COMPARATIVE PETROGRAPHY OF THE CHESTERIAN BATESVILLE DELTA AND EQUIVALENT SUBSURFACE DEPOSITIONAL SYSTEMS ON THE NORTHERN SHELF OF THE BLACK WARRIOR BASIN

By

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To my wife and children, my mother and father, and to my mother and father-in-law, I dedicate this thesis.

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CHAPTER I

ABSTRACT

The Black Warrior Basin is a triangular Late Paleozoic foreland basin whose primary sedimentary fill consists of Upper Mississippian (Chester Group) and Lower Pennsylvanian (Pottsville Group) terrigenous clastic rocks. Among the Chesterian deltaic sandstones, the Carter Sandstone, deposited on the structurally stable Northern shelf, contains significant quantities of natural gas and liquid hydrocarbons. The Carter Sandstone is the most productive hydrocarbon reservoir of the Black Warrior Basin, but is still poorly understood in regard to the diagenetic and depositional facies characteristics.

The Chester-age Batesville Delta complex was deposited in Northeastern Arkansas. This delta never reached the Arkoma Basin. Longshore currents carried detritus the westward creating a strandplain type depositional environment. It is difficult to determine the exact nature of the depositional system, because Mississippian sediments are absent east of Batesville, Arkansas in what is now called the Mississippian Embayment.

The principle subsurface source of data for this study were more than 900 electric logs, from which subsurface maps

in Mississippi were constructed. Production trends, as determined from published data, were related to isolith and structural contour maps generated by this study. Five cores from the Mississippi study area and three outcrop measured sections from the Arkansas study area were analyzed in order to determine the diagenetic controls of porosity and permeability and to determine whether the detrital constituents indicate a cratonic source.

The Carter Sandstone was deposited in an elongate, (high-constructional) cratonic delta complex that prograded from NNW to SE. Deposition of this fluvial-deltaic facies marked the end of a series of minor transgressive-regressive patterns of sedimentation in the basin.

The development of porosity and permeability within the Carter Sandstone was controlled by the absence/presence of authigenic quartz overgrowths and calcite cement, along with the absence/presence of pore-filling authigenic illite, kaolinite, dolomite, and siderite. Optimum conditions exist when secondary porosity, created by dissolution of detrital matrix and metastables, are free of the pore-filling and pore-lining authigenic kaolinite, illite, dolomite, and siderite, thus allowing connection of the enlarged pores created by dissolution.

Carter production trends tend to correlate well with the trends indicated on sandstone-isolith maps. Structural trapping, particularly the antithetic (down to the north) faults, and anticlinal features, played a major role in the entrapment of hydrocarbons in the basin. Stratigraphic trapping is minor within the study area but is one of the main trapping mechanisms to the east in Fayette and Lamar Counties, Alabama.

CHAPTER II

INTRODUCTION

Location of Study Area

The study area is comprised of all or parts of 10 counties in northeastern Mississippi and parts of two counties in northeastern Arkansas (Figure 1). These counties include Pontotoc, Lee, Itawamba, Calhoun, Chickasaw, Monroe, Clay, Lowndes, Oktibbeha and Noxubee in northeastern Mississippi, and Independence and Stone Counties in northeastern Arkansas. The study areas represent approximately 6700 square miles of what Cleaves (1983) referred to as the Northern Shelf of the Black Warrior Basin and what Glick (1979) referred to as the Batesville Channel of the western margin of the Mississippi Embayment.

Purpose and Scope of the Study Area

The main purpose of this research project is to determine whether time and depositional system equivalency exist between the Batesville Delta Complex of northeastern Arkansas and the Carter Delta System of the Black Warrior Basin in northeastern Mississippi. The specific objectives are:

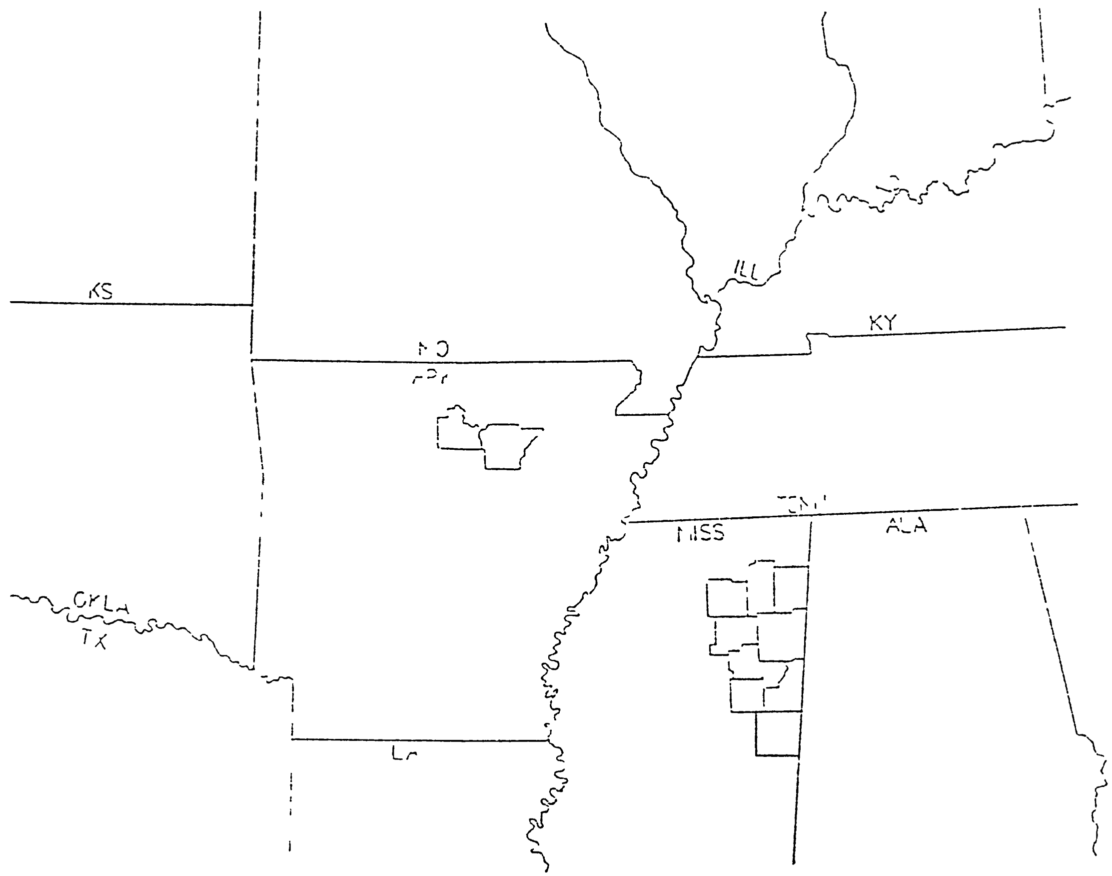


Figure 1. Geographic Location of Study Area

1. To map the regional distribution of the Carter Sandstone in the subsurface within the study area and to interpret the processes responsible its deposition.
2. To determine by thin section analysis of outcrop samples from Arkansas and core samples from Mississippi if any petrographic correlation exists within the detrital compositions to suggest either a cratonic or orogenic provenance.
3. To determine the source area(s) and direction(s) of transport of terrigenous clastic sediments of the Carter by examining four cores of Carter Sandstone.
4. To determine the time relationship between the Batesville Sandstone and the Carter Sandstone by examination and correlation of the micro- and macro-fauna from bounding shales.
5. To define the factors that regulated porosity and permeability development in the Carter Sandstone. This will be accomplished through analysis of four cores within the Mississippi study area.

Methods of Investigation

Subsurface Studies (northeastern Mississippi)

A total of 910 electric logs provided the data for construction of five subsurface maps. Although a few sample logs were available, correlations proved difficult; disregarded because of this uncertainty, they were not used. Well control was good throughout the study area, as most wells drilled in the area penetrate deep enough to include the Carter interval.

Five subsurface maps were prepared to show: 1) the structure of the overlying trangressive limestone, and 2) the "Millerella", Carter 'A', and Carter 'B' Sandstone facies distribution within the study area. These maps include a structure contour map on the base of the "Millerella" Limestone (Plate I), a net sand isolith on the "Millerella" Sandstone (Plate II), a net sand isolith on the Carter 'A' (Plate III), a net sand isolith on the Carter 'B' (Plate IV), and a net sand isolith on the total Carter Sandstone (Plate V). In the construction of the net sand isolith maps, a -20mv cutoff was used as the minimum SP deflection indicative of the presence of sandstone. One dip-oriented structural cross-section (A'-A", Plate VI), and one strike-oriented structural cross-section (B'-B", Plate VIII), were constructed to express basinal subsidence and faulting. Two dip-oriented stratigraphic cross-sections, (A-A', Plate VIII and B-B', Plate IX), and two strike-oriented stratigraphic cross-sections, (C-C', Plate X and D-D', Plate XI) were constructed for correlation purposes and to show the stratigraphic relationships of the existing sand units within the study area (Figure 2).

The "Millerella" Limestone, "Millerella" Sandstone, Carter 'A' Sandstone, and Carter 'B' Sandstone were studied in detail in six cores (Figure 2). The #1 J. T. Evans core, drilled in Monroe County, Mississippi (Sec.5-T15S-R6E) by Par Exploration and the #1 Leech core drilled in Monroe County, Mississippi (Sec.18-T12S-R18W) by Pruet and Hughes and Pelto Oil Company were studied to analyze the Carter 'A' Sandstone. The Carter interval was logged in both wells in order to study the vertical and textural trends, sandstone thickness, and environment of deposition. Twenty-five thin sections were cut from the two cores and examined under petrographic microscope to determine the types and amounts of detrital and diagenetic constitutents. One sample taken from the top, middle, and lower portions of each cores were analyzed with an x-ray diffractometer to help identify the diagenetic minerals within the Carter 'A' interval. Clay extractions were prepared from the same three samples of each core to help verify the diagenetic clays identified by thin section analysis and bulk x-ray diffraction.

The #1 Thomas core drilled in Monroe County, Mississippi (Sec.5-T15S-R7E) by Par Exploration and the #1 Malone core drilled in Lowndes County, Mississippi

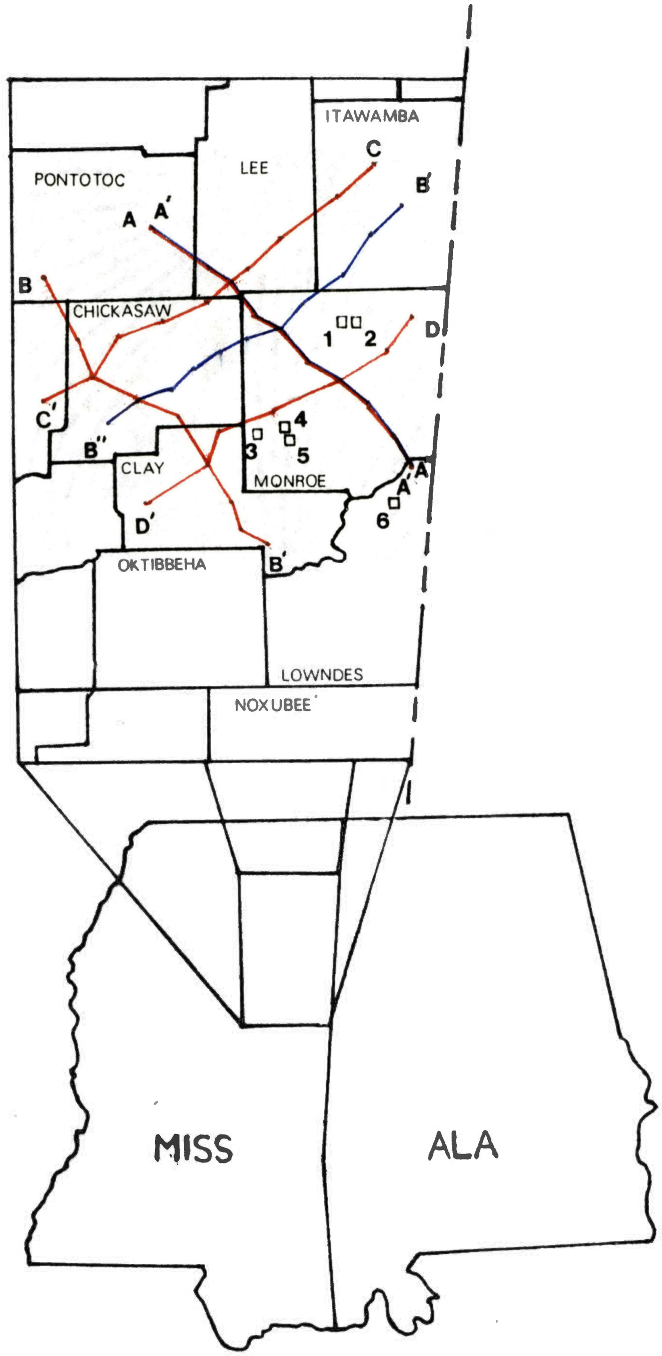


Figure 2. Locations of Dip Oriented and Strike-Oriented Cross-Sections and Cored Wells in Mississippi.

(Sec.25 - T16S-R18W) by Michigan Oil Company were studied to analyze the Carter 'B' Sandstone.

The Carter interval was logged in both wells to study vertical and textural trends, sandstone thickness, and evidence of environments of deposition. Twenty-eight thin sections were cut from the two cores and examined petrographically to determine the types and amounts of detrital and diagenetic constituents. One sample from the top, middle and lower portions of each core were analyzed with an x-ray diffractometer to help identify the diagenetic minerals present with the Carter 'B' interval. Clay extractions were prepared from the same samples to help verify the diagenetic clays identified by thin section analysis and bulk x-ray diffraction.

The #1 Mason core drilled in Monroe County, Mississippi (Sec.5 - T15S-R73) by Pan Am Petroleum Company was studied to analyze the "Millerella" Sandstone and overlying "Millerella" Limestone. The #1 Armstrong drilled in Monroe County, Mississippi (Sec.17 - T12S - R18W) by Pruet & Hughes Petroleum Company was studied to analyze the "Millerella" Sandstone and Carter 'A' Sandstone. The cored interval of each well were logged to examine the vertical and textural trends, sandstone thickness, and depositional environments. However, only two thin sections were cut from the "Millerella" Sandstone in the #1 Mason core to examine the petrographic constituents and determine the detrital and diagenetic constituents. One sample was taken from the same interval and analyzed with a x-ray diffractometer to help identify the diagenetic minerals. Clays were extracted to verify the diagenetic minerals identified by thin section analysis and bulk x-ray diffraction.

Outcrop Studies (northeastern Arkansas)

Five partial sections of the Batesville Sandstone were carefully measured and described within the outcrop study area of Independence and Stone Counties, Arkansas. The base and top of the Batesville were obscured by faulting and weathering in these sections. Because of this it became necessary to gather samples from the exposed basal sand and overlying shales 45 miles west of the proposed study area in Independence County, Arkansas (Figure 3).

Outcrop 'A' (C, SE, SW, NW, Sec.27-T13N-R6W) was measured and described by careful examination of fresh and weathered samples. Vertical textural trends, sedimentary structures and environment of deposition were noted. Fifteen thin section were cut from samples obtained at the outcrop. Outcrop 'B' (SE, NE, SW, NE, Sec.16-T13N-R8W) was measured and described but no thin sections were made from this interval. Outcrop 'C' (C, NW, SE, Sec.22-T13N-R6W) was measured and described to analyze the vertical textural trends, sedimentary structures and depositional environments but no thin sections were taken from this interval. Outcrop 'E' (NW/cor, NW, NW, Sec.16-T13N-R6W) was measured and described and eight thin sections were made from samples

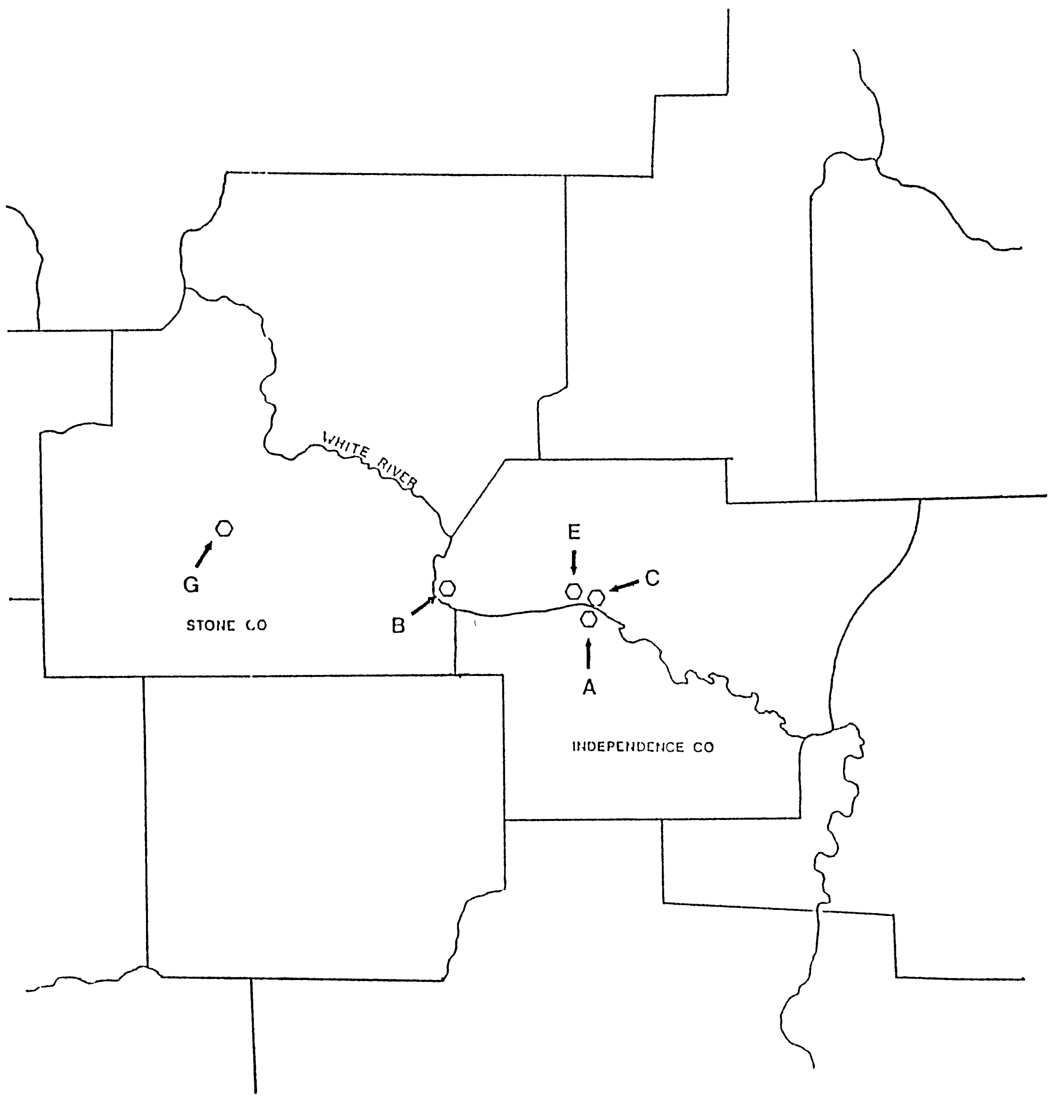


Figure 3. Locations of Sample Areas in Arkansas.

collected. Outcrop 'G' (C, SW, SW, SE, Sec.34-T15N-R12W) was measured and described and eight thin sections were made from these samples. All the thin sections prepared from outcrop samples were analyzed with a petrographic microscope to determine the detrital and diagenetic constituents. Two samples each from Outcrops A, E, and G, representing the lower and upper portions of each outcrop, were analyzed with a x-ray diffractometer in a bulk run to determine the diagenetic minerals present. Clay extractions were prepared from these samples and analyzed with an x-ray diffractometer to verify the diagenetic minerals present.

Sixteen samples were processed for the purpose of examining the conodont microfauna present. This would permit relative age dating of the stratigraphic units and perhaps enable time correlation with Chester units described in the literature. Four one-kilogram samples from bounding shales of the Carter Sandstone and two samples from the "Millerella" Limestone were collected from the #1 Malone core in the Black Warrior Basin. In northeastern Arkansas, four shale samples were collected from the overlying Fayetteville Shale, and six samples from the underlying Moorefield shale. Unfortunately, these samples were barren of useful microfossils.

Previous Investigations

Surface Studies of Northern Arkansas

Previous literature concerning studies of northern Arkansas are numerous and informative, although most deal with the Batesville Sandstone in a generalized fashion. For this reason only the more useful and important papers will be discussed. This literature review can be divided into the following categories: 1) descriptions of surface geology; 2) student theses related to surface or subsurface geology; 3) petrographic studies of individual surface or subsurface stratigraphic intervals; 4) stratigraphic synthesis of subsurface geology; 5) syntheses of surface and subsurface structural geology of northern Arkansas; and 6) short papers or brief descriptions dealing with oil and gas fields and exploration activities.

Surface exposures of Chester-age rock are restricted to a narrow east-west trending band through northern Arkansas. Early during the research all descriptive information was gathered resulting from state surveys (Penrose, 1891, Banner, 1892, Adams and Ulrich, 1904, and Croneis, 1930), the United States Geological Survey (Mayer and Lantz, 1952 and Frezon and Glick, 1959), and paleontological studies (Weller, 1897; Girty, 1915; Weller, 1948; Gordon, 1964; Saunders, 1973; Saunders, Manger, and Gordon, 1977; and Grayson, 1974). Another good source of information regarding surface stratigraphy and facies interpretation is found in geological society and university guidebooks. The Louisiana State University Department of Geology Guidebook (Handford and Baria, 1973) contains stops in the Moorefield Shale, Batesville Sandstone, and Hindsville Limestone in north-central Arkansas. The University of Arkansas, Sigma Gamma Epsilon Guidebook (Heathcote and others, 1977) highlights the Carboniferous exposures and related structure of northwestern Arkansas. Guidebooks prepared by the Geological Society of America, South-Central Section (Wise and Glick, 1973; and McFarland, Buse, Wise, and Holbrook, 1979) present examined section of Ordovician- to Mississippian-age strata in north-central Arkansas.

Student theses related to the Chester units of Northern Arkansas have been written at the University of Arkansas (Fayetteville), Northwestern University, and Northeast Louisiana University. The majority of theses written at the University of Arkansas are primarily confined to the northwest region of Arkansas. Some have been written on ore deposits of the Batesville mining district, but generally lack substantial information on the Batesville Sandstone (McGowan, 1981). Ogren (1961) dealt with determining the stratigraphic positions and petrographic characters of certain Chester-age units. Threinen (1961) worked on the same problem, but more specifically on the Chester-age Mayes Group in north-central Arkansas. The sole thesis which examines the Batesville Sandstone was written by Schell (1971). This thesis dealt primarily with economics and techniques of mining sandstone. Price (1981) discussed the transportation and depositional history of the Wedington Sandstone, which overlays the Batesville. Grayson (1976) studied the Hindsville Limestone, a stratigraphic equivalent to the Batesville located in the west half of northern Arkansas, he discussed the lithostratigraphy and conodont biostratigraphy.

Ogren (1961), Threinen (1961), and Schell (1971), included petrographic studies aimed at identifying detrital and heavy mineral constituents and determining a potential source area for the detrital clastic sediment.

Stratigraphic syntheses of Chester-age surface/subsurface units have been published in reviews and surveys summarizing the geology with special concern to oil and gas potential. Early papers include Penrose (1891), Adams and Ulrich (1904), and Croneis (1930), plus Gordon (1944), Caplan (1954 and 1957), Frezon and Glick (1959), Garner (1967), and Ogren (1968). Glick (1979) also provides excellent information regarding the stratigraphic relationships of Chester rock units in northern Arkansas.

A paper by Chinn and Konig (1973) uses stressed calcite twin lamellae in relation to the regional structure to provide a different insight on the structural processes. Caplan (1972 and 1979) published papers concerning the oil and gas potential of northern Arkansas.

Subsurface Studies in Mississippi and Alabama

Published literature concerning Chester rock units in the Black Warrior Basin can be subdivided into seven categories. These include: 1) descriptions of surface geology (predominantly in Alabama), 2) student theses relating either to surface or subsurface geology, 3) petrographic studies of individual surface or subsurface stratigraphic units, 4) stratigraphic syntheses of subsurface geology, 5) syntheses of surface and subsurface structural geology, 6) summary papers dealing with specific oil and gas fields, and 7) short papers concerning new discoveries in reviews of exploitation and development trends within the region.

Surface exposures of Chester-age rock units of the Black Warrior Basin are confined to the Northern Shelf, both in the Tennessee River Valley of Alabama and in the extreme northeastern portion of Mississippi. Summaries of surface stratigraphy and descriptions of measured sections for Mississippi are given by Morse (1930) and Bicker (1979). In Alabama, Butts (1926) and Thomas (1972a) have summarized the same for exposures. Welch (1959) and Thomas (1979) also provide additional summaries of the surface stratigraphy. Information provided by Henry and others (1985) correlates what had been previously considered Parkwood Formation in northwestern Alabama to time-equivalent units in the Ardmore Basin though analysis of macrofauna present in the Isbell section in Franklin County, Alabama.

Field trip guidebooks prepared by the Mississippi Geological Survey (Mack, 1954; Moore, 1978) contain field trip stops in the Tuscumbia, Pride Mountain, and Hartselle Formations. The carbonate facies in the Pride Mountain, Bangor, and Monteagle are highlighted in the Alabama Geological Society trip to the Alabama and Tennessee Chester-age sections (Smith, 1967). Thomas and others (1980) led a Geological Society of America Southeastern Section field trip to the Hartselle and lower Bangor exposures of Colbert and Franklin counties, Alabama. Other Geological Society of America guidebooks which contain discussions of Chester-age rocks in the Black Warrior Basin include Ferm and others (1967) and Horne and others (1976).

Student theses regarding Chester-age (Upper Mississippian) lithostratigraphy have been written at Louisiana State University, University of Alabama (Tuscaloosa), University of Mississippi, University of Southern Mississippi and Oklahoma State University. Ehrlich (1965) at Louisiana State University proposed that both the Chester and Pottsville clastic formations resulted from deposition of a single orogenic clastic wedge which was derived from a low-rank metamorphic source area southeast of the basin. Both White (1976) and Shepard (1979) of the University of Alabama, mapped the net sandstone distribution of the Carter interval, given the limited well control available in Alabama at that time, and provided petrographic description of Carter core from distal deltaic facies in Lamar and Fayette counties, Alabama. Broussard's thesis at the University of Mississippi (Broussard, 1978), dealt with outcrop measured sections in the Hartselle and Pride Mountain Formations as well as net sandstone isolith subsurface maps of the Lewis, Evans, Hartselle, and Muldon (combined Rea, Abernathy, Sanders and Carter) Clastics Interval. Utilizing approximately 400 electric logs over 20 counties of Mississippi and Alabama, his thesis presents a more regional scope than previous subsurface theses. He determined that the upper Mississippian Chester sand bodies were deposited as high-destructional and high-constructional deltiac systems. O'Conner (1984) analyzed the Lewis Sandstone, incorporating over 800 electric logs. Bat (1987) concluded that the Lewis Sandstone was deposited as a high-constructive delta complex and the Evans Sandstone formed as a high-destructive wave-dominated cratonic deltaic system. This was based on examination of 625 electric logs in Mississippi and Alabama. At the University of Southern Mississippi, Hughes (1987) examined the petrographic constituents of six Chester-age sand bodies including the Lewis, Evans, Rea, Abernathy, Sanders and Carter units. He concluded that the sands making up these units originated from a cratonic source. Michael Nix (1986) has published partial results of his study of the Muldon Clastics at the University of Alabama. He concluded that they all had a southwest source and prograded northeastward onto the Northern Shelf.

Shepard (1979), Holmes (1981), O'Conner (1984), Bat (1987), Hughes (1987), and Hughes and Meylan (1988) all included petrographic studies of all or portions of the Chester Group in their studies. Similarly, they all concluded that these Chester-age sandstones originated from a cratonic, sedimentary source area located north or northwest of the Black Warrior Basin. Contrary to this, Graham, Ingersoll, and Dickinson (1976) proposed a Ouachita provenance for all the Carboniferous terrigenous clastics in the basin. Thomas (1980) and Thomas and Mack (1982) determined that the Hartselle Sandstone, due to the presence of polycrystalline quartz, was derived from an orogenic source in the Ouachita Mountain complex of southern Mississippi. Mack, James, and Thomas, (1981) and Mack, Thomas, and Horsey (1983) analyzed the outcrop Parkwood units, and concluded that these also had a southwest orogenic source from southern Mississippi.

Stratigraphic syntheses of Chesterian subsurface geology have been published in papers reviewing the petroleum geology of the Black Warrior Basin. Early papers include Mellen (1947, 1953a, 1953b), and Everett (1968). Also, Pike (1968), Vernon (1971), Welch (1971), and Duschscherer (1972) supply brief descriptions of Chester stratigraphy and producing horizons. Welch (1978) prepared two subsurface structure maps and net sandstone isolith maps of the Sanders and Carter intervals, from which he concluded transport of sediment from the north (i.e. the Illinois Basin) by a major stream system. Scott (1978) outlined the facies components and porosity distribution on his lower Bangor carbonate map of Lamar and Fayette counties. Cleaves and Broussard (1980) and Cleaves (1983) applied deltaic depositional models to the Lewis, Evans/Hartselle and the Muldon Clastics Interval, postulating a cratonic, Ozark-region, provenance. Thomas (1972b; 1974) studied a total of 104 wells from all parts of the basin and concluded that the Parkwood and Floyd terrigenous clastics of the Chester Group were clastic wedge units of orogenic origin prograded into the basin from the Ouachitas of west-central Mississippi.

The majority of Thomas's research has dealt with explaining the tectonic history of the southern Appalachian and Ouachita Mountains (Thomas, 1973, 1976, 1977, 1980, 1984, and 1988).

In a recent paper, Higginbotham (1986), proposed that the Mississippian clastics between the Tuscumbia and Bangor Limestones originated from a southern orogenic source. Petroleum Information Corporation published an overview of the geology and petroleum potential of the Black Warrior Basin (Petroleum Frontiers, 1986). Gathering data from active explorationists in the basin and researchers from various universities, the publication gives an accurate description of the Mississippian and Pennsylvanian stratigraphy, the structural framework of the basin, and the economics involved with exploration in the basin.

Information on specific Chester-age gas fields are available in publications of the Mississippi Geological Society and the Mississippi State Oil and Gas Board. Enlisting the aid of Frascogna (1967) and Davis and Lambert (1963), the Mississippi Geological Society (Jackson) has published a type log, structural contour map, reservoir data, and production history for 17 Chester-age producing fields in Mississippi. The Mississippi Oil and Gas Board publishes an annual report listing the discovery dates and production summaries for producing pools in Mississippi. Most recently, the Oil and Gas Board (Miss. Oil and Gas Board, Annual Report, 1989) published a listing of field developments for every field in Mississippi. Small articles which examine specific Chester-age fields include Spooner (1976), Jones (1978), and Petroleum Information Corporation (Petroleum Frontiers, 1986).

Periodic reports published on exploration and production trends in the Black Warrior Basin are in the Oil and Gas Journal, and in the yearly domestic exploration summary in the American Association of Petroleum Geologists Bulletin (Spooner, 1977, Anderson, 1977, Devery, 1985). Mancini and others (1983), and McCaslin (1979, 1980a, 1980b, 1984, 1985), described exploration developments in the Oil and Gas Journal. Cate (1977, 1978, 1981, and 1982) and Cate, Carter and Jennings (1979) supplied the recent Bulletin summaries of exploration developments in the southeastern states.

Reelfoot Aulocogen of northeast Arkansas

Few papers deal primarily with the Reelfoot Aulocogen. Most discuss the reactivation processes and seismicity of northern extensions of the Reelfoot complex.

Ervin and McGinnis (1975) used gravity surveys and seismic data to construct a crustal model along a gravity profile perpendicular to the Mississippi Embayment axis. This, along with petrologic examinations of the Embayment igneous rock, allowed them to interpret the sequence of tectonic events culminating in formation of the Mississippi Embayment.

Kane, Hildenbrand, and Hendricks (1981) used aeromagnetic and gravity surveys of the northern Mississippi Embayment to delineate a northeast-trending basement and the current seismicity associated with it. They interpreted the Paleozoic graben formation, Mesozoic plutons, and sedimentation cycles as evidence of extensional events associated with periods of active rifting. They also suggested that this sequence of events can be explained by the action of a horizontal stress field on a crustal flow which persisted from Precambrian. To study the ancient rift complex and its relation to present seismicity in the New Madrid Seismic Zone, Braile, et al. (1982) used gravity, magnetic, geologic and seismicity data combined in a seismotectonic analysis of the zone. They proposed a northern terminus of the Reelfoot Rift forming a rift complex which correlates well with the seismicity of the region. This correlation suggests that the faults associated with this rift are being reactivated in a ENE compressional stress field.

Mooney, et al. (1983) used previous geological and geophysical data, along with more recent seismic refraction surveys, to lend additional support to the rifting hypothesis for this region. Their data show six primary layers of mantle, consolidated and unconsolidated sediments and apparent doming of layers due to injection of mantle material. They propose that the Reelfoot Rift Basin was the location for a triple junction associated with the rift complex.

Howe (1984) and Howe and Thompson (1984) determined the tectonics, sedimentation, timing of events, and the hydrocarbon potential of the Reelfoot Rift. This was accomplished by using seismic data, gravity surveys, geological data from wells, and examination of outcrop. Cox (1988) studied various aspects of the geology and geomorphology of Crowley's Ridge and its relationship to the Reelfoot Rift. Sexton (1988) conducted a study of the Reelfoot region using high resolution explosives, Mini-Sosie, and U.S.G.S. Vibroseis surveys. This work revealed several earthquake epicenters in the vicinity of large-scale Paleozoic normal and reverse faults which showed signs of reactivation.

CHAPTER III

TECTONIC SETTING

Southern Midcontinent Overview of Tectonic Setting

Reelfoot Rift

The Reelfoot Aulacogen extends from east-central Arkansas to southeastern Kentucky (Figure 4). It is a linear trough bounded by two major faults, the Ridgely and Reelfoot faults (Sexton, 1988), and is covered by Late Mesozoic and Cenozoic strata of the Mississippi Embayment. The southern portion of the Reelfoot Aulocogen links the Arkoma Basin in northeastern Arkansas, to the Black Warrior Basin in northeastern Mississippi. It is bounded by the Ozark Dome and Ozark Plateau region on the northwest, the Illinois Basin on the north and the Nashville Dome on the east.

The northern region of the aulacogen is structurally complex, acting as a junction for the Reelfoot Rift, the Ste. Geneveive Fault, the Fluorspar Area Fault Complex, the Rough Creek Graben and the Illinois Basin (Figure 4). This has been interpreted as a 'transverse offset' or 'bend' in a contiguous Cambrian rift system composed of the Reelfoot, Rough Creek, and Rome Rift basins (Howe, 1984).

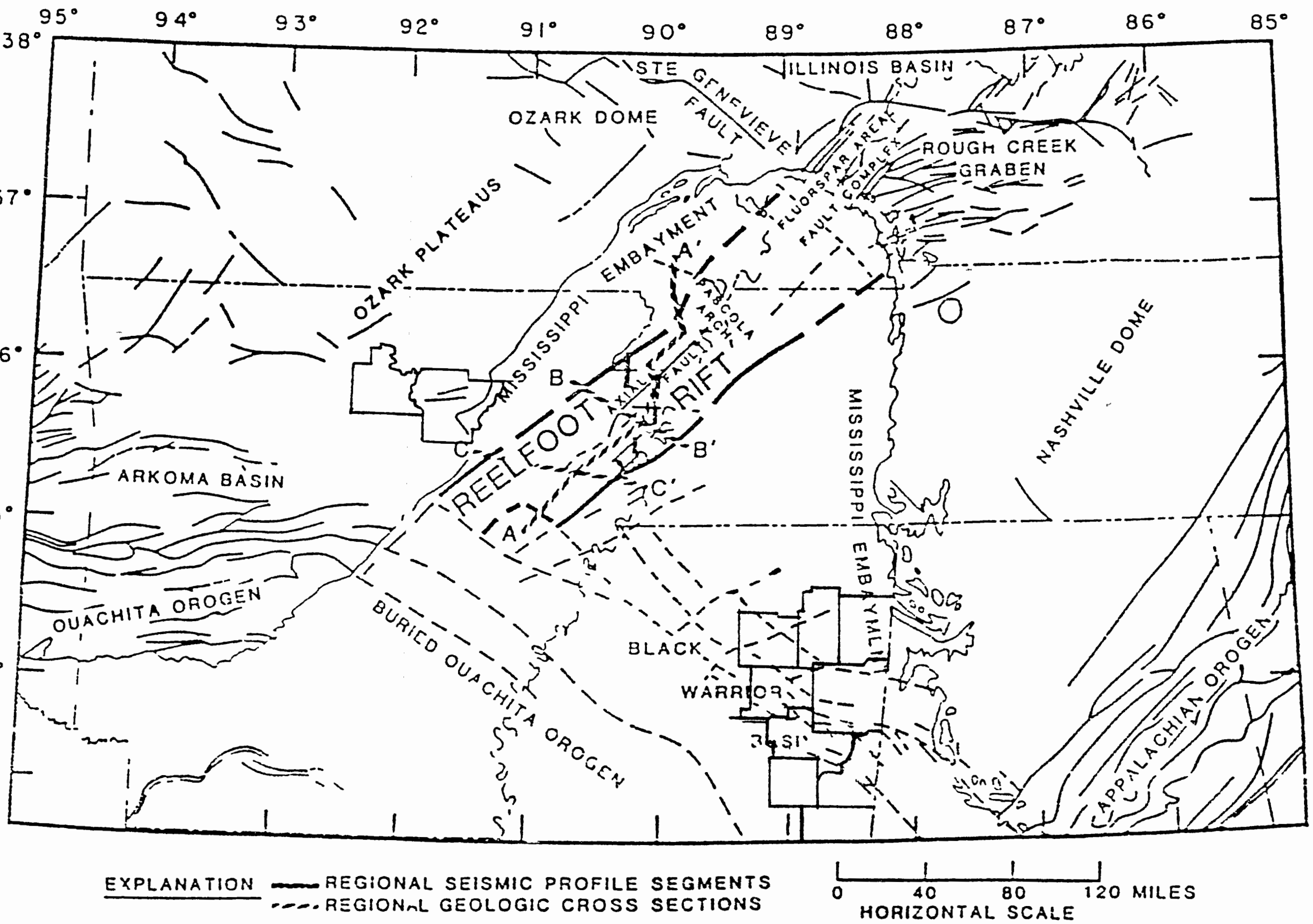


Figure 4. Regional Tectonic Map of the Reelfoot Rift (from Howe, 1984).

Rifting, which resulted from extensional stresses, was initiated in Late Precambrian. This was accompanied by uplift and intrusion of low-density mantle material. This was a portion of the extensive rift activity to which the North American continental mass was being subjected (Ervin and McGinniss, 1975). Rifting remained active in the Reelfoot region until the Middle Cambrian and it resulted in the formation of the series of horsts and grabens trending to the southeast. These grabens, acting as structural lows, became sediment traps for significant amounts of clastics shed from the north and from surrounding uplifted blocks (Fritts and Dean, 1985).

During the Late Cambrian through Ordovician major tectonic activity ceased. Regional downwarping along with transgression of the seas resulted from the cooling of the lithosphere. This broad, shallow-marine trough was the site of rapid carbonate deposition that attained a thickness of 6,000 to 8,000 feet. These rocks have been termed the Arbuckle-Knox Megagroup (Howe and Thompson, 1984).

The absence of Middle to Late Paleozoic strata from the central portion of the Reelfoot Aulacogen makes interpretation difficult, but by extrapolating information from surrounding regions, events may be summed up. Occasional mild uplifts with accompanying deformation on a widespread scale likely resulted from the collision of the European, and North American plates (Taconic and Acadian Orogens). This created a series of small regressions and transgressions which are expressed by the number of unconformities appearing in the rock record.

These intermittent events of uplift, coupled with earlier (Middle Ordovician) lateral displacement of mantle material beneath the rift, caused gradual, upward, movement of the Ozark and Nashville Domes. Lack of sedimentation during the Devonian through Middle Mississippian (Meramecian) was due to either bypassing of sediments north of the Illinois Basin, or sea level changes.

During the Middle Mississippian (Early Chester) there was a resurgence of clastic deposition into the Reelfoot trough due to erosion of uplifted regions in the northeast. These uplifts occurred during the early stages of the Alleghenian Orogeny. The renewed influx of clastics continued until the Middle Permian. During Late Mississippian time, the entire southeastern and southern region of the North American continent was affected by the Appalachian-Ouachita Orogeny. By Middle Pennsylvanian, convergence, collision and suturing of the plates led to the formation of Pangaea.

During these large-scale orogenic events there was reactivation of the fault zones within the Reelfoot Aulocogen. This caused a subsidence in the existing graben structures and allowed for more sediments to pass into and through the rift troughs.

The Reelfoot Rift and surrounding areas most likely experienced uplift intermittently from the Late Paleozoic to the Late Mesozoic, as much of the Silurian to Late Cenozoic strata have been stripped away. During the Late Mesozoic plutons were injected along some ancient faults causing renewed activity of certain faults. This was followed by cooling, regional subsidence, and the formation of the Mississippi Embayment.

Nashville Dome

The Nashville Dome is an elliptical uplift located in central Tennessee (Figure 5). It connects with the Cincinnati Arch on the north, and with the younger Pascola Arch in the subsurface to the west (Wilson, 1939). The dominant feature is a broad, relatively flat, crenulated dome surrounded by numerous outliers cresting at approximately 900-1000 feet above sea level (Wilson and Stearns, 1963).

The earliest structures of this region are a series of rift-related basins which formed about the same time as the Reelfoot Rift during Late Precambrian-Early Cambrian time (Stearns and Reesman, 1986). It is believed that these grabens are filled with Cambrian sediments. Overlying the Cambrian sediments are thick Knox carbonates. Minor swelling, which occurred contemporaneously with deposition of the Knox, has been thought to be the result of mantle material emplaced laterally from injected ingeneous plumes in the subsiding Reelfoot Trough (Ervin and McGinniss, 1975). During the Ordovician the trend of the axis was N10E in east-central Tennessee. Even though the trend of the axis was not

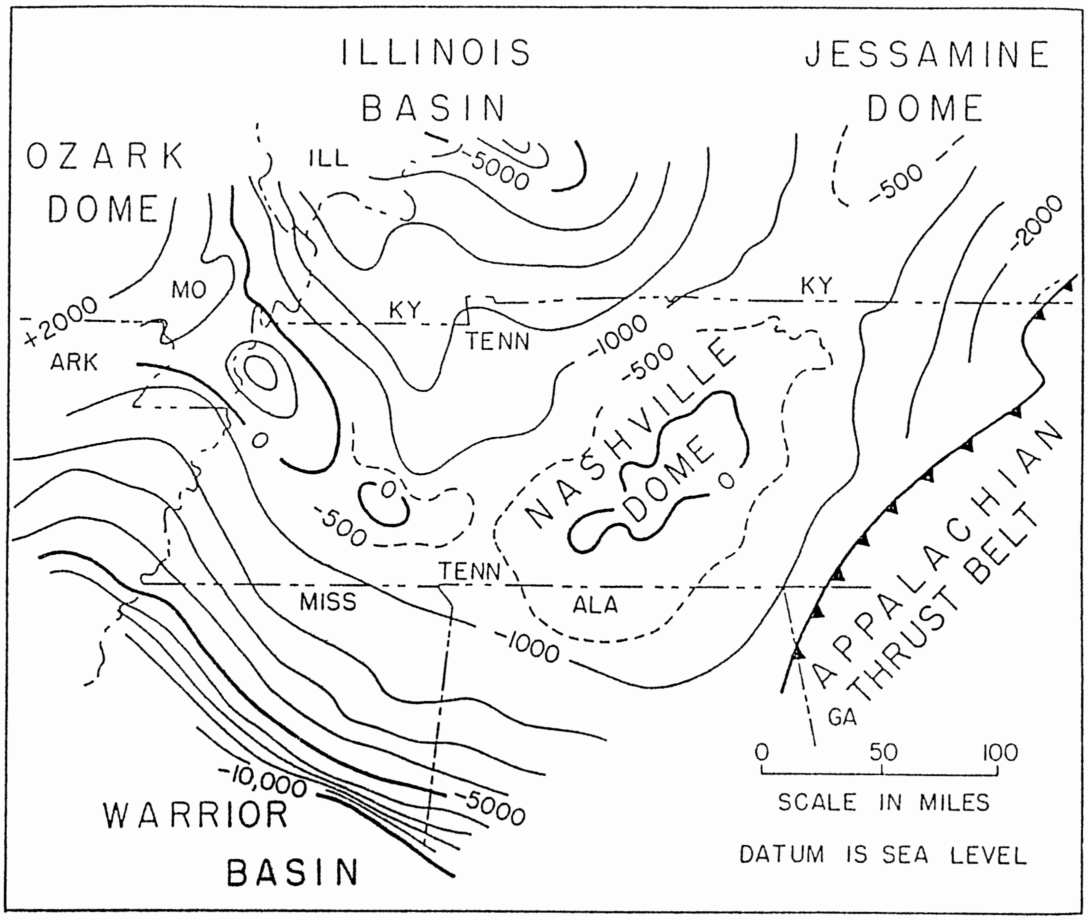


Figure 5. Structural Contour Map of the Nashville Dome and Associated Regional Structures (from Wilson and Stearns, 1963).

affected, it shifted approximately 50 miles west due to compression related to the converging plates associated with the Taconic and Acadian orogenies. During the Late Ordovician-Early Devonian only minor uplifts took place. Studies have indicated that these strata accumulated in a shallow water environment.

Late Mississippian to Permian strata have been stripped off the Nashville Dome, thus making interpretation of this interval difficult. The trend of the axis shifted to N50E sometime during this time period paralleling the N50E alignment of the Appalachian fold and thrust belt. It has been postulated that 6300 feet of Mississippian to Permian age clastics were eroded during renewed Middle Permian to Late Cretaceous uplift. (Stearns and Reesman, 1986). Because of continued northward compressional stresses, the trend of the dome's axis was finally shifted to its present east-west direction. The compression also caused the uplift of the Pascola Arch which formed adjacent to Nashville Dome on the west and effectively blocked sediments leaving the Illinois Basin until it was eroded.

Late Cretaceous to Eocene time was dominated by the deposition of gravels. Renewed uplift of the Nashville Dome has caused extensive erosion of the Cretaceous sediments. This uplift and subsequent erosion is continuing today.

Illinois Basin

The Illinois Basin is a broad, oval-shaped intracratonic basin located in central and southern Illinois, southwestern Indiana, and western Kentucky (Figure 6). The basin was bounded on all sides by weak positive structural features, except on the south where there was an open trough until the Late Paleozoic (Swann, 1968).

The Illinois Basin was located approximately 300 kilometers north of the craton margin during the Paleozoic. Basin formation was largely controlled by a combination of broad downward flexing in the north and the development of a deep, rapidly subsiding graben complex to the south. Several structural features contributed to the isolation and eventual formation of the Illinois Basin (Figure 6). The basin is separated from the Midcontinent region by the Ozark Uplift and the Mississippi River Arch on the west, and from the Appalachian Basin by the Cincinnati Arch-Nashville Dome to the east. On the northern margin it is bordered by the Wisconsin Arch and separated from the Michigan Basin by the Kankakee Arch. The southern margin is bordered by deeply buried remnants of the Reelfoot Aulocogen and the younger Pascola Arch.

In Precambrian time, the landscape was dominated by rugged basement rock which underwent a lengthy period of erosion. Formation of the Reelfoot Aulocogen, was the most significant structural related event to affect the Illinois Basin during the Precambrian. The Lower Cambrian to Middle

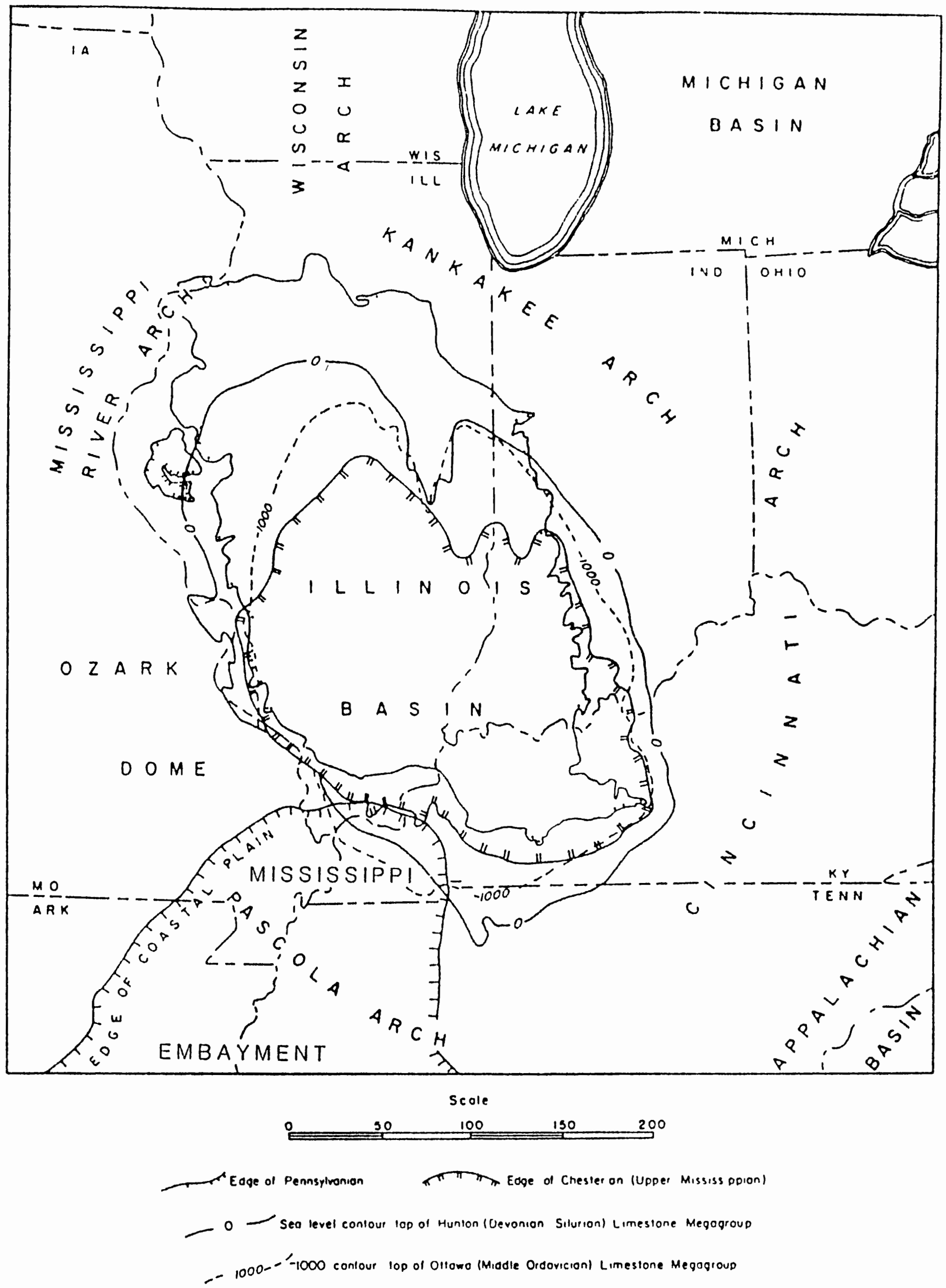


Figure 6. Generalized Structure Map of the Illinois Basin (from Swann, 1968).

Ordovician interval is represented by the Sauk Sequence marking the period of greatest siliclastic deposition in the basin. This detritis originated in the Canadian Shield and was transported to the southern reaches of the basin. Thickest accumulations of Cambrian sandstones are in the Rough Creek Graben of western Kentucky. Deformation during this time consisted of regional warping and localized subsidence that produced small arches, domes and basins (Collison, Sargent, and Jennings, 1988).

In Middle Ordovician to Early Devonian (Tippecanoe Sequence) time there was a series of minor transgressions and regressions. By Middle Ordovician time, seas retreated to the south leaving previously deposited sediments exposed to extensive erosion. The renewed transgression of shallow seas helped create extensive carbonate build-up as no new clastic material was introduced into the basin (Swann, 1968). Carbonate deposition continued through the Silurian and into the early Devonian until the seas receded. The deep surface erosion seen after previous regressions was not developed during this period of subaerial exposure.

The interval expressed as the Kaskaskia Sequence (Middle Devonian through Mississippian) can be divided into three periods of deposition. The presence of muds and clay deposited during the Acadian orogeny to the east, dominated early, with lenses of limestone and sandstone present. The sporadic deposition of either limestone or sandstone reflects a period of little sedimentation suggesting that during this time the Illinois Basin was a "starved basin" (Heidlauf, Hsui, and Klein, 1986). The Late Devonian to early Middle Mississippian was dominated by carbonate deposition. Clastics from the Canadian Shield reached the northern margin of the basin by Early Mississippian time and dominated deposition through the end of Mississippian. During this deposition of clastic material major subsidence within the Illinois basin, coupled with the filling of the Michigan Basin, allowed the ancient Mississippi River to bypass the Michigan Basin and empty into and through the Illinois Basin (Swann, 1964). Major deltas formed on the northeast margin of basin and prograded southward, dumping significant amounts of sediments in the basin. Towards the end of the Mississippian the seas returned and deposited a thin veneer of limestone over the Chester sandstones. The area was then uplifted and heavily eroded (Atherton and Palmer, 1979).

The Pennsylvanian Period is represented by the Absaroka Sequence. It is marked by cyclic deposition of carbonates, sandstones, and coals. Prior to renewed sedimentation, extensive erosional downcutting created valley systems over much of the basin. Shallow seas returned followed by a regression as deltas prograded out into the basin. These deltas consisted of less mature sandstones which had their source area in the newly formed mountains north and east of the Illinois Basin. The Pennsylvanian sediments show a high degree of compaction. This suggests that they were overlain by a thick sedimentary cover, but erosion at the end of

Absaroka time removed much of the Late Paleozoic strata (Swann, 1968).

Sometime between the Late Pennsylvanian and the Late Cretaceous the Illinois Basin became a closed structure with the emergence of the Pascola Arch. The southern region of the basin also experienced a significant amount of normal faulting and reactivation of the Ste. Genevieve and Rough Creek-Shawneetown Faults. Following Late Cretaceous movements, the region was uplifted as only the southern portion of the basin was covered by Cretaceous and Cenozoic Gulf Coast sediments. Erosion and four events of glaciation have shaped the surface topography of the basin as it is viewed presently.

The Appalachian - Ouachita Orogens

During the time period between the Late Precambrian and the Triassic a series of events culminated with the formation of two mountain systems, the Appalachian and the Ouachita Mountains (Figure 7a and 7b). They appear as a continuous belt of deformed rock along the continental margin, from NewFoundland to northern Mexico (Rast, 1989).

The Appalachian Mountains can be conveniently divided into zones based on the overall facies distribution. There are: 1) the Miogeoclinal Belt; 2) the Piedmont terrain; 3) the Dunnage terrain; 4) the Gander terrain; and 5) the Avalon terrain (Figure 7a).

The Miogeocline represents the ancient North American

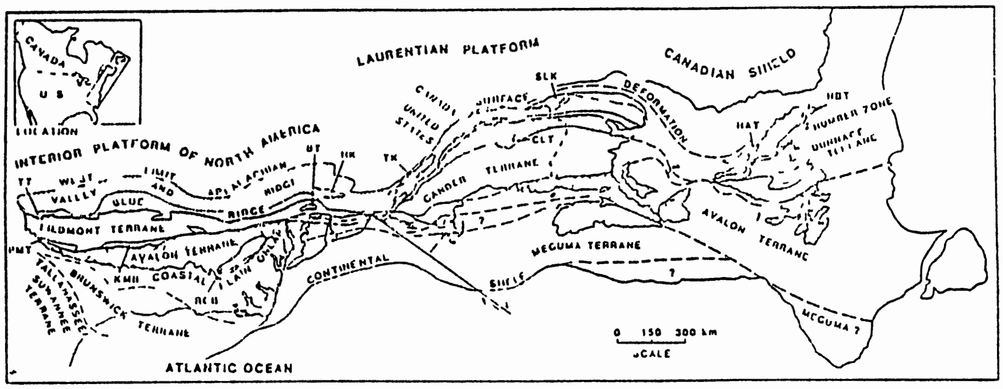


Figure 7a. Terrane Map of Eastern North America (from Rast, 1988).

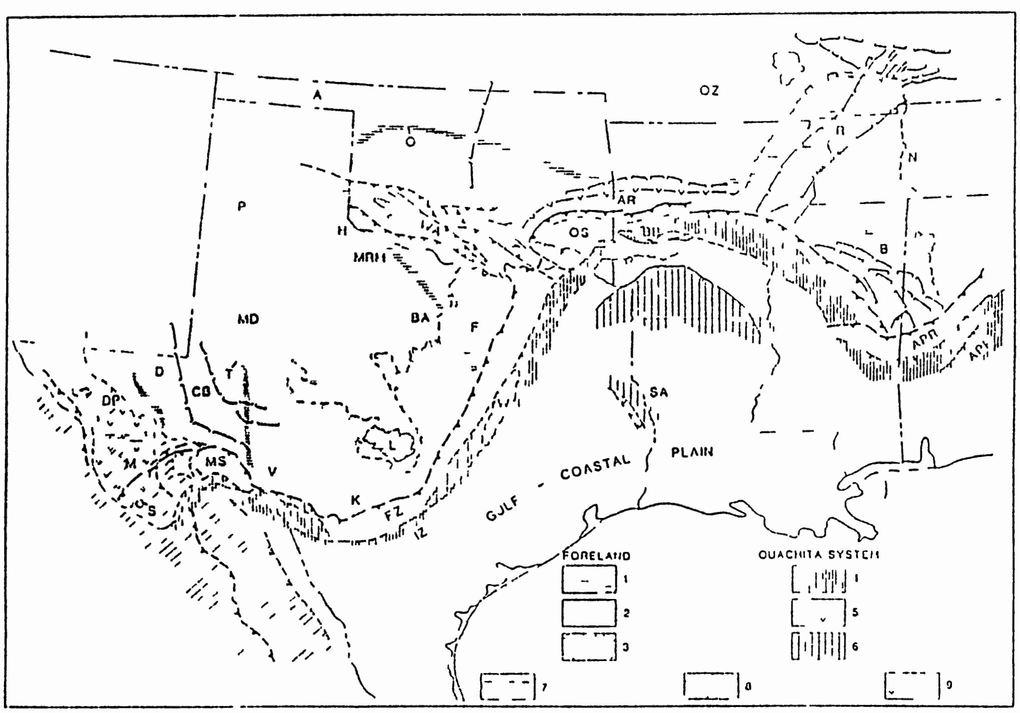


Figure 7b. Major Tectonic Elements of the Ouachita System (from Rast, 1988).

continental shelf which, as massive allochthonous slices, were thrust westward onto the continent. The allochthons are composed of volcani-clastics and thick carbonates, with some containing ophiolites (Williams and Hatcher, 1982). The Piedmont terrain is dominated by Late Precambrian-Early Paleozoic metamorphic and volcanic clastics which lie noncomformably on Greenville basement rock. The Piedmont rock was possibly derived from the eastern Miogeocline, and has been intensely deformed and metamorphosed to a greenschist-amphibolite facies. Seismic studies have revealed that the Piedmont terrain, in the southern Appalachians, is one continuous slice thrust onto Miogeocline (Cook and Oliver, 1981). The Dunage terrain is made up of mafic volcanoes, marine sedimentary rock, and melanges of volcanic and sedimentary rock which overlie ophiolite sequences. Deformation and metamorphism is generally weak throughout. It is suggested that these sediments represent remnants of the Iapetus (Proto-Atlantic) ocean. The Gander terrain consists of early Middle Ordovician rock of Canada and of volcanic rock and shales in New England. The Acadian Orogeny produced many granitic intrusions along with intense metamorphism and deformation of rock considered to contain back-arc basin sediments (Coleman-Sudd, 1980). The Avalon terrain consists of Precambrian sedimentary and volcanic rocks which were generally unmetamorphosed and undeformed. These rocks pass upwards into Cambrian shales which contain Atlantic type trilobite faunas. In the south, this terrain is represented by the Charlotte and Carolina Slate Belts (Windley, 1984). The Avalon terrain is a "suspect terrain which was unaffected until accretion from the Acadian orogeny" (Williams and Hatcher, 1982).

The Late Precambrian-Early Cambrian time period marks a time of significant rifting, initiating opening of the Iapetus ocean, and deposition of volcani-clastics. Great thicknesses of sediments are found in deep grabens associated with rifting (Thomas, 1977). A period of tectonic cessation followed, and the eastern and southern boundaries of the North American continent acted as "Atlantic-type" passive margins (Keller and Cebull, 1973). This, along with a decrease in clastics during the Middle Cambrian, created an environment conducive to the formation of massive carbonate build-ups. In some regions, the carbonate deposition continued up to the Early Silurian (Hatcher, 1972). Adjacent to these carbonates, a deep water complex of pellitic and clastic sediments formed, making up the Piedmont terrain. By the Early Ordovician, the Piedmont had been heavily metamorphosed. Offshore island-arc volcanism in the Dunnage terrain began in Early Ordovician time. Oceanic crust moving under the craton created an Ordovician subduction zone which is represented by the Dunnage melange.

By the Middle Ordovician the Taconic Orogeny, the first of three Paleozoic orogenic phases, took place. During this phase the Dunnage and Gander terrains were juxtaposed with the miogeocline; this represents the earliest accretionary phase (Williams and Hatcher, 1982). Deformation associated with emplacement of allochthons during the Middle Ordovician represents the main phase of the Taconic Orogeny. The deformation was concentrated along the north-central and northern continental margins. Rast (1988) suggests that this same type of deformation can be seen in the southern Appalachians, because the Piedmont moved onto the North American craton causing thrust faulting and nappe transport to the northwest.

