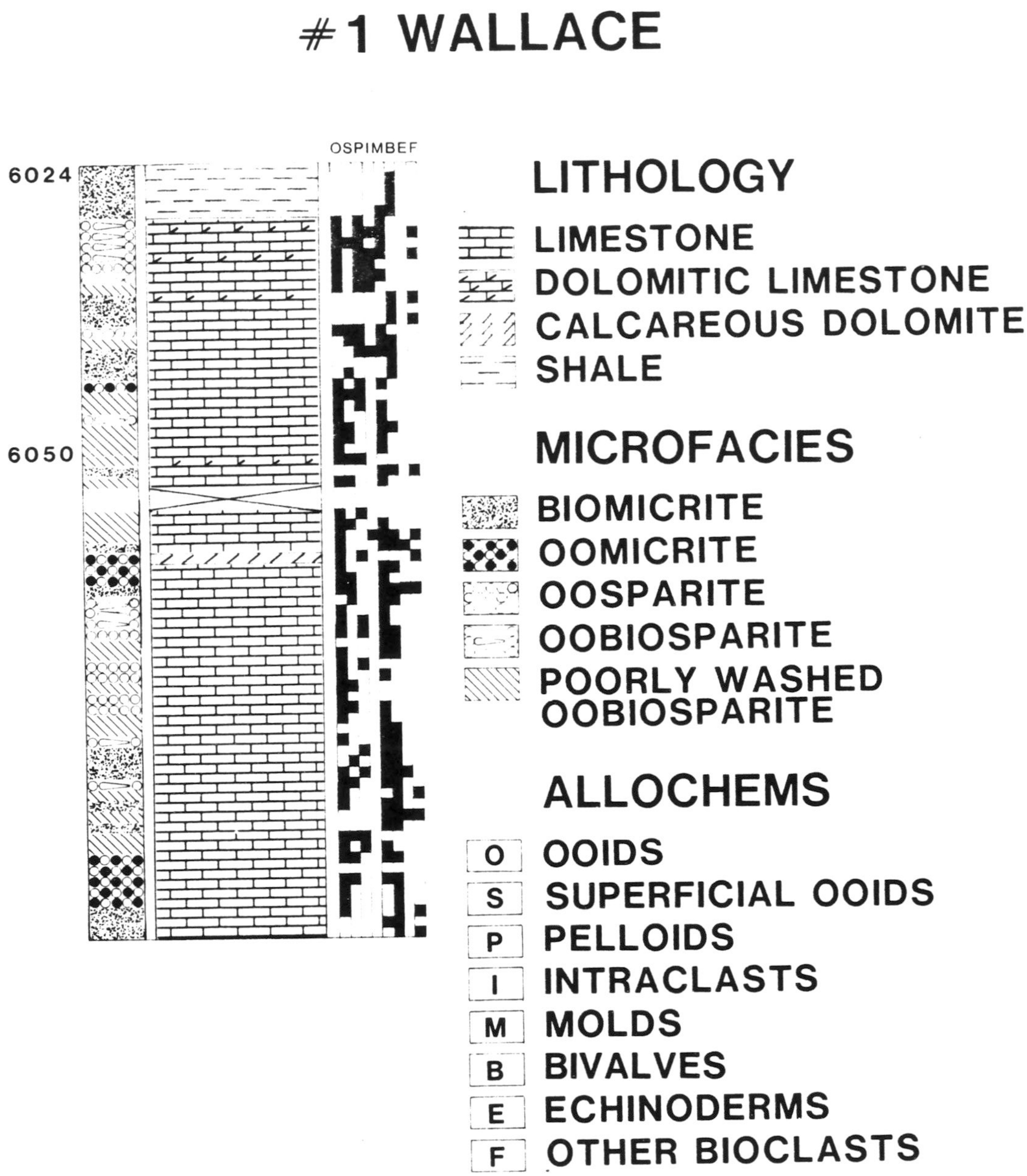

Figure 6. Stratigraphic column for the #1 Wallace well. Depths are in feet below the surface. The top of the Pettet is at the base of the uppermost shale and the base lies approximately 30 feet below the bottom of the column. Dark blocks represent an allochem abundance of greater than 10%.

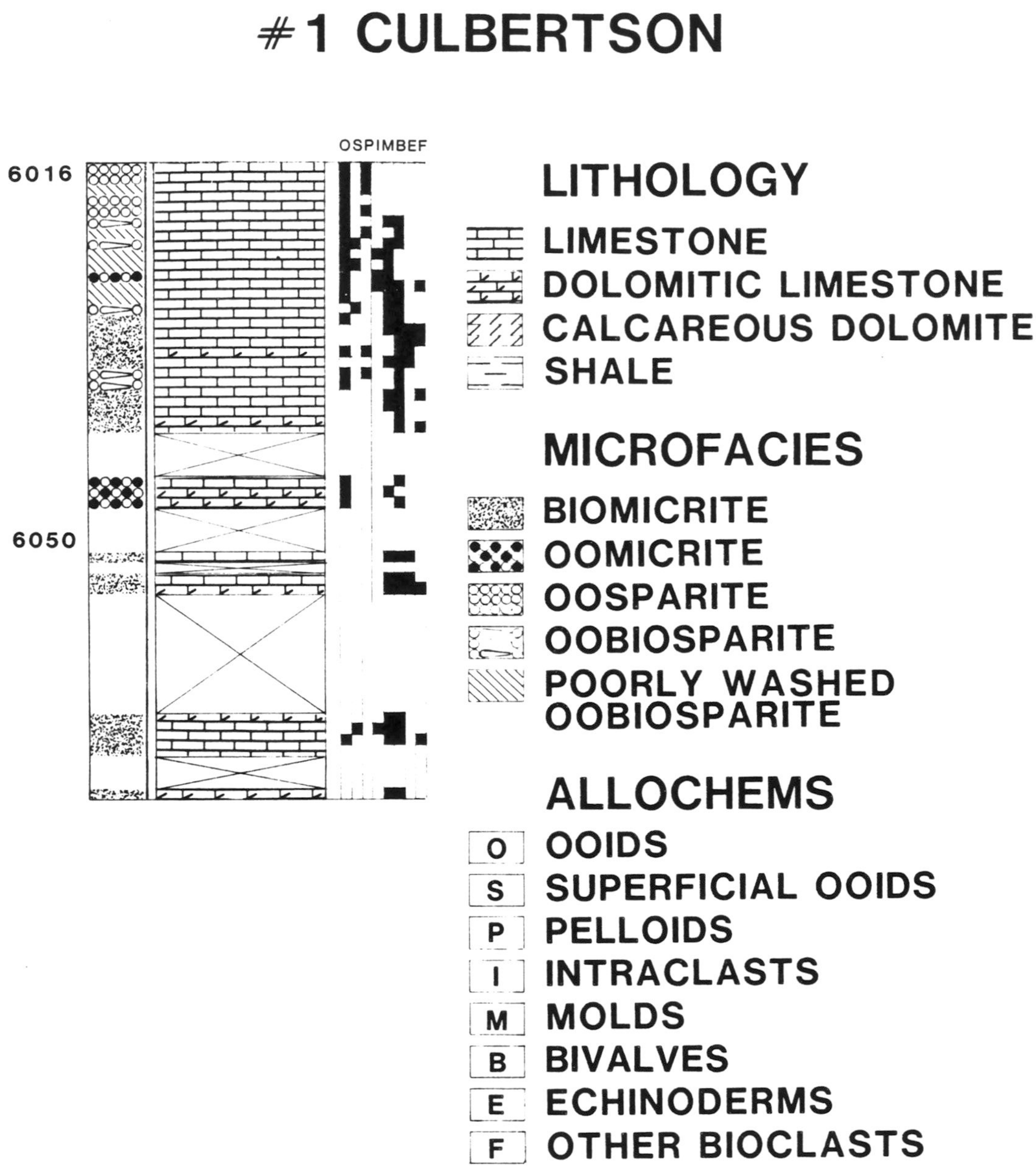

Figure 7. Stratigraphic column for the #1 Culbertson well. Depths are in feet below the surface. The top of the Pettet is approximately 50 feet above the top of the column and the Pettet base is approximately at the bottom of the column. Dark blocks represent an allochem abundance of greater than 10%.

STRUCTURE

REGIONAL

In northern Louisiana and adjacent areas two broad, flat-topped structural domes and an intervening negative area dominate the regional structure (Figure 3). The domes are the Sabine and Monroe Uplifts and the negative area between is the North Louisiana Syncline.

The Sabine Uplift of northwest Louisiana and east Texas is the largest structural feature of the Gulf coastal plain, covering an area approximately 85 by 60 miles (Despot, 1956). Growth began by the Early Jurassic but it was mainly to the west of the Texas-Louisiana border. Centers of maximum uplift shifted into northwest Louisiana at the end of Coahuila time and growth continued well into the Tertiary (Murray, 1961). Nichols (1958) attributed the cause of uplift to overloading of the proto-Gulf basin which resulted in crustal movements and isostatic adjustments.

The Monroe Uplift of northeast Louisiana, southeast Arkansas and west-central Mississippi is similar to the Sabine Uplift in terms of sediment record and structural development, though each developed separately (Murray, 1961). The early development of the Monroe uplift predates the Sabine uplift but the major growth occurred after the deposition of the Sligo Formation (Philpott, 1952). The cause of the uplift may be similar to that of the Sabine Uplift. Nichols (1958), however, attributes the Monre Uplift to batholithic emplacement.

The North Louisiana Syncline lies between the Sabine and Monroe uplifts. It grew in conjunction with the two uplifts beginning in Comanchean time. The thickest accumulation of Lower Cretaceous sediments of the region is located here. Today a number of salt domes and other salt-related features modify the structure.

The area proximal to the Louisiana-Arkansas state line was the site of Triassic-Jurassic block faulting. The faults have a generally east-west strike and they are at the northern edge of rifting associated with the opening of the Gulf of Mexico (Pilger, 1978). By the time of Sligo deposition the activity was largely over; and there is no evidence of faulting in the Sligo sediments of the study area.

LOCAL

The present structure of the Pettet interval in the study area is shown in Figure 8. The structure contours represent the top of the Pettet, identified using SP curves, in feet below sea level. The map shows a structural nose or anticline with a roughly east-west trend and a westerly plunge. Since the regional forces have been tensional since the Triassic-Jurassic rifting (Pilger, 1978), the cause of this structure was probably movement in the underlying Jurassic salt deposits.

An isopach map of the overlying Sligo, Pine Island and James Formations shows a south to north thinning over the study area (Figure 9). This may be a reflection of a regionally southward thickening wedge of sediments, similar to the Sligo-Hosston couplet. Alternately this could represent thinning due to local growth of structures in the Early Cretaceous.

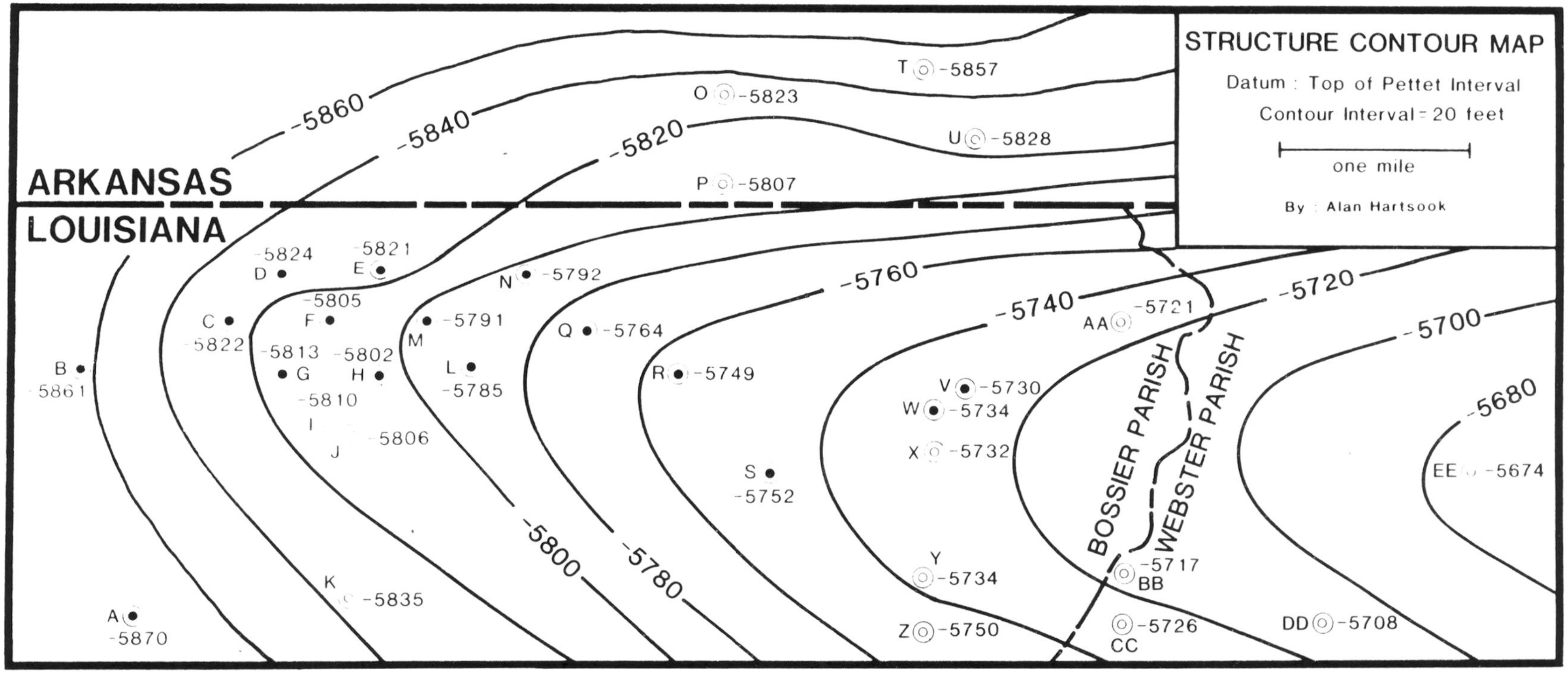

Figure 8. Structure contour map of the top of the Pettet interval. Depths are in feet below mean sea level. Dark dots represent Pettet production. Well names are in Appendix A.

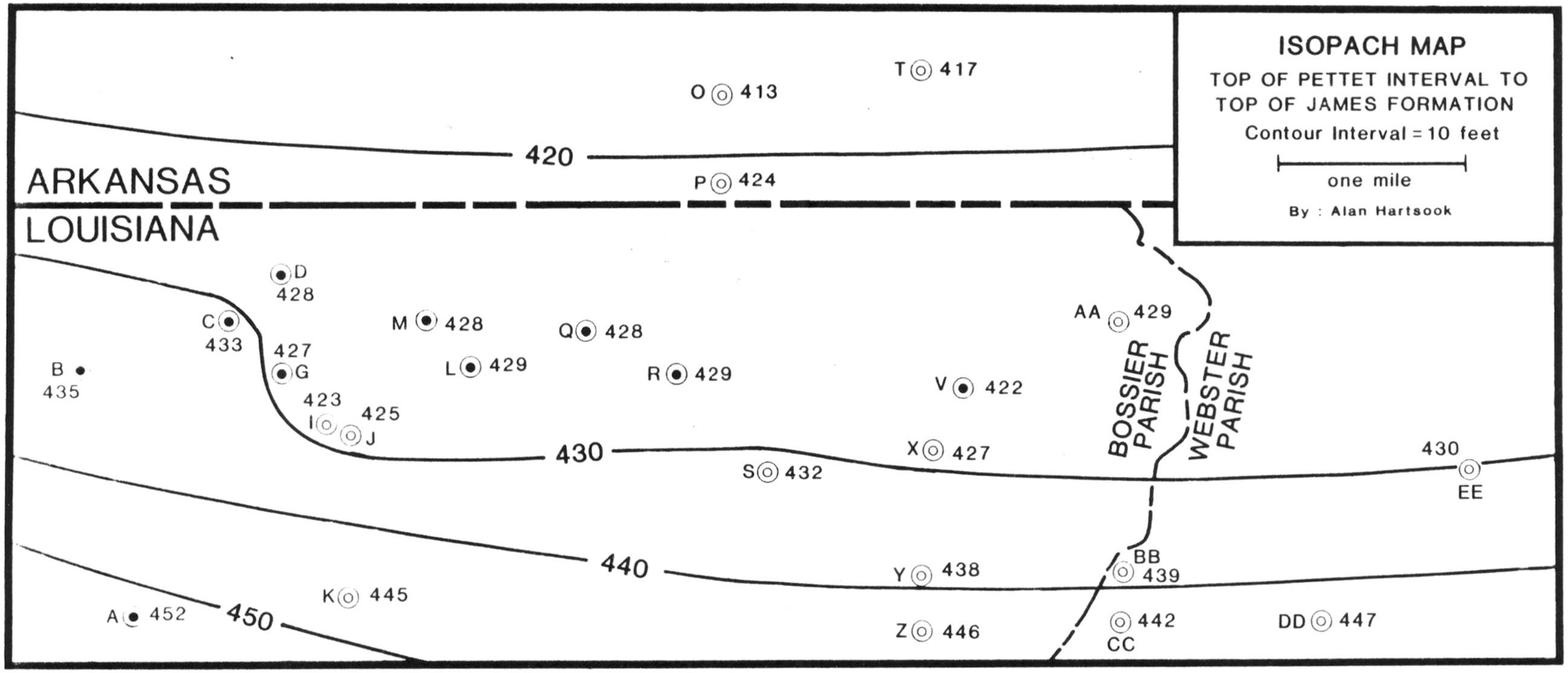

Figure 9. Isopach map of several formations above the Pettet interval. Thicknesses are in feet. Dark dots represent Pettet production. Well names are in Appendix A.

