A SUBSURFACE ANALYSIS OF THE LOWER CHESTERIAN LEWIS SANDSTONE OF THE BLACK WARRIOR BASIN IN MISSISSIPPI AND ALABAMA

By

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Finally, I dedicate this thesis to the memory of my uncle, Edmund Ignatius O'Connor, who died April 18, 1984.

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CHAPTER I

ABSTRACT

The Black Warrior Basin is a wedge shaped foreland basin whose primary sedimentary fill consists of Upper Mississippian (Chester Group) and Lower Pennsylvanian (Pottsville Group) terrigeneous clastic rocks. Significant quantities of natural gas and liquid hydrocarbons are contained within Chesterian sandstone units that were deposited on the basins' structurally stable northern shelf. The Lewis Sandstone is the second most productive of these reservoirs but its facies types and diagenetic characteristics are poorly understood by exploration geologists.

The principle sources of data for this study were more than 800 electric logs from which cross sections and subsurface maps were prepared. Production trends as determined from published data, were related to the isopach, isolith, and structural contour maps generated by this study. A core from the study area was examined to determine the controls on porosity and permeability.

The Lewis Sandstone was deposited by a high-constructive elongate and lobate cratonic delta complex that prograded from northwest to southeast. These fluvial deltaic facies mark the onset of deltaic sedimentation in the basin and also indicate an increase in basinal subsidence.

Permeability in the Lewis sand is largely dependent upon the absence of pore filling authigenic kaolinite. Optimum conditions exist when enlarged intergranular pores are free of authigenic kaolinite and

are thus able to interconnect larger dissolution pores created by the dissolution of mud clasts.

Lewis production trends correlate very well with the net sandstone trends indicated on the net sandstone isolith map. Structural trapping plays a greater role for the distal delta than the proximal delta where production is more dependent upon stratigraphic trapping.

CHAPTER II

INTRODUCTION

Location

The study area of this thesis comprises all or parts of 17 counties in northeastern Mississippi and northwestern Alabama (Figure 1). These counties include Pontotoc, Lee, Itawamba, Calhoun, Chickasaw, Monroe, Clay, Oktibbeha, and Lowndes in northeastern Mississippi and Franklin, Marion, Winston, Lamar, Fayette, Walker, Pickens and Tuscaloosa in northwestern Alabama. The area represents approximately 10,600 square miles of Cleaves (1983) refers to as the Northern Shelf of the Black Warrior Basin.

Objectives

The goal of this research is to enlarge upon the understanding of the Upper Mississippian (Chester) Lewis interval as found in the subsurface of the Black Warrior Basin in Mississippi and Alabama. Specific objectives are:

1. to identify on a regional scale, the distribution of the Lewis Sandstone in the subsurface and interpret the processes responsible for its deposition;
2. to determine the source area and transport direction of Lewis age terrigenous clastic sediment by examining Lewis sand morphology and orientation in the study area;

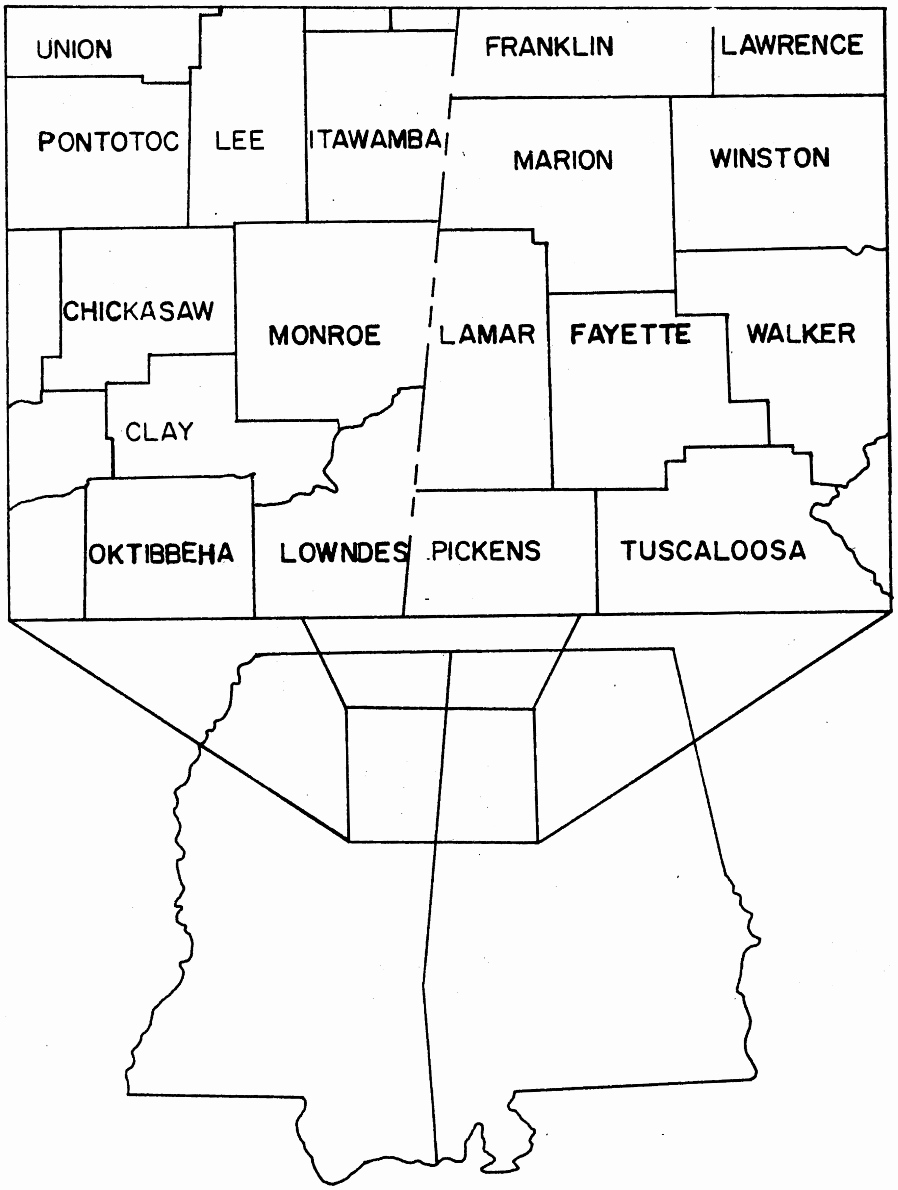


Figure 1. Geographic location of study area.

3. to determine Lewis production trends and compare these with both major structural elements and net sand configuration in order to better understand the controls on sedimentologic and structural hydrocarbon production;
4. to define the determinants of porosity and permeability development for the Lewis Sandstone from the Troy Field, Pontotoc County, Mississippi;
5. to present petroleum geologists with new exploration strategies based on a fresh interpretation of subsurface data.

Methods

A total of 832 electric logs provided the data for construction of the subsurface maps and cross sections. Over 100 commercially prepared sample logs were available to compare lithologies with electric log curves, but data were not taken directly from them. As a result of the Lewis Sandstone's low stratigraphic position in the Chester, many wells failed to penetrate it and the well control is less than that for higher units.

Three subsurface maps were prepared to establish: 1) the structure of the underlying shelf limestone; 2) the variation in thickness (isopach) of the study interval, and; 3) the sandstone facies distribution pattern for the study area. These maps are a structural contour map on the top of the Tuscumbia Limestone (Plate I), a net sandstone isolith of the interval (Plate II), and a gross isopach of the format interval between the top of the Lewis Limestone and the top of the Tuscumbia Limestone (Plate III). For the net sand map, a cutoff of -10mV was used as the minimum SP deflection indicative of a sandstone. When available, neutron and density porosity curves were cross plotted to resolve questions of lithologies.

Nine cross sections were constructed to determine the lateral and vertical continuity of the limestone, sandstone and shale components of the interval (Plates IV-VII)). The study interval is bounded above by the top of a persistent limestone marker (called the Lewis Limestone for simplicity) and below by the top of the Tuscumbia Limestone. The six East-West strike oriented cross sections intersect three North-South dip oriented cross sections to form a grid (Figure 2).

A core drilled in the southeast corner of Pontotoc County, Mississippi (Section 28, T.11S R.4E) by the Louisiana Land and Exploration Company was studied in detail. The Lewis Interval in the core was logged to determine textural trends, sand thickness, sedimentary structures, and to interpret depositional facies. Eleven thin sections were cut and examined with the petrographic microscope in order to identify detrital and diagenetic constituents. Fifteen samples were analyzed with the x-ray diffractometer. Scanning electron microscopy was performed on three samples to evaluate the relationships between authigenic minerals and permeability.

A map of Lewis Sandstone oil and gas production was made from data provided by publications of the State Oil and Gas Boards of Alabama and Mississippi. Distribution and character of production were scrutinized with respect to the subsurface maps generated by the present study. Integration of this information will serve as a meaningful point of departure for developing new Lewis Sandstone prospects.

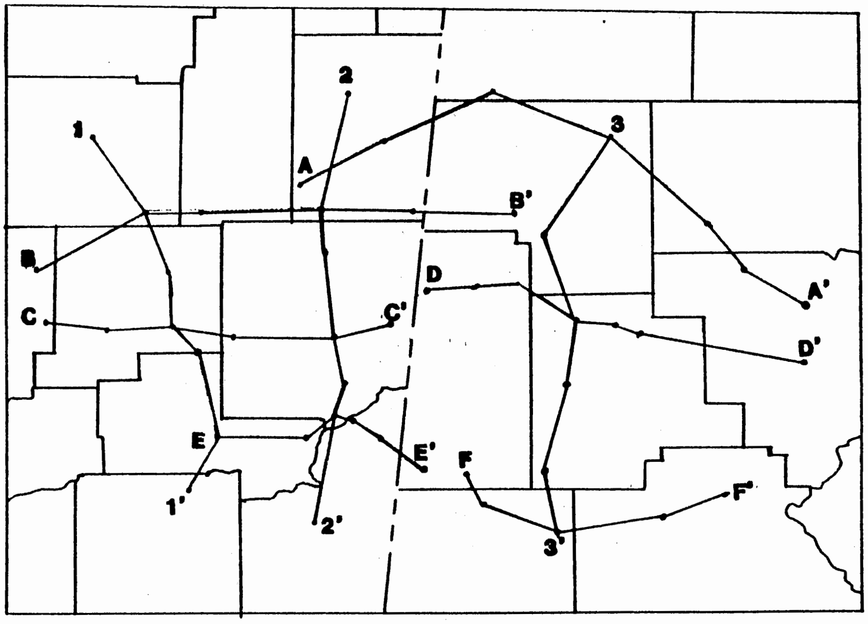


Figure 2. Locations of dip-oriented and strike-oriented cross sections.

Previous Works

Published literature concerning Chester rock units in the Black Warrior Basin can be divided into seven major categories. These are: 1) descriptions of surface geology (concentrated in Alabama); 2) student theses related to surface and/or subsurface geology; 3) petrographic studies of individual stratigraphic units, either surface or subsurface; 4) stratigraphic syntheses of subsurface geology; 5) syntheses of surface and subsurface structural geology in the Southern Appalachians; 6) short papers dealing with specific oil and gas fields, and; 7) brief descriptions of new discoveries in reviews of exploration and development trends in the region.

Surface exposures of Chester rock units in the Northern Shelf of the Black Warrior Basin are present in the Tennessee River Valley of Alabama and the extreme northeastern tip of Mississippi. Summaries of surface stratigraphy and descriptions of measured sections are given in state geological survey publications by Morse (1930) and Bicker (1979) for Mississippi and Butts (1926) and Thomas (1972a) for Alabama. Two other useful discussions of surface stratigraphy are provided by Welch (1959) and Thomas (1979).

Another significant source of information on surface stratigraphy and facies interpretation is included in various geological society guidebooks published over the last 25 years. Guidebooks prepared by the Mississippi Geological Society in 1954 (Mack, 1954) and 1978 (Moore, 1978) contain field trip stops in the Tuscumbia, Pride Mountain and Hartselle Formations. An Alabama Geological Society sponsored trip to the Alabama and Tennessee Chesterian units highlighted carbonate facies in the Pride Mountain, Bangor and Monteagle (Smith, 1967). Thomas and others (1980) led a Geological Society of America Southeastern Section, field trip to Colbert and Franklin Counties, Alabama, to examine exposures of the Hartselle and Lower Bangor. Other Geological Society of America guidebooks containing discussions of Chesterian rocks in the Black Warrior Basin include Ferm and others (1967) and Horne and others (1976).

Student theses concerning Chester (Upper Mississippian) lithostratigraphy have been written at Louisiana State University, University of Mississippi, and University of Alabama (Tuscaloosa). Ehrlich (1965) at Louisiana State University proposed that both Chester and Pottsville clastic systems were elements of a single orogenic clastic wedge derived from a low rank metamorphic source area southeast of the basin. Two students from the University of Alabama, White (1976) and Shepard (1979), mapped the Carter Sandstone in the subsurface and described Carter cores representing distal deltaic facies in Lamar and Fayette Counties, Alabama. Two other students from the University of Alabama completed theses evaluating the Lewis Sandstone of Alabama. Holmes (1981) mapped what he believed to be tidal sand ridges in the subsurface of Lamar, Fayette and Marion Counties. DiGiovanni (1984) interpreted the outcrop Lewis Sandstone as having been deposited as shallow marine bars in the Colbert County area. Broussard's thesis (Broussard, 1978) from the University of Mississippi integrated surface measured sections with subsurface maps of the Lewis, Evans, Hartselle and Muldon sandstones. Broussards' work was regional in scope, dealing with a total of 20 counties in both Mississippi and Alabama.

Petrographic studies of the Chester are included in theses by Holmes (1981) and Shepard (1979). Both believe the sandstones have a cratonic, sedimentary source area located to the north or northwest of the basin. An antithetical view by Graham, Ingersoll and Dickenson (1976) proposes a Ouachita provenance for all carboniferous terrigenous clastic rocks in the basin. Thomas (1980) and Thomas and Mack (1982) concluded that the Hartselle Sandstone had, based on the presence of polycrystalline quartz, a source area in the Ouachita Mountain Complex of Southern Mississippi. Mack, James, and Thomas (1981) and Mack, Thomas, and Horsey (1983) petrographically examined outcrop Parkwood units and concluded that these sandstones had an orogenic source area located to the southwest. They contend that the Parkwood, Hartselle, and Lewis (by inference) involved components of a northeastwardly-prograding clastic wedge derived from the Ouachita Complex of south-central Mississippi.

Stratigraphic syntheses of Chester subsurface geology have been published in reviews summarizing the petroleum geology of the Black Warrior Basin. Early papers include those by Mellen (1947, 1953a, 1953b) and Everett (1958). Also Pike (1968), Vernon (1971), Welch (1971) and Duschscherer (1972) furnish brief descriptions of Chester stratigraphy and producing horizons. Welch (1978) constructed two subsurface structure maps and two net sand isolith maps of the Sanders and Carter intervals. Scott (1978) outlined the facies components and porosity distribution on the Lower Bangor Carbonate ramp of Lamar and Fayette Counties. Cleaves and Broussard (1980) and Cleaves (1983) applied deltaic depositional models to the Lewis, Evans/Hartselle and Muldon Clastics systems and inferred a cratonic, Ozark-area, source terrain. Thomas (1972b,

1974) using a total of 104 wells from various parts of the basin contends that the Parkwood and Floyd terrigenous clastics are part of a clastic wedge originating in the Ouachita Orogen of Western Mississippi.

The bulk of Thomas' research in the Black Warrior Basin has attempted to explain the tectonic history of the Southern Appalachians (Thomas, 1973 and 1976). His most recent effort in this regard (Thomas and Neathery, 1980) is a diagnosis of the Paleozoic history of the Appalachian Orogen in Alabama.

Publications describing specific Chester oil and gas fields in Mississippi are made available by the Mississippi Geological Society and the State Oil and Gas Board of Mississippi. With Frascogna (1967) and Davis and Lambert (1963) the Mississippi Geological Society has published a type log, structural contour map, and reservoir data and production history for 17 Chester producing fields in Mississippi. Discovery dates and production summaries for producing pools in Mississippi are presented in annual reports of the Oil and Gas Board (Miss. Oil and Gas Board Annual Report, 1983). Similar statistics for Alabama are enumerated in annual Oil and Gas Reports published by the Alabama State Oil and Gas Board (Masingill and others 1978; Masingill and Hall, 1979; Masingill, 1982, Masingill and Bolin, 1982). Brief articles characterizing specific Chester fields include, Spooner (1976), Jones (1978), and Hooper and Behm (1978).

Periodic articles dealing with exploration and production trends in the Black Warrior Basin appear in occasional articles in the Oil and Gas Journal and in the yearly domestic exploration summary given to the American Association of Petroleum Geologists Bulletin. Mancini and others (1983) and McCaslin (1979, 1980a 1980b and 1984) describe exploration developments in the <u>Oil and Gas Journal</u>. Cate (1977, 1978, 1981 and 1982) and Cate, Carter and Jennings (1979) supplied the recent Bulletin summaries of exploration developments in the Southeastern states.

CHAPTER III

STRATIGRAPHY AND STRUCTURAL GEOLOGY

Regional Setting

The Black Warrior Basin is a triangular area bounded to the east by the Appalachian deformed belt to the southwest by the Central Mississippi Deformed Belt, an extension of the Ouachita trend and to the north by the Ozark Uplift and Nashville Dome (Figures 3 and 4). Mesozoic and Cenozoic sediments of the Gulf Coastal Plain cover the western 80 percent of the basin. The youngest sediments preserved in the outcrop portion of the basin are of Early Pennsylvanian (Morrowan) age. Situated in northeastern Mississippi and northwestern Alabama, the basin includes all or part of approximately 40 counties.

Structural Framework

The late Paleozoic (Mississippian) closing of the Iapetus Ocean and subsequent southern Appalachian - Ouachita Orogen are the result of a collision by the North American continent with either a continental mass or a volcanic arc located to the south (Thomas and Neathery, 1980). Specific continental masses have been proposed and include; a combined, African-South American Continent (Mack and others, 1983), or a microcontinent and/or South American Continent.

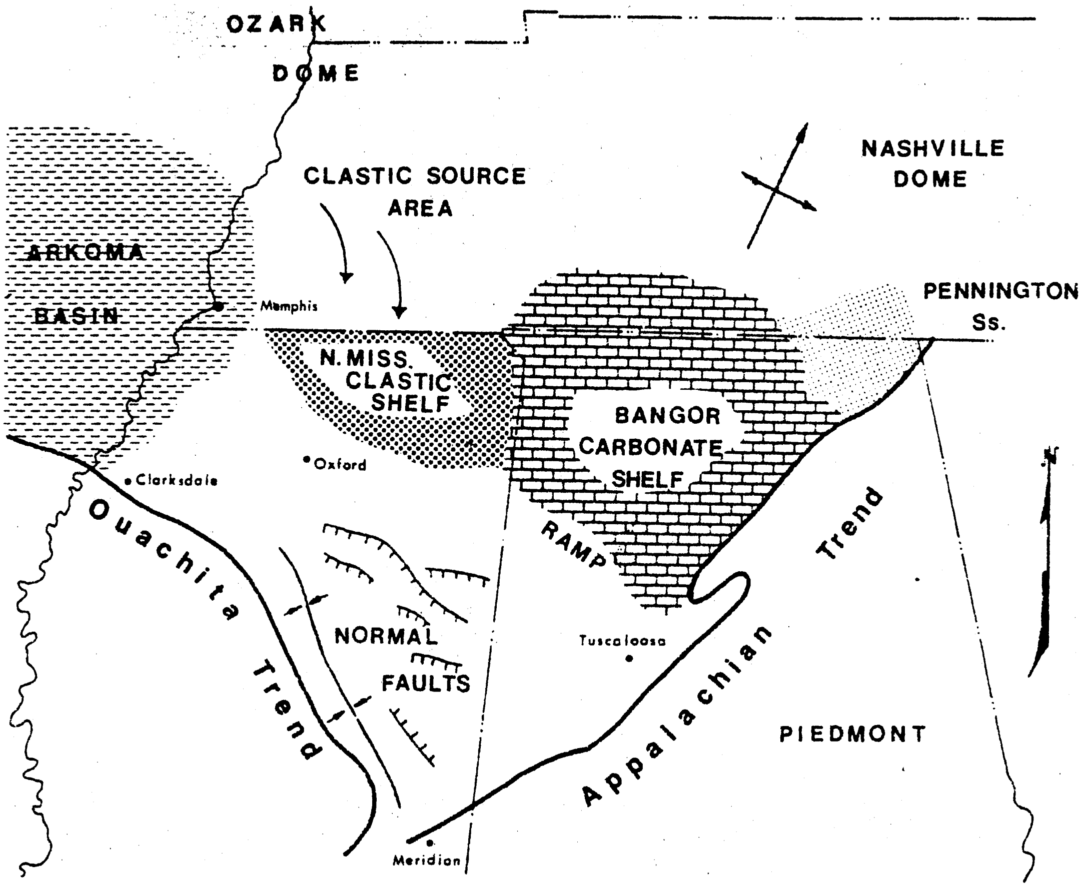


Figure 3. Regional setting for the Black Warrior Basin (from Cleaves, 1983).

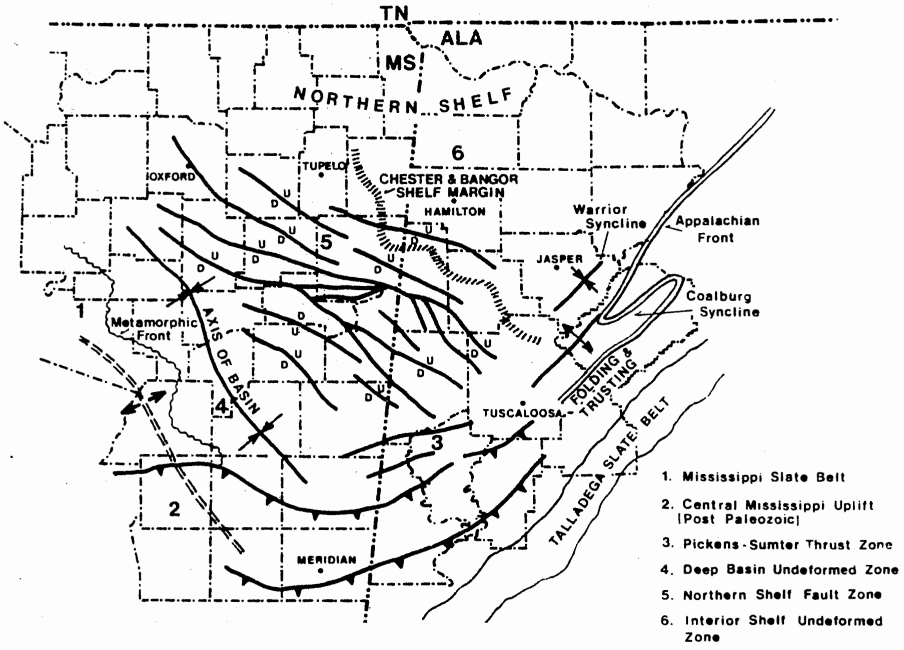


Figure 4. Structural features of the Black Warrior Basin (from Thomas, 1973).

The dominant compressive force associated with the collision was apparently from the southwest as reflected by an average strike of 325° for normal faults developed on the cratonic side of the evolving foreland basin. Generally, the faults are downthrown to the basin and the dips on the fault planes are nearly vertical. The Central Mississippi Uplift (Figure 4) borders the southern side of the deep basin and constitutes a structural high. It is composed of south-dipping, lower Paleozoic thrust faults and/or asymmetric anticlines steep on their north side and forms the boundary between the Black Warrior Basin and the Mississippi Salt Embayment.

Faults on the Northern Shelf which are upthrown toward the basin are usually associated with grabens or graben-like features located on their northern sides. Minor N-S and NE-SW striking faults exist and their orientations coincide nearly with the trends of major anticlines and synclines in the area. Major NW-SE striking normal faults are related to the Ouachita Orogen while the trends of major folds and minor NE-SW striking faults are associated with the Appalachian Orogen. The structures associated with the Ouachita deformation dominate in terms of displacement and frequency.

Chesterian strata in the study area range in dip from 30 feet/mile on the East Warrior Platform to over 200 feet/mile in the deeper shelf area. Direction of dip is to the SSW (approximately 198° azimuth).

Chester Group (Upper Mississippian) Stratigraphy

Floyd Shale-Pride Mountain Formations

The Pride Mountain Formation is the lowermost formation of the Chester Group and overlies the cherty, bioclastic Tuscumbia Limestone of the Meramecian Group (Figure 5). The upper boundary of the Pride Mountain is marked by the base of the Hartselle Sandstone. The Floyd Shale occupies the interval above the Hartselle Sandstone and below the Parkwood Formation. Southwestward of the Hartselle Sandstone pinchout in the subsurface, the Floyd Shale is indistinguishable from the Pride Mountain Formation. Consequently, the two units are grouped together for the purpose of this study.

The Pride Mountain Formation consists of shale units interbedded with thinner limestones, sandstones and siltstones. The nomenclature proposed by Butts (1926) for this sequence; St. Genevieve Limestone, Bethel Sandstone, Gasper Formation, Cypress Sandstone and Golconda Formation (in ascending order) is commonly used, but has little value for explaining subsurface stratigraphic relationships (Figure 6).

The Pride Mountain Formation is commonly medium to dark gray, fissile, shale. It frequently contains siderite nodules and less abundant pyrite (Thomas 1972b). Argillaceous limestone units contain abundant bryozoan and brachiopod fossils.

The formation contains a basal limestone that averages 20 feet thick, but increases to nearly 50 feet to the northeast on the Northern Shelf of Alabama. This limestone is shaly or oolitic and differs from the lower Tuscumbia by a lack of chert.

Two extensive, southeast-trending deltaic sandstones exist, within the formation. These are the Lewis and Evans of industry nomenclature. Average thickness of each is less than 100 feet. The Lewis Sandstone is present in and southwest of Franklin and Winston Counties, Alabama. The Evans Sandstone is confined primarily to Mississippi, with a tongue extending into Franklin and Marion Counties, Alabama.