Synclines located in Pennsylvania are dominated by the deposition of Early Silurian alluvial clastics derived from uplifts located to the east. In the Middle Silurian a transgression covered much of the North American craton and resulted in the accumulation of carbonates and evaporates.

By the Early Devonian, the Acadian Orogeny began with the most intense deformation occurring east of the Taconic deformation zone. This resulted from westward accretion of the Avalon terrain in the north, and in the south by the collapse of the back-arc basin located west of the Charlotte and Carolina Slate Belts (Windley, 1984). Uplift and erosion dominated the northern and central Appalachians through the Devonian. Massive volumes of clastics were shed westward, forming the extensive Catskill Delta in Pennsylvania.

The early Carboniferous (Mississippian) is represented by continued uplift in the northern Appalachians producing thick accumulations of clastics. During the Early Pennsylvanian, the Alleghnian orogeny created extensive thrust belts in the southern Appalachians with at least 175 km of movement northwest onto the North American craton (Secor, Snoke, and Dallmyer, 1986). This uplift, along with renewed uplift in the north, was subjected to heavy erosion and resulted in the widespread progradation of Pennsylvanian clastic wedges. The southern Appalachians continue into central Alabama where they disappear into the subsurface buried under thousands of feet of Mesozoic and Cenozoic sediments of the Gulf Coast Mississippi Embayment (Thomas, 1973). The Alleghanian orogeny was the result of collision between North America and Africa and with its termination, the formation of the Appalachians was complete.

The frontal length of the Ouachita System is approximately 2100 km, of which only 430 km are exposed. The outcrop zone is represented by the Ouachita Mountains and the Marathon Uplift (Figure 7b). The remaining portion of the Ouachitas were buried beneath Gulf Coastal Plain sediments (Arbenz, 1988). By using limited well data and geophysical surveys these exposed sections have been linked, to create a continuous belt of deformation extending from central Mississippi-Alabama to West Texas (Thomas, 1973).

Formation of the Ouachitas may be divided into two phases, the first phase passive and the second phase tectonically active. As with the Appalachians, Late

Precambrian-Early Cambrian rifting comprised the initiation of continental spreading and resulted in the formation of an ocean. The first phase began in Cambrian time and is represented by thick clastic wedges in the rifted basins and regional carbonate build-ups on the continental shelf. Continued plate spreading accompanied by subsidence of the ocean floor formed abyssal depths south of the continental shelf in the Ouachita Basin. Sediments accumulated in the basin at a very slow rate from Ordovician through Late Mississippian time and involved shale, chert and novaculite chert (Viele, 1979).

The second phase began with the earliest evidence of a constriction of the Ouachita Basin and uplift marking the convergence of the North American plate and a southern plate. This middle Mississippian convergence initiated a sudden influx of terrigenous clastics which were funnelled toward the northwest from the southeast through a deep trough which parallels the continental margin. A subduction zone formed parallel to the North American margin during the Ordovician and dipped to the south. This triggered volcanism as volcanic tuffs appear in some parts of the flysch deposits (Wickham, Roeder, and Briggs, 1976).

The continued encroachment of the southern plate caused significant extensional faulting from Alabama to West Texas from Early to Middle Pennsylvanian time. It has been suggested that continued thrust loading caused the faulting that formed deep water conditions in several foreland basins

(Arbenz, 1988). Continued convergence caused emplacement of allochthonous thrust sheets composed of continental shelf, abyssal, and flysch sediments onto the Paleozoic shelf of the southern North American margin (Pindell and Dewey, 1982). The climax of intense folding and large scale thrusting occurred in the Late Atokan (Mid-Pennsylvanian) or Early Desmonesian in the Ouachita segment of the belt. Suturing of the plates was not complete until Middle Permian time in the Marathon region. After a period of tectonic cessation in Late Permian, renewed Early Mesozoic rifting in the Ouachita - Appalachian region initiated opening of the present-day Gulf of Mexico and North Atlantic Ocean (Keller and Cebull, 1973).

The Arkoma Basin

The Arkoma Basin is a foredeep basin which extends from south-central Oklahoma to eastern Arkansas. This arcuate, east trending structural feature is approximately 40 to 80 km wide and 450 km in length. It is bounded by the northeast Oklahoma Platform and the Ozark Uplift on the north. The southern margin is expressed by the Choctaw fault in Oklahoma, and the Ross Creek fault in Arkansas, which define the northern cratonward margin of the Ouachita Mountains (Sutherland, 1988). The southwest margin is expressed by the Arbuckle Uplift (Figure 8).

The formation of the Arkoma Basin was the direct result from the creation of the Ouachita Mountains. This process

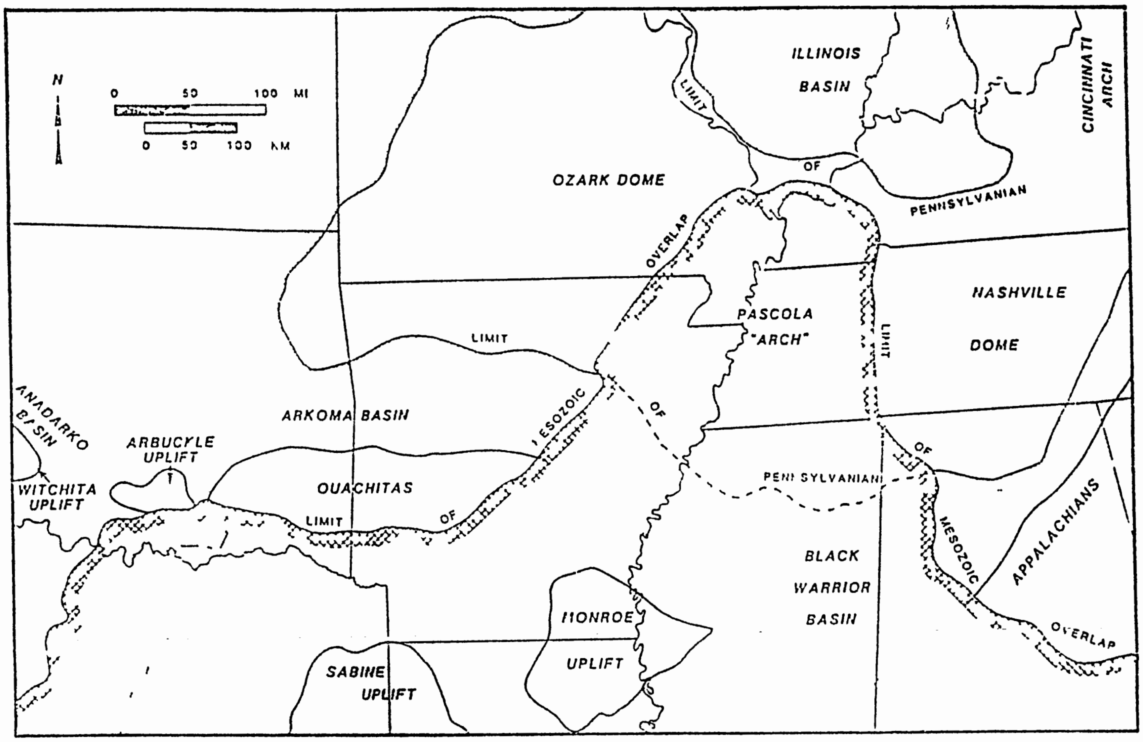


Figure 8. Regional Map of the Arkoma Basin and Associated Structural Elements (from Houseknecht, 1983).

was initiated by the Late Precambrian - Early Cambrian rifting. The spreading of continents and formation of a new ocean followed, and the southern continental margin of North America became a passive trailing edge (Keller and Cebull, 1973). The formation of a broad, relatively stable continental margin was dominated by the build-up of thick carbonates. Significant amounts of clastics were deposited in the Reelfoot Rift to the northeast and some made their way onto the shelf as small deltas. South of the shelf the deep Ouachita Basin had a relatively slow accumulation of deep water black shales and cherts through the Middle Mississippian.

By Mississippian time, a subduction zone had fully developed bordering the south margin of North America (Houseknecht and Kacena, 1983). The northward progression of the southern plate caused a tremendous influx of thick turbidites into the narrowing Ouachita Basin by the Middle Mississippian. The 11000 feet of Stanley Group turbidites, plus the Jackfork, Johns Valley, and the lower-most Atoka Formations represent several kilometers of flysch deposited from the Middle Mississippian to Early Pennsylvanian in the Ouachita Basin
(Briggs, 1974). Tuff deposits are present at various stratigraphic intervals within these flysch deposits; this suggests the presence of a volcanic island-arc associated with the subduction zone (Houseknecht and Kacena, 1983). The continental shelf, meanwhile, experienced no changes other

than increased amounts of clastics shed from the northeast through the Illinois Basin creating a shallow deltaic environment. One example is the Michigan River delta, which in Chesterian time prograded southward across the Illinois Basin and emptied clastics into the Ouachita trough (Swann, 1964).

During the Morrowan (Early Pennsylvanian), continued convergence caused uplift in the southeastern region of the Ouachita System. Further movement northward of the southern plate initiated uplift and deformation northwest along the continental margin. The first effects of compression were northeast - southwest trending normal faults partially overlain by the Ross Creek thrust fault. This in turn is overlain by narrow roll-over anticlines on listric normal faults (VanArsdale and Schweig, 1990).

Northward movement of the southern plate consumed the Ouachita Basin into the subduction zone and caused thrusting onto the continental shelf. This created tremendous downloading and continued collapse of the basin. The collapse resulted in a flexural bending of the basin causing normal faults to trend east-west in a down-stepping fashion into the basin (Sutherland, 1988). Deposition of Atokan sediments kept pace with the basin subsidence as deposits exceeded 8000 feet (Briggs, 1974).

At the end of the Atokan Epoch, collision was complete with the most severe deformation having past. The final collision resulted in the uplift of the subduction complex creating the Ouachita Mountains and the Arkoma foreland basin (Houseknecht, 1983).

By Desmoinesian time, sediments were being deposited in shallow water fluvial and deltaic environments as faulting ceased and the basin filled in. Clastic deposition continued until post-Desmoinesian time as major compression and deformation formed narrow asymmetrical anticlines associated with broad, shallow synclines whose arcs trend in an east-west fashion (Arbenz, 1988).

This deformational event was short-lived as deposition of clastics continued until regional uplift caused erosion and was followed by a transgression of seas.

Structural Elements of the Black Warrior Basin

The Black Warrior Basin is triangular shaped, Late Paleozoic foreland basin bounded by the Ozark uplift and Nashville Dome on the north, the Central Mississippi Deformed Belt on the southwest, and the southern Appalachian Fold and Thrust Belt on the east (Figures 9 and 10). The youngest sediments preserved in the outcrop portion of the basin are of Early Pennsylvanian (Morrowan) age. The basin includes all or part of approximately 40 counties situated in northeastern Mississippi and northwestern Alabama.

The Late Paleozoic closing of the Iapetus (proto-Atlantic) ocean caused the formation of the

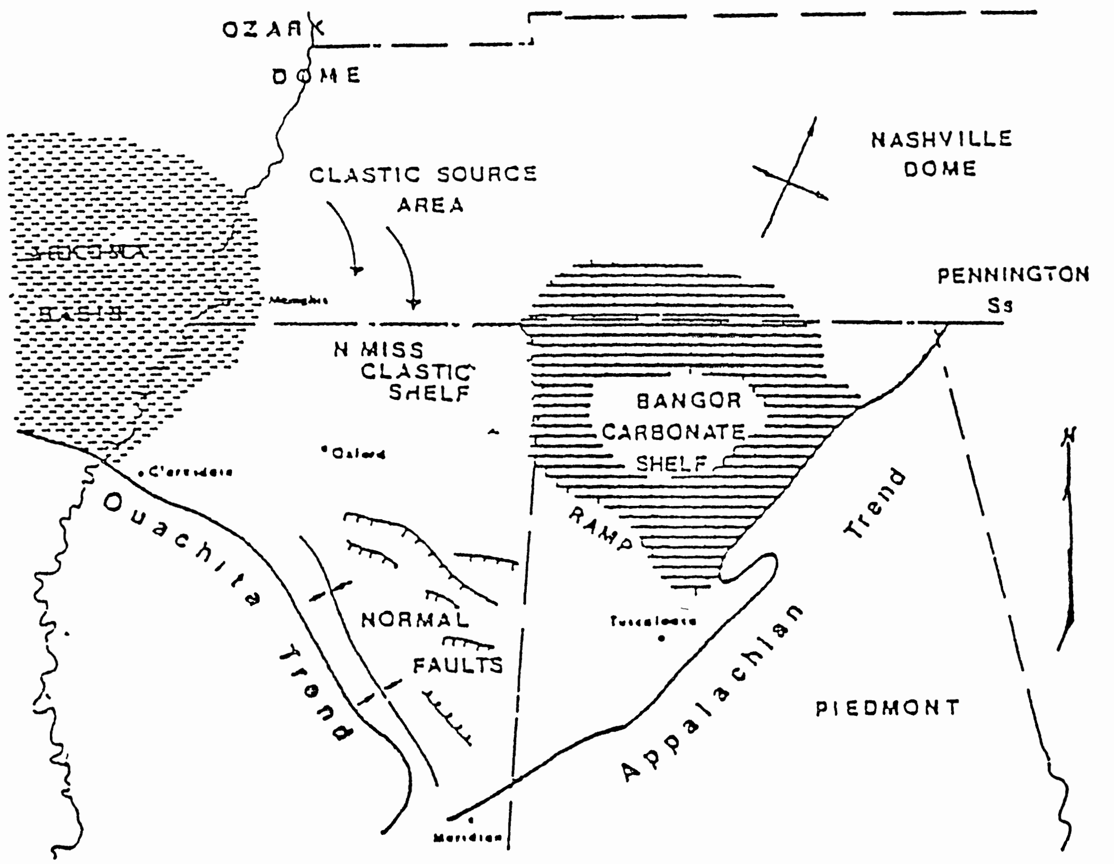


Figure 9. Regional Setting for the Black Warrior Basin (from Cleaves, 1981).

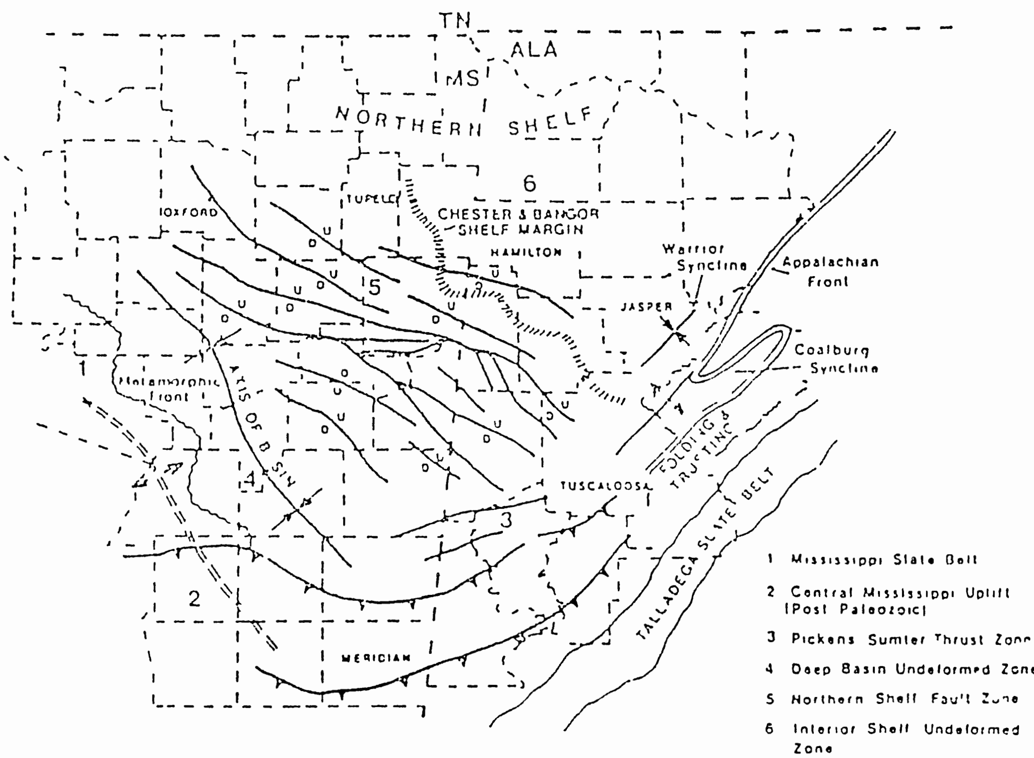


Figure 10. Structural Features of the Black Warrior Basin (from Thomas, 1973).

Appalachian and Ouachita fold belts by convergence of the North American continent and either a volcanic island-arc or southern continent (Thomas and Neathery, 1980). The dominant compressive force associated with the collision was apparently from the southwest, as reflected by an average strike of 325^{o} degrees for regional normal faults developed on the cratonic side of the evolving foreland basin. The basin is strongly asymmetric with its axis running parallel and adjacent to the Central Mississippi Deformed Belt. This zone of metamorphosed slate borders the south-southeastern side of the basin and forms the boundary between the Black Warrior Basin and the Mississippi Salt Embayment.

The Black Warrior Basin is characterized by numerous regional down-to-the basin normal faults which strike in a NW-SE direction. These regional faults are steeply dipping with offsets ranging from approximately 100 feet to over several thousand feet in the southwest region of the basin. Additional smaller-scale faulting with the downthrown block on the northern up-dip side gives rise to the formation of small grabens.

Origin of these regional faults has been a controversial topic. Interpretations range from the faults being related to late-stage Ouachita tectonism (Thomas, 1972b; 1973), Mesozoic rifting (Shepard, 1979) and/or tectonic loading (Bearden, 1985). The Pennsylvanian regional faults are inferred to be syndepositional, caused by significant subsidence due to thick deposition of clastics. The Appalachian-Ouachita orogens represent compressional features, whereas while the widespread regional faults found in the Black Warrior Basin are extensional features.

Smaller, antithetic faults trend in a parallel-subparallel fashion to the larger normal faults. These normal faults occur predominantly on the south side of the main faults and have displacements of several hundred feet or less.

Chesterian strata in the study area range in dip from 40 feet/mile on the East Warrior Shelf to over 300 feet/mile in the deeper basin to the southwest. The direction of regional dip is to the SSW (approximately 205° degrees azimuth).

Basinal Subsidence History of the Black Warrior Basin

The Black Warrior Basin contains a maximum Paleozoic sedimentary column of approximate 15000 feet (Mellen, 1947). As reflected by the subsidence rate curve, the basin has experienced three main phases of development (Figure 11).

After the region experienced significant Late Precambrian - Early Cambrian rifting, it became part of a passive continental margin from Cambrian to Ordovician. The basin subsidence curve reflects a relatively stable, even rate of subsidence of 50 feet/million years. Carbonate sedimentation (Arbuckle-Knox and Simpson Groups), dominated

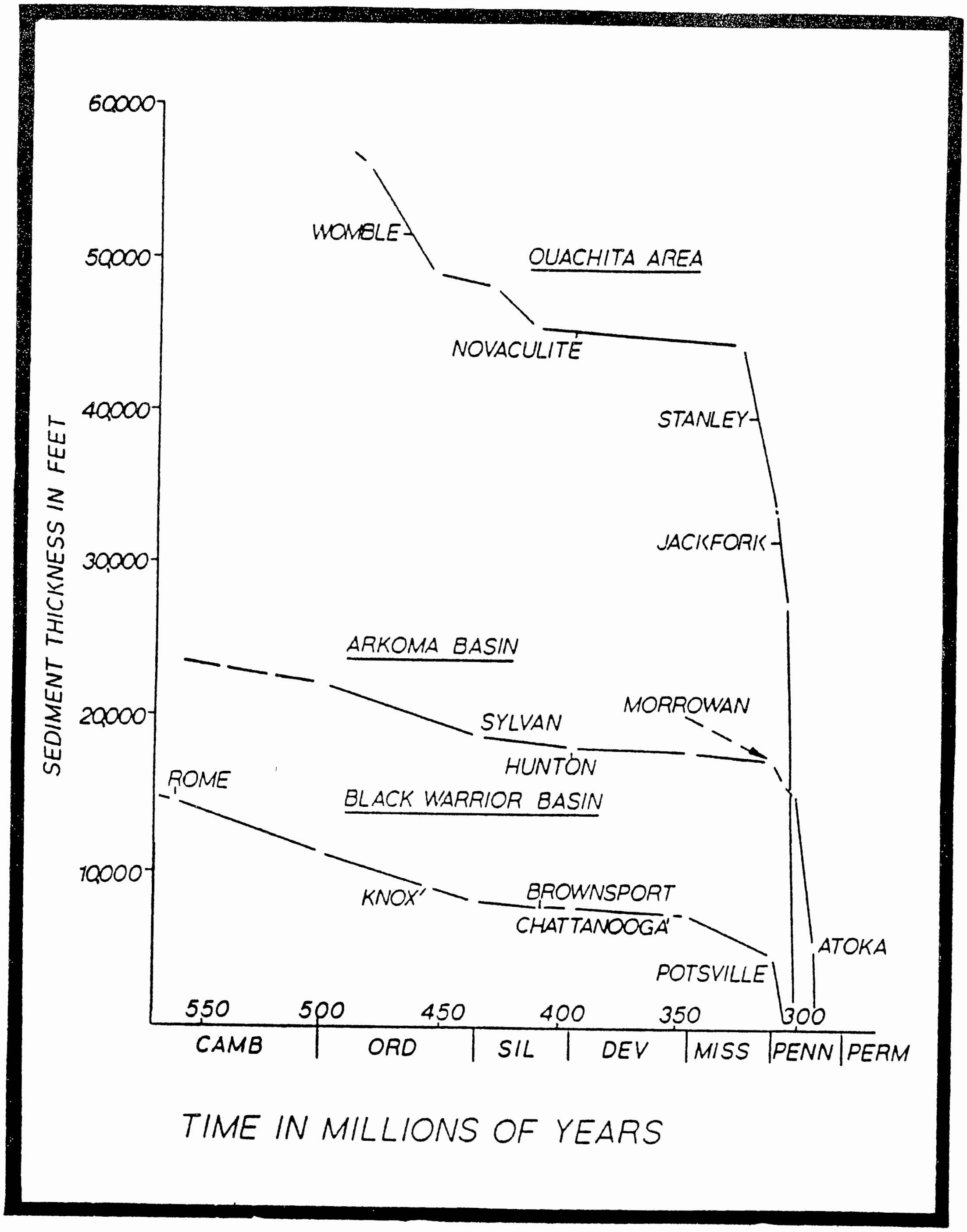


Figure 11. Basinal Subsidence History of Black Warrior Basin, Arkoma Basin, and Ouachita Area (from O'Conner, 1984).

the Black Warrior "Shelf" during this time while deep marine black shales and siliceous deposits developed in the adjacent basins.

Silurian and Devonian deposition is represented by a decrease in the sediment entrapment rate to 11 feet/million years. Carbonate shelf facies continued to dominate sedimentation and these units were characterized by bounding unconformities (Petroleum Frontiers, 1986).

The subsidence rate for the basin reached a sediment entrapment rate of 75 feet/million years by the end of the Mississippian period. This is the initiation of subsidence as a "full fledged" foreland basin. Relatively rapid subsidence was accompanied by the progradation of Chester age deltas from the north and northwest (Figure 12).

Finally, by Early Pennsylvanian time, basinal subsidence attained a maximum rate of 990 feet/million years. At this time, continental collision along the southern margin of the coastal shelf resulted in the formation of the Appalachian and Ouachita fold belts. The provenance also changed from a northerly cratonic interior to southerly or southwestern. During the Latest Paleozoic, regional uplift of the basin occurred and sediments down into Pennsylvanian age strata were removed. Later the basin was downwarped to the southwest resulting from the Ouachita Orogeny and then transgressed by Cretaceous-age oceans.

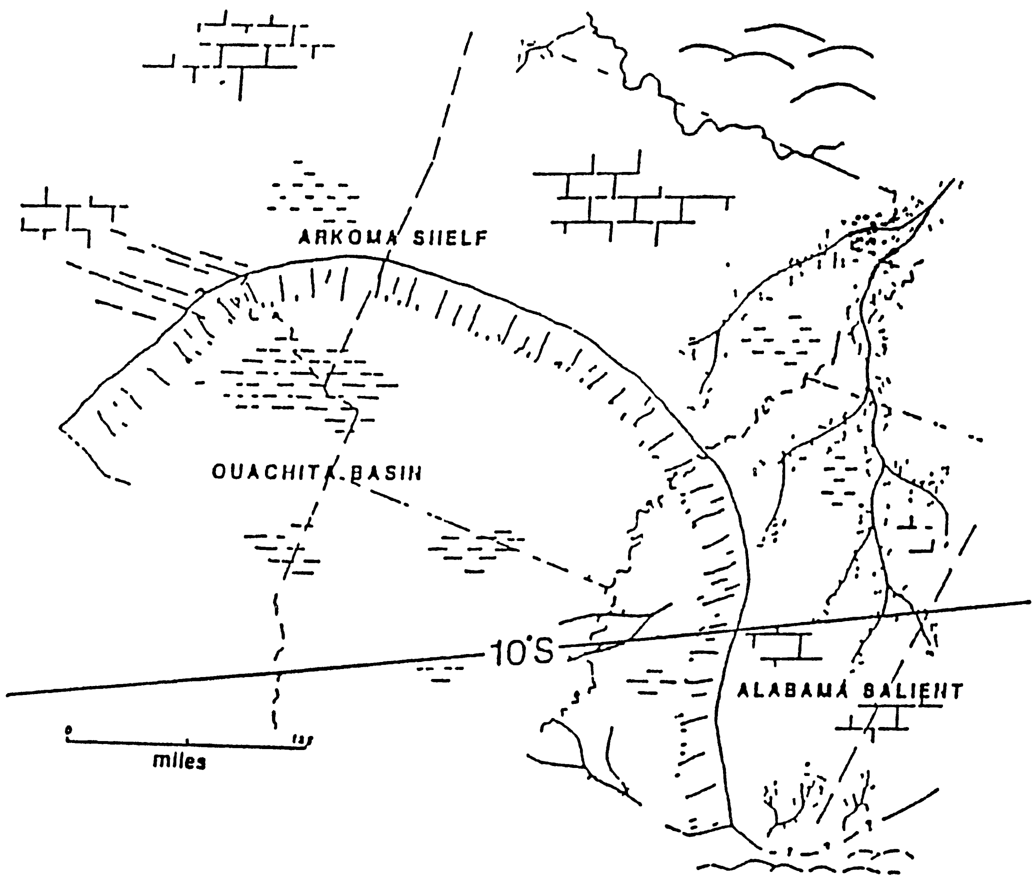


Figure 12. Chester Paleogeography and Deltaic Progradation in the Black Warrior Basin and Northeastern Arkansas (modified from O'Conner, 1984).

CHAPTER IV

CHESTER GROUP STRATIGRAPHY

Surface Nomenclature -Arkansas

Batesville Formation

The Batesville Formation is the lowermost Chester age unit in northern Arkansas and is the upper formation of the Mayes Group (Figure 13). It conformably overlies the Meramecian-age Moorefield Formation, which consists of interbedded calcareous black shales and sandstones. The lower contact of the Batesville is gradational but is usually placed at the base of the lower sandstone in the upper portion of the Moorefield Shale (Ogren, 1961). The top contact between the Batesville and overlying Fayetteville Formation is also gradational and is considered to be just below the black shales of the Fayetteville in the interbedded shales, sandstones, and limestones. In the west-northwest region of Arkansas, where the Moorefield is not present, the Batesville lies disconformably on the Boone Formation. To the south and southeast, the Batesville pinches out in the subsurface. It grades into a laterally equivalent black shale. West from Independence county, the sand thickness decreases and the

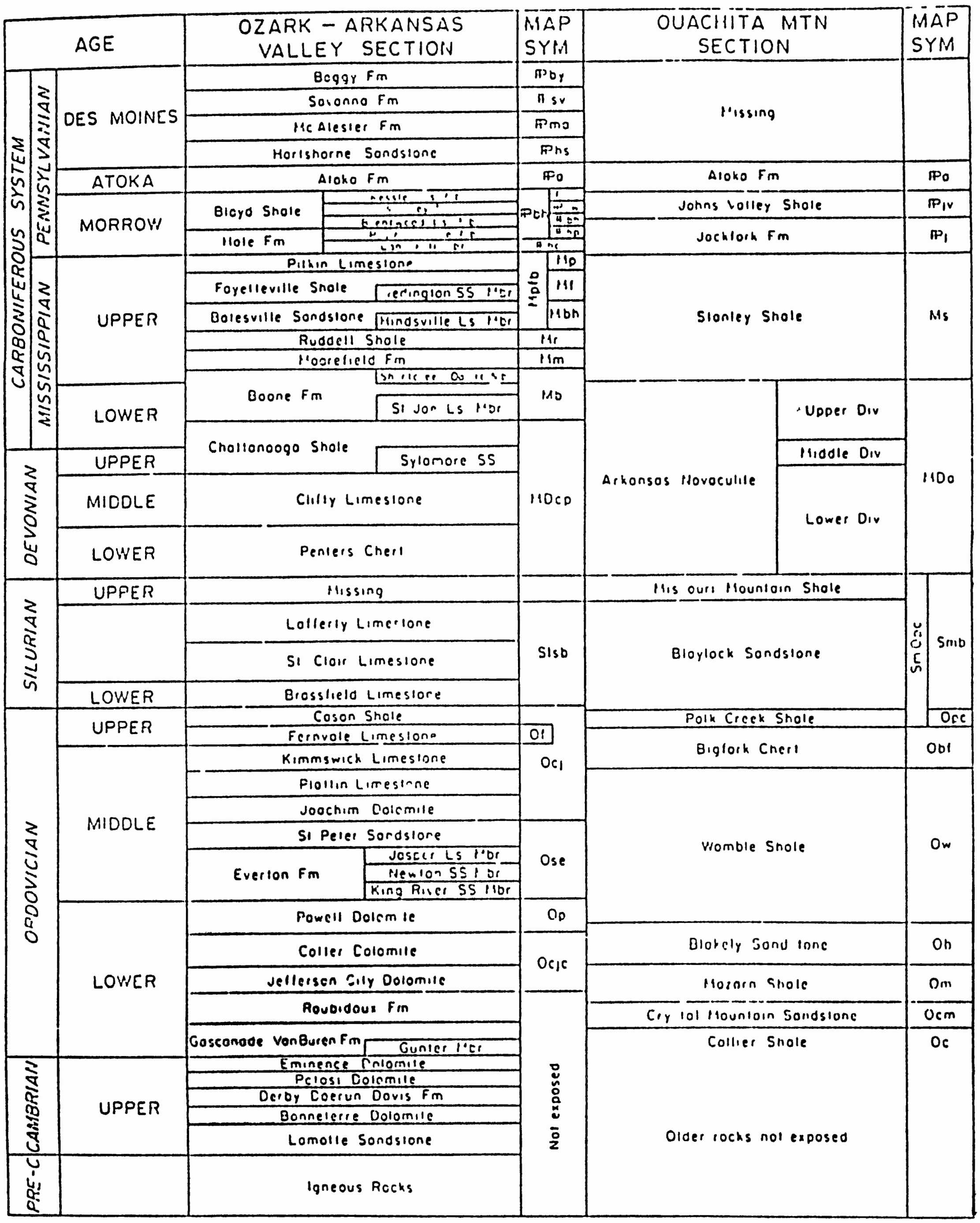


Figure 13. Stratigraphic Column of the Ozark-Arkansas Valley Section and the Ouachita Mountain Section (Heathcote, Susan, et al., 1977).

Batesville eventually grades into the carbonate dominated Hindsville Formation in northwestern Arkansas. This interfingering relationship is the result of topographic highs and lows on the surface of the Boone Formation in north-central Arkansas, where the Batesville generally overlies the Hindsville. The Batesville and Hindsville are considered to be laterally equivalent (Grayson, 1976).

The Batesville Sandstone is a yellow to buff colored, fine- to medium-grained sandstone. The grains are subangular to subrounded, moderately well sorted, and silica cemented. Small scale trough cross-bedding, planar cross-bedding and current lineations are common. Abundant brachiopods, pelecypods, gastropods and cephalopods were reported in the lower, softer sands (Weller, 1897; Girty, 1915), but were rare in the sections studied herein.

The Batesville Sandstone is said to be in excess of 200 feet thick and shows a thickness of 170 feet at bluffs on the Blue Creek northeast of the town Batesville (Penrose, 1891). Upon examination of the Blue Creek no bluffs were encountered and the thickest section measured in the study area was 67.5 feet thick. The sandstone is thickest in and around the town of Batesville. The source for the terrigenous clastics was probably from the northeast. The sediment was transported through the Reelfoot Rift region, with southward flowing currents in the Mississippi Embayment carrying mature clastics into northeast Arkansas (Glick, 1976); (Figure 14). Eventually marine currents reworked distal delta deposits and transported them westward. These deposits became thinner as they were reworked and interfingered with the Hindsville carbonates. The Batesville Sandstone pinches out before reaching the Arkansas-Oklahoma state line.

Hindsville Formation

The Hindsville Formation is the lateral equivalent of the Batesville Formation and is predominantly a carbonate facies interfingering with, and underlying the Batesville Sandstone in north-central Arkansas (Figure 13). This unit was initially given 'member' status by Purdue and Miser (1916) but elevated to a 'formation' by Miser (1955). Presently its rank depends on the lithology. Where more than 50 percent of the formation is limestone the term Hindsville Formation is used, and if less than 50 percent is limestone it is considered the Hindsville Member of the Batesville Formation (Ogren, 1968). This arbitrary boundary passes through Carroll, Newton, and Madison counties of northwestern Arkansas.

The Hindsville rests disconformably on the Boone Formation, which is composed of a light gray limestone and chert. The Hindsville is comprised of darker limestones with a limestone pebble conglomerate at the base (Ogren, 1961). The depositional environment is regarded as an

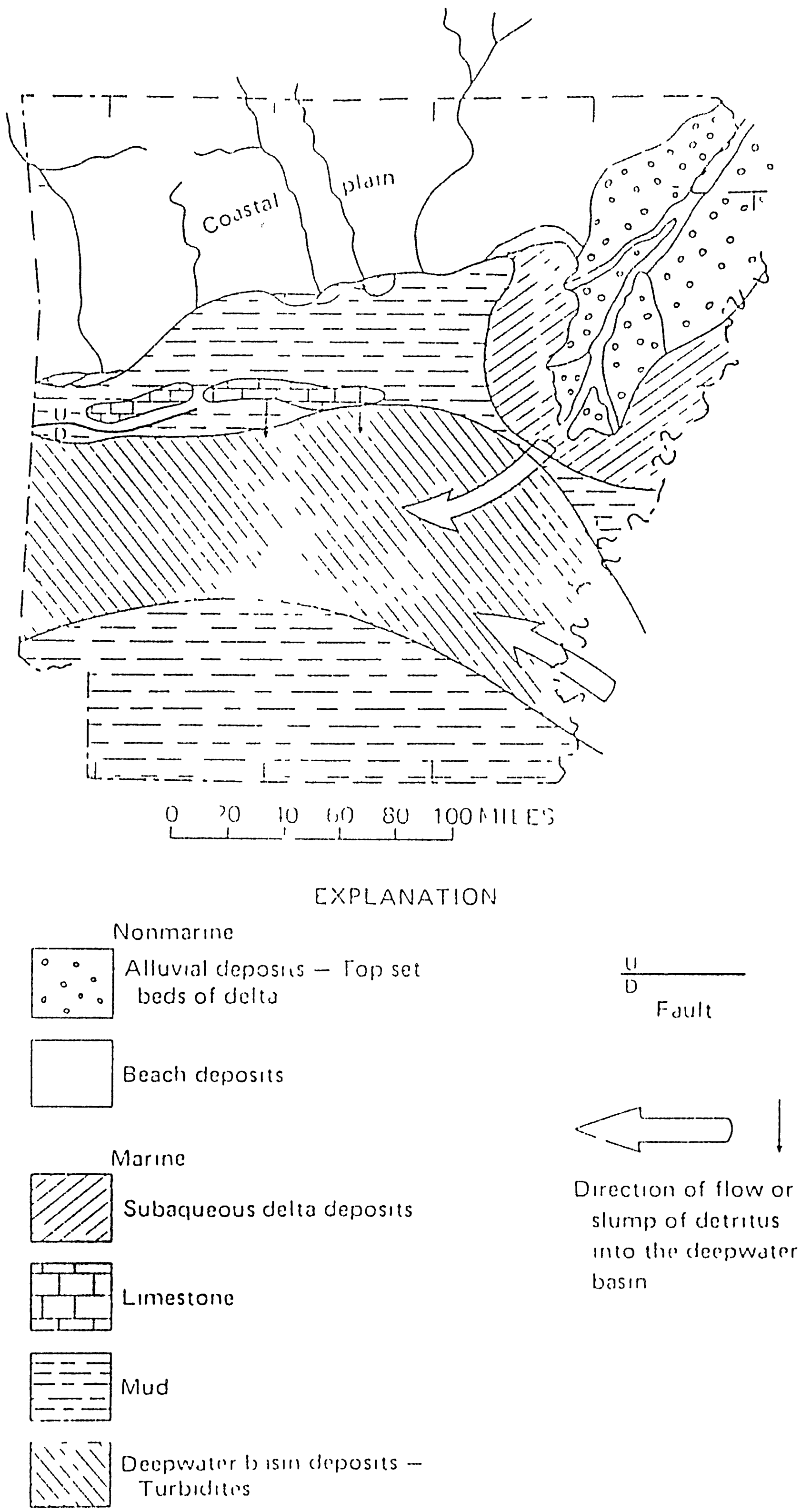


Figure 14. Distribution of Environments and Sediment Types in Arkansas at the end of Chesterian Time (from Glick, 1976).

agitated shallow sea that created a blanket of oolitic fossiliferous limestone (Glick, 1976). Garner (1967) proposed a region of lagoonal muds and isolated carbonate mounds and/or reefs. However, Grayson (1976) disputes this idea because of the widespread occurrences of recognizable facies in a fragmental limestone. He recognized four carbonate facies in the Hindsville: 1) calcilutite, 2) chert-bearing calcilutite-skeletal calcarenite, 3) skeletal oolitic calarenite, and 4) a shaly skeletal calcarenite. Based on the presence of crossbedded, fragmental limestones, an abundance of shallow water allochems, and carbonate muds, Grayson suggested the Hindsville was deposited in an ancient lagoonal to open shallow sea environment.

Fayetteville Formation

The Fayetteville Formation conformably overlies the Batesville/Hindsville Formations (Figure 13). In areas where they are not present, the Fayetteville has a discomformable contact with the underlying Boone Formation. The Fayetteville also has a transitional contact with the overlying Pitkin Formation, except in the western part of the state where there is a discomformable relationship existing. Although the Fayetteville varies in thickness, ranging from 3 to 400 feet, it usually averages 200 to 300 feet in thickness (Caplan, 1954).

The Fayetteville has been divided into two informal shale/limestone members and one formal sandstone member: 1) the lower black shale, 2) the Wedington Sandstone Member, 3) the upper interbedded limestones and black shales (Price, 1981). The lower black shale is an extremely fissile, dark gray to black, carbonaceous marine shale. The shale deposition resulted from marine transgression onto the shelf of northern Arkansas. Slightly pyritized concretions and brachiopods, along with bivalves and cephalopods are found in the lower shales (Glick, 1976).

The Wedington Sandstone member, present in northwest Arkansas, ranges in thickness from 2 feet to just over 100 feet. The Wedington is a fine- to medium-grained, moderately sorted, subrounded calcareous- to silica-cemented quartzarenite. The Wedington, contains large scale trough crossbedding, ripple sets, and sets of inclined strata and planar laminations (Price, 1981). A slight transgression created conditions for deposition of the Wedington. The first pulse of clastics involved deposition extending as far east as central Arkansas carried by longshore drift currents. The Wedington Sandstone is thought to be a fluvial deposition with a some marine reworked sands deposited and preserved and examined in exposed sections of northwest Arkansas.

The upper Fayetteville is comprised of black shales and limestones and has a conformable contact with the underlying Wedington. Where the Wedington is absent, the upper and lower Fayetteville shales are undifferentiated. Lithologically, the upper shale is similar to the lower shale but has fewer concretions and fossils. The highest section of the upper Fayetteville is made up of interbedded micritic limestones and shales. This indicates a transitional change to the overlying Pitkin Formation.

Pitkin Formation

The Pitkin Formation conformably overlies the Fayetteville Formation except in the western part of Arkansas where the contact is discomformable. The Pitkin extends from the Ozark escarpment in east-central Arkansas to northeastern Oklahoma. From Independence County to Newton County, Arkansas the Pitkin is overlain discomformably by the Imo Formation. In northwestern Arkansas it is overlain unconformably, and in localized instances cut out by the Pennsylvanian Cane Hill member of the Hale Formation (Figure 13).

Thickness of the Pitkin Formation ranges from a few feet to over 200 feet in eastern Arkansas. To the north, thinning of the Pitkin is likely due to truncation by pre-Pennsylvanian erosion (Tehan, 1977). According to Tehan, the Pitkin can be divided into five facies based on their macro-characteristics: 1) a bioclastic facies, 2) oolitic facies, 3) nodular limestone - shale facies, 4) mudstone facies, and 5) the mound facies. He based these facies changes on the differences, over time, in the shallow water environments in which the Pitkin sedimentation took place.

Imo Formation

The Imo Formation, which overlies the Pitkin Formation in north-central Arkansas, is the youngest Mississippian Formation in the area (Mapes and Rexroad, 1986). Although formational status was abandoned by the United States Geological Survey in 1970, it has been used in a general sense for the strata above the Pitkin in north-central Arkansas (Figure 13).

The lower interval of this unit is comprised of sandstones and shales with lenses of limestones. It grades upwards into a silty shale and sandstone (Saunders, Manger, and Gordon, 1977).

Surface Nomenclature - Alabama

Pride Mountain - Floyd Shale Formations

The Pride Mountain Formation is the lowermost formation of the Chester Group and overlies the cherty, bioclastic Tuscumbia Limestone of the Meramec Group (Figure 15). The upper boundary of the Pride Mountain is marked by the base of the Hartselle Sandstone. The Floyd Shale ~~Formation~~ occupies the interval below the Hartselle Sandstone and above the Lewis sandstone. Southeastward of the Hartselle Sandstone pinchout in the subsurface, the Floyd Shale is indistinguishable from the Pride Mountain Formation. As a result, the two units are combined for the purpose of this study.

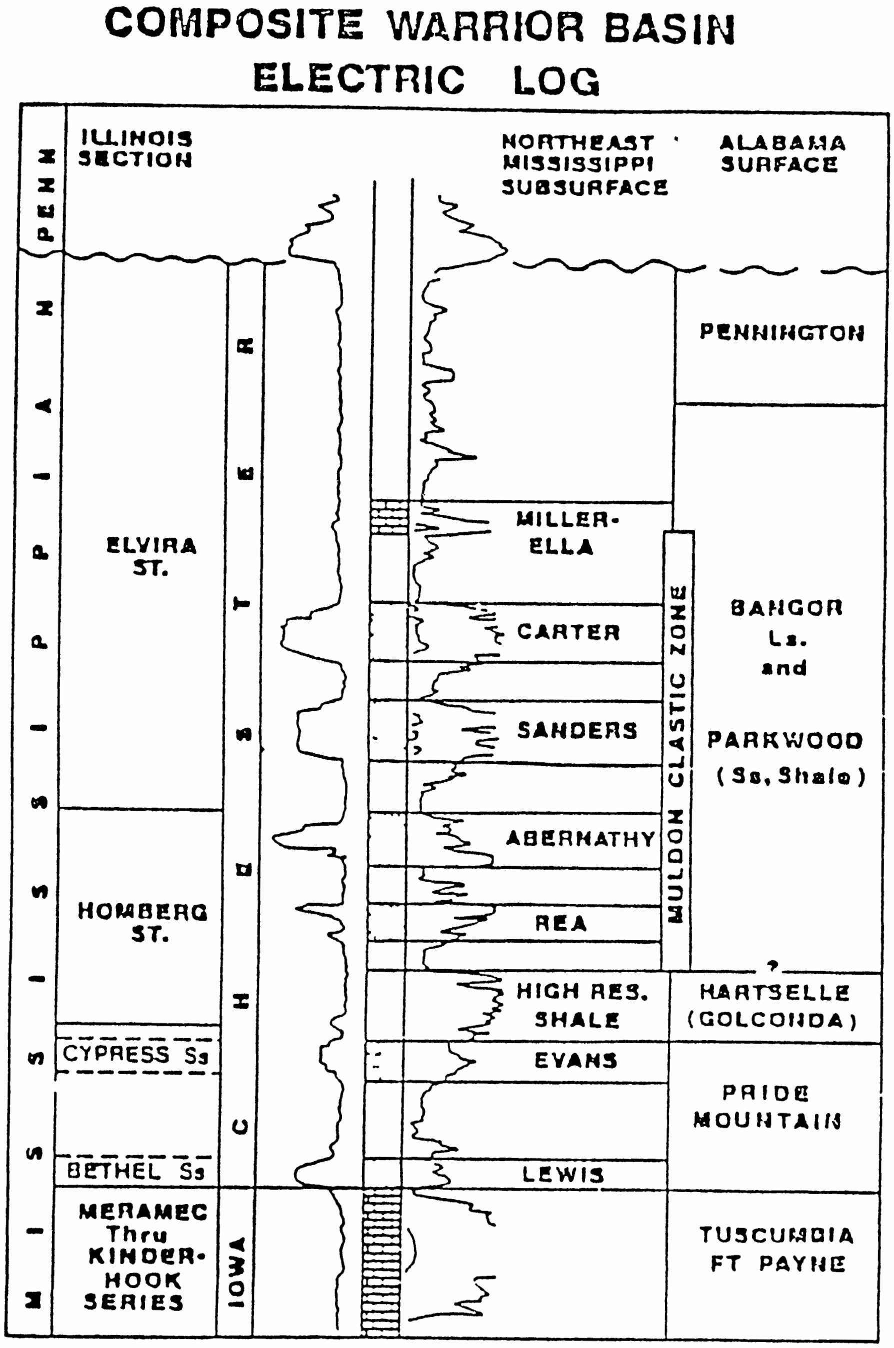


Figure 15. Generalized type log for the Chester Group of Northeastern Mississippi. Interval Between Base of Lewis and Top of Mississippian Ranges from 700-1600 ft. and Averages 1200 ft. (from Cleaves, 1983).

The Pride Mountain Formation is comprised of dark shales, interbedded with thin limestones, sandstones, and siltstones. Butts (1926) divided the Pride Mountain Formation into several units using Illinois Basin nomenclature. In ascending order they are: Ste. Genevieve Limestone, Bethel Sandstone, Gasper Formation, Cypress Sandstone, and Golconda Formation (Figure 15). These units were redefined by Welch (1958) who provided additional information regarding the units seen in outcrop. Upon further and more accurate examination Thomas (1972a), proposed a new set of nomenclature to coincide with the facies changes seen in outcrop (figure 16).

The Pride Mountain Formation is generally a medium to dark gray, fissile shale. It commonly contains siderite nodules and, less frequently pyrite (Thomas, 1972b). In certain regions of localized deposition in the Black Warrior Basin the shale is replaced by argillaceous, oolitic (and sometimes sandy) limestones. The shaly limestones contain abundant lenses of crinoids, brachiopods, and bryozoans.

The formation contains a basal limestone which has a maximum thickness of 50 feet. Generally however, it is less than 30 feet thick. This unit is called the Ste. Genevieve Limestone by Butts (1926) and the Alsobrook by Welch (1958). This basal limestone is shaly to oolitic, and lacks chert, which is characteristic of the underlying Tuscumbia Limestone.

The lower sandstone member of the Pride Mountain

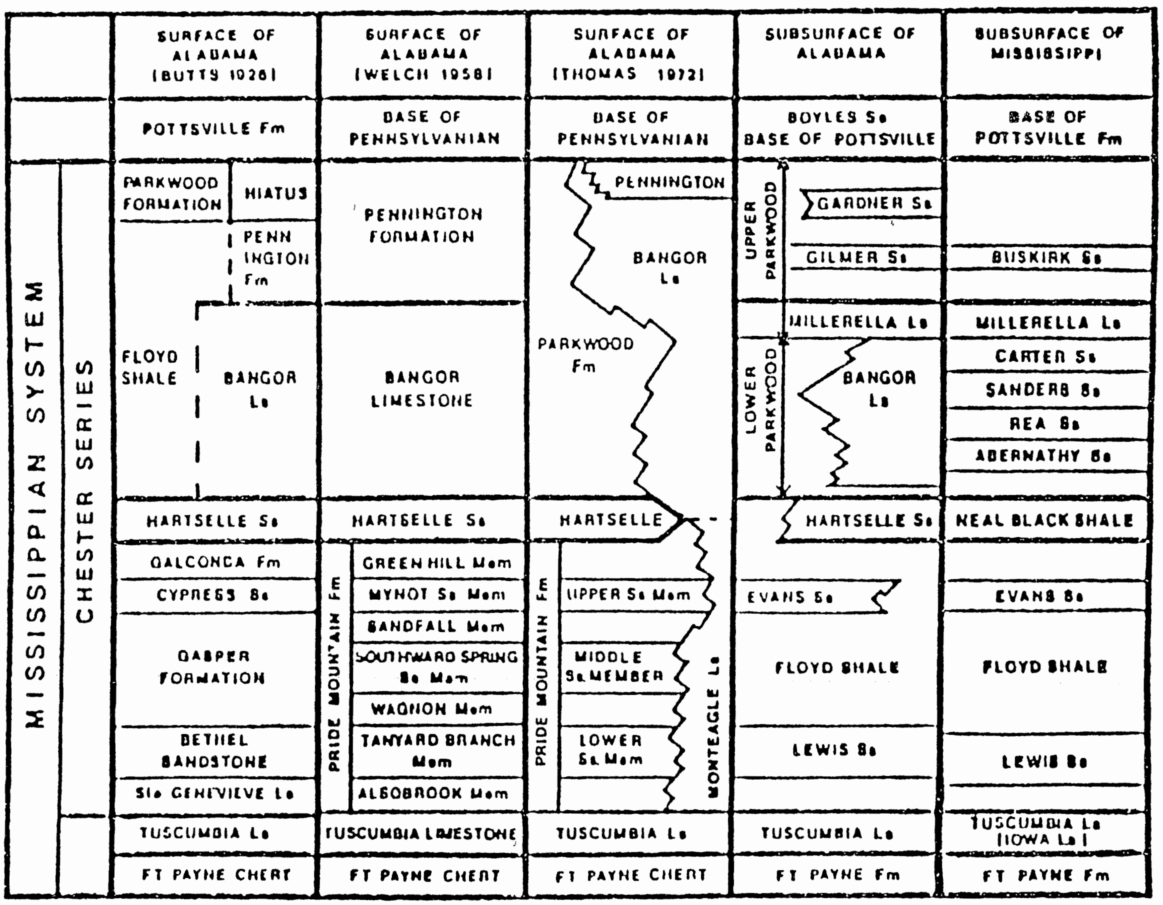


Figure 16. Surface and Subsurface Stratigraphic Nomenclature for Upper Mississippian Chester Group: Northern Shelf of Alabama and Mississippi (from Cleaves, 1983).

Formation is equivalent to the Bethel Sandstone of Butts (1926), Alsboro Sandstone and Crippled Deer Sandstone Member of the Alsobrook Formation of Morse (1928), and the Tanyard Branch Member of Welch (1958). The petroleum industry calls this the Lewis Sandstone. Overlying the sandstone is a regionally widespread carbonate packstone to grainstone marker which is informally called the "Lewis Limestone". (Bat, 1987). At the base of the formation it is locally interbedded with the basal limestone and elsewhere overlies it with a few feet of shale separating the two units. The middle sandstone member generally extends in a narrow, linear trend to the southeast (Thomas, 1972a). It is equivalent to the Southward Spring Sandstone of Morse (1928) and the Southward Spring Sandstone Member of the Pride Mountain Formation of Welch (1958). The unit ranges in thickness from one to 60 feet and is fine to very fine-grained, and locally calcareous. Clay drapes, interbedded sands and shales, and minor amounts of shale are also seen. The upper sandstone member also trends southeast but does not exhibit the lateral extent of the lower sandstone members. The unit is equivalent to the Cypress Sandstone of Butts (1926), the middle of the Southward Bridge Formation of Morse (1928), and the Mynot Sandstone Member of the Pride Mountain Formation of Welch (1958). The petroleum industry calls it the Evans Sandstone. The Evans is a fine- to very fine-grained, slightly calcareous sandstone with a capping limestone, (as the Lewis has), which is informally termed the "Evans Lime". The "Evans Lime" consists of a bioclastic packstone or grainstone.

The Floyd Shale Formation is a dark gray shale, similar in composition to the Pride Mountain Shale, with locally abundant siderite nodules in the upper part of the formation. It is believed to represent distal delta facies containing localized back barrier marine, lagoonal, and marginal marine shales (Thomas, 1972a). As previously mentioned, southeast of the Hartselle Sandstone pinchout the Floyd Shale is indistinguishable from the Pride Mountain Formation. The Floyd Shale is also believed to be laterally equivalent to the lower half of the Bangor Limestone (below the "Millerella" Limestone) and it occupies the stratigraphic position below the Hartselle Sandstone (Butts, 1928). Interbeds of argillaceous limestones and calcareous shales are characteristic of the Floyd Shale. In some places it is fossiliferous and contains brachiopods and crinoids.

Hartselle Sandstone

The Hartselle Sandstone is the thickest and most extensive of the sandstone units on the East Warrior Platform. It reaches a maximum thickness of 170 feet, but variations are abrupt (Cleaves, 1983). It is generally a light gray to buff, fine- to medium-grained quartzose sandstone which appears thick bedded to massive with crossbedding and ripple marks locally common. The sand bodies trend southeastward with the southwestern edge, which parallels the margin of the Bangor Shelf, overlapping the easternmost lobe of the Evans Sandstone in western Alabama. Believed by many to be time equivalent sandstones, Cleaves and Broussard (1980) propose that the Hartselle is actually a younger deltaic lobe of the Evans Delta Complex, but fed by the same trunk stream.

The environmental interpretation is still debated, even though the Hartselle is well exposed on the surface and well defined in the subsurface. By utilizing outcrop data alone, Thomas and Mack (1982) suggested that the Hartselle represents a barrier island complex. Cleaves and Broussard (1980), analyzing subsurface sandstone isoliths and three measured sections, proposed that the Hartselle represents a strike-elongate, wave dominated (high destructional) delta front deposit which parallels the margin of the Bangor Shelf.

Bangor Limestone

The Bangor Limestone comprises the variety of shallow, epeiric sea carbonate facies that are present above the Hartselle Sandstone and below the Pottsville Formation in northwestern and north-central Alabama. The Bangor can be subdivided in the subsurface into an upper unit that overlies the "Millerella" Limestone and a lower unit that includes the interval between the base of the Millerella and the top of the Hartselle. The lower Bangor thins to the south and west and grades into the clastics of the "Muldon"

Clastics Interval. In the northeastern part of Alabama, the upper Bangor Limestone interfingers with the terrigenous clastics of the Pennington Formation (Figure 16).

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

The Bangor Limestone is dominantly a light to dark gray, argillaceous, oolitic and bioclastic grainstone. Fossils include abundant solitary corals, brachiopods, crinoids, bryozoans, and gastropods. A significant oolitic facies predominates on the east Warrior Shelf trending NW-SE in west-central Alabama (Petroleum Frontiers, 1986). South of this oolitic margin a calcareous, micritic, shale facies predominates. The "Millerella" limestone, considered a tongue of the Bangor, extends across the central and western regions of the Black Warrior Basin and attains thicknesses of up to 50 feet.

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 thicknesses (approximately 600 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 lowest sandstone above the Floyd Shale 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 west central Alabama. Along the Appalachian synclines the clastics are thickest, where some of the sandstones in the formation exceed 100 feet thick locally. Sandstone percentage of the formation ranges from 15 percent on the platform to more than 40 percent in the basin (Thomas, 1972b). The sandstones of the Parkwood are characteristically medium gray, very fine to fine-grained, argillaceous, and partly silty. The lateral extent of the sandstone units varies greatly, with some appearing as lenses in shale units. The upper Parkwood consists of two sandstone units, which are informally named the Gilmer and Gardner Sandstones, and numerous intercalated limestone and shale units (Figure 16, column 4). There appears to be a thick limestone-shale zone that directly overlies the "Millerella" Limestone. The Gilmer Sandstone has been mapped and interpreted as a hybrid system, intermediate between a high-constructive lobate and a wave-dominated delta complex (Cleaves, 1983), thus being similar to the Lewis and Evans Sandstones much lower in the Chester interval. The lower Parkwood contains interbedded sandstones and shales and localized build-ups of carbonates. The base of the Parkwood rises northeastward because the lowest sandstone pinches out in this direction on the shelf.

Subsurface Nomenclature - Mississippi

Lewis Sandstone

The Lewis Sandstone interval includes the section between the top of the Tuscumbia Limestone and the top of the informal "Lewis" limestone (Figure 16). It is the lowest sandstone unit of the Chester Group and is also the lowest gas-producing Chesterian terrigenous clastic unit. The Lewis is considered to be the stratigraphic equivalent to the lower sandstone of the Pride Mountain Formation. The Lewis Sandstone is a fine- to medium-grained, gray to buff colored, moderately sorted, quartzarenite. It is overlain by a regionally extensive carbonate, serving as a marker unit, informally called the "Lewis" Limestone. This limestone is classified as a bioclastic packstone or grainstone (Bat, 1987).

The Lewis Sandstone is an extensive, deltaic sandstone that is present over most of the Black Warrior Basin shelf.

Gross sandstone averages less than 100 feet in thickness. It is suggested that the Lewis is a high constructive, elongate delta complex that prograded to the southeast across the study area during the early Chesterian.

Evans Sandstone

The Evans Sandstone is situated between the top of the "Lewis" Limestone and the top of the "Evans" Limestone (Figure 16). The Evans is considered the lateral stratigraphic equivalent to the upper sandstone member of the Pride Mountain Formation.

The Evans Sandstone is a light gray to buff colored, fine to medium grained, well sorted, quartzarenite. The unit is overlain by a laterally extensive carbonate bioclastic packstone to grainstone marker known informally as the "Evans" Limestone (Bat, 1987).

The Evans Sandstone is regionally less extensive than the Lewis Sandstone, as it is primarily confined within Mississippi. Unlike the Lewis Sandstone, the Evans is interpreted as being an extensive, southeast prograding high-destructive wave-dominated cuspate delta. Where the Evans is present, the unit is significantly thicker than the Lewis Sandstone.

Neal Black Shale

The Neal Black Shale is found stratigraphically between the top of the "Evans" Limestone and the base of the Rea Sandstone. Where the Rea is absent, the Neal Black Shale grades into the lowest shales of the Muldon Clastic Interval. The Neal Black Shale was informally named by Shell Oil Company geologists to describe this highly resistive black shale (Scott, 1978), (Figure 16).

The Neal Black Shale is a black, clayey, shale with interbedded, thin limestones. The unit has been interpreted as a lagoonal shale which was deposited between the Hartselle Sandstone in Alabama and a prograding Chesterian deltaic clastic wedge from the Ouachita deformed belt (Thomas and Mack, 1982). Contrary to this proposal, Cleaves (1988) believes the Neal Black Shale represents a deep water shale of low energy deposited in a segregated sub-basin along the margin of the lower Bangor carbonate build-up.

Muldon Clastic Zone

Rea Sandstone

The Rea Sandstone is the lowest sandstone in the Muldon Clastic Zone (Figure 15). The Rea is composed of fine-to very fine-grained quartzarenite which exhibits poor to moderate sorting.

The Rea Sandstone has three, nearly identical major lobes which are straight, narrow, and bifurcate down-dip.

The deltaic lobes are surrounded by a significant amount of prodelta muds and most likely represent a high constructive elongate delta complex (Cleaves, 1986).

Abernathy Sandstone

The Abernathy Sandstone is situated above the Rea Sandstone and below the Sanders Sandstone (Figure 15). It is composed of fine-grained quartzarenites which are moderately sorted.

Like the Rea Sandstone, the Abernathy delta complex is composed of three major lobes which branch down dip. They are straight, narrow sandstone belts which do not prograde into Alabama. The Abernathy Sandstone is interpreted as a high-constructive elongate delta complex (Cleaves, 1986).

Sanders Sandstone

The Sanders Sandstone is the lowest of the major producing Muldon units (Figure 15). The Sanders is divided into two reservoir units: 1) the upper Sanders 'A' and 2) the lower Sanders 'B' units. These are bounded by the Abernathy Sandstone below and the Carter sandstone above. The Sanders 'A' and 'B' are generally separated by a thin shale.

The Sanders is comprised of moderately sorted very fine- to fine-grained quartzarenites, that range in thickness from a few feet to almost 190 feet. There are three major lobes and one minor lobe in what is interpreted as a high-constructive, elongate delta complex. The characteristic depositional environments include point bars, bar finger sands, distributary channels, crevasse splays, interbedded delta fringe sands and shales, and interdistributary bay shales and siltstones.

Carter Sandstone

The Carter Sandstone is the most prolific producing unit within the Black Warrior Basin (Figure 15). Similar to the Sanders Sandstone, the Carter is divided into two sand units; 1) the upper Carter 'A' and 2) the lower Carter 'B' Sandstones. The Carter is bounded by the "Millerella" Sandstone above where it is present and by the Sanders 'A' Sandstone below. In some regions within the basin, the Carter 'A' and 'B' are stacked one on the other, but generally they are separated by a thin shale.