PETROLOGY

CLASSIFICATION

A number of carbonate classifications have been proposed, but only those of Folk (1962) and Dunham (1962) have gained widespread acceptance and use. Folk's classification was most suitable to the goals of my study. Whether or not a rock is grain supported is basic to Dunham's classification. Sediments may be grain supported while having up to 70 percent pore space (Dunham, 1962) and thin sections give only a two dimensional view of the three dimensional system. Therefore, recognizing grain support can be difficult. Folk's classification avoids this judgment but still includes the concept of particle packing. Though both classifications have some category boundaries set by the percentage occurrence of constituents; in this study Folk's boundaries more effectively grouped similar rocks into the same categories.

MATRIX

The four main constituents of matrix material in the Pettet interval are: 1) micrite, 2) microspar, 3) shale and 4) dolomite. Microspar and dolomite are discussed under diagenesis.

Micrite is a term used for microcrystalline calcite. The rock term is equivalent to mudstone (Dunham, 1962). Microcrystalline calcite is semiopaque, often appearing brown in thin section, with more or less equant crystals in the 1-4 um range (Folk, 1959). Origins of micrite include chemical and biological precipitation, mechanical abrasion of invertebrate skeletal material, boring activities and disintegration of biogenic hardparts.

The micrite of the Pettet interval is brown and usually has a homogenous texture. Rarely it takes on a pelleted to clotted texture (Plate 1). This texture probably represents an accumulation of fecal pellets rather than the problematical structure grumeleuse of Cayeux (1935). Terrigenous clay is occasionally found together with micrite forming a marl.

Shales in the Pettet interval are dark brown to dark gray, calcareous and fissile. Disseminated pyrite is common and often partially replaces small allochems such as foraminifera. Silt size, angular quartz grains are occasionally abundant in the shales.

ALLOCHEMS

Ooids

Ooids are spherical to ellipsoidal carbonate particles, less than 2mm in diameter, with concentric laminae surrounding normally distinguishable nuclei. Modern marine ooids are composed of aragonite and, until recently, most ancient ooids were assumed to have had an original aragonite composition. Sandberg (1975) suggested that some ancient ooids may have originally been composed of calcite or Mg-calcite.

Ooids in the Pettet interval range from 0.2 to 2.0 mm with 0.9 mm being a mean of 300 counts. Nuclei are most often skeletal fragments or

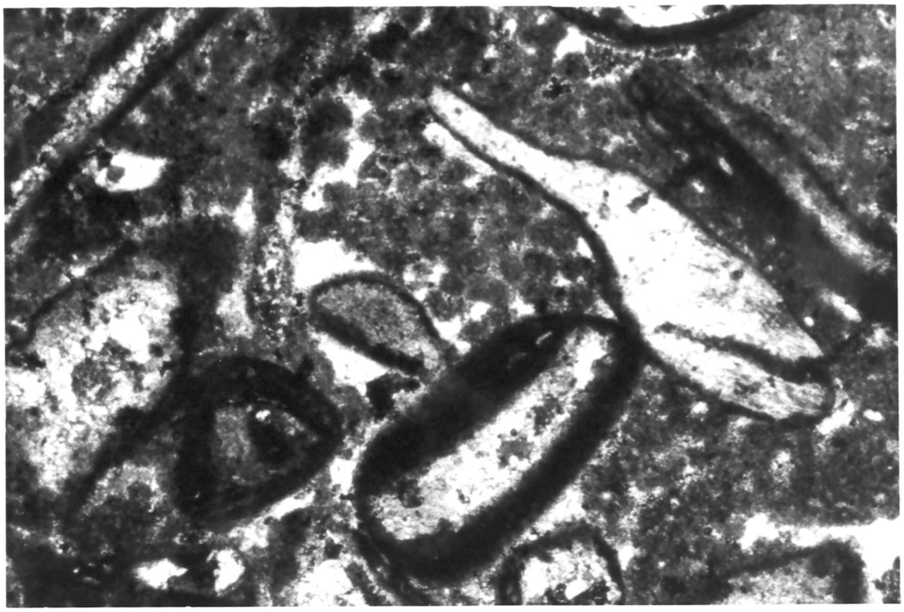

PLATE 1. Rare pelleted matrix. 1 cm = 0.26 mm.

PLATE 2. Intraclast composed of ooids and skeletal fragments in a micrite matrix. This intraclast shows significant abrasion. 1 cm = 0.26 mm.

pelloids. Ooids are usually well developed, with the cortex thickness exceeding the nucleus diameter. Similar modern ooids require from 100 to 1,000 years for growth (Flugel, 1981). Single, whole, undeformed ooids predominate throughout the Pettet though some polyooids and spastoliths are scattered among them.

Superficial Ooids

The superficial ooids of the Pettet are generally elliptical to rod-shaped allochems with one or very few concentric laminae surrounding a relatively large nucleus. The term proto-ooid is a synonym for these particles which normally represent early or incipient ooid formation. The Pettet superficial ooids range in size from 0.1 to 3.0 mm and the median size is approximately 0.6 mm. Nuclei are usually skeletal fragments and the cortex is generally less than 0.05 mm thick.

Pelloids

Pelloids are spherical to rod-shaped particles composed of micrite with no obvious structure. The term "pellet" implies a fecal origin and thus was not used. The wide range in size and shape of Pettet interval pelloids suggests that many of the pelloids were not of fecal origin but instead probably represent micritized ooids and superficial ooids. Pettet peloids range in size from 0.05 mm to 3.0 mm and average approximately 0.6 mm.

Intraclasts

Intraclasts are reworked fragments from penecontemporaneous, locally accumulating sediments. In the Pettet, intraclasts are normally composed of several ooids and/or skeletal fragments in a micrite matrix. They have rounded outlines but rarely show evidence of much abrasion (Plate 2). Intraclasts are large in comparison to other allochems, with maximum dimensions that range from 0.4 mm to 5.0 mm.

Bivalves

Bivalve shell fragments are very common in the Pettet interval but whole, unaltered shells were not encountered. Bivalve shells are commonly composed of two or three layers which may be calcite or aragonite or both. Lamellar structure is often well preserved (Plate 3) and prismatic structure is occasionally present. These structures are retained layers of original calcite composition, while layers of original aragonite have been leached or neomorphosed to calcite. Fragments range in size from 0.05 mm to almost 2 cm.

Spar Filled Molds

Molds formed when aragonite shell fragments were leached leaving empty micrite envelopes. The resulting voids were partially to completely filled with sparry calcite cement. Based on their size, shape and composition (Plate 4), most of the molds were originally aragonite

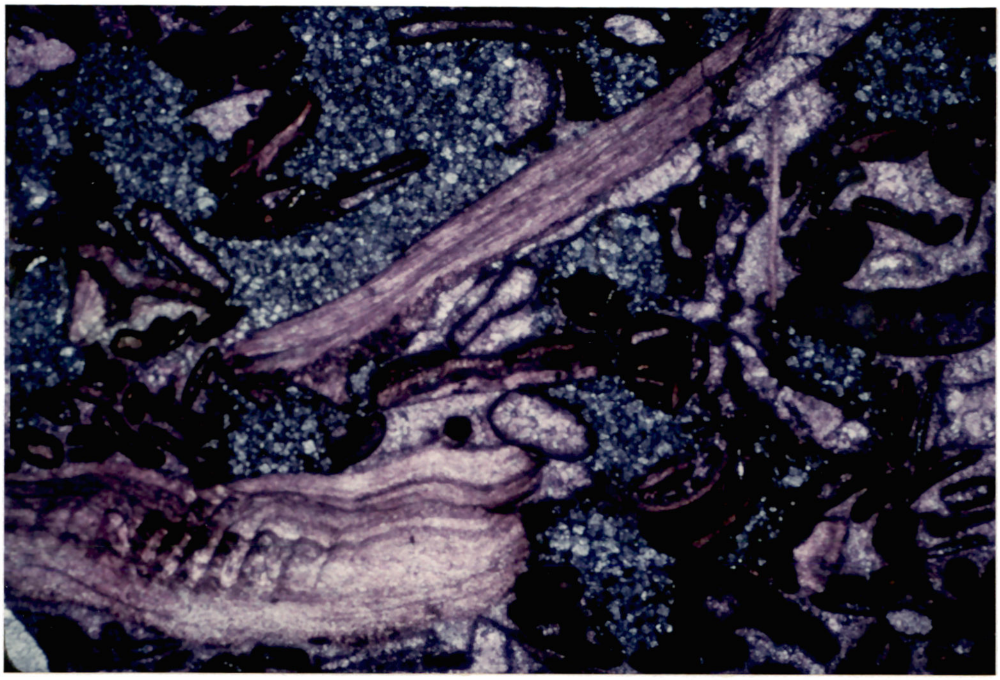

PLATE 3. Biomicrite with dolomitized matrix. Pelecypod shells retain original lamellar structure. 1 cm = 0.26 mm.

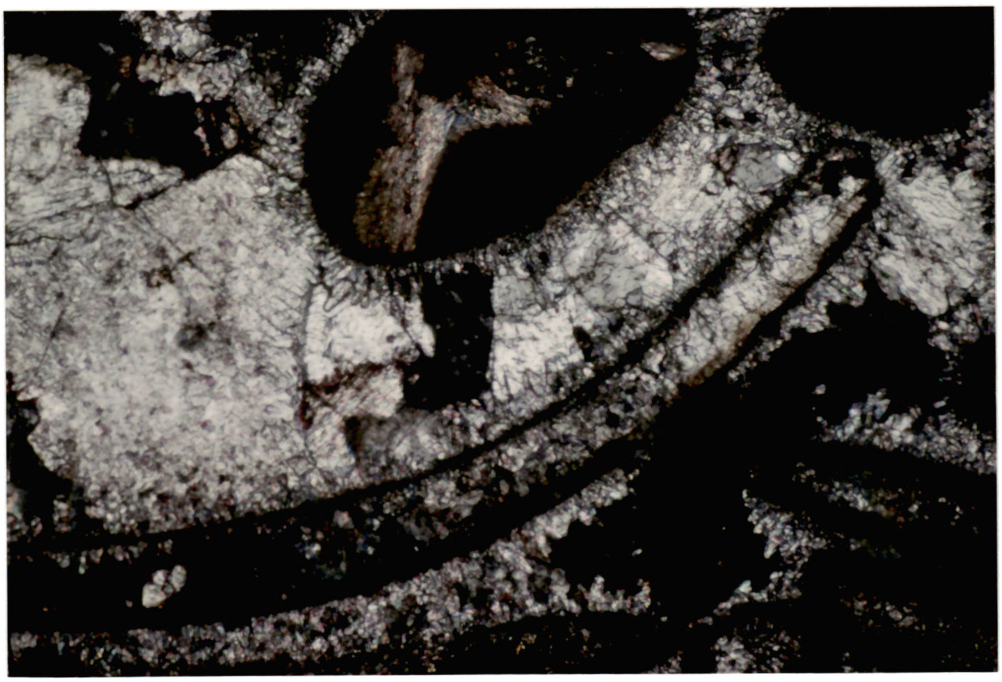

PLATE 4. Large spar filled pelecypod mold along with other allochems in an oobiosparite. 1 cm = 0.26 mm.

bivalve shells. Aragonitic gastropod shells were also leached and sometimes filled with cement but they are far less abundant. Molds are very abundant in some zones of the Pettet where they influence secondary porosity and therefore oil accumulation. Molds are from 0.2 to 5.0 mm in length and 0.05 to 0.5 mm in width.

Echinodermata

Echinoderm fragments are well preserved and occasionally abundant in the Pettet. They can be recognized by their single unit extinction under crossed polars. They often have a dusty appearance due to micrite in the pores. Frgaments range from 0.1 to 5.0 mm in size.

Others

Many other types of skeletal fragment were recognized in the Pettet but, with the exception of serpulid worm tubes, none was volumetrically important. Serpulids constitute up to 30 percent of the allochems where present, but they were only found in three samples. Gastropods were frequently found in muddy zones and occasionally constituted up to 5 percent of the allochems. Foraminifera (miliolids and several uniserial and biserial types) were also common in micritic sediments. Algal plates are normally highly micritized and difficult to recognize. Bryozoans are more easily recognized but are relatively rare.

Unknown

Highly micritized, nonspherical fragments and other unrecogizable grains were classified as unknowns. The abundance of these particles increased substantially in the stylolitic zones, where allochems are sometimes highly deformed.

MICROFACIES

INTRODUCTION

Microfacies refer to the total of all the paleontological and sedimentological criteria which can be seen in thin section (Flugel, 1982). These include allochem types, textures, sedimentary structures and some diagenetic features. Though microfacies represent more than a rock's lithology, they are often named for the most abundant lithologic type. Such is the case here, where each microfacies is named, according to Folk's classification, for its predominant lithology. A comparison of the microfacies by the percentages of various constituents is given in Table 1.

OOSPARITE MICROFACIES

The oosparite microfacies (Plate 5) is composed of approximately 61% allochems, 4% micrite matrix, 26% sparry cement and 9% pore space. The allochems contain 61% ooids, 7% superficial ooids, 13% pelloids, 4% intraclasts, 8% molds, 2% bivalves, 1% echinoids, 2% other bioclasts and 2% unknown. Ooids may comprise up to 85% of the allochems in some places. Intraclasts range in abundance from 0-23%, the latter figure being near the 25% necessary for classification as an intrasparite. Bioclasts are not abundant in any of the oosparite microfacies. Dolomite occasionally occurs as rhombs in selected allochems. The fabric

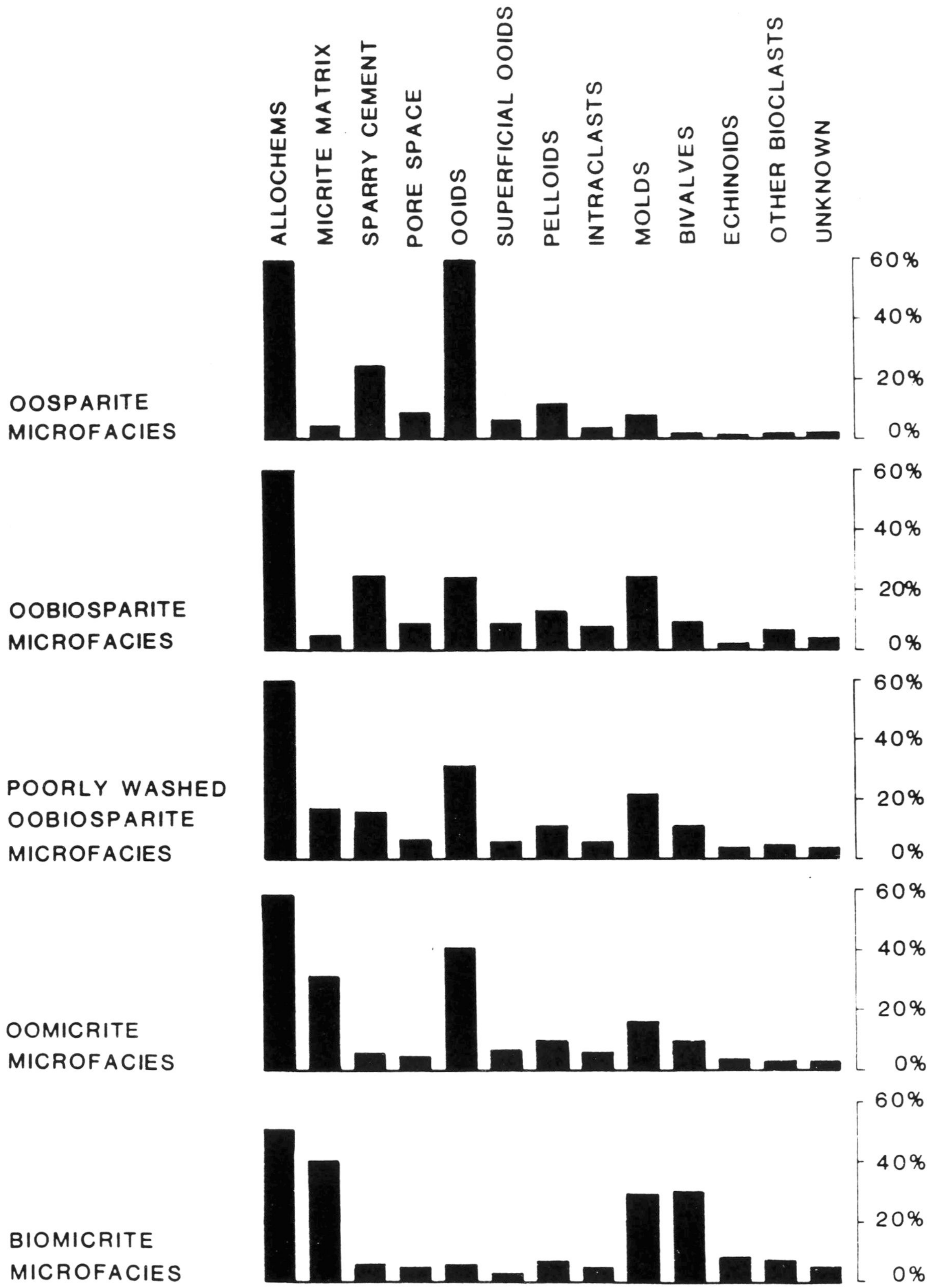

Table 1. Comparison of microfacies using percentages of constituents.