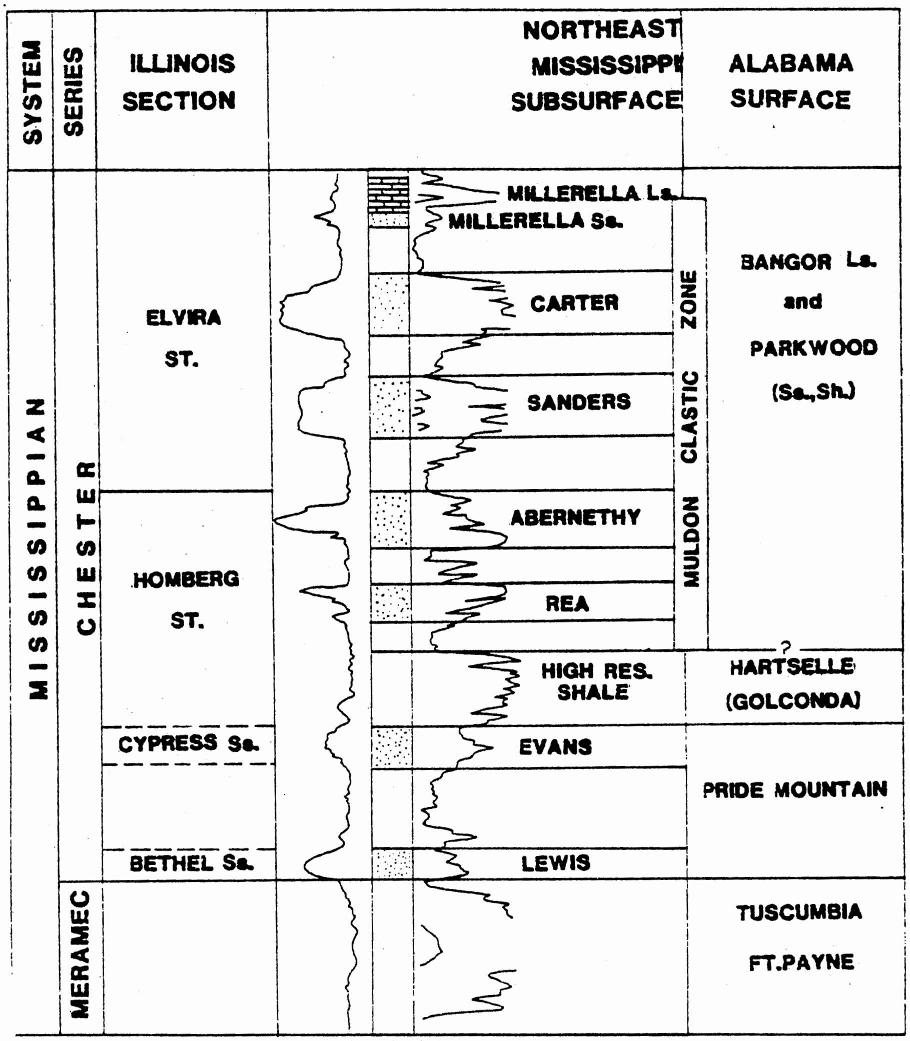


Figure 5. Type log for the Chester Group of northeastern Mississippi (from Cleaves and Broussard, 1980).

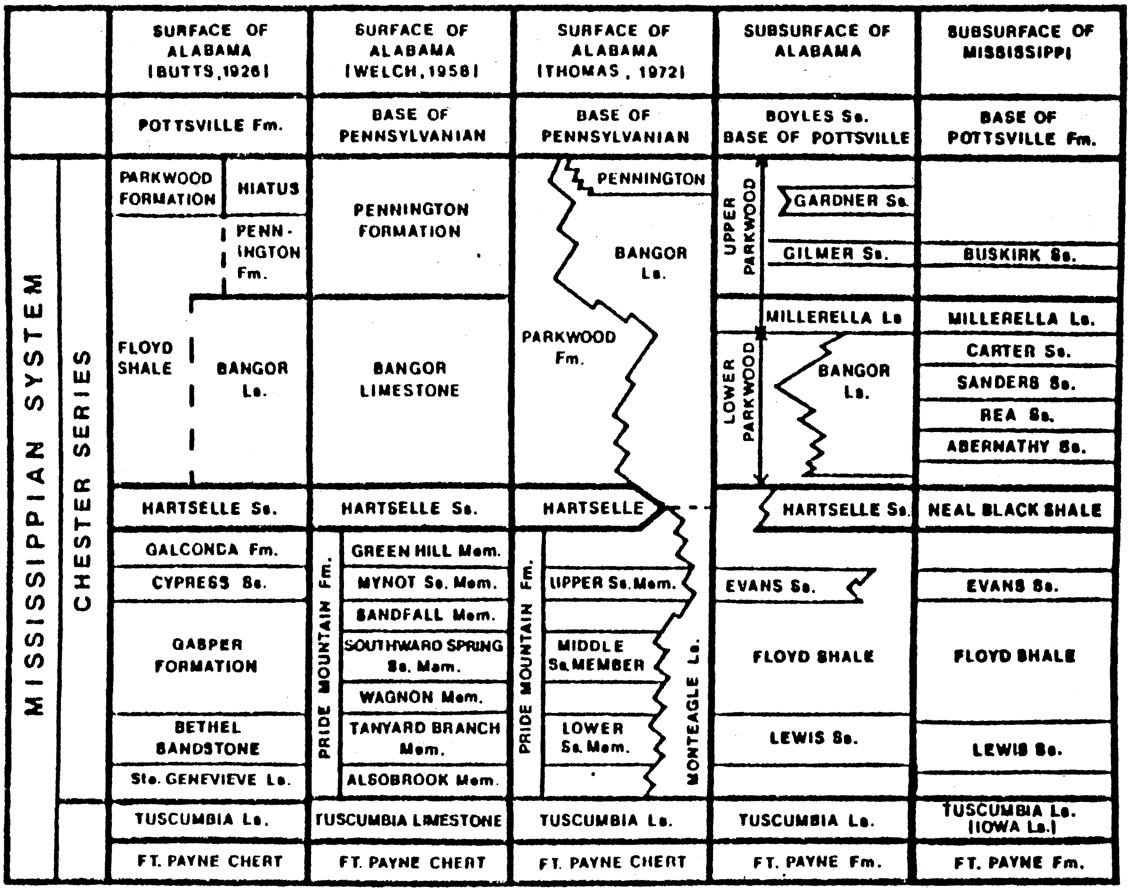


Figure 6. Surface and subsurface stratigraphic nomenclature for Upper Mississippian Chester Group: Northern Shelf of Alabama and Mississippi (from Cleaves, 1983).

The Lewis Sandstone is the lowest sandstone member of the Pride Mountain Formation. It is equivalent to: Bethel of Butts (1926); Allsboro Sandstone and Cripple Deer Sandstone Member of Alsobrook Formation of Morse (1928); Tanyard Branch member of Pride Mountain Formation of Welch (1958). The Lewis Sandstone is occasionally interbedded with the basal limestone but more often overlies it, separated by a few feet of shale.

The Floyd Shale is principally a dark gray shale similar in composition to the Pride Mountain shales (Thomas, 1978). As mentioned above, southwest of the Hartselle sandstone pinchout, the Floyd Shale is indistinguishable from the Pride Mountain Formation.

The Floyd Shale is thought to be laterally equivalent to the lower half of the Bangor Limestone (below the "Millerella" Limestone) and it occupies the stratigraphic position above the Hartselle Sandstone and below the Parkwood Formation (Butts, 1911). Interbeds of argillaceous limestones and calcareous shales are characteristics of the Floyd Shale. Thomas (1972a) described a tongue of lower Bangor Limestone interfingering toward the southwest with the Floyd Shale.

Hartselle Sandstone

Smith (1894) first employed the name Hartselle to describe a thick, persistent sandstone within the Bangor Limestone. The Hartselle reaches a maximum thickness of more than 150 feet but variations are abrupt (Cleaves, 1983). Sand bodies trend southeast and the southwestern limit of the Hartselle is nearly coincident with the southeastern edge of Thomas' East Warrior Platform (Northern Shelf).

The Hartselle Sandstone Formation overlies the Pride Mountain Formation and, locally in northeastern Alabama (where the Pride Mountain grades into the Monteagle Limestone), it rests on the Monteagle. It is overlain by the Bangor Limestone. The Hartselle sand pinches out into the Floyd Shale both to the southwest and the southeast (Thomas, 1972a).

Bangor Limestone

The Bangor Limestone comprises the variety of shallow, epeiric sea carbonate facies present above the Hartselle Sandstone and below the Pottsville Formation in northwestern and north-central Alabama. To the south and west, the Bangor Limestone grades into the clastics of the Parkwood and Floyd Formations. In northeastern Alabama, the upper Bangor Limestone interfingers with the terrigenous clastics of the Pennington Formation.

Thomas (1972a) proposed that the Bangor included all of the limestone sequence bracketed by the Hartselle Sandstone and Pottsville Formation in north-central Alabama. To reduce confusion concerning correlations he suggested the name Pennington be abandoned, except in and east Jackson, Marshall and Etowah Counties, where units equivalent to the Upper Bangor Limestone are predominantly clay, shale, mudstone, dolostone and sandstone.

The Bangor is dominantly a shallow water bioclastic and oolitic limestone. Micrites, shaly limestones and calcareous shales occur as well, but in lesser abundance. Green and maroon mudstones are present in the upper half of the formation, along with scattered chert nodules.

Development, distribution and thickness of the Bangor Limestone is directly related to the position of the East Warrior Platform of the

Northern Shelf. Greatest isopach values (approximately 500 feet) trend southeast along the west edge of the platform. This margin comprises a carbonate ramp which lacks a distinct shelf edge or reefal carbonate build-ups of regional extent.

Parkwood Formation

The Parkwood Formation is comprised largely of interbedded sandstone and shale units. The base of the stratigraphically lowest sandstone in the sequence marks the base of the formation and the top is defined by the base of the Shades Sandstone Member of the Pottsville Formation (Thomas, 1972a).

The Parkwood Formation thins and pinches out to the east in Franklin, Winston and Walker Counties, Alabama. Some sandstones in the formation exceed 100 feet thick locally and sandstone percentage of the formation is approximately 25%. Sandstone trends in the Parkwood Formation are NW-SE with a source terrain located to the northwest (Cleaves, 1983).

Typical Parkwood Formation sandstones are gray, very fine to fine grained, argillaceous and partly silty. The lateral extent of separate sandstone units differ greatly. In the area to the east, the Parkwood interfingers with the equivalent Bangor and limestone interbeds are common.

For the purposes of subsurface analysis the Parkwood can be subdivided into two distinct units (Figure 6, Column 4). The Lower Parkwood contains all of the rock units between the top of the Hartselle Sandstone, or the base of the first sandstone unit above the Evans Sandstone, and the base of the "Millerella" Limestone. Where the Evans is also absent, the base of the Parkwood involves the first sandstone unit overlying the highly resistive Neal (Fayetteville) Black Shale. The sandstone units within this Lower Parkwood interval have been referred to by Shell Oil Company geologists as the Muldon Clastics (Scott, 1978). The Muldon Clastics incorporate the most productive rock units in the Black Warrior Basin. In ascending stratigraphic order, these informally named sandstone units are the Rea, Abernathy, Sanders, Carter, and "Millerella."

The Upper Parkwood incorporates the interval between the base of the "Millerella" Limestone and the basal barrier bar sandstone body (Shades or Boyles on the surface and Robinson or Chandler in the subsurface) of the Pottsville Group. The informally named Gilmer and Gardner Sandstone units, as well as numerous intercalated limestone and shale units are present within the interval.

Basinal Subsidence History

The Black Warrior Basin contains a maximum Paleozoic sedimentary column of approximately 15,100 feet (Mellen, 1947). The subsidence rate curve for the basin reflects three phases of development (Figure 7).

The Cambrian-Ordovician segment of the curve reflects a relatively stable, even rate of subsidence of 50 feet/million years. Carbonate sedimentation dominated the Black Warrior "shelf" during this time, while deep marine facies of black shales and siliceous deposits developed in the adjacent Ouachita Basin. Shelf and basin sediments occasionally interfingered indicating sea level fluctuations.

Silurian and Devonian time is represented by a decrease in the sediment entrapment rate to 11 feet/million years. Carbonate shelf facies

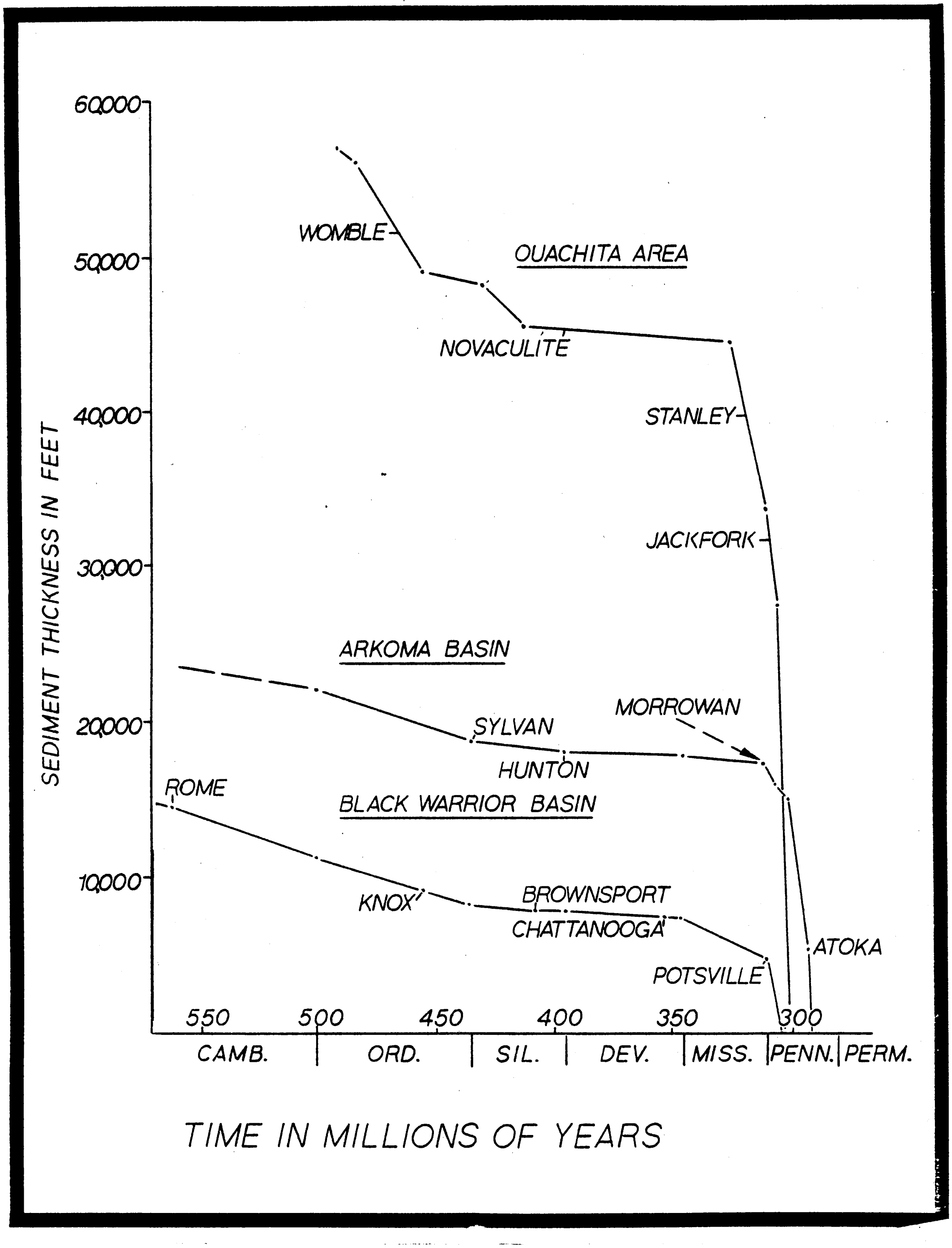


Figure 7. Basinal subsidence history of Black Warrior Basin, Arkoma Basin and Ouachita Area.

continued to dominate sedimentation. The reduced subsidence rate for this time may be explained by deeper water sedimentation, or by the existence of numerous unconformities, particularly in the Devonian.

The Mississippian entrapment rate reached 75 feet/million years marking a drastic increase from Devonian time and indicated the initiation of subsidence as a "full fledged" foreland basin. This rapid subsidence was accompanied by the progradation of deltas from the north and northwest (Figure 8).

Finally, subsidence attained a maximum rate of 990 feet/million years in the early Pennsylvanian. Continential collision along the southern margin of the shelf at this time resulted in orogenic highlands and a reversal in source area from north to south.

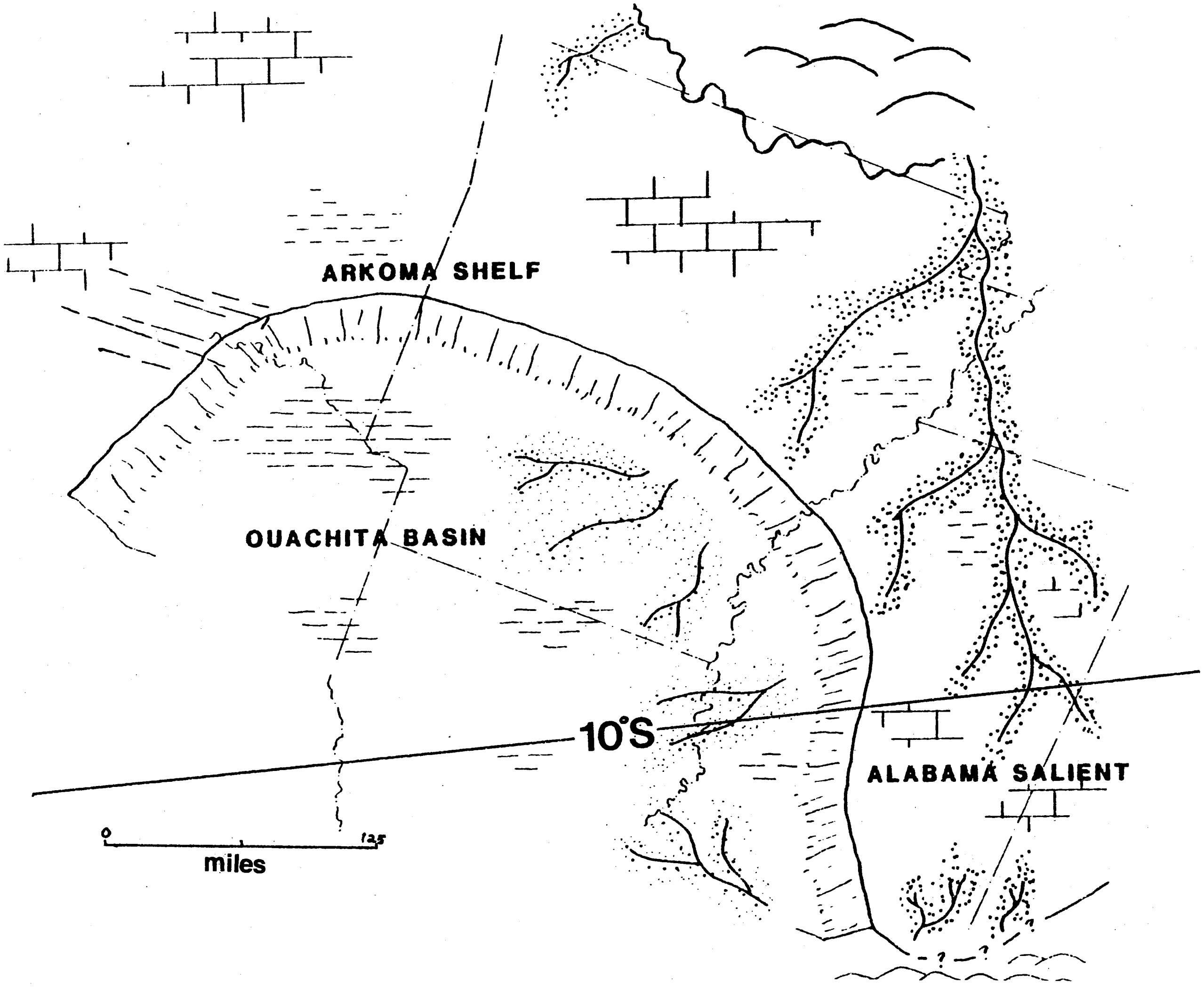


Figure 8. Chester paleogeography and deltaic progradation in the Black Warrior Basin and surrounding areas.

CHAPTER IV

REGIONAL ELECTRIC LOG STUDIES

Introduction

Eight hundred and thirty-two electric logs and 110 commercially prepared sample logs from the entire study area provided substantial control for the preparation of the subsurface maps. The type of log most often run on wells in the basin is the Dual Induction Log consisting of an S.P. (spontaneous potential) curve and three resistivity curves (laterolog, medium induction, deep induction).

The Tuscumbia Limestone was present in all but a few logs and served as a good marker for correlations because of its characteristic log signature. Once the Tuscumbia had been located, it was not difficult to move higher in the section to find the Lewis Limestone. In this study, the Lewis Limestone is defined as the first persistent limestone above the Lewis Sandstone. These two markers served as the lower and upper boundaries of the study interval.

The subsurface maps constructed were:

1. Structure on the top of the Tuscumbia Limestone (Plate I);
2. Net sand isolith of the format interval (Plate II).
3. Gross isopach of the total format interval (Plate III);

Stratigraphic cross sections were prepared using selected electric logs from the area. There were a total of nine cross sections constructed (Figure 2). Three are dip-oriented (1-1', 2-2', 3-3') and six are strike-oriented (A-A', B-B', C-C', D-D', E-E', F-F'), these are presented on Plates IV-VII.

The stratigraphic section between the top of the Tuscumbia Limestone and the top of the Lewis Limestone is a genetic interval of regional significance. The top of the Tuscumbia, at least on the Northern Shelf, comprises a broad, flat surface that is of roughly the same age throughout its complete extent. Higher, the deltaic and shelf terrigenous clastics between the carbonate facies constitutes a regional marine regression over the western 60% of the Northern Shelf. Capping the sequence is a second, thinner, carbonate unit that is also regionally persistent. Such a marker-bound stratigraphic unit has been termed a Format Unit by Forgotson (1957), a transgressive-regressive couplet by Shelton (1973), and a Genetic Increment of Strata by Busch, 1971).

The principal value for defining a format unit is that all of the terrigenous clastics between the two marker units are assumed to have been deposited during one regional cycle of sedimentation. The included reservoir sandstone units were laid down as facies components of one or more essentially contemporaneous depositional systems. Subsurface maps prepared from data incorporating the complete format interval are exceedingly valuable for identifying specific depositional systems, reservoir rock, and trends of elongation for discrete sandstone bodies. With the present study, a total interval net sandstone isolith map and a format isopach map have been found the most useful for delineating Lewis Sandstone facies distribution.

Tuscumbia Structure Map

The surface at the top of the Tuscumbia is disturbed by numerous folds and faults (Plate I). Generally, dip is to the SSW and it varies from 30 ft/mile in Winston County, Alabama to over 200 ft/mile in Pickens County, Alabama. Normal faults that have an average strike of 325° often truncate south-plunging anticlines and synclines. Scattered highs and lows with as much as 300 feet of closure are present within the area. Grabens exist locally and can be interpreted as being consistent with the extensional regime responsible for the normal faulting.

Two distinct structural trends are apparent from the map. Normal faults striking NW-SE, related to the Ouachita Orogen, outnumber and have greater displacements than N-S and NE-SW striking faults associated with the Appalachian Orogen. However, major folding orientation seems likely to have formed in response to stresses related to the Appalachian orogen.

Lewis Net Sandstone Isolith Map

The Lewis Sandstone was mapped on a contour interval of 10 feet (Plate II). The geometry of the sands is distinctively deltaic with four major "feeders" and two minor feeders (upper delta plain fluvial systems). The fifty-foot contour conveniently highlights what could be considered as the major distributary channels. The major distributaries of the delta complex exhibit a rather elongate, parallel nature with low-angle bifurcation. This may be suggestive of moderate tidal influence in distal deltaic facies. The largest accumulations of sand (80+ feet) are situated within the major distributary trends. Major crevasse splay morphologies are present in the following areas: North-central Chickasaw County, Mississippi; southeast Chickasaw County, Mississippi; southwest corner of Monroe County, Mississippi; northeast corner of Lowndes County, Mississippi; north-central Lamar County, Alabama, and; west-central Lamar County, Alabama.

Source direction appears to be a north to northwesterly one. This pattern is indicated by both the thickening of the entire format interval to the northwest, as well as by the thickening of individual sandstone bodies in that direction. Major distributaries extend south of the study area possibly as far as the basin's depocenter at that time. It is likely that the basin's depocenter migrated from east to west with progressive collision from the south, resulting in the preferred orientation of distributaries seen.

To the northeast, in Marion, Franklin and Winston Counties, Alabama there is a departure from the character of distributaries seen elsewhere in the basin. Channel trends are more diffuse and sand accumulation is generally thinner. It is postulated that these distributaries have been reworked by storms and tides on a shallow marine shelf to form linear sand ridges. Sands originally transported fluvially have been reworked in some cases into the tidal bars described by Holmes (1981).

Format Interval Isopach Map

A gross isopach map of the study interval was constructed (Plate III). It also reflects a distinct deltaic affinity. Isopach "highs" closely resemble maximum sandstone trends from the net sand map. Major distributary trends translate to the areas of maximum isopach thickness. This clearly indicates that the depositional setting involved was fluvially dominated systems. The interval thickness seems unaffected by faulting. This pattern tends to refute the possible interpretation that growth faulting was a prominent mode of deformation in the basin.

Cross Sections

Nine cross sections in all were used to analyze the lateral and vertical continuity of units in the area (Plates IV-VII). The Lewis Limestone was chosen as the datum for all cross sections.

Strike-Oriented Cross Sections

Cross section A-A' is an east-west stratigraphic cross section extending from Itawamba County, Mississippi to Walker County, Alabama (Plate IV). It traverses the northern portion of the study area.