The Carter Sandstone is comprised of moderate- to well-sorted, fine- to medium-grained quartzarenites, and ranges in thickness from a few feet at the distal portions to just over 300 feet in incised channels which downcut into the Bangor Limestone in Itawamba county, Mississippi. Although it is usually a gray to buff color, the Carter is darker in some intervals due to the infiltration of migrating oil causing the sands to appear brown. Notable sedimentary structures are horizontal bedding, inclined planer bedding, small- to medium-scale trough cross-bedding, ripples, and clay drapes. The beds are usually thick to massive with subangular to subrounded grains.

The environments of deposition include point bars, bar finger sands, distributary channel sands. crevasse splays, interbedded delta fringe sands and shales, and interdistributary bay shales and sands. The sandstone are deposited in a NW-SE trend, extending to the southeast into west-central Alabama. Both the Carter 'A' and 'B' Sandstones are interpreted as fluvially dominated, high-constructive, elongate delta complexes.

"Millerella" Sandstone

The "Millerella" Sandstone is a hybrid unit whose stratigraphic position varies from the base of the "Millerella" Limestone to a position ranging from approximately 50 feet above the Carter 'A' Sandstone to resting directly upon it in the northeast region of the Mississippi portion of the Black Warrior Basin (Figure 15).

This thin sandstone unit is composed of moderate- to well-sorted, very fine- to fine-grained, dark gray to gray, sands and siltstones. Small-scale trough cross-bedding and horizontal planar cross-bedding are observed. The dominant sedimentary structure observed in core was ripples.

The "Millerella" Sandstone is distributed over the majority of the Black Warrior Basin as disarticulated sandstone bodies. The thickest deposits are found in Monroe County, Mississippi where it attains thicknesses of just over

50 feet. The "Millerella" is interpreted as marine reworked sandstone originating from up-dip Carter sands in the northeast region of deltaic deposition.

"Millerella" Limestone

The "Millerella" Limestone is a regionally extensive finger of the Bangor "Shelf" Limestone. The unit is located stratigraphically between the base of the Gilmer Sandstone and underlying "Millerella" Sandstone (Figure 15).

The "Millerella" is a multi-colored, micritic to bioclastic packstone with an abundance of pisolites. This extension of the Bangor Limestone is represented by three to five fingers of limestone extending from northwestern Alabama to the west-central part of the Black Warrior Basin where it disappears. The "Millerella" Limestone represents a moderate transgression at the end of deposition of the Muldon Clastic Interval.

Buskirk Sandstone

The Buskirk Sandstone is stratigraphically equivalent to the Gilmer Sandstone of the upper Parkwood Formation (Figure 16, column 5). The Buskirk is bounded by the "Millerella" Limestone below and the Pennsylvanian Pottsville Formation above. This sand unit is a regionally extensive network of interconnecting deltaic sands which prograde from the N-NW to the S-SE well into west-central

Alabama. The Buskirk is better developed and more widespread in Alabama than in Mississippi, with a maximum inferred thickness ranging from 100 to 120 feet.

The Buskirk Sandstone, like most of the Muldon Group sandstones, is interpreted as a fluvially dominated, high constructive, elongate, delta complex comprised of many more lobes than the lower Muldon units.

Provenance Determination of the Chester Group

The Pride Mountain Formation, Hartselle Sandstone, Bangor Limestone, and the Parkwood Formation together comprise the Mississippian age Chester Group. Numerous provenance interpretations have been proposed over the years for the Upper Mississippian sediments. These interpretations have been based primarily on subsurface data including net sandstone isolith maps, electric log analysis, electric log cross-sections, lithologic descriptions from well cuttings and core, and from outcrop exposures in the Tennessee Valley Highlands and Appalachian Fold belt of Alabama. As a result, two major concepts are used regarding the source area for these units: 1) a northeastward prograding clastic wedge derived from an orogenic belt to the southwest and 2) a terrigenous clastic wedge prograding southeastward onto the stable northern shelf from a cratonic source to the north.

Swann (1964) suggested that the late Mississippian formations of the Illinois Basin and those in the study area had a common source from the north (Figure 17). Swann identified a river system, which he called the Michigan River, that originated in eastern Canada. This river system flowed southwestward through the Michigan and Illinois basins during static or lowered sea levels carrying with it sediments which were deposited on the northern side of the Black Warrior Basin. On the basis of stratigraphic relationships, Swann correlated time-equivalent Chester-age sediments of the Illinois Basin with those in the Black Warrior Basin.

In contrast to Swann, Thomas (1980), Thomas and Mack (1982), Mack, James, and Thomas (1981), and Mack, Thomas, and Horsey (1983) have all conducted petrographic outcrop studies on the Hartselle and/or the Parkwood units in Alabama. They concluded that the Chester-age sediments were derived from a northeasterly prograding clastic wedge. Their conclusions were based on the presence of polycrystalline quartz and low-grade metamorphic rock fragments. There are two major problems with these studies. First, all of the sample locations are restricted to either the Tennessee Valley Highlands of northern Alabama and/or the folded Appalachians of Central Alabama. No samples were taken from within the basin itself. Second, the Parkwood Formation in Franklin County (Tennessee Valley Highlands) contains Pennsylvanian rather than Mississippian age faunas. This fauna also correlate to those in the Appalachian Fold Belt near Birmingham, Alabama (Henry, et al., 1985).

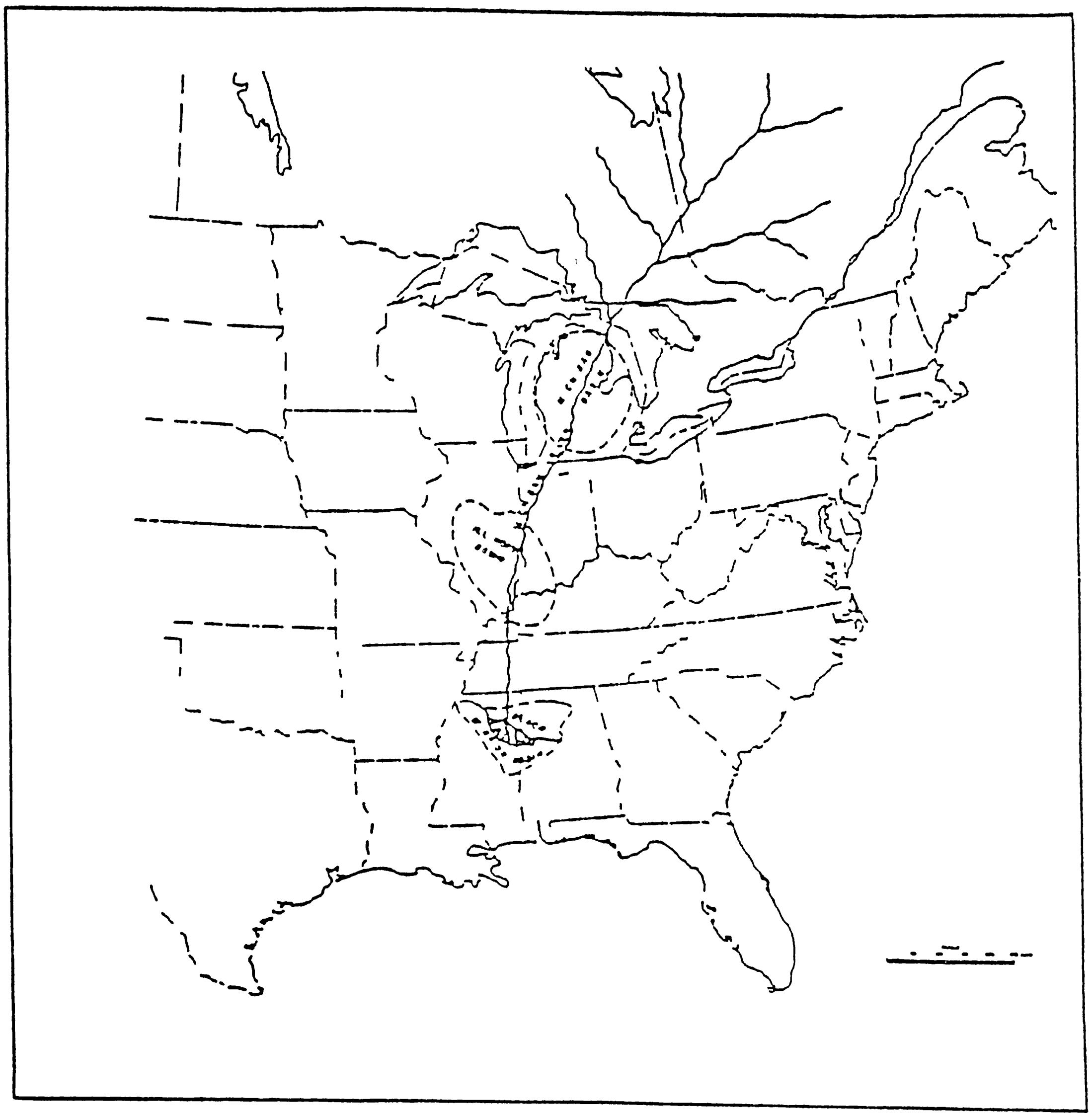


Figure 17. Michigan River System During Chester Time (from Swann, 1964).

Cleaves and Broussard (1980) proposed that the Chester age deltas prograded in a southeasterly direction and were derived from a northerly source (Figure 18). Cleaves (1983) also proposes that the cratonic source for these Chester-age sediments were derived from the Ozark Uplift. Based on paleocurrent data, isopach data, paleontological information, and facies patterns, Shepard (1979) concluded that the source for the Chester age deltas was to the northwest. Cleaves (1983) demonstrated a northwest to southeast progradational trend for those deltaic sediments. Further, he concluded that the units lying below the "Millerella" Limestone have a tendency to thicken updip towards the line of post-Carboniferous erosional truncation in net sandstone isolith maps. The isopach map of the Tuscumbia - "Millerella" interval indicate a general thickening to the north, away from the Ouachita orogenic source area. Also, petrographic evidence from the Lewis, Evans, Rea, Abernathy, Sanders and Carter Sandstones in the subsurface on the Northern Shelf indicate a dominance of monocrystalline quartz and a lack of any indicators of an orogenic provenance. This was demonstrated in studies by Shepard (1979), O'Conner 1984), Bat (1987), Hughes (1987) and Witt (this study).

The sandstones from both core and outcrop in this study are all classified as quartzarenite as defined by Folk (1980). As a population their framework grains are composed of an average of 95.3% monocrystalline quartz, 0.03% polycrystalline quartz, 0.001% sedimentary rock fragments,

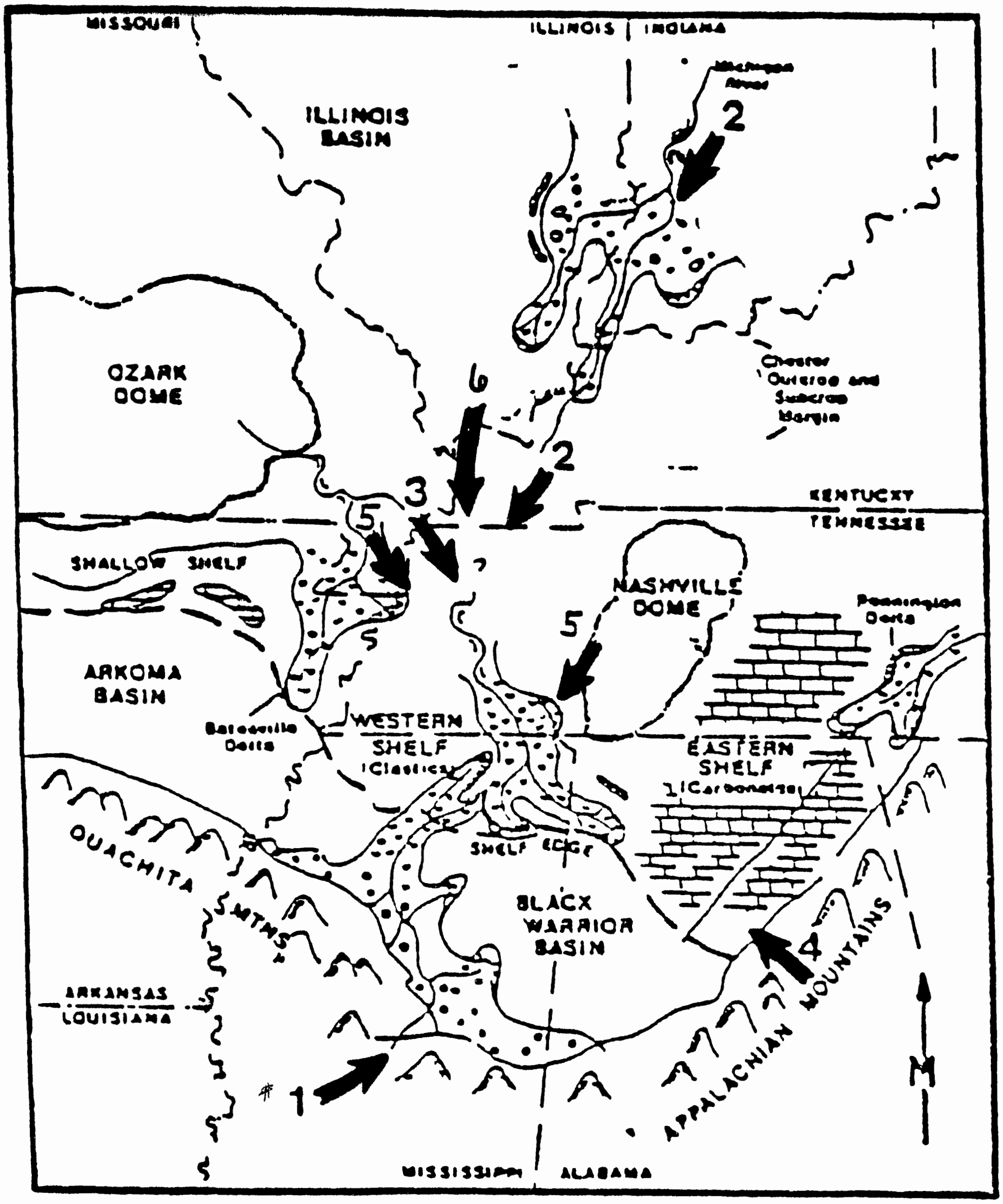


Figure 18. Chesterian Depositional Setting for the Black Warrior Basin. Arrows Denote Hypothesized Source Areas for Chester Terrigenous Clastic Sediments. #1 Thomas and Mack (1980), #2 Swann (1964), #3 Cleaves and Broussard (1980), #4 Ehrlich (1965), and Higginbotham (1986), #5 Bat (1987), and #6 Witt (this paper).

0.001% metamorphic rock fragments, 0.0% volcanic rock fragments, 0.002% mica, 0.01% chert, and 0.01% feldspars. Based on these percentages it is suggested that the source area was recycled sedimentary rock material from the craton.

Point count data were used for the purpose of studying the provenance relations, using the procedure devised by Dickinson and others (1983). They used ternary diagrams which specifically relate framework grain composition to a type of provenance area. The three poles represent recalculated figures of the key grain types determined in point counts. There are two sets of poles (QFL and QmFLt) which were devised by Graham and others (1976) (Figure 19). Using the Dickinson, et al. ternary diagram for the Chester sandstones of this study, a provenance involving the craton interior is indicated (Figure 20 and 21).

For QFL diagrams:

Q = Total quartzose grains, including polycrystalline lithic fragments such as chert and quartzite

F = Monocrystalline feldspar grains

L = Unstable polycrystalline lithic fragments of either igneous or sedimentary parentage, including metamorphic varieties.

For QmFLt diagrams:

Qm = Quartz grains that are exclusively monocrystalline

F = Monocrystalline feldspar grains

Lt = Total polycrystalline lithic fragments including quartzose varieties.

Figure 19. Grain Parameter determinations for provenance - petrology (modified from Dickinson and others, 1983).

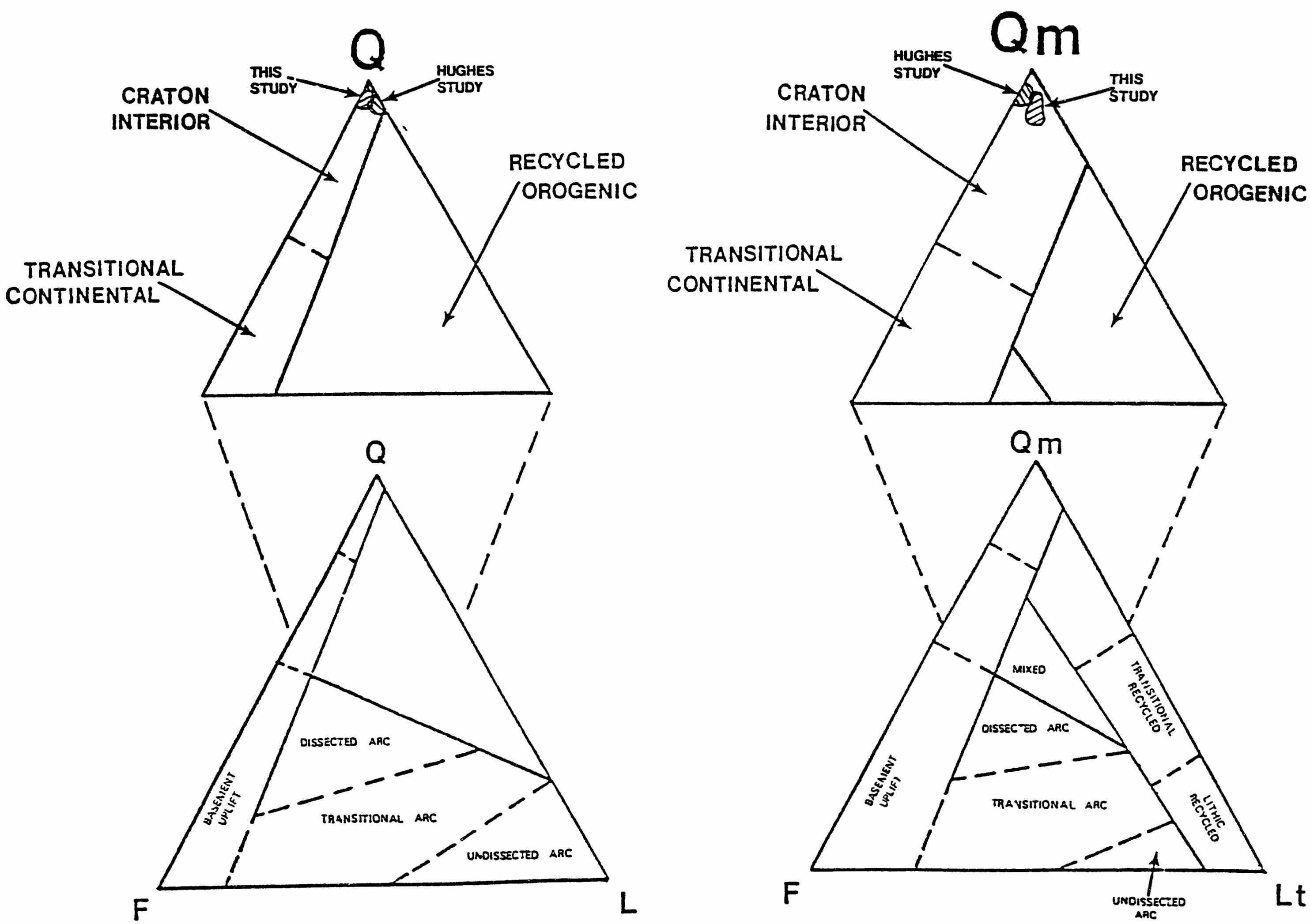


Figure 20. Ternary Diagrams of Dickinson and others (1983) with plots for Carter Sandstone of Hughes (1987) and this study (1990).

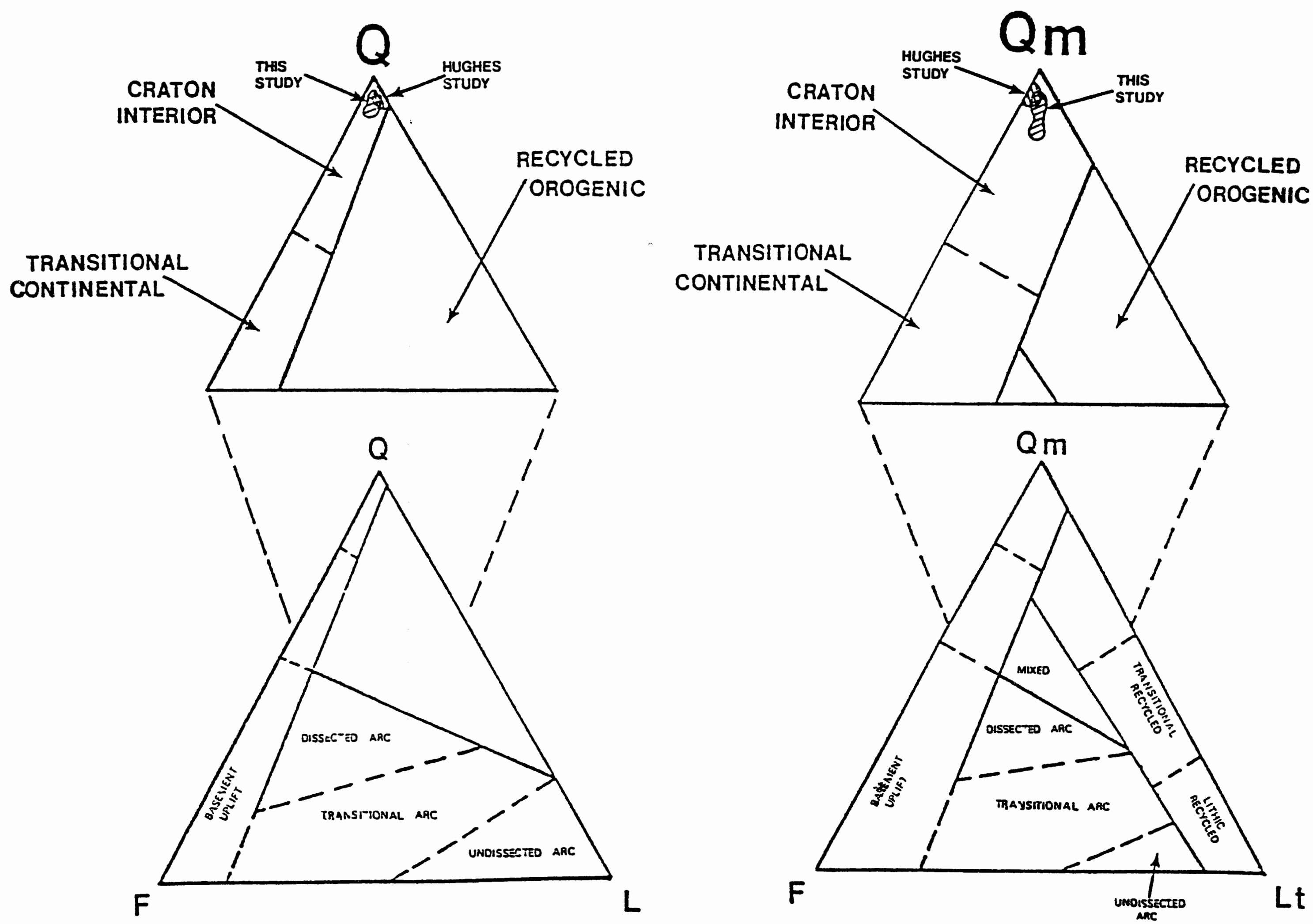


Figure 21. Ternary diagrams of Dickinson and others (1983) with plots for Batesville Sandstone of Hughes (1987) and this study (1990).

CHAPTER V

REGIONAL SUBSURFACE GEOLOGY BASED ON ELECTRIC LOG STUDIES

Introduction

Nine hundred and ten electric logs from the Mississippi study area, as noted in Chapter II, provided substantial control for the preparation of the subsurface cross-sections, a regional structure map, and isolith maps. The Dual Induction Log, which consists of a S.P. (spontaneous potential) curve and three resistivity curves (laterolog, medium induction, and deep induction), is the type of log most often run in the basin.

The "Millerella" Limestone and Neal (Black Shale) are present in all but a few logs and serve as good markers for correlations. Once the "Millerella" Limestone had been located, it was not difficult to move lower in the section to find the "Millerella", Carter 'A' and Carter 'B' Sandstones on the log charts. In this study, the "Millerella" Limestone is defined as the first persistent limestone above the Carter Sandstone (Figure 15). The upper and lower boundaries of the study interval are the top of the Sanders Sandstone (directly underlying the Carter Sandstone), and the top of the "Millerella" Limestone.

The subsurface maps constructed are:

1. Structure of the base of the "Millerella" Limestone...............................(Plate I);
2. Net sand isolith of the "Millerella" Sandstone..............................(Plate II);
3. Net sand isolith of the Carter 'A' Sandstone.............................(Plate III);
4. Net sand isolith of the Carter 'B' Sandstone..............................(Plate IV);
5. Net sand isolith of the Total Carter Sandstone...............................(Plate V);

Stratigraphic and structural cross-sections were prepared using selected electric logs from the study area. There are a total of six cross-sections prepared (Figure 22). Two cross-sections are strike-oriented (A-A'; B-B'), and two cross-sections are dip-oriented (C-C'; D-D') stratigraphic sections (Plates VI and IX). Also constructed were strike-oriented (A'-A") and dip-oriented (B'-B") structural cross-sections (Plates X and XI).

The stratigraphic interval between the top of the Neal Black Shale and the top of the "Millerella" Limestone may be regarded as a genetic interval of regional significance. The top of the "Millerella" Limestone comprises a broad, flat surface that is of roughly the same age throughout its complete extent, indicating a quick transgression of shallow marine waters. Below this, there are the deltaic and shelf terrigenous clastics represented by four intervals of clastic input. The clastic units constitute a regional regressive sequence over the western 60 percent of the Northern Shelf. At the base of the interval is the laterally persistent Real Black Shale. These units cannot

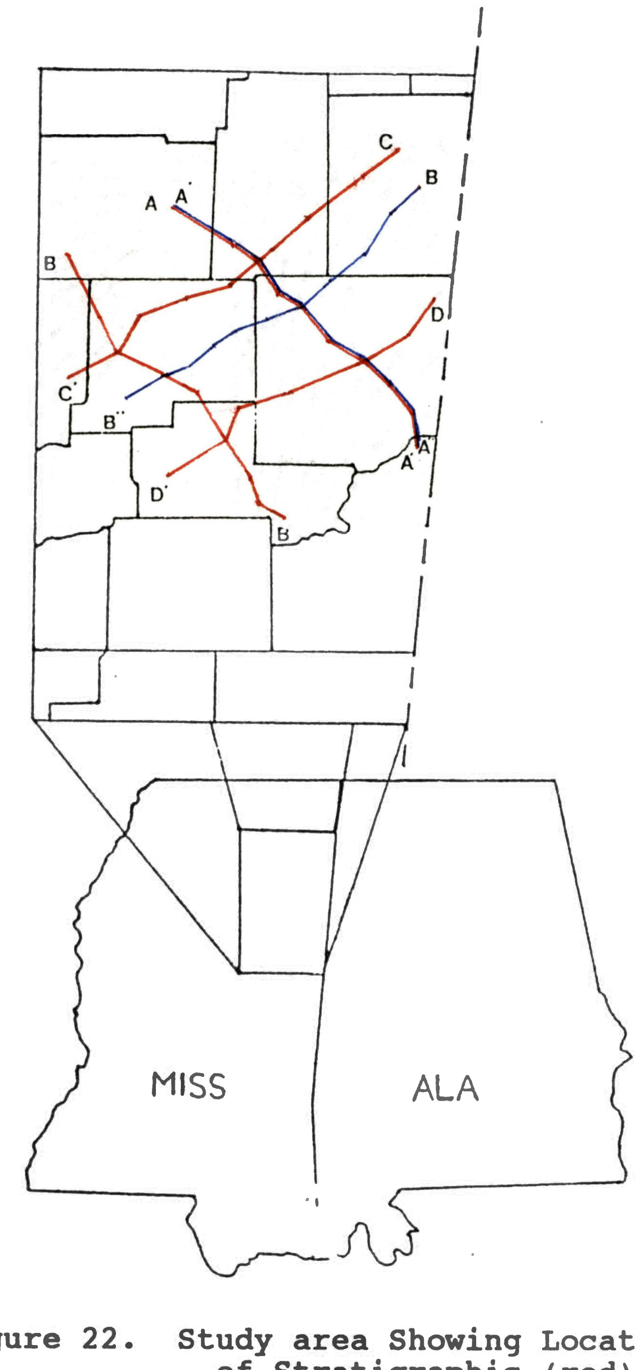


Figure 22. Study area Showing Location of Stratigraphic (red) and Structural (blue) Cross-Sections.

be broken out into distinct format units because of the lack of interbedded carbonates.

The principle value for defining a Format Unit is that all of the terrigenous clastics between the marker units are assumed to have been deposited during one regional cycle of sedimentation (Forgotson, 1957) The units of the Muldon Clastic Interval represent four seperate episodes of deltaic progradation. Reservoir sandstone units were laid down as facies components of one or more essentially coexistent depositional systems. Subsurface maps prepared from data incorporated for the upper one-fourth of the Muldon Clastics Interval are exceedingly valuable for identifying specific depositional systems, reservoir rock, and trends of elongation for discrete sandstone bodies. With the present study, the net isolith maps were the most useful for delineating the "Millerella", Carter 'A', and Carter 'B' Sandstone facies distribution.

Cross-Sections

A total of six cross-sections were used to analyze the vertical and lateral continuity of units within the study area (Plates VI to XI). The base of the "Millerella" Limestone was chosen as the datum for the stratigraphic cross-sections and 1000 and 1500 foot datums were used on the structure cross-sections.

Strike-Oriented Structural Cross-Section

Cross-Section A'-A" is a NW-SE structure cross-section extending from east-central Pontotoc County to northeastern Lowndes County (Plate VI). Units correlated are those including and between the top of the Evans unit and the base of the "Millerella" Limestone. This cross-section illustrates the significant displacement which resulted from post-depositional normal faulting along strike of the study area. The most extensive amount of down-drop can be seen in Lowndes County in the area of the #1 Ralph Thomas well (T16S-R17W) with over 1000 feet of down to the basin displacement.

Dip-Oriented Structural Cross-Section

Cross-section B'-B" is a NE-SW structure cross-section extending from east-central Itawamba County to southwestern Chickasaw county (Plate VII). Units correlated are those including and between the Evans unit and the "Millerella" Limestone. This cross-section illustrates the extensive displacement of section moving into the basin which results from significant post-depositional normal faulting in the Black Warrior Basin. A graben-like structure exists in the area of the #2 C.P. Coggin well in northeastern Monroe County. The most extensive amount of displacement is found in southwestern Chickasaw County and shows over 3000 feet of displacement down to the south.

Strike-Oriented Stratigraphic Cross-Sections

Cross-section A-A' is a NW-SE stratigraphic cross-section extending from east-central Pontotoc County to northeastern Lowndes County (Plate VIII). This line traverses the central portion of the study area.

Correlated units include the "Millerella" Sandstone, Carter 'A' Sandstone, Carter 'B' Sandstone, Sanders Sandstone, Abernathy Sandstone, Rea Sandstone, Neal Black Shale, Bangor Limestone, and the Evans Unit. "Phantom tops" were used in some instances, based on resistivity curves, to allow continuity of correlations. This section illustrates the areas of well developed Carter Sandstone and shows the abrupt pinch out between the #1 Anderson-Homan and the #1 Beasley. Between the #1 Boyette-Smith and the #1 Airport, the cross-section shows the vertical thickening of the Carter 'B' and the increase in shale in the area of the #1 Smith Estate.

Cross-section B-B' (Plate IX), is a NW-SE stratigraphic cross-section that parallels cross-section A-A' in the southwest region of the study area. The line of cross-section extends from southwest Pontotoc county to southeast Clay county. The Carter Sandstone is thickest in the area of the #1 Jarrett well and also in the #1 Dexter well. A lateral facies change to the northwest near the #1 S.A. Farr well can be observed. Channel sands of the Carter 'B' are observed in cross-section near the #1-A J.W. Clarke well. Only minor amounts of "Millerella" Sandstone are present in the upper interval of the cross-section near the #1-A J.W. Clarke well and the #1 Jarrett well.

Dip-Oriented Stratigraphic Cross-Sections

Cross-section C-C' (Plate X), is a NE-SW stratigraphic cross-section extending from central Itawamba County to southeast Calhoun County. This line of cross-section shows the individual sand units pinching out up onto the Bangor Shelf. The Carter 'A' Sandstone in the #1 Leslie clearly represents the incised valley sands on the Bangor. Some of more significant deposition of the "Millerella" sandstone is shown in the area of the #1 Houston Hospital well. The cross-section also shows the individual thickening and thinning of the Carter 'A' and 'B' sandstone from the #1 Hill well to the #1 Houston Hospital well.

Cross-section D-D' (Plate XI), is a NE-SW trending stratigraphic cross-section extending from northeast Monroe County to southwest Clay County. The gradational thinning of sand units is observed as they approach the southern region of the Bangor Limestone. Individual channel sands of the Carter 'B' can be seen from the #1 Scott well to the #1 Henley well. Smaller Carter 'A' channel sands may be observed near the #1 Scott, #1 Airport, and #1 Henley wells. The thick Carter 'B' interval in the #1 Weyerhauser well is comprised of channel sands deposited onto the Bangor 'Shelf'.

The thickest deposits are Carter 'B' sands seen between the #1 Mary Lou Lang well and the #1 Minnie Plant Whitaker well. Cross-section D-D' shows the lateral change from channel lobes to a shaly interdistributary bay sequence.

Structural Contour Map: Base of the "Millerella" Limestone

The structural contour map on the base of the "Millerella" Limestone (Plate I), presents a clear picture of the complexity of folding and faulting within the study area. This structure map was contoured on 100 foot intervals. Generally, dip is to the SSW and varies from approximately 90 feet/mile in the northwest region of the study area to approximately 300 feet/mile in Oktibbeha and Noxubee counties.

Structurally, the basin is characterized by regional NW-SE trending, down to the basin, normal faulting with offsets ranging from 75 feet to over 2000 feet. Associated with some of these regional faults are NW-SE trending antithetic faults on the downthrown side. Offset of these faults ranges from about 50 feet to over 200 feet. This type of faulting acts as a good trapping mechanism and is associated with several producing fields in Mississippi. Graben-like structures are present in northeastern Monroe County and can be interpreted as being consistent with the extensional regime responsible for the normal faulting.

Plunging anticlinal and synclinal features are prominent throughout the west-central and southern regions of the study area, with the fold axis appearing to trend in a NE-SW direction. The NE-SW trending normal faulting could be associated with the compressive pressure resulting from the Appalachian orogeny. Also the NW-SE trending normal faults could have as resulted from compressive stresses of the Ouachita Orogen. The Ouachita compressive regime occured later than the Appalachian and could have caused further offset in the "Appalachian" faults resulting from the renewed stress regime.

"Millerella" Net Sandstone Isolith Map

The "Millerella" Sandstone was mapped using a 10 foot contour interval (Plate II). These sand bodies trend NW-SE; the thickest Mississippi accumulations are found in the northwestern and southeastern part of the study area. Sand thickness exceeds 50 feet in the southeast and 40 feet in the northwest.

Lacking continuity, the sand geometry gives the appearance of a reworked marine sands. It appears that after the Carter sands were deposited a minor transgression took place with the ensuing deposition of the "Millerella" Limestone culminating this event. With the initial overlapping of marine waters some Carter Sandstone was eroded, reworked, and randomly deposited. The "Millerella" Sandstone could have been deposited as either marine barrier complex or as subaqueous sand shoals. These are not conclusive as more data is needed.

Carter 'A' Net Sandstone Isolith Map

The Carter 'A' Sandstone was mapped on a contour interval of 20 feet. The geometry of the sands suggests a fluvially dominated delta with five "feeder" channels present which have bifurcated from the main "trunk" stream further to the N-NW. The 40 foot contour easily outlines what could be considered the major distributary channels. Five sub-lobes, formed by bifurcation of the trunk stream to the northwest beyond the erosional boundary, enter the study area.

Sub-lobe #1 is located in T9S - R8E of west-central Itawamba County; sub-lobe #2 is present in T10S - R6E and T10S - R7E of southeast Lee County; sub-lobe #3 is centered in T10S - R3E in east-central Pontotoc County; sub lobe #4 is found in T11S - R2E of south-central Pontotoc County; and sub-lobe #5 is centered in T11S - R1E of southeast Pontotoc County. With the exception of sub-lobe #5, all other sub-lobes tend to lose their individual identities as they bifurcate and commingle with each other. Sub-lobe #1 and sub-lobe #2 are good examples of the characteristic feature. The maximum recorded thickness for Carter 'A' data points is 150 feet in T10S-R9E of Itawamba County.

Sub-lobes #1 through #5 are all interpreted as being upper delta plain facies, bifurcating and commingling with southeast progadation into distal delta plain facies.

Sub-lobe #1 is a narrow, linear, incised channel cut into the Bangor 'Shelf' Limestone. It bifurcates and joins with sub-lobe #2. Sub-lobes #3 and #4 appear as though they originate from the same 'feeder' channel having separated just north of the erosional boundary. Sub-lobe #3 exhibits crevasse splay deposits in southeast Lee county and southwestern Monroe County, then continues a southward progradation commingling with remnants of sub-lobe #1 and #2. Sub-lobe #4 progrades southeast paralleling sub-lobe #3. In western Clay County, the map geometry indicates bifurcation and eventual abandonment of the western-most channel. The southeast region of Clay County represents either overbanking and a massive crevasse splay or development and rapid abandonment of a channel. Although rapidly abandoned, thick sands of over 40 feet accumulated. Interdistributary bay marshes and swamps identified with electric logs are located at T12S-R2E, T12S-R6E, T14S-R7E, and T12S-R8E. Sub-lobe #5 is the only lobe which maintains its distinctive identity, but shows little southward progradation. It is likely that sub-lobe #4 joins with sub-lobes #4 and #3 further northwest beyond the erosional boundary. These could be interpreted as high-constructive elongate delta lobes. Prograding southeast these sands are deposited along the shelf margin. The geometry of the sands suggest a source from the north or possibly northwest.

Carter 'B' Net Sandstone Isolith Map

The Carter 'B' Sandstone was mapped on a contour interval of 20 feet. The geometry of these sands shows a tendency to parallel the Carter 'A' deposition. The Carter 'B', in the study area, appears to be an upper delta plain facies. The five main 'feeder' channels are narrow, elongate sand bodies positioned in approximately the same locations as those of Carter 'A'. Sub-lobe #1 is located in T9S - R8E, Itawamba County; sub-lobe #2 is situated in the northern portion of T10S - R6E, Lee County; sub-lobe #3 is located in T103 - R3E, Pontotoc County; sub-lobe #4 is located in T11S - R2E, Pontotoc County; and sub-lobe #5 is centered in T11S - R1E, Pontotoc County.

The forty-foot contour line conveniently highlights the major distributary channels. The progradation of these delta lobes is not down-dip, but rather, for the most part parallel to the shelf edge in a southeasterly direction. This suggests that at the time of deposition the depocenter was further to the east and thus shifted to the west through time.

The direction of the source would appear to be the same as for the Carter 'A', as the sub-lobes from each map tend to 'mirror' each other. The sub-lobes are narrow, elongate, and thicker than those of the Carter 'A'. Sub-lobe #1, an incised valley fill, is greater than 200 feet thick. Maximum thickness of this sand body is 201 feet, with the average thickness of the middle delta plain around 70 to 80 feet. The identity of each sub-lobe is only maintained for a short distance as all sub-lobes commingle with each other. The sole exception is sub-lobe #5 which maintains its own identity. The southwestern portion of sub-lobe #4, in south-central Clay County, suggests breaching of the levee and new channel development with a limited life-span. This could also be splay deposits, as suggested by the geometry of the sand body deposited in T17S - R5E.

Important depositional environments are possible crevasse splays observed in T11S-R5E and T12S-R6E, possible point bar accumulations found in T14S-R3E, T15S-R5E, and T16S -R6E and interdistributary bay deposits at T14S-R6E, T11S-R5E, and T13S-R18W.

Total Carter Sandstone Isolith Map

The total Carter Sandstone was mapped on a contour interval of 20 feet. The channel geometry is conveniently highlighted by the 100 foot contours and suggests deposition in a fluvially-dominated deltaic environment. Five main feeder channels indicate bifurcation upstream in a north-northwesterly direction from the trunk stream.

Sub-lobe #1, located a T9S - R8E, fills a valley incised into the Bangor 'shelf' Limestone. This is the thickest accumulation of Carter Sandstone in the Black Warrior Basin. Sub-lobe #1 passes through south-central Itawamba County and splits into several channels in northern Monroe County. Sub-lobe #2, located in T10S - R6E and T10S -

R7E, appears to be two channels which have commingled leaving a thin veneer of sand through the center of the sub-lobe. The identity of sub-lobe #2 is only maintained a short distance until it combines with other channels. Sub-lobe #3 bifurcates into a northern, elongate, thick channel which combines with sub-lobe #2, and a southern companion channel, which commingles with sub-lobe #4, and passes on as a thick channel sequence and joins remnants of sub-lobes #1 and #2. Sub-lobe #4, immediately combines with sub-lobe #3 in the study area and passes southeast parallel to and combining with sub-lobe #3. In T13S - R4E, sub-lobe #4 shows indications of channel bifurcation progressing southeast from Sec. 20 - T13S - R4E to T15S - R4E. In the southeast region of T16S - R5E, inferred overbanking and thick sand deposition indicate either massive crevasse splay deposits or new channel development with quick abandonment. Other crevasse splay morphologies are observed in southeast Lee County, and west-central Monroe County. Possible point bar accumulations exist at T14S - R6E and T12S - R3E.

With the exception of sub-lobe #1, the thickest accumulations of sand are located in the main channels and where these channels amalgamate. As a result of the incised nature of sub-lobe #1, 308 feet of sandstone was deposited on the Bangor Shelf.

Source of the Carter Sandstone appears to be from north or northwest. These deltas were fed by a trunk stream which likely originated from the Illinois Basin region or further to the north. The Carter Sandstone depositional trend continues into Alabama, where reworking of the distal deltaic sands produced a barrier bar environment, but a map of its total extent was not included for the scope of this study.

Electric Log Patterns For Individual Wells

Electric log signatures (particularly S.P. and resistivity) are a useful tool for identifying a particular facies within a terrigerous clastic system. The response of the electric log tool is proportional to the textural property of the rock. Texture is defined as the size, shape, and arrangement of component particles and is a function of the hydrodynamic environment of deposition. The natural gamma ray curve, along with the S.P. curve, can be helpful in estimating the sand/shale ratio as well as permeability and porosity in a given interval.

Determining different facies can be made easier by identifying certain characteristic shapes seen in S.P. curves. Fining-upward sequences are noted by a "inverted bell" shape. Coarsening-upward sequences are denoted by a "bell" shaped curve and a distributary channel exhibit a "cylinder" pattern with sharp upper and lower contacts. Careful identification of such patterns prove valuable when determining sandstone units. Several examples of deltaic facies curve shapes for the Carter Sandstone are illustrated in Figure 23.

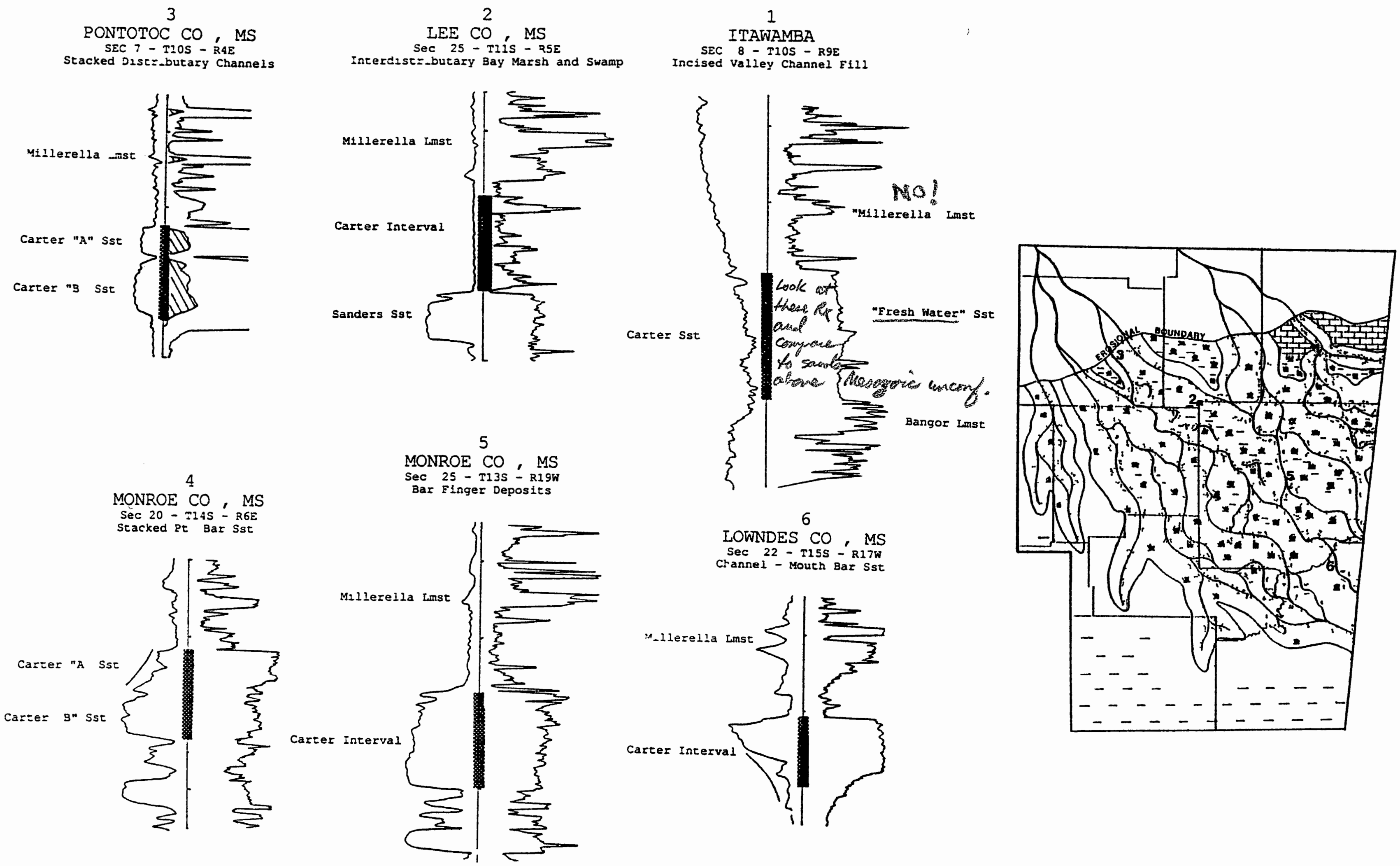


Figure 23. Suggested Carter Depositional Environments Interpreted from Electric Log Patterns.

CHAPTER VI

FACIES ANALYSIS OF THE BATESVILLE AND CARTER INTERVALS

Introduction

Several papers have been published with regard to interpretation of the depositional environments of Chesterian units of both northern Arkansas and the Black Warrior Basin. In northern Arkansas, those include Caplan (1954, 1957), Croneis (1930), Deviene (1972), Easton (1942), Garner (1967), Glick (1979), Ogren (1961), Price (1981), Schell (1971), and Threinen (1961).

Chesterian sedimentation in northern Arkansas occurred on the northern Arkansas structural platform and in the region which is occupied by the present day Arkoma Basin (Figure 15). The succession of depositional units was apparently formed by one major episode of transgression and regression with many minor fluctuations along the cratonic margin. Within the study area, the depositional record can be divided into four major formations which include: 1) the Batesville Sandstone, 2) the Hindsville Limestone, 3) the Fayetteville Shale with the Wedington Sandstone Member and 4) the Pitkin Limestone.

The Batesville Sandstone represents deltaic, coastal and shallow shelf environments and the Hindsville Limestone represents a near shore environment. The dark, micritic and algal muds of the Fayetteville Formation accumulated during the maximum transgression, which was interrupted by a regressive progradation during which the Wedington Sandstone was deposited in the area. The shallow seas related to the regressive sequence produced the carbonate environments in which the Pitkin Formation accumulated.

The depositional framework of Chesterian units of the Black Warrior Basin has been previously discussed by Bat (1987), Broussard (1978), Cleaves (1980), Cleaves (1983), Cleaves and Bat (1988), Cleaves and Broussard (1980), Di Giovanni (1983), Ehrlich (1965), Higgenbotham (1986), Holmes (1981), Hughes (1987), Hughes and Meylon (1988), Nix (1985), Scott (1978), Shepard (1979), Thomas (1980), Thomas and Mack (1982), Thomas and others (1980), Welch (1978), and White (1976).

The environments of Chesterian sandstones of the area reflect seven cycles of deltaic prorogation onto the structurally stable northern shelf of the Black Warrior Basin. These prograding deltaic sequences had a cratonic source originating from the north in the mid-continent region (Figure 24). Marine transgressions interrupted the deltaic events, resulting in carbonate and marine clastic sedimentation. Such an idealized cratonic delta sequence is show in Figure 25.

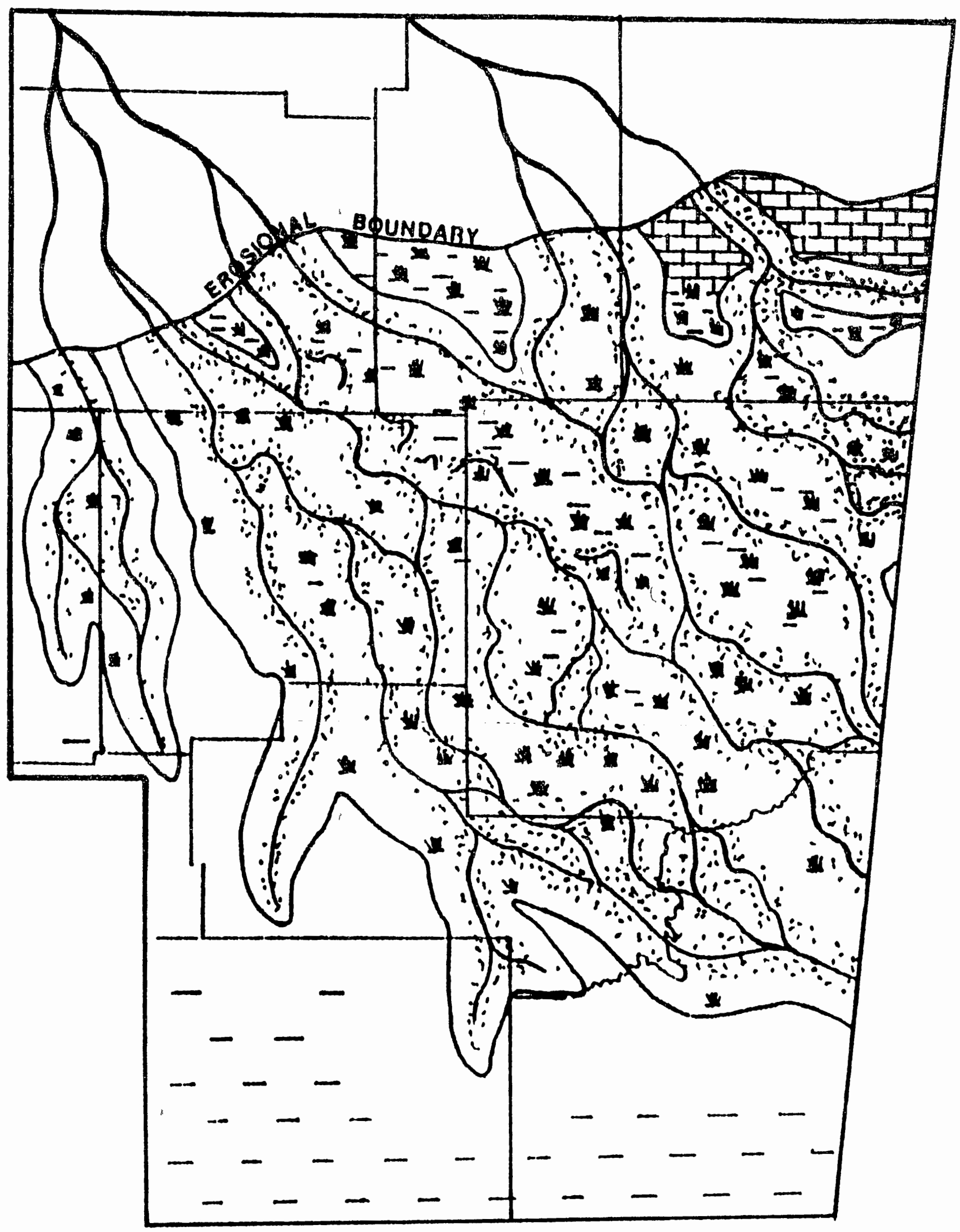


Figure 24. Paleoenvironment map of the Carter Deltaic Facies of the Black Warrior Basin.

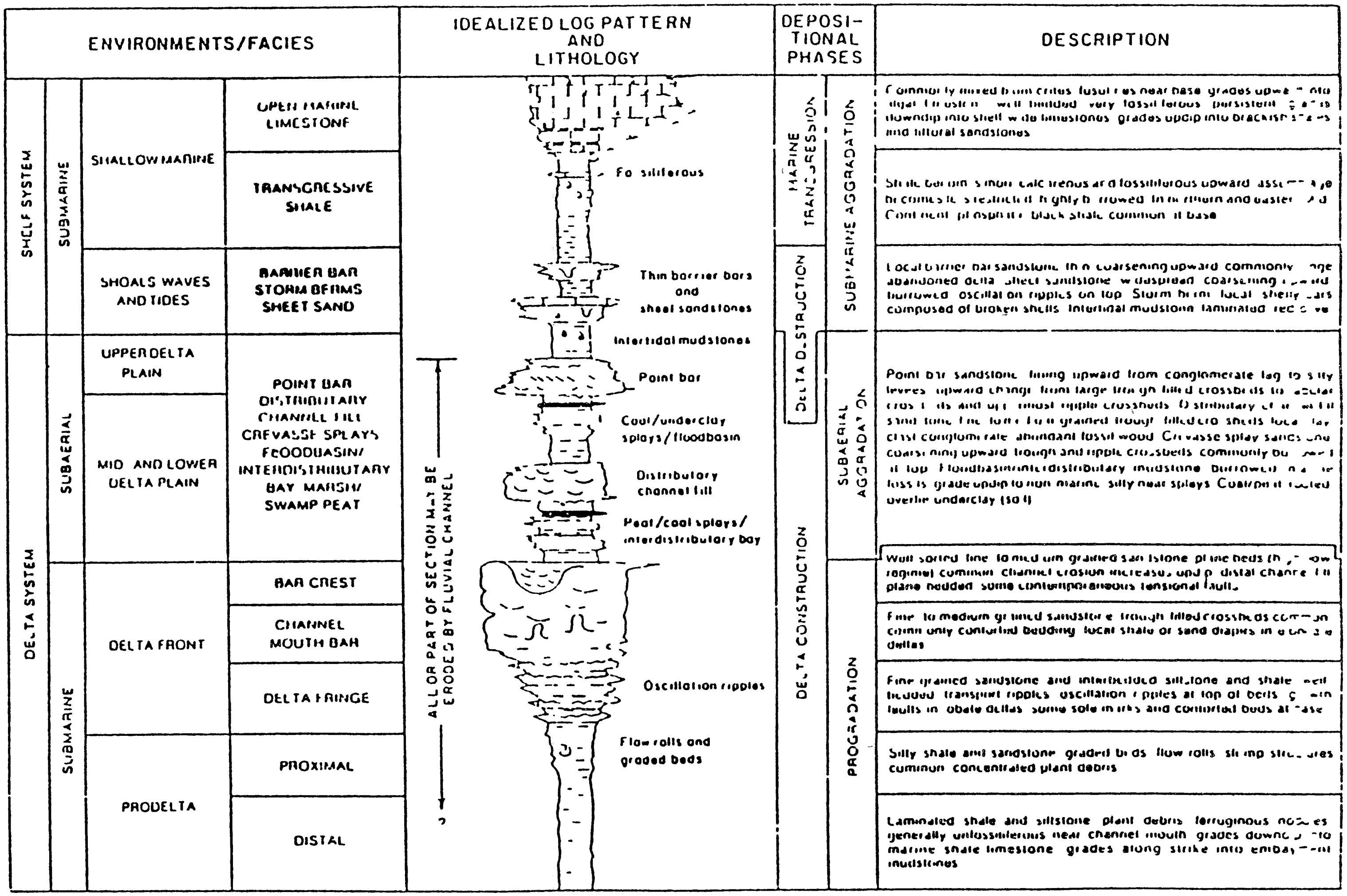


Figure 25. Idealized Cratonic Delta Sequence

The Carter Delta System, deposited as high-constructive elongate delta lobes, was active in the study area during Middle Chesterian time. The basinward progradation in a southeastwardly direction was halted due to eustatic rise in sea level. This is evidenced by the overlying marine shales and reworked marine sands of the "Millerella" Sandstone capped by the transgressive "Millerella" Limestone. This was followed by another regressive sequence leading to the deposition of the Gilmer Delta System.

Depositional Models and Facies

Fluvial Models

A significant segment of the sediment-dispersal system is the stream. Figure 26 offers an idealized exhibition of the range of depositional variations including: braided streams, course-grained meanderbelts, fine-grained meanderbelts, and distributaries, which are associated with deltas. This allows for a general view of some of the factors which determine the type of fluvial system or that result from deposition of a particular fluvial system. These factors include gradient, channel flow, discharge rate, character of sediment load, geometry of resulting sand bodies, and the nature of levees. When dealing with the analysis of ancient sand bodies within basins, understanding the geometry of the resulting fluvial sandstone deposit is very important.

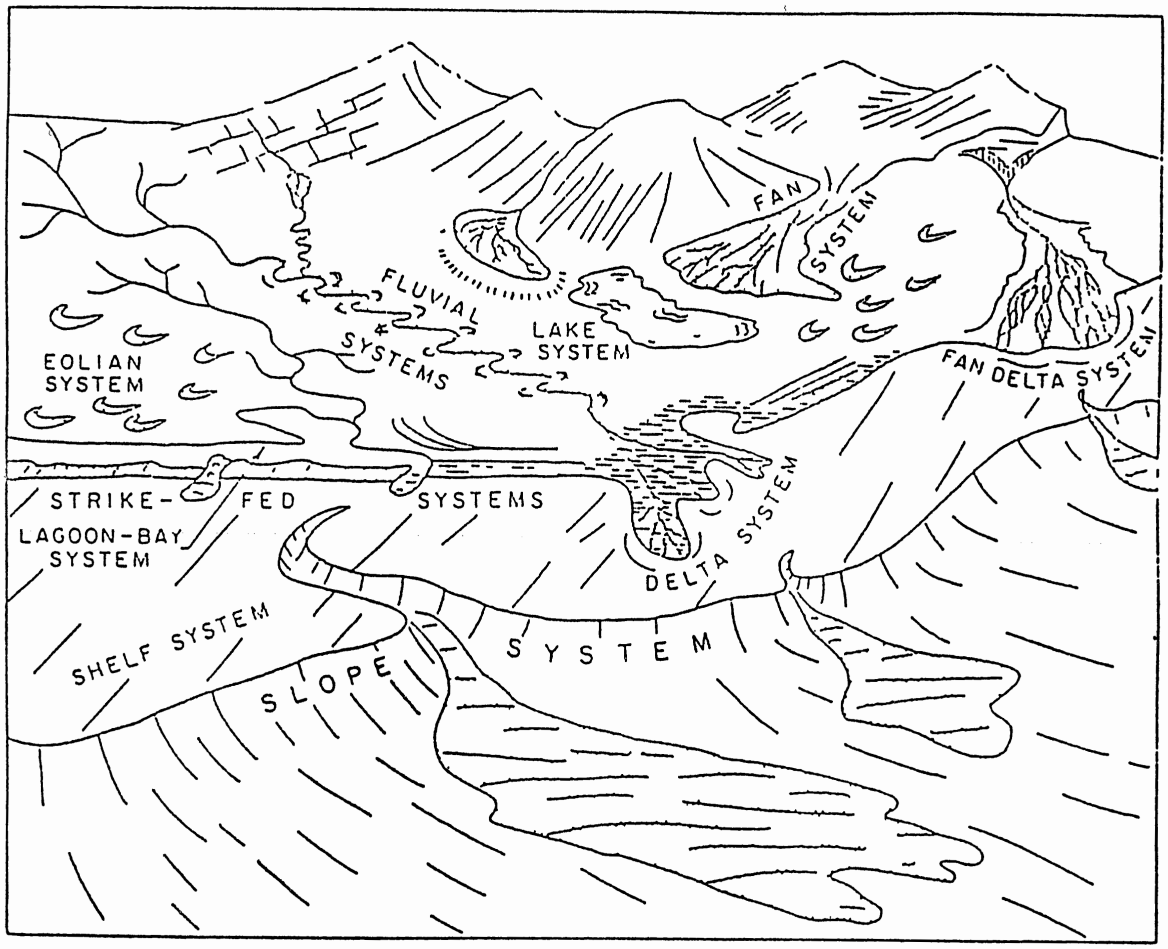


Figure 26. Schematic Perspective of Terrigenous Clastic Depositional Systems (Modified from Brown, 1973).

Meandering Streams

Meandering streams may be described as a broad, intermediate, assemblage of channel segments that are moderately to highly sinuous. They are composed of a series of wave-like loops with areas of deposition called point bars located on the inside of each bend of the river. Meandering streams generally reflect a more controlled environment than braided streams due to thicker, more heavily vegetated floodplains. Only during floodstage, when the cohesive deposits experience a loss of integrity , or overbanking by floodwaters, do crevasse splays or avulsion of channels form.

Within river systems numerous sub-environments exist, each indicative of certain processes. The presence or absence of certain types of environments allows for the classification of rivers. The same holds true for meandering streams which, based on a combination of sediment particle size and discharge characteristics, are divided into two types: 1) coarse-grained meanderbelts, and 2) fine-grained meanderbelts. Typically, they occur downstream of braided streams, but upstream of deltaic depositional systems.