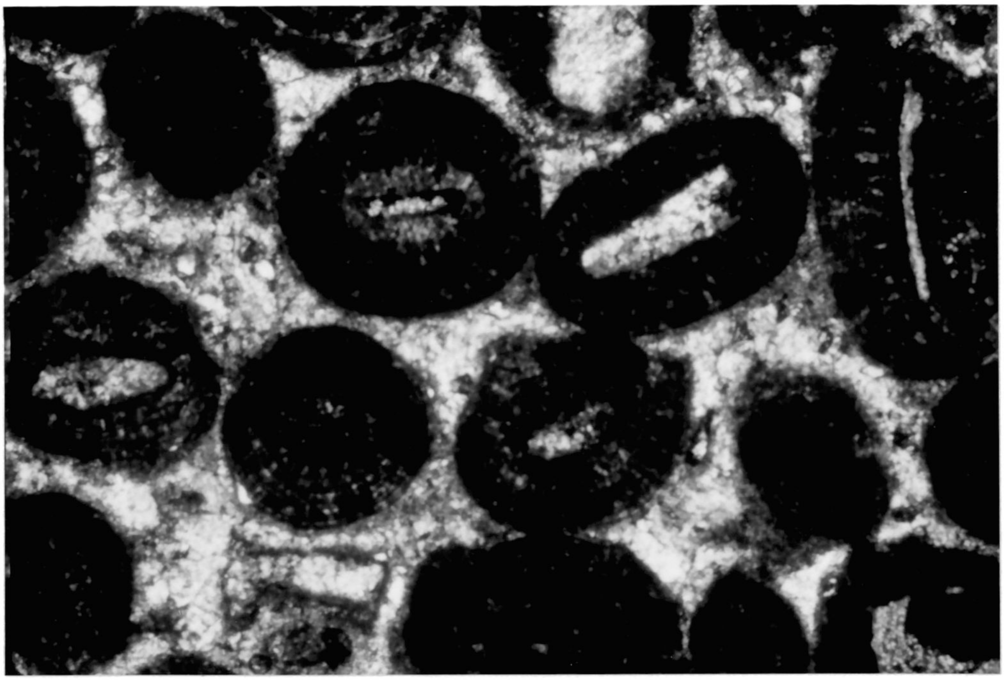

PLATE 5. Oosparite microfacies with vadose cement. 1 cm = 0.26 mm.

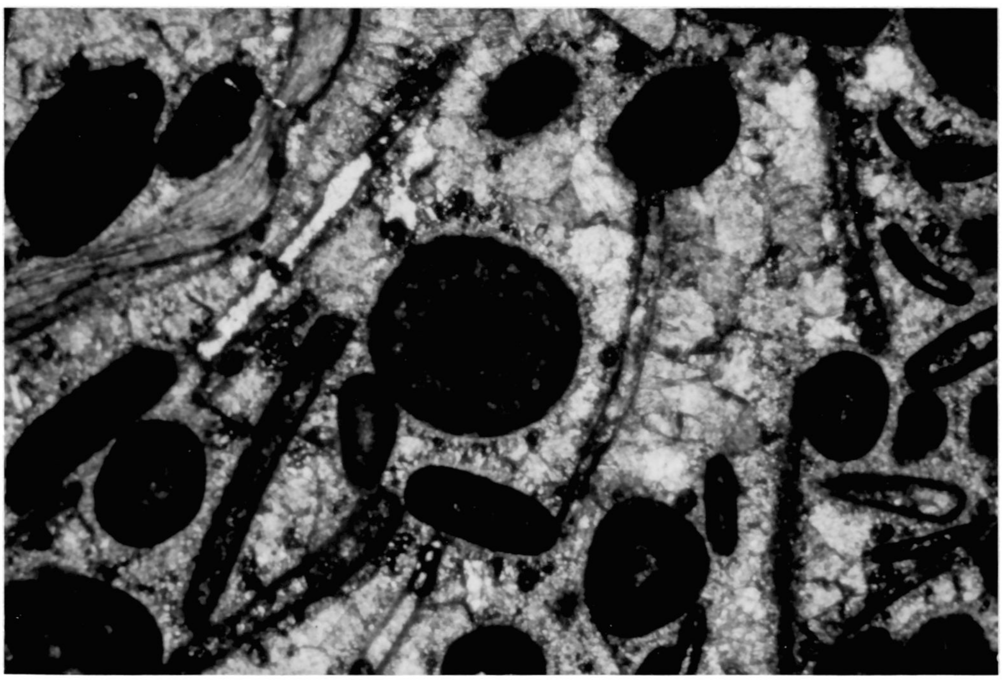

PLATE 6. Oobiosparite microfacies. 1cm = 0.26 mm.

seems to be grain supported and point contacts between grains are most common. The sediments are well rounded and well sorted.

OOBIOSPARIRE MICROFACIES

The oobiosparite microfacies (Plate 6) is composed of approximately 61% allochems, 5% micrite matrix, 25% sparry cement and 9% pore space. The allochems are 24% ooids, 9% superficial ooids, 13% pelloids, 8% intraclasts, 24% molds, 9% bivalves, 2% echinoderms, 7% other bioclasts and 4% unknown. The frequency of molds is highly variable, from 8% to 50%, and bivalve fragments range up to 27%. Ooids are sometimes scarce and thus the term biosparite accurately describes some samples in this microfacies. These "shell hashes" are dominated by molds and bivalve fragments. Dolomite occurs rarely as rhombs in certain allochems. The fabric appears to be grain supported and due to abundant rod-shaped allochems, both tangential and point grain contacts are common. Allochems are moderately to well rounded and poorly to moderately well sorted.

POORLY WASHED OOBIOSPARITE MICROFACIES

The poorly washed oobiosparite microfacies (Plate 7) is composed of approximately 60% allochems, 17% micrite matrix, 16% sparry cement and 7% pore space. The allochems are 32% ooids, 6% superficial ooids, 10% pelloids, 6% intraclasts, 22% molds, 11% bivalves, 4% echinoderms, 5%

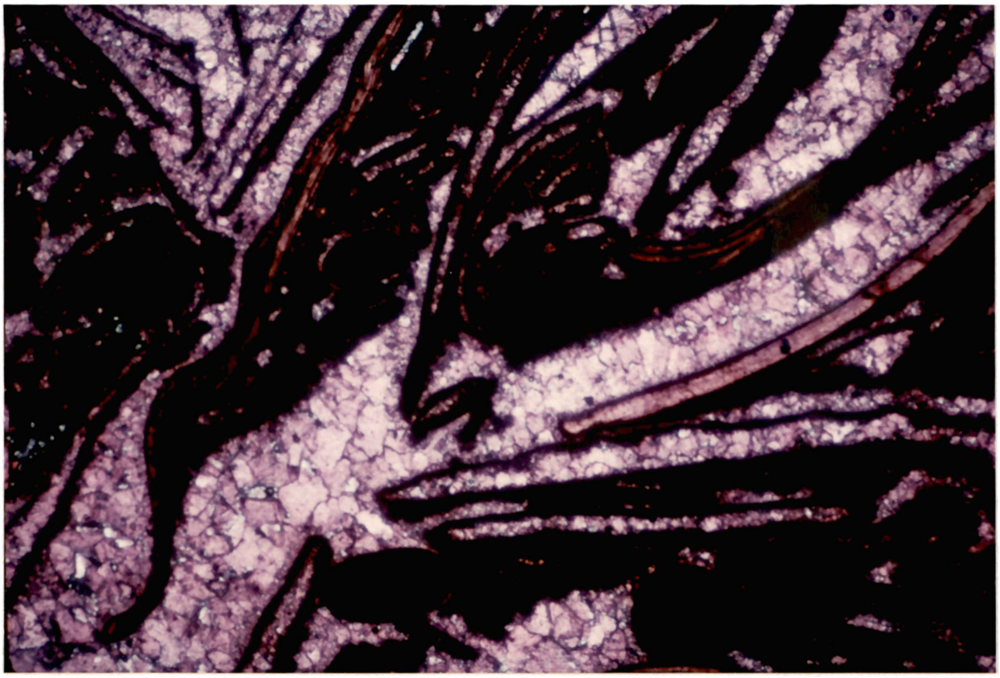

PLATE 7. Poorly washed oobiosparite microfacies. 1 cm = 0.26 mm.

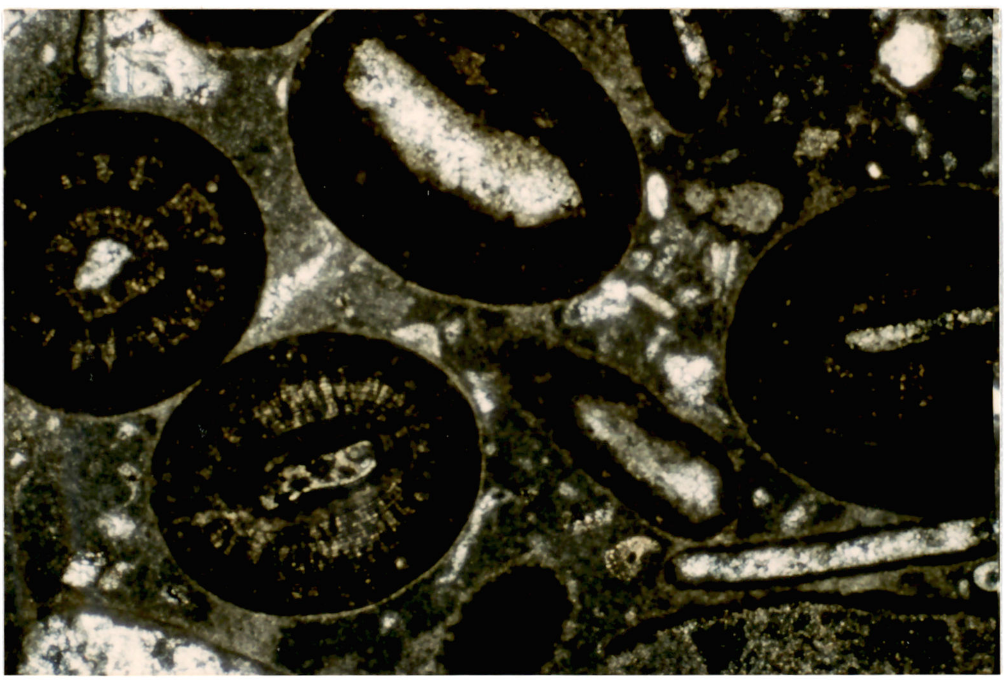

PLATE 8. Oomicrite microfacies. 1 cm = 0.13 mm.

other bioclasts and 4% unknown. The grains are sparsely to closely packed. This is the most variable microfacies in terms of the abundance of various allochems. For example: ooids 0-75%, molds 4-58% and bivalves 0-52%. For this reason many compound names such as poorly washed pelloidal bivalve biosparite and poorly washed echinoderm-bearing moldic oobiosparite could be used for individual samples. Dolomite occurs in patches in the micrite matrix and as individual rhombs in some allochems. The fabric seems to be mostly grain supported and tangential and point grain contacts commonly occur. The sediments are extremely variable in rounding and sorting.

OOMICRITE MICROFACIES

The oomicrite microfacies (Plate 8) is composed of approximately 58% allochems, 31% micrite matrix, 6% sparry cement and 5% pore space. The allochems are 41% ooids, 7% superficial ooids, 10% pelloids, 6% intraclasts, 16% molds, 10% bivalves, 4% echinoderms, 3% other bioclasts and 3% unknown. The average sample is a packed oomicrite. The range of allochem frequency (from 33% to 73%) indicates that sparse oomicrites also occur. Ooids constitute up to 73% of allochems in places, and all allochems are quite variable in abundance. Dolomite is found replacing micrite matrix and occasionally as individual rhombs in allochems. The fabric may be both grain supported and matrix supported and grain contacts are most often point contacts. The sediments are poorly to well rounded and sorted.

BIOMICRITE MICROFACIES

The biomicrite microfacies (Plate 9) is composed of approximately 49% allochems, 40% micrite matrix, 6% sparry cement and 5% pore space. Allochems are 6% ooids, 3% superficial ooids, 7% pelloids, 5% intraclasts, 29% molds, 30% bivalves, 8% echinoderms, 7% other bioclasts and 5% unknown. The 49% value for allochems lies near the classification boundary between sparse biomicrite, 10% to 50% allochems, and packed biomicrite, greater than 50% allochems. The allochem range is from 15% to 68%, therefore, samples fall into both categories. Echinoderms, other bioclasts, bivalves and molds compose high percentages of allochems in some samples, up to 28%, 35%, 70% and 75% respectively. A concentration of serpulid worm tubes accounts for the highest values in the other bioclast category. Sparry calcite cement fills original shelter porosity in some packed biomicrites. Dolomite is common as a micrite matrix replacement and to a lesser extent a secondary pore filling. Dolomitic micrites and calcareous dolomites are placed in the biomicrite microfacies. The fabric of this microfacies appears to be mostly grain supported. When in contact, grains have tangential fitted and point contacts. Sediments are generally poorly rounded and poorly to extremely poorly sorted.

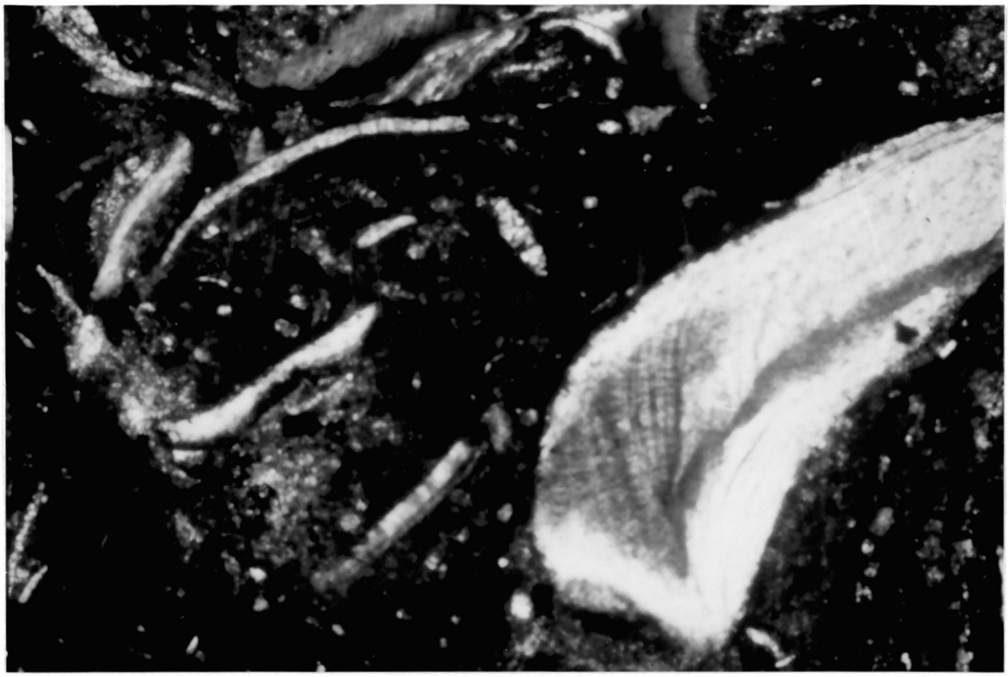

PLATE 9. Biomicrite microfacies. 1 cm = 0.26 mm.