Units correlated above the datum are the Hartselle and Evans Sandstones. This section illustrates the overlap and pinchouts of the two deltas in the area of well FraA-11. The Evans clearly underlies the Hartselle and comprises a separate deltaic system. Also in well WkrA-19, it appears evident that two lobes of the Hartselle Sandstone are present.

The Lewis Sandstone thins and pinches out to the east of well FraA-11. The interval isopach thins significantly as well moving to the east and Lewis sandstone is replaced by the limestone and shale of the lower part of the Pride Mountain (Ste. Genevieve) Formation.

Cross section B-B' is an east west stratigraphic cross section extending from Calhoun County, Mississippi to Marion County, Alabama (Plate IV). It crosses an area of well developed Lewis Sandstone and shows a rather abrupt pinchout to the east between wells ItM-54 and MarA-34.

The Evans Sandstone above is rather thin in wells PoM-31 and LeeM-9 but continuous and probably "shales out" in well MarA-34.

Cross section C-C' (Plate V) is an east west stratigraphic cross section that joins on a line of strike with cross section D-D'. Cross section C-C' extends from east-central Calhoun County, Mississippi to east central Monroe County, Mississippi. The Evans Sandstone above is fairly uniform and consistent in thickness. Again it appears to "shale out" to the east in well MnrM-35. Mapping of the Evans by Cleaves (1983) indicates that the Evans does pinch out eastward in Mississippi.

The Lewis Sandstone is thickest where the interval isopach is greatest. This is demonstrated with well ChiM-26. Two distinct channel sands are readily correlated across the section. Thinning and thickening is seen to correspond with structural highs and lows of the Tuscumbia, respectively.

Cross section D-D' (Plate V) is an east-west stratigraphic cross section continuing along strike from cross section C-C' across Lamar and Fayette Counties into Walker County, Alabama. The Evans Sandstone pinches out east of well LamA-83 and the Hartselle Sandstone pinches out to the west of well WkrA-60. For illustrative purposes the Rea Sandstone or its equivalent have been traced across the area.

The Lewis Sandstone seems to consist of two distinct channel sands as was seen in cross section C-C'. Both sands, however, pinch out to the east as the interval isopach thins again in the vacinity of well LamA-45. A thin lens of Lewis sand is present in the area of well FayA-7 but absent in adjacent wells.

Cross section E-E' (Plate VI) is an east-west stratigraphic cross section extending from Clay County, Mississippi to southwestern Lamar County, Alabama. The Evans Sandstone pinches out east and down-dip from well ClyM-16 and is represented stratigraphically by the laterally equivalent resistive shale.

The Lewis Sandstone in this section is thick and laterally continuous. Strikingly apparent is the variation in thickness of the prodelta muds beneath the Lewis Sand. Though the interval isopach changes very little between LowM-30 and LowM-56, the Lewis distributary channel has cut more deeply into the underlying prodelta shale and rests almost directly on top of the Tuscumbia Limestone.

Cross section F-F' (Plate VI) is an east-west stratigraphic cross section extending along the line of strike with E-E'. It begins in south-central Lamar County, Alabama and ends in north-central Tuscaloosa, Alabama. A tongue of lower Bangor Limestone has been correlated above the datum. No Evans or Hartselle sandstone units are present in this area and their stratigraphic position is occupied by a resistive (Neal) black shale. The section shows three laterally discontinuous "fingers" of Lewis sand and a significant thinning of the interval isopach to the east. These fingers are the distal extremities of three different delta lobes.

Dip-Oriented Cross-Sections

Cross section 1-1' is a dip-oriented stratigraphic cross section extending from north-central Pontotoc County Mississippi south to northern Oktibbeha County Mississippi (Plate VII). The top of the Evans Sandstone has been correlated and the thickness between it and the datum increases to a maximum in well ChiM-22. The Lewis Sandstone is laterally continuous but thins at highs in the Tuscumbia and thickens where the Tuscumbia is low. Much of the thickening in lows is accounted for by prodelta muds.

Cross section 2-2' (PLate VII) is a dip oriented stratigraphic cross section that extends from north-central Itawamba County, Mississippi south to north-central Lowndes County, Mississippi. In this section the Evans Sandstone pinches out south of well MnrM-86. To the south of this well, the equivalent resistive shale can be correlated. The Lewis Sandstone is fairly uniform in thickness across this section with the exception of well MnrM-56 which represents a Tuscumbia high. Lewis Sandstone is absent in this well and pinchouts north and south may constitute attractive prospects.

Cross section 3-3' (Plate VII) is a dip oriented stratigraphic cross section that extends from northeastern Marion County, Alabama south to northeastern Pickens County, Alabama. The Evans Sandstone can be correlated in Marion County but rapidly "shales out" to the south. The Lewis Sandstone is poorly developed in the north with only a thin lens in the MarA-44 well. Lewis sand is present in west central Fayette County Alabama and generally thickens continuously to the south.

Electric Log Patterns For Individual Wells

Electric log signatures (particularly S.P. and resistivity) often serve as useful tools in facies interpretations. This is so because the electrical properties of rocks are influenced most by their texture. Texture is defined as the size, shape and arrangement of component particles and as such, texture is a function of the hydrodynamic environment of deposition. For example, a textural fining upward sequence can be identified from an electric log and the inference of decreasing flow regime can be made. An interpretation of facies should be carefully chosen, consistent with the overall depositional framework and it should be supported (when possible) by analysis of sedimentary structures, mineralogical composition and biological evidence.

Four important Lewis deltaic facies and their electric log curves are shown on Figure 9.

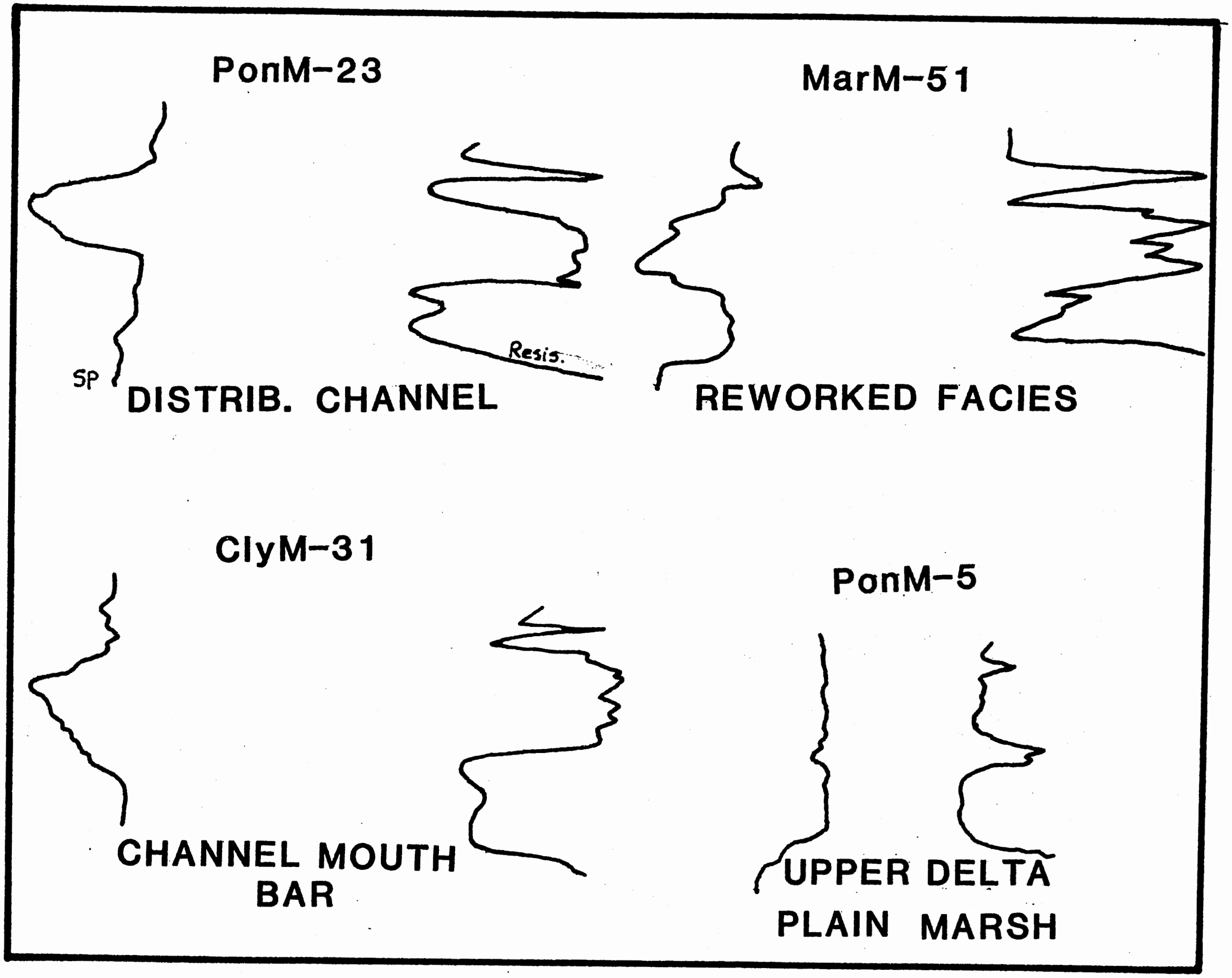


Figure 9. Characteristic electric log curves for various facies.

CHAPTER V

FACIES ANALYSIS OF THE LEWIS INTERVAL

Introduction

The general depositional framework of Chesterian units of the Black Warrior Basin has been discussed by Broussard (1978), Cleaves (1980), Cleaves (1983), Cleaves and Broussard (1980), Di Giovanni (1983), Ehrlich (1965), Holmes (1979), Holmes (1981), Scott (1978), Shepard (1979), Thomas (1980), Thomas and Mack (1982), Thomas and others (1980), Welch (1978), and White (1976).

Chesterian sandstones of the area represent numerous events of fluvial deltaic deposition on the structurally stable, cratonic, Northern Shelf of the Black Warrior Basin. The area was characterized in Chesterian time by prograding deltaic systems originating from a northern or northwestern source area (Cleaves, 1983) (Figure 10). These deltaic events were interrupted regularly by marine transgressions resulting in carbonate and marine clastic sedimentation. Such an idealized sequence of sedimentation for a cratonic delta is shown in Figure 11.

The Lewis Delta System was active in the study area during the earliest Chesterian time. Progradation basinward over shelf carbonates was halted by either a eustatic rise in sea level or delta lobe abandonment. This event is evidenced by the Lewis marine transgressive limestone overlying the fluvial deltaic sands.

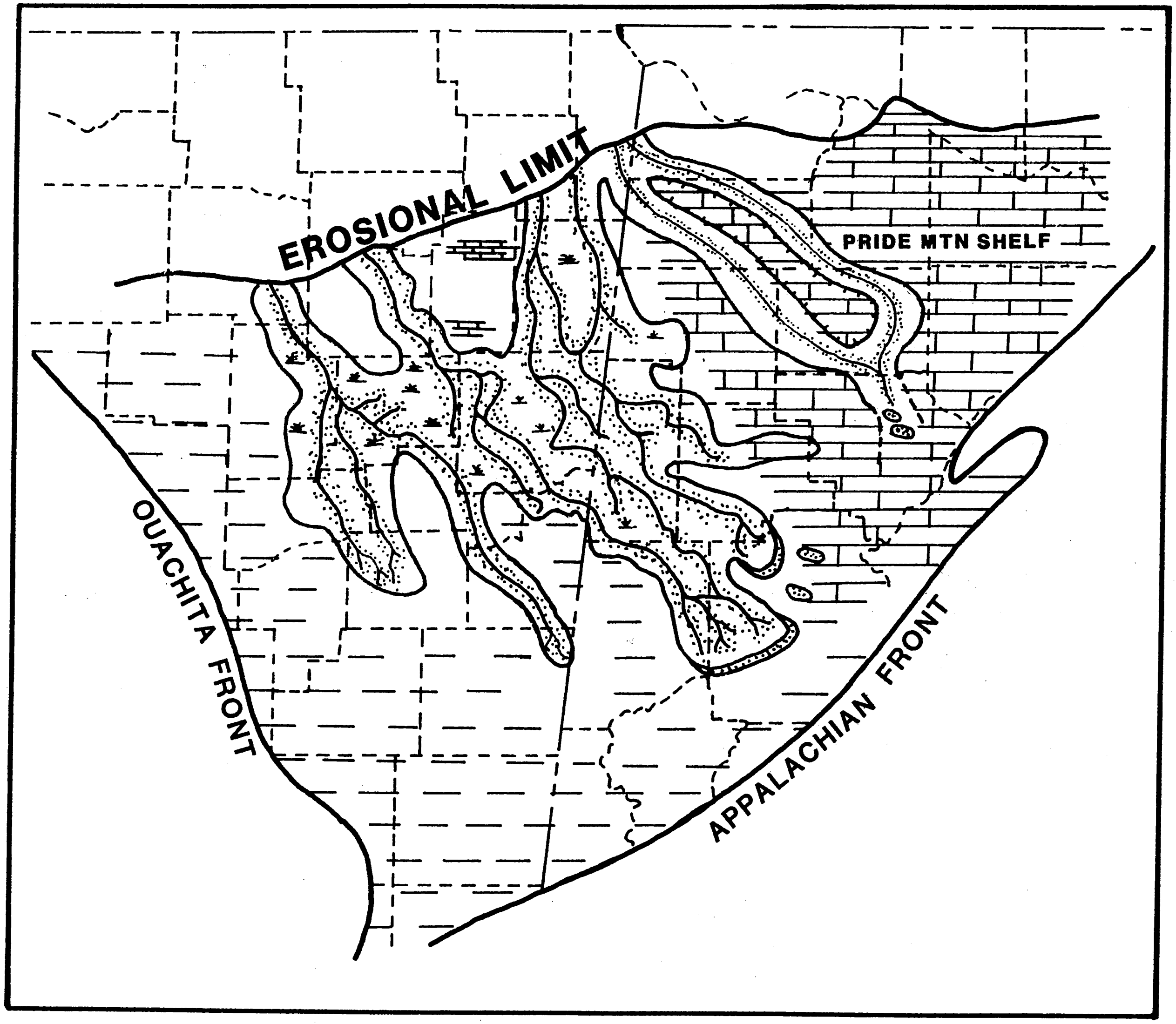
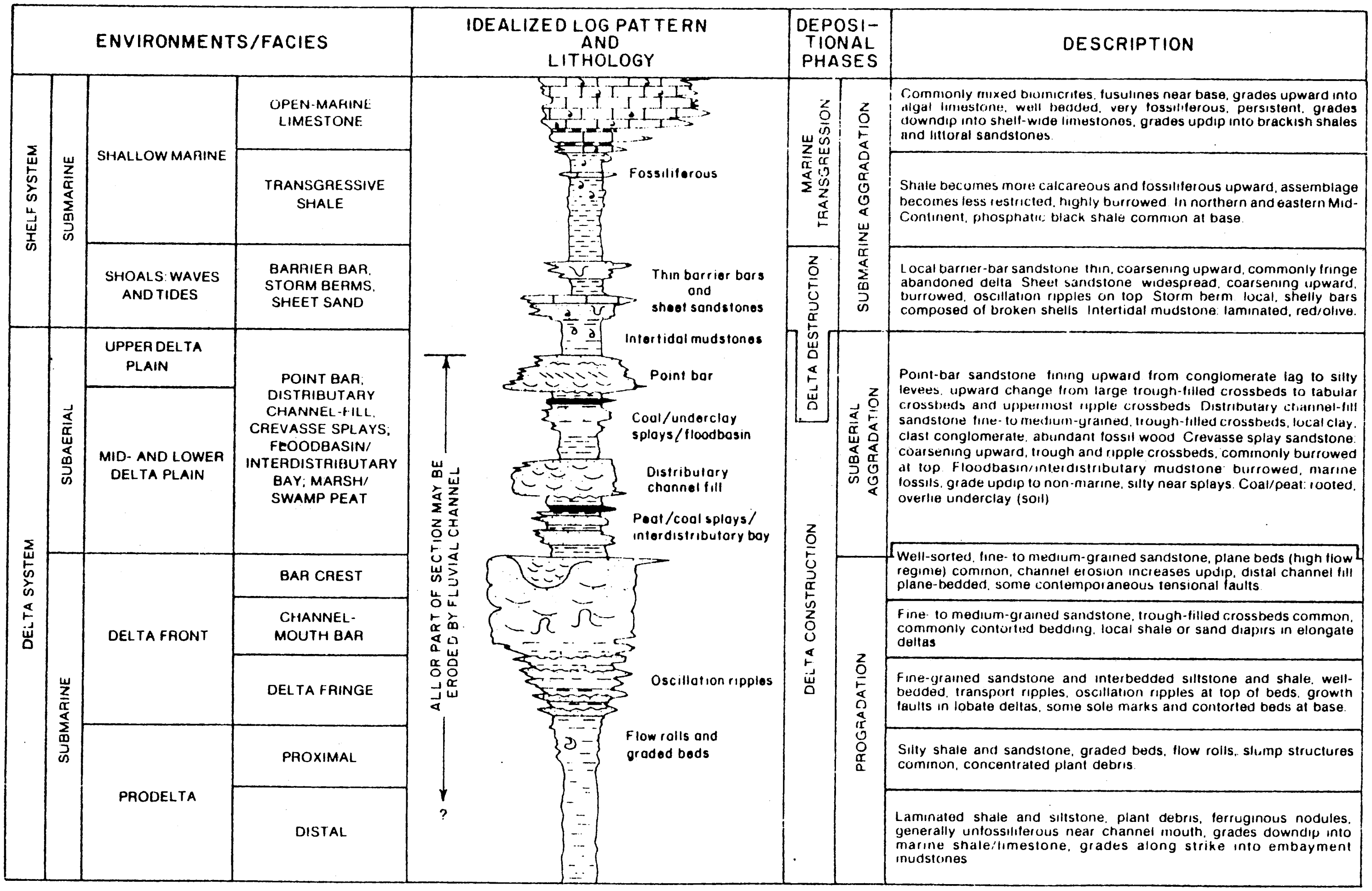


Figure 10. Lewis deltaic facies elements of the Black Warrior Basin.



ENVIRONMENTS/FACIES				DEPOSITIONAL PHASES		DESCRIPTION
SHELF SYSTEM	SUBMARINE	SHALLOW MARINE	OPEN-MARINE LIMESTONE	MARINE TRANSGRESSION	SUBMARINE AGGRADATION	Commonly mixed biomicrites, fusulines near base, grades upward into algal limestone, well bedded, very fossiliferous, persistent, grades downdip into shelf-wide limestones, grades updip into brackish shales and littoral sandstones.
			TRANSGRESSIVE SHALE			Shale becomes more calcareous and fossiliferous upward, assemblage becomes less restricted, highly burrowed In northern and eastern Mid-Continent, phosphatic black shale common at base.
		SHOALS: WAVES AND TIDES	BARRIER BAR, STORM BERMS, SHEET SAND	DELTA DESTRUCTION		Local barrier-bar sandstone thin, coarsening upward, commonly fringe abandoned delta Sheet sandstone widespread, coarsening upward, burrowed, oscillation ripples on top Storm berm local, shelly bars composed of broken shells Intertidal mudstone: laminated, red/olive.
DELTA SYSTEM	SUBAERIAL	UPPER DELTA PLAIN MID- AND LOWER DELTA PLAIN	POINT BAR; DISTRIBUTARY CHANNEL-FILL, CREVASSE SPLAYS; FLOODBASIN/ INTERDISTRIBUTARY BAY; MARSH/ SWAMP PEAT	DELTA CONSTRUCTION	SUBAERIAL AGGRADATION	Point-bar sandstone fining upward from conglomerate lag to silty levees, upward change from large trough-filled crossbeds to tabular crossbeds and uppermost ripple crossbeds Distributary channel-fill sandstone fine- to medium-grained, trough-filled crossbeds, local clay-clast conglomerate, abundant fossil wood Crevasse splay sandstone: coarsening upward, trough and ripple crossbeds, commonly burrowed at top Floodbasin/interdistributary mudstone burrowed, marine fossils, grade updip to non-marine, silty near splays. Coal/peat: rooted, overlie underclay (soil)
	SUBMARINE	DELTA FRONT	BAR CREST		PROGRADATION	Well-sorted, fine- to medium-grained sandstone, plane beds (high flow regime) common, channel erosion increases updip, distal channel fill plane-bedded, some contemporaneous tensional faults.
			CHANNEL-MOUTH BAR			Fine- to medium-grained sandstone, trough-filled crossbeds common, commonly contorted bedding, local shale or sand diapirs in elongate deltas
			DELTA FRINGE			Fine-grained sandstone and interbedded siltstone and shale, well-bedded, transport ripples, oscillation ripples at top of beds, growth faults in lobate deltas, some sole marks and contorted beds at base.
		PRODELTA	PROXIMAL			Silty shale and sandstone, graded beds, flow rolls, slump structures common, concentrated plant debris.
			DISTAL			Laminated shale and siltstone, plant debris, ferruginous nodules, generally unfossiliferous near channel mouth, grades downdip into marine shale/limestone, grades along strike into embayment mudstones

Figure 11. Idealized vertical cratonic delta sequence (from Brwon, 1979).

Deltaic Models and Facies

A valuable classification scheme for describing deltas was first proposed by Fisher (1968, 1969) and was later refined by Galloway (Galloway, 1975). This approach delineates the relative influences of fluvial processes versus marine processes in constructing the surface geomorphic features of delta systems and the geometric distribution of framework sand bodies. When fluvial processes predominate and down dip progradation is a significant aspect of delta construction, the system can be termed high-constructive. On the other hand, when marine processes such as tides, longshore drift, and marine wave attack result in a dominance of marine reworked facies, the term high-destructive should be applied.

Figure 12 illustrates the four basic elements of Fisher's classification of marine deltas. High-constructive deltas can be subdivided into two distinct types based on the coastal geomorphology (modern deltas) or the net sandstone isolith map of the aggregate sandstone bodies within the system (subsurface deltas). Elongate deltas are characterized by well-defined, finger-like sandstone bodies comprised of the distributary channel-fill and channel-mouth bar (bar fingers). These deltas also have a thick prodelta mud facies that allows for the almost complete storage of the deltaic sands by compactional subsidence. Such delta lobes usually form by progradation into a low energy marine setting where the depth becomes abruptly greater. The best Holocene example of a high-constructive elongate delta is the presently active lobe (Balize Lobe) of the Mississippi Delta Complex (Coleman, 1967).

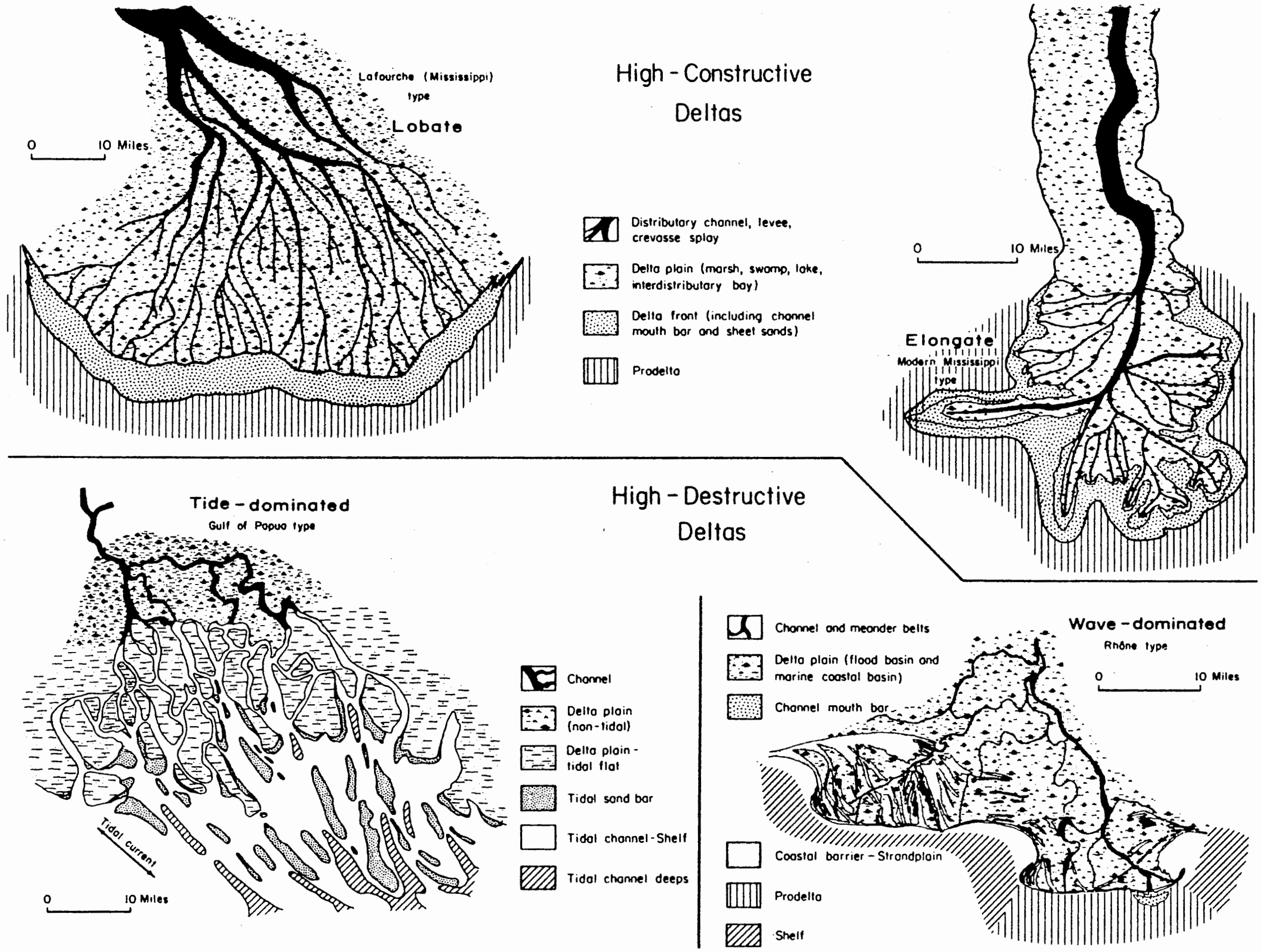


Figure 12. Four basic delta types (from Bureau of Economic Geology, 1969).