Course-Grained Meanderbelt Systems

The coarse-grained meanderbelt is basically a transition between braided streams and meandering stream deposition (Figure 27). They are categorized in the lower range of moderate-to high-bed load dispersal systems controlled by moderate gradients and/or moderate sandy bed-load source areas (Brown, 1973). The stream pattern is only slightly to moderately sinuous and braiding occurs in the system if the levees are not stabilized by vegetation. The deposits include multilateral sand bodies composed by partially developed point bars and channel fill (Figure 27a).

Coarse-grained meanderbelts are composed of coarse-grained sand and gravel with almost no mud or silt occurring in the system. The coarsest grains occur as channel lag and in chute bar deposits (Figure 27a and b).

Fine-grained Meanderbelt Systems

Fine-grained meanderbelts develop under low gradients, with a moderate to high and generally uniform discharge, and a high suspended load (Figure 28). A cross-section view shows the channel-fill units are multistoried and asymmetric. The complete, idealized sequence displays a fining upward sequence of texture and corresponding decrease in the size of sedimentary structures.

Sand bodies display a moderate width/thickness ratio and generally are multistoried. Levees are well developed and overlap the point bars as the meanders shift laterally. The channels are highly sinuous within the system, making directional features such as cross-beds highly variable.

Fine-grained meanderbelts are enclosed with overbank or levee muds. The associated abandoned channels are filled

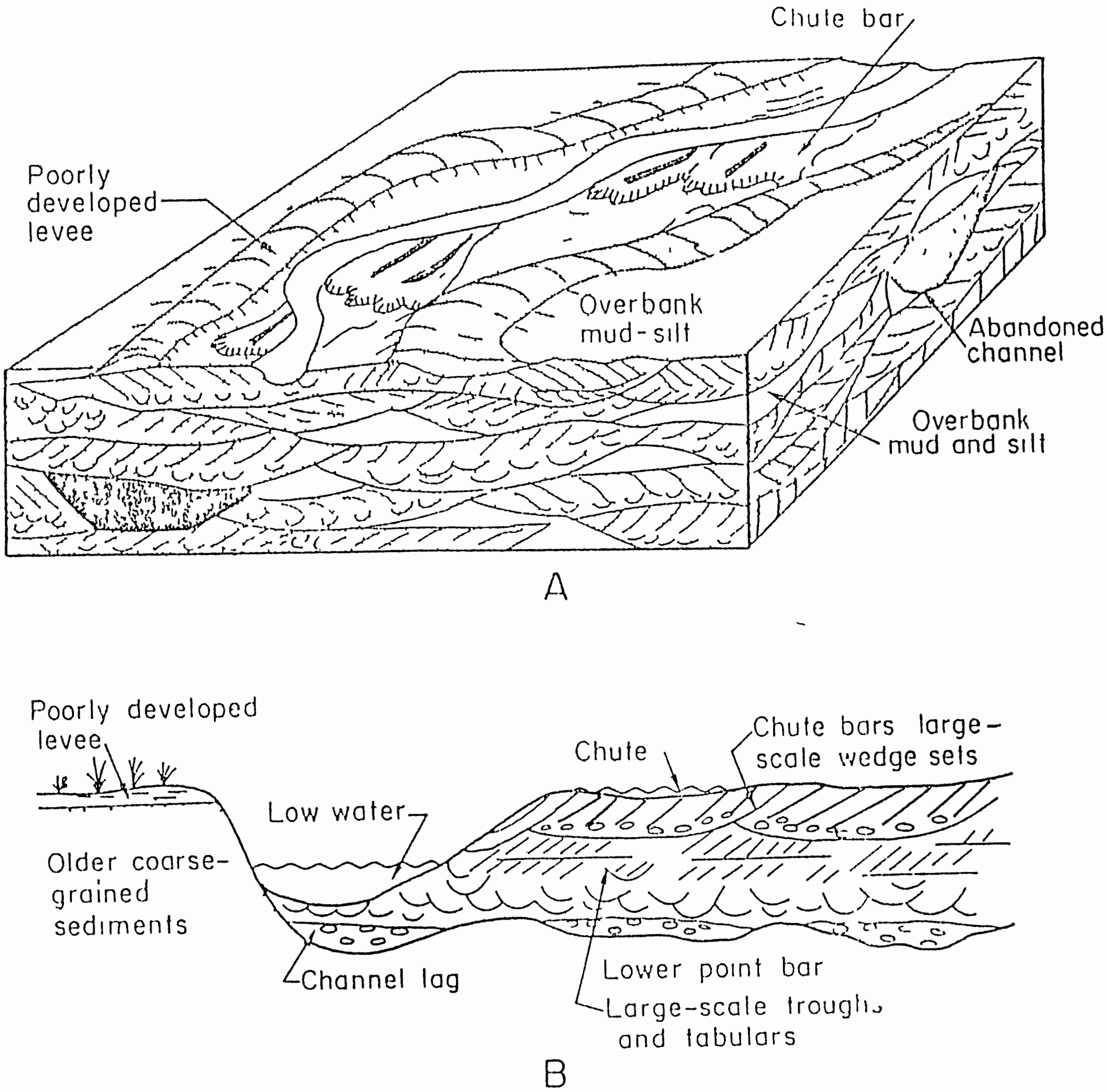
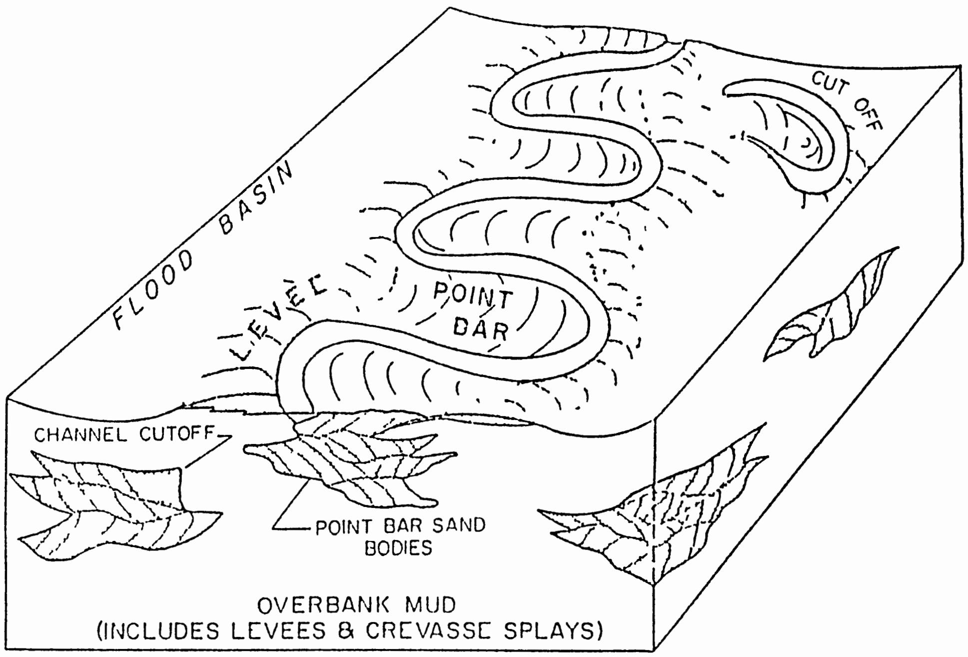


Figure 27. Depositional Model of an Idealized Coarse-Grained Meanderbelt Fluvial System.
A. Block Diagram Showing Bedforms, Sedimentary Structures, and Multilateral-Sand Geometry.
B. Schematic Cross-Section of Coarse-Grained Point Bar Deposits. (modified from Brown, 1973).



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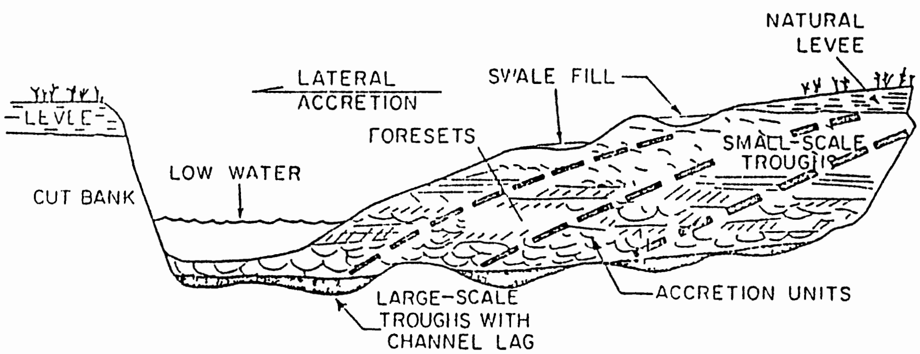

B

Figure 28. Depositional Model of an Idealized Fine-Grained Meanderbelt Fluvial System. A. Block diagram showing bedforms, sedimentary structures, and multistory geometry. B. Schematic cross-section of fine-grained point-bar deposits. (modified from Brown, 1973).

with splay deposits and/or fine-grained, plant-rich sediments creating organic plugs. They generally lack gravel and exhibit a broad, meandering pattern where the overall thickness of individual sand units reflects the depth of water within the channel during peak discharge (Figure 26a and b).

Distributary Channels

Distributary channels generally provide sandstones of good reservoir quality and usually are composed of clean, well-sorted, coarse to fine-grained sands. Although they commonly consist of a slight fining-upwards sequence, their geometry can be very complex. Distributary channels tend to be rather stable and normally do not migrate in a lateral sense. This is the result of significant levee build-up in the lower delta plain (Figure 29). Commonly, channels tend to conform to a down-dip progradational pattern of deposition. This was not the case, however, as the Carter Sandstone was deposited somewhat along strike of the Black Warrior Basin.

Distributary channels tend to downcut with little lateral migration and, as a result, are laterally equivalent to levee, swamp, crevasse splay, marsh, and lake deposits of the delta plain environment. They are generally overlain by either transgressive marine sediments, alluvial deposits, or aggradational delta front deposition.

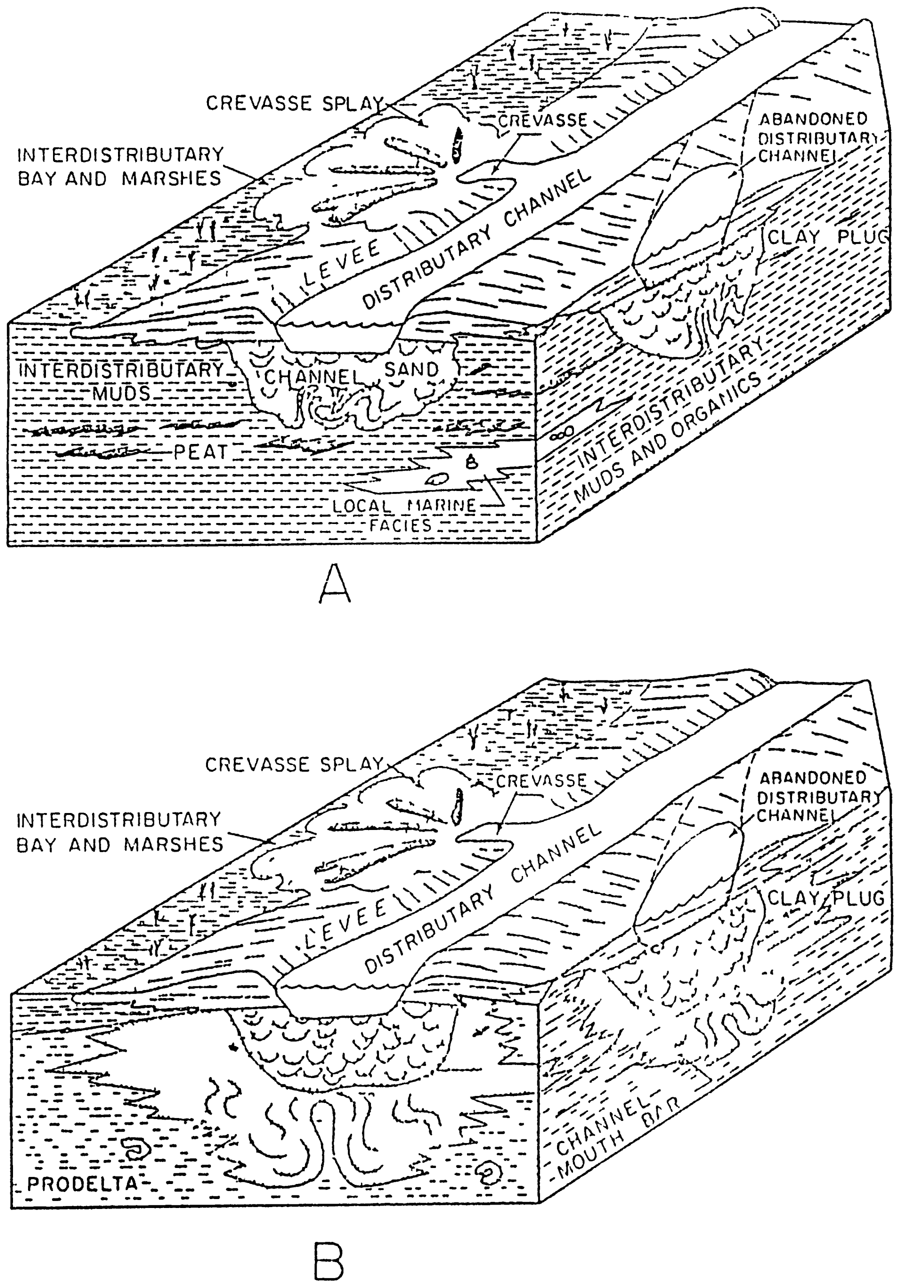

Figure 29. Depositional Model of Idealized Distributary Channel-Fill and Associated Deposits. A. High-constructive lobate delta-plain setting displaying extensive aggradation. B. High-constructive elongate delta setting displaying extensive progradation (from Brown, 1973).

Incised Valley Fill

Incised Valley fill sediments are characterized by long, narrow, linear bodies of deposition. Depending on the type and size of the river within the valley, the sediments may be either coarse or fine-grained. Generally they consist of gravel and coarse to medium-sized sands and exhibit a poorly developed fining-upwards sequence.

The valleys develop on alluvial plains due to base level changes which include: 1) eustatic sea-level change, 2) differential tectonic subsidence, or 3) major avulsion in an over extended fluvial-deltaic system followed by readjustment in response to a steeper gradient (Figure 30).

Because of the confining nature by the bounding bedrock valley walls, there is little chance of avulsion and the coarse of the channel is somewhat restricted. In relatively narrow valleys which approximate the width of the meander channel within, the channel facies may fill the entire valley with only isolated floodplain and abandoned channel plug sequences being preserved from the finest grained sediment fraction. This type of deposition also exhibits rapid abandonment as the coarse-grained sands and gravels are abruptly overlain by muddy organics.

Deltaic Models

Because of the diversity and complexity of deltas as depositional systems it became necessary to devise

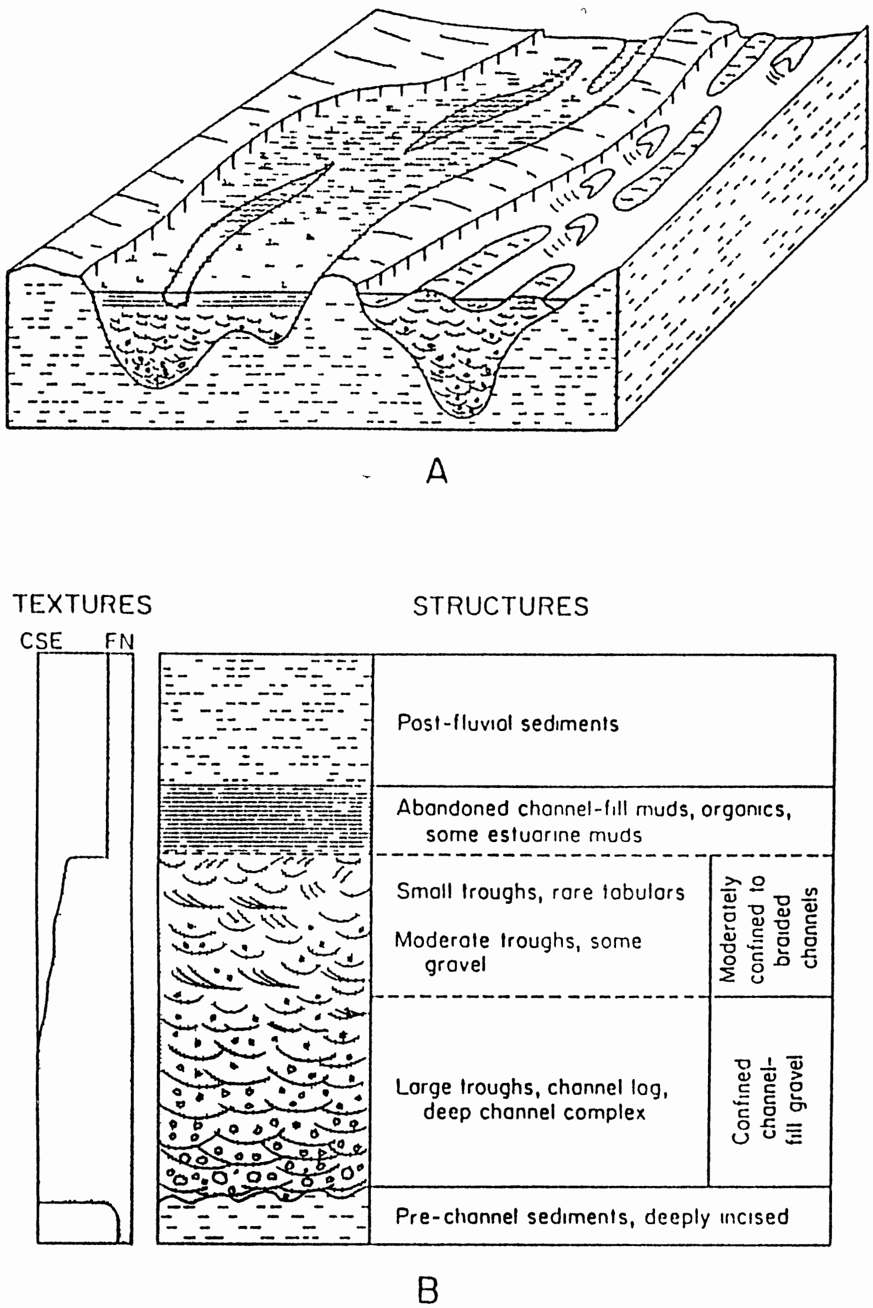

Figure 30. Depositional Model of an Idealized Valley-Filled Fluvial System. A. Block diagram showing nature of aggradational-fill deposits. B. Idealized vertical sequence (modified from Brown, 1973).

classification schemes to describe them. Most notable of these schemes are Coleman and Wright (1975), and Fisher (1968, 1969), whose classification was revised somewhat by Galloway in 1975.

Coleman and Wright (1975) devised a spectral classification system made up of six delta depositional systems (Figure 31). The six types of sand distribution patterns are based on the coastal processes which exert significant control on the geometry, genesis, and distribution of deltaic facies (Coleman, 1976). Fisher (1968, 1968) constructed a useful classification scheme in which the models are based on the relative influences of fluvial processes versus marine processes in the characteristic morphologies and facies distributions of delta environments. Galloway used a ternary diagram to show the main influences on deltas whether it be fluvial-, wave-, or tide-dominated (Figure 32).

The Fisher classification scheme will be used for the purpose of this discussion. Fisher established four delta types which provide some insight into deltaic systems, their processes, environments, and resulting facies. He further defined high-constructive elongate and high-constructive lobate deltas based on their sand geometry. Fisher classifies high-destructive deltas on the basis of the dominant marine process and includes high destructive wave-dominated, and high-destructive tide-dominated deltas.

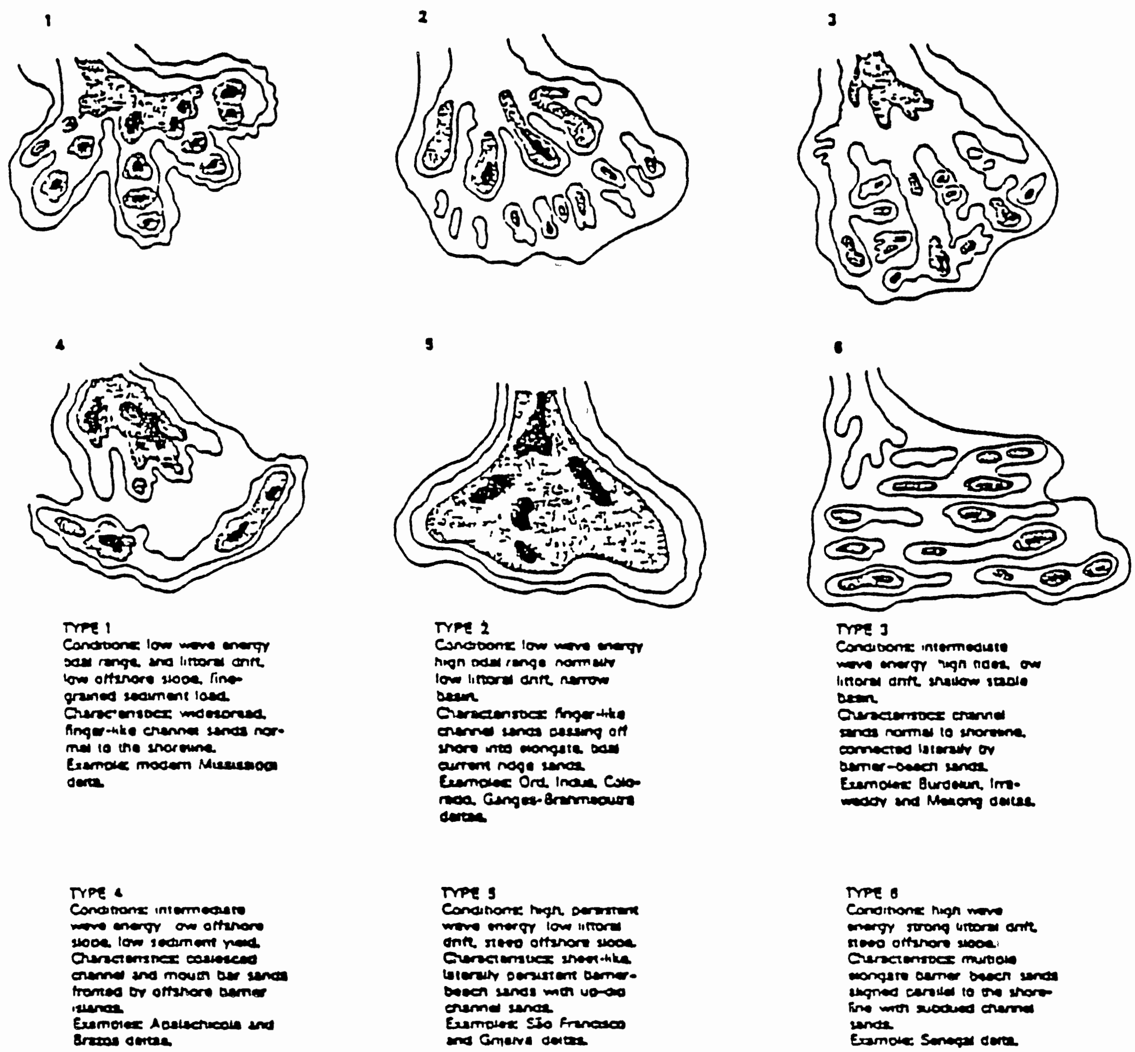

Figure 31. Delta Models Based on Multivariate Analysis of Parameters from a Wide Range of Modern Deltas; Increasing Density of Shading Indicates Increasing Sand Thickness (from Coleman and Wright, 1975).

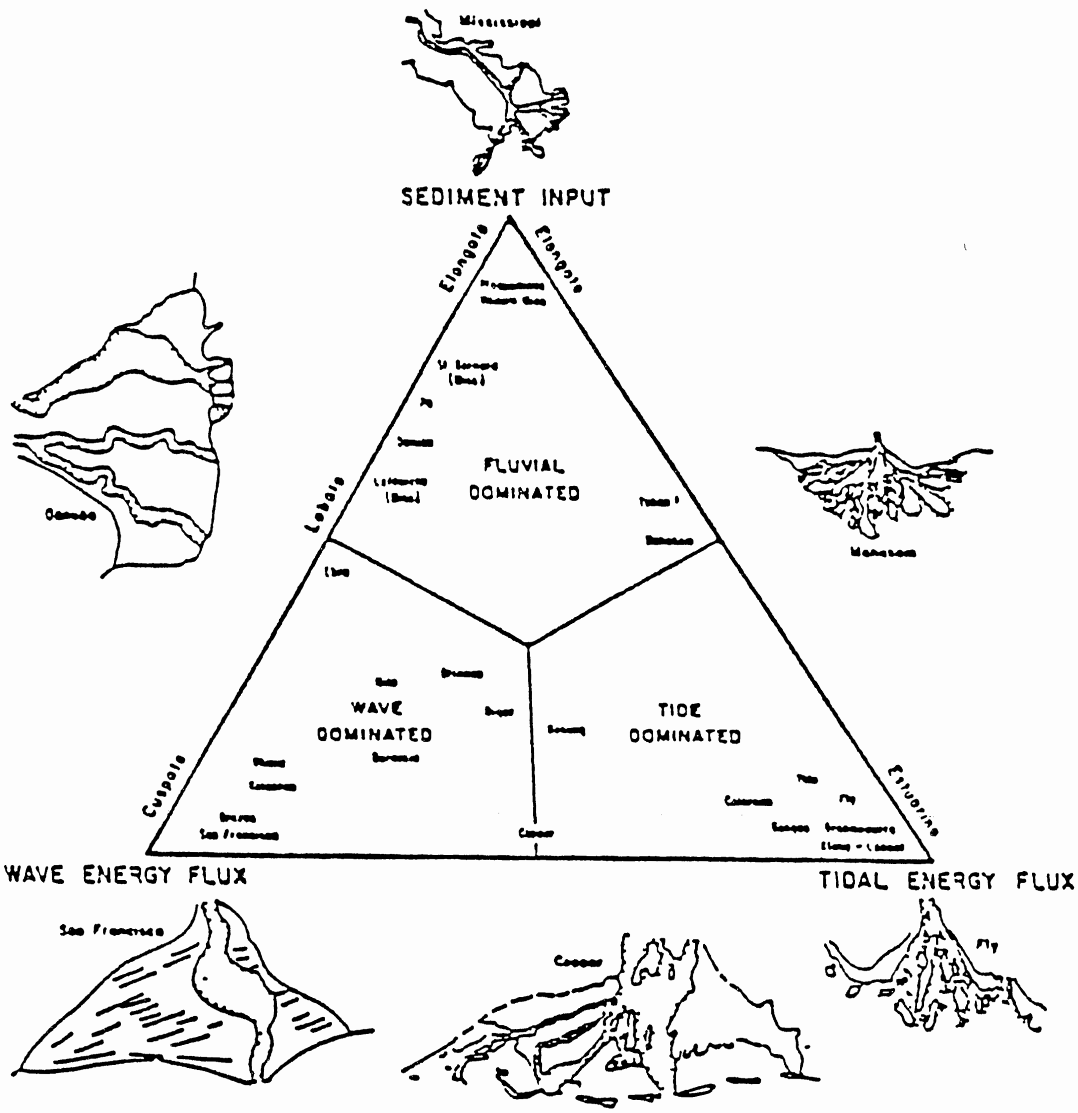

Figure 32. Ternary Diagram of Delta Types, Based on Relative Intensity of Fluvial and Marine Processes (modified from Galloway, 1975).

The four basic elements of Fisher's classification scheme is illustrated in Figure 33.

High Constructive Deltas

High-constructive deltas are generally large-scale features which are river-dominated and prograde a considerable distance seaward. Depending on the magnitude of the marine processes, these sediments will be deposited in either an elongate or lobate fashion. The elongate delta, represented by the active birdsfoot delta of the Mississippi River, develops by an extensive progradation of the constructional facies in which the sediment load is much higher than the marine energy. Low-wave energy, low-littoral drift, and a low tide range typify the marine energy setting. The destructional facies encompasses only a minor amount of the entire depositional package of a constructional delta, allowing for a thin destructional facies to overlie the constructional facies following delta abandonment. 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 34 illustrates the lateral facies distribution of an elongate delta complex.

High-constructive lobate deltas are characterized by well-bedded, sheet-like delta-front sands lacking the

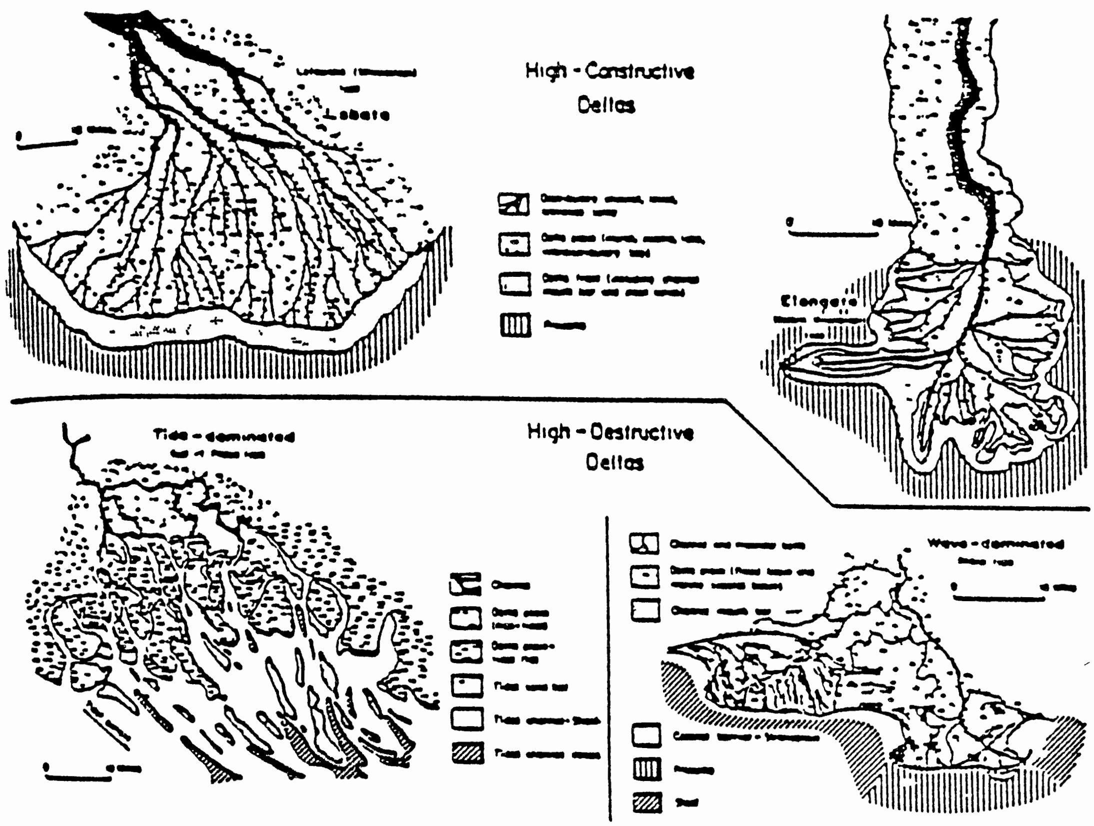

Figure 33. Four Basic Delta Types
(Fisher, et al., 1969).

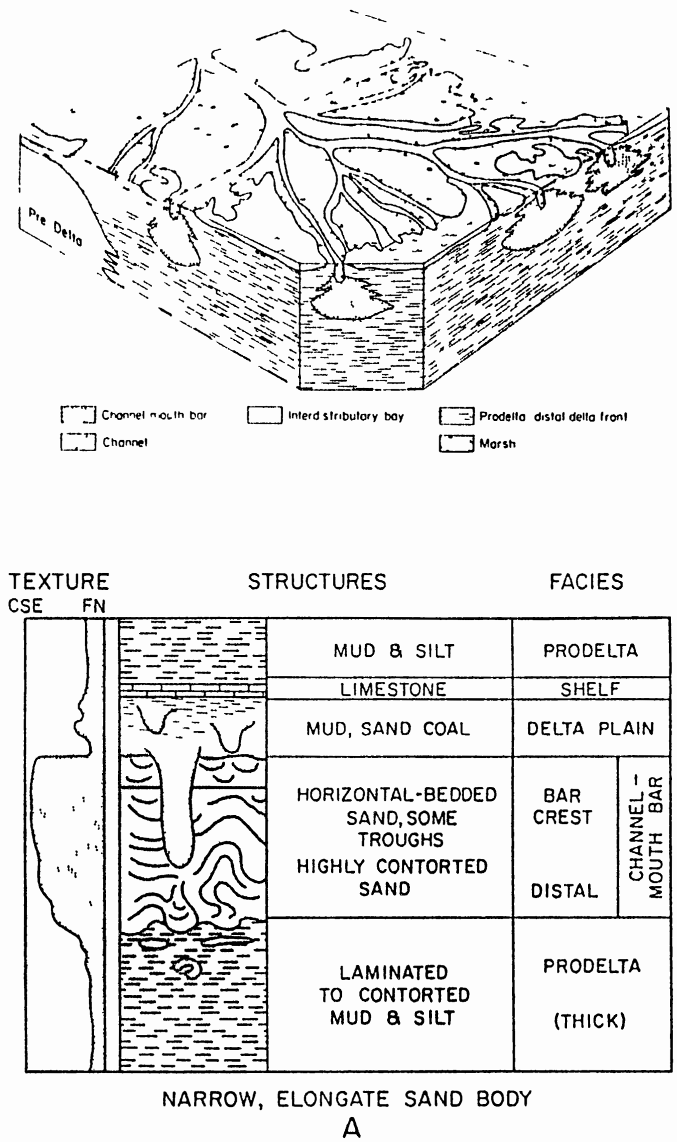

Figure 34. Block Diagram and Vertical Sequence of a High-Constructive Elongate Delta (modified from Brown, 1973).

protruding bar finger sands of the elongate type and having a smooth, more rounded shoreline. The sheet sands of the delta front are formed by a coalescence of the distributary-mouth bars. These sands are underlain by thin prodelta muds as deposition occurs in a shallow water setting and do not experience significant compaction (Fisher, et al., 1969). Not experiencing subsidence allows for extensive reworking of the sands by marine processes. The Lafourche Lobe of the Holocene Mississippi Delta complex is an example of a high-constructive lobate delta. Figure 35 represents the lateral distribution of facies within a lobate delta system and a hypothetical net sandstone isolith map of the same delta system.

High Destructive Deltas

High-destructional deltas are predominantly controlled by marine processes and the type of dominant marine process dictates whether the delta is classified as a high-destructional wave-dominated or tide-dominated.

In the wave-dominated high-destructional deltas, the principle deposition occurs as a series of marine reworked coastal barriers. These deposits flanking the river mouth parallel to strike give a cuspate- to arcuate-shaped delta morphology. Typically, cuspate deltas are characterized by having only one or two major distributaries, as the delta plain facies is dominated by a series of strandplain beach ridges. The Brazilian Sao Francisco Delta is a Holocene

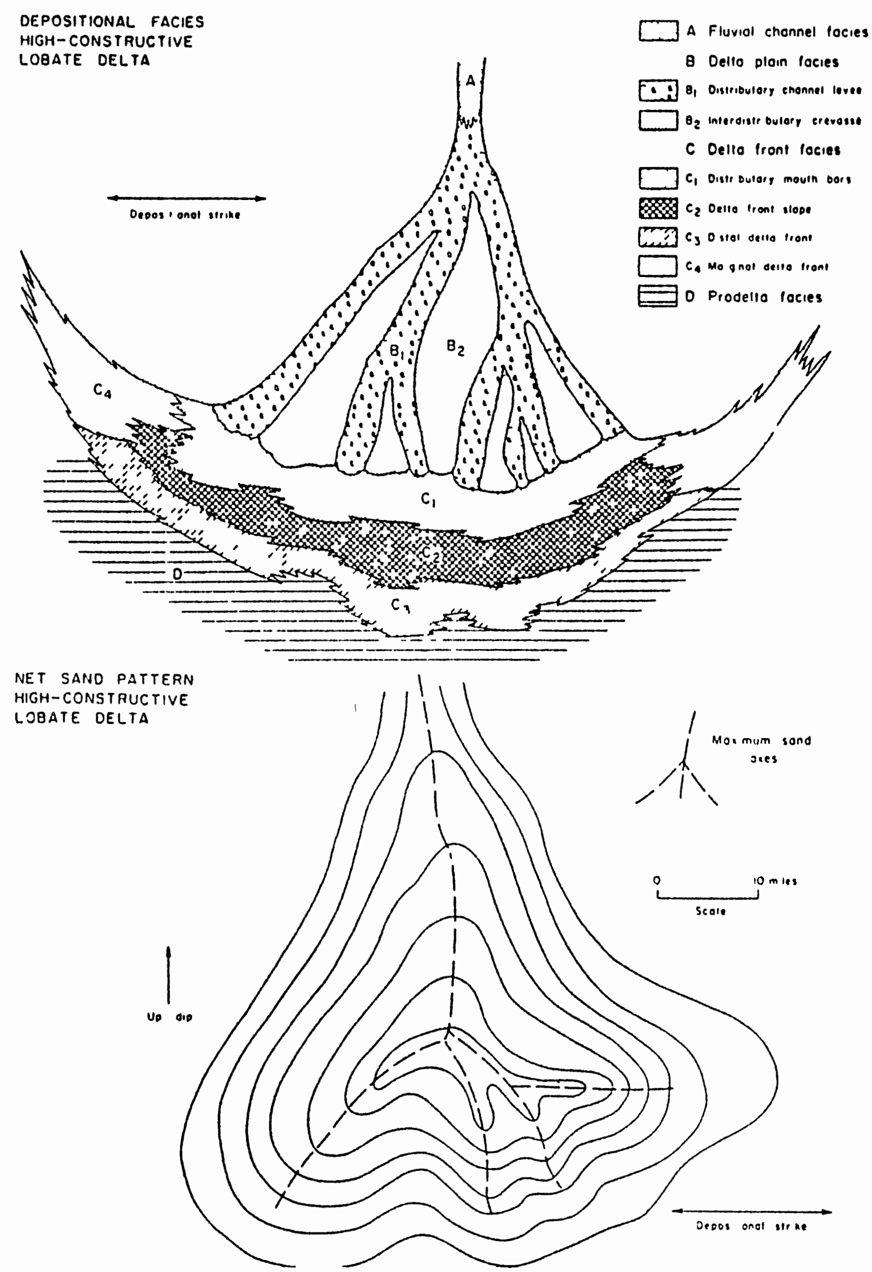

Figure 35. Sand Pattern and Lithologic Facies Distribution in High-Constructive Lobate Deltas (from Fisher, et al, 1969).

example of a cuspate, high-destructional wave-dominated delta. Figure 36 illustrates the lateral facies distribution and hypothetical net sandstone isolith map for a wave-dominated delta. Figure 37 represents an idealized coarsening-upward sequence described from the Sao Francisco Delta.

High-destructive tide-dominated deltas are the least understood of the principle deltaic species. The geometry of the delta fronts can be highly variable, depending on the configuration of the coastline. Generally, the fluvially-introduced sediments are reworked by tidal currents into a series of digitate sand bodies which radiate from the front of the river mouth. The distributary channels are generally choked by sand due to the flood tidal currents. Low wave energy, high tidal range, and a narrow, restricted depositional basin which is indented to the coastline appear to be the type of environment conducive to the formation of tide-dominated high-destructional deltas (Coleman, 1981). The best Holocene depositional models include the Klang (Malaysia) and Ord (Australia) deltas, both of which were described by Coleman (1981). Figure 38 is an example of a tide-dominated delta as represented by the Gulf of Papua delta. Figure 39 presents a theoretical net sandstone isolith map that might result from a tide-dominated delta.

All of the delta models of the Fisher classification scheme have been used to describe one or more of the

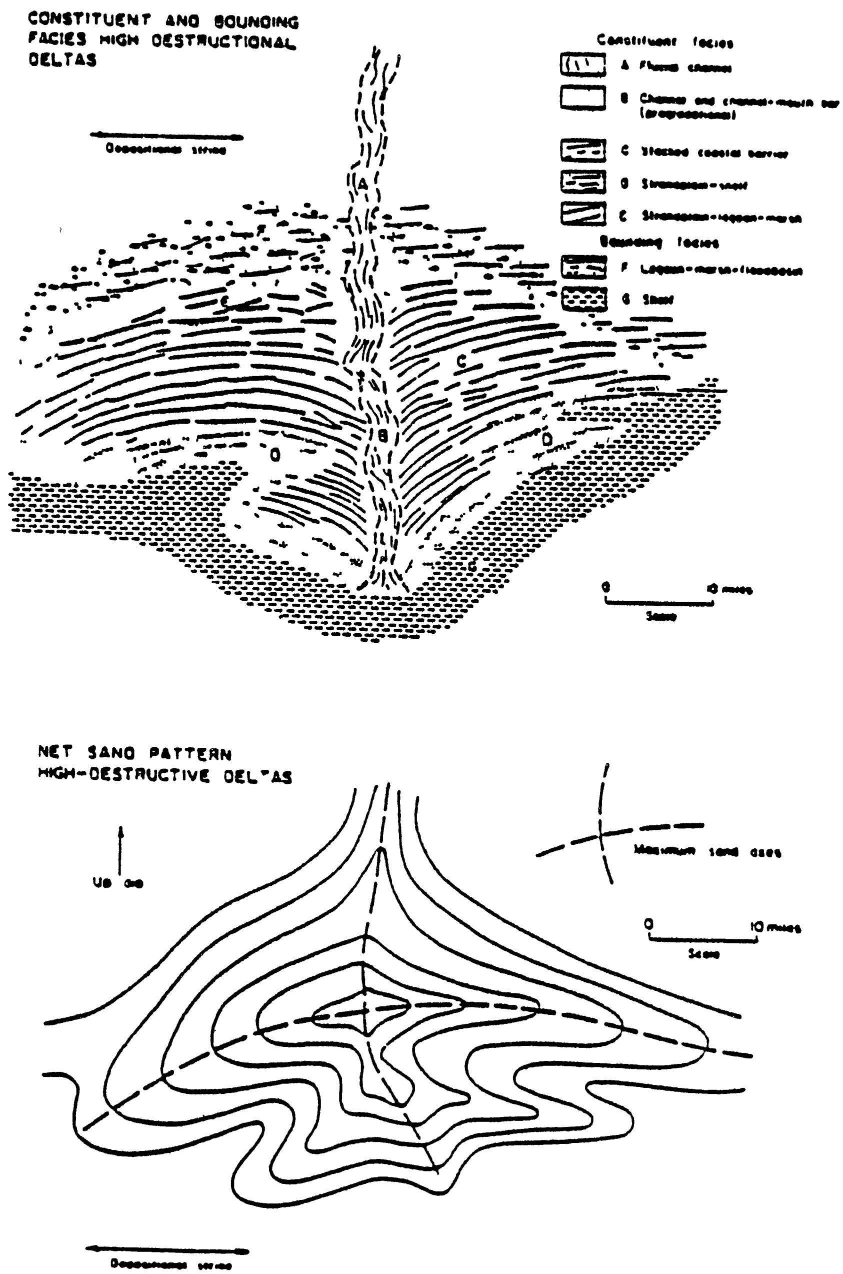

Figure 36. Net Sand Pattern and Lithologic
Facies of High-Destructive
Wave-Dominated Deltas
(from Fisher et al, 1969).

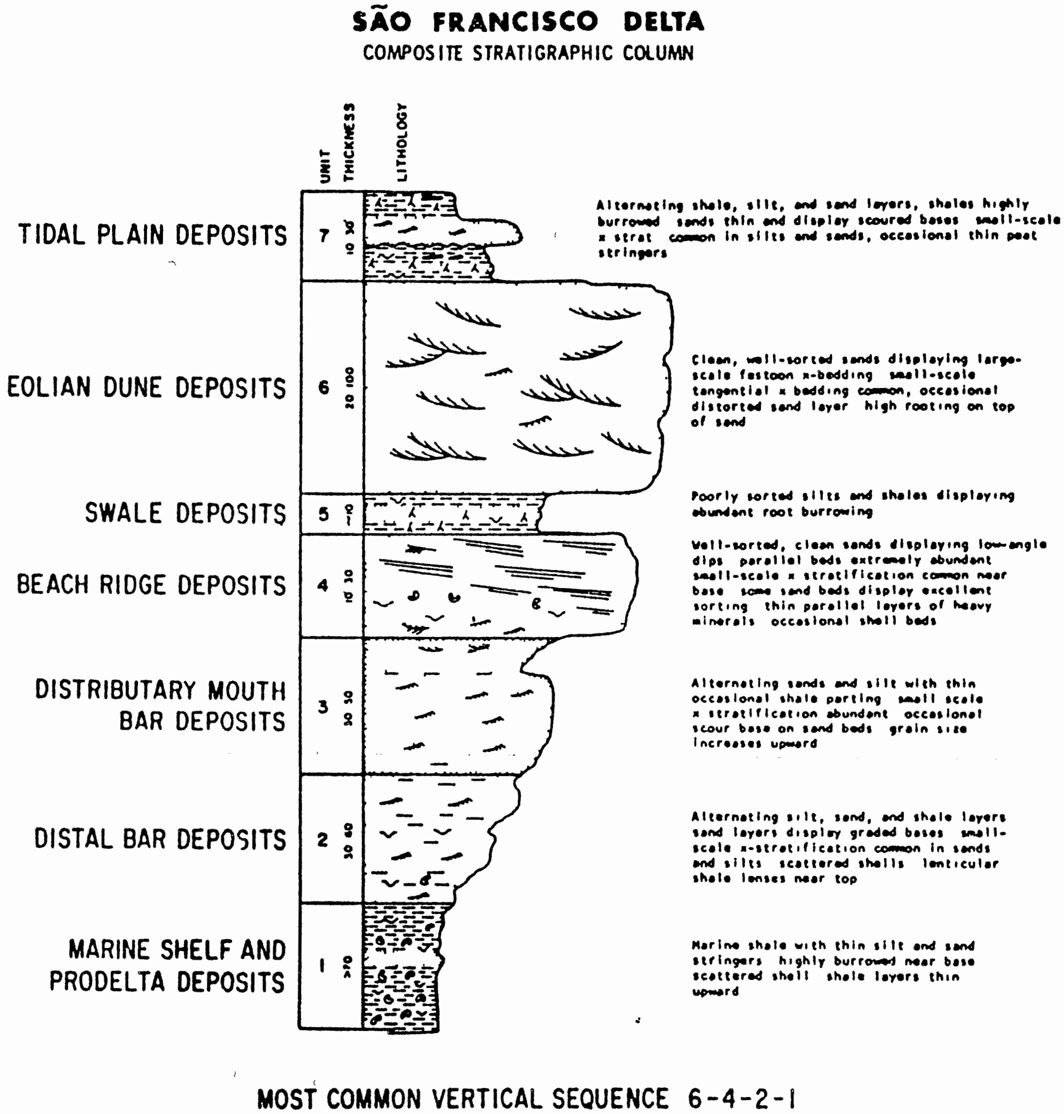

Figure 37. Composite Stratigraphic Column of Sao Fransisco River Delta (from Coleman, 1981).

Chester-age deltas on the Northern Shelf within the Black Warrior Basin. Cleaves (1980, 1983) and Cleaves and Broussard (1980) described the Rea and Carter Sandstones as representing high-constructive elongate systems, the Lewis and Sanders 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 systems. O'Connor interpreted the Lewis as being a high-constructive elongate and lobate delta complex. Bat (1987) also describes the Lewis Sandstone as a high-constructive elongate and lobate delta system. He further notes that Evans deposited in a high-destructive wave-dominated delta environment. Holmes (1981) and DiGiovanni (1984) describe the Lewis Sandstone as shallow marine bars deposited by tidal processes. Shepard (1979) interpreted the Carter Sandstone as an high-constructive elongate delta complex.

Marine Transgressive Sandstone Bodies

Within the Black Warrior Basin, the Carter Sandstone is regarded as a constructive elongate delta environment. As the Carter progrades into the Alabama part of the basin, the Carter Sandstone is interpreted to be deltaic deposits predominantly consisting of lower delta plain barfinger and distal bar sands (Mancini et al., 1983). Marine fossils, found only in the southeast region of Carter deposition,

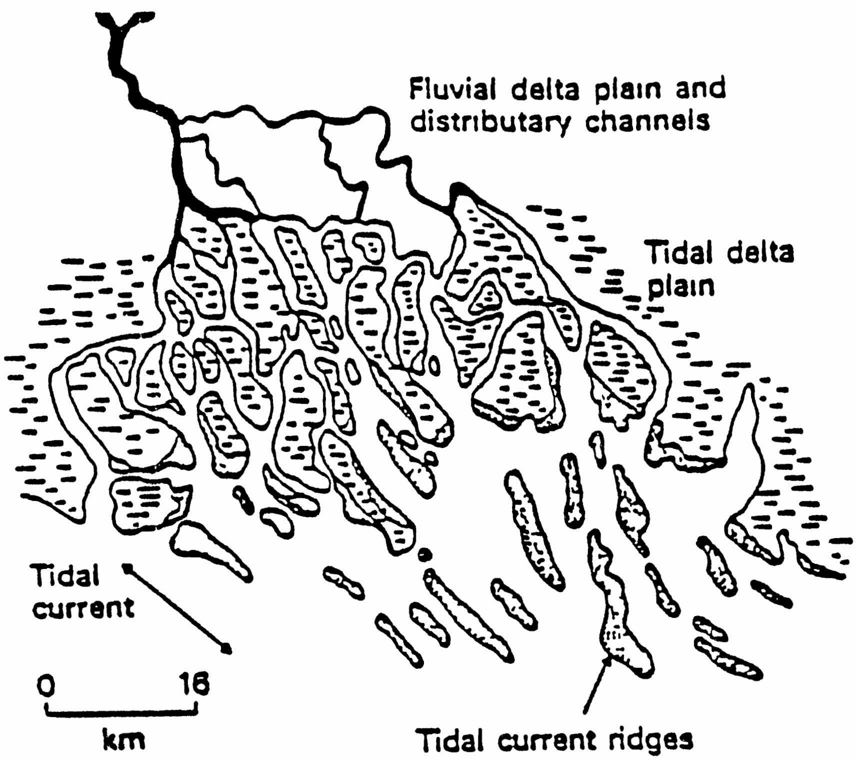

Figure 38. The Gulf of Papua Delta with Extensive Fields of Tidal Current Sand Ridges at the Delta Front (from Fisher, et al., 1969).

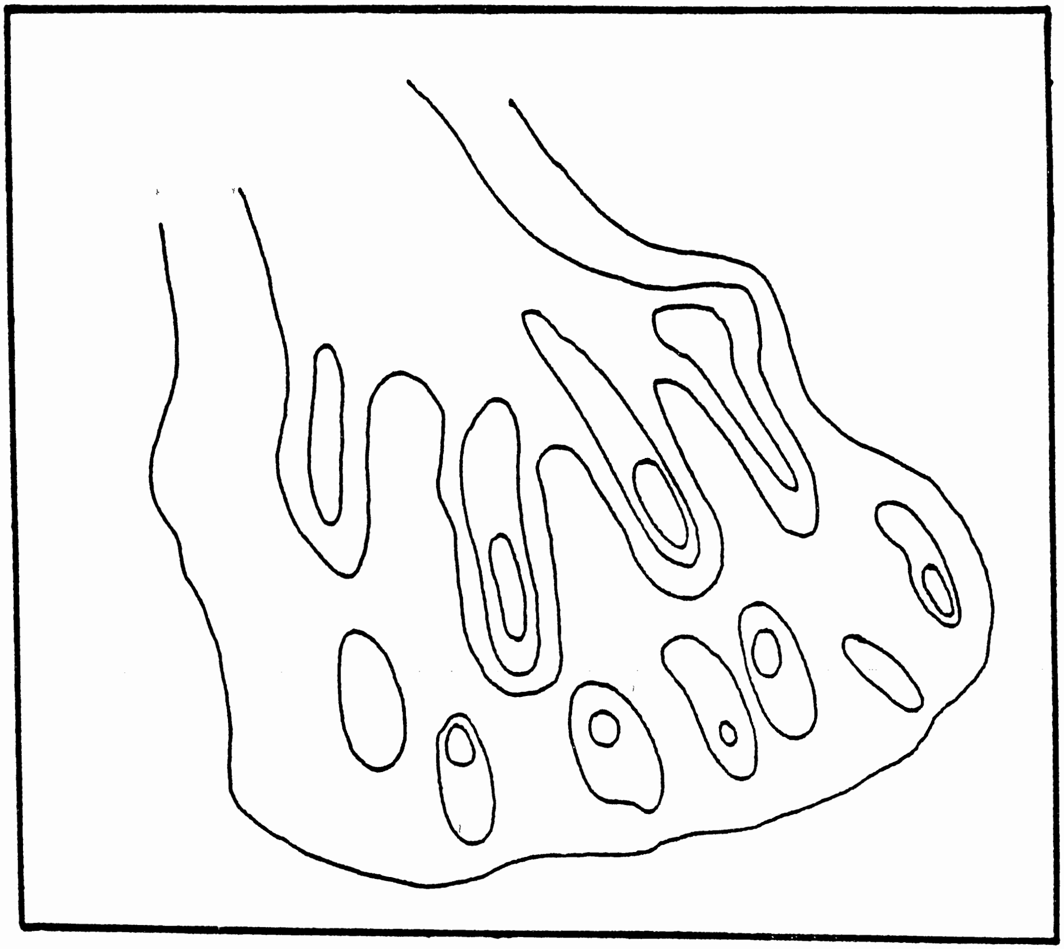

Figure 39. Net Sand Distribution Pattern
for a Tide-Dominated Delta
(from Coleman and Wright, 1975).

indicate the likely influence of marine processes. The distal bar sands are finer grained, well sorted, and are dominated by low-angle planar cross-bedding and ripple laminations. Distal bar sands are characterized by bioturbation and marine shell debris (Coleman and Gagliano, 1965). Progradation into the southeastern region of the basin shows an obvious thinning of deposits and electric log analysis indicates deposition of bar sands in a higher marine energy setting.

The "Millerella" Sandstone is a fine-grained, reworked sandstone that is deposited as a series of marine sandstone bodies which lack continuity with each other. Thickest deposits are in southeastern Monroe County. Only in localized regions in Pontotoc and western Itawamba counties do the sands directly rest on and tie-in with the Carter sandstone. In Alabama, the "Millerella" sandstone forms elongate belts that directly overlie the Carter 'A' Sandstone. Despite the continuous nature of the "Millerella" in Alabama and in localized areas in Mississippi, it appears to have been reworked from the Carter sandstones.

After deposition of the Carter 'A' Sandstone, a transgression followed, causing portions of the Carter to be reworked across the Northern Shelf in the Black Warrior Basin. This transgression is further evidenced by the overlying "Millirella" Limestone deposits. Admittedly only limited studies have been done regarding the "Millerella"

Sandstone, but it does appear to be reworked by marine processes. More studies need to done analyzing this problem.

Depositional Facies Elements Associated With High-Constructional Deltas

High-Constructional Elongate Deltas

Bar Finger Sands

High-constructive elongate deltas are characterized by linear, sandstone bodies oriented at a high-angle to the shoreline or depositional strike. Bar-finger sand units form an integral part of the overall progradational facies sequence. The sands are moderately well-sorted, fine-to medium grained, and dominated by trough cross-bedding. In elongate deltas, bar finger sands are generally underlain by thick prodelta muds. As progradation of the elongate delta lobe continues seaward over the thick muds, differences in the compatibility of the mud and sand allow for differential subsidence. When the sands are brought in and deposited, this causes the water-saturated (up to 80%) muds to be displaced both vertically and laterally. This subsidence of sand into the surrounding mud allows for storage of the progradational distributary channel and channel mouth bar units as bar finger sands. Rapid subsidence of the sands into the muds allows for little to no marine reworking, resulting in narrow, elongate sand deposition parallel to axis of the distributary channels. Although parallel to the channels, the bar finger sands themselves are actually up to eight times wider than the channel due to the lateral dispersion of the bar finger sands into the prodelta muds.

Bar finger sands generally experience soft-sediment deformation, if not complete destruction of the sedimentary structures in the lower regions of the deposits. This is due to the high amount of water contained within the sediments, along with the displacement of the muds, creating mud diapirs from muds injected into the sands. This also results in contorted bedding and the sand can fail along fault planes giving rise to growth faults. These types of sedimentary structures,and faulting are characteristic of high-constructive, elongate deltas.

Crevasse Splays

Crevasse splays develop initially as breaches in the adjacent levees during periods of flooding. Splays are generally active only during flooding, and in flood-prone river systems they may become very large and cover several square kilometers.

Crevasse splays, build by progradation as small distributary channels or braided streams or by aggradation as suspended load sediments, are deposited as flow spreads across the splay surface. These splay deposits commonly occur on the concave banks of meanders or in the distal portion of the delta, due to the lower levee as a fan-shaped deposit.

The infrastructure of a crevasse splay is characterized by its heterogeneity but does show some fining upward tendencies. The sands may display planar bedding or trough cross-bedding with interbedded clays and silts in the form of clay drapes and laminations. Ripples, climbing ripples, and scour and fill structures are common. Also, large amounts of plant debris and mud clasts, either deposited randomly or in large masses, can be found within crevasse splay deposits.

Due to the lengthy healing process of the breached levee, crevasse splays may be reactivated during multiple flood events or may only involve a single-event accumulation.

Prodelta Muds

Prodelta muds form one of the more homogeneous and laterally continuous units of deposition of the high-constructive elongate, delta systems. These sediments, consisting of very fine sands, silts and a dominance of clay, represent the first terrigenous components introduced into the receiving basin by the advancing delta. Very thin laminated muds are deposited by a process know as 'flocculation'. This process results from a fluvial fresh water system with a high suspended sediment load emptying into a salt water receiving basin.

The prodelta muds contain up to 80 percent water allowing for localized events such as slumping features, contorted bedding, and other soft sediment deformational features. Intraformational faulting and fractures are common with associated isolated lenses of sandy sediments, reflect periods of mud flow, and slumping of the prodelta slope (Galloway and Hobday, 1983).

High-Constructive Lobate Deltas

Distributary Channels

Distributary channels serve as the primary conduits for the discharge of the sediments carried by the river into the receiving basin. Found in the delta plain region, they share many common characteristics with other types of fluvial channels. Stream discharge and sediment load are variable due to seasonal flooding. Channel patterns tend to straighten out showing low sinuosity, except on the upper delta plain where the stream may meander with deposition of point bar sands. These streams are flanked by well developed levee deposits which are best developed on the upper delta plain and decrease in height, width, and grain size downstream.

Channels are generally filled with the coarsest sediments brought downstream by the river. Dominated by trough cross-bedding and ripple laminations, the channels have many features which are indicative of the soft sediment deformation. Such features include dewatering and differential compaction, both of which usually destroy the primary cross-bedding, and mud diapirs. These features are generally seen in elongate deltas, as the sands are deposited on thick prodelta muds. With lobate deltas, channel sands are deposited in a shallow water environment and the prodelta muds are much thinner. As a result these sands have fewer deformation features at the distal ends of the delta and are predominantly horizontal bedded due to the reworking of the channel-mouth bar sands by marine processes. Trough cross-bedding is rare with some ripple laminations present.

Distributary channel fills constitute the sandy framework of the delta-plain facies and are laterally equivalent to levee, crevasse splay marsh, swamp and lake deposits of the delta plain.

Channel-Mouth Bar Sheet Sandstone

The distributary channel-mouth bar is generally the locus of sand deposition and storage in the fluvial-dominated delta system. The seaward face and crest of the bar experience winnowing and reworking of the sands. If this occurs in a shallow water environment, as with lobate deltas, these sands are reworked and redistributed along strike. The redistribution of sands creates an environment of strandplain and delta-front sheet-sands. These sands are clean, well sorted, and generally deposited low-angle planar laminations.

Reworking of the channel-mouth bars connects the many distributary-channels, giving the delta the overall lobate shape. Reworking and redistribution of the sands are totally dependent on the level of energy of the marine process. These sheet sands show a typical coarsening-upward texture, but tend to fine away from the distributary mouth bar.

Because the sands are so well sorted and clean they are considered ideal reservoirs for hydrocarbons. They are also deposited directly on top of excellent source rock.

CHAPTER VII

PETROGRAPHY AND DIAGENISIS
OF THE
BATESVILLE AND CARTER SANDSTONES

Introduction

Three exposed sections in Independence and Stone Counties in Arkansas and six cores from various wells in Lowndes and Monroe Counties in Mississippi, were used in this study (Figure 40). Outcrop 'A', 'E', and 'G' were used to analyze the Batesville Sandstone. Outcrop 'A' is located at C, SE, SW, NW, Section 27, Township 13N, Range 6W, Independence County, Arkansas. The total measured thickness of the exposed Section is 67.5 feet with 18 feet of covered interval. Outcrop 'E' is located in the NW corner, NW, NW, Section 16, Township 13N, Range 6W, Independence County, Arkansas. The measured thickness of this exposure is only 24.5 feet, as the upper one-third is covered interval. Outcrop 'G' is located in the C, SW, SW, SE, Section 34, Township 15N, Range 12W, Stone County, Arkansas approximately five miles west of the junction of highways 66 and 87. This section was chosen, because no other outcrop in Independence County was the base of the Batesville exposed. This Section has a measured thickness of 23 feet with the upper portion being covered. The three measured sections described in this study were logged on a scale of 1" equals 10' (Figures 41, 42, 43, and 44). Samples were taken from these three sections for thin sections, clay extractions, and x-ray diffraction.