DIAGENESIS

INTRODUCTION

Diagenesis refers to all modifications and transformations, exclusive of metamorphism and weathering, undergone by sediment after initial deposition. A variety of factors, such as porosity, permeability, composition of sediments and pore waters, time, temperature, pressure, etc. determine the type and extent of diagenetic alteration. Therefore, many aspects of diagenesis are not well understood. Diagenetic events are often classed as early or late. These are rather vague terms which relate more to depth of burial and change of environment than actual time. Normally, neither a certain depth nor an amount of post-burial time can be assigned to most types of diagenetic events. Where possible, the timing of diagenetic events, relative to other diagenetic events, is given in the following discussion.

MICRITE ENVELOPES

Perhaps the earliest diagenetic event was the formation of micritic rims of variable thickness that surround many of the skeletal fragments. These micritic envelopes are common in modern and ancient limestones and are originally composed of aragonite or Mg-calcite (Winland, 1968). The formative process occurs at or near the sediment-marine water interface and is penecontemporaneous with deposition. Micrite envelopes commonly form by the infilling of anastomosing, endolithic algal and fungal borings (Bathurst, 1966; Kobluk and Risk, 1977). The process by which the borings are filled with micrite is unknown, but algal photosynthesis may play an important part (Petta, 1977). When the process is able to continue, entire allochems can become micritized. Micritization by algae and fungi is rapid and the entire process may be completed in a matter of a few years (Alexandersson, 1972).

Allochems in the Pettet interval show the entire range of alternation from thin envelopes to completely micritized fragments. Many of the allochems classified as pelloids may be ooids with their internal structure obliterated by micritization. Most micrite envelopes held up under the pressure exerted by the sediment load when the aragonite skeletal material they surrounded was leached. This implies a degree of structural strength in the micrite envelopes and a relatively early leaching and subsequent sparry cement filling.

Mg-CALCITE STABILIZATION

A natural division exists between calcite and Mg-calcite. Calcite normally contains less than 5 mole% Mg whereas Mg-calcite contains approximately 11-19 mole% Mg. Mg-calcite is metastable and it stabilizes rapidly in meteoric water (Land, 1970). The stabilization occurs either by exsolution of Mg to form calcite or by absorption of Mg to form dolomite (Land, 1967). Within the zone of freshwater, Mg-calcite can change to calcite in 7,000 to 10,000 years (Gavish and Friedman, 1969).

Echinoderms, some foraminifera and algae and perhaps some micrite envelopes and ooids, were originally composed of Mg-calcite. With the exception of the ooids, these allochems were not selectively dolomitized. Therefore, the Mg-calcite stabilization was produced by the incongruent dissolution of Mg. This process retained the original texture of the allochems (Stehli and Hower, 1961; Friedman, 1964).

ARAGONITE DISSOLUTION

Aragonite is metastable in a meteoric environment. Stabilization occurs either through polymorphic transformation to calcite or through aragonite dissolution. Polymorphic transformation, also termed inversion by Folk (1965), yields sparry allochems which may contain relict shell structures. Dissolution often forms moldic pores which retain the external shape of the original allochems. Early development of fabric selective moldic porosity represents preferential leaching of aragonite under a freshwater system (Matthews, 1968). This type of porosity is very common in the Pettet interval.

Many types of bivalve shells are composed of aragonite or have both aragonite and calcite layers. Based on the bivalve mineralogy, the shape of moldic pores, the rare presence of articulated, leached bivalve shells and the association of moldic pores and calcitic pelecypod fragments, most moldic pores are considered to be leached bivalves. Micrite envelopes commonly surround moldic pores, thus preserving their shape. Most molds are partially to completely filled with sparry calcite.

Spar-filled micrite envelopes are considered to be cement-filled molds rather than inverted aragonite shells because of the existence of occasional collapsed micrite envelopes, lack of preserved shell structures and other criteria proposed by Bathurst (1971) for aid in distinguishing between the two possibilities.

Ooids in the Pettet were not leached. This suggests that their original mineralogy was Mg-calcite or calcite rather than the aragonite composition of modern ooids. Bebout and others (1981) suggest an original Mg-calcite mineralogy for Sligo Formation ooids in south Texas.

ISOPACHOUS CALCITE CRUST

A finely crystalline, isopachous, sparry calcite crust surrounds most allochems in the sparry lithofacies (Plate 10). The calcite crystals are equant to bladed and 10 um to 40 um in length. Crystals are oriented normal to the pore walls. Contact with the next generation of cement ranges from abrupt to gradational.

Equant calcite should precipitate from water with a Mg/Ca ratio of 1:1 or less, whereas bladed calcite should precipitate from water with a Mg/Ca ratio of 2:1 or more (Folk, 1973; Folk, 1974; and Land, 1975). The Mg/Ca ratio is approximately 3:1 in modern marine waters, from 1:4 to 1:10 in modern fresh waters and it spans the gap between marine and fresh waters in mixing zone environments. .

In the Pettet, precipitation of the isopachous crust came both before and during freshwater diagenesis. Factors indicating the former

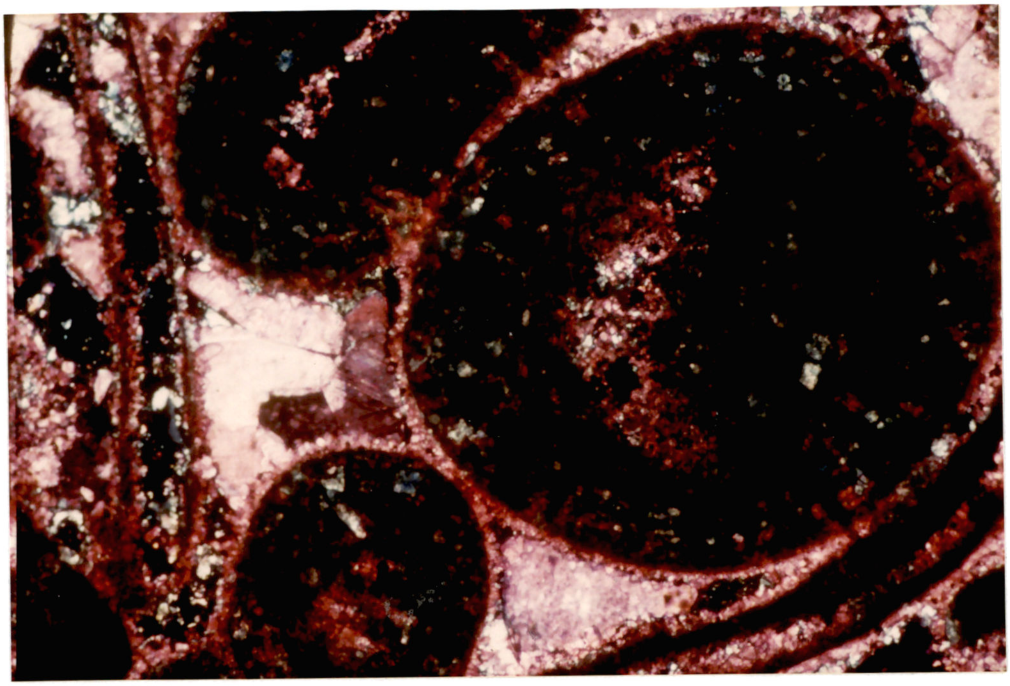

PLATE 10. Ooids partially replaced with dolomite are surrounded by isopachous calcite cement. Remaining porosity was later filled by medium to coarse equant cement. 1 cm = 0.13 mm.

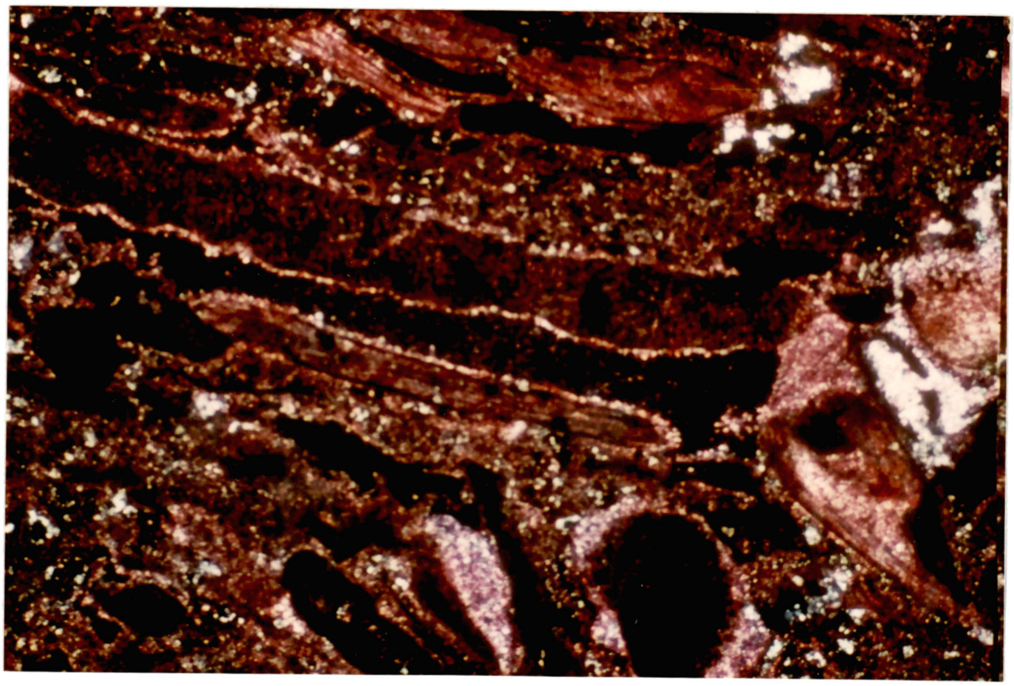

PLATE 11. Isopachous calcite cement separates echinoderm fragment and syntaxial cement. 1 cm = 0.13 mm.

are: bladed cystal morphology, isopachous crusts occasionally precede syntaxial cement and normal lack of isopachous crusts in spar-filled molds. Factors indicating the latter are: equant crystal morphology, normal lack of isopachous crusts preceding syntaxial cement and occasional isopachous crusts inside moldic pores. Cementation probably began in the marine or mixing zone environment and continued into the meteoric phreatic environment.

SYNTAXIAL CALCITE CEMENT

Syntaxial cement is sparry calcite formed in optical continuity with a host grain. Syntaxial cements are commonly precipitated into pore spaces and occur as overgrowths on echinoderm fragments. This cement is easily recognized by its simultaneous extinction with the host fragment under polarized light. Syntaxial cementation is an early diagenetic event which occurs in the meteoric phreatic environment (Land, 1970; Kerr, 1977).

In the Pettet interval, syntaxial cement formed both before and after the isopachous calcite cement (Plate 11). It also filled large amounts of pore space as compared to other sparry cements surrounding adjacent allochems. This suggests a relatively rapid rate of precipitation (Evamy and Shearman, 1965). Even so, the amount of syntaxial cement is minor in comparison to other sparry cements because of the small percentage of echinoderm fragments in cemented zones.

Syntaxial calcite that is optically identical to the cement described above formed in the micritic facies. The lack of original porosity in micritic samples suggests that this type of syntaxial spar probably results from aggrading neomorphism rather than cementation. It is not always possible to tell the neomorphic spar from the cement spar in cases where sparry cements and micrite matrix coexist.

MENISCUS AND GRAVITATIONAL CEMENTS

Meniscus and gravitational cements are discussed together because they are essentially the same type of cement with different morphologies. Meniscus cement (Dunham, 1971) is formed at grain contacts and is hourglass shaped in cross-section (Plate 12). Gravitational cement (Muller, 1971) forms preferentially on one side of individual grains and often has a crescent or lens shape (Plate 5). Gravitational cement is also known as microstalactitic druse (Purser, 1969) and dripstone cement (Flugel, 1982).

Both cement types owe their morphologies to formation in the vadose zone where pore space is largely air filled most of the time. Water at grain contacts has the shape of a biconcave lens due to the surface tension created at the air-water interface. The resulting cement has the characteristic shape of the meniscus. Water films tend to be thicker on the bottom of grains due to the effect of gravity. Here the resulting cement is formed in a stalactitic manner on the underside of individual grains.

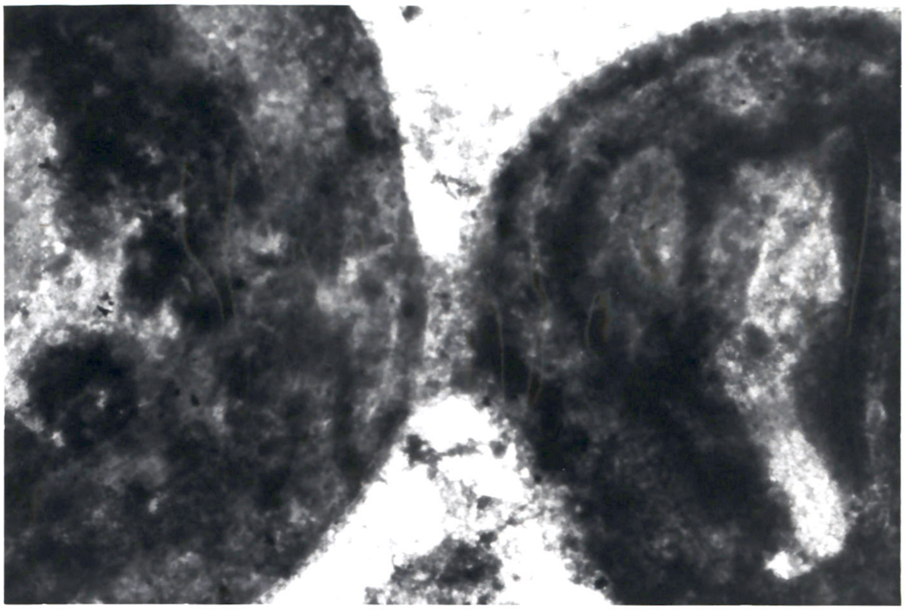

PLATE 12. Meniscus cement. 1 cm = 0.13 mm.

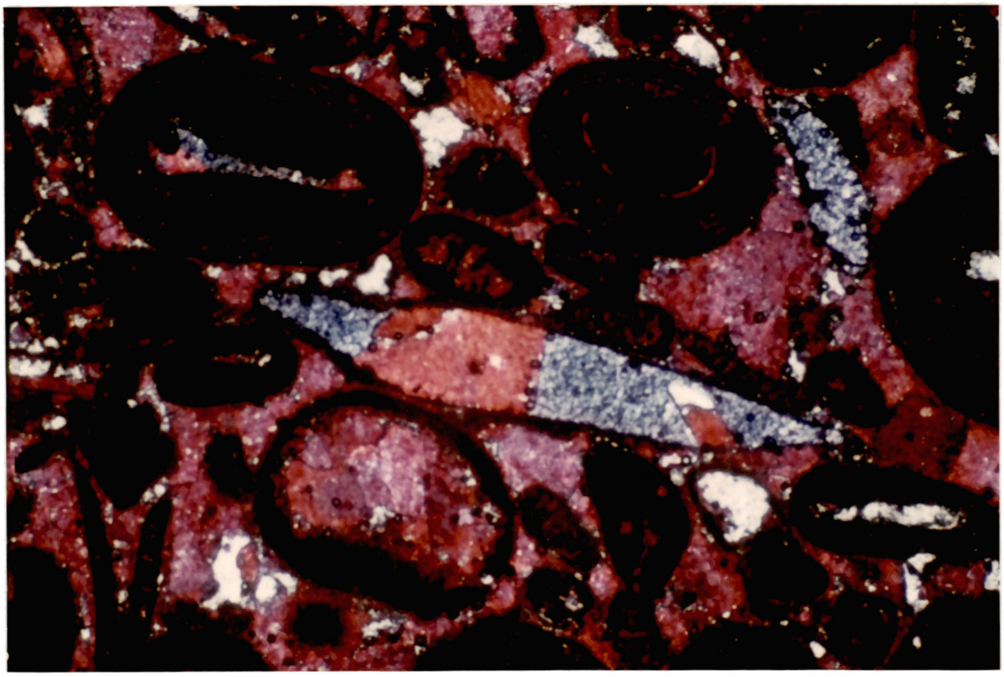

PLATE 13. Two large calcite crystals and several large dolomite crystals fill molds in an oobiosparite. 1 cm = 0.26 mm.

The vadose cements of the Pettet interval are composed of micrite and represent the first generation of cement. This indicates a relatively early emergence. These cements were only recognized in one thin zone in the Pettet, either because they are initially rare or because later diagenesis makes recognition impossible. The latter is often the case in ancient limestones (Dunham, 1971).