High-constructive lobate deltas lack the well-defined barfingers of the elongate delta species and instead have a more smooth, rounded coastline. The delta front is made up of a sheet sand formed through the coalescence of channel-mouth bars of distributaries. This coalescence results from the facts that the delta front is underlain by a thinner prodelta platform than with elongate deltas and that the slower rate of compactional subsidence with lobate deltas allows for extensive marine reworking of distributary channel-mouth bars (Fisher and others, 1969). The Lafourche Lobe of the Holocene Mississippi Delta Complex is the type example of a lobate delta. Figure 13 demonstrates the lateral distribution of facies within a lobate delta system and a hypothetical net sandstone isolith map of the same delta system.

With high-destructional deltas, marine processes are dominant in the formation of sand facies elements. The specific kind of marine process determines the delta species, that is, high-destructional wave-dominated or tide-dominated. Distinctive facies of high-destructive wave-dominated deltas develop when waves and longshore currents rework fluvially derived sediment parallel to strike and down-dip progradation of deltaic distributaries is not significant. The resultant delta morphology is cuspate. Typically, cuspate deltas only have one or two major distributaries and the principal sand facies on the delta plain is a series of strandplain beach ridges. The Brazilian Sao Francisco Delta is a Holocene example of a cuspate, wave-dominated delta. Figure 14 illustrates the lateral facies distribution and hypothetical net sandstone isolith map for a wave-dominated delta. Figure 15 summarizes the vertical sequence of textures and sedimentary structures for the Sao Francisco Delta.

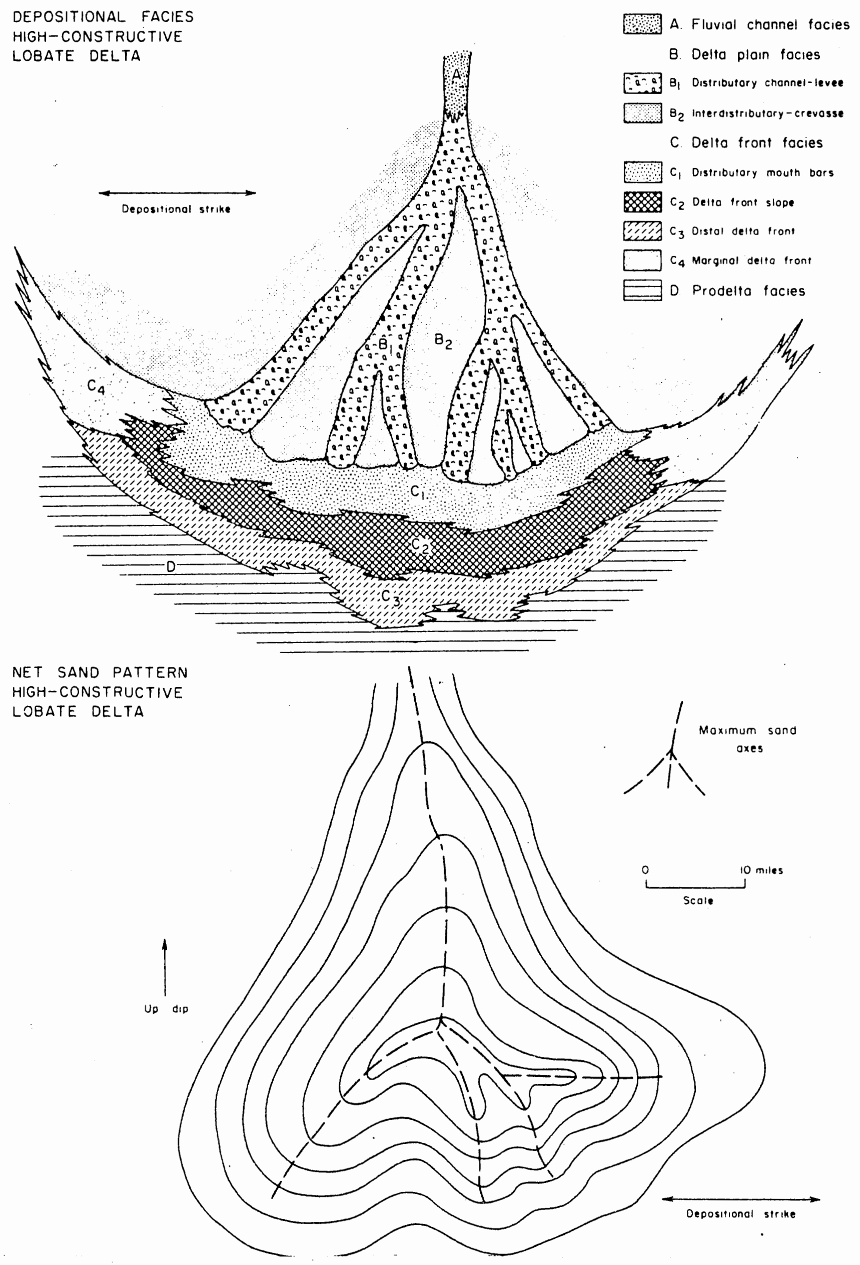


Figure 13. Sand pattern and lithologic facies distribution in high-constructive lobate deltas (from Fisher, 1969).

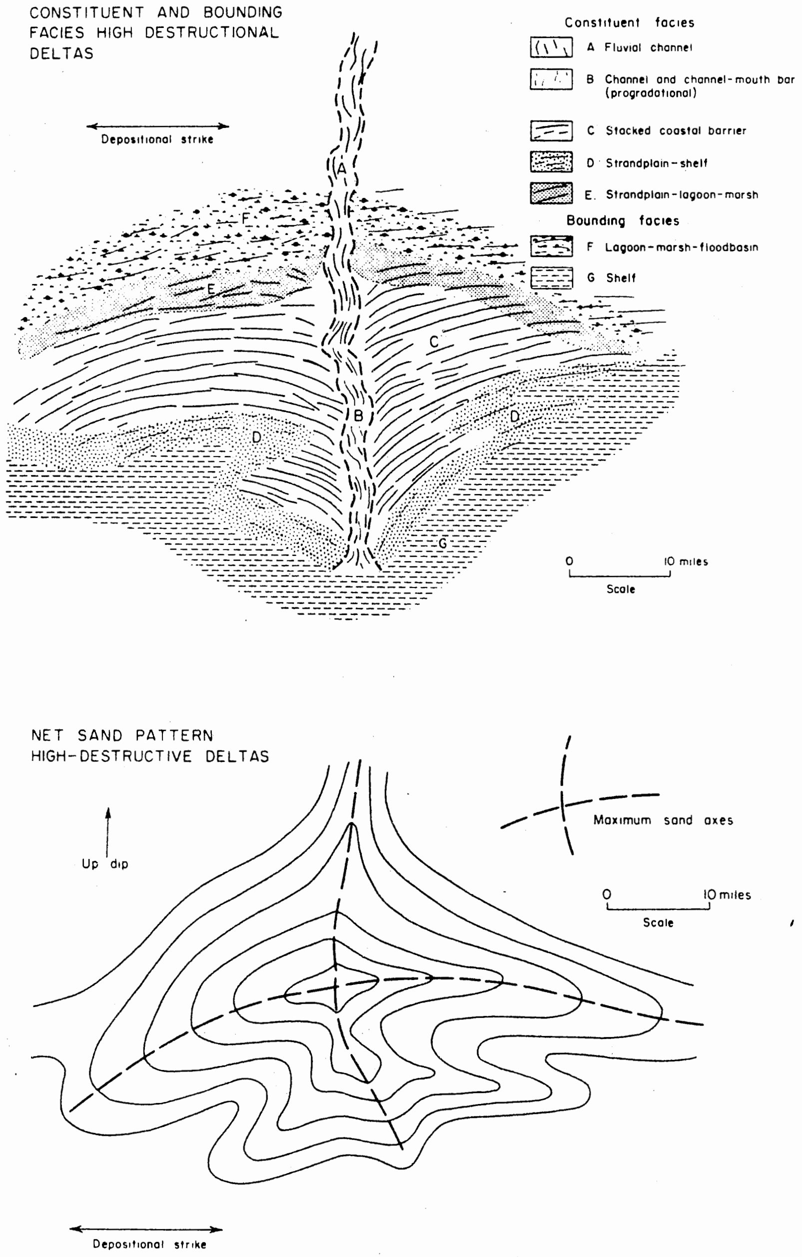


Figure 14. Net sand pattern and lithologic facies of high-destructive wave dominated deltas (from Fisher, 1969).

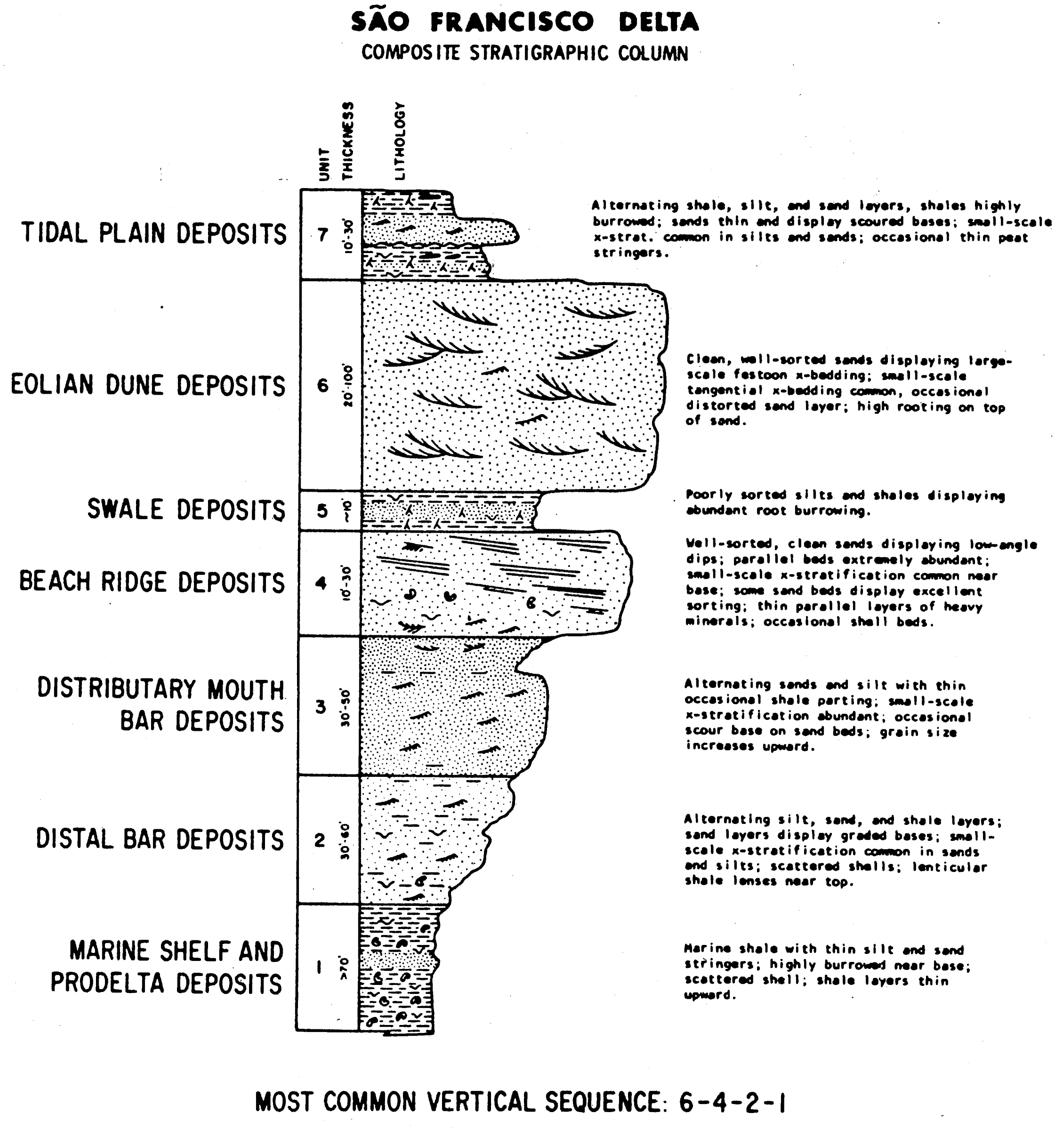


Figure 15. Composite stratigraphic column of Sao Francisco River Delta (Coleman, 1981).

High-destructive tide-dominated deltas are the least understood of the principal deltaic species. No clear-cut examples from the stratigraphic record have been described in the geological literature. The best Holocene depositional models include the Klang (Malaysia) and Ord (Australia) Deltas, both of which were described by Coleman (1981). The Klang Delta seems more pertinent to the Chesterian rocks, because of the wet climate. Important, preservable facies present with the Klang include tidally produced shelf sands, distributary mouth bar deposits, and tidal flats (Figure 16). Distributary channels, when preserved, show significant evidence of bimodal cross bedding.

Figure 17 presents a theoretical net sandstone isolith map that might result from a tide-dominated delta. The map consists of finger-like protrusions of channel sands and a large number of isolated sand bodies present seaward from the shoreline (Coleman, 1981). The fingers represent sand-filled channels that should display a scoured base, whereas the offshore linear sand bodies form by tidal reworking and deposition of fluvial sediment at the channel mouth bar. These linear sand bodies may parallel depositional strike, particularly with narrow, open ended seaways, or may show an approximate dip orientation, where the seaway is narrow and closed at one end. The environmental setting most conducive for the formation of high-destructional tide-dominated deltas thus include low wave energy, a high tidal range, and narrow, restricted depositional basins that are indented to the coast (Coleman, 1981).

All four of the Fisher delta models have been applied to Chester sandstone bodies on the Northern Shelf of the Black Warrior Basin. Cleaves (1980, 1983) and Cleaves and Broussard (1980) described the Rea and Carter Sandstones as representing high-constructive elongate

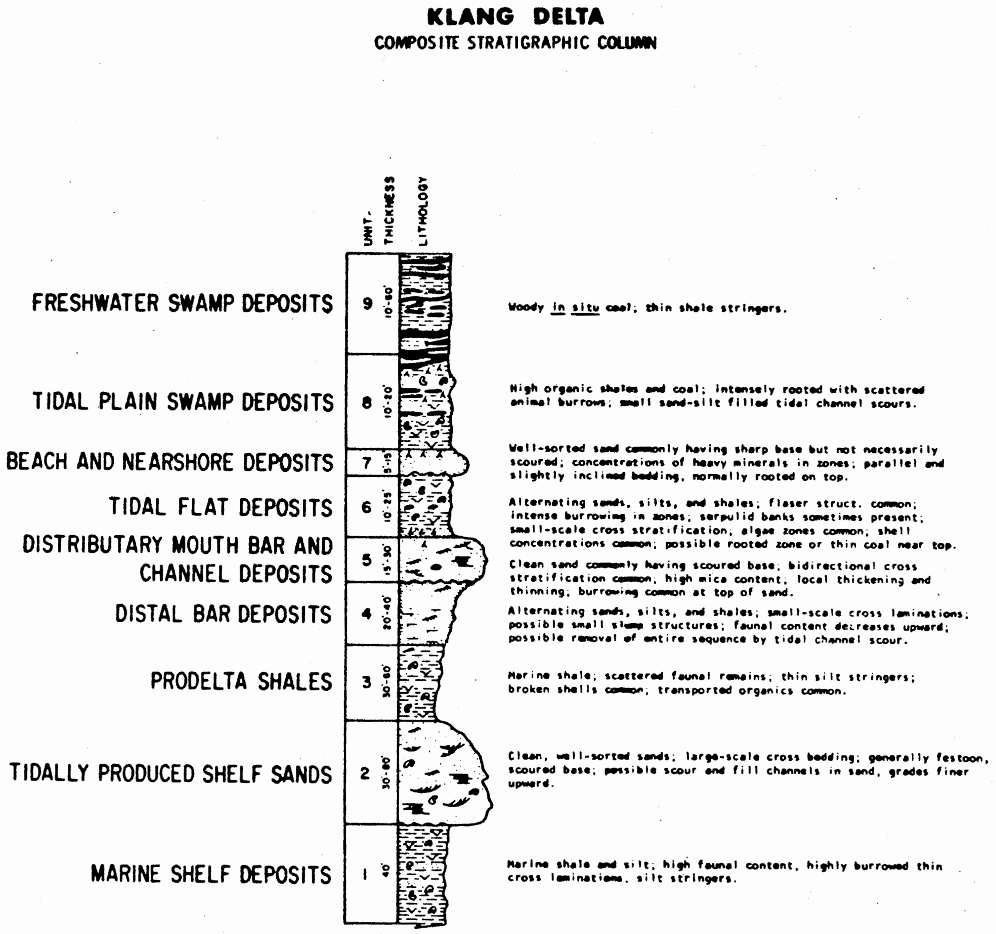


Figure 16. Composite stratigraphic column of Klang River Delta (from Coleman, 1981).

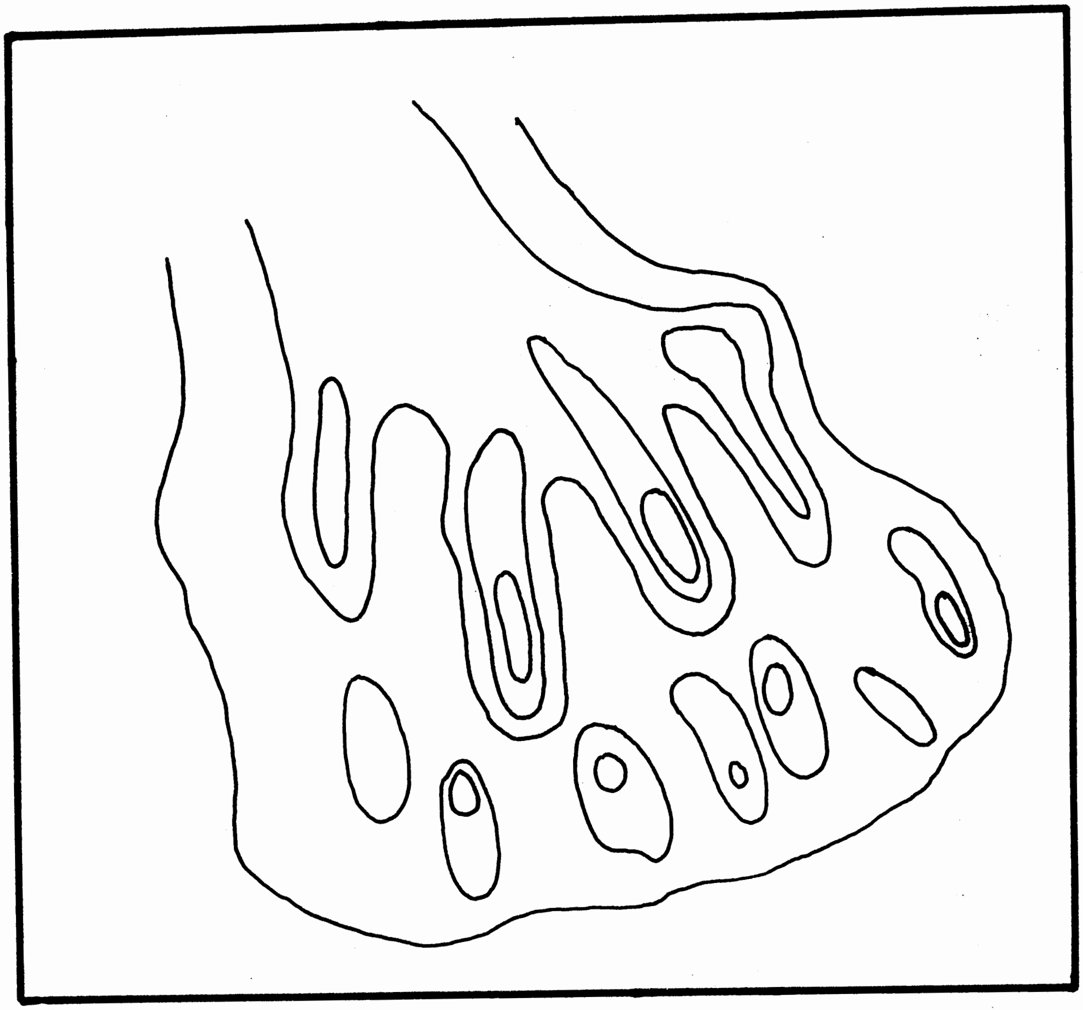
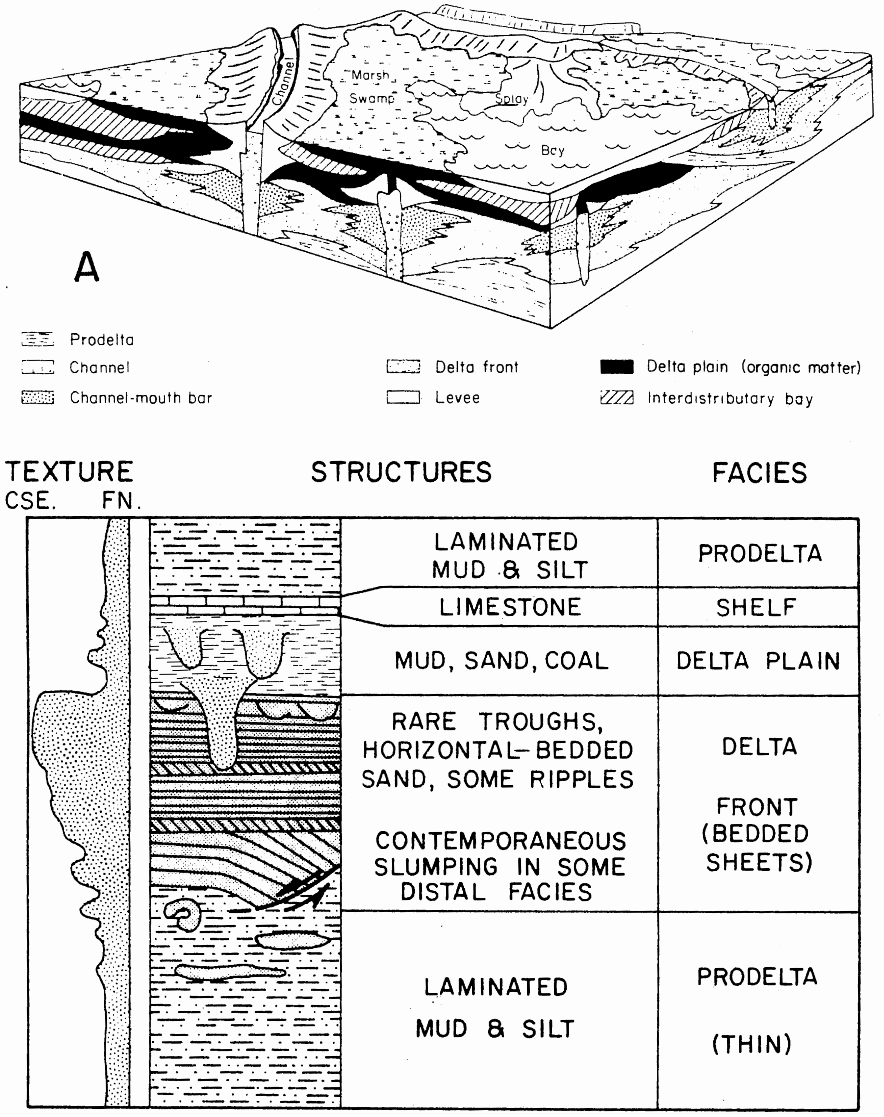


Figure 17. Net sand distribution pattern for a tide-dominated delta (after Coleman and Wright, 1975).

systems, the Lewis and Sanders Sandstones as being high-constructive lobate deltas, the Hartselle and Evans as being high-destructive wave-dominated deltas, and the Gilmer as being a hybrid intermediate between high-constructive lobate and high-destructive tide-dominated delta species. Holmes (1979, 1981) and Di Giovanni (1984) have interpreted Lewis Sandstone bodies mapped in Colbert, Franklin, Lamar, Walker, Marion, and Fayette Counties, Alabama as being shelf linear sand ridges that were deposited by tidal processes. With this interpretation, up-dip Lewis deltaic facies of Mississippi would represent tide-dominated deltas. Thomas (1980) and Thomas and Mack (1982) reject any deltaic interpretation for the Hartselle Sandstone and have it as being a barrier bar complex.

Delta systems laid down on the Chesterian Northern Shelf of the Black Warrior Basin accumulated in a stable, cratonic setting on the margin of an epeiric sea. Brown (1973, 1979) has developed a cratonic delta model applicable to stable shelf depositional settings. The two vertical sequences furnished in Figures 18 and 19 supply vertical sequences of textures and sedimentary structures characteristic of cratonic high-constructive elongate and lobate delta sequences. With the elongate type, the coarsening upward progradational sequence is commonly quite abrupt and soft-sediment deformation in the bar-finger is prominent; thick prodelta mudstones underlie this sequence. By way of contrast, the progradational sequence in the lobate delta front evidences a more gradual textural coarsening upward and contains a distinctive sheet sandstone facies dominated by oscillation ripple cross stratification. The prodelta underlying a lobate deltaic progradational sequence is much thinner than with the elongate sequence. Commonly, with smaller lobate



B LOBATE TO SHEET-LIKE SAND BODY

Figure 18. Lobate delta model - (A) Lafourche lobe, Holocene Mississippi Delta; (B) Idealized vertical sequence of lobate deltas in intracratonic basins.