The #1 Leech core, drilled by Pruet & Hughes and Pelto Oil Co., and the #1 Armstrong core drilled by Pruet & Hughes were used to analyze the Carter 'A' Sandstone. The #1 Leech core is in Four Mile Creek Field, Section 18, Township 12S, Range 18W, Monroe County, Mississippi. Total depth reached was 2386 feet and the well was completed the week of April 27, 1973. Gas production was established in the Carter 'A' horizon and cumulative production up to 1-1-90 is 2.1 MCF. The #1 Armstrong is also in Four Mile Creek Field, Section 17, Township 12S, Range 18W, Monroe County, Mississippi. Total depth reached was 3319 and it was completed the week of January 3, 1973. Gas production was established in both the Carter 'A' and 'B' horizons with cumulative production up to 1-1-90 at 1.4 MCF.

The #1 J. T. Evans core drilled by Par Exploration, the #1 W. R. Thomas, drilled by Par Exploration, the #1 Malone core drilled by Michigan Oil Co, and the #1 Armstrong core drilled Pruet & Hughes were used to analyze the Carter 'B' Sandstone. The #1 J. T. Evans is a wildcat in Section 5, Township 15S, Range 6E, Monroe County, Mississippi. Total depth reached was 4695 and was completed the week of January 17, 1978. Production was not established in this well. The

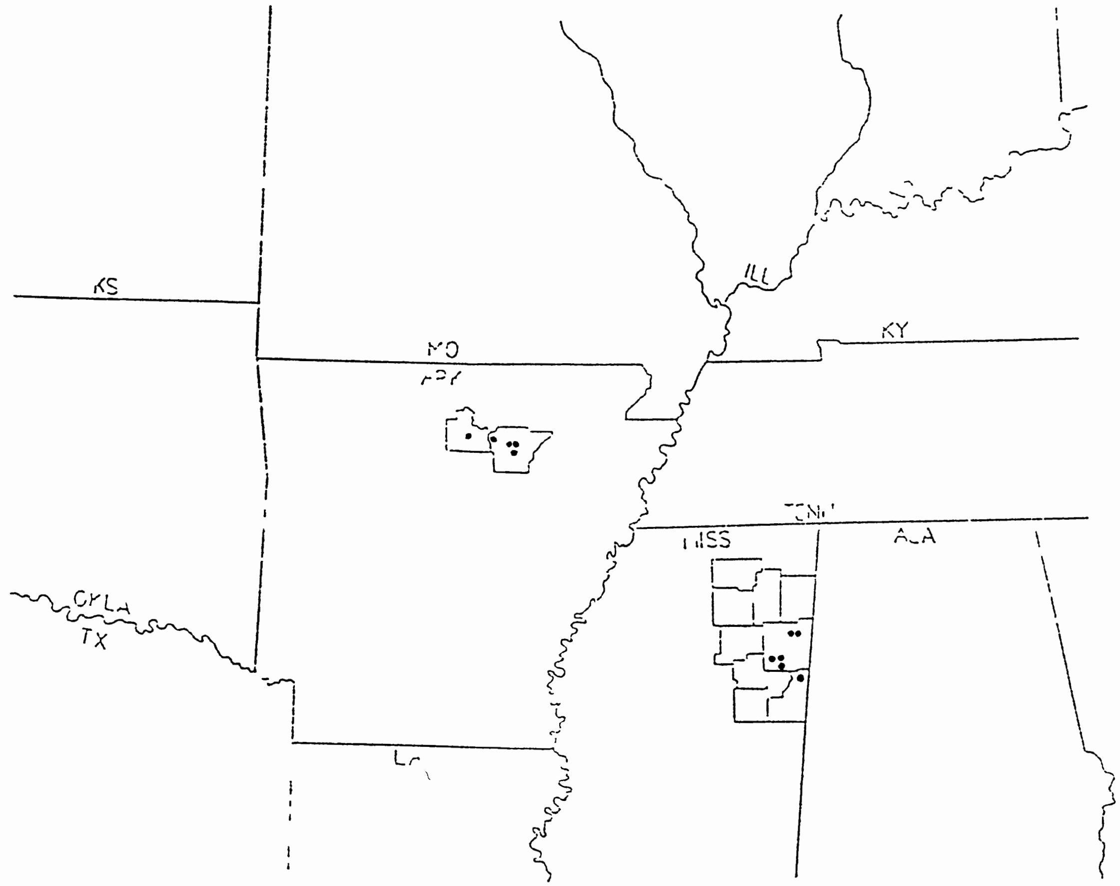

Figure 40. Locations of Cores (Mississippi) and Outcrops (Arkansas) Used in the Study.

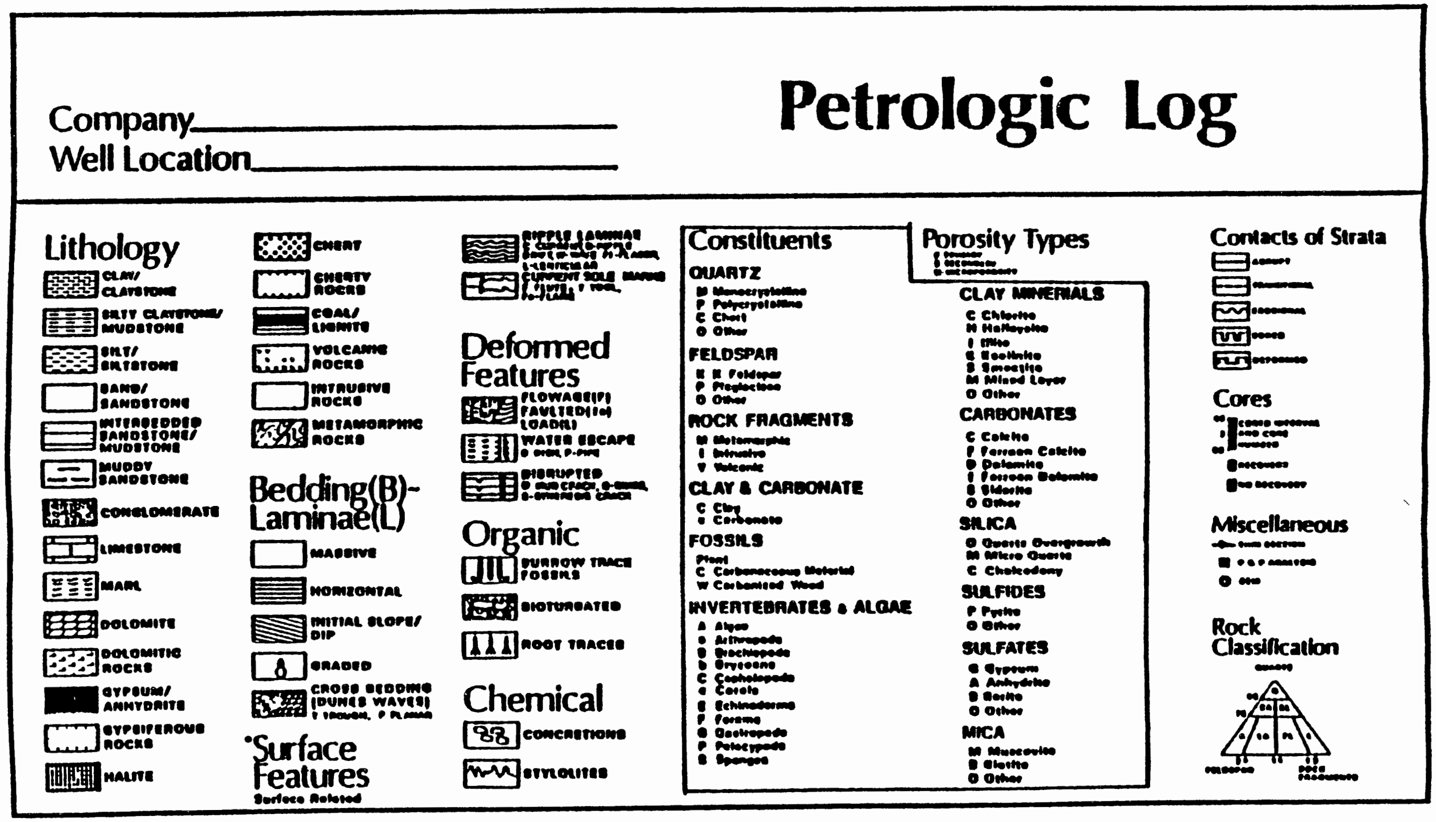

Figure 41. Table of Symbols for Petrologic Logs.

#1 W. R. Thomas is a wildcat in Section 5, Township 15S, Range 7E, Monroe county, Mississippi. The total depth reached was 4804 feet and the well was completed in the week of March 9, 1974. The #1 Malone is a Kolola Springs Field, Section 25, Township 16S, Range 18W, Lowndes county, Mississippi. The total depth reached was 5645 feet and this well was completed the week of October 5, 1986. The #1 Malone is a new field discovery well and production was established in the Lewis horizon with an initial production rate of 13 BO per day. The #1 Armstrong was discussed previously.

The #1 Nason core, drilled by Pan Am Petroleum Co., was used to analyze the "Millerella" Sandstone. The #1 Nason is a wildcat in Section 5, Township 15S, Range 7E, Monroe county, Mississippi. The total depth reached was 4600 feet. The well was completed the week of August 1, 1964. No production was established.

The six cores described in this study were logged on a scale of 1" = 10' (Figures 41, 57, 58, 59, 60, 61, and 62). Samples were taken from five of those core for thin sections, clay extractions, and x-ray diffraction analysis.

Outcrop Description of the Batesville Sandstone

Outcrop 'A"

The outcrop 'A' is located at the C, SW/4, SW/4, NW/4, sec.27-t13n-r6w Independence County, Arkansas. It involves a total measured thickness of 67.5 feet. The section of rock examined is composed of a fine- to medium-grained sandstone. The rock is well-sorted except at the base of channel sequences which contains a mix of coarse- to fine-grained sand with channel lag. The sand grains are predominantly subangular to subrounded. The outcrop is a weathered buff color. A fresh sample is tan with zones of red staining from the presence of hematite. The portion of outcrop from 45 to 63 feet, was covered interval. There are at least four intervals expressing a fining-upward sequence ranging from at 3 to 15 feet, 15 to 30 feet, 30 to 39 feet, and 39 to 45 feet from the base of the outcrop. The top of the measured Section is an imcomplete fining-upward sequence (Figure 42). The base of each trend begins with channel scour and a lag of granule-pebble size which grades upward to a fine-to-medium-grained sandstone. These trends suggest a system of multi-storied distributary channels grading from one channel sequence to the next. For the most part, porosity values tend to reflect the grain size trends as the higher porosity values are generally at the base of each channel but decrease upwards as the grain size values become smaller. Cementation appears to have little influence on the amount of porosity observed in thin Section analysis.

Neither the lower nor upper contacts of the Batesville Sandstone were exposed for examination in the outcrop. Sedimentary structures in the Batesville include small-scale trough cross-bedding, horizontal bedding, small ripples and

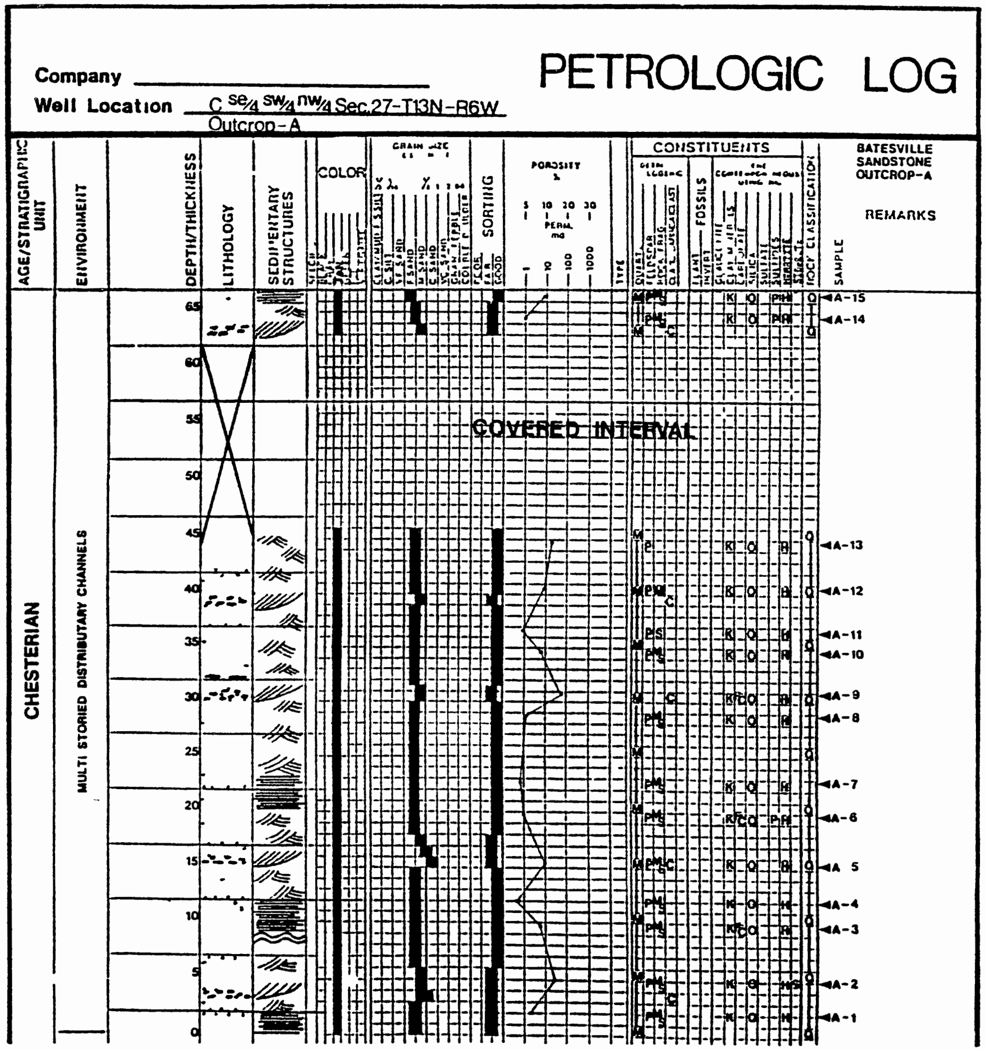

Figure 42. Petrologic Log for the Batesville Sandstone in Outcrop `A'.

planar bedding.

Outcrop 'E'

Outcrop 'E' is located at the NW/cor, NW/4, NW/4, Sec 16-T13N-R6W. It involves a total measured thickness of 24.5 feet of continuous Section. This outcrop is made up of many beds which range in thickness from 7 inches to three and one-half feet thick. These beds are composed of a quartzose sandstone. Grain sizes range from very fine- to medium-grain sand. The weathered rock is a buff color and fresh samples are tan with red zones from hematite staining. Thin shales, ranging from a few inches to one foot in thickness, are observed throughout the interval. Siltstones are present containing coarse silt and minor amounts of very fine sand. Although the grain sizes appear erratic, two trends can be seen. In the lower one-half a coarsening-upward trend is observed from 0 to 7.5 feet and in the upper one-half fining-upward trends are seen from 13 to 19 feet and 19 to 22 feet (Figure 43). The grain sorting is generally good throughout with small intervals of fair to good sorting. The trends observed indicate marine reworked delta front sheet sands overlain by regressive distributary channel sands. It is difficult to assess the influences on the amounts of porosity but is appears that the higher the porosity, the finer the grain texture is. Diagenetic processes appear to have had some effect on the nature of this porosity distribution.

The sedimentary structures include small-scale trough

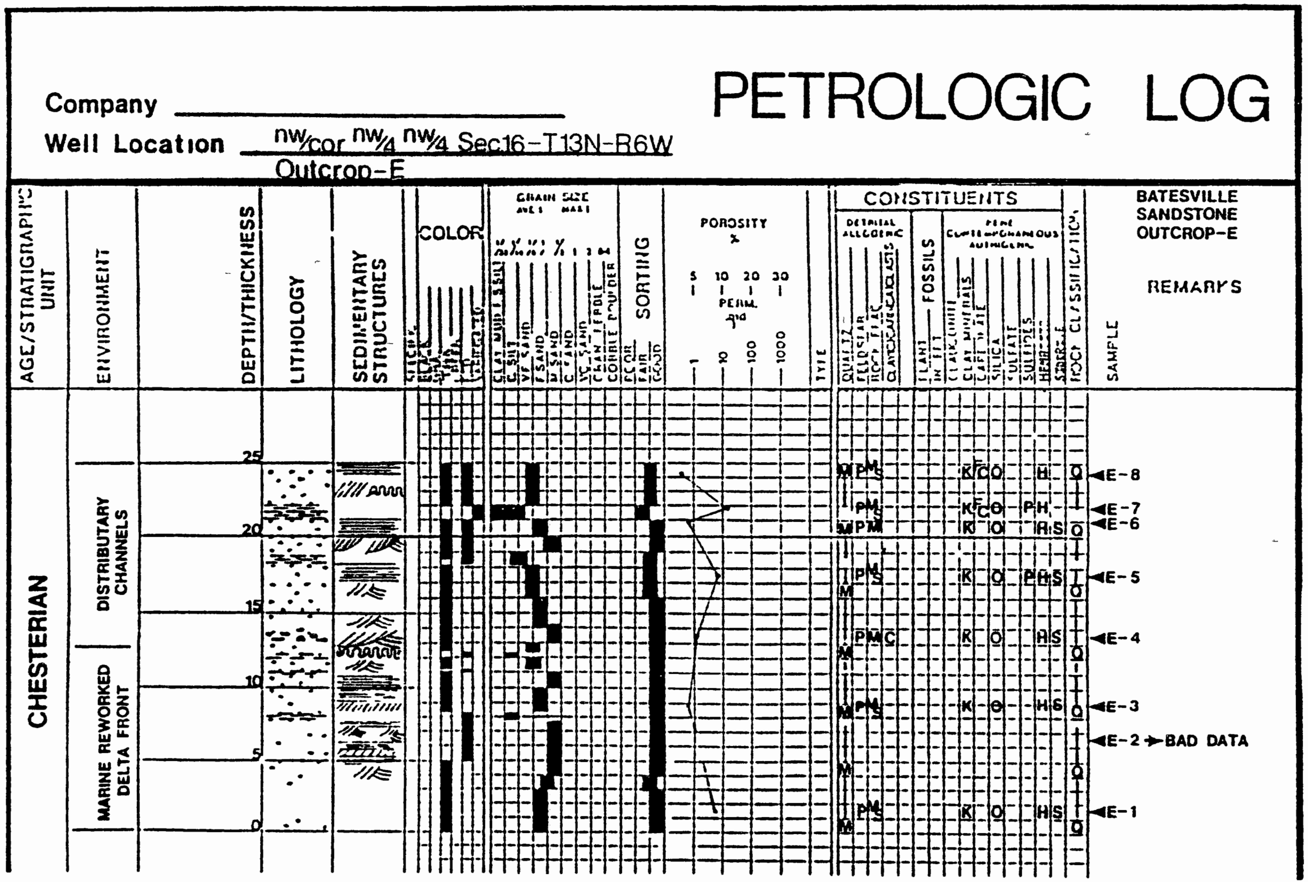

Figure 43. Petrologic Log for the Batesville Sandstone in Outcrop `E'.

cross-bedding, horizontal bedding, and soft sediment flowage features. Neither the lower nor upper contacts of the Batesville Sandstone were exposed in outcrop.

Outcrop 'G'

Outcrop 'G' is located in the C, SW/4, SW/4, SE/4, Sec. 34-T15N-R12W in Stone County, Arkansas. It involves a total measured thickness of 23 feet of continuous section. The outcrop is made up of limestones and sandstones. The sandstone beds Range from one and one-half to four feet thick. They are composed of subangular to well-rounded grains. Unweathered samples are tan with red staining from hematite. Sorting is eratic and ranges from poor to good. One distinct coarsening-upward trend was observed from 7.5 to 19.5 feet (Figure 44). At the base of this trend are two separate limestone beds. One limestone bed is six inches and the lower bed is three and one-half feet thick. They are packed with fossil fragments and show some minor trough cross-bedding. These features, including lithologic and grain size trends, indicate marine influence and suggest a marine reworked delta front environment. From eleven and one-half to 19 and one-half feet, shaly sand and siltstone exists with some small planer cross-bedding. The porosity values are erratic and the diagenetic processes which have acted on the rock cannot be discounted as an influence on the porosity.

The sedimentary structures observed in this section are

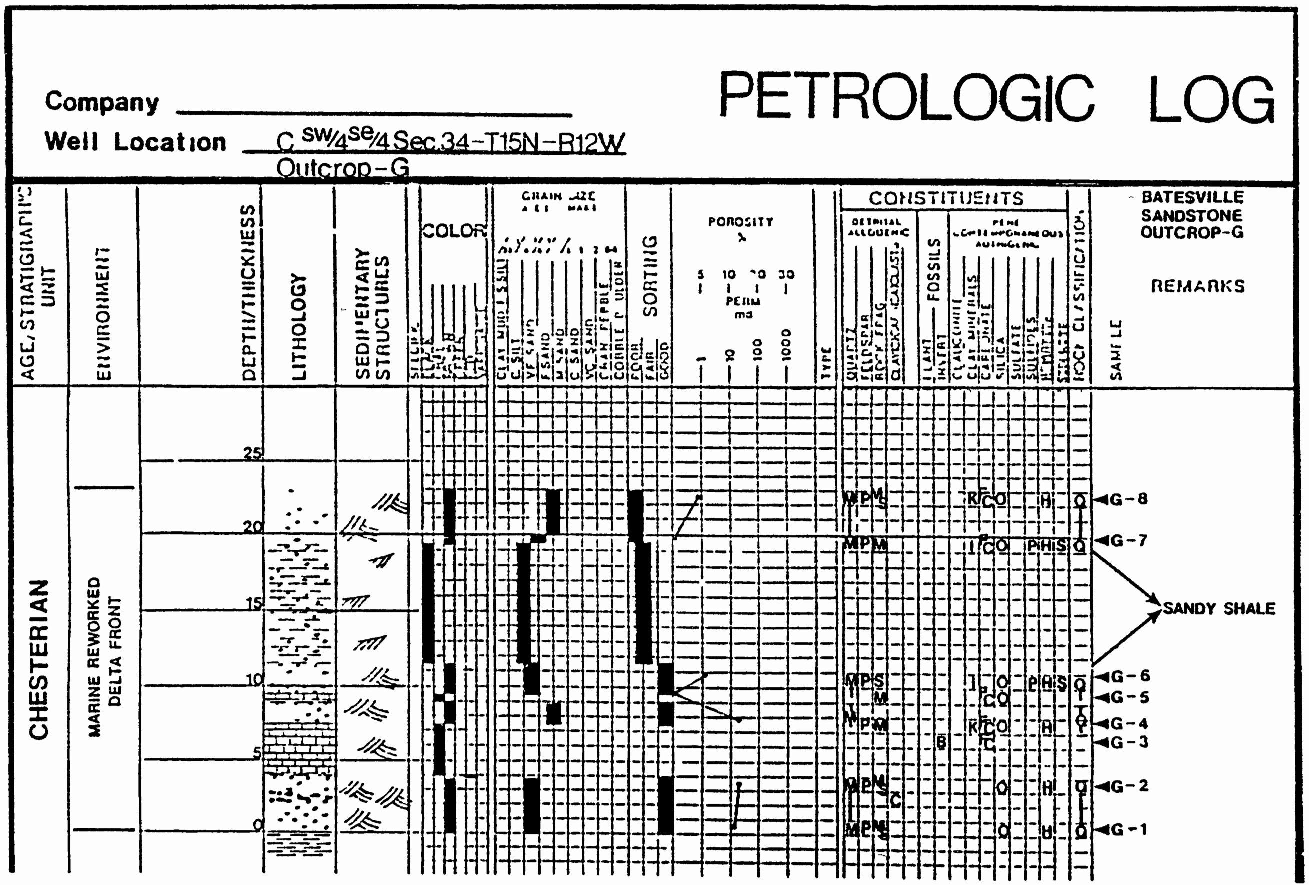

Figure 44. Petrologic Log for the Batesville Sandstone in Outcrop `G'.

predominantly small-scale trough cross-bedding with some planar bedding.

This outcrop was chosen for the study because it has an exposed basal contact with the Moorefield Shale. No other sections available contained this contact. The contact is an abrupt change from a black, fissile shale to a very fine-grained sandstone.

Composition and Classification of the Batesville Sandstone

Plotted on a Q-R-F diagram without regard for metastable constituents now dissolved or replaced, the average composition of the Batesville Sandstone from the studied intervals of Outcrops 'A', 'E', and 'G' plot within the quartzarenite subdivision of the triangle (Figures 45, 46, and 47). Only three of the 31 thin sections examined in the studied intervals of outcrops plot outside the quartzarenite subdivision in the triangles.

Detrital Constituents

Figure 48 shows the relative abundance of allogenic constituents found to approximate the average of Outcrop 'A'. Monocrystalline quartz grains, ranging from coarse to fine sand size, account for an average of 77.5 percent of the bulk volume (Figure 49) with polycrystalline quartz averaging only 1.3 percent of the total volume. Plagioclase feldspar grains account for 1.3 percent of the total.

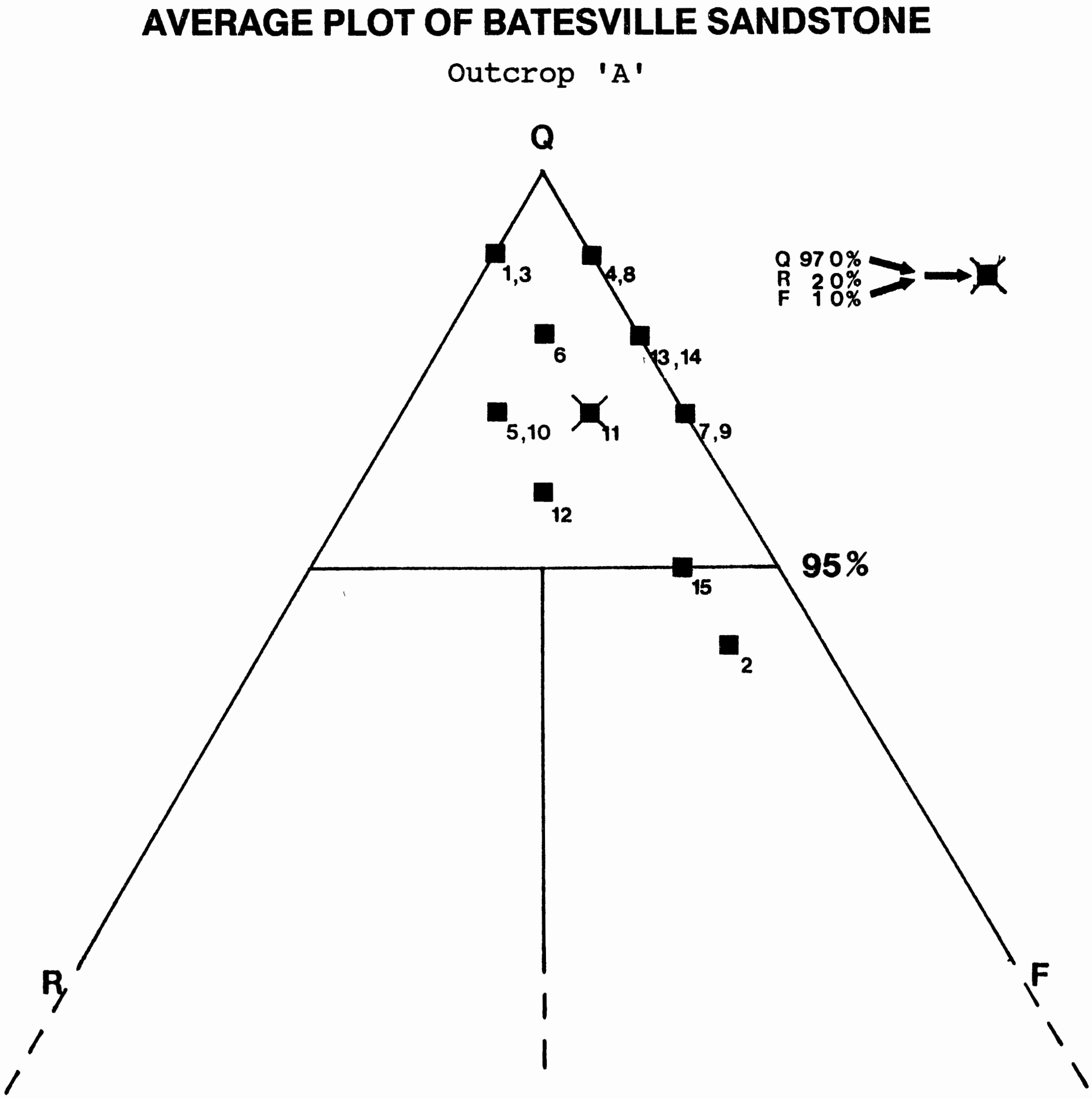

Figure 45. Q-R-F plot of Batesville Sandstone without Regard for Partially Dissolved Metastable Constituents.

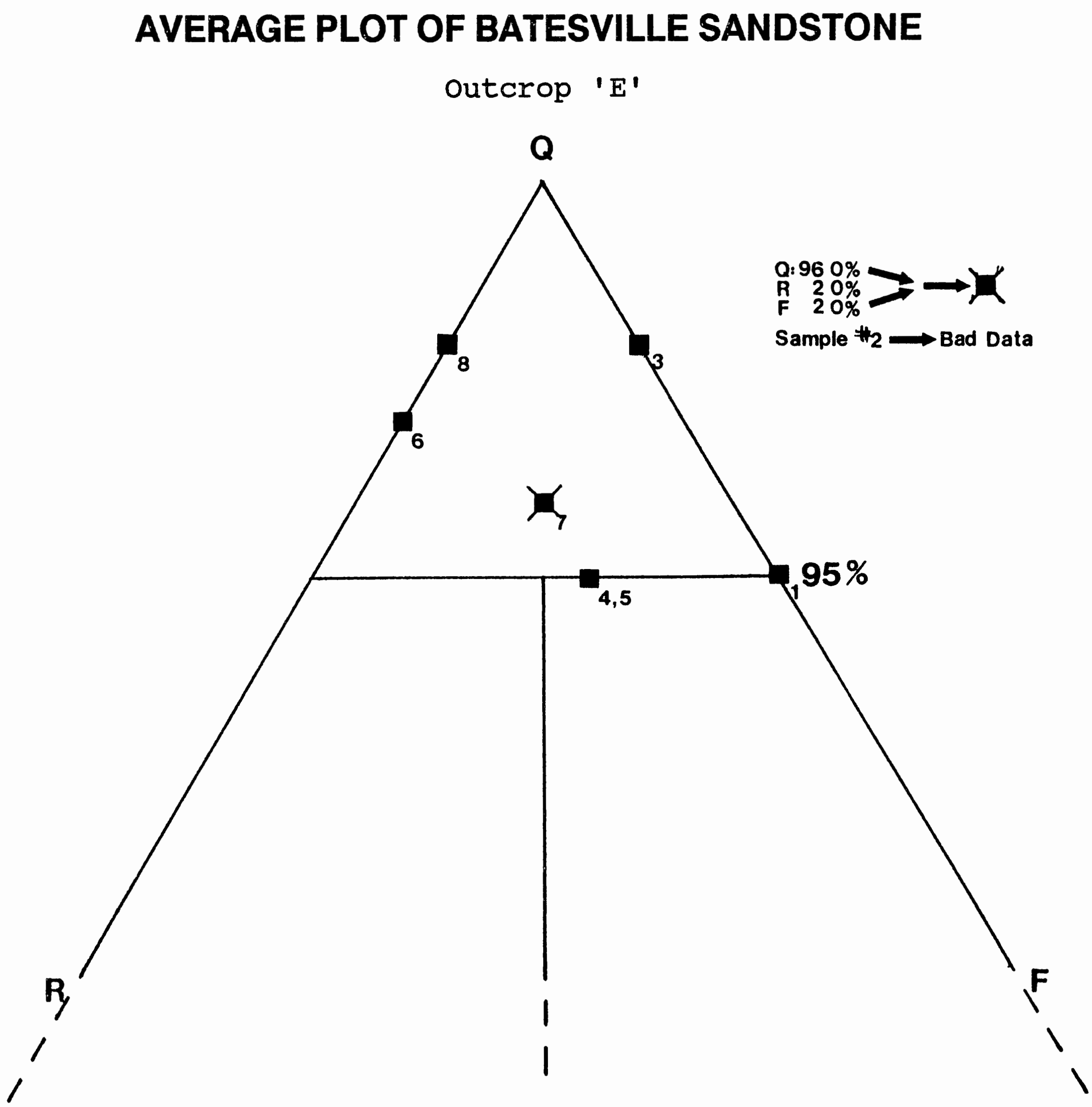

Figure 46. Q-R-F Plot of Batesville Sandstone without Regard for Partially Dissolved Metastable Constituents.

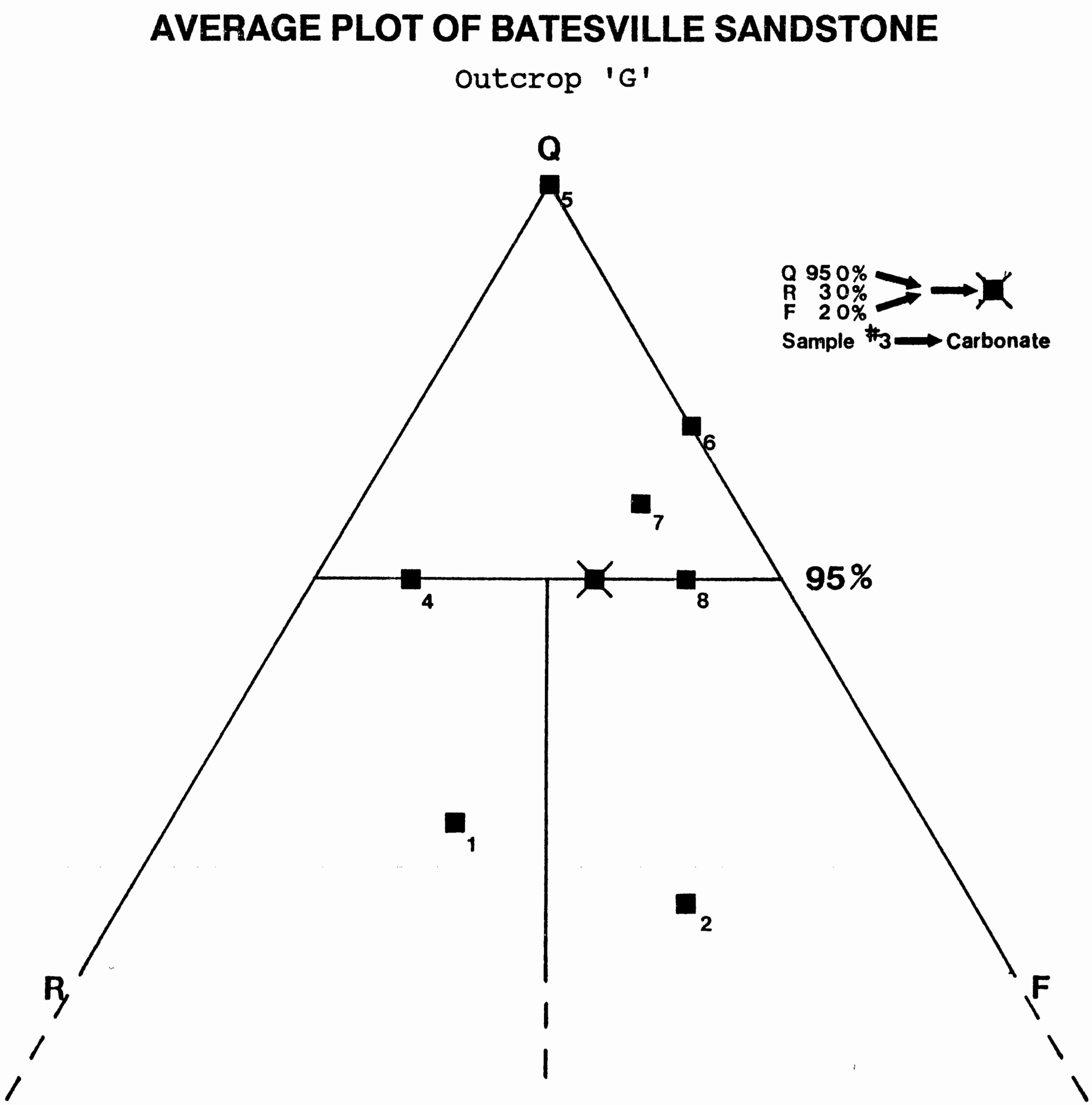

Figure 47. Q-R-F Plot of Batesville Sandstone without Regard for Partially Dissolved Metastable Constituents.

Identification of these metastable grains proved to be difficult in some cases, yet albite was observed to be the dominant feldspar (Figure 50). Shale clasts are represented in trace amounts in all but two of the studied intervals. Chert accounts for only 0.7 percent of the total and are observed throughout the studied interval; they range from a trace to 2.3 percent. The accessory minerals are rarely found to be represented by more than trace amounts. The only exception is zircon which ranges from a trace up to 0.8 percent. These accessory minerals include chlorite, zircon, tourmaline, and rutile.

Figure 51 shows the relative abundances of allogenic constituents. These approximate the averages in Outcrop 'E'. Monocrystalline quartz averages 81.2 percent of the bulk volume with polycrystalline quartz contributing only 1.6 percent of the total. Concentration of feldspars averages 1.7 percent of the total, ranging from a trace to 3.8 percent. Shale rock fragments (trace), chert (1.2 percent), and low-grade metamorphics (0.1 percent) are normally found in trace quantities, except chert which ranges from 0.3 to 2.0 percent. The accessory minerals include muscovite, tourmaline, zircon, and rutile. Abundances of any one of these range from a trace to 0.5 percent, but total 0.2 percent of the studied interval.

Figure 52 shows the relative abundances of the allogenic constituents. This approximates the average in Outcrop 'G'. The dominating detrital grain type is

OUTCROP 'A'

BATESVILLE SANDSTONE

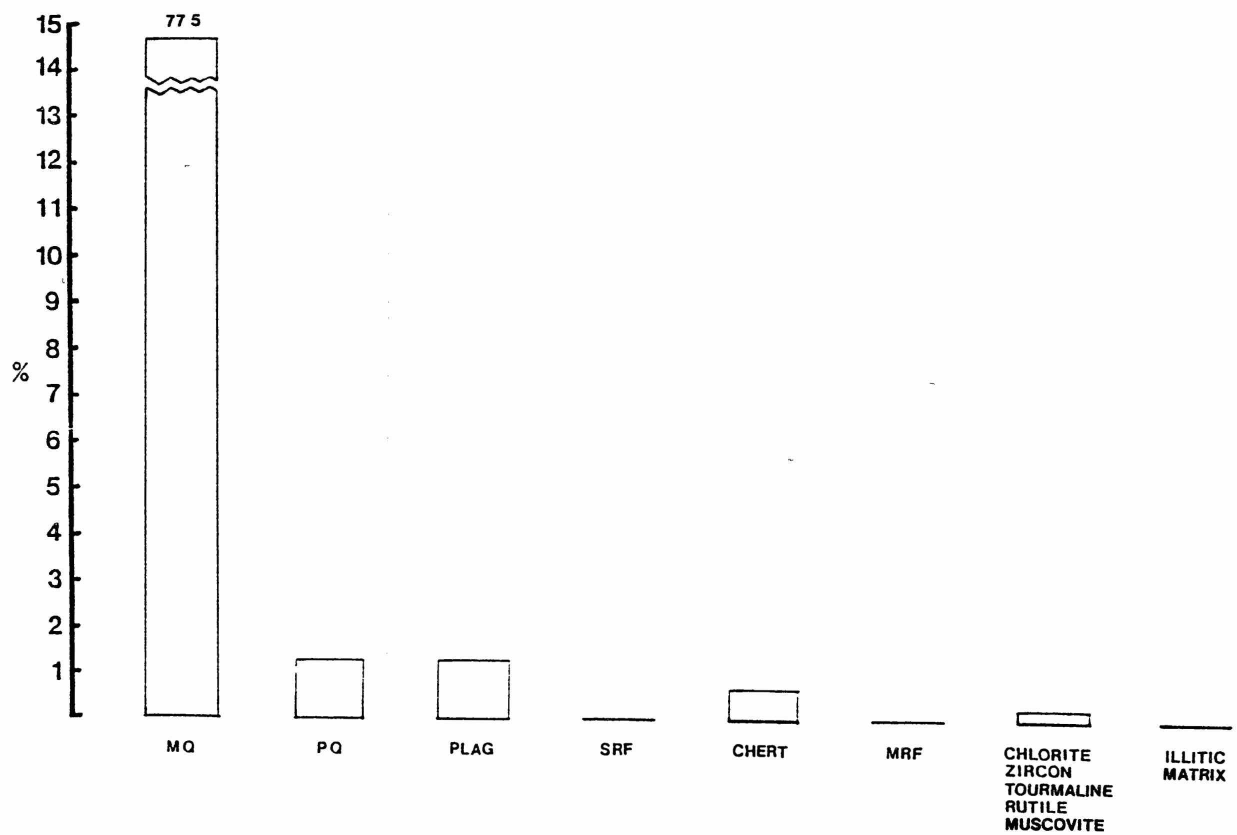

Figure 48. Allogenic Composition of the Batesville Sandstone in Outcrop `A' from Thin Section Analysis.

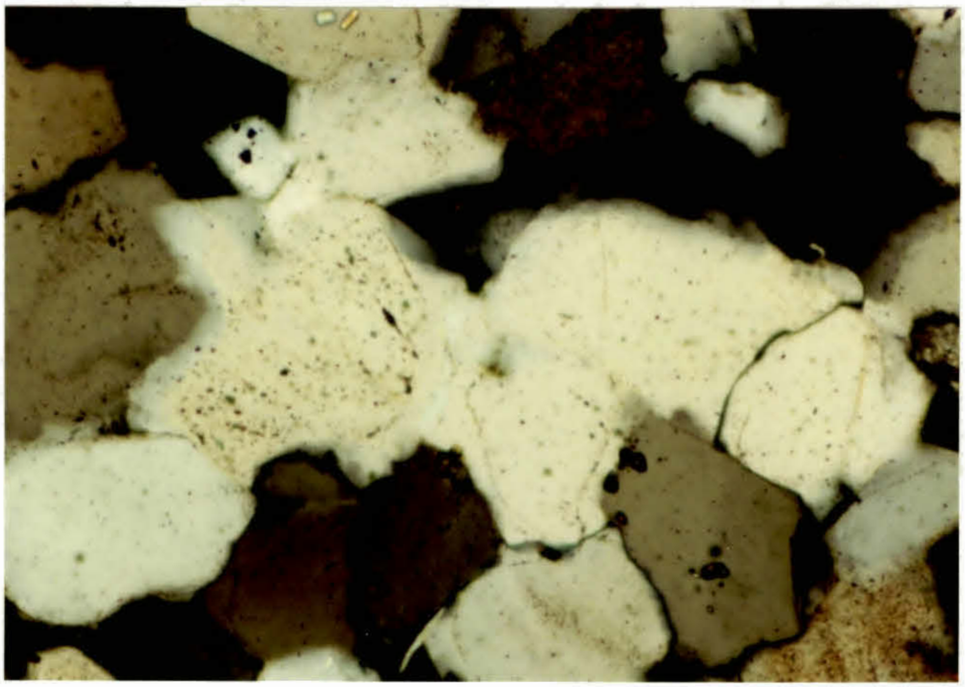

Figure 49. Photomicrograph of Monocrystalline Quartz Grains with Syntaxial Quartz Overgrowths and Chemical Compaction at Grain Boundaries (100x, Crossed Nichols Light, 12 feet Above Base of Outcrop `A').

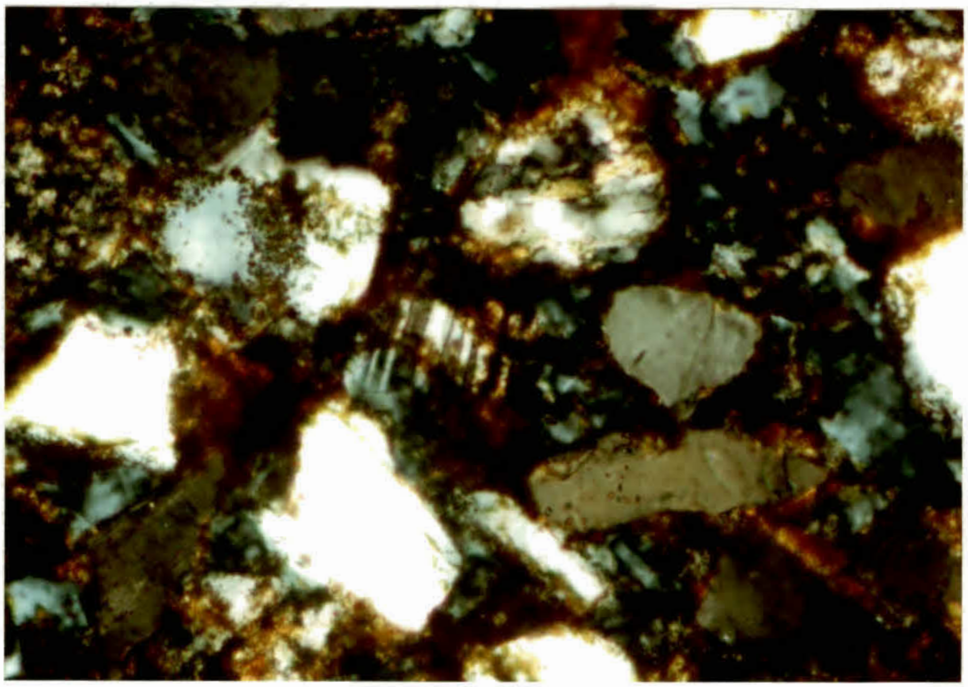

Figure 50. Photomicrograph of an Albite Grain in the Batesville Sandstone (200x, Crossed Nichols Light, 1 foot above Base of Outcrop `G').

OUTCROP 'E'

BATESVILLE SANDSTONE

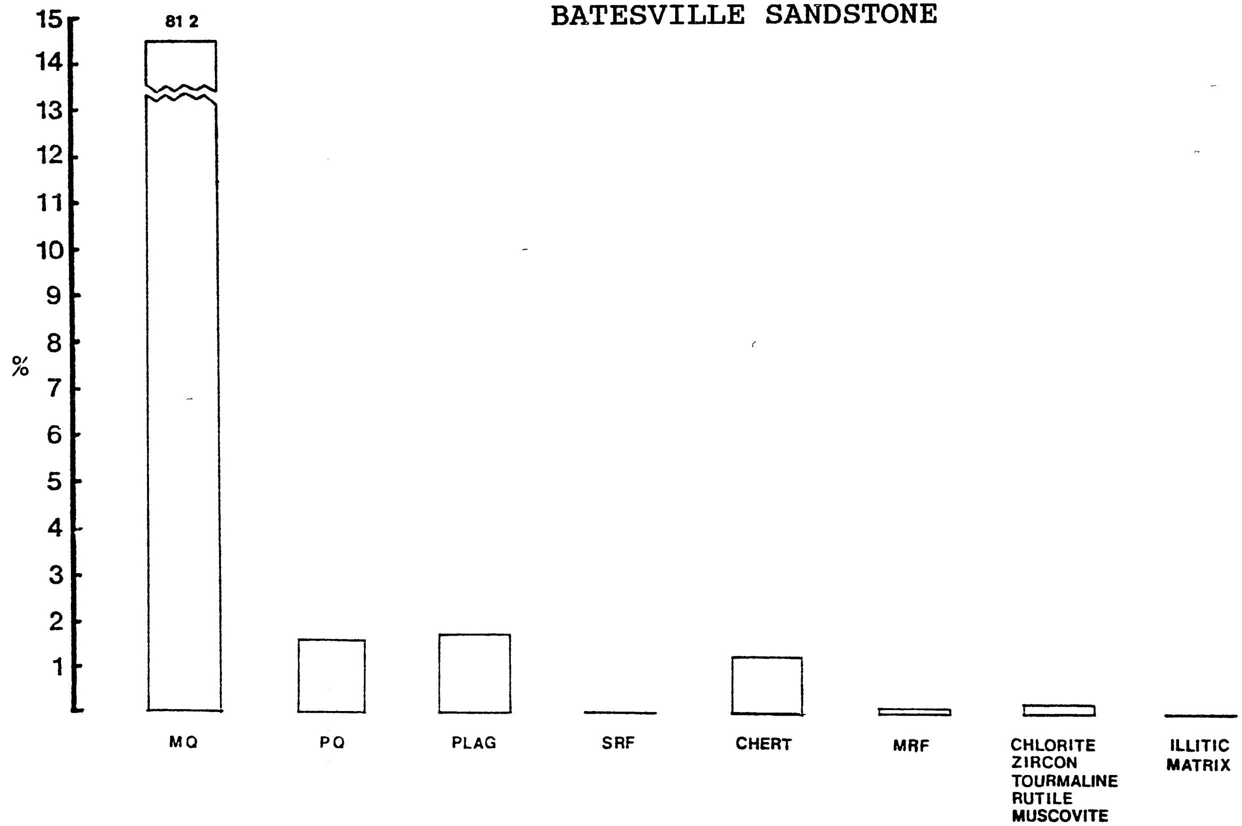

Figure 51. Allogenic Composition of the Batesville Sandstone in Outcrop `E' from Thin-Section Analysis.

monocrystalline quartz which averages 60.4 percent in the studied interval. Polycrystalline quartz averages 1.9 percent and ranges from a trace to 4.5 percent of the total. Feldspar was observed in all the thin sections, except in the middle of the studied interval, and ranges from a trace to 3.3 percent. It averages 1.8 percent of the total volume. Shale rock fragments occur in one-half of the thin sections, averaging 0.3 percent of the total. They never exceed more than 1.0 percent in any slide. Chert is generally seen only in trace quantities in the studied interval, but is as high as 3.3 percent. Metamorphic rock fragments are present in all but two of the studied intervals. Their abundance ranges from a trace to 1.5 percent and averages 0.4 percent of the total rock interval (Figure 53). Accessory minerals include chlorite (trace), muscovite (0.1 percent), tourmaline (trace), zircon (trace), and rutile (trace).

Fossil Constituents

Two zones of limestone exist within Outcrop 'G' at 6.5 and 9.5 feet above the base. Although both intervals contain fossil fragments the upper zone (9.5 feet) is predominantly quartz grains (63.5 percent). The lower zone is a 3.5 foot thick packed biosparite.

Both zones are dominated by echinoid and bryozoan fragments (Figure 54). Fossil debris observed in the lower zone includes: brachiopods (1.8 percent), crinoids (trace), pelecypod (1.0 percent) and mollusk (bivalve) (3.3 percent),

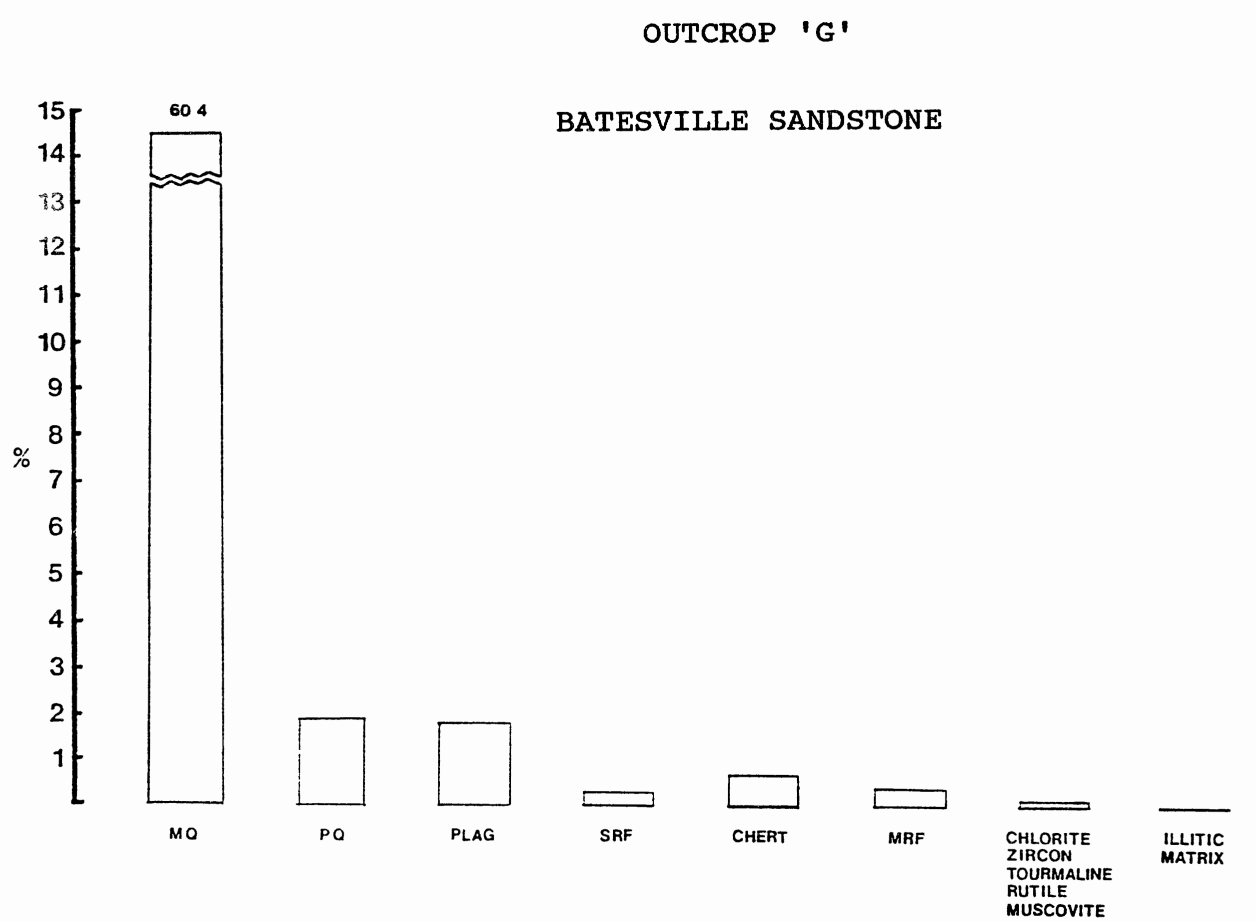

Figure 52. Allogenic Composition of the Batesville Sandstone in Outcrop `G' from Thin-Section Analysis.

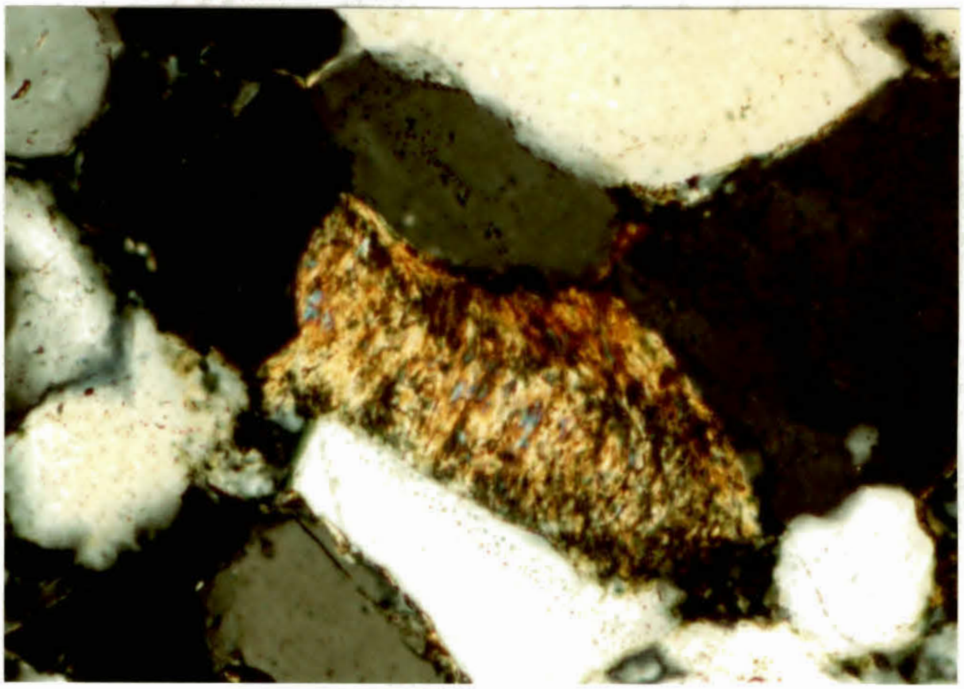

Figure 53. Photomicrograph of a Low-Grade Metamorphic Rock Fragment Surrounded by Monocrystalline Quartz Grains (200x, Crossed Nichols Light, 12 feet above Base of Outcrop `A').

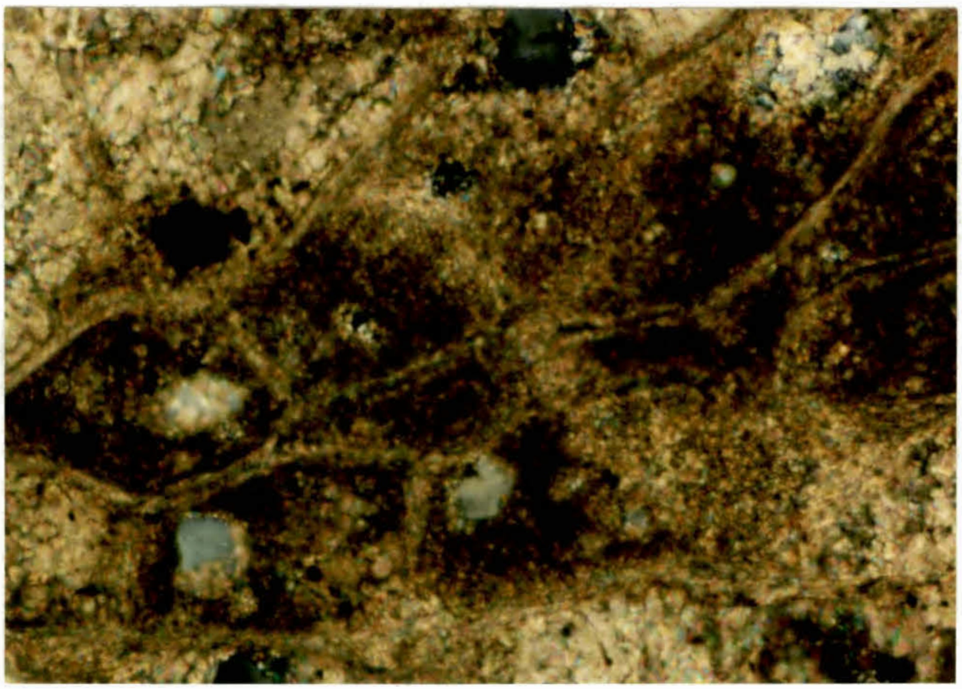

Figure 54. Photomicrograph of a Bryozoan Fragment Cemented by Calcite (200x, Crossed Nichols Light, 6.5 Feet above Base of Outcrop `G').

fragments. Other allochemical constituents are ooids (1.5 percent), peloids (trace), and intraclasts (3.3 percent). The allochemical constituents found in the upper zone mirror that described in the lower zone, as the average percentages are approximately the same.

Diagenetic Constituents

The diagenetic constituents and their average percentages as found within Outcrop 'A' include: quartz overgrowths (3.9 percent), ferroan calcite cement (trace), siderite cement (trace), pyrite cement (0.1 percent), hematite cement (4.5 percent), and kaolinite (2.5 percent) (Figure 55). Quartz overgrowths occur throughout the studied interval ranging from 2.5 to 5.3 percent of the total. Ferroan calcite and siderite cements exist in trace quantities. Those are observed in only a few of the thin sections ranging from a trace to 0.5 percent of the total. Hematite is the predominant cement and is found in all of the studied interval ranging 0.8 to 16.8 percent of the total volume. Kaolinite is the only authigenic clay found in this section. Observed as a pore filling clay, kaolinite ranges from a trace to 5.3 percent of the total.

The diagenetic constituents observed in Outcrop 'E' show a distinct similarity to those found in Outcrop 'A'. The constituents and their average percentage include: quartz-overgrowths (3.4 percent), ferroan calcite cement (trace), siderite cement (1.0 percent), pyrite cement

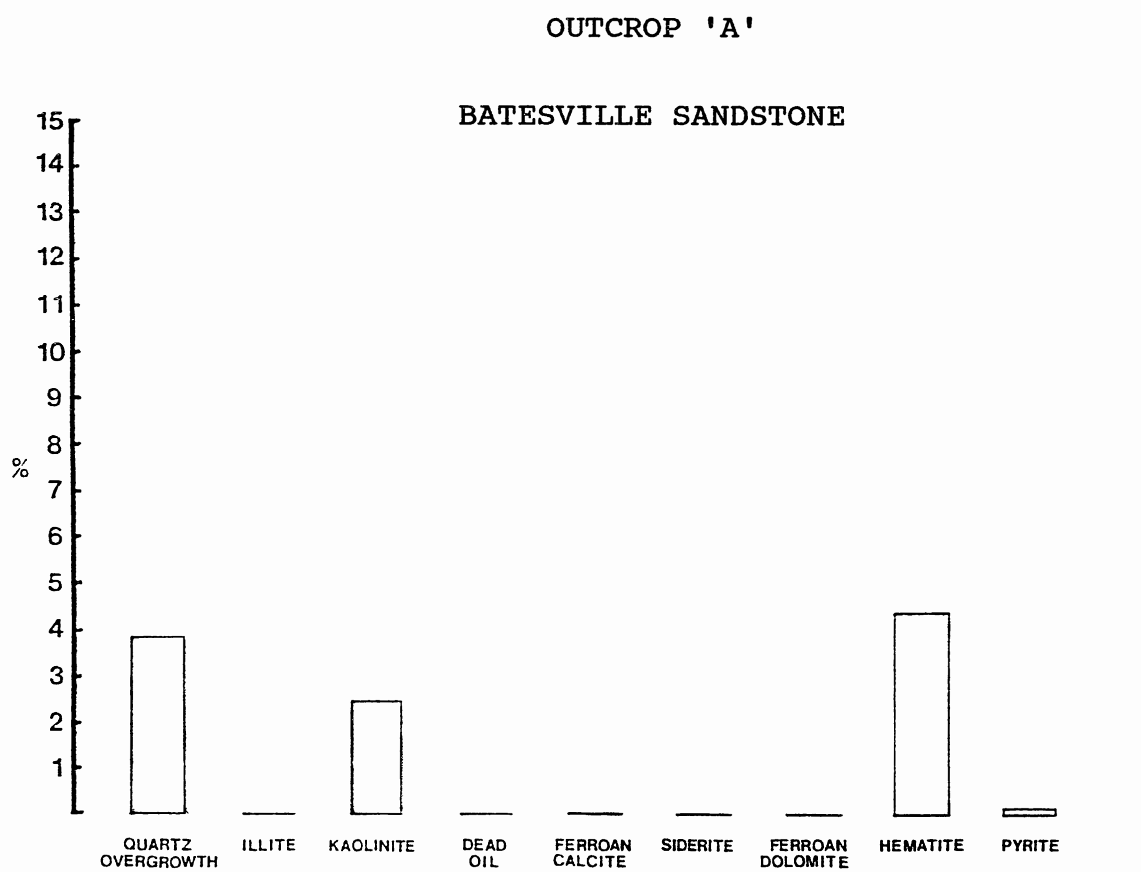

Figure 55. Diagenetic Compositions of the Batesville Sandstone in Outcrop `A' from Thin-Section Analysis.