MEDIUM TO COARSE, EQUANT CALCITE CEMENT

Medium to coarsely crystalline, Fe-poor, equant calcite cement fills primary interparticle and secondary moldic porosity (Plates 5, 7, 10). Crystals range in size from 0.03 mm to 1.0 mm, or rarely up to 1.5 mm. Two types of sparry calcite occurs as pore filling: 1) numerous crystals which increase in size away from pore walls, 2) one or several large crystals which occlude the entire pore space (Plate 13).

Equant sparry calcite crystal morphologies result from precipitation of cement from waters with a Mg/Ca ratio of less than 1:1 (Folk, 1973; Folk, 1974; Folk and Land, 1975). Such waters occur is the meteoric phreatic zone and the deep subsurface. Loucks (1977) suggested that early meteoric phreatic cements may be more gradational with isopachous cements and smaller in crystal size than spar precipitated later in the deeper subsurface. A deep origin for coarse, equant calcite cement was also suggested by Badiozami and others (1977), who determined experimentally that increased temperatures caused larger crystals.

The equant sparry cement always formed after the isopachous cement in the Pettet. The contact between the smaller equant crystals and the isopachous crust is gradational, but the contact between the coarser cement and the isopachous crust is abrupt. The mosaic of smaller crystals grew competitively with the syntaxial cements. The large crystals sometimes are associated with baroque dolomite, which is recognized by curved crystal faces and strong undulose extinction (Folk and Assereto, 1974). This all points to initial precipitation of equant cement in the meteoric phreatic zone during early diagenesis and continuing or resuming in later, deeper burial.

MICROSPAR

By definition, microspar is equant to oblate sparry calcite with small crystal diameters, which formed by aggrading neomorphism of micrite (Plate 14). The exact size limits have not yet been standardized. The upper size limit of micrite has been placed at 30 um (Flugel, 1982). Folk (1959) placed microspar in the 4-10 um range and micrite in the 1-4 um range. A size range of 4-30 um corresponds to the micrite II of Bossellini (1964) and is used here for the microspar range. Neomorphic spar greater than 30 um is termed pseudospar.

Recent carbonate muds are normally composed of Mg-calcite and/or aragonite. During lithification of Mg-calcite mud, the Mg ions are expelled and attach to the surface of the micrite crystals (Folk, 1974). Thus, a Mg ion "cage" is formed. Mg has long been recognized as an inhibitor of calcite growth. Therefore, the removal of the Mg ion "cage" is the key to the formation of microspar (Longman, 1977).

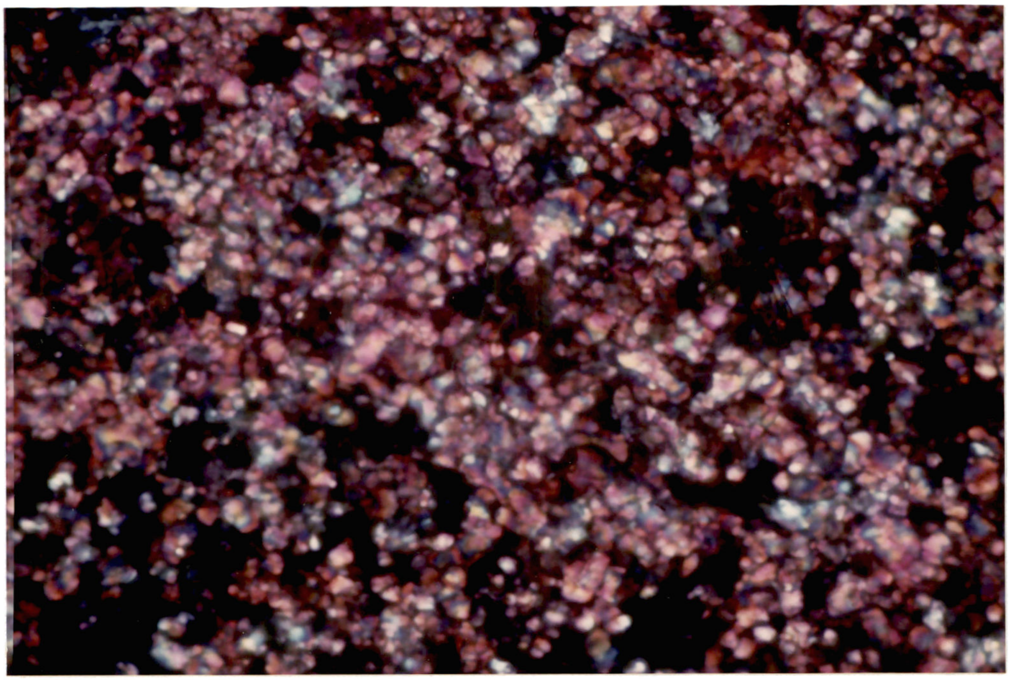

PLATE 14. Microspar. 1 cm = 0.03 mm.

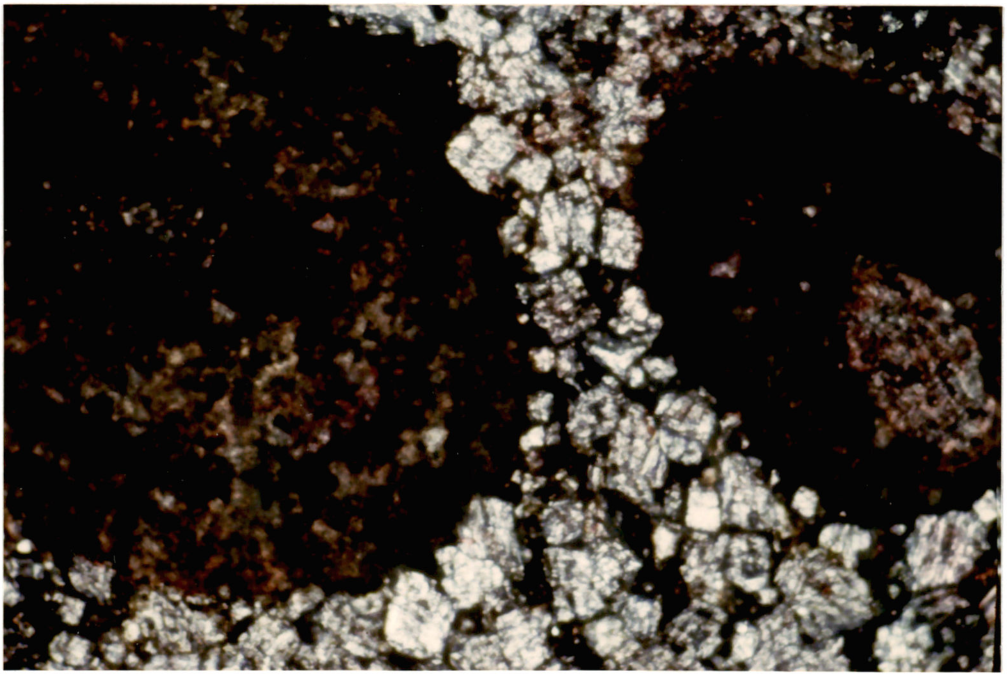

PLATE 15. Dolomite matrix impinging on ooids. 1 cm = 0.13 mm.

Three basic methods for removal of Mg ions are: 1) flushing with fresh water, 2) dolomitization and 3) absorption of ions by clay minerals (Folk, 1974). Several lines of evidence already discussed indicate fresh water diagenesis in the Pettet interval. It is likely that fresh water flushing played a major part in the creation of microspar. Small, patchy areas of fine rhombic dolomite associated with microspar suggest a minor role for dolomitization in microspar formation. There are several shale interbeds in the Pettet but there is no noticeable increase in the amount of microspar near them, even though shale beds may act as a Mg ion sump over a distance of a meter or so (Longman, 1977).

DOLOMITE

In scattered horizons throughout the Pettet, zones of dolomite replace micrite matrix (Plate 3). Distribution and degree of dolomitization is highly variable, even within single thin sections. The dolomite occurs as subhedral to euhedral rhombs that are commonly 0.01 to 0.2 mm in size. The SEM revealed rhombs as small as 0.5 um scattered in a micrite matrix. In highly dolomitized zones rhombs embay ooids and pelloids but skeletal fragments are unaffected (Plate 15). None of the dolomite examined luminesced and staining showed it to be ferroan. This probably indicates a reducing environment (Peterson, 1962; Evamy, 1969).

The following criteria were used by Fisher and Rodda (1969) in a study of the Edwards Formation (Lower Cretaceous) in Texas as evidence of dolomitization occurring before lithification: 1) fine grain size and intergrown fabric, 2) nondolomitization of solid shells, 3) interbedded dolomitized and nondolomitized rocks of identical texture, 4) thin nature of dolomitized units, and 5) occurrence chiefly in mudstone. They also apply to the micrite replacing dolomite of the Pettet interval, suggesting that its formation was porosity controlled and thus occurred prior to lithification.

The causes and methods of dolomitization are not well understood and there are several proposed models to explain dolomite forming environments. Of the possible choices, dolomitization in the schizohaline environment seems to best fit the fabric selective dolomite in the Pettet. Formation of dolomite in the schizohaline environment has been suggested by Folk and Seidlecka (1974), Folk and Land (1975) and Land and others (1975). The schizohaline environment is where fresh and salt water mix. The presence of fresh water features already discussed implies the existence of such a mixing zone during Pettet diagenesis. The prelithification timing of dolomitization does not conflict with the proposed diagenetic environment. The 1/1 Mg/Ca ratio favorable for dolomitization (Chilingar and others, 1979) is in the range of ratios found in mixing zones. SEM study revealed euhedral dolomite rhombs with hollow centers (Plate 16). Folk and Siedlecka (1974) described dolomite in which the nuclei of the rhombs grew in more saline water than the later formed parts of the crystal. In other words, the dolomite grew in the schizohaline environment. Later, when the environment changed to fresher water, the nuclei were less stable than the rest of the rhombs and dissolution occurred. A similar explanation is proposed for hollow dolomite rhombs, in the Pettet.

PLATE 16. Hollow dolomite rhombs. 1 cm = 6 um.

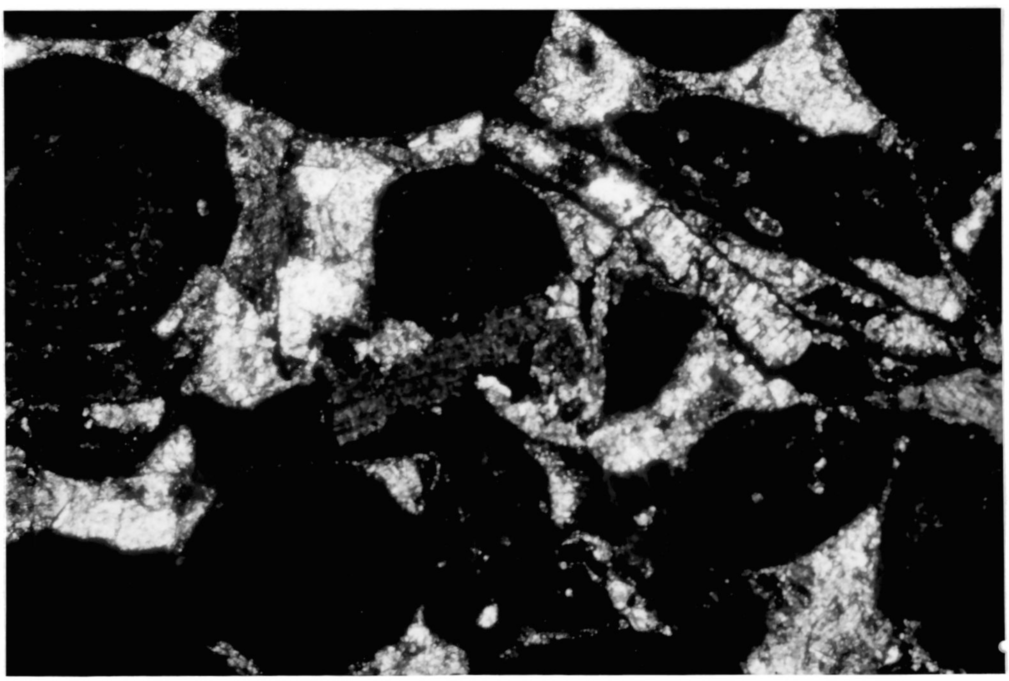

PLATE 17. Stylolite. 1 cm = 0.26 mm.

In some oosparite and oobiosparite microfacies pelloids and the cortices of ooids and superficial ooids contain dolomite rhombs (Plate 10). The rhombs usually do not occur in the matrix or in skeletal fragments. They are 0.01 to 0.1 mm in size and are normally ferroan. Control of this fabric selective dolomitization may be the porosity, crystal size and/or mineralogy of the affected particles. The particles are composed of micrite sized crystals, whereas the skeletal fragments are composed of larger crystalline constituents. Small crystals require less energy for replacement than larger ones (Bathurst, 1971). Microporosity of these particles is higher than that of the skeletal fragments. This would allow for greater contact with dolomitizing fluids. The composition of affected particles may have been Mg-calcite. Exsolution of Mg from Mg-calcite can cause dolomite formation (Land, 1967). Because echinoderms, which are initially composed of Mg-calcite, do not contain dolomite rhombs, original mineralogy cannot be the sole controlling factor of this type of dolomitization. The fabric selective nature, the size and composition of rhombs and the presence of some hollow rhombs suggest that this dolomite also formed in a schizohaline environment.

Medium to coarsely crystalline baroque dolomite occurs in the lower portions of the cores. This dolomite, which is ferroan and anhedral to subhedral in habit, often fills moldic pores with a single crystal and sometimes appears to have grown competitively with medium to coarse calcite cements (Plate 10). Coarse crystal size and association with late forming calcite cement suggests a late diagenetic origin.

Dolomite is rarely found in association with stylolites. It occurs in individual ferroan rhombs approximately 0.03 to 0.1 mm in size. Their concentration among stylolitic seams indicates a late diagenetic formation.

PRESSURE SOLUTION

When pressure resulting from a sedimentary pile or tectonic movement surpasses the hydrostatic pore pressure of interstitial fluids, dissolution may occur. The type of pressure solution feature formed depends, in part, on lithology, porosity, permeability and amount of cement. Using the terminology of Wanless (1979), two basic pressure solution features are recognized in the Pettet. They are sutured solution surfaces and nonsutured solution surfaces.

Sutured solution surfaces are common throughout the Pettet. They include grain to grain sutures and stylolites. Grain to grain sutures are nonconnected interpenetrations between pairs of grains. Stylolites are irregular, commonly discontinuous surfaces with mutual penetration on both sides (Plate 17). Insoluble residues are concentrated along stylolites, creating permeability barriers for fluids attempting to cross stylolite zones. These features form within or at the boundaries of limestone units having structural resistance to stress and little or no platy insoluble material.

Nonsutured solution surfaces are relatively uncommon in the Pettet. They are anastomosing swarms of fine clay seams (Plate 18) found in

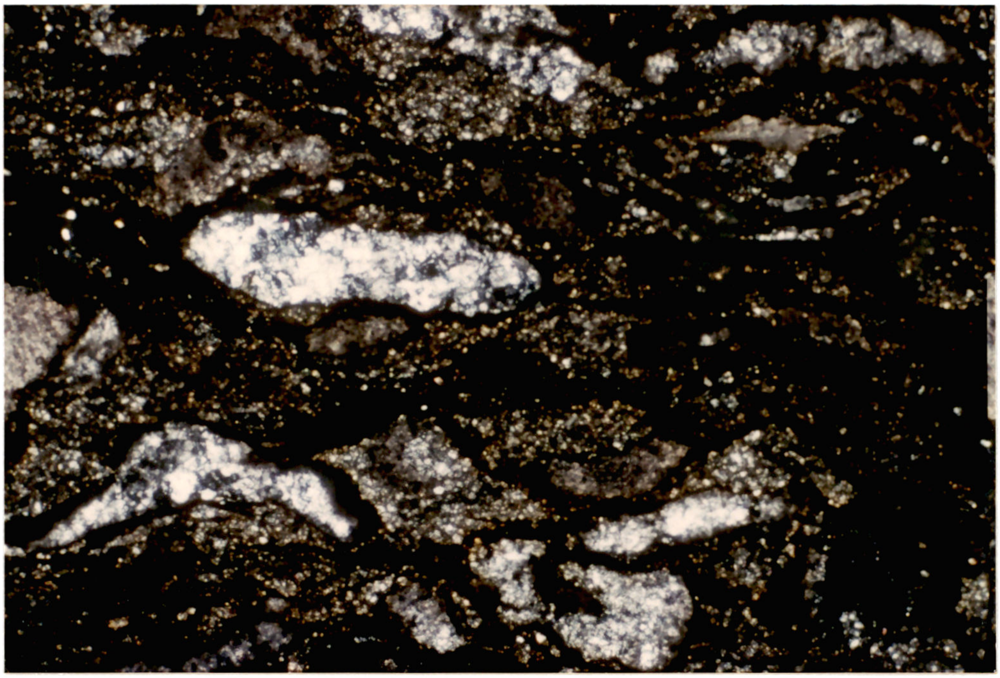

PLATE 18. Clay seams in a biomicrite. 1 cm = 0.26 mm.

limestone intervals which contain fine platy insoluble particles. As Wanless (1979) points out, these clay seams have also been called horsetails, wispy laminae, wavy laminae, pseudostylolites and microstylolites. He differentiates between microstylolites, thin undulating surfaces with a relief of 20-40 um, and clay seams, which are thicker seams of clay and platy silt. Both microstylolites and clay seams are found in the terrigenous-rich zones of the Pettet.