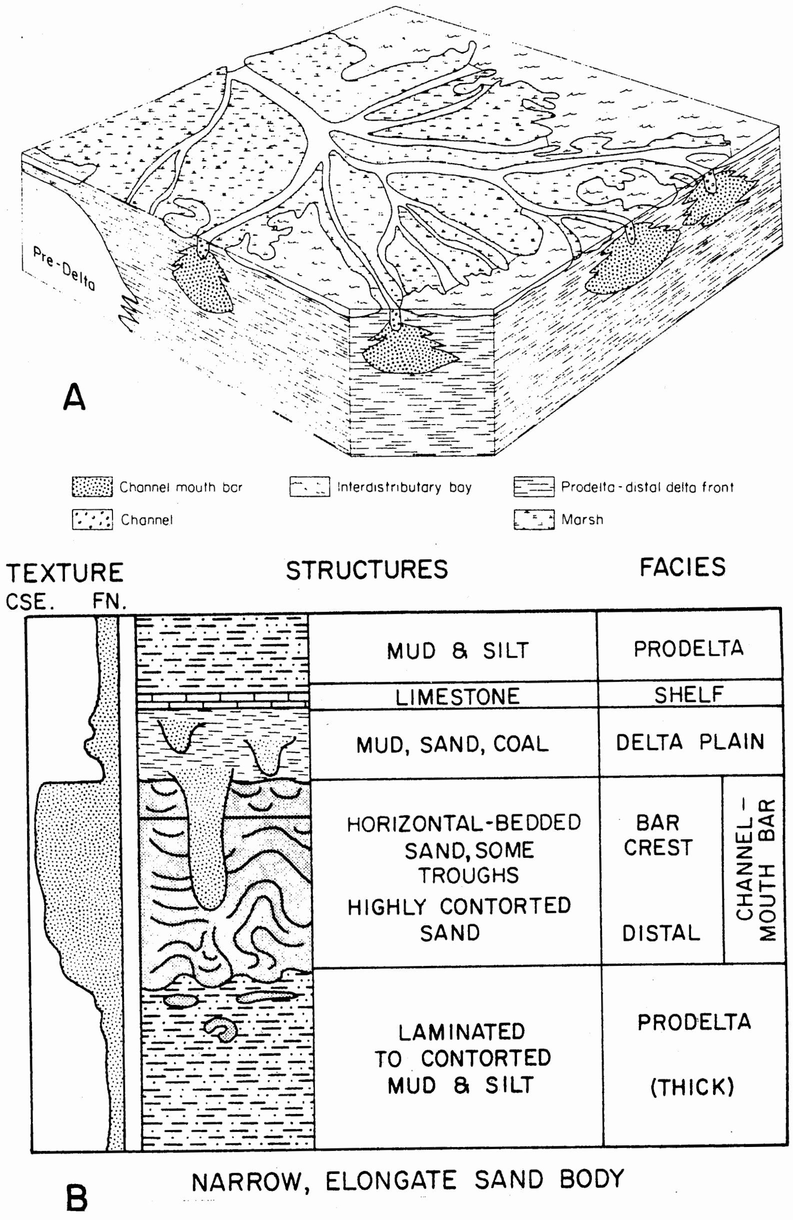


Figure 19. Elongate delta model - (A) Birdfoot lobe, Holocene Mississippi Delta (after Fisk et al., 1954); (B) Idealized vertical sequence of elongate deltas in intracratonic basins (after Brown, et al., 1973).

delta sequences, the distributary channel cuts through the entire progradational sequence. Under such circumstances a "naked" distributary channel-fill deposit may be the only locally preserved coarse-grained deltaic facies.

Figure 20a and 20b illustrate a spectrum of marine deltaic types that develop under differing reservoir energy (waves) and sediment input situations. Low marine reservoir energy and high dip-fed sediment input from a fluvial source will give rise to high-constructional elongate or lobate deltas, whereas the reverse will produce a cuspate, high-destructional wave-dominated delta (Figure 20a). The absence of a direct fluvial source for the sediment means that a strike-fed strandplain will form.

A similar interplay between sediment input and wave reworking is demonstrated by the net sandstone isolith patterns of Figure 20b. The lobate represents the setting of maximum sediment input and lowest wave energy, whereas the strike-elongate pattern represents the complete overwhelming of the river system by wave energy and longshore drift. Cleaves (1980, 1983) has interpreted Lewis Sandstone delta lobes using the lobate model, the Evans lobes using the cuspate model, and the Hartselle Sandstone utilizing the strike-elongate model.

Constructional Delta Exploration Targets

Introduction

Because the high-constructional delta models seem to be the most applicable to the Lewis Sandstone, particularly in Mississippi, the principal coarse-grained facies of these deltas will be described in further

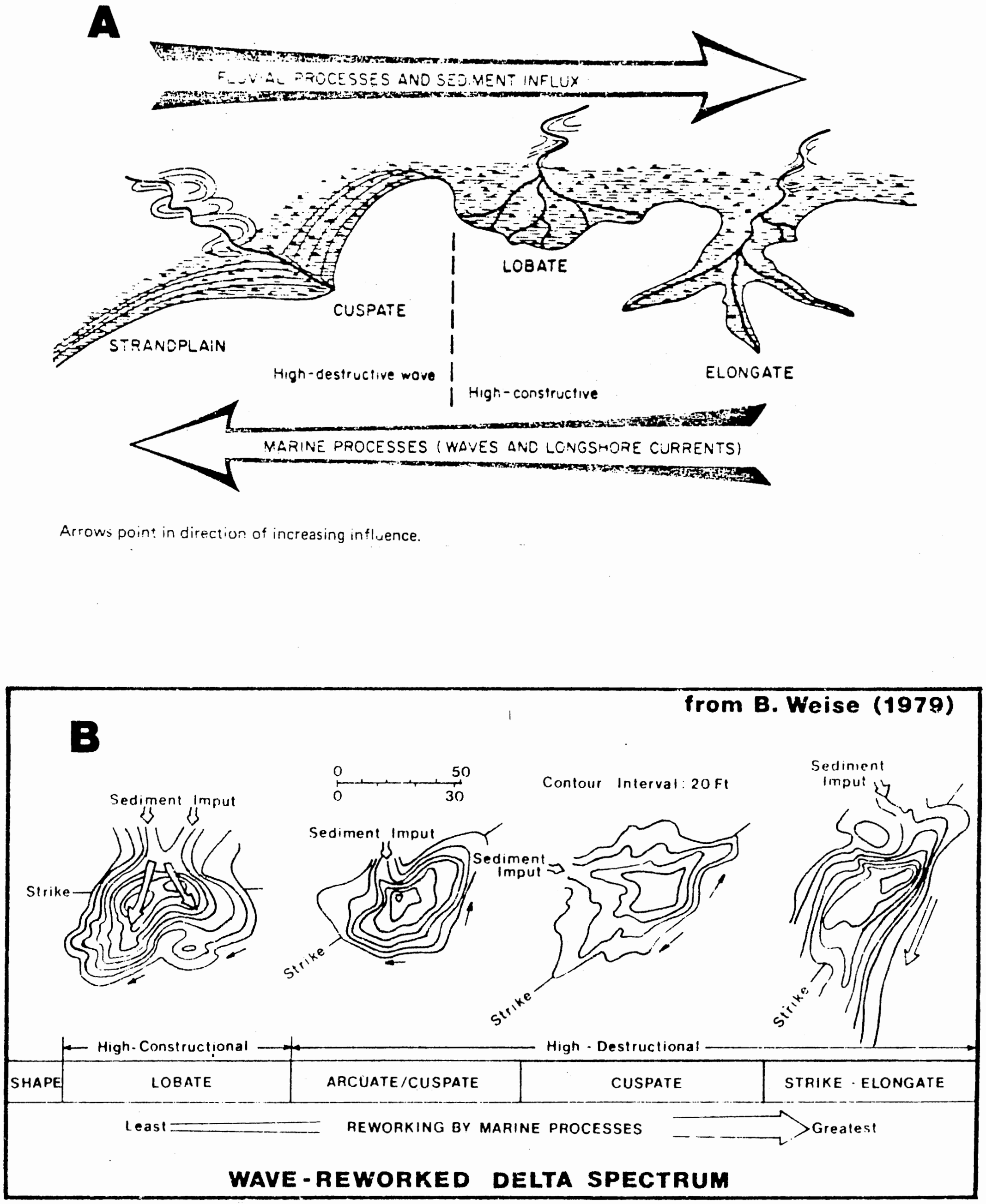


Figure 20. Delta spectrum - (A) Variations of morphologies with increasing marine influence (from Fisher et al., 1969); (B) Wave reworked delta spectrum (from B. Weise, 1979).

detail. According to Galloway and Hobday (1983) the framework (coarse-grained) facies of fluvially-dominated deltas include distributary channel-fill, channel-mouth bars, crevasse splays, and laterally reworked delta-front sheet sands. Figure 21 depicts the major facies of the constructional deltaic depositional setting, as well as the electric log characteristics of these facies.

Distributary Channels

Distributary channels often contain clean, coarse sands and constitute good reservoirs in many cases. Their geometry however can be complex. Channel trends do not always conform strictly to a depositional down-dip direction (particularly in high-destructive delta cases). They commonly wander, travelling along strike or even up-dip. The process of avulsion increases complexity by creating cross cutting or superimposed channels.

Channel fill sequences cut down into their mouth bars and are laterally equivalent to levee, crevasse splay, marsh, swamp and lake deposits of the dynamic delta plain environment. They are overlain by either aggradational delta front or alluvial deposits or transgressive marine sediments.

Channel Mouth Bar

The distributary mouth bar is the site of greatest sand accumulation in the high-constructive delta environment. The compaction of mouth bar sands into underlying prodelta muds combined with low wave energy serves to preserve the sands from reworking. The mouth bar sequence of sediments coarsens upwards in response to the superimposition

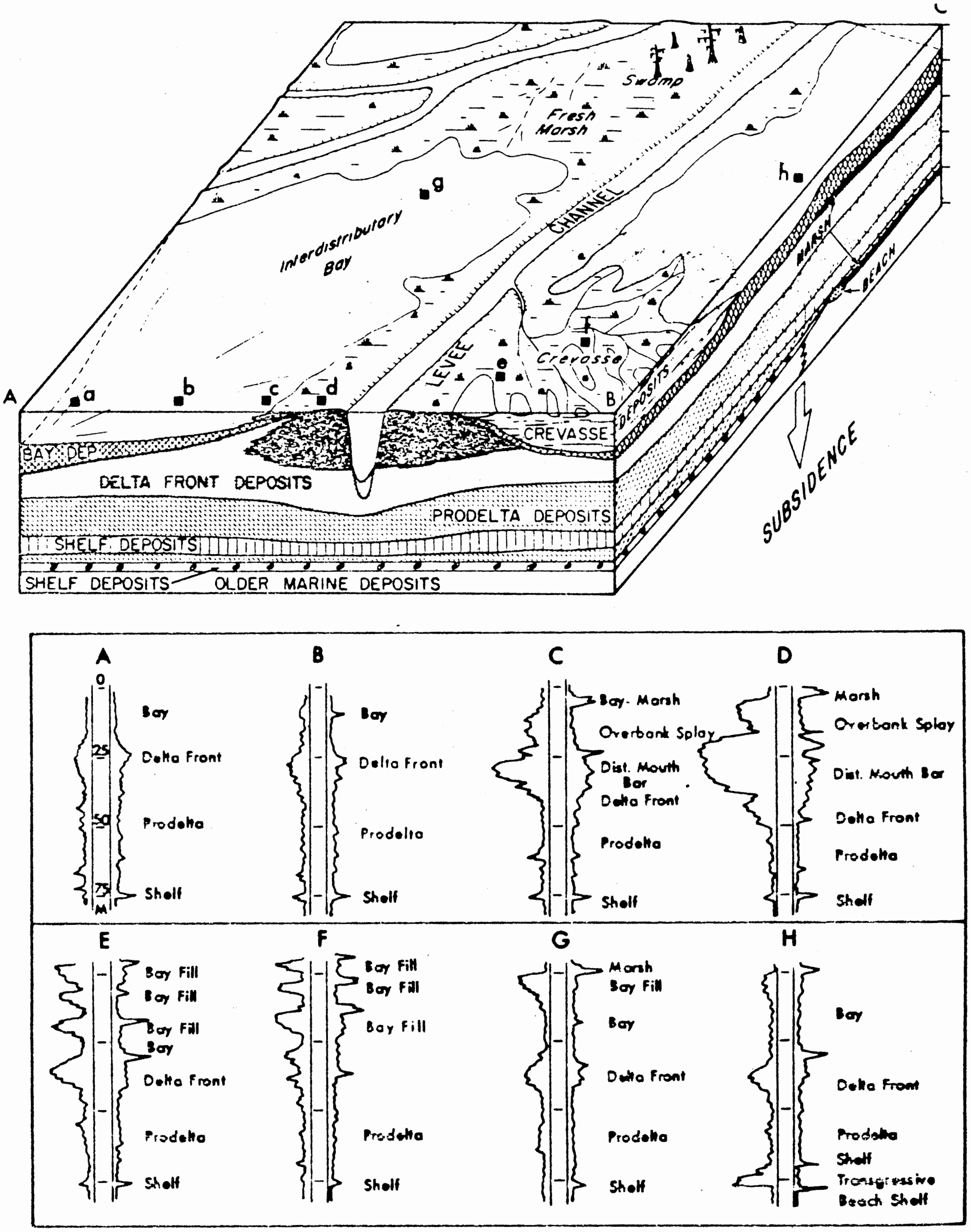


Figure 21. Major deltaic facies and associated electric logs signatures (from Coleman, 1981).

of more proximal facies with progradation. It is underlain by muds of the prodelta and overlain by levee and delta plain marsh deposits. Laterally adjacent, mouth bar sands interfinger with interdistributary sand, silt and mud.

The channel mouth bar is scoured into by the advancing distributary channel. Brown (1979) and Hobday (1978) have stated that in many cases of intracratonic basins, scouring by the advancing channel is so extensive as to leave only remnants of the bar on either side of the channel. As the distributary channel is abandoned it alluviates with fine grained sediment forming a plug.

Crevasse Splays

Crevasse splays break off main distributaries and fill interdistributary bays. They extend themselves seaward through a system of bifurcating channels similar in plan to the veins of a leaf. They are generally relatively thin deposits (3-15m) resulting from a breach of the channel levee during flood stage. Subsidence follows the cessation of sedimentation and cycles are repeated often overlapping each other. Cycles are normally composed of an original, marine bay bottom grading up into prodelta and delta front deposits of silts and clays. This is then topped by the coarsest sediments of the splay corresponding to distributary mouth bars. Uppermost in the cycle are marsh deposits.

Delta Front Sheet Sands

Lobate deltas exhibit reworked sand bodies adjacent to active distributary mouth bars. These sheet sands connect the bifurcating distributary mouth bar network and are composed themselves of relatively thin, upwardly coarsening sand transported by longshore drift. They are typically well sorted by wave or current action. Sedimentary structures include "ripple lamination, low angle planar lamination and burrows and trails" (Galloway and Hobday 1983). Delta front sheet sands overlie prodelta and interdistributary muds and are overlain by either destructional marine facies or delta plain sediments.

Destructional Storm and Tide Reworked Shelf Facies

The subject of storm and tide reworked shelf facies is addressed here because their presence has been documented by several recent authors. The authors have noted what they interpret as shallow marine bars reworked by storms and/or tides acting on the shallow shelf area of northwestern Alabama.

Mancini and others (1983) proposed that the Lewis sands were deposited as sand ridges by tidally induced currents acting on a shallow marine, storm traversed shelf. The authors of that article used the following substantiating evidence in their interpretation: Identification of distinct bar lithofacies and interbar muds; elongation of sand bodies parallel to present day structural strike; dimensions similar to modern North Sea sand ridges, and; a vertical sequence of sedimentary structures consistent with those described for modern and ancient shelf sands.

Di Giovanni (1984) cites three compositional indicators of marine shelf sandstones found in the Lewis Sandstones of Colbert County, Alabama. They are mineralogical maturity, detrital carbonate content and the presence of marine fossils. In contrast to the article by Mancini and others (1983) Di Giovanni (1984) postulates that the Lewis sands were deposited as storm initiated shelf bars. Supporting this interpretation he documented the existence of both a characteristic vertical sequence of sedimentary structures and horizontal burrowing.

A similar environmental interpretation of the Lewis Sandstone as marine bars was made by Holmes (1981) based on a sequence of sedimentary structures found in the subsurface of Alabama. The sequence of structures observed by Holmes is: Massive sandstone overlain by inclined, parallel, even laminae; overlain by ripples; overlain by shale. This sequence is very similar to the one seen by Di Giovanni (1984). Thus the correlation of subsurface to surface geology and the highly questionable extension of their interpretation to the remainder of the basin.

Several objections were raised by Cleaves (1983) in response to the aforementioned environmental interpretations of the Lewis Sandstone by Holmes (1981), Mancini and others (1983) and Di Giovanni (1984). First he points out that the author's sandstone isolith map constitutes only the distal portions of two delta lobes that extend northwestward into Mississippi. Second, he finds fault with the lack of explanation for additional sandstone units found only in Mississippi. Third, sand ridges or bars form by reworking of relict sands which requires the existence of sub-Lewis sand bodies. No such sands exist and the logical assumption made by Cleaves is the Lewis Sandstone represents a relict facies of fluvial-deltaic sand overlain by a wave reworked facies. Fourth, he favors the more abundant wave reworked evidence from outcrop over negligible evidence for tidal influence.

The findings of this study are consistent with the environmental interpretation by Cleaves (1983). Lewis sandstone units in the subsurface of northwestern Alabama represent wave reworked sheet sands underlain by relict, distal deltaic facies.

Discussions of shelf facies are included in Reineck and Singh (1973, Davis (1983), Pettijohn, Potter and Siever (1973), Klein (1977) and Galloway and Hobday (1983).

CHAPTER VI

PETROLOGY AND DIAGENESIS OF THE LEWIS SANDSTONE

Introduction

The core used in this study is from the #2 J. R. Falkner 28-2 well drilled by the Louisiana Land and Exploration Company in the Troy Field, section 28, township 11S, range 4E, Pontotoc County, Mississippi (Figure 22). Total depth reached was 2592 feet. The well was completed the week of October 19, 1981. Total initial production from two zones was 2,449 mcfg per day. The Lewis accounted for 1,424 mcfgd per day of the total.

The core described for this study was logged on a scale of 1/2" =10 feet (Figure 23). Samples were taken for thin sections, clay extractions, x-ray diffraction and scanning electron microscopy.

Core Description

The principal unit evaluated in the core involved 41 feet of uninterrupted, fine to medium grained Lewis Sandstone. A scoured base of granule-pebble sized conglomerate and the presence of climbing ripples at the top suggest deposition in a distributary channel or upper delta plain fluvial environment (Figure 23). The well developed spontaneous potential curve is also characteristic of channel deposition. Other

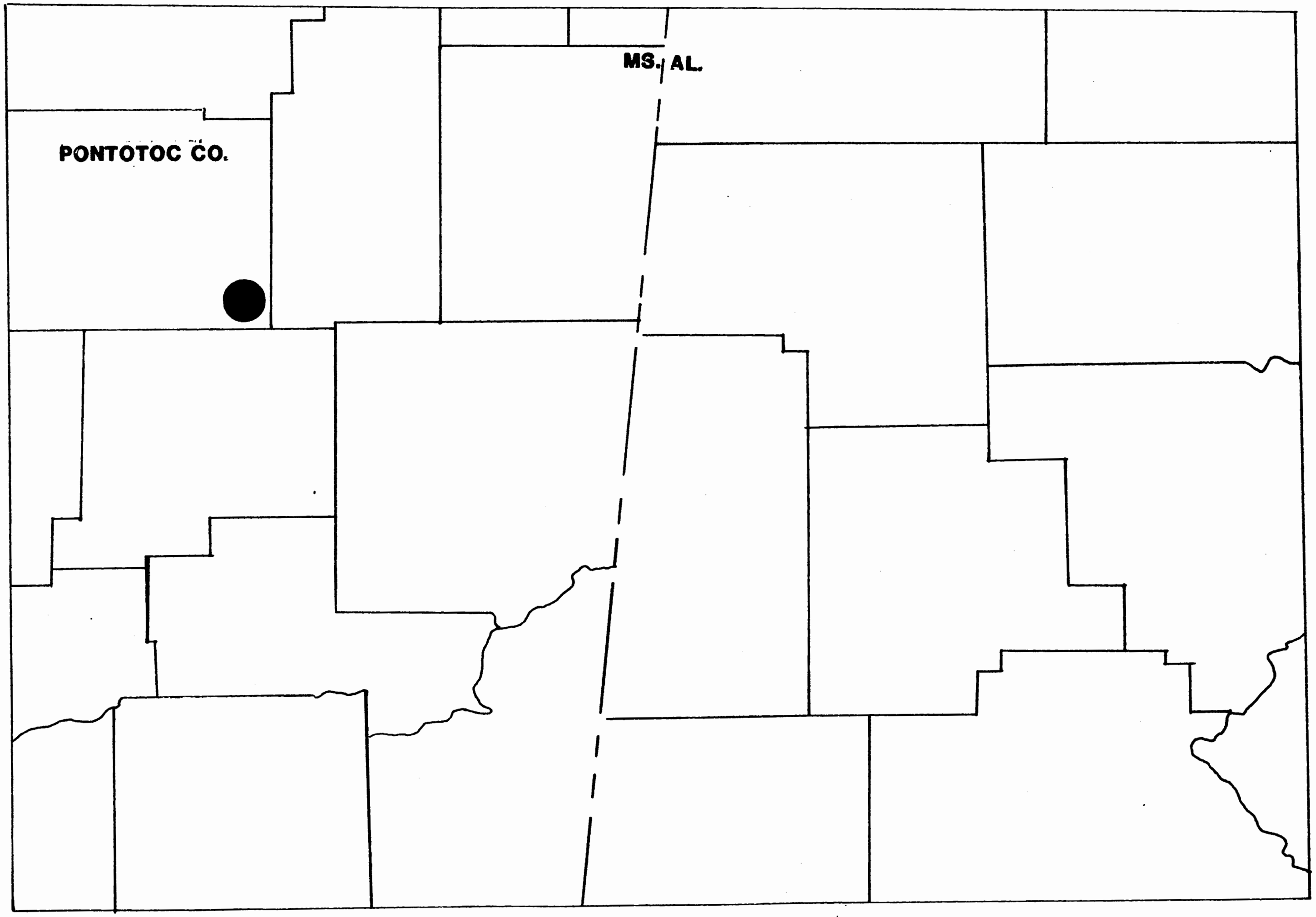


Figure 22. Location of core used in the study.

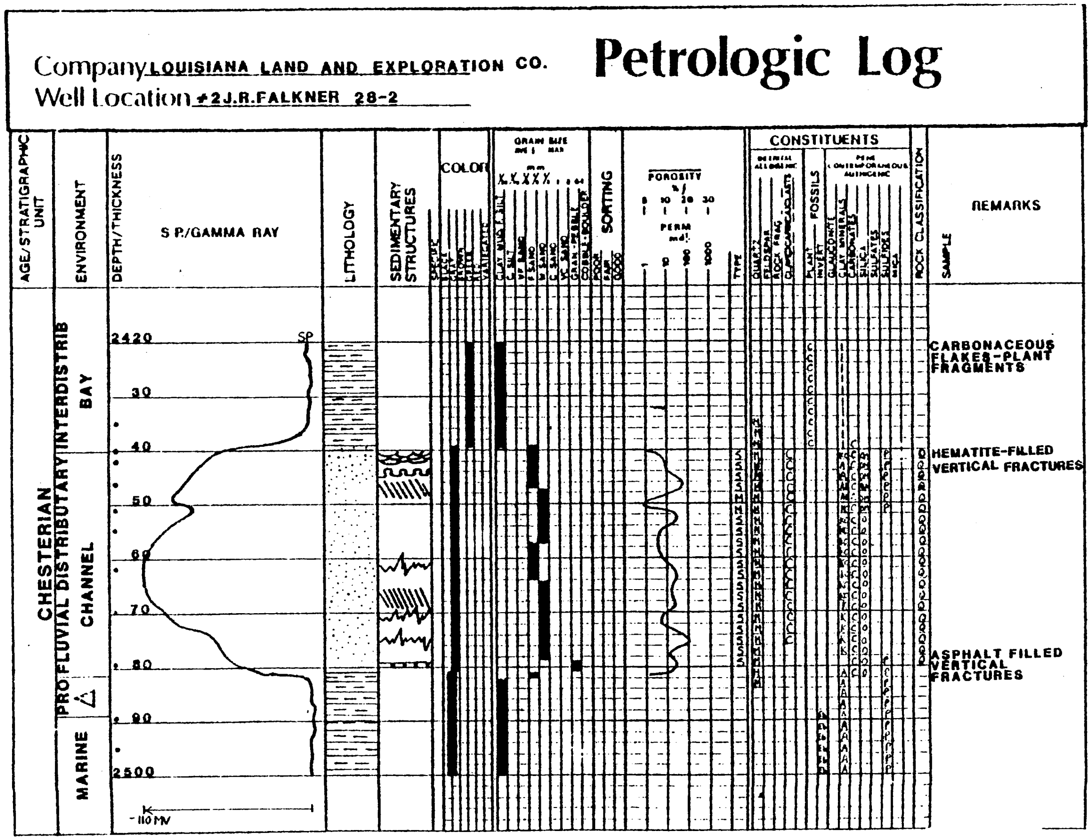


Figure 23. Petrologic log for the #2 J. R. Falkner 28-2 core.

sedimentary structures include bioturbation, stylolitization, inclined laminae, and soft sediment deformation (Figures 24 and 25).

Composition and Classification of the Lewis Sandstone

Plotted on a Q-F-R diagram without regard for metastable constituents now dissolved or replaced, the average Lewis composition falls within the quartz-arenitz subdivision of the triangle (Figure 26). Based on the common occurrence of remnant rock fragments lining dissolution pores, it seems likely that the original sediment was a sublitharenite.

Detrital Constituents

Figure 27 shows the relative abundance of allogenic constituents found to approximate the averages in the core. Monocrystalline quartz grains ranging from fine to medium sand size account for an average of 73% of the bulk volume (porosity included) (Figure 28). Polycrystalline quartz averaged 3% of the total. Single grains of microcline and plagioclase feldspar were seen in a few thin sections. Shale, chert and metamorphic rock fragments were commonly observed. Shale clasts ranged from a trace to 5% over the studied interval. Chert fragments consistently accounted for 1% of the total (Figure 29). Metamorphic rock fragments occurred as one or two grains in a few thin sections (Figure 30). Accessory minerals, which were rarely seen as more than a trace, include muscovite, biotite, zircon, hematite, pyrite and kerogen (Figure 31). Detrital matrix, where present, was illitic and ranged from a trace to 12%.