(trace), hematite cement (1.3 percent), and kaolinite (2.1 percent), (Figure 56). Pore-filling kaolinite is the only authigenic clay observed. It ranges from a trace to 3.8 percent of the bulk volume. The cementing agents are the same as in Outcrop 'A' only observed in smaller amounts. Quartz-overgrowths range from 2.5 to 4.5 percent of the total and are present throughout the interval. Ferroan calcite cement is found only in two thin sections ranging from a trace to 0.3 percent of the total volume. Pyrite cement, like ferroan calcite, is found in only two intervals and varies from a trace to 0.3 percent of the total volume. Siderite cement exists in all but the two lowest thin sections, ranging from 0.3 to 2.5 percent of the total. Found in all of the studied interval, hematite cement ranges from 0.3 to 3.0 percent of the total bulk composition.

The diagenetic constituents and their average percentages as found within Outcrop 'G' are: quartz-overgrowths (2.5 percent), ferroan calcite cement (8.4 percent), siderite cement (1.1 percent), hematite cement (18.7 percent), illite (1.5 percent), and kaolinite (0.1 percent) (Figure 57). Quartz-overgrowths occur in all thin sections except those from the carbonate rock. The average percentage ranges from 0.3 to 5.8 percent. The ferroan calcite was observed in five of the eight studied intervals ranging from a trace to 46.8 percent of the total bulk volume. The highest percentages of calcite were obviously in the two zones of limestone (refer to Figures 44

OUTCROP 'E'

BATESVILLE SANDSTONE

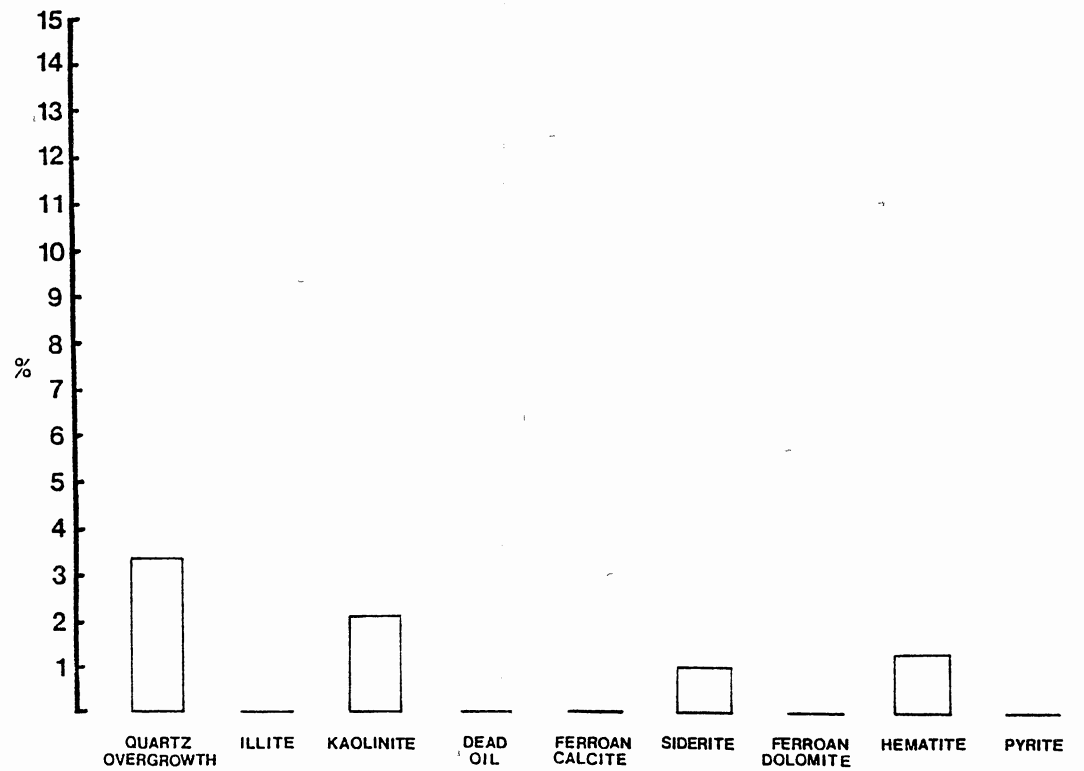

Figure 56. Diagenetic Compositions of the Batesville Sandstone in Outcrop `E' from Thin-Section Analysis.

OUTCROP 'G'

BATESVILLE SANDSTONE

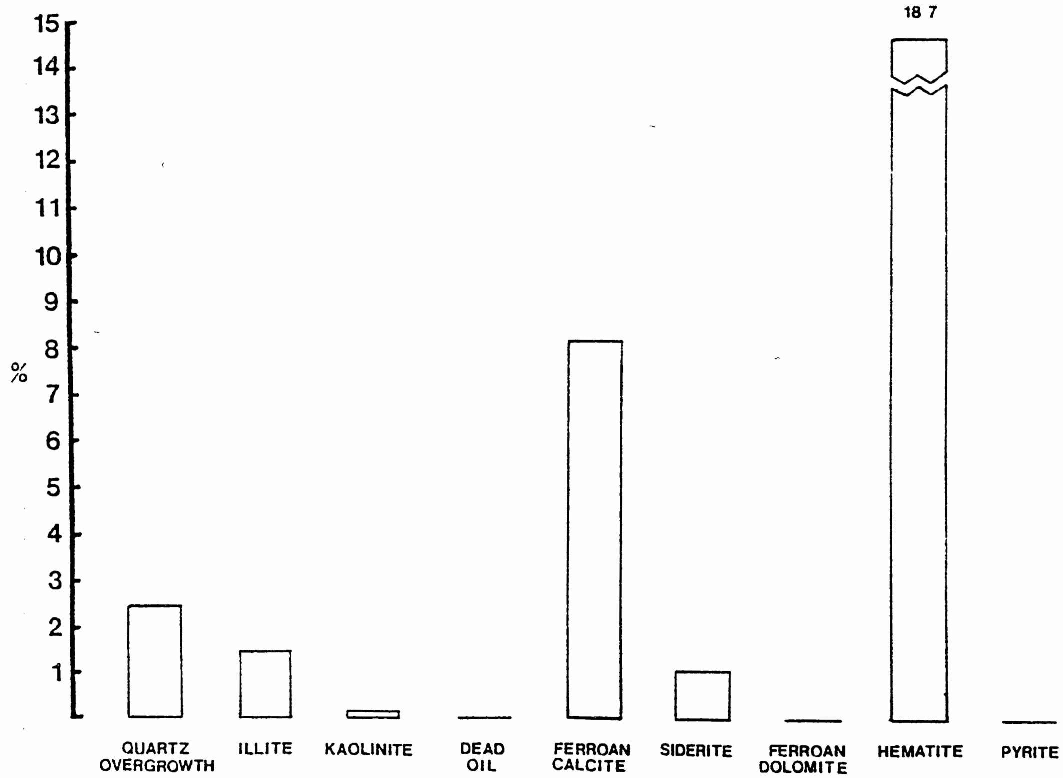

Figure 57. Diagenetic Compositions of the Batesville Sandstone in Outcrop `G' from Thin-Section Analysis.

and 57). Siderite cement was observed in two thin sections in the upper portion of the section ranging from 3.5 to 4.0 percent. Hematite cement was seen in all but one of the studied intervals ranging from 2.8 to 44.8 percent of the bulk volume (Figure 58). The highest percentages occurred in the upper and lower horizons of the exposed section. The major authigenic clays are kaolinite and illite and were observed in the middle to upper zones. The kaolinite range from a trace to 0.5 percent, whereas the illite ranges from 4.8 to 5.5 percent.

Core Description of the Carter 'A' and 'B' and the "Millerella" Sandstone

Carter 'A' Sandstone

The #1 Leech core ranges in depth from 1778' to 1828' and involves 50 feet of continuous medium-grained Carter 'A' Sandstone. The sandstone is subangular to subrounded and buff colored except where oil staining is present to give it a brown color. There is one distinctive fining-upward trend from 1828' to 1809', and two less distinct fining-upward trends from 1809' to 1798' and 1798' to 1778'. Each trend begins with granule-pebble sized clasts at the base and grades upward to a fine- to medium-grained sandstone. Also present are small-scale trough cross-bedding and ripples in the upper-most part of the core. The spontaneous potential curve of the interval is well defined; it exhibits an abrupt

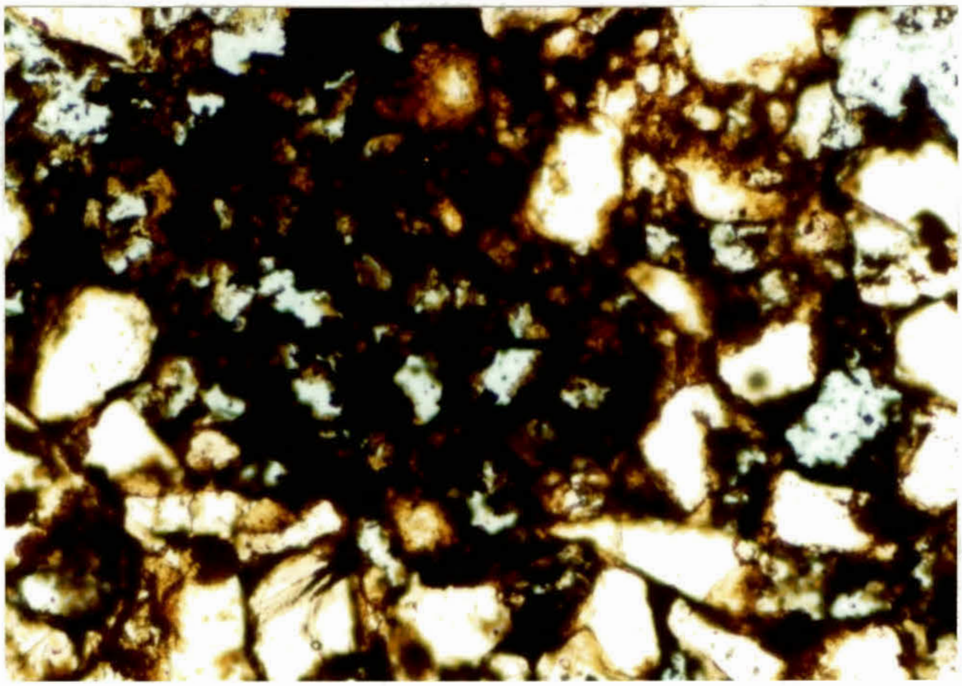

Figure 58. Photomicrograph of Pore-Lining and Pore-Filling Hematite Cement (100x, plane polarized light, 1 foot above Base of OUtcrop `G').

lower base, cylindrical shape, and a fining-upward sequence at the top of the Carter 'A' interval (Figure 59). The spontaneous potential curve and analysis of the vertical trends in texture and sedimentary structures suggest the presence of stacked channels which grade upward into levee deposits and deposition of crevasse splay sands. The Carter 'A' Sandstone is generally well-sorted throughout the cored interval. The porosity values vary somewhat, ranging from two to almost 12 percent of the bulk volume. Porosity decreases somewhat in the interval from 1801' to 1803' (Figure 59) likely due to the increase of siderite cementation. Grain size apparently has no effect on the level of porosity, as the porosity is variable yet the grain size is fairly constant throughout the core. When trying to determine controls of porosity, one cannot overlook the diagenetic processes involved in the strata as exemplified earlier in the increase of siderite cementation/loss of porosity.

Neither the lower nor upper contacts of the Carter 'A' Sandstone were available in the core. Sedimentary structures in the Carter 'A' Sandstone include small-scale trough and planar bedding, horizontal bedding, small sets of ripples and stylolites (Figure 59).

The #1 Armstrong core ranges in depth from 1739' to 1800' and includes 13 feet of well-sorted, fine-grained Carter 'A' Sandstone, 31 feet of underlying fissile, black shale, and 17 feet of Carter 'B' Sandstone (Figure 60).

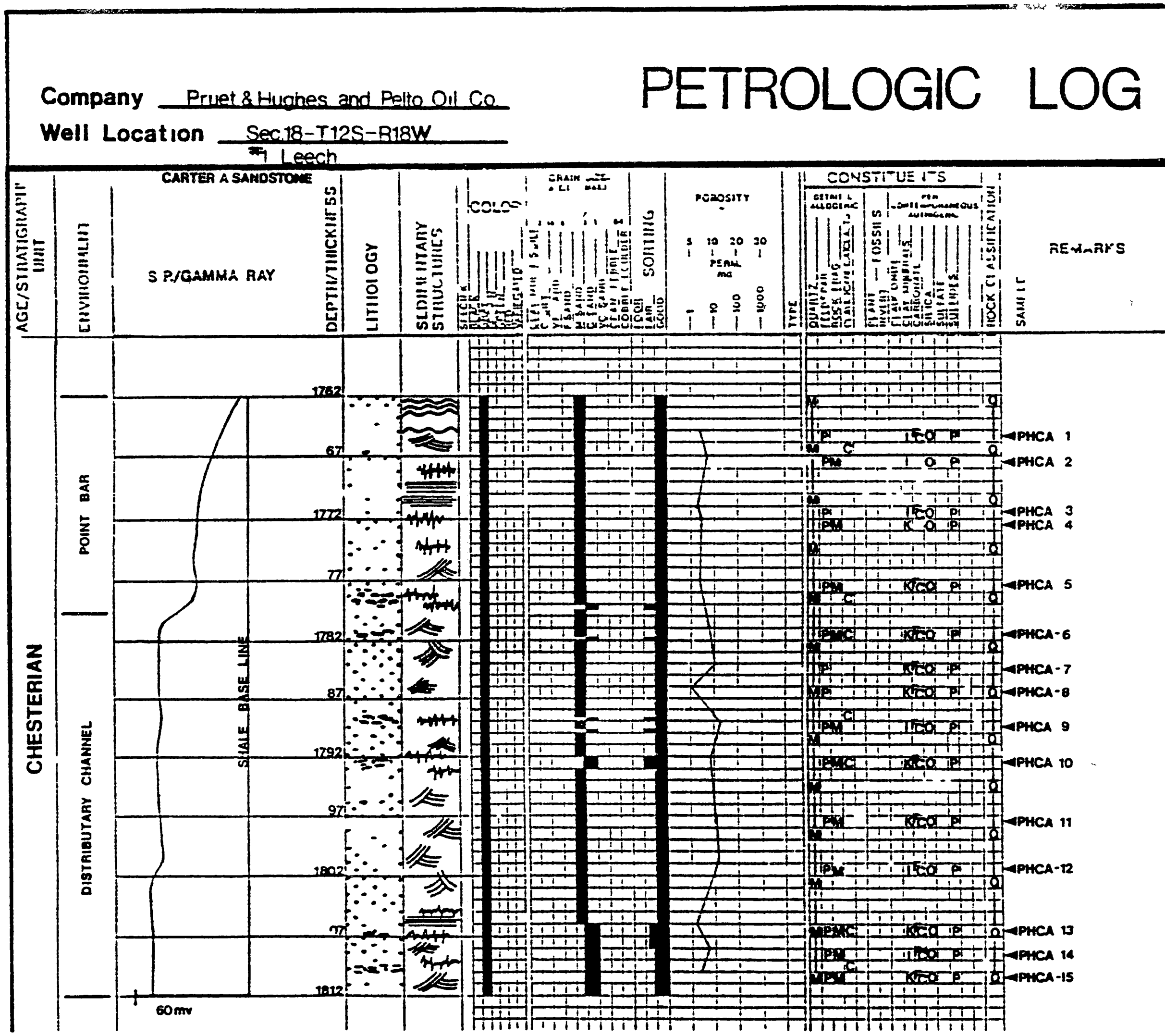

Figure 59. Petrologic Log for the Carter `A' Sandstone in the #1 Leech Core.

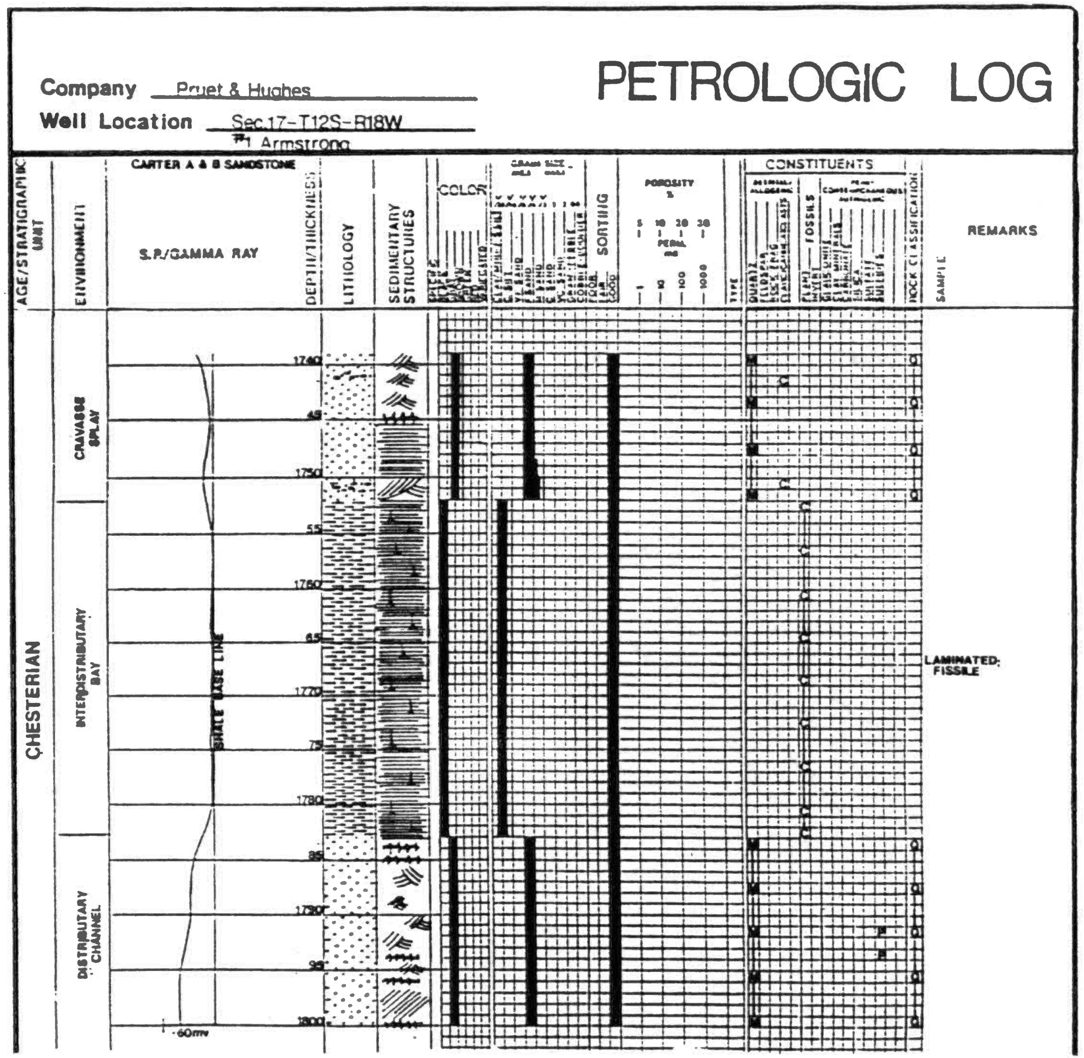

Figure 60. Petrologic Log for the Carter `A' and 'B' Sandstone in the #1 Armstrong Core.

The sand grains are subangular to subrounded. The interval is buff colored except where it is stained by oil. The Carter 'A' interval ranges from 1752' to 1739' and appears to show a slight fining-upward trend. There is a distinct sand-shale contact at the base and what appears to be channel scour with coarse-grained sand and small granule-pebble channel lag. The interval grades upward to a fine-grained sandstone with small-scale trough cross-bedding, horizontal bedding, small sets of organic stringers, and stylolites. The sandstone is well-sorted with no marine characteristics present. From inspection of the core, it would appear that the lower sequence represents fluvial channel deposits. However, the spontaneous potential curve shows a coarsening-upward sequence in the lower-half, and a fining-upward sequence in the upper-half.

Carter 'B' Sandstone

The #1 J. T. Evans core ranges from 4165' to 4197' and involves 32 feet of continuous very fine-to fine-grained Carter 'B' Sandstone (Figure 61). The sands are well-sorted and buff colored except where stained by oil. The interval from 4177' to 4165' appears to be a fining-upward sequence. Channel lag and medium-grained quartz are present at the base and this changes upward to a fine-grained sandstone up the core. Proceeding up the core from 4177' one observes inclined, tabular-planer bedding, small-scale trough cross-bedding, and small sets of clay ripples. The

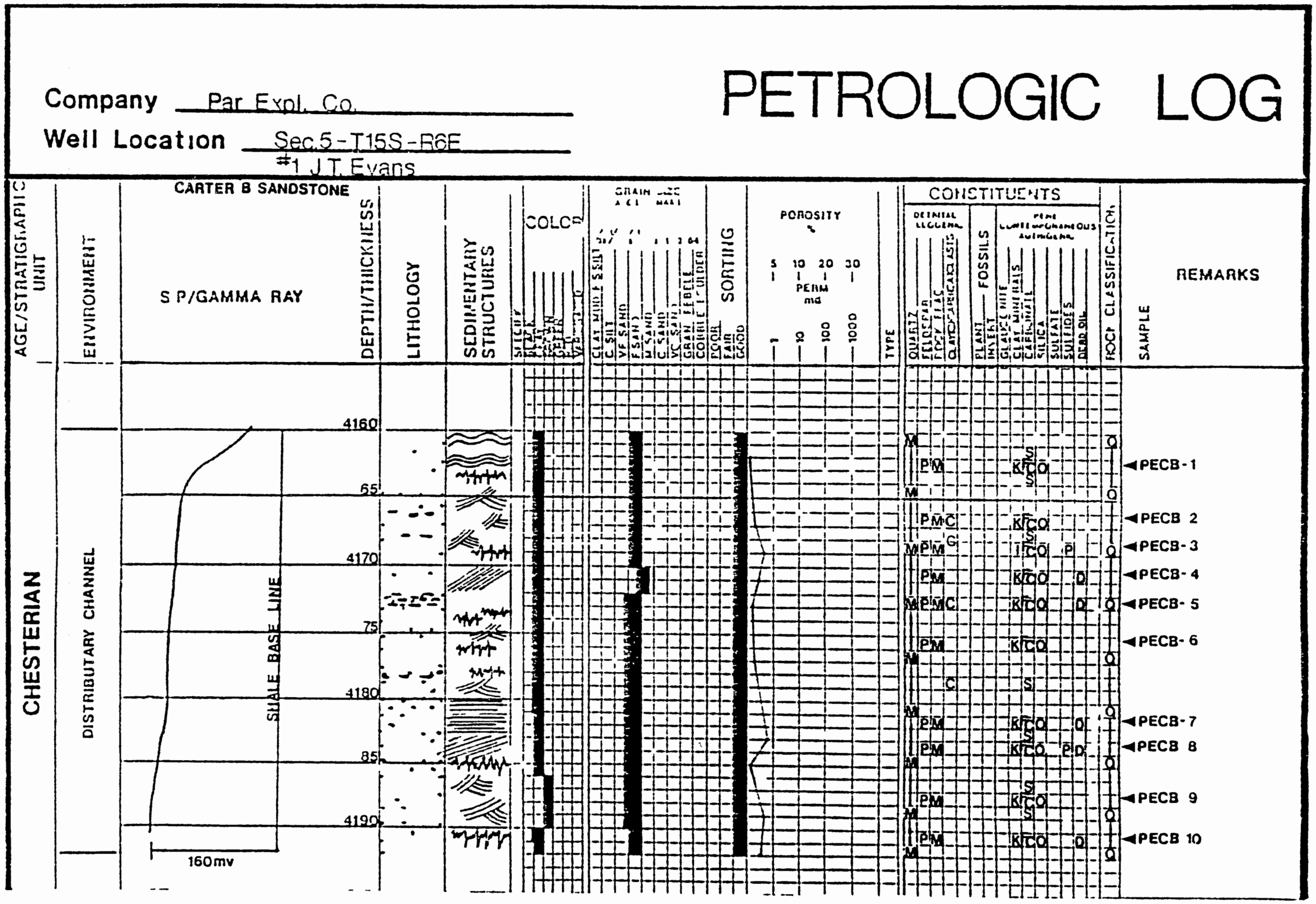

Figure 61. Petrologic Log for the Carter `B' Sandstone in the #1 J. T. Evans Core.

spontaneous potential curve is well defined with abrupt upper and lower contacts which is indicative of a channel environment. The Carter 'B' Sandstone is well-sorted throughout the cored interval. The porosity is low ranging from zero to four percent. There is some variability however, and this is attributed to diagenetic controls, as porosity is low where diagenetic clays and cements are high.

The #1 Thomas core ranges in depth from 3938' to 3987' and involves 49 feet of well-sorted, very fine- to medium grained Carter 'B' Sandstone. There are four fining-upward sequences involved in the multi-storied channel system. (Figure 62). These sequences occur from 3938' to 3958', 3958' to 3967', 3967 to 3978' and 3978' to 3987'. The lowest interval is not complete as the core ends at 3987'. The spontaneous potential curve, with abrupt lower and upper contacts and a cylindrical to slight bell shaped curve, is characteristic of channel deposition. The spontaneous potential curve also indicates an abrupt and distinct fining upward texture that correlates fairly well with the core analysis from 3978' to 3987'.

The Carter 'B' Sandstone is generally well-sorted throughout the core except at 2978' to 3980'. This interval represents the abrupt change in grain size in the lower part of the channel. At the base of each fining-upward sequence, clay rip-ups and/or clasts are present and represent channel lag. There were no marine indicators found in the core.

The porosity is slightly variable, but generally low in

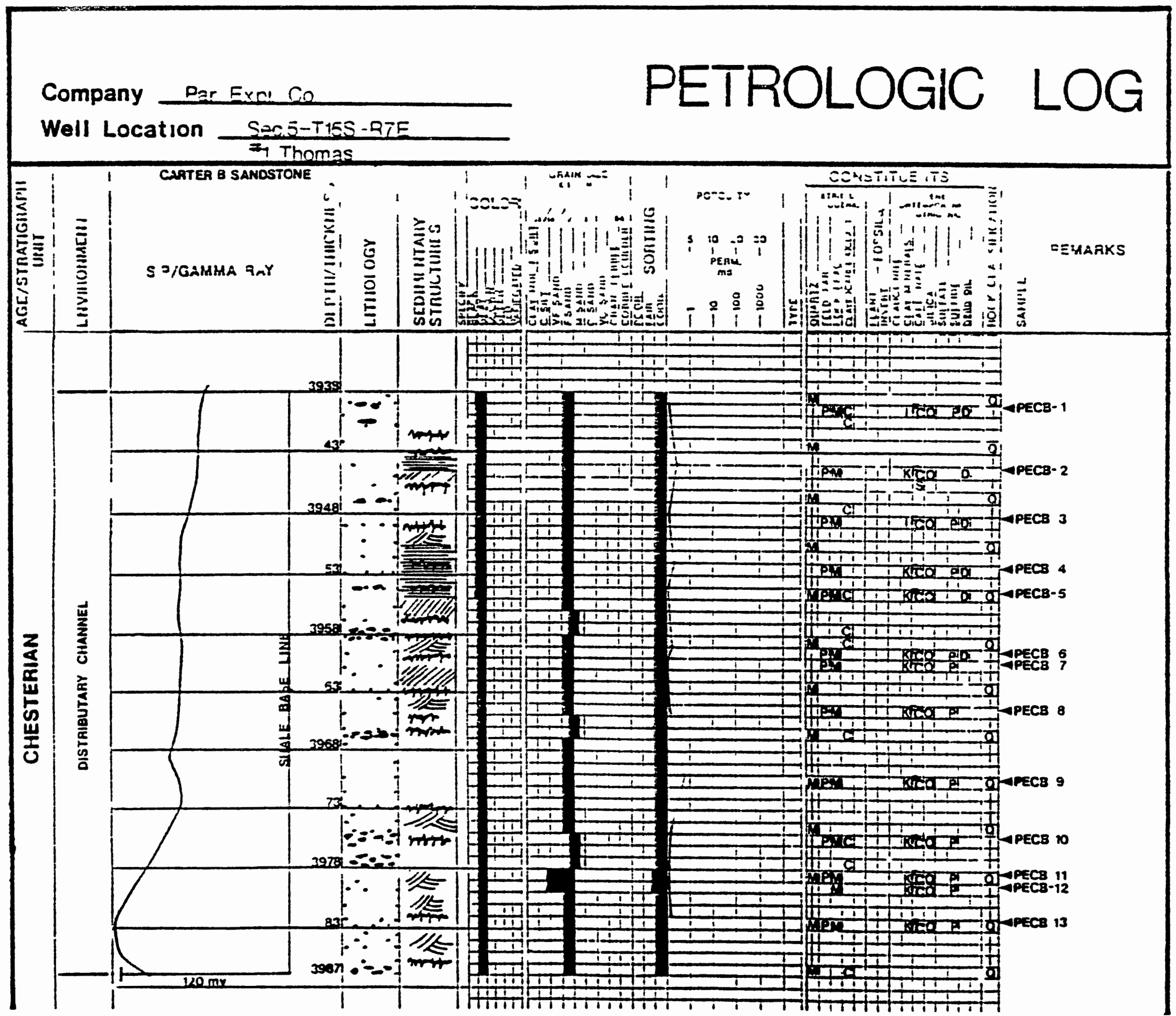

Figure 62. Petrologic Log for the Carter `B' Sandstone in the #1 W. R. Thomas Core.

the core. The porosity ranges from zero to approximately four percent and is diagenetically controlled.

The sedimentary structures that are present in the #1 Thomas interval include: massive bedding, horizontal and inclined tubular-planar cross-bedding, small scale trough cross-bedding, and stylolites filled with dead oil. The occurrence and distribution of these sedimentary structures can be seen in the petrographic log.

The #1 Malone core ranges in depth from 4916' to 4947', 4961' to 4967' and 4975' to 5001' and incorporates 35 feet of moderately well-sorted, very fine to medium grained Carter 'B' Sandstone. Individual grains are subangular to subrounded. The core is gray with some zones of staining for oil migration through the rock. There are two fining-upward sequences in the upper interval from 4927' to 4937' and 4937' to 4947' and one fining-upward sequence from 4975' to 4984' (Figure 63). The grain size trends, along with small-scale trough cross-bedding and ripples, represent deposition in a distributary channel environment on an upper delta plain. The spontaneous potential curve exhibits abrupt upper and lower contacts and has approximately -105mv negative deflection from the shale base line. This indicates a fairly clean and permeable sandstone. Although the spontaneous potential curve suggests a permeable sand, the porosity is generally low ranging from zero to almost five percent due to the amount of clays present.

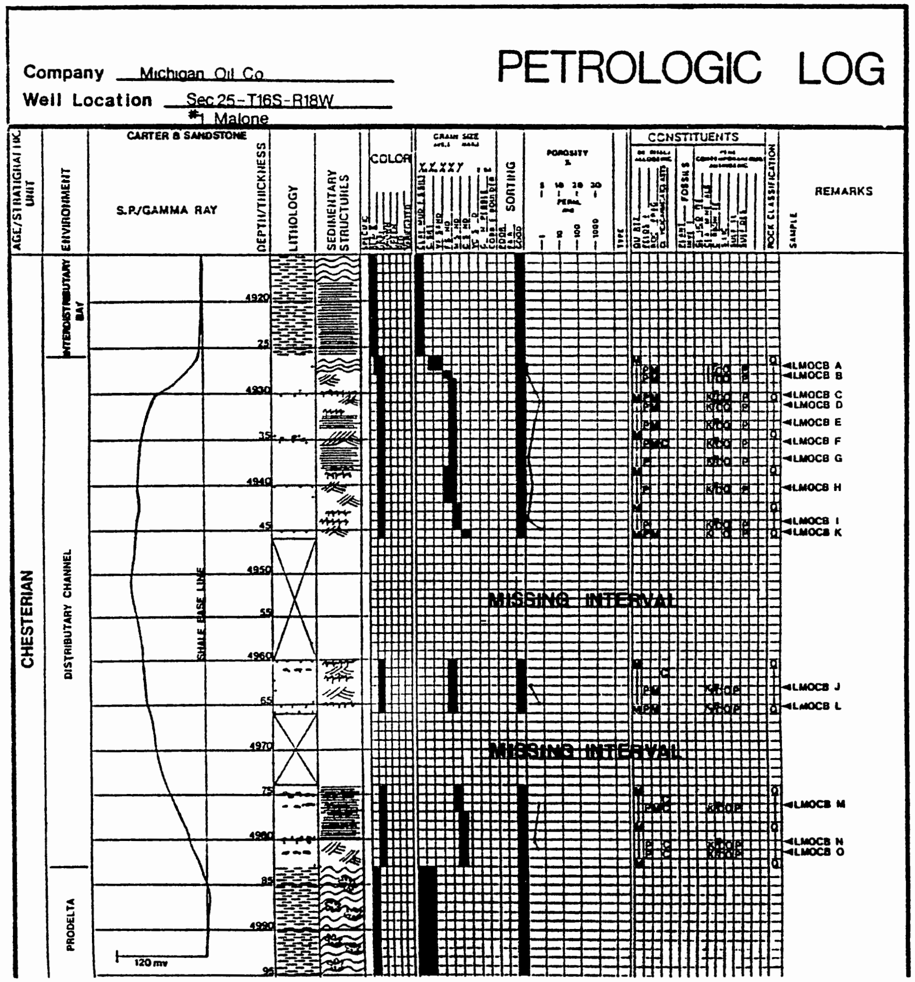

Figure 63. Petrologic Log for the Carter `B' Sandstone in the #1 Malone Core.

The base of the channel in the #1 Malone core is demonstrated by the occurrence of interclasts and mud chips, which directly overlie shales. The one complete fining-upward sequence, from 4927' to 4937', contains intraclasts of mud chips at the base and fines upward into ripples and laminated shales of overlying levee muds. No marine indicators such as burrowing, fossils, or marine cementation were present in this core.

The sedimentary structures present include small-scale trough cross-bedding, horizontal and inclined planar cross-bedding, channel scour, ripples, and stylolites. Representation of these sedimentary structures are illustrated on the petrologic log (Figure 63).

The #1 Armstrong core ranges in depth from 1739' to 1800' and the basal 17 feet includes very fine- to fine-grained, moderately well-sorted Carter 'B' Sandstone. This interval of sandstone represents deposition in the upper portion of a distributary channel (Figure 60).

The spontaneous potential curve exhibits abrupt lower and upper contacts, a general cylindrical shape, and is characteristic of channel deposition. The grain size is relatively uniform throughout the core, but does show a very slight coarsening upward trend in the upper seven feet of the Carter 'B' in the #1 Armstrong core. The sedimentary structures include inclined planar cross-bedding, small-scale trough cross-bedding, ripples and stylolites, all of which are illustrated on the petrologic log (Figure 60).

"Millerella" Sandstone

The #1 Nason core ranges in depth from 3971' to 3724', 3749' to 3769' and incorporates eighteen feet of silty-to very fine-grained sandy "Millerella" Sandstone. The "Millerella" represents reworked marine sandstone deposited as disarticulated barrier sands within the basin. There is a slight coarsening-upward sequence from the base of the core (3769') to the top (3751') of the cored interval (Figure 64). The spontaneous potential curve is fairly suppressed giving little aid in the determination of the depositional environment. Most likely this is due to the shaliness of the interval and the presence of relatively thin beds which are difficult for a spontaneous potential tool to detect.

The "Millerella" Sandstone exhibits moderate to good-sorting. The porosity ranges from two to four percent. The lack of porosity could be diagenetically controlled, but it also is affected by the high amount of shale in the interval.

From 3961' to 3723', 32 feet of the "Millerella" Limestone marker bed is represented in the #1 Nason core. This marine transgressive limestone is a multicolored bio-micrite which is extremely fractured and contains preserved fossil fragments. These fossils include brachiopods, bivalves and echinoid fragments. The dominant sedimentary structure is ripples throughout the sandstone interval, but some small-scale trough cross-bedding and horizontal bedding

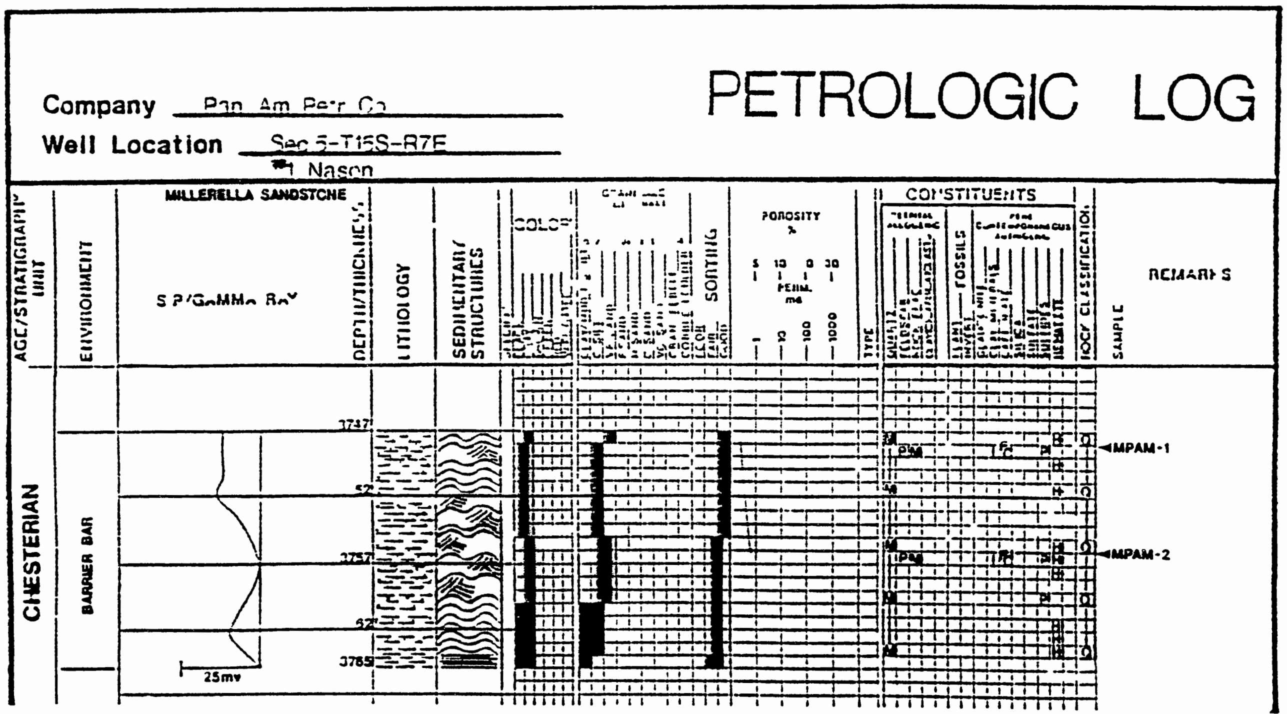

Figure 64. Petrologic Log for the "Millerrella" Sandstone in the #1 Nason Core.

is present. These sedimentary structures can be seen on the petrologic log in Figure 64.

Composition and Classification of the Carter 'A' Sandstone

Plotted on a Q-R-F diagram without regard for metastable constituents now dissolved or replaced the average composition of the Carter 'A' sandstone in the #1 Leech core falls within the quartzarenite subdivision of the triangle (Figure 65). All of the thin sections examined in the studied interval of the core plot within the quartzarenite range.

Detrital Constituents

Figure 66 shows the relative abundance of allogenic constituents found to approximate the average of the #1 Leech core. Monocrystalline quartz grains ranging from coarse-to medium-grained account for an average of 81.9 percent of the bulk volume (Figure 67). Polycrystalline quartz averaged approximately 2 percent of the total. Single grains of plagioclase feldspar account for approximately 1 percent of the total volume. Although identification of the extensively altered feldspar grains was difficult, albite appears to be the dominant feldspar. Shale clasts are present in trace amounts throughout the studied interval. Chert fragments account for only 0.4 percent of the total and are represented by only trace

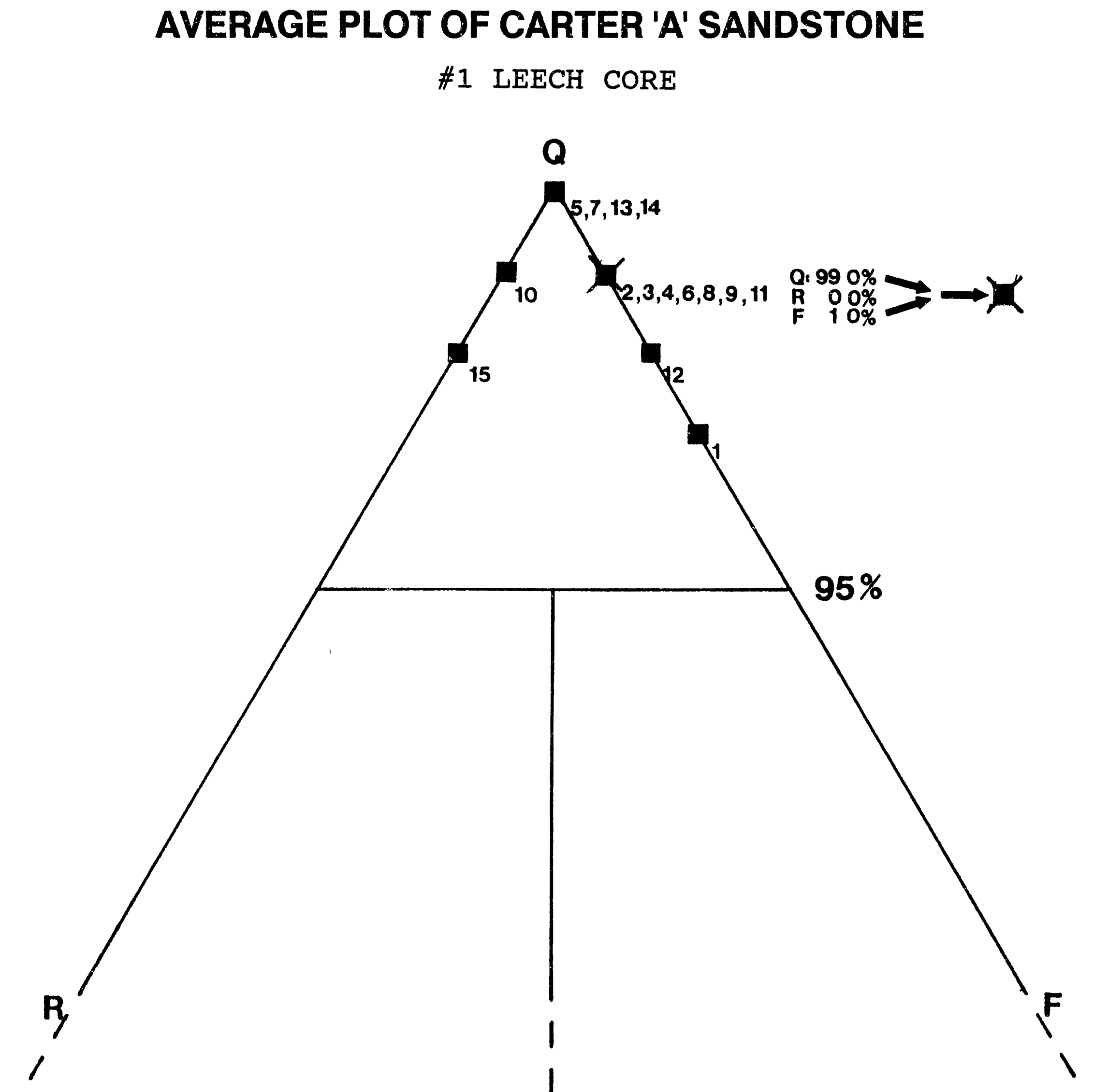

Figure 65. Q-R-F plot of Carter `A' Sandstone Without Regard for Partially Dissolved Metastable Constituents.

#1 LEECH CORE

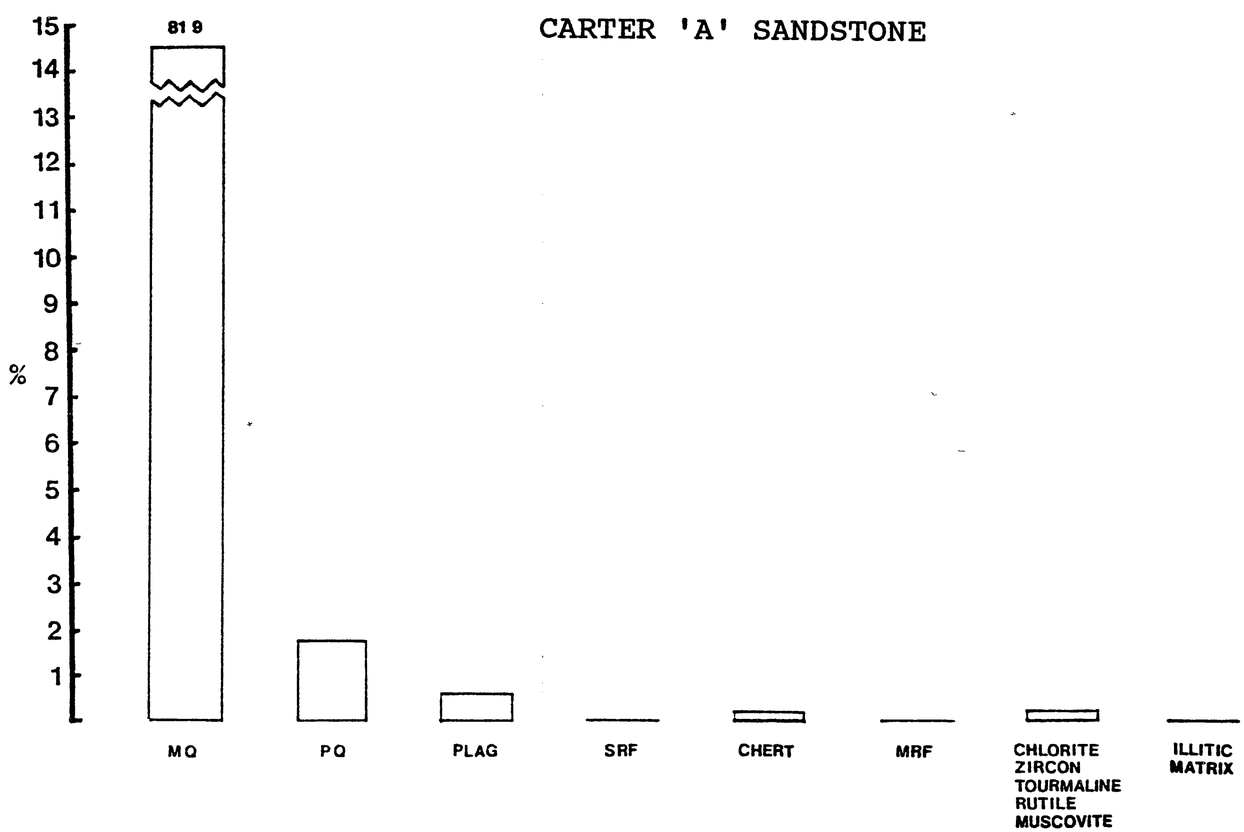

Figure 66. Allogenic Composition of the Carter `A' Sandstone in the #1 Leech Core.

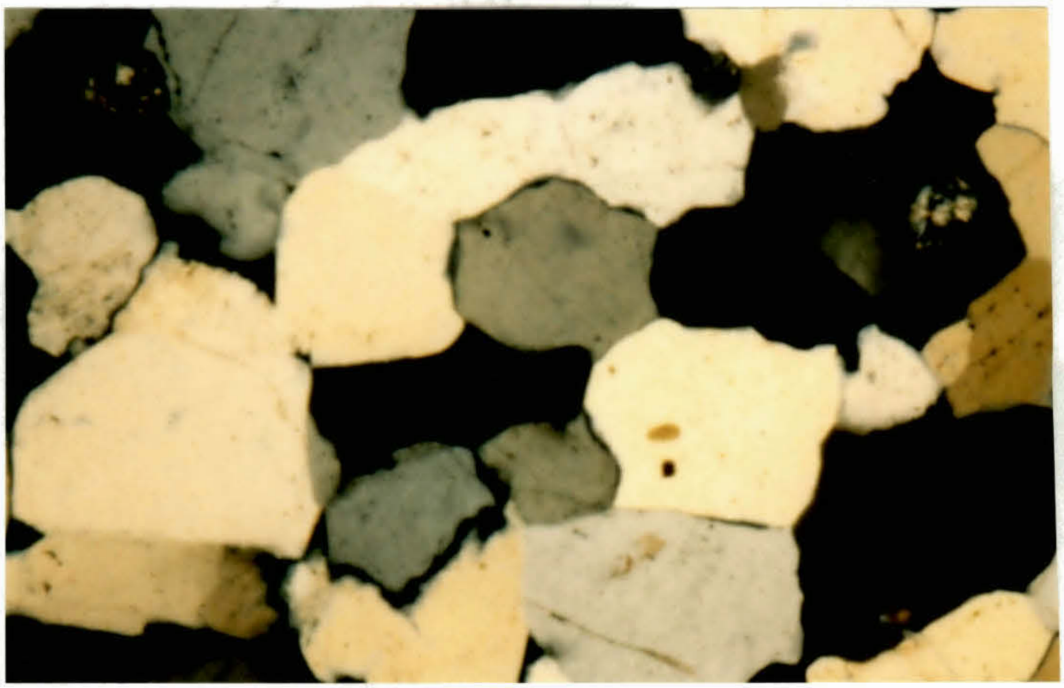

Figure 67. Photomicrograph of Monocrystalline Quartz Grains with Syntaxial Quartz Overgrowths and Chemical Compaction at Grain Boundaries (40x, Cross Nichols Light, 1809').

amounts in most of the studied interval. Accessory minerals, which are rarely seen as more than a trace, include muscovite, chlorite, zircon, tourmaline, and rutile.

Diagenetic Constituents

The following diagenetic constituents, along with average percent of occurrence are found in the #1 Leech core: Quartz overgrowths (1.8 percent), ferroan calcite cement (trace), ferroan dolomite cement (0.6 percent), siderite cement (1.7 percent), hematite cement (trace), pyrite cement (0.2 percent), illite (1.7 percent), and kaolinite (1.3 percent) (Figure 68). Quartz overgrowths were observed in all the studied intervals and ranged from a trace to 4.2 percent of the total rock volume. Ferroan dolomite cement was present in the majority of slides and ranged from a trace to 16.7 percent of the bulk volume. Most of the studied interval contained only trace quantities of dolomite except at the base, where the dolomite was a major cementing agent averaging 16.7 percent at 1785' in the core (Figure 69). Hematite cement was observed in all but one thin section and ranged from a trace to 10 percent of the total. Pyrite cement was observed in all the studied interval ranging from a trace to one percent of the bulk volume. The major authigenic clays were pore-filling kaolinite, and pore-lining illite. Both were observed in all the studied intervals with kaolinite ranging from a trace to 3 percent and illite

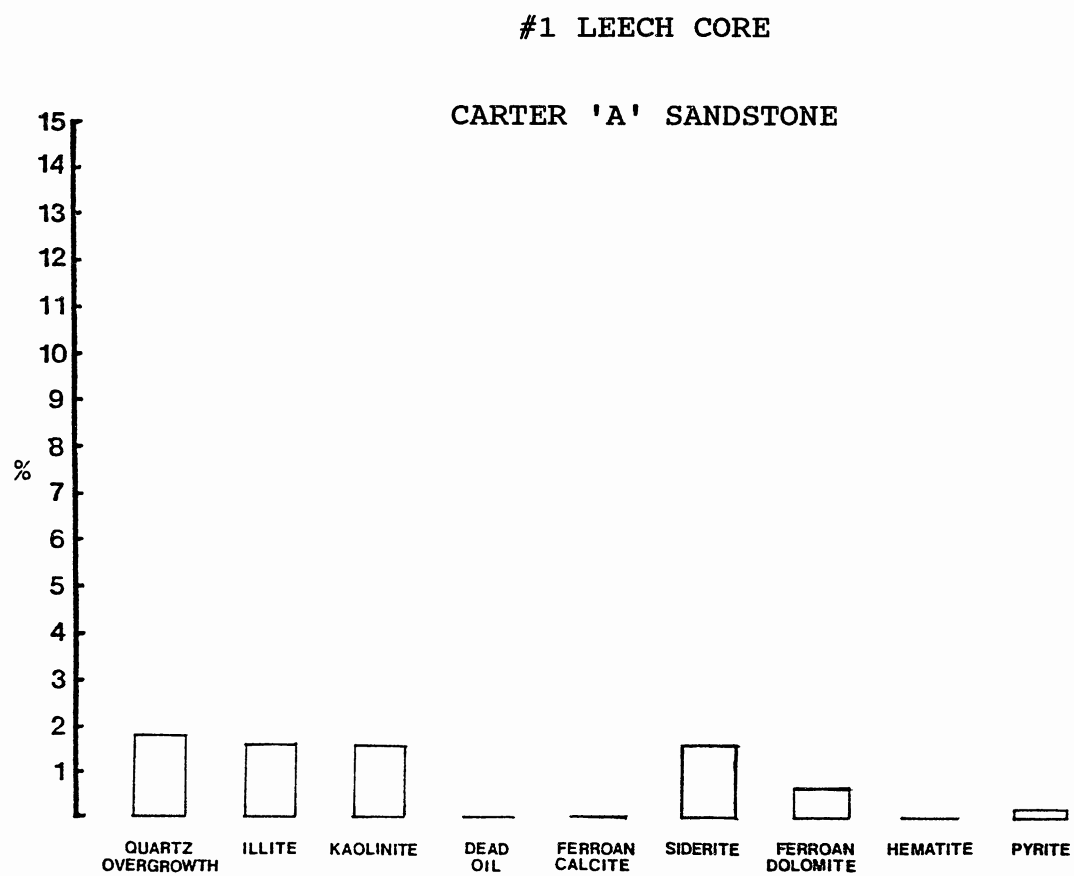

Figure 68. Diagenetic Compositions of the Carter `A' Sandstone in the #1 Leech Core.

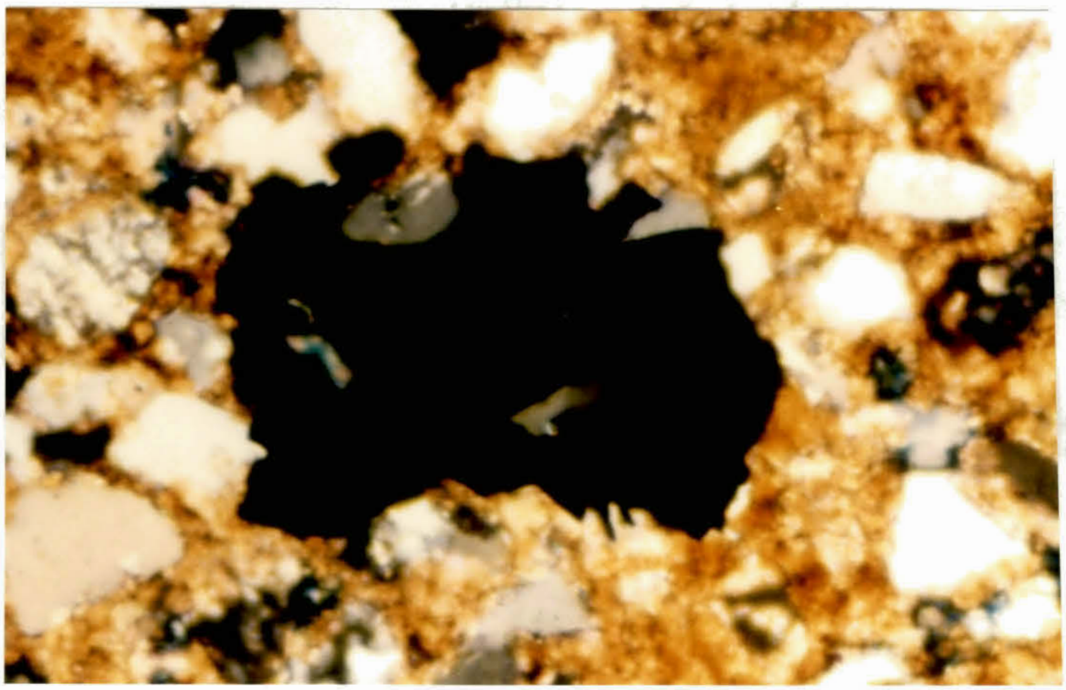

Figure 69. Photomicrograph of Pore-Filling Pyrite Cement (200x, Crossed Nichols Light, 1812').

ranging from a trace to 4.2 percent.

Composition and Classification of the Carter 'B' Sandstone

Plotted on a Q-R-F diagram without regard for metastable constituents now dissolved or replaced, the average composition of the Carter 'B' Sandstone in the #1 T. J. Evans, #1 W. R. Thomas, and the #1 Malone cores plot within the quartzarenite subdivision of the triangle (Figures 70, 71 and 72).

Detrital Constituents

Figure 73 shows the relative abundances of allogenic constituents found to approximate the averages in the #1 T. J. Evans core. Monocrystalline quartz averages 82.4 percent of the bulk volume, whereas polycrystalline quartz averaged only 3.2 percent of the total. Concentration of feldspar averaged only 1.1 percent of the total ranging from a trace to 3 percent. Once again, extensive alteration causes difficulty with identifying feldspars. Other detrital constituents include: shale rock fragments (trace), chert (0.2 percent), and low-grade metamorphic rock fragments (0.2 percent). As in the previous core, some of the metastable constituents were difficult to identify due to the advanced degree of alteration. Accessory minerals, ranging from a trace to 0.7 percent consisting of chlorite, muscovite, rutile, tourmaline, and zircon.

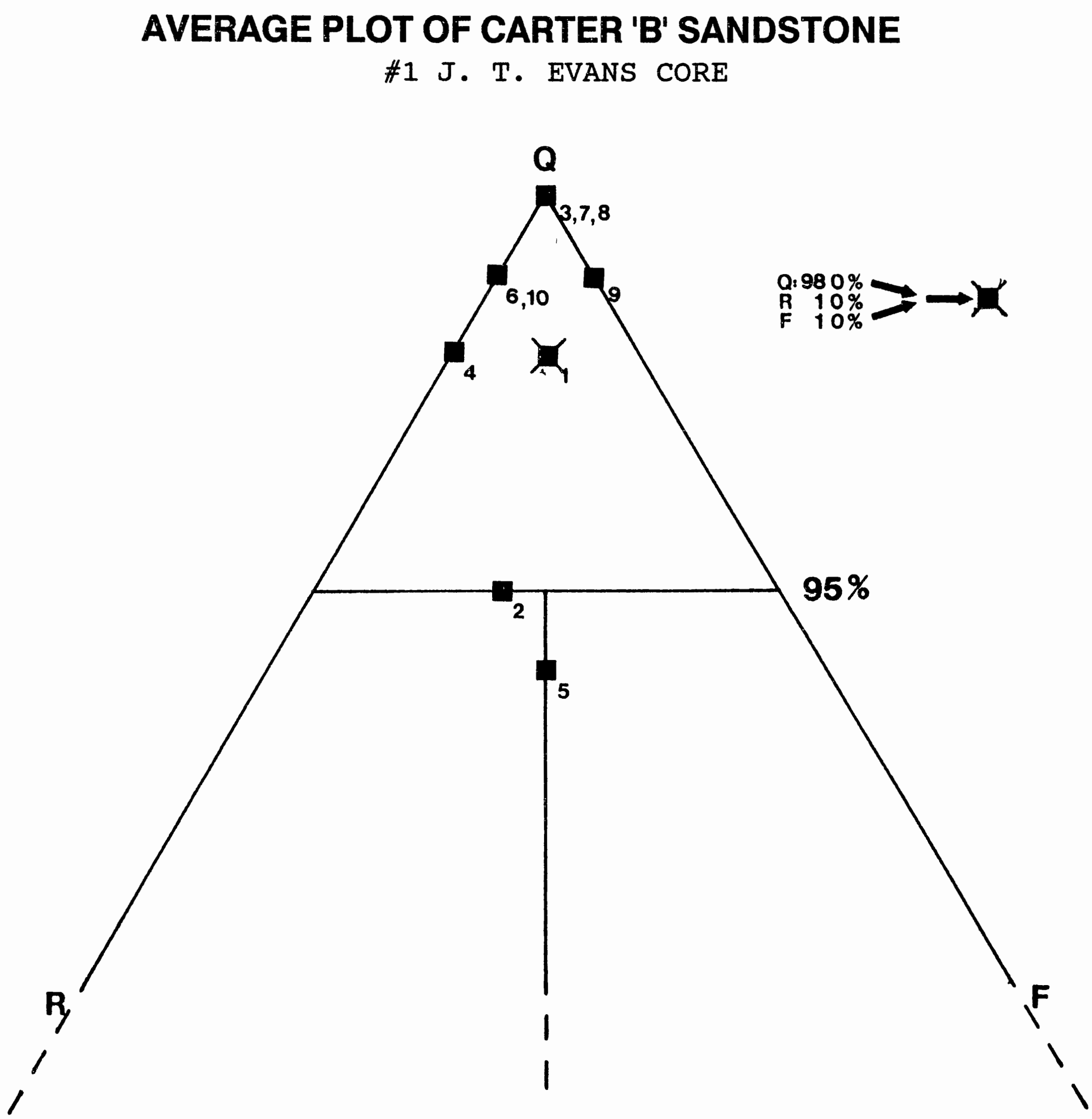

Figure 70. Q-R-F plot of the Carter `B' Sandstone Without Regard for Partially Dissolved Metastable Constituents.