The forces that created pressure solution features in the Pettet were probably caused by the weight of overlying sediments, rather than by tectonic events, because of the gentle nature of the folding in the study area and the basic lack of regional post-Coahuilian compressive forces. Depth of burial sufficient to produce pressures capable of causing solution varies. Dunnington (1967) reported that in most cases overburdens of 1800-2700 feet have been operative. However, clay seams have been known to form at depths of 270 feet or less (Schlanger, 1964). The timing of pressure solution features relative to some other diagenetic events can be deduced. Grain to grain sutures form before the emplacement of a second generation of cement and thus precede precipitation of medium to coarse equant spar (Bathurst, 1971). Stylolites and nonsutured seams formed after the secondary cements (Bathurst, 1971) and were, therefore, the result of a late diagenetic event.

SUMMARY

Diagenesis of the Pettet sediments began upon deposition and continued until relatively deep burial. The majority of the diagenetic events occurred in a meteoric-phreatic environment. Argonite leached in this environment was precipiated as calcite cement as pore waters became supersaturated with $CaCO_3$. Therefore, porosity was being increased and decreased in the same diagenetic environment. The diagenetic environments and products are summarized in Table 3.

DIAGENETIC ENVIRONMENTS AND PRODUCTS

	SUBMARINE	VADOSE	MIXING ZONE	METEORIC-PHREATIC	DEEP SUBSURFACE
MICRITE ENVELOPES	■				
MG-CALCITE STABILIZATION		■		■	
ARAGONITE DISSOLUTION		■		■	
ISOPACHOUS CALCITE CEMENT	■		■	■	
SYNTAXIAL CALCITE CEMENT				■	
MENISCUS CEMENT		■			
GRAVITATIONAL CEMENT		■			
MEDIUM TO COARSE EQUANT CALCITE CEMENT				■	
MICROSPAR				■	
DOLOMITE			■		■
PRESSURE SOLUTION					■

Table 2. Diagenetic environments and products.

DEPOSITIONAL ENVIRONMENT

REGIONAL

During the Early Cretaceous, a broad, shallow, gently sloping shelf rimmed the proto-Gulf of Mexico (Bebout and others, 1981). In the northern Gulf Coast states the sea transgressed to the north and north-east. The transgression was mainly due to an eustatic rise in sea level, though inland uplift and shelf subsidence may have played a part (McFarlan, 1977). Terrigenous clastics derived from the Ouachita Mountains were deposited progressively farther to the north as marine waters encroached and deposited limestones. Major depositional facies transgressed approximately 40 to 60 miles. By Sligo time much of Arkansas was an area of brackish water (Philpott, 1952) and a rudist reef complex had begun to form on the shelf edge in central Louisiana. The reef complex grew to a thickness of at least 450 feet during Sligo time (Herrmann, 1971). The main reef trends roughly east-west and was formed on a hingeline that separated the relatively slowly subsiding area to the north from the more rapidly subsiding area to the south.

LOCAL

From north to south, the Sligo shelf was divided into an inner shelf, ooid sand flats, an outer shelf and a shelf edge reef complex

(Figure 10). This depositional model resembles one proposed by Loucks (1977) for the Pearsall Formation (Lower Cretaceous) of south Texas. The model does not depict a specific time during Pettet deposition nor a precise paleogeographic area, but rather the relationship between environment and microfacies. The ooid sand bodies were areas of shallow, agitated water where carbonate mud was winnowed, leaving primary interparticle porosity to be filled later. The inner and outer shelf were areas of lower energy conditions where micritic sediments accumulated. This implies at least slightly deeper waters in the outer shelf than over the ooid sand bodies. Where shoals were well developed they provided a protected environment in their lee. Thus, the inner shelf depth is difficult to infer because muddy sediments could have accumulated in very shallow water.

There are many lines of evidence indicating that the Pettet interval was deposited in shallow marine water, the most convincing of which is the presence of ooid accumulations. Modern marine ooids form in shallow, well agitated environments where water depths are generally less than six feet. Conditions for growth include warm water and normal to increased salinity (Flugel, 1982). Ooid accumulations occur in a number of geometries and often form at a break in slope. The presence of micrite envelopes and intraclasts also indicates relatively shallow water deposition. Though micrite envelopes can form at considerable depths (Friedman and others, 1971), the commonly recognized formational processes are limited to the photic zone, specifically in shallow, current swept areas (Perkins and Halsey, 1971). The Pettet samples support this concept as the skeletal fragments with micrite envelopes

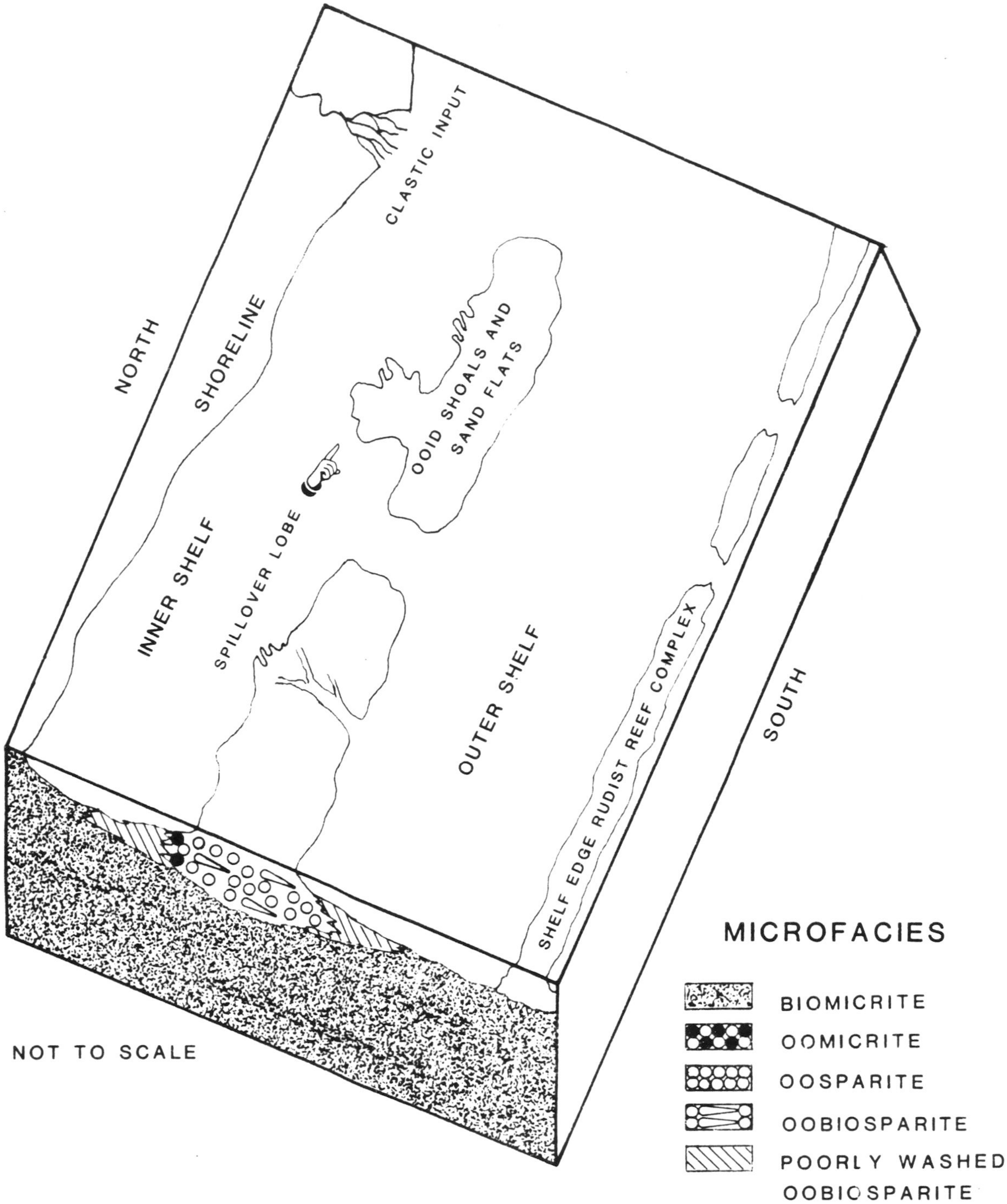

Figure 10. Depositional model for the Pettet interval.

are much more common in the sparry facies than in the micritic facies. Intraclasts formed when partially indurated sediments were ripped up and redeposited. This suggests a relatively shallow seafloor which was occasionally subjected to high current or wave energies.

The various microfacies described earlier each correspond to specific areas of deposition. These microfacies were compared to the standard microfacies of Wilson (1975) for determination of their depositional environments. Wilson's description of the SMF (standard microfacies) similar to those found in the study area is given in Table 3.

The oosparite microfacies is comparable to SMF 15, which is the product of a shoal environment with agitated water. It was deposited in the shallowest water of the ooid shoals. This is where large, well developed, well sorted ooids accumulate in modern environments (Bathurst, 1971).

The oobiosparite microfacies formed in areas of slightly lower current and wave energies surrounding the shallowest zones. This microfacies corresponds with SMF 11 and SMF 12, which also represent the shoal environment. Here, muds were kept in suspension, as in the oosparite microfacies, but the sorting is not as good and the grains are often not as thickly coated. Absence of oolitic coatings does not necessarily imply a lower environmental energy, but may be due to a lack of other favorable conditions (Boyer, 1972).

The poorly washed oobiosparite microfacies was deposited in front of and behind ooid shoals. It represents a transition zone between high and low energy environments and is somewhat similar to SMF 10. Wilson (1975) places this microfacies in the shelf facies-open circulation environment.

Shelf Facies-Open Circulation

SMF-9 Bioclastic wackestone (Dunham, 1962) or bioclastic micrite (Flugel, 1972). Almost invariably the sediment contains fragments of diverse organisms jumbled and homogenized through burrowing. It is formed in shallow neritic water of open circulation at or just below wave base. Bioclasts may be micritized.

SMF-10 Coated and worn bioclasts in micrite; packstone-wackestone (Flugel, 1972). This sediment shows textural inversion and formed in swales in proximity to shoals. Dominant particles are of high energy environment and have moved down local slopes to be deposited in quiet water.

Shoal Environment in Agitated Waters

SMF-11 Coated bioclasts in sparite, grainstones (Flugel, 1972). Bioclasts may be micritized. The sediment formed in areas of constant wave action, at or above wave base so that lime mud is removed.

SMF-12 Coquina, bioclastic grainstone or rudstone, shell hash (Flugel, 1972). Sediment formed in an environment of constant wave or current action with mud removed by winnowing. Concentrations of special types of organic debris may be significant; e.g., dasycladacean grainstones accumulate in very shallow water. Encrinites are a special microfacies of SMF-12, requiring winnowing but less strong water movement for their formation. This type of concentration is a common slope and shelf edge sediment.

SMF-15 Oolite (Flugel, 1972), ooid grainstone. Well-sorted well-formed multiple-coated ooids, ranging commonly from 0.5 to 1.5 mm in diameter; commonly the fabric is overpacked. The sediment is always crossbedded. It originates through water movement on oolite shoals, beaches, and tidal bars. The best-formed ooids are typically produced on tidal bars.

TABLE 3. Standard microfacies (SMF) of Wilson (1975), which are similar to those found in the Pettet interval.

The oomicrite microfacies is an extreme version of SMF 10. It is an example of textural inversion with high energy ooids in a low energy micrite matrix. This type of texture could form by: 1) ooids moving down slope from ooid shoals to deeper water, 2) spillover lobes of ooid sands encroaching on protected muddy sediments in the lee of the shoal, 3) formation of a protective barrier seaward of shoals allowing fine sediments to filter into ooid sands, or 4) movement of ooids by storm activity. Deposition of oomicrites in relatively close proximity to ooid shoals is indicated regardless of the method of formation.

The biomicrite microfacies represents the deepest and calmest environment of deposition and is comparable to SMF 9, a shelf facies of open circulation. Here carbonate mud was deposited along with skeletal particles which were broken and abraded by scavenging and boring organisms. Classification of each biomicrite sample as an inner or outer shelf deposit is tenuous. If the inner shelf received good tidal exchange and was thus not a restricted environment, its sediments could have been virtually identical to those of the outer shelf. Characteristics of tidal flat environments such as algal stromatalites, birdseye structures, mud cracks, laminated mudstones with associated dolomite and evaporites, etc. (Lucia, 1973; Burgess, 1979) were not found in the Pettet interval. The Pettet ooid shoals formed on a shallow shelf at least 100 miles from the shelf edge. A modern analogy of this setting is the western edge of Florida Bay. Here the platform edge is approximately 100 miles from the ooid shoals. The shoals form an incipient, discontinuous sand belt on the edge of a muddy environment (Ball, 1967). The belt parallels a slope break which has a relief of less than 10 feet.

On at least one occasion, the Pettet sediments built up above sea level. This is indicated by the presence of meniscus and gravitational cements which form in the vadose zone. The extent of the build-up is not discernible because vadose cements have been obscured by later cementation. The existence of carbonate sediments above sea level may have enabled the creation of a lens of meteoric water. Theoretically, a body of fresh water one foot above sea level can project 40 feet into the subsurface (Tolman, 1937). This would create the meteoric phreatic and mixing zones necessary for several of the previously discussed diagenetic events. Alternately, ground waters could have extended out from the mainland to Pettet sediments buried at shallow depths. This type of situation exists in Florida where a shallow subsurface extension of the groundwater system occurs up to 60 miles east of the shoreline (Manheim, 1967).

Overall, the Pettet interval is a shoaling upwards sequence. The biomicrites, representing deeper water, are much more common lower in the sections, and the ooid shoal complexes are best developed near the top. The faunal diversity decreases from the bottom to the top of the cores as faunal dominance increases. This suggests a more open marine environment early in the Pettet deposition, later becoming shallower and more difficult for a variety of organisms to adapt. The stenohaline echinoderms are often used as a paleosalinity indicator (Flugel, 1982), and they are much more abundant in the lower sections of the core than in the upper, again suggesting a more open marine environment early during Pettet deposition.

The large-scale shoaling sequence contains several minor shoaling upwards oolite cycles (Figure 11). Biomicrite microfacies form the basal sediments of these cycles. Poorly washed oobiosparites and oomicrites were deposited next, followed by oosparite-oobiosparite that caps the sequence. The cycles are mainly hemicyclic. Wilson (1975) states that this pattern would occur if:

> ". . . a relatively rapid rise of sea level occurred repeatedly on a steadily subsiding shelf and was followed persistently by sedimentary progradation and a fill-in of the inundated area over some period of time."

He also notes that the same results could come from episodic and abrupt shelf subsidence. However, as previously discussed, the Early Cretaceous transgression in the Gulf coast is attributed mainly to an eustatic rise in sea level.