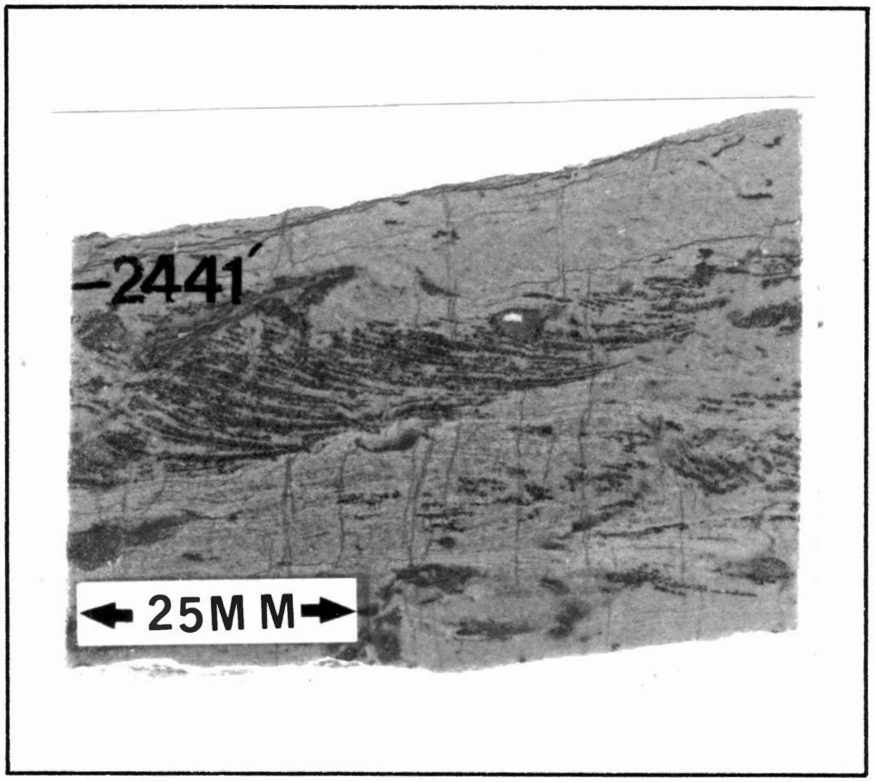


Figure 24. Photograph of cut core showing climbing ripples.

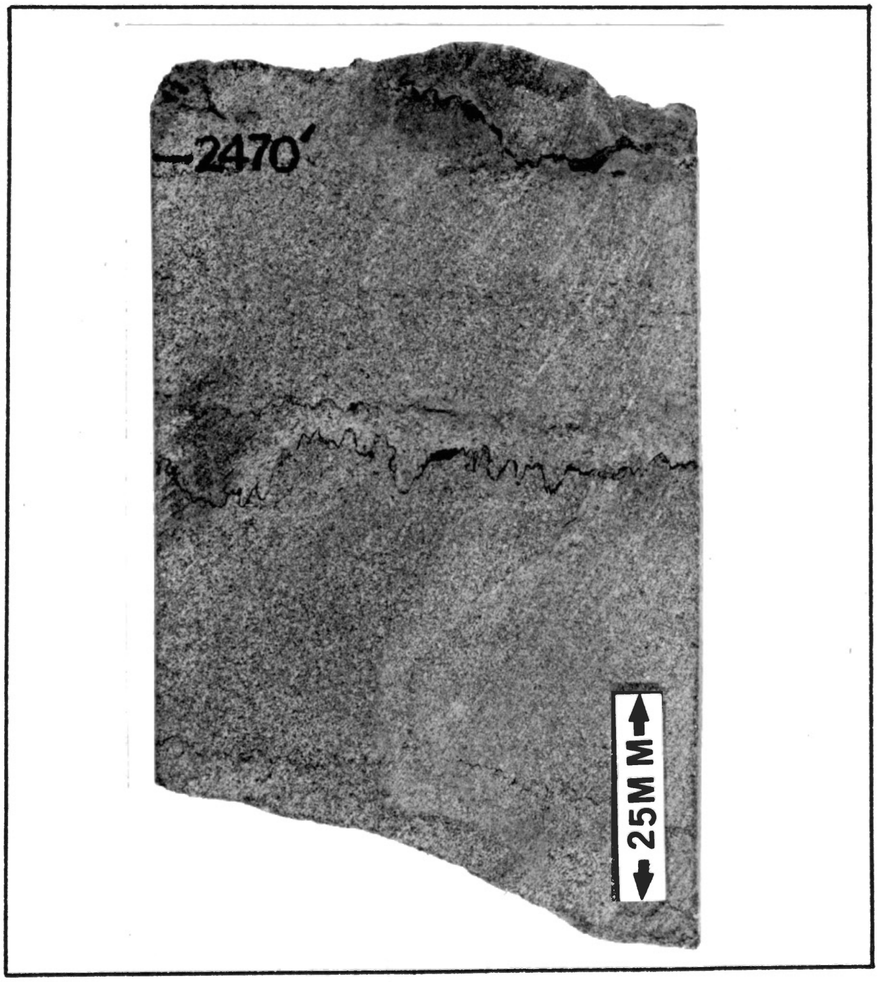


Figure 25. Photograph of cut core showing stylolites.

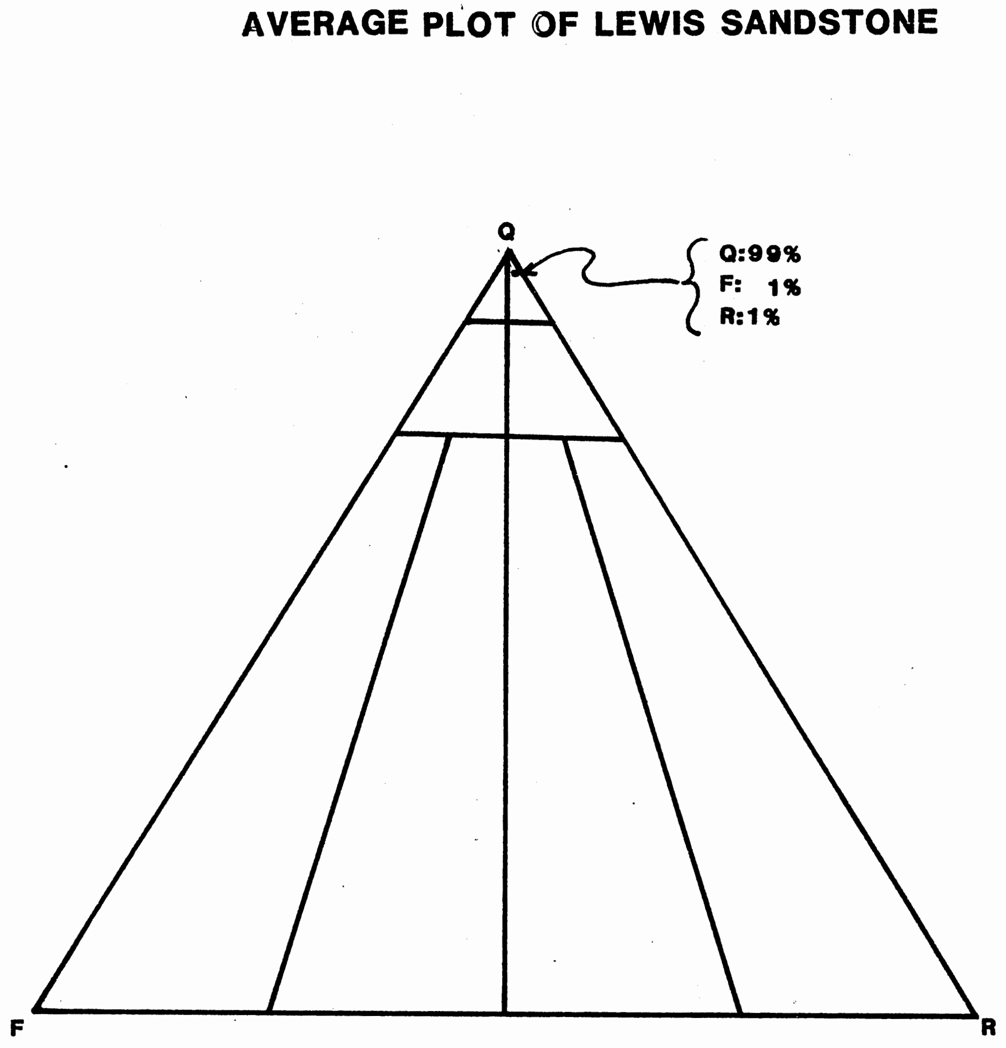


Figure 26. Q-F-R plot of Lewis Sandstone without regard for partially dissolved metastable constituents.

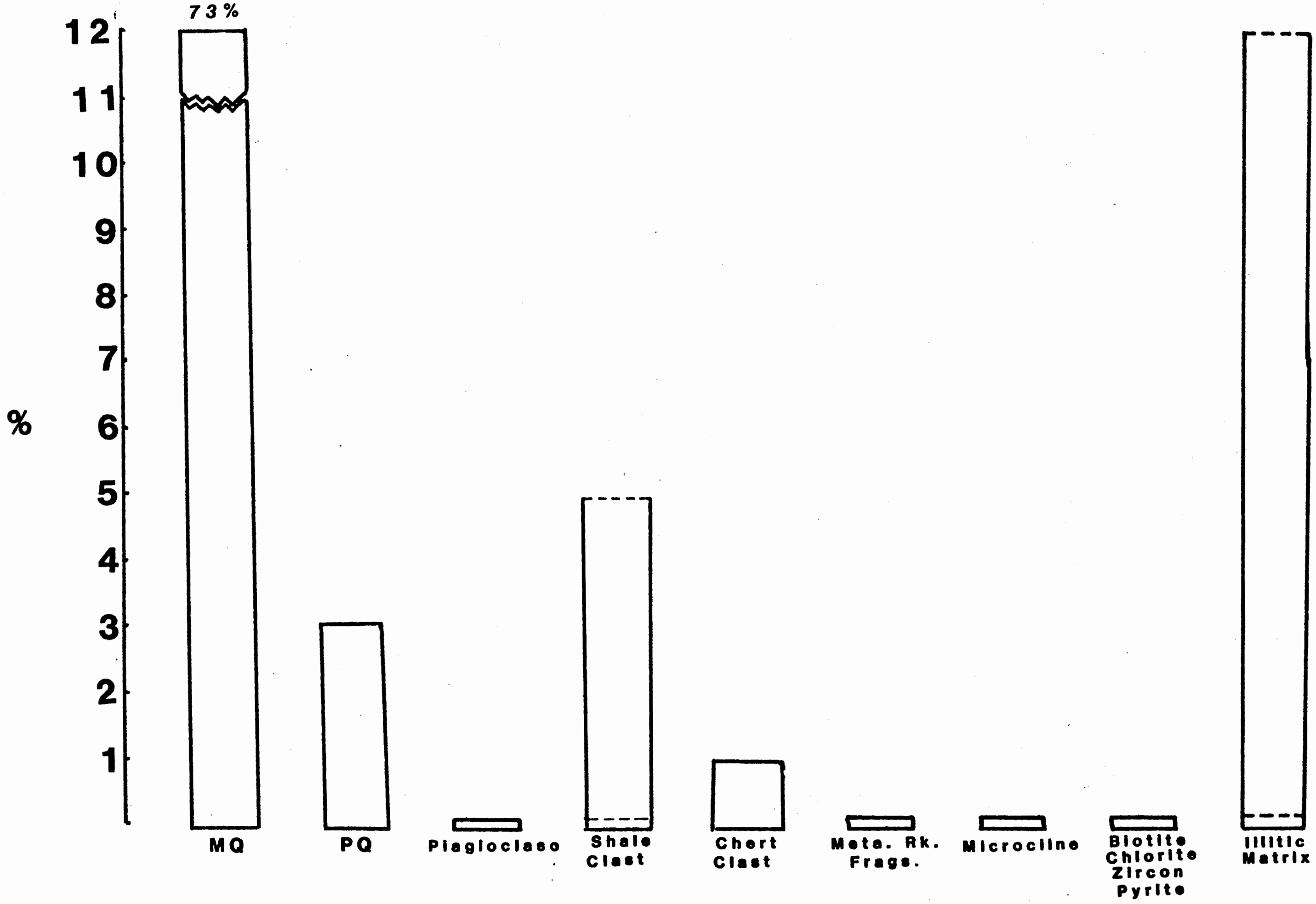


Figure 27. Allogenic compositions from thin section analysis.

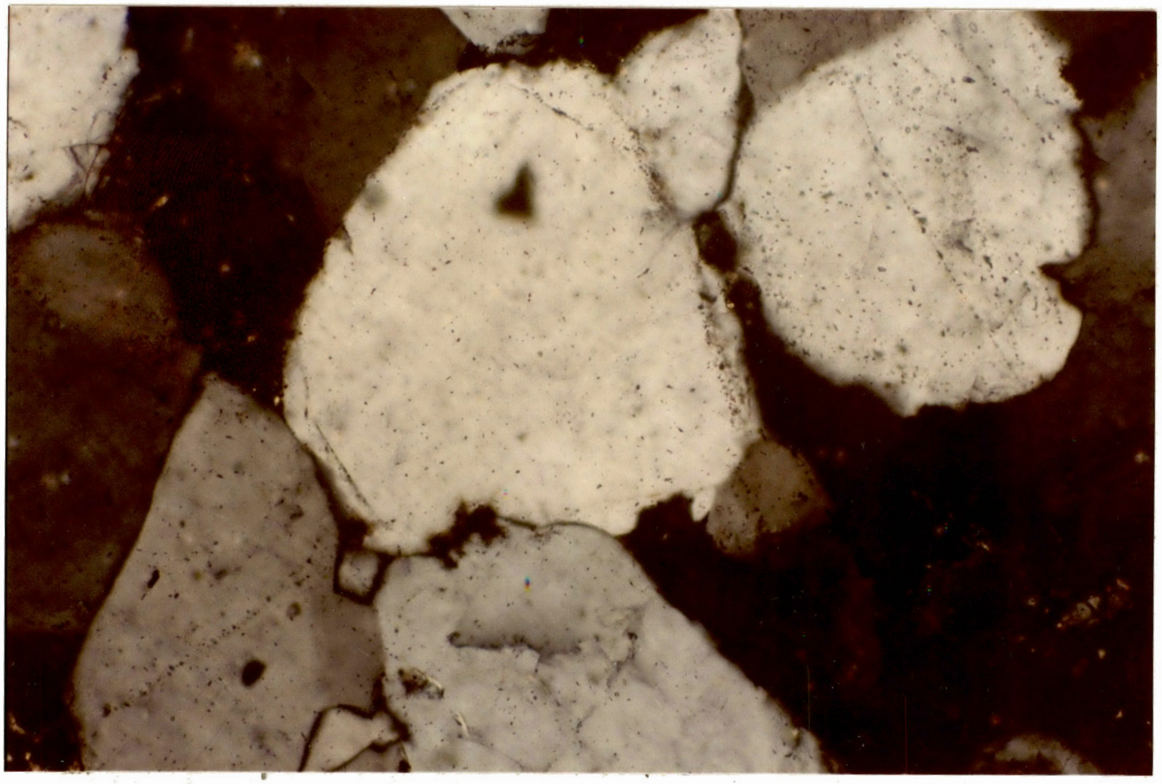


Figure 28. Photomicrograph of monocrystalline quartz grain with syntaxial quartz overgrowth and chemical compaction at grain boundaries (200X, crossed polarized light, 2462').

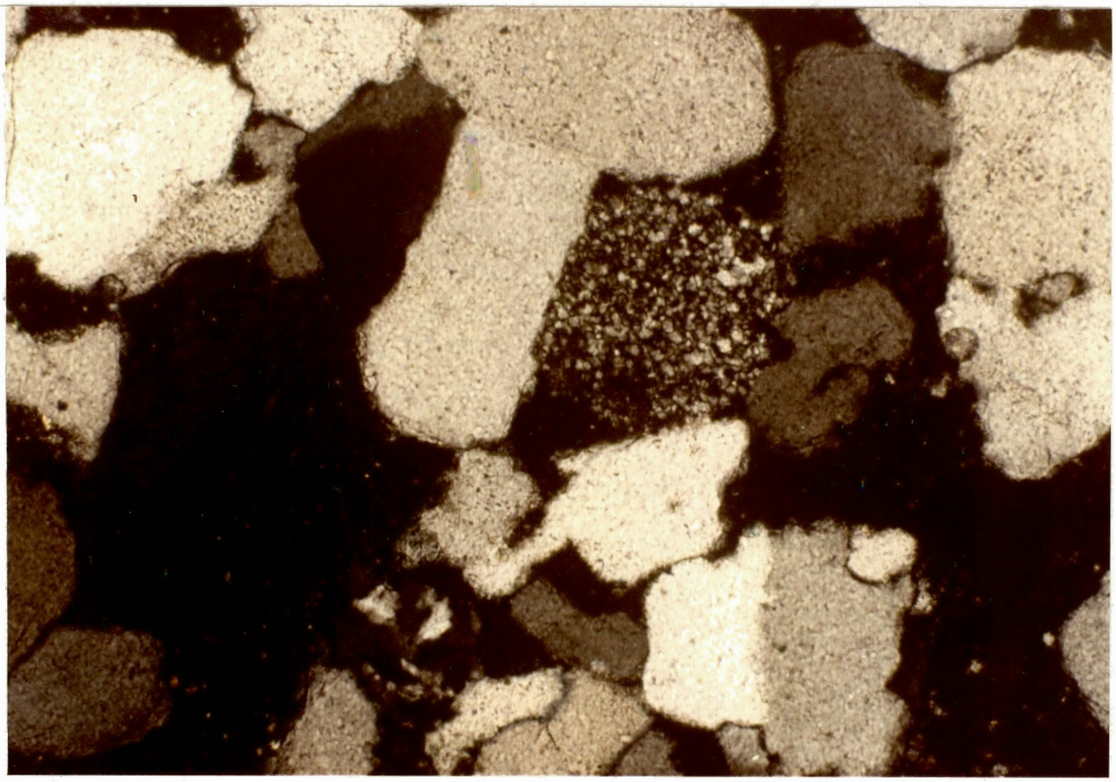


Figure 29. Photomicrograph of a chert rock fragment (100X, c.p.l., 2479').

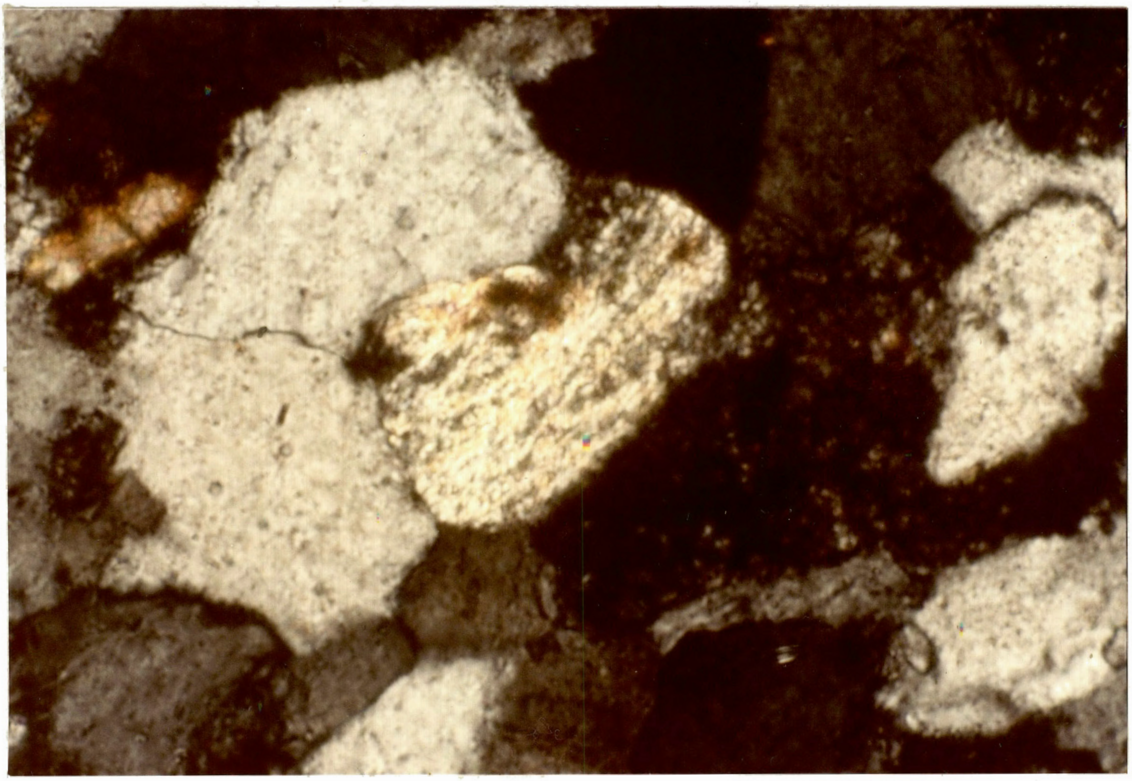


Figure 30. Photomicrograph of a low grade metamorphic rock fragment (200X, c.p.l., 2446').

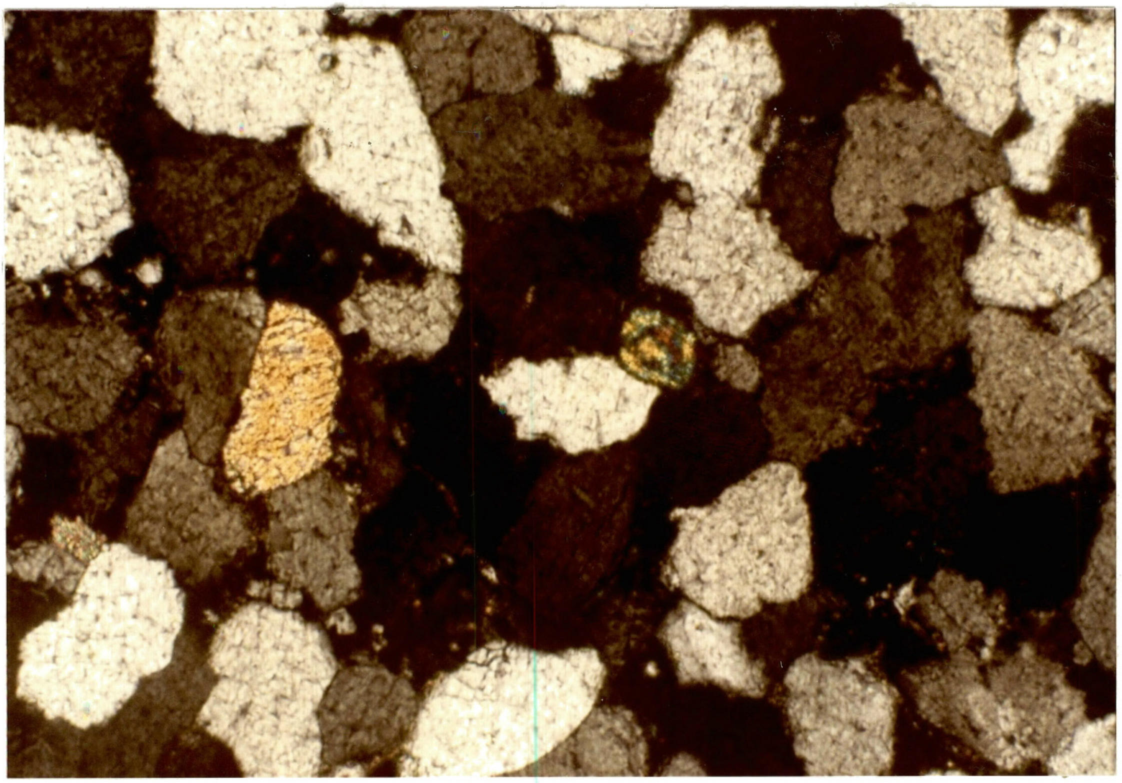


Figure 31. Photomicrograph of accessory minerals biotite and zircon (100X, c.p.l., 2451').

Diagenetic Constituents

Diagenetic constituents present in thin sections of the Lewis Sandstone included quartz overgrowths, chert cement, calcite cement, and authigenic clays. Overgrowths existed everywhere in the sand and averaged 6% of total bulk volume. Chert cement was seen only in the upper ten feet of sand and ranged in content from 1-10%. Calcite cement was present in all thin sections examined and ranged from a trace to 6%. Authigenic clays were kaolinite, illite and minor chlorite (Figure 32). The predominant clay was pore filling kaolinite (Figure 33).

Paragenesis

The paragenesis or sequence of diagenetic events versus relative time is shown on Figure 34. As stated previously, the original sediment was likely a sublitharenite.