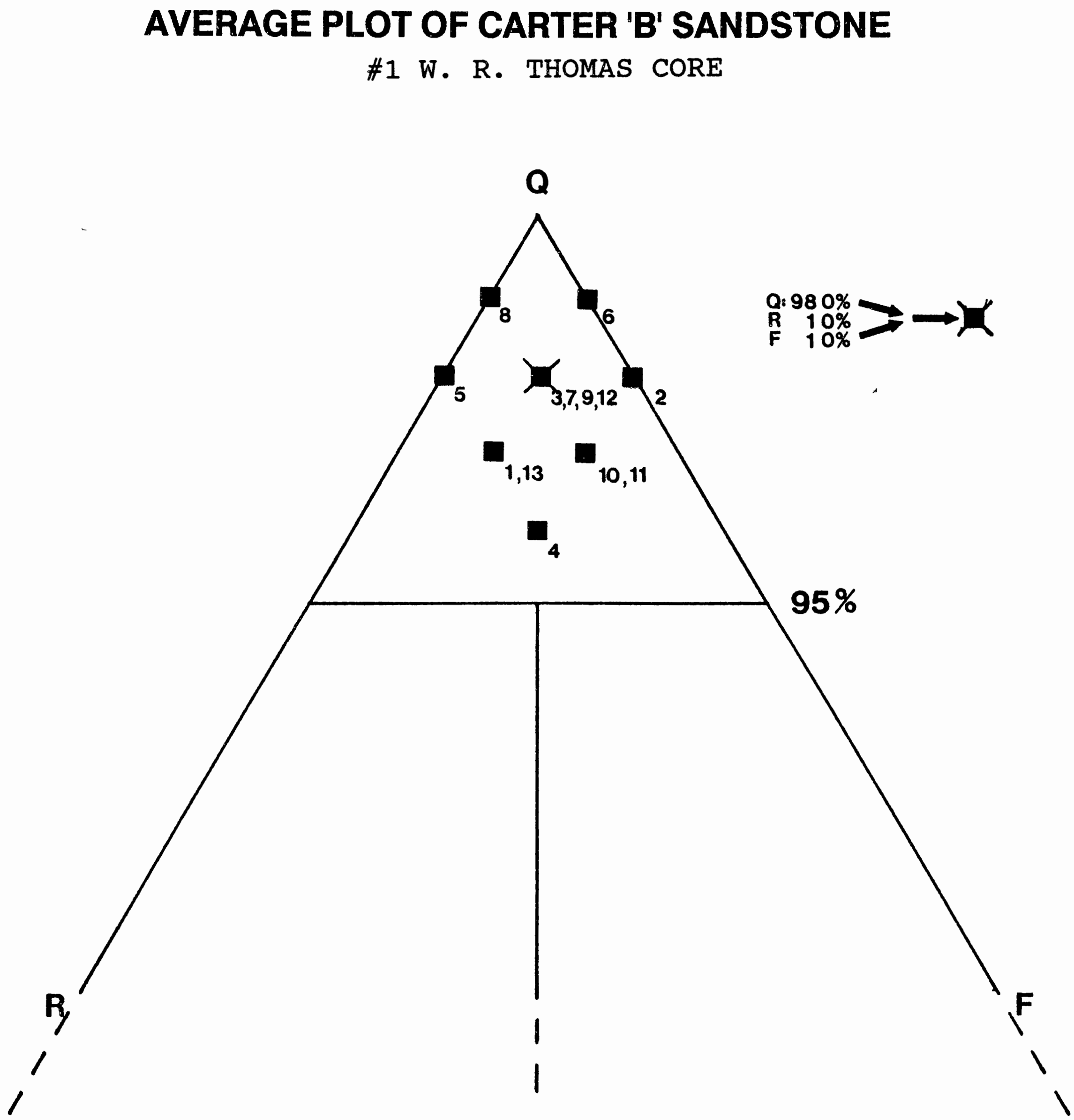

Figure 71. Q-R-F plot of the Carter `B' Sandstone Without Regard for Partially Dissolved Metastable Constituents.

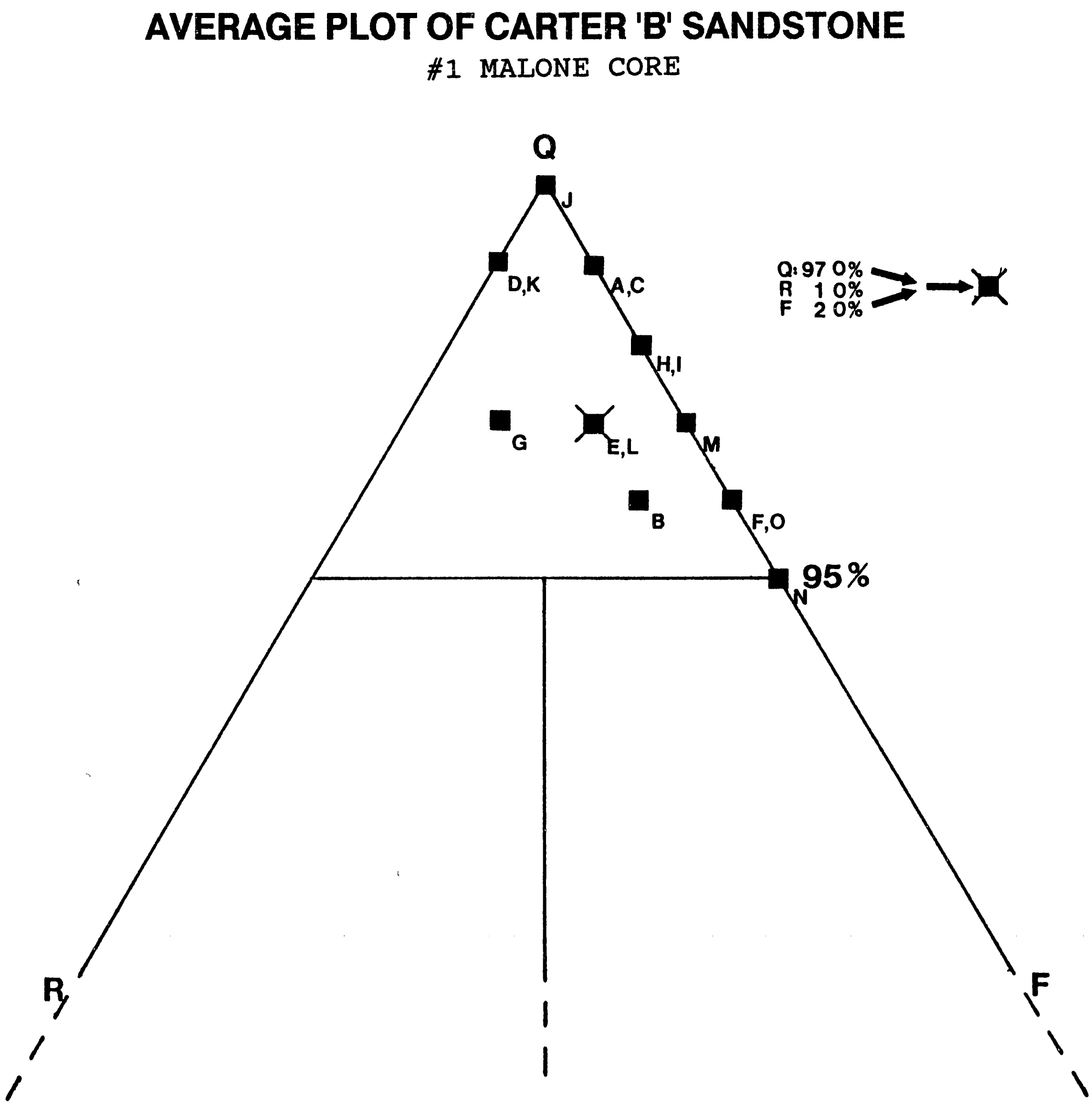

Figure 72. Q-R-F plot of the Carter `B' Sandstone Without Regard for Partially Disolved Metastable Constituents.

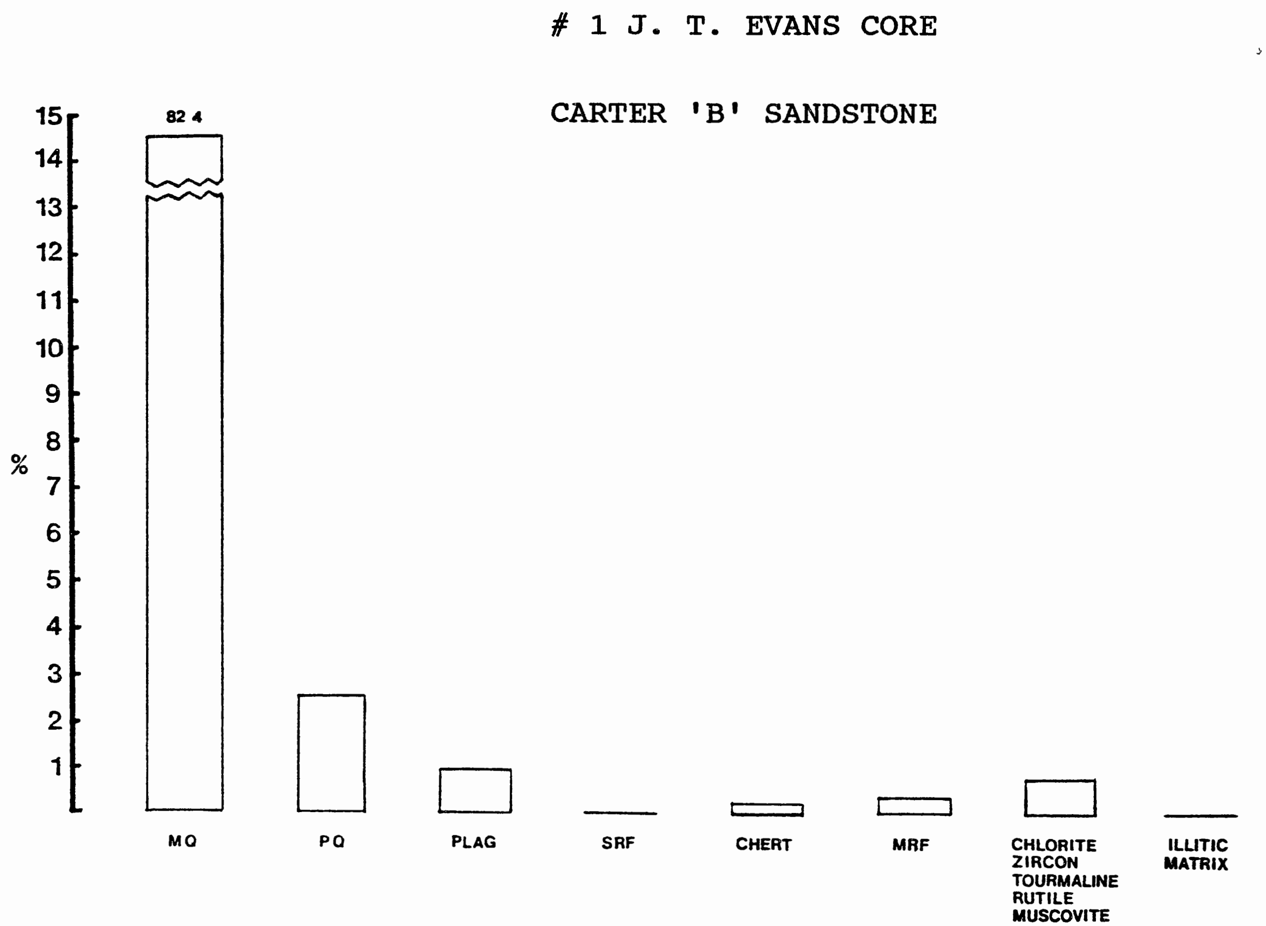

Figure 73. Allogenic Composition of the Carter `B' Sandstone in the #1 J. T. Evans Core.

Figure 74 shows the relative abundances of allogenic constituents found to approximate the averages in the #1 W. R. Thomas core for the Carter 'B' sandstone. The dominant detrital constituent was monocrystalline quartz which averages 82.0 percent of the bulk volume. Polycrystalline quartz contributes very little to the total rock volume, averaging only 1.8 percent. Feldspar averages only 0.9 percent of the total, but identification is extremely difficult as alteration has effectively distorted the single grains. Shale rock fragments (0.3 percent), chert (0.6 percent) (Figure 75), and low-grade metamorphic rock fragments (0.4 percent) are normally found in trace quantities and contribute from a trace to 1.8 percent, totalling 2.6 percent of the total volume. The contributing accessory minerals are muscovite, rutile, tourmaline, zircon, chlorite, and sphene (Figure 76).

Figure 77 shows the relative abundances of allogenic constituents found to approximate the averages in the #1 Malone core for the Carter 'B' sandstone. Monocrystalline quartz is the dominant grain type averaging 79.6 percent in the studied interval. Polycrystalline quartz averages only 2.3 percent. Feldspar concentrations averaged only 1.7 percent of the total volume and albite was observed as being the dominant plagioclase feldspar. Chert (0.4 percent) and low-grade metamorphic rock fragments (0.3 percent) contribute little to the total volume and show slight alteration. Accessory minerals include chlorite, muscovite, zircon,

#1 W. R. THOMAS CORE

CARTER 'B' SANDSTONE

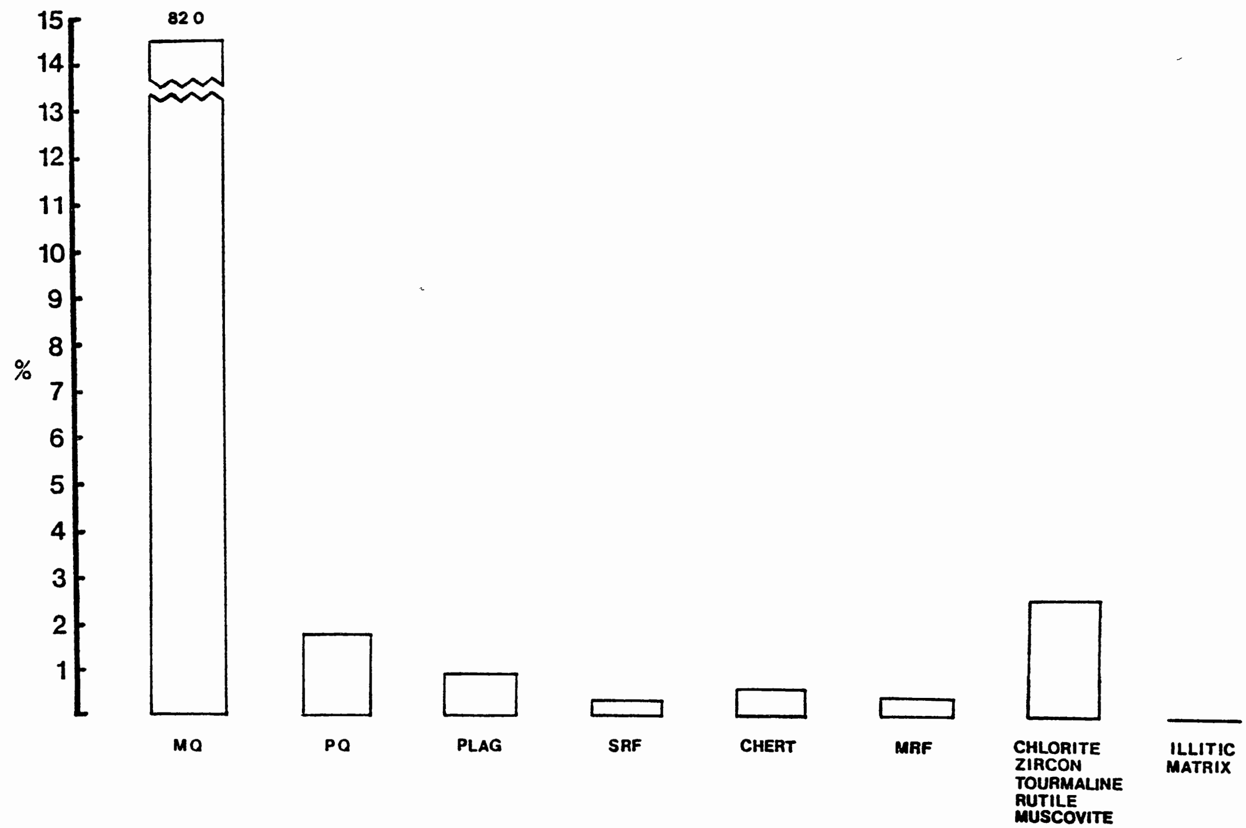

Figure 74. Allogenic Composition of the Carter `B' Sandstone in the #1 W. R. Thomas Core.

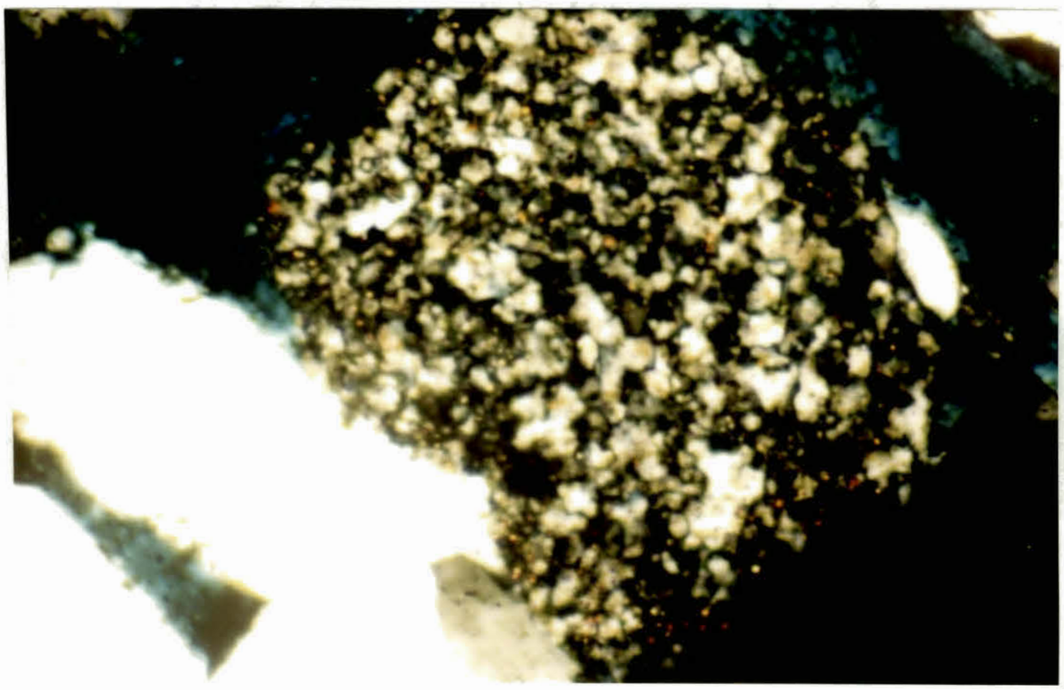

Figure 75. Photomicrograph of a Detrital Chert Grain (40x, Crossed Nichols Light, 1809').

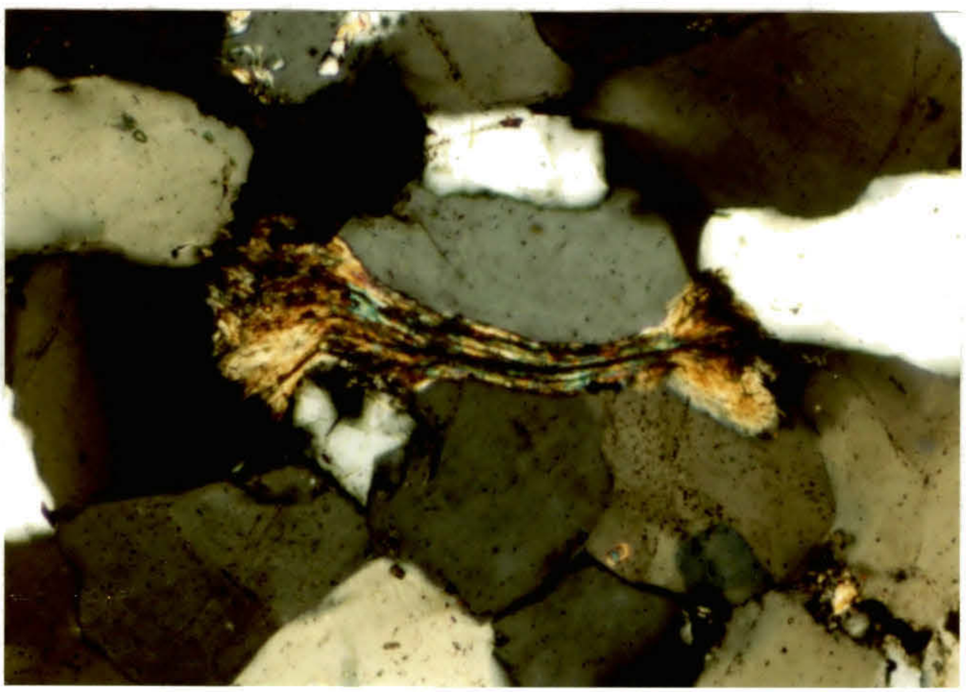

Figure 76. Photomicrograph of a Muscovite Grain Showing Compaction (100x, Cross Nichols Light, 3952').

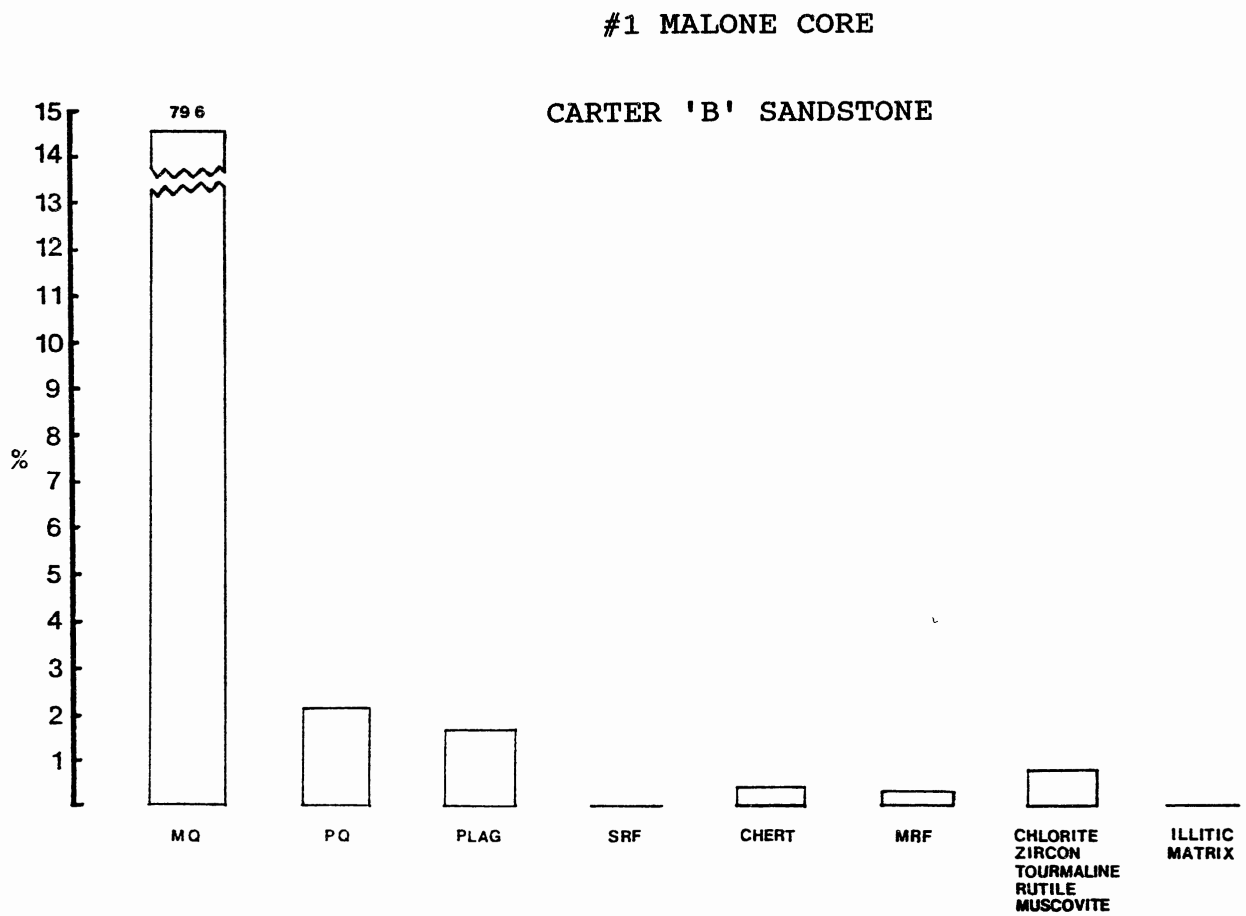

Figure 77. Allogenic Composition of the Carter `B' Sandstone in the #1 Malone Core.

tourmaline, and rutile and the abundance of any one of these ranges from a trace to 0.6 percent, totalling 0.8 percent of the studied interval.

Diagenetic Constituents

The types of diagenetic constituents present in the #1 T. J. Evans, #1 W. R. Thomas, and #1 Malone core for the Carter 'B' sandstone are all closely related. The following diagenetic constituents and their average percentages in relation to the bulk volume found in the #1 T. J. Evans core are: quartz overgrowths (3.6 percent), ferroan calcite cement (trace), siderite cement (0.8 percent), ferroan dolomite cement (1.7 percent), hematite cement (0.4 percent), pyrite cement (trace), "dead" oil residue (0.3 percent), illite (0.6 percent), and kaolinite (3.1 percent) (Figure 78). Quartz overgrowths were observed in all of the studied intervals and ranged from 2.3 to 4.3 percent. Ferroan dolomite cement was observed in all of the thin sections. Siderite cement was observed in one-half of the thin sections, ranging from a trace to 8 percent (Figure 79). Three intervals of siderite cementation were observed at 4167' (0.7 percent), 4174' (8.0 percent), and 4194' (1.0 percent). Hematite cementation was found to exist in all but two of the studied intervals and contributed a trace to 0.7 percent of the bulk volume. Pyrite cement was found in only three of the thin sections and only in trace quantities. "Dead" oil residue can be seen in five of the thin sections

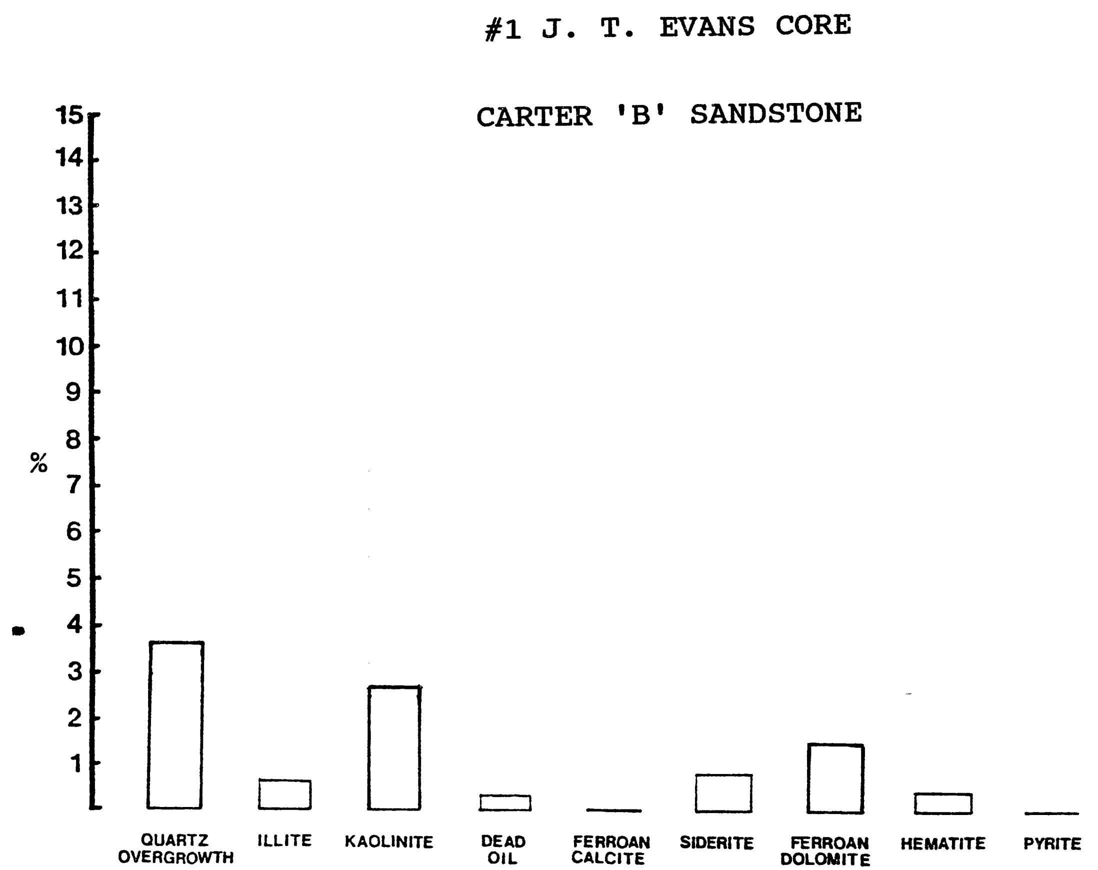

Figure 78. Diagenetic Compositions of the Carter `B' Sandstone in the #1 J. T. Evans Core.

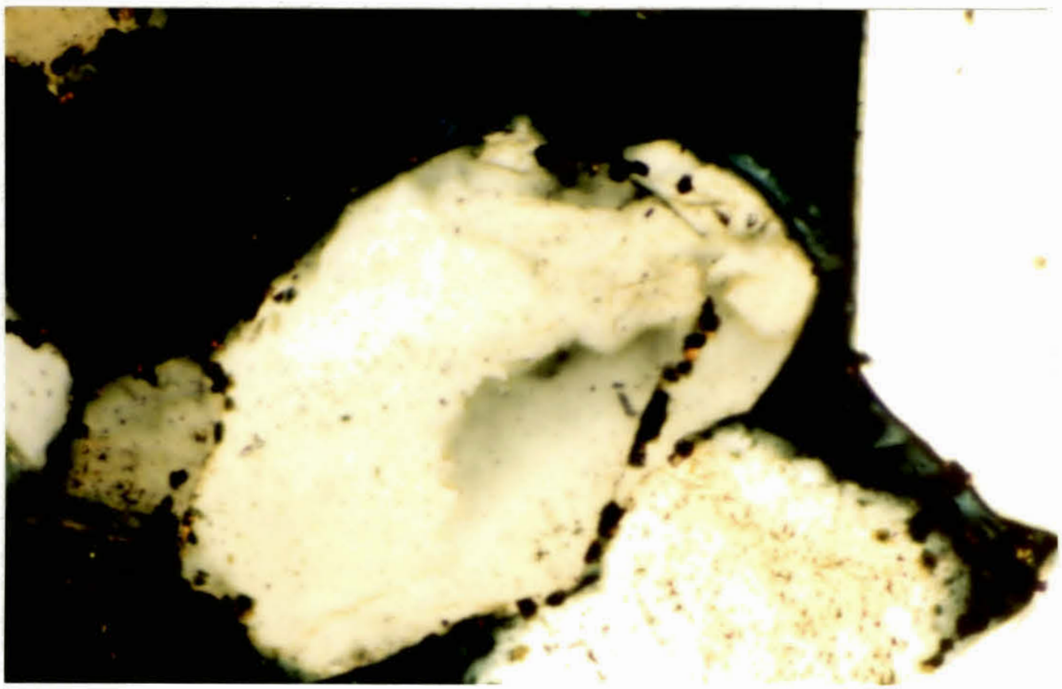

Figure 79. Photomicrograph of Pore-Lining Siderite cement (100x, Plane Polarized Light, 3982'),

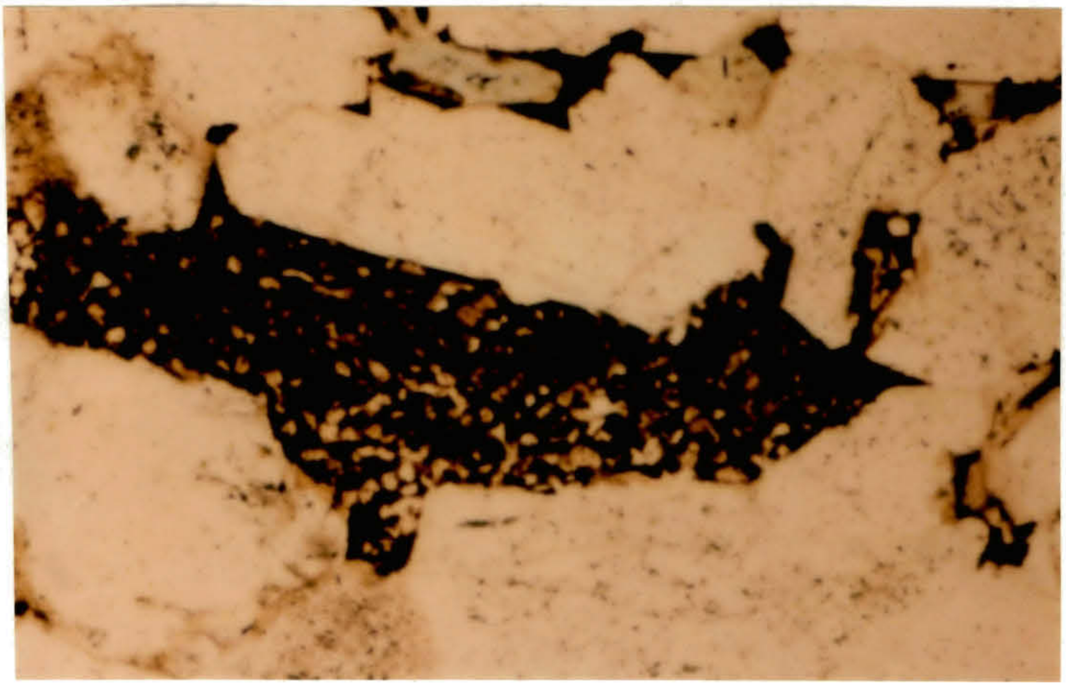

Figure 80 Photomicrograph of Oil-Stained Kaolinite Infilling a Large Dissolution Pore in the Carter `B' Sandstone 9100x, plane Polarized Light, 4168').

ranging from a trace to 2.3 percent (Figure 80). The major authigenic clays are pore-filling kaolinite and pore-lining illite. Kaolinite was the dominant clay at 3.1 percent with only 0.6 percent illite being present.

The diagenetic constituents and their average percentages as found within the #1 W. R. Thomas core include: quartz overgrowths (trace), ferroan calcite cement (0.4 percent), siderite cement 3.7 percent), hematite cement (1.5 percent), pyrite cement (0.3 percent), illite (1.4 percent), and kaolinite (3.3 percent) (Figure 81). Quartz overgrowths occur throughout the studied interval and Range from 0.8 to 7.6 percent. Ferroan calcite cement was observed in trace quantities. Ferroan dolomite cement was observed in all but two of the thin sections in the lower portion of the core. Siderite cement, making up 3.7 percent of the total, was observed in only two intervals ranging from 6.8 to 9.7 percent. Hematite cement was found in all but the upper two thin sections ranging from a trace to 6.0 percent. Pyrite, like hematite, was observed in all but two of the studied intervals and varied from a trace to 1.6 percent. Pore-filling "dead" oil residue concentrations Range from 0.2 to 5.6 percent and was observed only in the upper one-half of the core. The major authigenic clay minerals observed were pore-filling, kaolinite, pore-lining illite, and to a much lesser extent pore-lining chlorite.

The diagenetic constituents and their average percentages in relation to the bulk volume within the #1

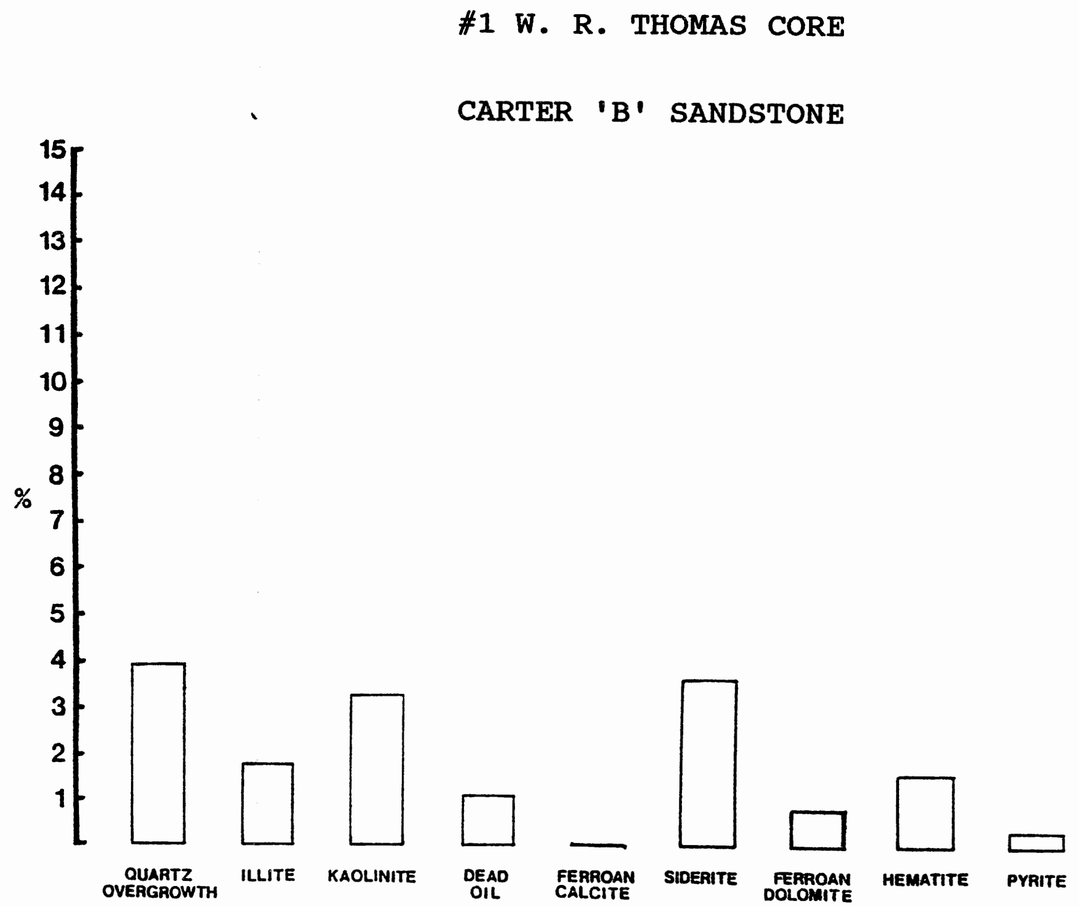

Figure 81. Diagenetic Composition of the Carter `B' Sandstone in the #1 W. R. Thomas Core.

Malone core are: quartz overgrowths (3.2 percent), hematite cement (0.5 percent), ferroan dolomite cement (2.6 percent), pyrite cement (0.3 percent), illite (2.1 percent), and kaolinite (2.4 percent) (Figure 82). Quartz overgrowths were observed throughout the studied interval, ranging from 0.8 to 6.6 percent. Ferroan dolomite cement was found in all the thin sections and is present in a 5 foot interval from 4952' to 4957' and ranges from 8.2 to 12.2 percent (Figure 83). Hematite cement is seen in all the studied intervals ranging from a trace to 1.2 percent. Pyrite cement was also observed in all thin sections ranging from a trace to 1.6 percent. The authigenic clays are dominated by the presence of pore-filling kaolinite and pore-lining illite. Pore-lining chlorite is found only a few intervals in trace quantities. Kaolinite ranges from 0.2 to 14.2 percent (Figure 84), and illite ranges from a trace to 15 percent.

Composition and Classification of the "Millerella" Sandstone

Plotted on a Q-R-F diagram without regard for metastable constituents now dissolved or replaced, the average composition of the "Millerella" Sandstone in the #1 Nason core plots within the quartzarenite subdivision of the triangle (Figure 85). Neither of the slides examined in the study intervals of the core fell outside of the quartz-arenite subdivision in the ternary diagram.

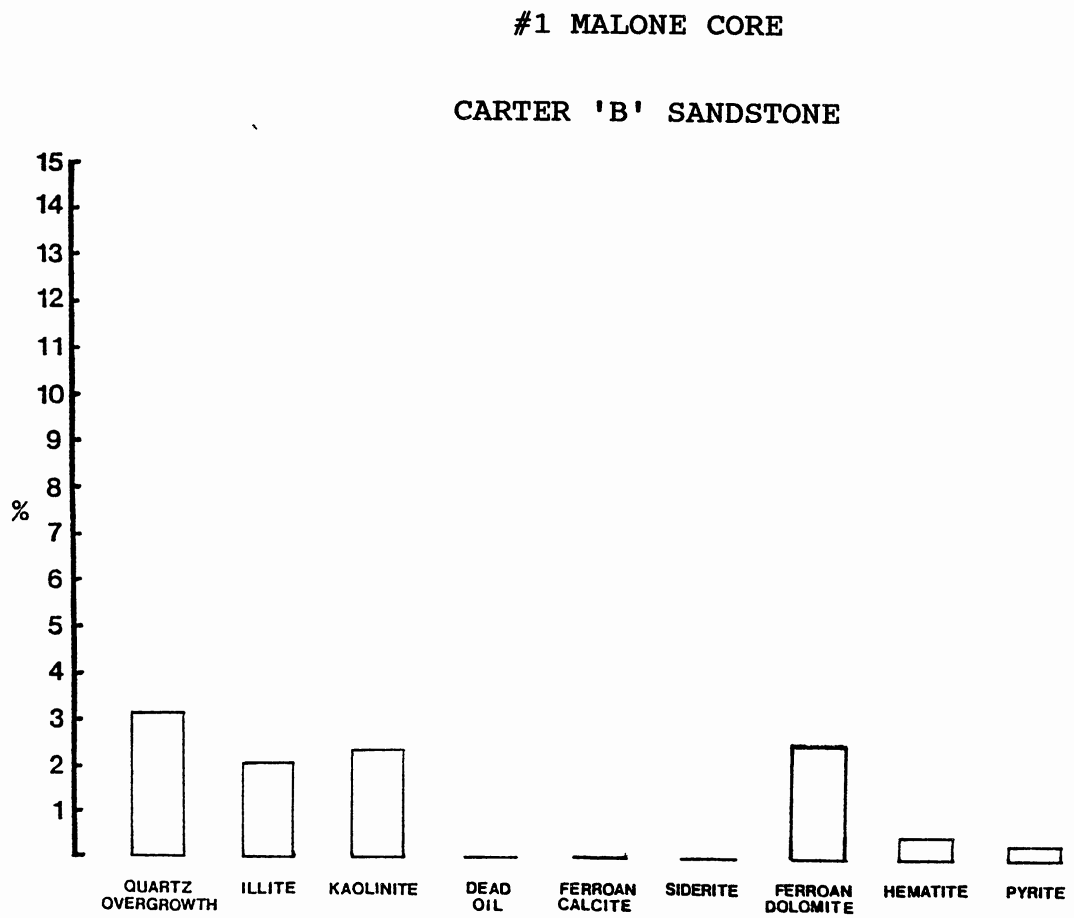

Figure 82. Diagenetic Composition of the Carter `B' Sandstone in the #1 Malone Core.

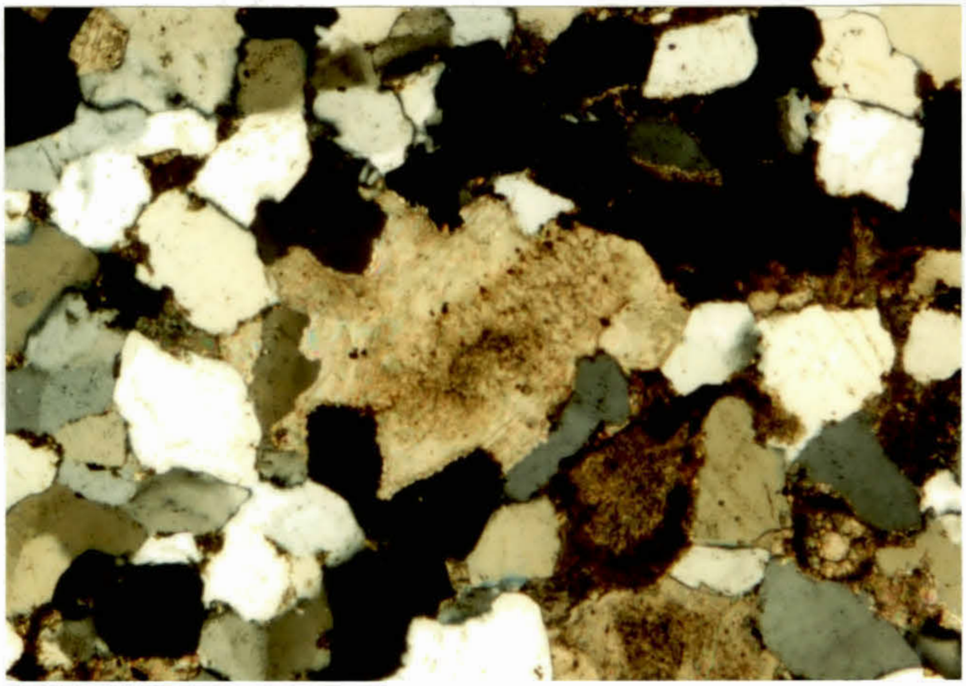

Figure 83. Photomicrograph of Dolomite Cement and Monocrystalline Quartz Grains (40x, Crossed Nichols Light, 4930').

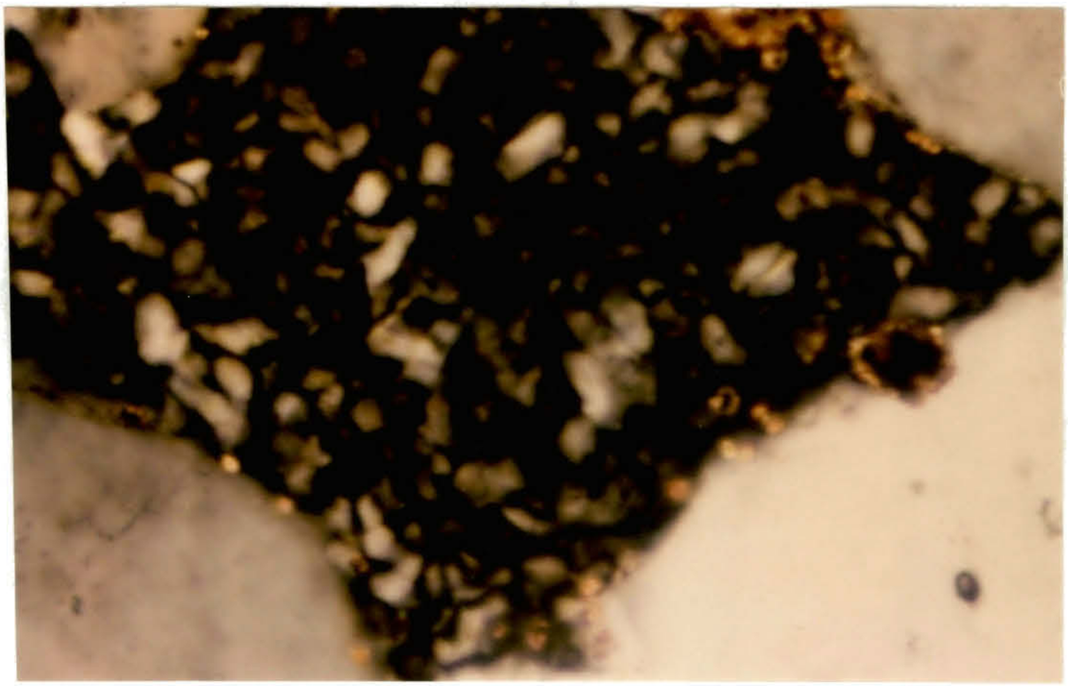

Figure 84. Photomicrograph of Pore-Filling Kaolinite in the Carter `B' Sandstone Exhibiting Micro-porosity (100x, Crossed Nichols Light, 3965').

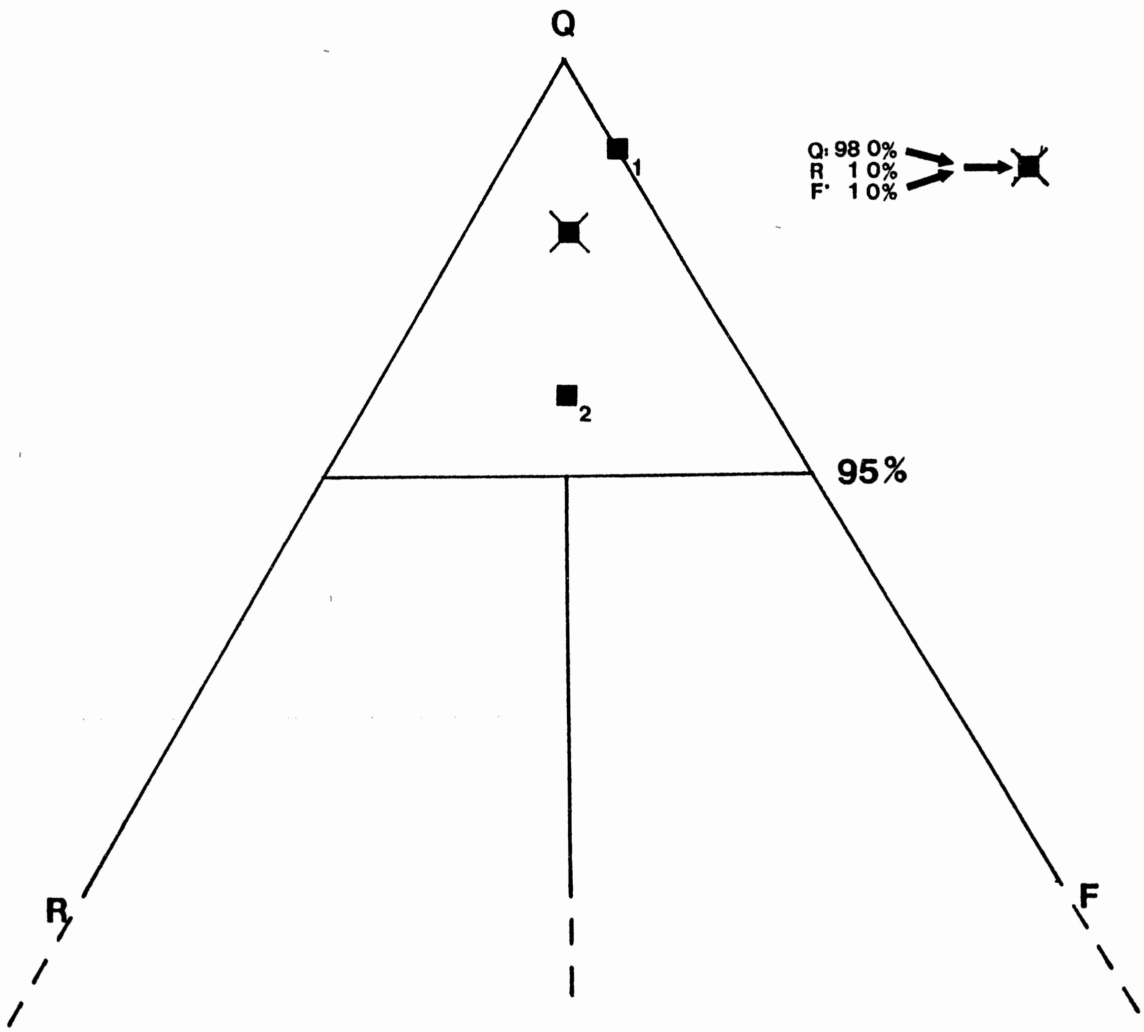

Figure 85. Q-R-F plot of the "Millerella" Sandstone without Regard for Partial Dissolved Metastable Constituents.

Detrital Constituents

The detrital constituents present within the "Millerella" Sandstone are closely related to those found in the previously discussed cores. Figure 86 shows the relative abundance of allogenic constituents in the #1 Nason core. The total monocrystalline quartz percentage average 65.2 percent of the bulk volume and ranged from 48.3 to 82 percent. Polycrystalline quartz contributes minor quantities to the bulk volume ranging from a trace to 4.0 percent. Single grains of plagioclase account for approximately 0.7 percent (Figure 87). Chert fragments average 0.4 percent and shale rock fragment account for only a trace of the total. Accessory minerals are rarely seen as more than trace quantities and include chlorite, muscovite, tourmaline, zircon, and rutile.

Diagenetic Constituents

Figure 88 shows the types and percentages of diagenetic constituents present in the #1 Nason core for the "Millerella" sandstone. The following diagenetic constituents and their average percentage observed in relation to the bulk volume in the #1 Nason core are: illite (9.7 percent), ferroan dolomite cement (15.7 percent), and hematite cement (3.0 percent). Quartz overgrowths are nonexistent as the quartz grains were "coated" by cementing agents or clays before the silica cementation was allowed to

#1 NASON CORE

"MILLERELLA" SANDSTONE

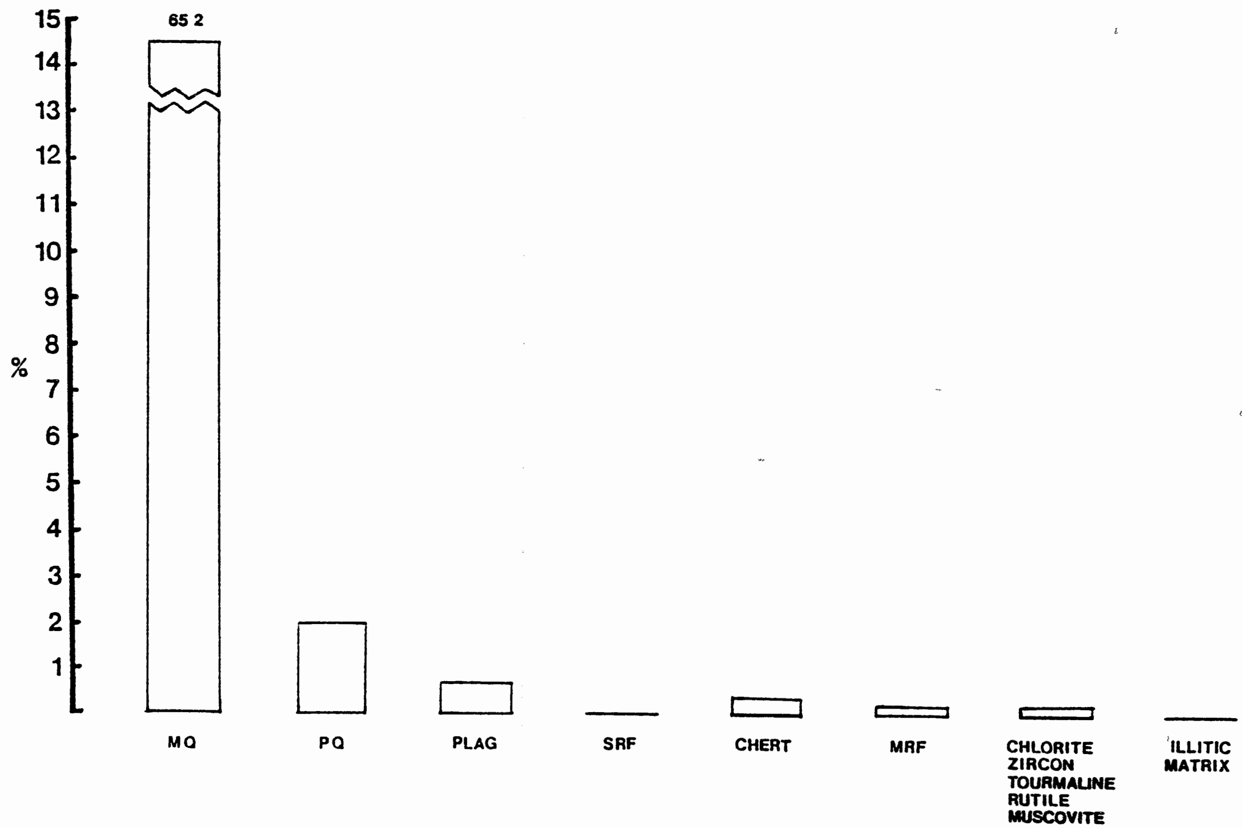

Figure 86. Allogenic Composition of the "Millerella" Sandstone in the #1 Nason Core.

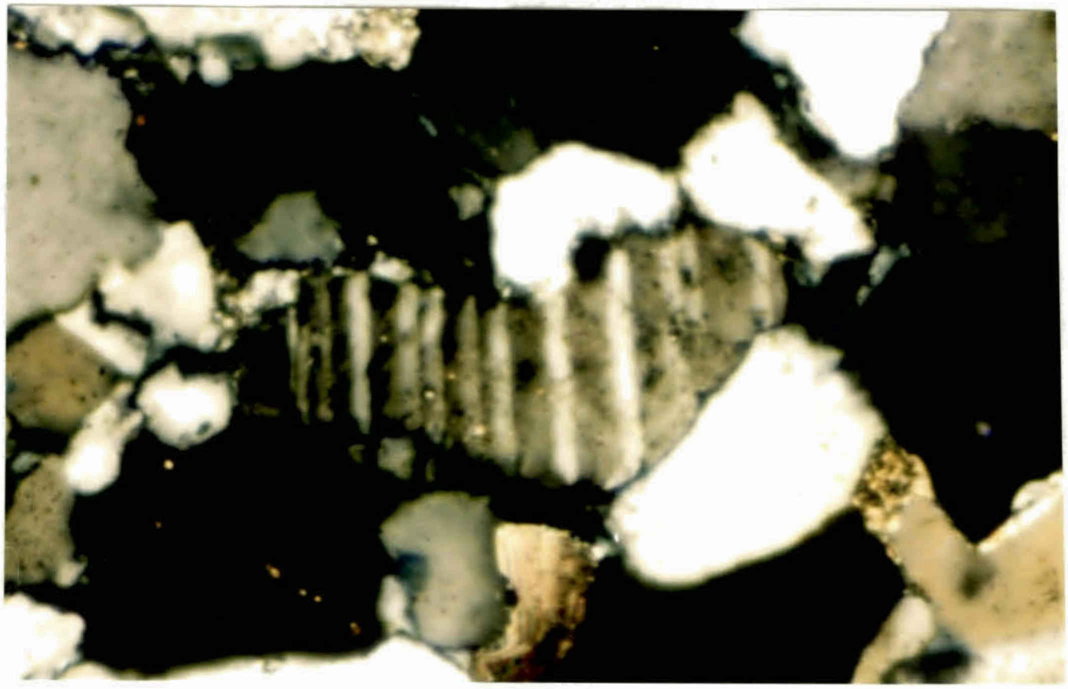

Figure 87. Photomicrograph of Plagioclase Showing Characteristic "Albite Twinning" (200x, Crossed Nichols Light, 3748').

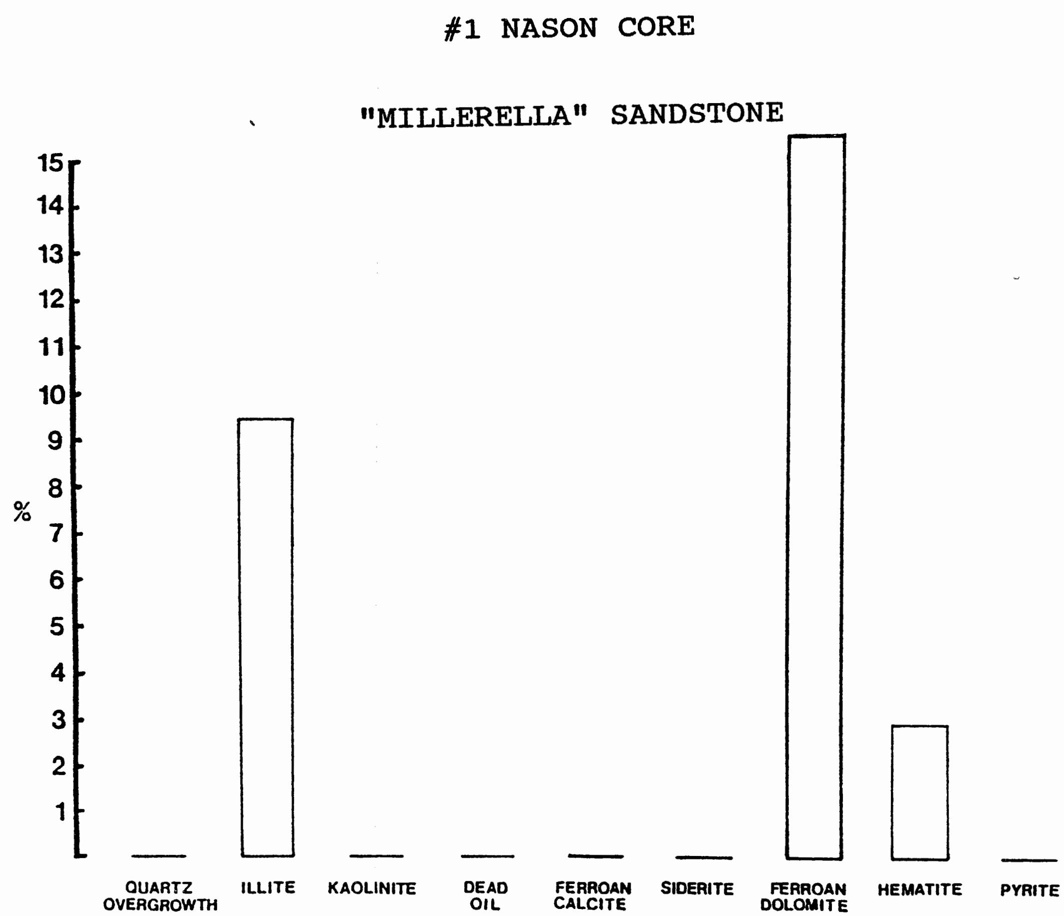

Figure 88. Diagenetic Composition of the "Millerella" Sandstone in the #1 Nason Core.

take place. Although it is possible that other authentic constituents are present, due to the "dirty" nature of the samples, identification is extremely difficult. The two cementing agents are ferroan dolomite, ranging from 7.3 to 24 percent, and hematite, ranging from a trace to 6.0 percent. Illite ranges from 7.7 to 11.7 percent and was the only clay mineral identified.