By using the SP curves, the Pettet interval can be divided into three zones (Figure 12). The top two, zones A and B, correspond to the two uppermost shoaling upwards oolite cycles. Zone A is well defined in all of the well logs in the study area. It maintains approximately the same depth below the top of the Sligo Formation and the same thickness throughout the study area, which suggests that its geometry is that of a platform interior sand blanket (Ball, 1967). Zone B is also present in all of the available well logs, though it is more variable than zone A. It occurs immediately below zone A and it also has the characteristics of a sand blanket. The interval from zone B to the base of the Pettet is classified as zone C. In many cores zone C is divisible into separate subzones, but due to the considerable variation among cores

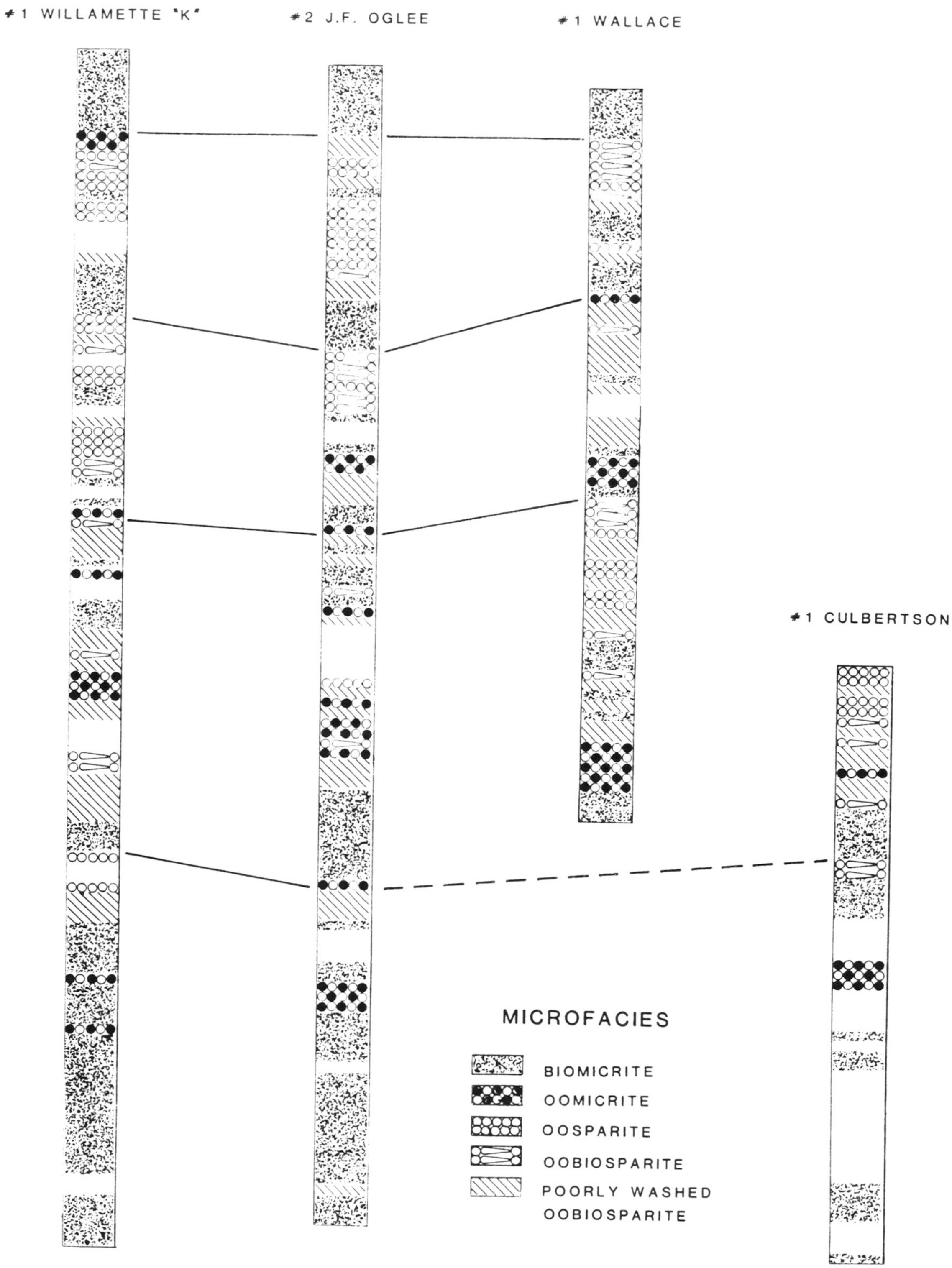

Figure 11. Upwards shoaling oolite cycles within the Pettet interval.

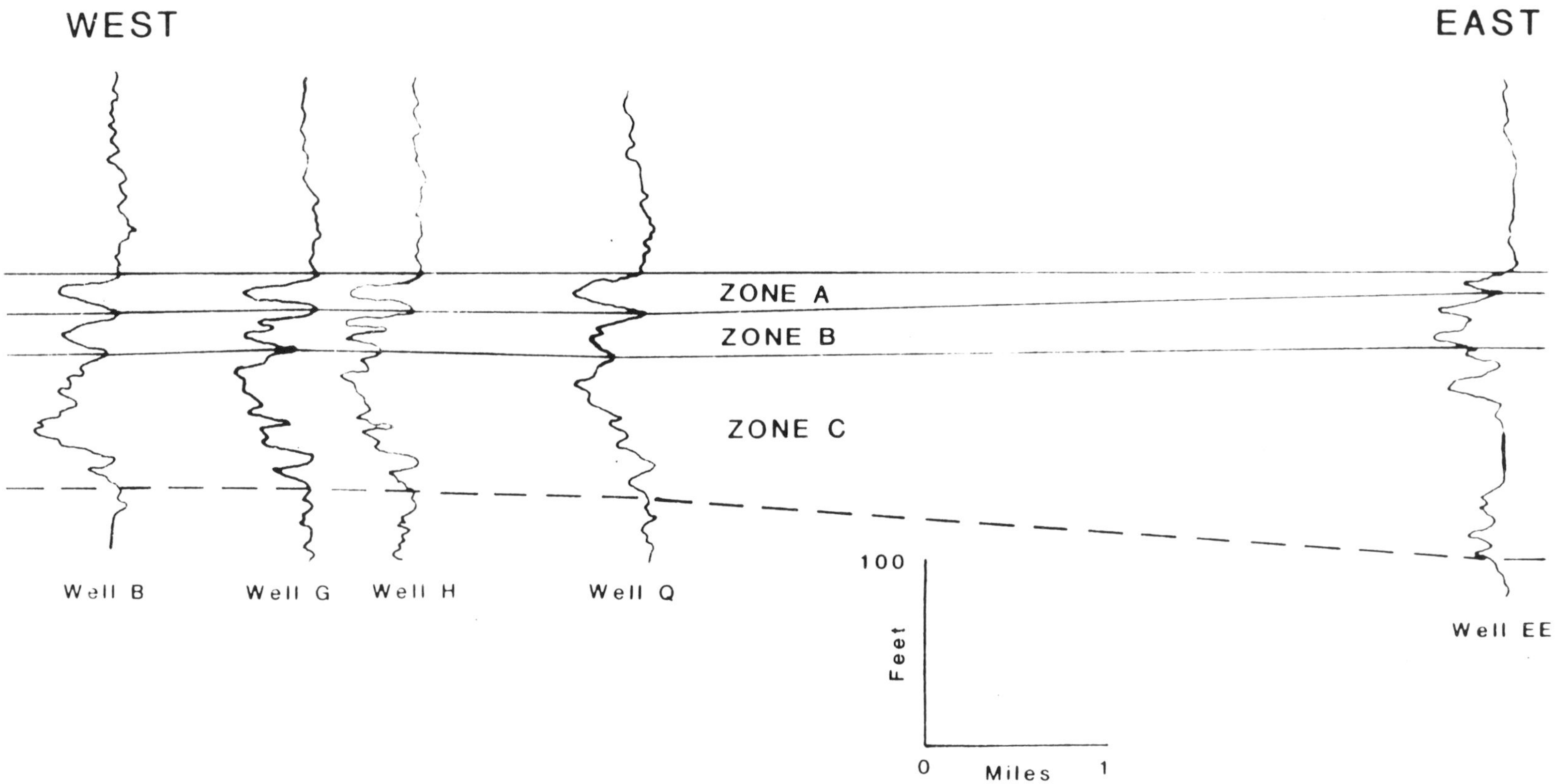

Figure 12. East-west cross section through field area using SP curves. Zones A & B reflect the shoaling sequences in Figure 11.

this was not attempted here. Its ooid accumulations are thin and not easily correlated beween the four wells. As compared to zones A and B, zone C represents a deeper, calmer marine environment where small, discontinuous ooid shoals formed.

HYDROCARBON PRODUCTION

The four wells from which samples were available all produce oil. In late 1982 they were producing approximately the following volumes per month: #1 Willamette "K"-360 B.O.; #2 J. F. Oglee-655 B.O.; #1 Wallace-975 B.O. and #1 Culbertson-52 B.O. The low value for the #1 Culbertson may be due to poor well completion techniques rather than low permeability (Moody, personal communication). Wells in the study area typically do not produce high amounts of oil per day but they tend to produce for many years.

Production in the North Carterville Field and adjacent areas is from the Pettet B and/or C zones. To the north, in the Kerlin Field of southern Arkansas, production is from the A zone (Boland, 1980). This means that in the study area, production does not come from the best developed oolitic sand body. Production in oolites is usually from zones of high interparticle porosity or oomoldic porosity. In the Pettet oomoldic porosity was not developed and sparry calcite cements greatly reduced original interparticle porosity.

By Core Laboratories standards, a zone with a permeability of 0.10 millidarcies is considered a potential producing area. Values of 0.10 md or more are represented in each of the five microfacies of the Pettet interval (Figure 13). Statistically, there is no good correlation between the abundance of the various allochems and either porosity or permeability (Table 4). The porosity in the permeable zones is dominantly secondary moldic. The development and preservation of moldic porosity in the Pettet was dependent upon concentration of aragonitic

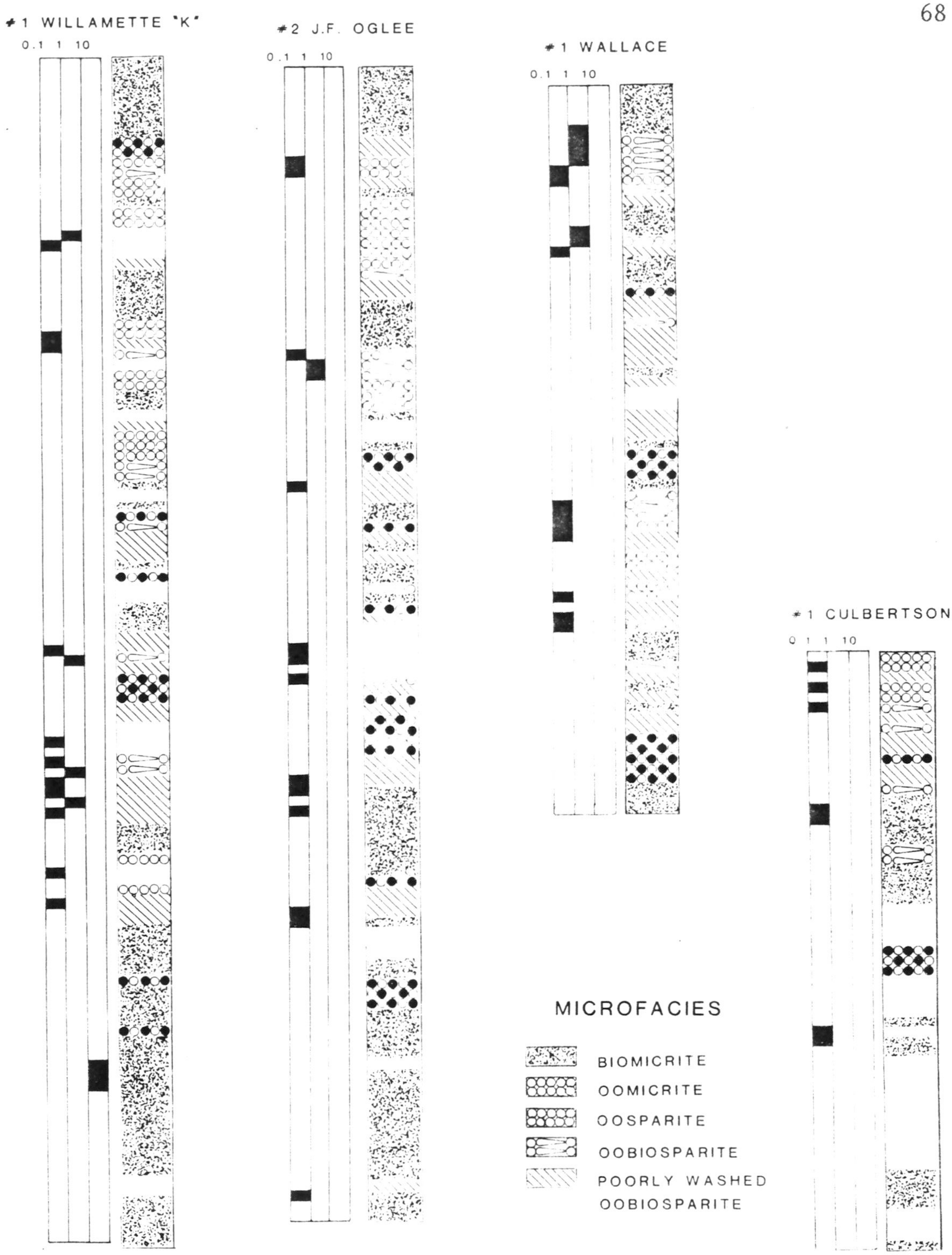

Figure 13. Comparison of permeability and microfacies. Permeability values are in millidarcies. Darkened areas represent permeabilities that fall in a particular range.

TABLE 4

	Porosity	Permeability
Ooids	0.158	0.104
Superficial ooids	0.126	0.056
Pelloids	0.181	0.072
Intraclasts	0.114	0.019
Molds	0.178	0.004
Bivalves	0.212	0.133
Echinoids	0.081	0.159
Other	0.013	0.052

Table 4. Pearson correlation coefficients for porosity and permeability with allochem percentages. A value of 1 is a perfect positive correlation, a value of 0 is no correlation and a value of 1 is a perfect negative correlation. Values represented here are not statistically significant at a 95% confidence level.

bivalve shell fragments, leaching by fresh water and the failure of equant sparry calcite cements to develop.

The Pettet typically produces from long, narrow, discontinuous permeable zones. These permeable zones produce both on and off structure and have been difficult for the geologist to explain (Nichols, 1958). The Pettet in the study area also produces from a linear trend (Figure 8). In this case the producing trend coincides with the crest of an anticline. Whether or not this structure controls hydrocarbon accumulation, the past successes indicate that future drilling on or near the anticlinal crest would have the best chance of success.

CONCLUSIONS

1. There are five recognizable microfacies in the Pettet interval. They are: 1) oosparite 2) oobiosparite, 3) poorly washed oobiosparite, 4) oomicrite, and 5) biomicrite.
2. These microfacies represent deposition in nearshore, shallow water marine environments on a broad carbonate shelf. They were deposited as shoals and along adjacent inner lagoons and more open outer shelf environments.
3. The Pettet represents a shoaling sequence that can be divided into several shoaling upwards oolite cycles.
4. Fresh water and mixing zone diagenetic environments were created.
5. Porosity was reduced by several stages of cementation and secondary moldic porosity was created by the leaching of aragonitic bivalve fragments.
6. There is no good statistical correlation between the percentages of various allochems and porosity or permeability.
7. The Pettet interval is divisible into three zones. Production is from zones B and/or C in the study area.
8. Permeability is not microfacies controlled.
9. A narrow zone trending east-west along the crest of an anticlinal feature has the best potential for successful hydrocarbon exploration.

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APPENDIX A

CODE	COMPANY	WELL NAME
A	White & Hinton	#1 La. Real Est. & Dev. Co.
B	D. E. Vasser	#1 J. M. Morgan
C	Hunt Oil Co.	#2 Nebo Oil Company
D	Hunt Oil Co.	#3 Nebo Oil Company
E	A. J. Hodges Ind. Inc. et al (Choctow Oil Co.)	#1 Bolinger
F	Hunt Oil Co.	#1 Nebo Oil Company
G	Hunt Oil Co.	#1 Brownlee
H	Hunt Oil Co.	#1 J. F. Oglee
I	Hunt Oil Co. et al	#2 H. H. Boucher et al Unit
J	Hunt Oil Co. et al	Boucher-Oglee et al Unit
K	Stanolind Oil & Gas Co.	#1 Nebo Co.
L	Crystal Oil & Land Co.	#1 Williamette K
M	Shell Oil Co. Inc.	#1 S. H. Bolinger & Co.
N	A. J. Hodges Ind., Inc. et al	#6 Bolinger
O	Atlantic Refg. Co.	#1 R. S. Warnock, Jr.
P	McAllister Fuel Co.	#A-1 Warnock & LeCroy
Q	Crystal Oil & Land Co.	#2 J. F. Oglee
R	Crystal Oil & Land Co.	#1 Wallace
S	Hunt Oil Co.	#P-1 Nebo Unit
T	Skylar & Phillips Oil Co.	#1 State Line Unit
U	Skylar & Phillips Oil Co.	#1 Horn
V	Pend Oreille Oil & Gas Co.	#1 Maude Green Heirs
W	Pend Oreille Oil & Gas Co.	#1 Culbertson
X	Harvey Broyles (Occidental Petroleum Co.)	#1 J. H. Gibson
Y	Hunt Oil Co.	#A-1 Pardee Co.
Z	Lamar Hunt	#1 Pittman Unit
AA	Hunt Oil Co.	#1 Frank Bilbray
BB	Magnolia Petroleum Co.	#C-1 Pardee
CC	Pan American Petroleum Corp.	#1 Frazier Unit
DD	Nebo Oil Co., Inc.	#89 Nebo Fee
EE	Ross (Carter Oil Co.)	#1 W. E. Timmons et al

APPENDIX B

Percentages of various allochems counted in thin section.