The first stage of diagenesis consisted of the physical compaction of the sediment, resulting in the reduction of primary intergranular porosity by ductile deformation, rotation, and fracturing of grains. Syntaxial quartz overgrowths were formed before the total destruction of primary porosity. As burial continued, the first stage of mesogenetic calcite precipitation took place. This event precipitated calcite in primary voids that remained after mechanical compaction and quartz overgrowth development. With all primary porosity being occluded by this time, two additional diagenetic events were initiated nearly simultaneously. They were: dissolution of both calcite cement and detrital constituents. These events were probably a response to the decarboxylization of organic matter in underlying shales and the accompanying

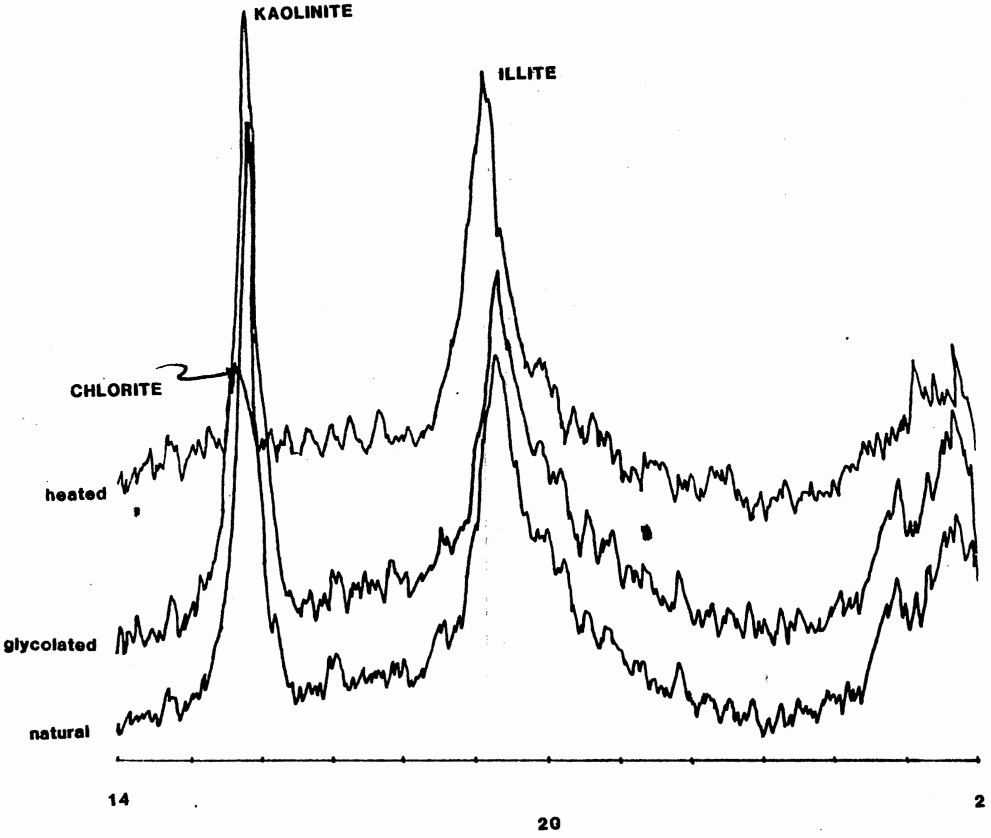


Figure 32. X-ray diffractogram of major clays found in the core.

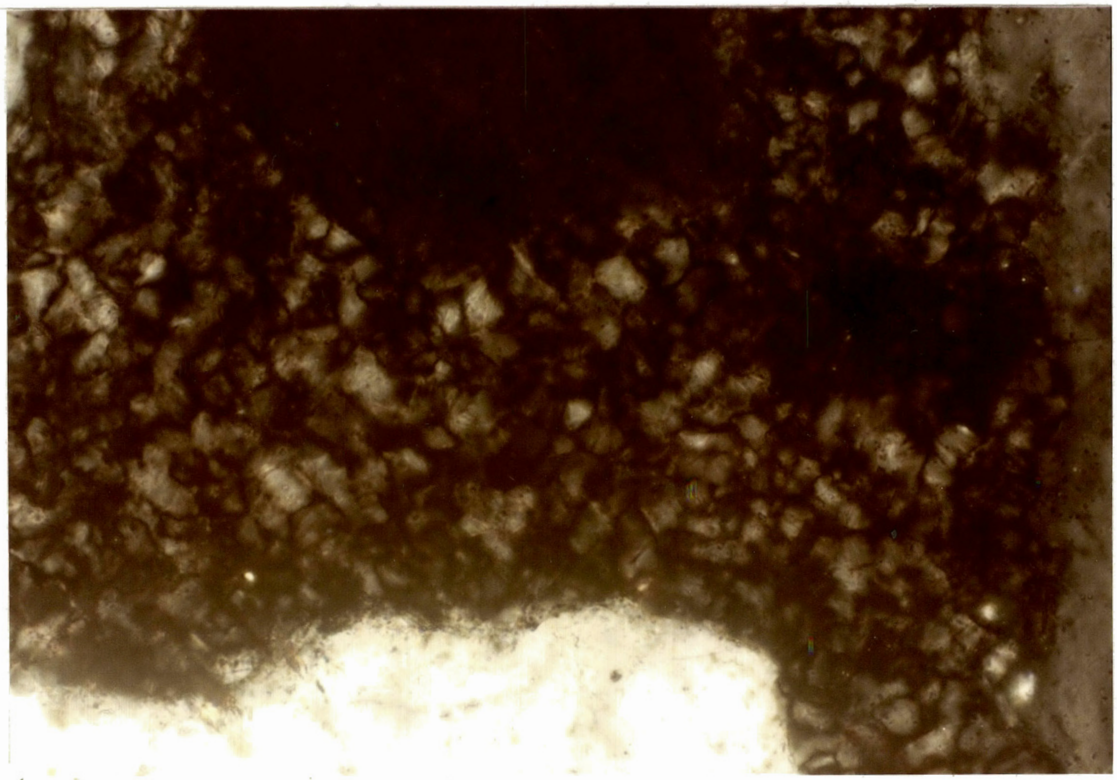


Figure 33. Photomicrograph of pore filling kaolinite (400X, c.p.l., 2455').

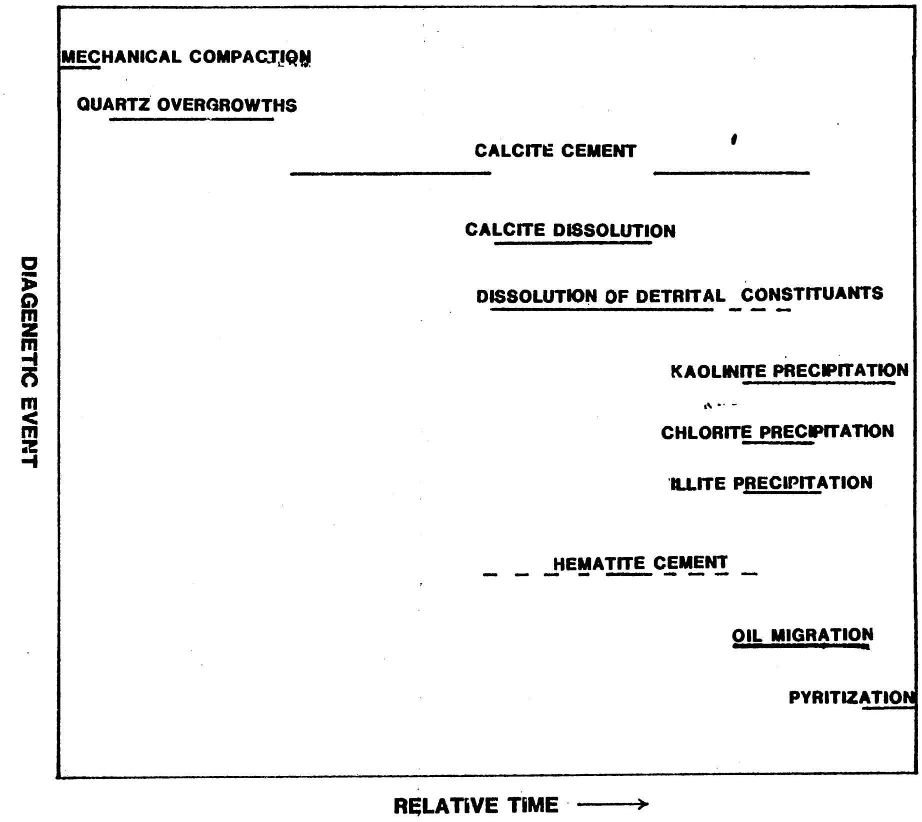


Figure 34. Paragenesis for the core studied.

release of H+ ions. The detrital constituents dissolved were illite matrix, rock fragments (mainly shale clasts), feldspars, and biotite (Figure 35). This stage is responsible for the development of secondary porosity.

A second phase of calcite cementation followed the dissolution phase. A relatively minor amount of calcite cement was deposited in enlarged intergranular and dissolution pores at this time. Shortly after the second phase of calcite cementation, the authigenic clays began to precipitate. Kaolinite was the most prominent authigenic constituent, indicating high permeability and fresh water influence. The kaolinite occurs as pseudohexagonal, pore filling plates (Figure 36). Authigenic illite and chlorite were rare and both were seen as pore linings.

Sometime soon after the dissolution of calcite cement and detrital constituents, hydrocarbons migrated into the formation. This is evidenced by bitumen that lines dissolution pores and positions itself "inside" of remnant rock fragments (Figure 37). Finally, pyrite is assumed to have formed late by the hydrogenation of sulphur leached from the organic matter.

Porosity Types and Evolution

Porosity in the core is restricted to secondary types. They were intergranular, micro and dissolution porosity types. Lab analysis for the core was available and values of porosity and permeability at 1 1/2 foot intervals were plotted on Figure 38. This figure graphically illustrates the sporadic development of porosity and permeability in the Lewis Sandstone section.

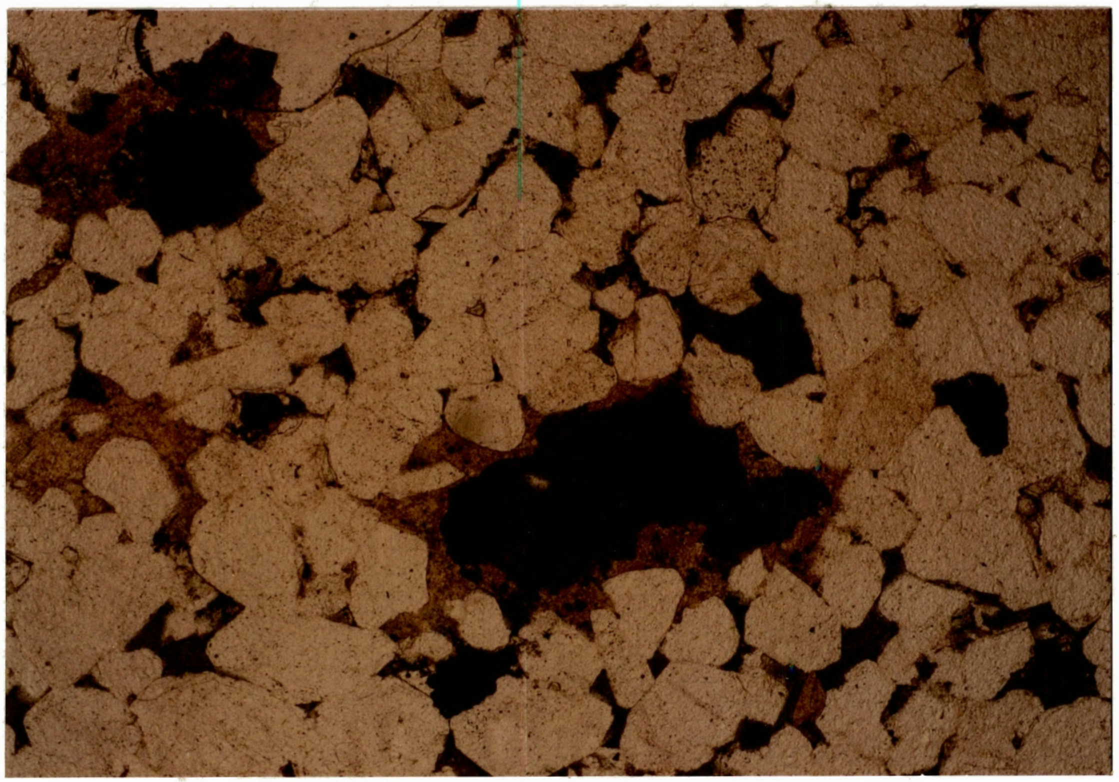


Figure 35. Photomicrograph showing large dissolution pores interconnected by intergranular pores (40X, plane polarized light, 2479').

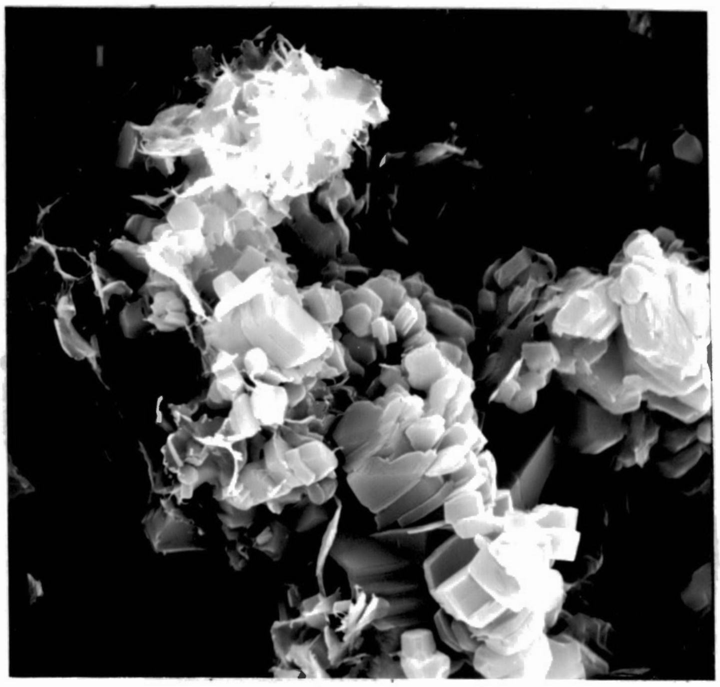


Figure 36. Scanning electron microscope photograph of pseudohexagonal kaolinite plates (1600X, 2455').

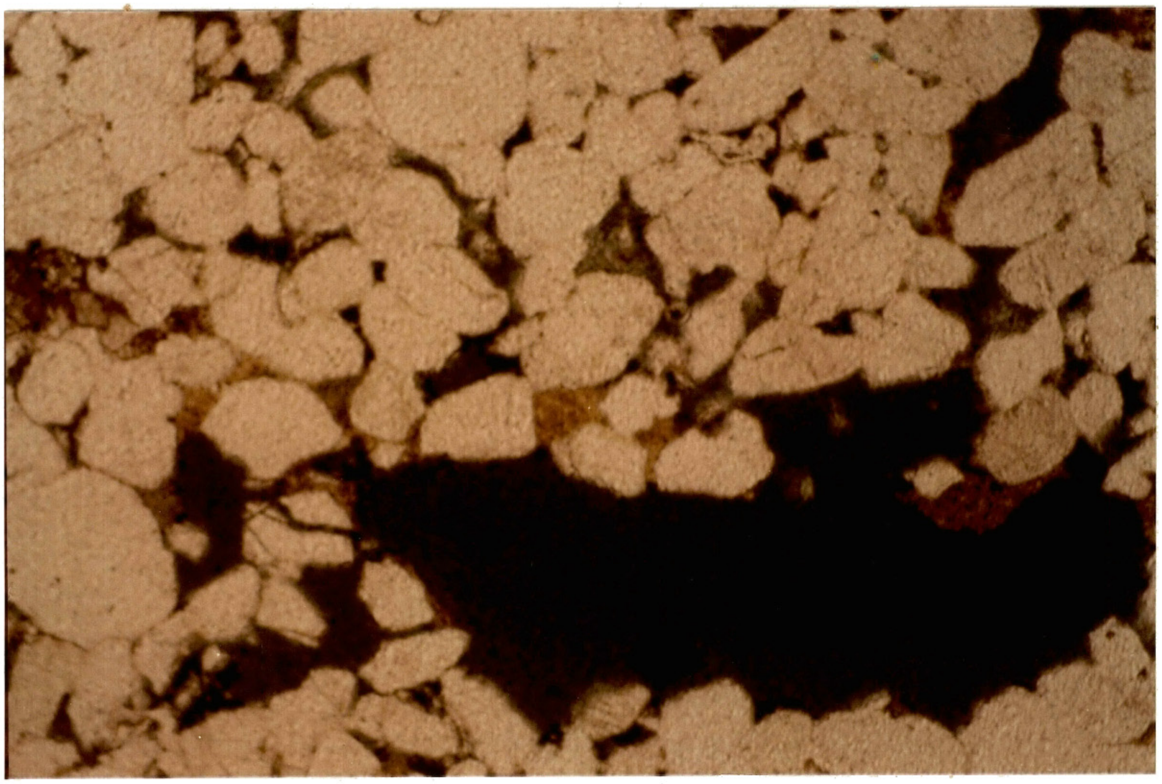


Figure 37. Photomicrograph showing bitumen within a dissolution pore (40X, p.p.l., 2479').

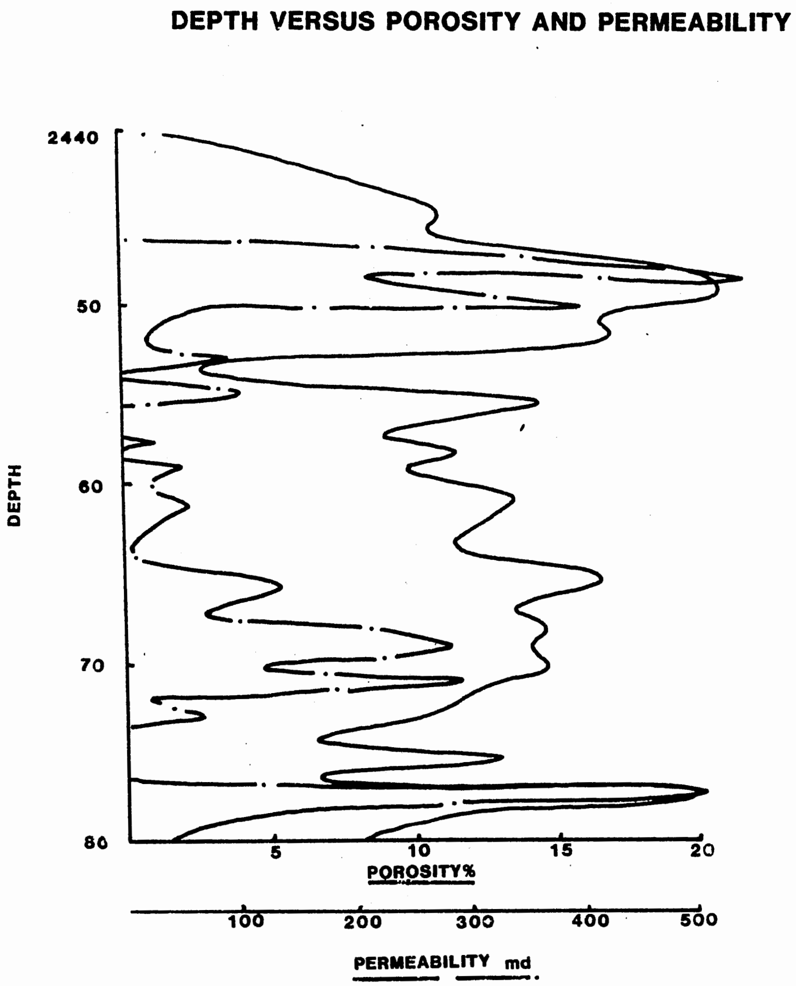


Figure 38. Porosity and permeability values versus core depth.

Clearly, there are three zones of higher permeability which are separated by two zones of lower permeability. Figure 39 shows that kaolinite content becomes much greater at a depth corresponding to the upper zone of lower permeability (-2452'). It is reasonable to assume that with greater data control this same relationship could be demonstrated in the lower impervious zone.

Figure 40 illustrates on a ternary diagram several secondary porosity types and their relationship to permeability as proposed by Pittman (1979). Careful reexamination of thin sections revealed the presence of two distinct fields. The circle approximates the range of values and the dot, the mean. These fields correspond to the zones of relatively high and low permeabilities spoken of before. It seems clear from this diagram that in the case of lower permeabilities, critical intergranular porosity is being clogged by authigenic kaolinte, yielding microporosity. Only a very slightly greater volume of dissolution pores existed in the more permeable plot and dissolution of calcite was uniform in the section. Hence, kaolinite stands out as the critical determinant of porosity and permeability.

Conclusions

Primary porosity in the core has been diminished to irreducible levels, whereas secondary porosity types include intergranular, microporosity and dissolution porosity. It is the interaction of these porosity types that determines the presence or absence of effective porosity and permeability. Specifically, in order to develop relatively high permeabilities, there must be a three dimensional interconnection of oversized dissolution pores by a network of enlarged intergranular pores. In the cases

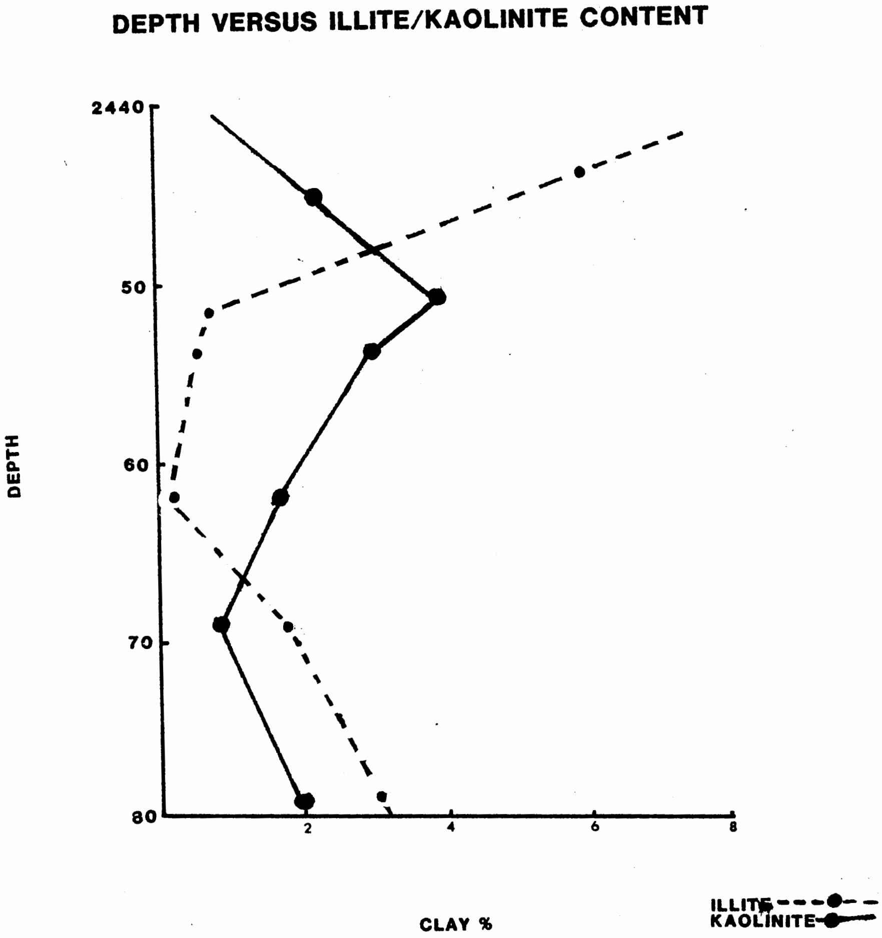


Figure 39. Illite and kaolinite content versus core depth.

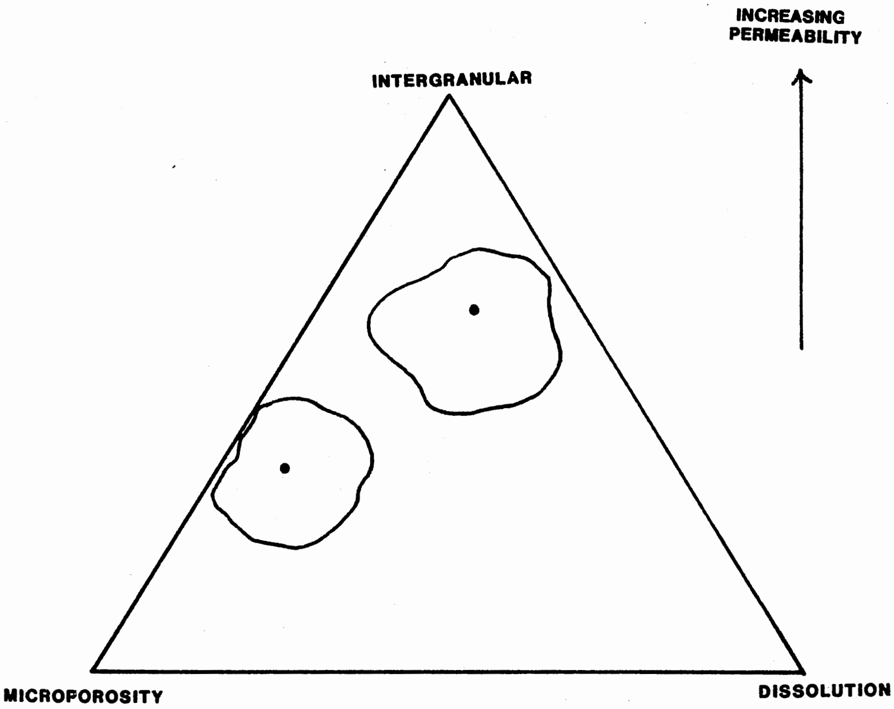


Figure 40. Ternary diagram of secondary porosity types (after Pittman, 1979).

of low permeability zones, this network, and to a lesser extent dissolution pores, have been occluded by authigenic kaolinite (Figure 41).

Preferential precipitation of kaolinite may be an expression of the original character of the sediment. Perhaps these zones contained more mud fragments or feldspars which either altered in place to kaolinite or were dissolved and later precipitated as kaolinite.

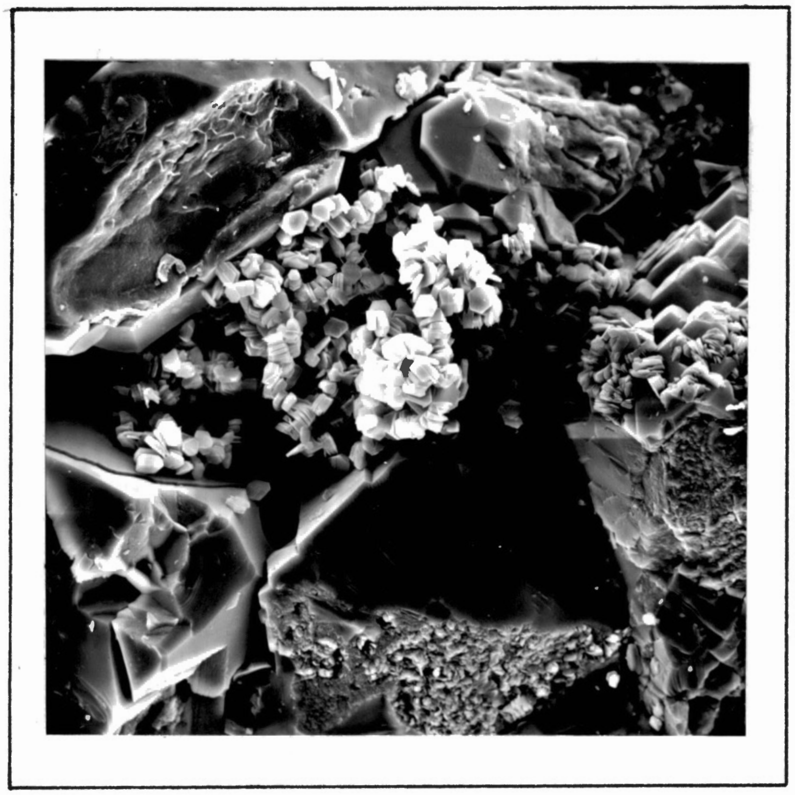


Figure 41. Scanning electron microscope photograph of kaolinite clogging an intergranular pore (400X, 2455').

CHAPTER VII

PETROLEUM GEOLOGY OF THE LEWIS INTERVAL

Introduction

The Black Warrior Basin of Mississippi and Alabama is an attractive area for oil and gas exploration for a number of reasons:

1. shallow pay zones (800 to 6,000 feet) result in relatively low drilling costs;
2. the presence of 12 recognized Mississippian pay zones allows for a multiple-target exploration strategy;
3. there is a high success rate for wildcats, and;
4. very little drilling activity took place prior to 1970, meaning exploration in the region is relatively immature.

In 1909, a test well searching for coal in Fayette County, Alabama encountered oil at less than 500 feet. That well led to two other deeper tests that flowed gas estimated at 1.6 and 4.5 million cubic feet of gas per day. By 1917, 40 wells had been drilled in the area and a pipeline was constructed for gas transmission to Fayette, Alabama.

For more than 60 years after the Fayette discovery exploration was slow and sporadic. In 1970, activity picked up with the discovery of the East Detroit Oil Field of Lamar County, Alabama. This success in the Carter sand led to intensified leasing and the discovery of three gas fields (East Detroit, Fairview and Dug Hill) and one oil field

(Henson Springs) the following year. These profitable discoveries were made at depths between 1500 and 2500 feet below sea level. Exploration spread rapidly over the entire basin and by 1981, 1105 wells were producing in Alabama alone.

Drilling activity in Mississippi has been less hectic, but has covered greater areal extent. Recent discoveries of gas fields have been made in Monroe, Lowndes, Chickasaw and Clay Counties. Exploratory wells drilled in Monroe County have encountered the greatest success. This is due primarily to the presence of faulting and anticlinal structures affecting Lewis and Carter Sandstone reservoirs.

Mississippian age sediments are the most prolific in the basin and account for 90% of all production. Table 1 outlines the major reservoirs in Alabama and their production statistics for 1981.

Distribution and Trapping Mechanisms of Producing Fields

Figure 42 shows the distribution of fields producing from the Lewis Sandstone for 1983. It also depicts the character of production, major structural features and sandstone isolith contour lines. In short, this figure is a synthesis of the data collected in the course of this study. By superimposing these, an attempt has been made to relate production trends to structure and net sand configurations.

Production in the basin can be broadly separated into two categories. First, there is the production from the more proximal delta associated with major distributary channels and minor structure. Production is minor and restricted to gas. Examples of such fields are the Troy, Nettleton, Cowpenna Creek, Beans Ferry and Splunge Fields: Secondly,

TABLE I

MISSISSIPPIAN PRODUCTION STATISTICS IN ALABAMA BY HORIZON, 1981 (FROM MASINGILL AND BOLIN, 1981)

Mississippian Producing Horizon	Oil (BBLS)	Gas (Mcf)
Gilmer Ss.	989	221,961
Millerella Ss.	61,891	2,858,977
Carter Ss.	285,213	34,261,626
Bangor Lmst.	---	5,624
Hartselle Ss.	---	316,473
Lewis Ss.	3,152	4,379,409
Unnamed	497	3,934
TOTAL	351,742	42,048,004

Figure 42. Distribution of fields producing from the Lewis Sandstone in 1983.

there are the larger fields to the south and southeast in the distal portions of the delta complex. These more productive fields are likely exploiting reworked delta front sheet sands. Contributing to the concentration of production in this region is the increased incidence of faulting.

Proximal-delta production is controlled by sand trends and trapping is dominantly stratigraphic (Figure 43). Exploration targets are distributary channels, channel mouth bar sands, point bar deposits and crevasse splays. An example of such a stratigraphic trap is the South Hamilton Field of eastern Monroe County. Structures that block the updip migration of oil and natural gas through deltaic facies are more common in the distal delta. Normal faulting without significant anticlinal closure is the trapping mechanism at the Beans Ferry (south-central Itawamba County) Field. Faulted anticlines provide the best conditions for hydrocarbon entrapment and are responsible for many of the most productive fields in the Black Warrior Basin. The Corinne, Splunge and McKinley Creek Fields of Monroe County, and the Star Field of Lamar County all produce from faulted anticlines.

Identification of effective traps requires a geometric analysis of faults and sandstone bodies. As mentioned earlier, the Lewis Sandstone bodies have a well-defined NW-SE trend and as such, tend to intersect the "Ouachita" faults at a low angle. This relationship results in a large cross sectional area of sandstone being in contact with the fault trace and increases the probability of updip migration across the fault into other porous and permeable units. Therefore, "Appalachian" faults often constitute the better fault traps because their angle of intersection with sand bodies is higher and leakage is less likely. An example

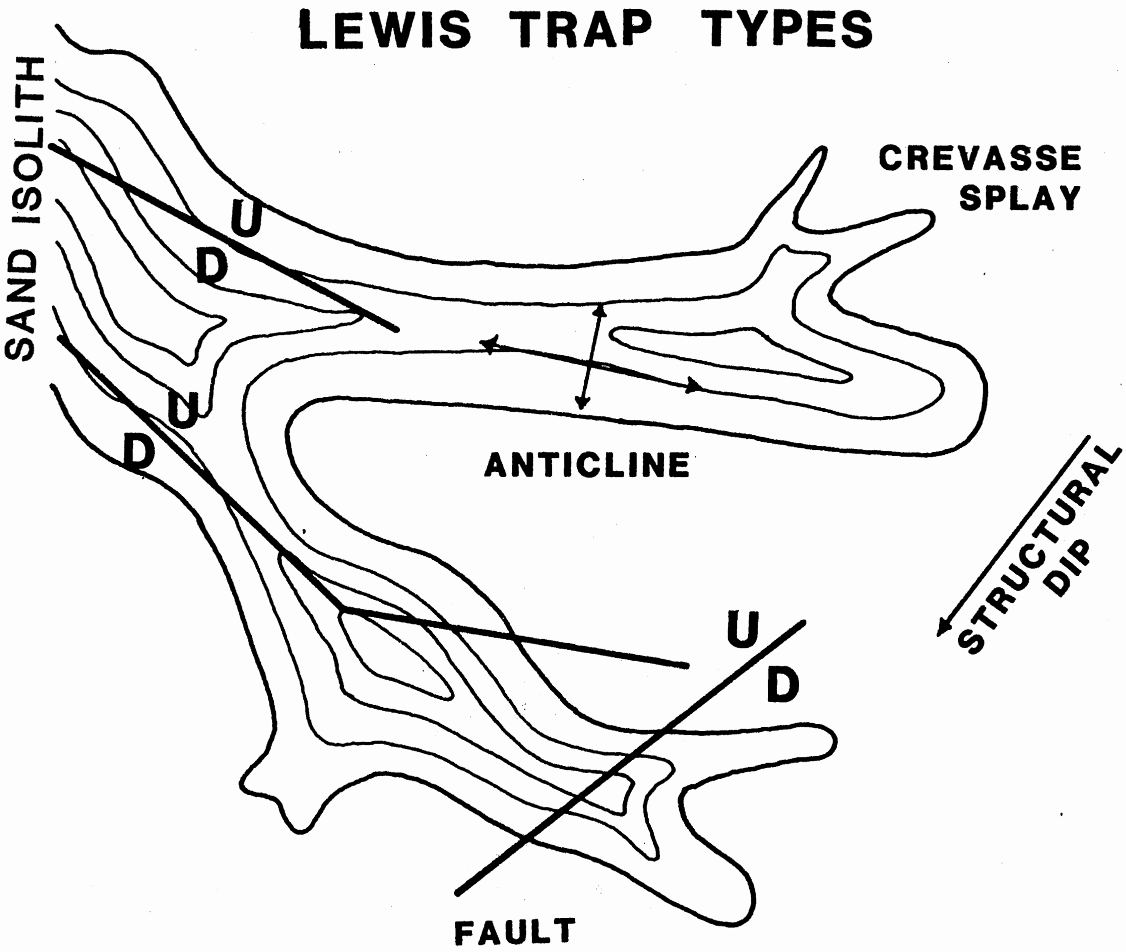


Figure 43. Lewis trap types.

of a faulted anticline involving only "Ouachita" faults is the Star Field of Lamar County. A faulted anticline with prominant "Appalachian" faulting is seen at the Aberdeen Field of Western Monroe County.

Production Statistics

Summaries of Lewis Sandstone hydrocarbon production by fields for 1983 are given in Tables 2 and 3. Table 2 contains statistics for Mississippi published in the Annual Production Report by the Mississippi State Oil and Gas Board. Table 3 presents statistics for Alabama that were provided in the latest publication by the State Oil and Gas Board of Alabama.

Production from the Lewis Sandstone is dominantly natural gas but a few fields in Mississippi produce significant quantities of oil as well. These fields are the South Hamilton, Maple Branch and McKinley Creek Fields of southern Monroe County. The largest amounts of natural gas being produced by the Lewis are from the Corinne Field of Monroe County followed by the McCracken Mountain Field of Fayette County. There are only three fields that produce from the Lewis Sandstone exclusively. They are the Beaver Creek (Lamar County), Berry Junction (Fayette County), and Bluff (Fayette County) Fields.

TABLE II

LEWIS PRODUCTION STATISTICS FOR MISSISSIPPI BY FIELD*

Field	Company	Lease	Well Number	Annual Production 1983 Oil (BBL)	Annual Production 1983 Water (BBL)	Annual Production 1983 Gas (Mcf)	Cumulative Production Oil (BBL)	Cumulative Production Water (BBL)	Cumulative Production Gas (Mcf)
Aberdeen	Louisiana Land & Explor.	Minnie Plant Whitaker	1	0	499	30,469	174	2,065	256,168
	MWJ Producing	Harrington	1	0	0	42,955	0	0	156,967
	Pruett Production	Dr. Leonard J. Goodgame 32-4	1	0	20	1,036	0	20	1,036
Bacon	Pruett Production	R. L. Farned 26-1	1	33	130	45,358	205	130	91,240
Beans Ferry	Itawamba Insustrial Gas	Gilmore Puckette LBR Co. U2	1	0	0	4,863	0	0	1,109,117
		Elsie Maxcy U	2	0	0	0	0	0	461,063
		W. H. Summers Et al.	1	0	0	4,491	0	0	289,841
Buttahatchie River	Pruett Production	Dobbs Unit 29-5	1	58	0	77,163	202	0	544,786
		Dobbs Unit 29-12	1	0	0	26,937	989	0	351,133
		Irons 25-3	1	64	0	140,892	1,016	0	1,119,549
		Monroe Co. Tractor Co. 31-3	1	80	517	64,256	890	517	370,981
Cooper Creek	Placid Oil	Caldwell 28-10	1	0	0	7,488	100	85	75,420
Corinne	Grace Petroleum	Dabbs-Richardson	6-2-LT	42	10	26,026	309	97	225,804
		Dr. R. T. Dabbs	1-LT	215	15	185,969	6,669	193	1,624,389
		T. A. Richardson	6	0	0	0	720	33	272,097
		Self II	1	130	12	149,927	3,179	108	1,031,334
	Pruett Production	James E. Cook 24-5	1	232	23	60,993	232	23	60,993
		Weyerhaueser 25-4	1	164	0	32,184	164	0	32,184
	Thompson-Monteith	Columbus AFB Parcel 1	2	56	0	17,510	54	0	17,510
		Camp 24	2-T	86	0	130,557	3,134	33,059	1,370,441
		Cunningham 24	1-T	74	0	86,812	2,708	19,088	713,462
		Martin 14	1-T	502	0	132,981	502	0	132,981
		Martin 19	4-T	0	0	0	1,795	0	330,336
		Self 13	2-T	181	0	51,998	5,964	0	1,392,088

TABLE II (Continued)

				Annual Production 1983			Cumulative Production		
Field	Company	Lease	Well Number	Oil (BBL)	Water (BBL)	Gas (Mcf)	Oil (BBL)	Water (BBL)	Gas (Mcf)
Corinne (cont)		Self-Day 14	1-T	115	0	72,301	8,212	0	1,251,691
		Weyerhaueser 24	1-T	144	0	128,815	4,048	0	1,479,851
Cowpenna Creek	Louisiana Land & Explor.	Coggin 1-16	1	0	2	72,178	0	50	155,313
		Murff 6-15	3	0	454	27,412	0	3,100	65,681
		Murff	1	0	12	74,006	0	193	174,684
South Hamilton	Pruett Production	James R. Gilland 34-16	1	9,098	673	3,161	9,098	673	3,161
		Owens Unit 3-11	1	3,173	0	1,457	27,587	0	27,915
		L. A. Stewart 3-7	1	1,427	0	32	7,629	4	8,037
		L. A. Stewart 3-3	1	812	20	17	2,943	80	9,115
Maple Branch	Kelton	Sanders 35-9	2	3,960	0	8,635	9,423	0	17,680
	Pruett Production	Coleman 36-5	1	1,148	170	49	1,148	170	49
		S. J. Creekmore Jr.	2	3,849	585	106,443	44,104	585	583,126
		Gurley 31-16	1	106	0	23,813	1,106	0	209,744
		Robinson	13-1	8,330	0	13,526	16,053	442	18,462
		Creekmore Unit 36-9	1	22,090	114	86,396	110,477	14	315,659
		Fields 35-7	1	2	0	0	1,466	0	221
		Lawrence 8-3	1	74	0	7,438	944	0	36,635
		Pounders Unit 6-11	1	2,307	0	17,363	53,733	0	206,307
		Stephenson 7-15	1	31,907	60	69,688	33,802	60	69,688
		Troupe Unit 36-11	1	8,916	30	30,158	82,506	30	156,619
		Van Wells 6-9	1	3,679	80	13	9,129	80	13
		Wells Unit 6-3	1	1,219	0	7,592	10,536	0	27,698
McKinley Creek	Grace Petroleum	Collins 22-10	1	970	0	371	5,836	113	3,928
	Pruett Production	Amer. Pot. & Chem 19-14	1	1,794	65	29	3,358	76	29
		Mollie Nevins	1	589	16	12	589	16	12

TABLE II (Continued)

Field	Company	Lease	Well Number	Annual Production 1983 Oil (BBL)	Annual Production 1983 Water (BBL)	Annual Production 1983 Gas (Mcf)	Cumulative Production Oil (BBL)	Cumulative Production Water (BBL)	Cumulative Production Gas (Mcf)
Nettleton	Getty Oil	Stovall 3-11	1	0	524	70,454	0	996	154,913
Splunge	Grace Petroleum	Miller Unit 29-2	1-T	0	0	0	0	0	213
Troy	Louisiana Land & Explor.	J. R. Falkner	1	0	0	122,535	0	0	122,535
		J. R. Falkner	2	0	0	83,143	0	0	83,143
		B. Flaherty 29-2	1	0	1,086	33,455	0	0	33,455
		Ward 27-4	1	0	0	108,167	0	0	108,167

*Compiled from 1983 Annual Production Report, published Mississippi State Oil and Gas Board.

TABLE III

LEWIS PRODUCTION STATISTICS FOR ALABAMA BY FIELD*

Field	Company	Well Name	Permit Number	Monthly Oil Production (Barrels)	Cumulative Production (Barrels)	Monthly Gas Production (Mcf)	Cumulative Production (Mcf)
Beaver Creek	Morrow Oil & Gas	Babcock-Cole 10-13	3699	0	0	6,289	79,623
		Cole-Babcock 10-15	3771	0	0	13,318	92,030
		Massey-Evans 5-16	3857	0	0	3,364	3,364
Beaverton	Dawson	Loggins "A" Unit 1	2264	0	0	23,603	1,503,185
	Grace Petroleum	Ogden 4-6	2512	0	0	26,298	792,363
		Ogden 5-1	2651	0	0	6,920	386,025
	Southland Royalty	D. J. Loggins 4-9	2415	0	0	9,163	1,010,072
		D. W. Strawbridge 33-14	2471	0	0	31,749	1,491,106
Berry Junction	Howell Petroleum	J. R. Williamson 21-10	1247	0	7	0	30,736
		Robt. Honeycutt 27-4	2272	0	1	0	19,956
		Williamson-Shepard 28-8	2095	0	0	0	91,610
Bluff	Grace Petroleum	Murphy 6-3	2924	0	0	1,445	125,568
	MWJ Production	Thomas Atkinson 5-5	3872	0	0	3,226	3,226
Fernbank	Pruett Production	Bryant 30-1 #1	3305	0	564	0	134,696
Hells Creek	Grace Petroleum	Wheeler-Boyette 25-7	2741	0	0	3,420	150,183
McCracken Mtn.	Browning & Welch	Edna M. Branyon 5-4 #1	3399	0	79	544	16,348
	Howell Petroleum	L. Ellis 32-1	2698	0	2	1,002	288,617
		McCracken-King-Hodges #1	1987	0	7	15	171,361
	Morrow Oil & Gas	Arthur 21-7 #1	3092	0	0	4,487	410,730
		Canaan 34-13 #1	3565	0	0	32,187	98,768
		Southern Railroad 33-2 #1	3416	0	0	23,904	306,543
	Terra Resources	D. Gray #1	2453	0	0	1,850	2,012,922
		George Cannon #1	2265	0	0	4,888	847,436
		H. G. Woodward #1	2242	0	0	24	51,050

TABLE III (Continued)

Field	Company	Well Name	Permit Number	Monthly Oil Production (Barrels)	Cumulative Production (Barrels)	Monthly Gas Production (Mcf)	Cumulative Production (Mcf)
McCracken Mtn. (cont.)	Terra Resources (cont.)	Hodges-South 28-5	2804	0	0	1,305	1,203,633
		Lawrence 27-4	2743	0	296	222	584,157
		Southern Railroad 32-9	3593	0	0	2,078	8,880
		Yarborough 34-3	3122	0	0	3,685	213,368
		Z. D. Vick #1	2230	0	0	972	484,335
McGee Lake	Anderman/Smith Oper.	Cherie Arin Odom 24-8 #1	3292	1	127	593	51,018
	Southland Royalty	H. L. Patrick 32-10 #1	2906	7	460	6,832	491,748
		J. A. Stacy 19-13 #1-D	2994	20	1,726	34,248	1,742,655
		S. C. Sprouse 30-10 #1	2886	0	91	0	63,015
Millport	Pruett Production	Boyette 32-8	2953	0	286	4,253	469,369
Malloy	Hughes & Hughes	Richards 33-11 #1	2848	16	1,693	2,348	313,498
N. Fayette	Anderman/Smith Oper.	Robertson 32-3	3567	0	0	2,173	29,364
	Grace Petroleum	Hubbert 30-10	3276	96	131	1,402	27,103
Star	Anderman/Smith Oper.	McGee Weyerhaueser 13-9 #1	3197	1	120	597	66,116
		Odom 18-12 #1	3433	48	1,254	4,544	143,270
	Grace Petroleum	Tinnie B. Hayes 1-5	2850	7	1,040	14,528	1,173,756
	Hughes & Hughes	Bonzell McGee 13-8 #1	3074	0	473	1,258	77,700
	Pruett Production	C. C. Day #1	2079	4	362	6,284	308,251
		Falkner #1	2333	0	724	14,508	748,012
Total Production from Lewis Sand				200	9,443	299,576	18,311,766

*Compiled from latest production statistics published by the State Oil and Gas Board of Alabama.

CHAPTER VIII

SUMMARY AND CONCLUSIONS

The investigation of this topic has yielded evidence upon which several conclusions can be drawn. The conclusions are:

1. The Lewis Sandstone was deposited on the Northern Shelf of the Black Warrior Basin in a high-constructive lobate cratonic delta environment.
2. Lewis Delta distributaries exhibit a preferred orientation and low angle bifurcation indicative of tidal influence.
3. The northeastern portion of the study area existed as a shallow marine, storm and tide reworked shelf. Sediment was supplied to the area by fluvial-deltaic processes.
4. Permeability of the Lewis Sandstone from the #2 J. R. Falker core is destroyed when authigenic kaolinite plugs enlarged intergranular and dissolution pores.
5. Oil and gas production trends can be correlated with net sand and structure trends.
6. Stratigraphic trapping is more prevalent in the proximal delta region while structural traps predominate in the distal delta.

The topic of hydrocarbon generation in the Lewis along with a regional diagenetic study would greatly enhance further understanding the Lewis Sandstone as a hydrocarbon reservoir.

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APPENDIX A

WELLS USED IN CROSS SECTIONS

E-W STRIKE-ORIENTED STRATIGRAPHIC CROSS SECTIONS

A-A'

Well Number	Well Name	Company
ItM-19	#1 Patterson	Moon and Hines
ItM-12	#1 Heckman	Moon and Hines & H, Best etal.
FrA-11	#1 G. Pierce Webber	Shenandoah Oil
MarA-1	#1 Claborn 14-16	Marion Corporation
WinA-18	J. T. Harris #1	Sinclair Oil and Gas
WkrA-2	#3 First Nat. Bank 29-11	Shenandoah Oil
WkrA-19	---	Shenandoah Oil

B-B'

Well Number	Well Name	Company
CalM-9	D. R. Davis # 2	Honolulu Oil
PonM-31	#1 B. Flaherty 29-2	Louisiana L. & E.
LeeM-9	#1 W. H. Neely	K. A. Ellison
ItM-22	#1 Barnett & Patterson	Kerr McGee
ItM-54	#1 Edgeworth	Kerr McGee
MarA-34	#1 Arthur Ritch	Harry L. Cullet
MarA-34	#1 Arthur Ritch	Harry L. Cullet

C-C'

Well Number	Well Name	Company
CalM-11	#1 J. L. Ashby	Pan American Petroleum
ChiM-26	#1 Allen F. Futvoye	Getty Oil
ChiM-22	#1 Mabel Neal	Louisiana L. & E.
MnrM-103	#1 Ada W. King	Enserch Explor.
MnrM-86	#1. E. Westmoreland	H. L. Ladner, J. W. Harris & Gibraltar Oil
MnrM-351	#1 Nason 24-8	Pruett Production

D-D'

Well Number	Well Name	Company
LamA-83	#10-10 Blaylock	Apco Oil
LamA-213	Austin 10-11	Grace Petroleum
LamA-45	#1 T. R. Allman Unit	Petr. Corp. of Texas
FayA-3	#1 Conner 36-7	Cleary Petroleum
FayA-15	Quinton Box #1	Warrior D & E
FayA-7	Thomas White #1 15-1	Warrior D & E
WkrA-60	#1 Marigold	Pelican Production

E-E'

Well Number	Well Name	Company
ClyM-16	#1 Mattie B. McFadden	Carter Oil
Clym-33	Watsom 35-7	Hughes & Hughes et al.
MnrM-190	#1 Self	Triad Oil and Gas
LowM-30	Sanders 22-4	Pruett & Hughes-Aquitane-America Hess
LowM-56	#1 Wood	Placid Oil
LamA-270	#1 Jordan 21-2	Pruett Production

F-F'

Well Number	Well Name	Company
LamA-315	#1 Herron 29-1	Pruett Production
PicA-3	#1 Shaw Unit 10-10	Pruett & Hughes
PicA-7	Turner 32-10	Shell Oil
TuscA-54	#1 Cobb 30-12	Carless Resources
TuscA-11	#1 Wiley Unit 16-3	Gulf Oil

N-S DIP-ORIENTED STRATIGRAPHIC CROSS SECTIONS

1-1'

Well Number	Well Name	Company
PonM-5	Wilson Estate #1	L. E. Salmon
PonM-31	#1 B. Flaherty 29-2	Louisiana L. & E.
ChiM-50	#1 R. L. Farned 26-1	Pruett Production
ChiM-22	#1 Mabel Neal	Louisiana L. & E.
ChiM-40	Henley #1	Lear Petroleum
ClyM-16	#1 Mattie B. McFadden	Carter Oil
OktM-11	#A-1 W. P. Sudduth	McAlester Fuel

2-2'

Well Number	Well Name	Company
ItM-2	#1 Bon Adams	O. W. Killam
ItM-22	#1 Barnett & Patterson	Louisiana L. & E.
MnrM-56	#1 Armstrong	Pruett &Hughes
MnrM-86	#1 E. Westmoreland	H. L. Ladner, J. W. Harris & Gibraltar Oil
MnrM-272	Willis #1	Shell Oil
MnrM-190	#1 Self	Triad Oil & Gas
LowM-22	#1 Gearhiser	Shell Oil

3-3'

Well Number	Well Name	Company
MarA-1	#1 Claborn 14-16	Marion Corporation
MarA-44	#1 Vick 4-9	McMo Ran Explor.
FayA-3	#1 Conner 36-7	Cleary Petroleum
FayA-284	#1 McLendon 21-2	Bow Vally Petroleum
PicA-7	Turner 32-10	Shell Oil

APPENDIX B

EXAMPLE OF DATA SHEET
USED IN STUDY

LOWER CHESTER RESEARCH

OPERATOR				S T R
PERMIT NO.	CLEAVES' NO.			
COUNTY	TD			
KB, DF, GL				
T. MILLER.	BSE. MILLER.			
T. TUSC.				ISOPACH
T LEWIS Ls	Σ Ss	Σ Ls	ΣSh	
T LEWIS Ss	# Ss	Max Ss	Ss %	
LEWIS CURVE SHAPE				

OPERATOR				S T R
PERMIT NO.	CLEAVES' NO.			
COUNTY	TD			
KB, DF, GL				
T. MILLER.	BSE. MILLER.			
T. TUSC.				ISOPACH
T LEWIS Ls	Σ Ss	Σ Ls	ΣSh	
T LEWIS Ss	# Ss	Max. Ss	Ss %	
LEWIS CURVE SHAPE				

VITA

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