Samp*	Allo	Ooid	S-od	Pell	Intr	Mold	Pely	Ech	Oth	Unk
16022	48.5	51.2	5.6	16.0	11.7	9.3	9.6	0.0	0.6	0.0
16023	55.2	48.6	8.2	19.7	3.8	6.6	3.8	0.5	4.9	3.8
16024	66.2	51.7	7.1	14.2	4.3	8.1	5.2	0.9	3.8	4.7
16025	60.4	84.9	2.5	2.0	1.0	6.5	1.5	0.0	0.0	1.5
16026	64.2	68.7	8.3	13.8	0.0	6.0	0.9	0.0	0.5	1.8
16028	65.5	52.1	11.2	20.5	0.9	7.4	0.9	0.0	3.3	3.7
16029	63.8	81.9	3.3	12.9	0.0	1.4	0.0	0.5	0.0	0.0
16033	53.6	0.0	9.0	9.6	1.8	58.4	17.5	0.0	3.6	0.0
16039	69.1	46.0	7.1	19.2	6.7	14.3	3.1	2.7	0.0	0.9
16041	67.7	7.6	4.4	20.9	8.9	22.7	13.3	0.9	11.1	10.2
16040	57.6	47.4	6.3	12.1	3.7	14.2	2.6	4.2	5.8	3.7
16042	60.0	22.1	11.3	6.7	11.8	23.6	8.2	1.5	10.3	4.6
16044	68.6	75.8	5.6	11.2	1.4	2.8	0.5	0.5	1.9	0.5
16049	56.4	47.8	5.5	14.8	1.1	15.9	4.4	0.0	3.8	6.6
16052	61.6	55.8	5.5	10.6	5.5	14.6	5.5	1.5	0.5	0.5
16053	63.2	11.5	5.0	4.5	2.0	48.0	14.0	0.5	7.0	7.6
16055	36.9	11.5	2.5	4.1	8.2	18.9	30.3	6.6	7.4	10.7
16058	64.4	44.7	9.5	19.1	2.5	15.1	2.0	1.0	3.0	3.0
16060	60.7	25.4	9.3	19.7	6.2	21.2	9.3	0.0	5.2	3.6
16062	65.2	13.3	6.4	13.3	11.8	22.7	8.9	7.4	6.9	9.4
16064	64.9	40.0	4.5	6.0	6.5	22.5	7.5	2.5	5.0	5.5
16067	55.3	20.3	1.2	1.7	0.6	50.0	19.8	1.7	1.7	2.9
16068	65.3	67.7	2.5	8.0	1.0	12.9	4.5	0.5	1.0	2.0
16071	62.1	7.0	6.1	8.0	1.9	22.5	15.0	16.0	12.7	10.8
16072	70.1	18.5	13.4	21.4	3.8	13.4	7.6	2.9	8.4	10.5
16075	63.8	42.7	7.3	5.5	2.4	14.6	4.9	1.0	5.3	6.3
16078	60.2	32.1	7.9	7.4	6.3	25.3	10.5	4.7	1.6	4.2
16082	62.3	16.0	4.5	7.3	6.7	28.7	23.0	2.2	3.9	6.7
16083	59.5	7.8	13.2	6.8	4.4	37.6	10.2	6.3	9.3	4.4
16084	61.7	7.3	5.4	2.9	16.1	27.8	17.6	10.2	7.8	4.9
16085	49.7	19.0	13.5	9.2	1.8	22.7	12.3	8.6	6.7	6.1
16087	61.7	22.5	3.9	4.9	11.3	33.3	16.7	2.5	2.5	2.5
16090	45.1	4.2	8.4	2.1	7.0	49.7	23.1	4.2	0.0	1.4
16096	59.5	21.2	2.0	14.6	9.1	5.1	22.7	9.6	7.6	8.1
16099	37.0	0.0	0.0	0.9	0.9	17.1	70.9	3.4	4.3	2.6
16101	43.2	2.2	3.7	15.6	13.3	13.3	33.3	6.7	5.9	5.9
16102	49.6	5.2	2.0	20.9	5.9	22.9	26.1	3.9	2.0	11.1
16104	46.5	29.7	2.7	9.5	6.1	14.9	23.0	7.4	0.7	6.1
16107	49.0	11.0	7.1	14.2	21.9	12.3	15.5	2.6	5.8	9.7
16109	62.0	27.4	10.8	7.5	12.9	14.0	17.7	2.7	2.2	4.8
16112	45.8	0.0	0.0	1.3	5.7	22.6	43.4	14.5	6.3	6.3
16115	40.3	0.0	0.0	4.0	0.0	75.2	16.8	1.6	2.4	0.0
16118	14.1	0.0	5.7	6.6	2.8	13.2	60.4	8.5	2.8	0.0
16121	48.9	0.0	0.7	0.0	0.0	40.4	20.5	0.0	34.4	4.0
16123	14.6	0.0	6.7	24.4	0.0	26.7	26.7	0.0	6.7	8.9

Appendix B cont'd.

Samp*	Allo	Ooid	S-od	Pell	Intr	Mold	Pely	Ech	Oth	Unk
16126	59.0	4.4	0.0	9.3	4.9	47.3	19.2	9.3	1.4	4.4
26012	61.4	54.2	4.7	16.1	6.3	5.2	2.1	2.6	2.6	6.3
26013	52.3	58.4	5.8	16.2	4.6	8.1	0.6	0.6	0.0	5.8
26014	55.0	61.8	4.8	14.0	1.6	11.3	2.7	1.1	0.0	2.7
26016	59.5	74.0	3.6	10.9	2.6	7.3	0.0	0.5	0.5	0.5
26021	48.3	37.7	14.2	22.2	11.1	2.5	6.2	0.0	2.5	3.7
26023	32.6	28.0	3.7	5.6	0.0	14.0	17.8	18.7	2.8	9.3
26024	54.7	45.5	14.8	14.8	6.8	11.4	1.1	3.4	0.6	1.7
26018	56.3	69.4	4.8	16.7	4.3	2.7	1.1	0.0	0.0	1.1
26025	57.4	0.0	1.1	5.4	8.1	41.6	9.7	2.7	20.0	11.4
26027	51.1	3.8	5.1	5.1	7.1	52.6	9.6	3.2	8.3	5.1
26033	57.5	28.0	11.0	28.5	3.5	15.5	0.5	1.0	10.0	2.0
26034	57.5	36.7	9.7	18.8	11.1	7.7	3.4	0.0	9.7	2.9
26036	63.9	55.6	2.3	10.7	4.2	18.2	0.5	1.4	3.7	3.3
26038	65.6	39.8	2.4	19.0	17.5	9.5	7.6	0.5	2.8	0.9
26039	33.7	11.4	0.0	4.8	6.7	23.8	46.7	1.9	1.9	2.9
26042	56.7	21.3	2.7	13.1	16.4	31.7	6.6	4.9	2.7	0.5
26043	52.1	46.1	4.2	15.0	9.0	19.2	4.2	0.0	0.6	1.8
26044	33.1	28.8	1.9	20.2	5.8	20.2	23.1	0.0	0.0	0.0
26045	60.7	35.4	6.8	13.0	9.4	24.0	4.7	0.5	3.6	2.6
26046	57.5	5.3	6.4	6.4	2.7	52.7	10.1	6.4	5.3	4.8
26047	57.3	1.6	1.6	15.0	3.2	52.4	9.1	1.1	11.8	4.3
26048	53.0	2.9	1.2	19.1	3.5	43.4	10.4	1.7	12.7	5.2
26049	45.6	11.8	2.1	6.3	4.5	31.2	27.8	5.6	9.0	2.1
26050	57.7	73.2	7.8	11.2	0.0	5.6	1.1	0.0	0.0	1.1
26053	61.4	4.7	4.7	13.5	7.8	38.0	20.8	1.6	6.8	2.1
26054	33.1	2.8	2.8	2.8	2.8	29.0	52.3	5.6	0.0	1.9
26055	41.0	4.5	6.0	6.8	15.8	30.1	7.5	8.3	15.8	5.3
26056	63.4	27.8	16.7	16.7	5.6	25.3	0.5	3.0	2.5	2.0
26057	55.5	9.1	9.1	9.1	4.6	24.6	20.0	9.7	3.4	10.3
26065	69.9	48.7	8.9	10.2	5.5	13.1	2.1	5.9	4.7	0.8
26066	45.9	14.2	7.4	5.4	1.4	45.3	6.1	13.5	5.4	1.4
26067	54.0	39.0	3.4	4.5	2.8	32.2	5.1	2.3	5.1	5.6
26070	60.1	66.1	7.0	9.7	1.1	8.1	2.2	4.3	1.1	0.5
26071	64.3	30.7	11.6	7.0	10.6	26.1	8.0	3.5	1.0	1.5
26072	64.9	51.0	8.4	6.9	3.5	14.4	6.4	4.0	3.0	2.5
26074	61.9	30.5	10.7	5.1	7.1	23.9	12.7	2.0	5.6	2.5
26075	64.2	6.1	2.4	3.3	4.2	32.5	23.1	15.1	5.2	8.0
26077	50.4	3.1	2.5	6.3	5.7	32.7	25.8	8.8	9.4	5.7
26080	60.4	26.3	4.1	7.7	4.1	21.6	16.5	8.2	7.2	4.1
26081	55.0	0.0	0.0	4.0	5.2	9.2	54.3	7.5	12.7	6.9
26085	71.8	37.6	7.4	7.4	5.2	9.2	14.8	3.9	9.2	5.2
26086	61.7	42.1	3.5	7.4	10.4	5.9	13.4	9.9	3.5	4.0
26089	59.7	7.0	1.0	8.5	11.1	5.5	29.6	23.1	6.5	7.5
26092	62.6	18.1	7.0	13.1	17.6	16.1	18.1	5.0	2.0	3.0

Appendix B cont'd.

Samp*	Allo	Ooid	S-od	Pell	Intr	Mold	Pely	Ech	Oth	Unk
26096	62.3	38.9	6.6	10.1	10.1	7.1	13.6	4.5	8.1	1.0
26099	32.2	6.9	2.9	1.0	4.9	16.7	31.4	22.5	6.9	6.9
26101	37.2	2.5	0.0	1.7	1.7	38.1	44.1	2.5	3.4	5.9
26104	48.3	0.6	1.9	7.8	4.5	20.8	34.4	8.4	16.9	4.5
26108	40.7	0.0	0.0	1.6	0.8	26.2	46.7	9.8	7.4	7.4
36016	51.6	63.1	3.4	14.5	1.7	5.6	4.5	4.5	1.7	1.1
36017	61.8	67.8	2.4	9.5	4.7	7.1	2.8	3.3	0.9	1.4
36018	54.9	74.6	3.8	10.3	0.5	4.9	5.4	0.0	0.5	0.0
36019	55.7	73.9	3.2	3.7	4.8	5.9	4.8	1.1	0.5	2.1
36022	49.2	55.6	3.1	12.3	6.2	9.3	11.1	1.9	0.6	0.0
36024	62.3	41.4	4.4	3.4	15.3	22.7	6.9	2.0	2.0	2.0
36026	57.0	41.6	5.4	7.0	20.5	16.2	3.8	2.2	3.2	0.0
36028	69.2	32.3	5.5	6.4	5.9	15.5	19.1	5.5	6.8	3.2
36030	47.3	18.5	2.6	6.6	5.3	37.7	20.5	2.6	1.3	4.6
36032	46.5	4.4	2.5	5.7	3.2	8.9	31.6	27.8	9.5	6.3
36035	63.2	40.1	7.7	15.5	9.2	8.2	12.6	1.9	3.9	1.0
36038	38.3	5.6	0.8	1.6	2.4	23.8	56.3	4.8	4.8	0.0
36046	52.2	48.0	7.5	9.2	8.7	11.6	8.1	4.0	1.2	1.7
36052	37.6	2.4	4.0	2.4	8.8	27.2	38.4	12.0	4.0	0.8
36055	47.0	0.0	0.0	2.1	5.7	17.7	46.1	12.1	9.2	7.1
36067	53.8	6.3	5.2	6.9	8.0	35.1	16.7	8.6	8.6	4.6
36072	61.0	8.2	2.6	4.1	3.6	42.8	16.5	8.2	5.2	8.8
46029	55.3	38.2	8.4	12.0	6.3	23.0	4.7	1.0	3.7	2.6
46030	60.3	22.8	9.7	18.0	9.7	16.0	6.3	2.4	10.2	4.9
46031	57.8	28.4	11.2	20.3	7.1	18.3	5.6	1.5	5.6	2.0
46032	63.8	20.1	7.5	16.8	12.6	18.7	9.3	1.9	11.7	1.4
46033	46.0	45.2	5.8	13.5	23.2	4.5	4.5	0.0	3.2	0.0
46034	67.1	33.3	5.0	19.8	13.5	12.6	5.0	1.8	7.2	1.8
46035	67.8	47.7	3.7	11.2	17.3	9.3	5.1	0.9	3.3	1.4
46039	64.8	55.0	10.5	11.4	3.2	14.1	1.8	0.9	2.3	0.9
46040	50.1	6.7	9.8	19.0	3.7	23.9	14.7	4.9	8.0	9.2
46041	43.3	6.9	9.2	25.4	11.5	16.2	12.3	7.7	3.8	6.9
46044	72.7	48.2	9.2	14.2	3.2	10.1	6.9	0.5	5.0	2.8
46046	62.1	64.6	5.6	10.3	1.0	15.9	1.0	0.5	0.0	1.0
46047	54.9	39.2	8.0	9.1	2.8	35.2	2.8	1.1	0.0	1.7
46049	64.2	59.4	12.4	9.4	0.5	14.4	2.5	0.5	0.5	0.5
46050	61.0	28.4	6.6	6.6	5.6	33.5	8.6	0.5	4.6	5.6
46052	61.4	6.1	3.5	8.1	3.5	21.7	34.3	4.5	9.6	8.6
46056	77.7	69.5	2.1	11.6	1.7	3.9	1.7	3.4	3.0	3.0
46060	35.9	63.7	4.4	12.4	3.5	8.0	3.5	0.0	3.5	0.9
46062	60.5	38.9	14.2	8.4	5.8	21.6	4.2	1.6	3.2	2.1
46064	46.5	6.6	10.5	7.9	0.0	50.0	19.1	1.3	2.6	2.0
46066	59.7	38.5	4.5	25.5	2.0	11.0	7.5	4.5	3.5	3.0
46068	43.0	8.3	2.1	1.4	0.0	48.3	28.3	2.1	1.4	8.3
46070	66.1	65.1	5.2	11.3	4.2	7.5	2.4	0.5	2.8	0.9

Appendix B cont'd.

Samp*	Allo	Ooid	S-od	Pell	Intr	Mold	Pely	Ech	Oth	Unk
46073	70.3	84.1	3.6	8.2	0.5	2.3	0.9	0.0	0.0	0.5
46075	57.6	41.0	25.5	6.4	1.6	13.8	6.4	3.7	0.0	1.6
46076	68.1	9.6	5.7	4.8	1.7	32.3	25.3	7.0	4.4	9.2
46077	65.0	17.8	5.8	5.8	6.7	22.1	27.4	7.2	3.8	3.4
46078	68.4	4.2	4.2	12.6	2.8	34.9	24.2	5.6	5.1	6.5
46080	60.8	11.2	3.1	11.2	4.1	26.0	20.4	12.2	3.6	8.2
46083	68.4	15.6	2.8	5.2	3.3	28.4	26.5	7.1	2.4	8.5
46085	46.0	2.1	0.0	9.2	0.0	39.4	33.8	0.0	2.1	13.4
46086	66.2	55.5	10.0	12.8	3.8	9.0	2.8	2.4	0.9	2.8
46087	66.5	42.0	6.8	17.4	6.8	14.0	9.7	1.4	1.9	0.0
46088	58.3	33.1	12.2	8.8	5.5	16.0	12.2	6.6	2.2	3.3
46090	64.4	34.7	12.6	8.5	6.0	16.6	14.6	3.5	0.5	3.0

* Samp = Sample number, first digit represents well from which sample came: 1 = #1 Willamette 'K', 2 = #2 J. F. Oglee, 3 = #1 Culbertson, 4 = #1 Wallace. Last four digits represent depth below surface.
Allo = % of rock composed of allochems,
Ooid = % ooids, S-od = % superficial ooids, Pell = % pelloids,
Intr = % intraclasts, Mold = % leached molds, Pely = % pelecypods,
Ech = % echinoderms, Oth = % other bioclasts, Unk = % unknowns.