Diagenetic History of The Carter Sandstone

Porosity types and Evolution

The porosity in the Carter Sandstone examined in this study includes both primary and secondary types. Primary porosity in present in localized areas of the thin sections studied, making up only a minor portion of the total porosity. Secondary porosity includes: partial dissolution of detrital grains, enlarged intergranular porosity with "floating" grains, corroded grains, and honeycombed grains (Figure 89).

The amounts of porosity developed in the five cores were highly variable, and dependent on the types and amounts of dissolution which each core experienced. The amount of dissolution porosity developed is controlled by many factors. Two of the main factors appear to be the amount of detrital matrix and the amount of metastable constituents present. Detrital matrix, which was significant at one time,

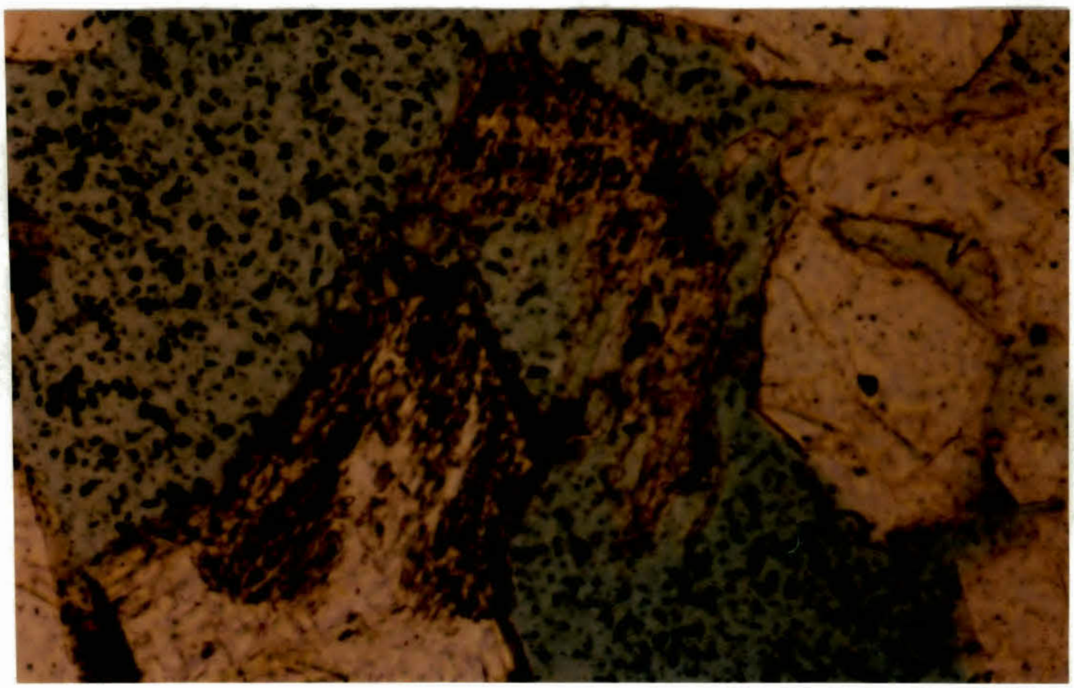

Figure 89. Photomicrograph of "Honeycombed" Porosity Created by Dissolution of a Feldspar Grain (200x, Plane Polarized Light, 3939').

was observed in trace amounts only. This allowed formation fluids of varying pH to cause significant dissolution porosity in many zones of the studied intervals.
Those areas where dissolution porosity is low or not even present are due to the high amounts of cementation, creating an impermeable passage way. As the metastable constituent content increased or decreased, the porosity varied inversely.

The most common types of porosity observed in the cores was enlarged intergranular and corroded grains (Figure 89). Higher porosities exist where metastable detrital matrix was once abundant. Effective permeabilities were inhibited by the formation of pore-filling and pore-lining authigentic clays, such a kaolinite, chlorite, or illite, which occlude pore space and with an absence of enlarged intergranular porosity. The effective porosity and permeability were also inhibited by formation of quartz overgrowth cement, calcite cement, dolomite cement, hematite cement, siderite cement, pyrite cement, and "dead" oil residue which filled pore space.

Paragenesis of the Carter Sandstone

Figure 90 shows a generalized paragenetic sequence of diagenetic events in the Carter Sandstone versus relative time. The metastable constituents noted for this study include plagioclase feldspar, low-grade metamorphic rock fragments, shale rock fragments, detrital matrix and muscovite.

The first stage of diagenesis consisted of the precipitation of an early authigenic siderite which began shortly after mechanical compaction of the sediments. The siderite is then followed by the precipitation of quartz overgrowths. This is evidenced by siderite rhombs lining quartz grains which have then been enshrouded by quartz overgrowths. As burial continued, it is presumed the first stage of mesogenetic calcite precipitation took place, occurring approximately the same time as hydrocarbon generation. The calcite filled the void spaces left after compaction and quartz overgrowth formation. This event was followed by the precipitation of microquartz (chert) which formed in pores. The precipitation of microquartz is followed by the formation of dolomite. The formation of dolomite at depth requires temperatures greater than 80 degrees Celsius (usually between 80 and 100 degrees Celsius), in which calcite precipitation is completely inhibited. Decarboxylation of organic matter will occur in this temperature range. This process most likely occurred in the underlying shales, causing a release of hydrogen ions into the formation fluid, elevating the pH, and creating an acidic fluid again.

The renewed phase of acidic formation fluids moving through the strata caused partial dissolution of matrix and metastable constituents. The formation of pyrite as a minor cementation agent followed, as a result of the hydrogenation of sulfur which is leached from the organic matter. The formation of pore-filling kaolinite, which was the dominant

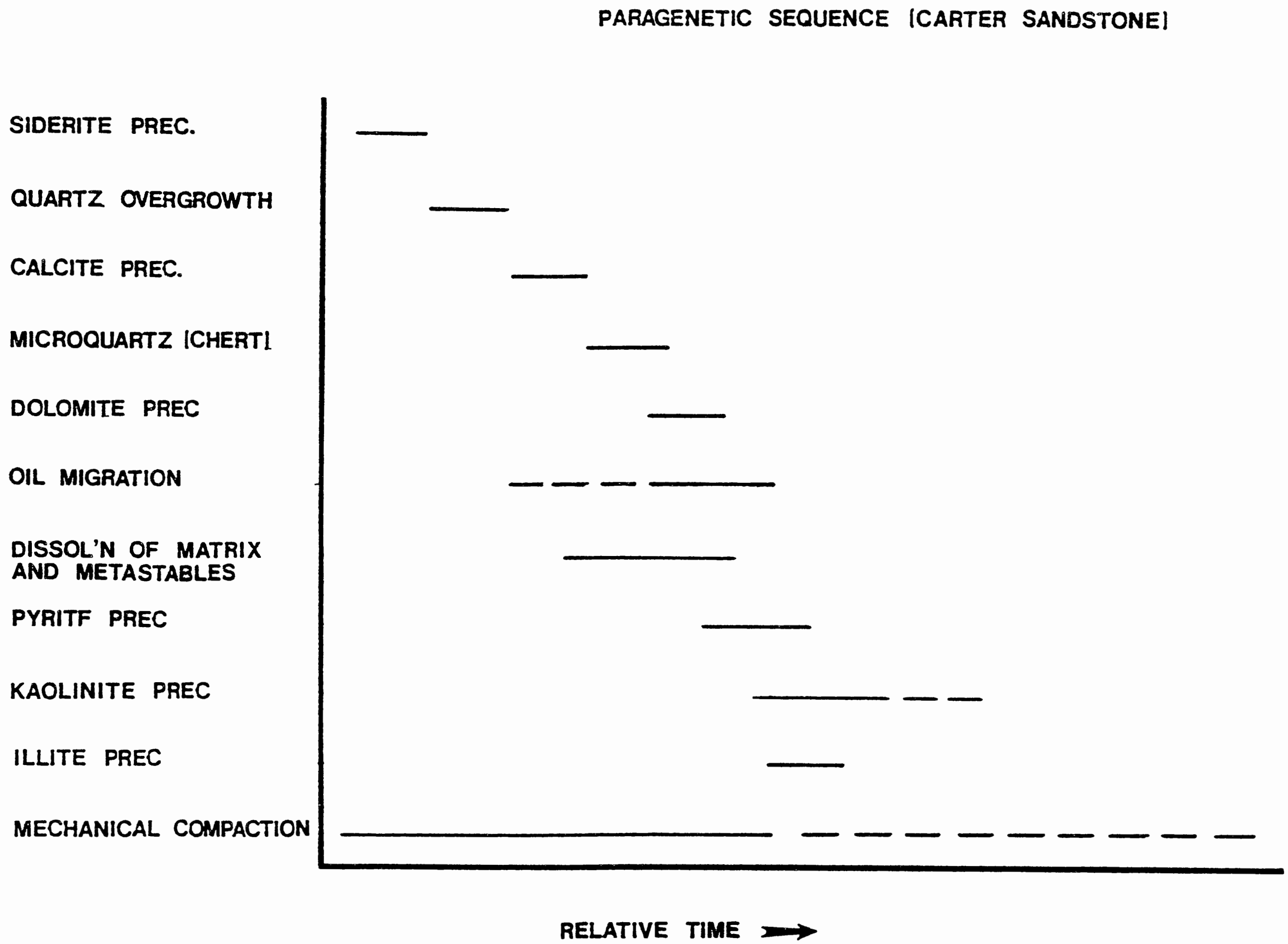

Figure 90. A Generalized paregenetic Sequence for the Carter `A' and `B' Sandstones.

authegenic clay observed in all the core studied, follows due to the release of potassium ions from the dissolution of the illitic matrix. Significant amounts of kaolinite, as seen in the #1 Malone and #1 Thomas core, are indicative of relatively high permeability. The kaolinite precipitation began at the end of the migration of oil, as evidenced by the oil stained kaolinite (refer to Figure 78). It is possible there were several events of oil migration, as it was observed lining and filling pores in other zones. Pore-lining illite can be seen in extremely minor amounts formation at about the same time as kaolinite.

Mechanical compaction was ongoing throughout the sequence of diagenetic events. This is evidenced by long grain contacts and stylolites. As a consequence, partial loss of primary intergranular porosity by ductile deformation, rotation and fracturing of grains took place.

Conclusions

Secondary porosity, which includes enlarged intergranular porosity, honeycombed grains, corroded grains, and partial dissolution of detrital grains, predominates as most of the primary porosity has been diminished. Effective porosity and permeability depends on the interconnective relationship between these porosity types throughout the rock. Where low valves of porosity and permeability are observed it usually is due to pore space having been occluded by the precipitation of kaolinite. Although kaolinization of feldspars can be of local importance, this usually is associated with arkosic sandstones. Not one of the cores studied revealed percentages of feldspar high enough for this phenomenon to take place and was not a factor in this study.

CHAPTER VIII

PETROLEUM GEOLOGY OF THE CARTER INTERVAL

Introduction

The Black Warrior Basin of Mississippi and Alabama is an attractive region for oil and gas exploration for many reasons including:

1. The presence of 15 consistently proven Paleozoic reservoirs allows for a multiple-target exploration strategy;
2. There is a very high success rate for wildcats with an average of over 50%;
3. Shallow pay zones (800 to 6000 feet) generally with average depths less than 4000 feet result in low drilling costs;
4. Little, if any, drilling and completion problems are noted, and;
5. Very little drilling activity took place prior to 1970, which indicates that the Black Warrior Basin as a hydrocarbon producer is still in the younger stages of development.

Exploration History

In 1909, gas production was established as a result of a stratigraphic test well searching for coal in Fayette County, Alabama. This well led to two other deeper test wells which became the basin's earliest gas wells, flowing at initial rates of 1.6 and 4.5 million cubic feet of gas per day. By 1917, more than 40 new wells had been drilled and a small "boom" began in the Black Warrior Basin (Petroleum Frontiers, 1986).

During the next 35 years exploration continued within the basin, increasing or decreasing as demand and pricing dictated. In 1926, the Amory gas field was discovered making this the first Black Warrior Basin field established in Mississippi. It yielded 1.5 billion cubic feet of gas before it was abandoned 12 years later (O'Connor, 1984).

Several fields were discovered in Mississippi between 1953 and 1956. These include Beans Ferry, Coleville, New Hope, Siloam, Trebloc, Hamilton, and Okolona. All of these newly discovered fields produced from the Chester-age sands, except of the New Hope field which produced from an upper Ordovician carbonate interval.

In 1970, the discovery of the East Detroit Oil Field of Lamar County, Alabama caused a "flurry" of activity as leasing picked up and the discovery of three gas fields (East Detroit, Fairview, and Dug Hill) and one oil field (Henson Springs) followed in the next year. These profitable discoveries were made in producing zones ranging from about 1300 to 2500 feet below sea level.

The Black Warrior Basin experienced its best year in 1979, as there were 25 new discovery pools found (15 in Alabama, 10 in Mississippi). This was matched in 1980 as 25 more new pools were discovered, in which 13 were in Mississippi. From 1981 to 1985 a high level of activity continued in Alabama with 80 new wells being discovered. In contrast, Mississippi showed a decline in activity as only 27 new pools were discovered (Bat, 1987).

The present potential for future successful exploration in the Black Warrior Basin appears excellent, as the current Mississippian play is far from spent. New discoveries are annually made in the Carter and Lewis sands. The hidden potential of much deeper carbonate plays continues to provoke much interest due to the limited success already experienced and because of the correlatives to the west (Hunton and Ellenburger Groups) are known to be highly productive in Oklahoma and Texas.

Mississippian-age sediments are the most prolific producers in the basin and account for 90% of all hydrocarbon production. Table 1 outlines the major Mississippian age reservoirs in Mississippi and their production statistics up to 1987.

The most prolific hydrocarbon producing unit in the Black Warrior Basin is the Carter Sandstone. Although the Carter produces some oil (Table I), the unit is the most significant gas producer in the basin. Table II represents a compilation of all the fields in the Mississippi Black Warrior Basin which produce from the Carter 'A' and/or 'B' Sandstones.

Distribution and Trapping Mechanisms of Producing Fields

Exploration with the Black Warrior Basin has generally been carried out by independents and smaller exploration companies. Almost all of the exploration and drilling activity has been exclusively in the shallow, low-risk targets on the Northern Shelf. As a result, there is limited information on the deeper portions of the basin.

Trapping mechanisms within the Black Warrior Basin are structural (high-angle fault-contained), stratigraphic (sand pinchout, permeability barriers) and combination. Virtually all the fields in Mississippi produce from either fault-generated structures (Beans Ferry Field), faulted anticlines (Muldon Field) or from unmodified anticlincal structures (Four Mile Creek Field). Although pure stratigraphic traps are not important exploration targets in Mississippi there has been limited success in some areas. The greatest success with stratigraphic traps has been seen in Lamar and Fayette Counties, Alabama.

Faulting alone as an effective trapping mechanism is generally inadequate on the Northern Shelf of Mississippi. This is due to the fact that the major NW-SE trending "Ouachita" normal faults have an orientation that is subparallel to parallel to the orientation of the progradational trends of the delta lobes. This results in a large cross-sectional area of sandstone offset by the fault increasing the probability of updip migration across the fault (see Figure 91). Faults that have an "Appalachian" trend (N65^{O}E) do have the ability to trap hydrocarbons. The Beans Ferry Field of central Itawamba County and the Muldon Field of southwest Monroe County formed as a result of "Appalachian" faults which are oriented perpendicular to the progradational axis of the producing sandstone bodies.

By superimposing the net sandstone isoliths of the Carter 'A' and 'B' units with the structure map on the base of the "Millerella" Limestone, along with the distribution of production of the Carter 'A' and 'B', some observations have been made in regard to the trapping mechanisms within the study area.

Carter 'A' production in Mississippi occurs in the upper delta plain associated with the secondary (generally down to the north) faults with closure on the upthrown side and in unmodified anticlinal structures. Some examples include Four Mile Creek Field, Splunge Field, Corinne Field, Okolona Field, and the Muldon Field. These fields occur depositionally in a fluvial-deltaic environment that contained enough metastable constituents to allow for moderate secondary porosity to evolve. More specifically these fields are producing from distributary channel sands, point bar accumulations, and crevasse splays deposits.

TABLE I

MISSISSIPPIAN PRODUCTION STATISTICS IN MISSISSIPPI BY HORIZON (1987)

Mississippian Producing Horizon	Oil (BBLS)	GAS (McF)
Buskirk Sst.	2,077	218,719
Millerella Sst.	10,193	1,109,029
Carter Sst.	307,164	183,923,252
Sanders Sst.	269,928	117,057,819
Abernathy Sst.	17,583	2,332,624
Rea Sst.	914	2,362,320
Evans Sst.	803	9,807,397
Lewis Sst.	784,931	30,955,682
Total Mississippian	1,393,593	347,766,842
Commingled Pools		
Carter/Abernathy	12,479	39,420
Sanders/Lewis	113,795	626,599
Evans/Lewis	0	52,351
Total Commingled	126,274	718,370
Grand Total	1,519,867	348,485,212

*Compiled from 1988 Annual Production Report, published by Mississippi State Oil and Gas Board.

TABLE II

MISSISSIPPI FIELDS PRODUCING FROM CARTER 'A' AND/OR CARTER 'B'

FIELD NAME	COUNTY, STATE	LOCATION	DISC DATE
Aberdeen	Monroe, MS	31-14S-7E	12-09-80
Aberdeen, S.	Monroe, MS	9-15S-7E	11-01-85
Aberdeen, N.	Monreo, MS	26-14S-7E	05-05-89
Amory	Monroe, MS	7-13S-17W	10-06-26
Amory, S.	Monroe, MS	36-13S-18W	04-20-71
Athens	Monroe, MS	7-14S-18W	08-19-81
Bacon	Chickasaw, MS	15-12S-4E	03-21-79
Beans Ferry	Itawamba, MS	17-10S-93	11-01-63
Buttahatchie River	Monreo, MS	30-15S-17W	08-13-77
Caledona	Lowndes, MS	34-15S-17W	06-04-77
Ceder Grove	Monroe, MS	17-15S-17W	01-10-74
Cooper Creek	Lowndes, MS	34-16S-17W	01-28-81
Cornine	Clay, Lowndes, Monroe, MS	19-16S-8E	02-18-75
County Line	Lowndes, MS	22-15S-17W	02-02-85
Cowpenna Creek	Monroe, MS	12-12S-6E	10-03-81
Fourmile Creek	Monroe, MS	17-12S-18W	01-03-73
Gibson	Chickasaw, Clay, MS	34-14S-5E	12-05-78
Glenhaven	Monroe,MS	1-15S-17W	10-11-85
Goodwin	Itawamba, Lee, Monroe, MS	28-11S-7E	04-13-85
Greenwood Springs	Monroe, MS	15-14S-17W	11-14-78
Hamilton	Monroe. MS	12-15S-18W	09-23-54
Houston	Chickasaw, MS	11-14S-3E	04-21-84
Kinney Creek	Monroe, MS	21-13S-17W	12-06-84
Maple Branch	Lowndes, Monroe, MS	1-16S-18W	08-17-76
McKinley Creek	Monroe, MS	21-15S-18W	06-06-75
Okolona	Monroe, MS	28-12S-6E	02-27-56
Pleasant Grove	Monroe, MS	17-14S-6E	04-20-85
Riverline	Monroe, MS	7-15S-18W	01-18-83
Shannon	Lee, MS	23-11S-5E	09-28-85
Siloam	Clay, MS	36-16S-6E	06-13-53
Smithville	Monroe,MS	17-12S-18W	01-07-73
Splunge	Monroe, MS	24-12S-17W	07-11-73
Splunge, S.	Monroe, MS	2-13S-17W	08-02-73
Steens	Lowndes, MS	22-17S-17W	06-20-82
Stinson Creek	Lowndes, MS	4-17S-18W	02-11-85
Stonewall, Creek	Monroe, MS	29-14S-18W	08-12-88
Strong	Monroe, MS	6-16S-18W	01-07-73
Sugar Run Creek, S	Chickasaw, MS	15-12S-5E	06-10-84
Thorn	Chickasaw, MS	22-13S-2E	06-10-78
Tombigbee River	Monroe, MS	1-15S-7E	01-04-84
Trebloc	Chickasaw, MS	19-14S-5E	03-14-53
Wise Gap	Monroe, MS	30-14S-17W	06-13-83

The Carter 'B' production in Mississippi, like the Carter 'A', occurs in the upper delta plain. It is associated with the secondary faults with closure on the upthrown side. Further, there is good production associated with unmodified anticlinal highs in various portions of the study area. Faulted anticlines provide the best conditions for the entrapment of hydrocarbons and are responsible for many of the productive fields. The Muldon, Corinne and Greenwood Springs Fields all produce from faulted anticlines. However, other fields simply produce from anticlinal structures with no associated faulting. These fields include Maple Branch Field and Four Mile Creek. Exploration targets include distributary channel sands, channel mouth bar sands, point bar deposits and crevasse splay deposits.

In conclusion, the most promising targets for Carter production are faulted anticlinal structures and unmodified anticlines. The most significant factors involved in the quality of the reservoirs are the dominant depositional settings of the rock and the post-depositional modifications of the detrital and diagenetic constituents in which porosity evolves.

<u>Production Statistics</u>

Summaries of the Carter Sandstone hydrocarbon production by fields for 1989 are given in Table 3. Table 3 contains statistics for Mississippi production published in

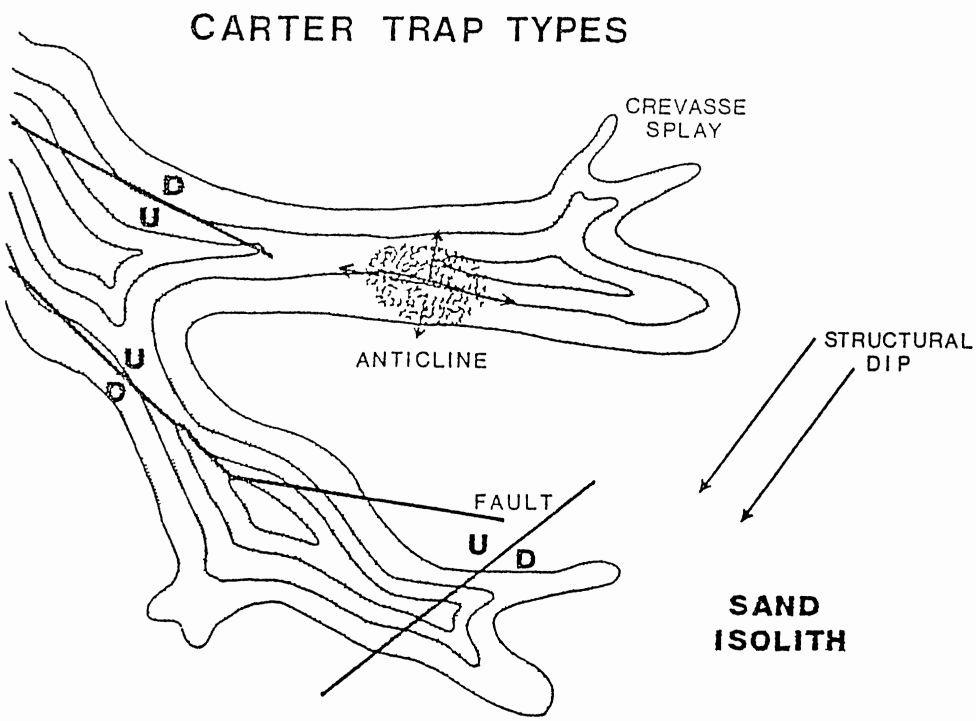

Figure 91. Carter Trap Types. (Cleaves, 1983).

the Annual Production Report by the Mississippi State Oil and Gas Board.

Production from the Carter Sandstone is predominantly natural gas, but a few wells in Mississippi produce moderate to low quantities of oil as well. The dominant gas producing fields are Buttahatchie River, Corinne, Splunge, and Wise Gap Fields, whereas the major oil producing fields are the Buttehetchie River, Corinne, Pleasant Grove, and Trebloc Fields.

TABLE III

CARTER PRODUCTION STATISTICS FOR MISSISSIPPI BY FIELD*

				Annual Production			Cumulative Production		
Field	Company	Lease	Well Number	Oil (BBL)	Water (BBL)	Gas (MCF)	Oil (BBL)	Water (BBL)	Gas (MCF)
Aberdeen	Pacific Enterprises Oil Co	L. T Senter 30-15	1	0	0	0	0	235	211544
Aberdeen, S	Moon, Hines & Tigrett	Bradley 16-4	1	0	0	55763	0	0	55763
	Pruet Prod. Co	James L. Cosby et al 9-11	1	14	126	172585	14	150	1006523
Aberdeen, E	Pacific Enterprises Oil Co	Patterson 26-12	1	0	0	163644	0	0	1006523
Amory, S	Ralph Crump	A E Crump	1	0	0	0	0	275	575379
Athens	Vision Oper Co.	Dalrymple	1	0	402	20453	0	748	153540
Bacon	Holleman & Parks Oil	Travis Davis 15-5	1	0	0	7327	0	0	7327
		Charlotte Hendrick 15-10	1	0	0	47536	0	0	47536
Buttehatchie R	Pruett Prod Co.	Day Brothers	1	35	55	278486	413	117	3753455
		Dobbs Unit 29-5	1	2	50	25843	995	93	2833497
		Dobbs Unit 29-12	1	3	30	27011	1474	149	2325535
		Dobbs Unit 30-7	1	19	22	126793	460	209	3336058
		Harmon 24-16	1	22	0	205084	520	63	3743189
		Irons 25-3	1	6	17	30888	1257	30	1883914
		Monroe Co Tractor Co 31-3	1	0	0	0	1032	1064	417062
		Sartor	1	30	41	190145	459	142	3615392
		Weyerhauser	1	0	0	144234	1893	134	3966289
Caledonia	ElfAquitane Oper. Inc	L Smith	1-4	0	90	752232	1903	525	6631280
		Ralph Williamson	1-33	0	55	574752	903	342	6227372
	Pruet Prod. Co	Brock et al 10-4	1	5	14	25012	17	81	578743
	Norcen Explorer Inc	Bowen 2-15	1	2694	219	319	2694	219	319
Corinne	Grace Petroleum Corp.	Dabbs	4-T	0	0	0	12313	329	219633
		Dabbs	2-2C	8	4	31072	623	3056	917377
		Dabbs-Richardson	6-2-UT	0	0	0	2313	959	1496485
		Gore Heirs	1-T	240	0	60292	8100	101	728864
		Self II	1	48	0	24702	4042	421	1115148
		Self 12	1	70	7	49571	2336	258	1403834
		Self	12-2C	66	20	35893	565	284	643217

*Compiled from 1989 Annual Production Report, published by the Mississippi State Oil and Gas Board

TABLE III (cont.)

Field	Company	Lease	Well Number	Annual Production Oil (BBL)	Annual Production Water (BBL)	Annual Production Gas (MCF)	Cumulative Production Oil (BBL)	Cumulative Production Water (BBL)	Cumulative Production Gas (MCF)
	Pruet Prod. Co.	Weyerhauser 23-16	1	0	0	678	1230	36	422575
	Torch Oper. Co.	Martin 19	3-T	66	25	39800	5409	59	2253620
		Columbus AFB Parcel 3	1	0	0	0	203	0	95671
		Self 13	4	20	6	18642	373	6	163944
		Cunningham 24	1-C	3	9	11692	162	22	132021
		Self-Day 14	2-C	24	129	39937	10423	129	3995317
	TXO Production Corp.	Columbus AFB 19-15	1	0	0	23006	2090	7	1366682
	Blue Valley Petr	Federal CAFB 25-2	1	120	52	122063	4559	45929	1872803
	Grace Petr. Corp	Self	12-2L	0	8	55327	1559	404	1758168
		Dr R. T. Dabbs	1-UT	35	0	44453	12180	388	2701035
		Richardson	5-2	63	0	329217	16788	257	8625917
		SelfII	1	0	3	98521	6028	361	3758517
		Self 12	1	0	28	147713	1917	427	3937448
	Torch Oper. Co.	Camp 19	1	0	0	5247	345	0	106751
		Camp 24	1-C	376	37	95818	5397	27381	3256486
		Columbus AFB Parcel 1	2	0	0	252	668	0	303344
		Columbus AFB Parcel 4	1	0	0	0	217	0	100759
		Campbell 19	1	65	2	33369	9281	39	3290109
		Campbell 30	1	74	0	3606	15573	21939	3184784
		Columbus AFB Parcel 1	1	20	8	18260	282	8	211838
Corinne	Torch Oper Co.	Columbus AFB Parcel 3	1	42	65	43918	11685	65	2438188
		Cunningham 24	2	0	0	3396	2682	0	1153941
		Martin 19	1-C	149	0	56992	15896	20213	5511121
		Martin 19	2-T	176	0	100583	11722	25077	3899644
		Martin 24	1-C	72	0	57599	413	36	694868
		Self 13	1-T	0	0	0	3011	0	432604
		Self 13	2-C	19	0	32341	1301	0	418288
		Laws 23	1-T	270	39	25363	2521	70	356196
		Self-Day 14	2-T	19	0	20627	10223	0	383304
		Self 14	5-T	0	0	0	1495	0	388970
		Self-Day 23	1-T	235	63	79538	18594	66	3765641

TABLE III (cont.)

Field	Company	Lease	Well Number	Annual Production Oil (BBL)	Annual Production Water (BBL)	Annual Production Gas (MCF)	Cumulative Production Oil (BBL)	Cumulative Production Water (BBL)	Cumulative Production Gas (MCF)
		Weyerhauser 24	2-C	0	0	711	872	0	179201
		Wilson 24	1-T	0	2	20692	12801	2	3000472
		Wilson 24	2-T	0	0	0	0	0	1480
	TXO Production Corp.	Columbus AFB 19-15	1	72	58	130907	1204	408	1696858
	Torch Oper. Co.	Columbus AFB parcel 5	1	0	0	0	309	0	65653
County Line	Norcen Explorer Co.	Harrison 27-2	1	0	0	166096	0	0	533545
	Pruet Prod Co.	Grant 22-14	1	39	180	198070	53	337	1786892
Cowpenna Creek	Sierra Prod Co.	Felix Coggin	1	0	0	290	0	111	321662
		H. J. Murff	1	0	0	30937	0	0	30937
Fourmile Creek	Anderman-Smith Oper. Co.	Tubb 20-11	1	0	0	37250	0	0	210430
	Grace Petr Corp.	Armstrong Unit	1	0	26	284044	0	216	2319889
		Glascow	1	0	0	0	0	2457	2131661
		Leech Unit	1	0	1052	28192	0	1352	3634519
		Tubb	1	0	0	317660	0	3	2822051
	TXO Prod Corp.	Tubb 20-10	1	0	3	66560	0	13	350294
Goodwin	Puret Prod. Co	Hinson 28-6	1	0	0	51741	0	0	282071
Greenwood Springs	Puret Prod. Co	Bd. of Supervisors 16-8	1	0	0	0	429	2777	352456
		Davis 10-13	1	0	0	0	0	0	1242
Hamilton	George H Miller	Mrs. L. W. Rea	1	0	0	0	0	0	240425
Kinney Creek	Energy Three Inc.	Weyerhauser 21-1	1	0	0	0	0	0	8131
Maple Branch	Pruet Prod. Co.	Aldridge 17-13	1	6	2	46732	104	116	843833
		Egger 20-11	1	0	0	0	148	1344	355240
		Stephenson 7-15	1	1	12672	294583	390	18273	2012951
		L. M. Wright 29-1	1	34	754	51308	264	3369	341042
McKinley Creek	Grace Petr Corp.	James B. Cokerham	1	0	0	408083	953	70086	4330345
		Simmons-Boyd	22-13	0	3554	23566	35	20575	1015751
		West et al	1	0	56	132132	269	16692	2148635
Pleasant Grove	Morrow Oil & Gas Co.	Herndon 20-2	1	3324	1853	48030	3324	1853	48030
	Pruet Prod Co	Millender 17-13	1	188	3604	277829	617	12603	669231
Shannon	Moon, Hines & Tigrett	Godwin 23-5	1	0	0	0	0	0	146479
		West 25-4	1	0	0	0	0	0	135535

TABLE III (cont.)

Field	Company	Lease	Well Number	Annual Production Oil (BBL)	Annual Production Water (BBL)	Annual Production Gas (MCF)	Cumulative Production Oil (BBL)	Cumulative Production Water (BBL)	Cumulative Production Gas (MCF)
Siloam	Brusoil Inc.	Federal Land Bank et al	1	0	0	35241	15279	10891	4901860
		Jarrett et al	1	0	0	39160	25132	11117	7040162
		Rogers et al R.	1	0	0	22042	1271	19196	1109108
Splunge	Grace Petr. Corp.	Collier Unit 20-1	1	0	5	129310	0	5	1109108
		Crowe Unit 25-1	1	0	6	81924	0	6	973783
		Dalrymple Unit 24-1	1	0	0	47017	0	0	1363044
		Jones 24-6	1	0	0	83057	0	0	1512887
		Knight Unit 29-4	1	0	9	559159	0	9	3062135
		Markham Unit 19-10	1	0	0	271079	0	0	2210514
		Miller Unit 29-2	1-C	0	0	308370	0	0	2465052
		Ray Unit 30-2	1	0	63	363203	0	63	2114013
		Silas Unit 21-4	1	0	5	82173	0	5	921783
Splunge	Grace Petr Corp.	Weyerhauser 13-14	1	0	0	39269	0	0	1055836
		Weyerhauser 17-12	1	0	5	88830	0	5	961311
		Weyerhauser 18-13	1	0	6	132318	0	6	1714486
		Weyerhauser 19-3	1	0	0	179654	0	0	2430880
		R E. Williamson Unit 20-11	1	0	0	258456	0	0	2605639
		Williamson Unit 28-6	1	0	6	29560	0	6	1326550
	TXO Prod. Corp.	Williamson 21-15	1	0	0	123905	0	626	1803460
	TXO Prod. Corp.	Weyerhauser	1	2	0	44454	17	54	302598
	Grace Petr. Corp	Lochridge 21-14	1	0	0	18800	0	0	30872
		Weyerhauser	18-10	0	0	77311	0	0	501716
	TXO Petr. Corp.	Gilmer-Puckett 1808	1	0	0	81196	0	2	903213
	Grace Petr. Corp.	Gilmer-Puckett 17-5	1	0	0	18606	0	0	194288
Stinson Creek	Pruet Prod Co.	Newman 4-3	1	17	9	25773	142	47	64772
Stonewall Creek	Justiss Oil Co., Inc.	W. L. Scott 29-1	1	0	0	94519	0	4	112684
		Weyerhauser 28-5	1	0	2604	27725	0	2604	27725
Strong	Howard G. Nason	Watson	1	0	0	61592	0	0	515555
		Watons 5-13	1	393	0	0	4252	226	7856
So Sugar Run Creek	Gibraltar Energy Co.	Franklin Ellis 15-9	1	0	19	27375	0	316	107042
Thorn	Sam I. Smith	Henry I. Black Unit 1	1	0	0	0	0	44	2688

TABLE III (cont.)

Field	Company	Lease	Well Number	Annual Production Oil (BBL)	Annual Production Water (BBL)	Annual Production Gas (MCF)	Cumulative Production Oil (BBL)	Cumulative Production Water (BBL)	Cumulative Production Gas (MCF)
Trebloc	Ceja Corp.	Baskin Heirs	2	3560	0	2796	14852	1325	190362
		Pulliam	1	2393	0	17019	2962	942	750283
Wise Gap	Ensource Inc.	E. C Brewer	1	0	0	0	0	1098	210642
		J. Cockerham 33-4	1	0	0	878323	0	0	2036850
	Norcen Explorer, Inc.	Cockerham Unit 32-2	1	0	0	633852	0	8	1860006
	Pruet Prod Co.	C. C. C. Inc 29-14	1	0	33	682084	0	70	1932771
		C. C. C Inc. 30-9	1	10	498	288482	10	1268	897544
		TN River P & P. Co 30-1	1	0	11971	316480	0	12804	1389041

CHAPTER IX

SUMMARY AND CONCLUSIONS

The subsurface/surface and petrographic analysis of the Carter and Batesville Sandstones, along with the study of the distribution and depositional environments of the Carter 'A' and 'B' Sandstones, has yielded evidence upon which several conclusions can be drawn. The conclusions are:

1. The Carter 'A' and 'B' Sandstones were deposited on the Northern Shelf of the Black Warrior Basin in a high-constructive elongate delta complex.
2. Preferred orientation of the Carter Sandstone indicates the depocenter to be further north and east than the present-day axis of the basin which is southwest of deposition.
3. Analysis of the petrographic detrital constituents reveals very similar percentages, and graphing these results indicates a cratonic source for both the Carter and Batesville Sandstones.
4. The Carter Sandstone had a northerly source, most likely from the Illinois Basin, or further north to northeast, as evidenced by the predominance of monocrystalline quartz and presence of only minor amounts of polycrystalline quartz and metamorphic

rock fragments in thin sections.

5. Original primary porosity and permeability, in the four (4) Carter cores studied, has been destroyed by compaction and cementation of the detrital grains. The existing porosity is secondary and results from the dissolution of matrix, authigenic clays and cements, and metastable grains.

6. Secondary porosity and permeability development from analysis of the Carter cores are partially to fully occluded when authigenic kaolinite, illite, calcite, dolomite, hematite, siderite, pyrite and quartz infill and/or line the corroded, honeycombed, and enlarged intergranular dissolution pores.

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APPENDIX A

PETROGRAPHIC DATA FROM OUTCROP AND CORE

DETRITAL CONSTITUENTS
CARTER 'A' SANDSTONE
#1 J. T. EVANS
MONROE COUNTY, MISSISSIPPI
SEC 5-T152-R6E

SLIDE NUM	DEPTH (FEET)	MQTZ	PQTZ	FELD	MRF	SRF	CHRT	CHL	MUSC	TOUR	ZIRC	RUTL	POROSITY PRI	SEC
PECA1	-4167	83 3	5 7	0.7	0.7	0 9	9.9	--	0 0	0 0	0.0	---	---	0.0
PECA2	-4172	79 0	5.0	3.0	1.0	0 7	0.0	---	0.0	0.0	0.0	---	0.7	1.7
PECA3	-4174	81.0	0.0	0.0	0 0	0.0	0.0	---	0.7	0.0	0.0	---	---	3.3
PECA4	-4176	85.3	3.3	1.7	0.0	0.0	0.3	---	0.0	0 0	0.0	---	---	2.7
PECA5	-4178	79.0	4.0	3.0	0.0	0.0	2.0	---	0 3	0.0	0.0	0.0	---	1.0
PECA6	-4182	80.3	6.0	0.3	0.7	0.0	0 0	0 0	0.0	0.0	0.0	0.7	---	1.0
PECA7	-4188	81.3	2 7	0 0	0.0	0.0	0 0	---	0.0	0.0	0.0	---	---	3.3
PECA8	-4190	81 3	1.3	0.0	0 0	0.0	0.0	--	---	0.0	0.0	---	---	0.0
PECA9	-4194	89.7	0 0	1 3	0.0	0 0	0.0	--	0.0	0.0	0.0	0.0	2.0	1.3
PECA10	-4198	83.3	3 7	0 0	1.0	0.0	0 0	0 0	0.0	0 0	0.0	---	---	2.3

DIAGENETIC CONSTITUENTS
CARTER 'A' SANDSTONE
#1 J. T EVANS
MONROE COUNTY, MISSISSIPPI
SEC. 5-T15S-R6E

SLIDE NUM	DEPTH (FEET)	KAOL	ILL	CHLR	HEM	PYR	SID	SER	DOLO OIL	DEAD	CEMENT CARB	QTZ	FSP
PECA1	-4167	2.0	0 0	---	0 3	- -	0 7	1 0	0 0	0.0	3.3	2 3	---
PECA2	-4172	2.7	0.7	---	0 7	---	0.0	0.3	---	---	0.7	2.7	---
PECA3	-4174	0.7	1.0	---	1 7	---	8 0	0.3	---	---	0.3	3.0	---
PECA4	-4176	1.3	0.0	---	0 0	---	---	0.0	---	0 0	1 0	4 3	---
PECA5	-4178	2.7	0 0	---	0.0	---	0.0	0.0	---	2 3	2.0	2.7	---
PECA6	-4182	2.3	1 0	---	--	---	---	0.0	---	---	0.0	3.7	---
PECA7	-4188	7.7	0.7	---	0.0	---	---	0.0	-	0.0	0.3	4.0	---
PECA8	-4190	7.3	0.0	---	0.3	0 0	---	1 3	--	0 0	5 0	3.3	---
PECA9	-4194	1 0	0 0	---	0 7	---	1 0	0.0	---	0 0	0.0	3.0	---
PECA10	-4198	3 0	0.0	---	0.0	---	---	1.3	---	0 7	0.3	4.3	---

0.0% = TRACE AMOUNTS NOTED IN THIN SECTION EXAMINATION.
--- = CONSTITUENT NOT SEEN IN THIN SECTION EXAMINATION.

DETRITAL CONSITUENTS
CARTER 'A' SANDSTONE
#1 LEECH
MONROE COUNTY, MISSISSIPPI
SEC. 18-T12S-R18W

SLIDE NUM.	DEPTH (FEET)	MQTZ	PQTZ	FELD	MRF	SRF	CHRT	CHL	MUSC	TOUR	ZIRC	RUTL	POROSITY PRI	POROSITY SEC
PHCA1	-1740	80.4	3.4	2.4	---	---	0 0	---	---	---	0.0	---	1.4	5.6
PHCA2	-1742	80.8	2.0	0.4	---	---	0.0	---	---	0.0	0 0	---	1.6	6.6
PHCA3	-1746	85.8	0.0	0.6	---	---	0.0	---	0.0	0.0	0.2	0.0	0.4	5.6
PHCA4	-1747	86.0	0.0	8.0	---	---	0.0	---	0.0	---	---	---	1.4	6.2
PHCA5	-1752	76.6	1 2	0 0	---	---	0.0	0.0	0.0	0.0	0.0	0.0	3.2	3.4
PHCA6	-1756	82.6	1.4	0.4	---	---	0.0	0 0	0.0	0.2	---	0.0	3.4	4.4
PHCA7	-1759	80.2	3.6	0.0	---	---	0.0	---	---	0.0	0.2	---	2.0	8.2
PHCA8	-1761	80.0	2.8	0.8	---	---	0.0	0.0	---	0.0	0.0	0.0	3.6	1.6
PHCA9	-1764	83.0	1.4	0.4	---	---	0.0	---	0.0	0.0	0.2	0.0	6.8	5.0
PHCA10	-1767	83.2	2.8	0.0	0.0	---	0.4	0.0	---	0.0	0.2	0.0	2.2	7.0
PHCA11	-1772	83.2	0.8	0.4	0 0	---	0.0	--	0.0	0.0	0.0	0.0	2.8	7.2
PHCA12	-1776	83 2	0.2	1.8	0.0	---	0.0	---	---	0.4	0.0	0.0	5.2	6.2
PHCA13	-1781	87.7	1.3	0.0	0.0	0.0	0.0	---	0.0	0.0	0.0	0.0	0.0	5.7
PHCA14	-1783	84.3	2.7	0.0	0.0	---	0.0	---	0.0	0.0	0.0	0.0	4.7	3.7
PHCA15	-1785	72.0	2.7	0.0	0.0	0.0	1.3	---	0.0	0.0	0.0	0.0	3.7	3.7

DIAGENETIC CONSTITUENTS
CARTER 'A' SANDSTONE
#1 LEECH
MONROE COUNTY, MISSISSIPPI
SEC. 18-S12S-R18W

SLIDE NUM.	DEPTH (FEET)	KAOL	ILL	CHLR	HEM	PYR	SID	SER	DOLO	DEAD OIL	CEMENT CARB	CEMENT QTZ	CEMENT FSP
PHCA1	-1740	1.0	3.0	---	0.0	0.0	---	0.0	---	---	0.0	2.8	---
PHCA2	-1742	2.0	4.2	---	0.0	0.0	---	0.0	---	---	---	2.2	---
PHCA3	-1746	0.6	2.2	---	0.0	0.4	---	0.0	0.6	---	0.6	2.2	---
PHCA4	-1747	2.4	0.2	---	0 6	0.0	---	0.8	0.0	---	0.0	1.4	---
PHCA5	-1752	1.4	0.8	---	10.0	0.2	---	0.4	---	---	0.0	2.8	---
PHCA6	-1756	3.0	0.0	---	0.4	0.0	---	12.4	1.6	---	0.0	3.0	---
PHCA7	-1759	2.0	0.0	---	---	0.2	---	0.4	---	---	1.0	2.2	---
PHCA8	-1761	1.4	0.8	---	---	---	---	---	4.8	---	---	4.2	---
PHCA9	-1764	0.8	2.2	---	0.0	0.0	---	---	---	---	0.0	1.4	---
PHCA10	-1767	1.2	0.8	---	1.4	0.0	0.0	---	---	---	0.0	0.8	---
PHCA11	-1772	2 4	1.2	---	0.4	0.2	---	---	---	---	0.4	0.8	---
PHCA12	-1776	0.6	0.4	---	0.0	0.6	---	---	---	---	0.0	1.4	---
PHCA13	-1781	0.7	0.0	---	0.0	0.6	---	---	---	---	0.0	1.4	---
PHCA14	-1783	0.0	1.3	---	0.0	0.3	---	---	---	---	0.3	2.7	0.0
PHCA15	-1785	0.0	0.0	---	---	---	---	---	16.7	---	0.0	0.0	---

DETRITAL CONSTITUENTS
CARTER 'B' SANDSTONE
#1 THOMAS
MONROE COUNTY, MISSISSIPPI
SEC. 5-R15S-T7E

SLIDE NUM.	DEPTH (FEET)	MQTZ	PQTZ	FELD	MRF	SRF	CHRT	CHL	MUSC	TOUR	ZIRC	RUTL	POROSITY PRI	SEC.
PECB1	-3939	84.4	3.4	1.0	0.2	0.0	1.6	---	0.0	---	0.0	0.0	---	0.8
PECB2	-3944	73.4	1.0	1.2	---	0.0	0.0	---	0.4	0.0	0.4	0.0	0.6	1.8
PECB3	-3948	83.4	1.8	0.8	---	0.2	0.4	---	0.0	0.0	---	0.0	---	0.0
PECB4	-3952	79.4	1.4	1.8	---	0.4	1.4	0.0	0.0	0.0	0.0	0.0	0.6	0.6
PECB5	-3954	81.6	3.4	0.0	---	1.0	0.8	0.0	0.0	0.0	0.0	0.0	---	0.6
PECB6	-3959	83.6	0.0	0.0	---	---	1.0	---	0.0	0.0	1.2	0.0	0.6	0.8
PECB7	-3960	86.0	2.4	0.8	---	0.0	0.6	---	0.0	0.2	0.0	0.0	---	0.4
PECB8	-3964	76.6	1.4	0.0	---	0.2	- 8	---	0.8	0.0	0.0	0.0	---	0.2
PECB9	-3970	86.4	1.4	1.2	---	0 6	0.4	---	0.6	0.0	0.0	0.0	0.6	0.4
PECB10	-3975	83.8	1.4	1.4	---	0.2	0.4	---	0.6	0.0	0.0	0.0	0.6	1.2
PECB11	-3978	85.8	0.6	1.4	---	---	0.6	0.4	0.4	0.0	0.0	---	---	0.0
PECB12	-3979	84.2	0.4	1 0	---	---	0.6	0.4	0.4	0.0	0.0	---	---	0.0
PECB13	-3982	77.2	4.6	1.2	---	---	0.0	0.0	1.8	0.0	0.2	---	---	1.4

DIAGENETIC CONSTITUENTS
CARTER 'B' SANDSTONE
#1 THOMAS
MONROE COUNTY, MISSISSIPPI
SEC. 5-T15S-R7E

SLIDE NUM.	DEPTH (FEET)	KAOL	ILL	CHLR	HEM	PYR	SID	SER	DOLO OIL	DEAD	CEMENT CARB	QTZ	FSP
PECB1	-3939	0.4	1.2	---	---	1.6	---	0.0	---	0.2	0.4	4.8	---
PECB2	-3944	1.8	0.8	0.0	---	---	9.6	0.0	---	0.6	1.6	6.8	---
PECB3	-3948	0.6	1.0	---	---	0.0	---	0.8	---	4.8	0.0	5.8	---
PECB4	-3952	2.0	0.6	---	---	0.0	---	0.0	---	5.6	1.0	5.2	---
PECB5	-3954	2.6	0.6	---	0.0	---	---	0.2	--	2.4	0.8	2.6	---
PECB6	-3959	1.0	0.6	---	2.6	0.0	---	0.0	---	0.4	0.6	7.6	---
PECB7	-3960	3.8	0.0	0.0	0.0	0.0	---	0.8	---	---	0.0	5.0	---
PECB8	-3964	11.4	0.0	---	5.4	---	---	1.2	---	---	0.0	2.0	---
PECB9	-3970	2.0	0.4	---	0.6	0.4	---	0.4	---	---	0.0	2.0	---
PECB10	-3975	2.6	1.0	0.0	2.2	0.2	---	1.4	---	---	0.2	2.8	---
PECB11	-3978	5.6	1.0	---	1.6	0.6	---	1.2	---	---	---	0.8	---
PECB12	-3979	6.4	---	0.0	2.2	0.0	---	3.2	---	---	---	1.2	---
PECB13	-3982	2.6	---	---	0.6	0.0	6.8	1.6	---	---	0.0	2.0	---

DETRITAL CONSTITUENTS
CARTER 'B' SANDSTONE
#1 MALONE
MONROE COUNTY, MISSISSIPPI
SEC. 25-T16S-R18W

SLIDE NUM.	DEPTH (FEET)	MQTZ	PQTZ	FELD	MRF	SRF	CHRT	CHL	MUSC	TOUR	ZIRC	RUTL	POROSITY PRI	POROSITY SEC
MOCBA	-4944	83.2	2.2	1.2	---	---	0.0	---	0.0	0.0	0.0	0.0	---	0.0
MOCBB	-4945	76.4	0.8	2.6	---	0.0	0.0	0.0	0.8	0.0	0.0	0.0	---	0.0
MOCBC	-4947	84.6	0.0	1.2	---	---	0.2	---	0.0	0.0	0.0	0.0	1.4	1.4
MOCBD	-4948	83.0	5.0	0.2	---	---	0.6	---	0.6	0.0	0.0	0.0	0.0	3.0
MOCBE	-4950	83.4	0.8	1.6	---	---	0.8	0.0	0.0	0.0	0.2	0.0	---	2.4
MOCBF	-4952	73.4	2.2	3.2	---	---	0.0	0.0	0.2	0.0	---	0.0	---	1.6
MOCBG	-4954	69.2	5.6	0.4	---	---	---	---	0.2	---	0.0	0.0	---	0.2
MOCBH	-4957	75.2	2.4	1.4	---	---	0.0	---	---	0.2	0.0	0.0	---	1.2
MOCBI	-4961	73.0	4.0	1.4	---	---	0.0	---	---	0.0	0.0	0.0	---	0.0
MOCBK	-4962	88.2	1.2	0.0	---	---	1.2	---	0.0	0.6	0.0	0.0	0.8	3.4
MOCBL	-4982	81.4	1.2	2.0	---	---	0.8	0.0	0.0	0.0	0.4	0.0	0.6	3.2
MOCBM	-4993	82.2	1.4	2.8	---	---	0.0	---	---	0.0	0.0	0.0	0.2	2.4
MOCBN	-4997	76.8	0.8	4.0	---	---	0.0	---	---	---	0.0	0.0	---	1.8
MOCBO	-4998	74.6	4.8	3.0	---	---	0.0	0.0	---	---	0.0	0.0	0.4	2.0

DIAGENETIC CONSTITUENTS
CARTER 'B' SANDSTONE
#1 MALONE
MONROE COUNTY, MISSISSIPPI
SEC. 25-T16S-R18W

SLIDE NUM.	DEPTH (FEET)	KAOL	ILL	CHLR	HEM	PYR	SID	SER	DOLO OIL	DEAD	CEMENT CARB	CEMENT QTZ	CEMENT FSP
MOCBA	-4944	0.8	5.0	---	0.8	0.0	---	0.4	---	---	0.2	6.2	---
MOCBB	-4945	0.8	15.0	0.0	1.2	0.0	---	0.0	---	---	0.0	2.4	---
MOCBC	-4947	1.4	0.4	0.0	0.6	0.0	---	0.4	---	---	5.2	3.2	---
MOCBD	-4948	2.2	0.0	---	0.8	0.2	---	1.2	---	---	0.6	2.6	---
MOCBE	-4950	2.8	0.0	---	1.0	0.4	---	0.4	---	---	2.8	3.4	---
MOCBF	-4952	1.0	0.0	0.6	0.0	0.0	---	---	12.2	---	4.8	0.8	---
MOCBG	-4954	3.0	1.0	---	0.2	0.0	---	---	8.2	---	9.6	0.8	---
MOCBH	-4957	0.2	0.0	---	0.8	0.0	---	---	11 2	---	5.2	2.2	---
MOCBI	-4961	14.2	1.2	0.0	1.0	0.8	---	0.8	---	---	0.2	3.4	---
MOCBK	-4962	0.2	0.2	---	0.2	0.2	---	---	---	---	0.6	3.2	---
MOCBL	-4982	2.2	2.2	---	0.6	0.2	---	---	---	---	1.2	4.0	---
MOCBM	-4993	1.8	0.8	---	0.2	1.6	---	---	---	---	0.0	6.6	---
MOCBN	-4997	1.4	0.6	---	0.0	0.8	---	0.0	---	---	---	2.6	---
MOCBO	-4998	2.2	0.8	---	0.2	0.2	---	0.0	---	---	7.4	4.4	---

DETRITAL CONSTITUENTS
MILLERELLA SANDSTONE
#1 MASON
MONROE COUNTY, MISSISSIPPI
SEC. 5-T15S-R7E

SLIDE NUM.	DEPTH (FEET)	MQTZ	PQTZ	FELD	MRF	SRF	CHRT	CHL	MUSC	TOUR	ZIRC	RUTL	POROSITY PRI	SEC
MPAM1	-3748	82.0	0.0	0.3	0.3	---	---	0.0	0.0	0.0	0.0	0.0	---	2.3
MPAM2	-3756	48 3	4.0	1.0	---	0.0	0.7	---	0.3	0.0	0.0	---	---	3.7

DIAGENETIC CONSTITUENTS
MILLERELLA SANDSTONE
#1 MASON
MONROE COUNTY, MISSISSIPPI
SEC 5-T15S-R7E

SLIDE NUM.	DEPTH (FEET)	KAOL	ILL	CHLR	HEM	PYR	SID	SER	DOLO OIL	DEAD	CEMENT CARB	QTZ	FSP
MPAM1	-3748	-	7.7	---	0.0	0.0	---	---	---	---	7.3	0.0	---
MPAM2	-3756	---	11.7	---	6.0	--	---	---	---	---	24.0	0.0	---

0.0% = TRACE AMOUNTS NOTED IN THIN SECTION EXAMINATION.
--- = CONSTITUENT NOT SEEN I THIN SECTION EXAMINATION.

DETRITAL CONSTITUENTS
BATESVILLE SANDSTONE
OUTCROP 'A'
INDEPENDENCE COUNTY, ARKANSAS
C SE/4 SW/4 NW/4 SEC. 27-T13S-R6W

SLIDE NUM.	DEPTH (FEET)	MQTZ	PQTZ	FELD	MRF	SRF	CHRT	CHL	MUSC	TOUR	ZIRC	RUTL	POROSITY PRI	POROSITY SEC
A-1	2.0	83.0	1.5	0.3	0.0	0.0	0.5	---	0.0	0.0	0.3	---	---	6.5
A-2	5.0	68.8	0.3	3.8	0.0	0 0	0.8	0.0	0.0	0.0	0.0	---	---	14.8
A-3	10 0	77.5	4.3	0.0	0.0	0.0	0.8	---	0.0	0.0	0.0	---	---	8.0
A-4	12.0	82.5	0.3	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	---	---	3.0
A-5	16.0	76.3	0.5	1.0	0.0	0.0	1.3	---	---	0.0	0.0	0.0	---	10.0
A-6	20 0	81.3	0.5	0.5	0.0	0.0	1.0	---	0.0	0.3	0.3	---	---	5.0
A-7	23.0	80.8	0.8	2.3	0.0	0.0	0.0	---	---	0.0	0.0	0.0	---	4.0
A-8	29.0	85.0	0.8	0.5	0.0	0.0	0.0	---	---	0.0	0.3	---	---	5.5
A-9	30.0	71.0	0.5	---	0.0	0.0	2.3	---	0.0	0.0	0.0	---	---	17.5
A-10	35.0	79.5	0.8	1.0	0.0	0.0	2.0	---	---	0.;0	0.8	---	---	7.3
A-11	35.5	84.0	1.5	1.8	---	0.0	0.5	---	---	0.0	0.3	---	---	4.8
A-12	40.5	75.8	1.0	1.3	0.0	---	1.5	--	---	0.0	0.0	---	---	9.3
A-13	44.5	73.3	2.8	1.5	---	---	0.0	---	0.0	0.0	0.0	0.0	---	13.5
A-14	65 0	82.3	2.5	1.3	0.0	0 0	0.0	---	---	---	0.3	---	---	5.0
A-15	67.5	61.8	1.8	2.8	0.0	0.0	0.0	---	0.0	0.0	0.8	0.0	---	9.0

DIAGENETIC CONSTITUENTS
BATESVILLE SANDSTONE
OUTCROP 'A'
INDEPENDENCE COUNTY, ARKANSAS
C SE/4 SW/4 NW/4 SE. 27-T13N-R6W

SLIDE NUM.	DEPTH (FEET)	KAOL	ILL	CHLR	HEM	PYR	SID	SER	DOLO OIL	DEAD	CEMENT CARB	CEMENT QTZ	CEMENT FSP
A-1	2.0	1.8	---	---	3.0	---	---	---	---	---	---	3.3	---
A-2	5.0	0.3	---	---	6.8	---	0.0	---	---	---	---	4.8	---
A-3	10.0	3.5	---	---	2.3	---	---	---	---	---	0.0	3.3	---
A-4	12.0	5.3	---	---	3.3	---	---	---	---	---	---	4.8	---
A-5	16.0	4.3	---	---	3.5	---	---	---	---	---	---	3.3	---
A-6	20.0	4.0	---	---	4.5	0.0	---	---	---	---	0.0	2.8	---
A-7	23.0	3.5	---	---	5.0	---	---	---	---	---	---	3.8	---
A-8	29.0	1.0	---	---	4.3	---	---	---	---	---	---	2.8	---
A-9	30.0	1.5	---	---	4.8	---	---	---	---	---	0.0	2.5	---
A-10	35.0	4.5	---	---	1.3	---	---	---	---	---	---	2.8	---
A-11	35.5	1.8	---	---	0.8	---	---	---	---	---	---	4.8	---
A-12	40.5	0.0	---	---	6.0	---	---	---	---	---	---	5.3	---
A-13	44.5	1.5	---	---	2.5	---	---	---	---	---	---	5.0	---
A-14	65.0	2.0	---	---	2.5	0.5	---	---	---	---	---	3.8	---
A-15	67.5	1.8	---	---	16.8	0.3	---	---	---	---	---	5.0	---

DETRITAL CONSTITUENTS
BATESVILLE SANDSTONE
OUTCROP 'E'
INDEPENDENCE COUNTY, ARKANSAS
NW/COR NW/4 NW/4 SEC. 16-T13N-R6W

SLIDE NUM.	DEPTH (FEET)	MQTZ	PQTZ	FELD	MRF	SRF	CHRT	CHL	MUSC	TOUR	ZIRC	RUTL	POROSITY PRI	POROSITY SEC
E-1	1.5	79.8	0.5	3.8	0.0	0.0	0.3	---	0.0	0.5	0.0	---	---	8.0
E-2	6.5		BAD DATA											
E-3	9.0	82.3	0.3	1.5	0.0	0.0	0.3	---	0.0	0.0	0.0	---	---	3.8
E-4	13.5	81.0	1.0	2.3	0.5	0.0	1.0	---	0.0	0.3	---	---	---	5.5
E-5	17.5	78.0	3.5	2.8	0.0	0.0	1.3	---	0.0	0.0	0.3	---	---	8.3
E-6	21.0	81.3	1.5	0.3	0.5	0.0	2.0	---	0.0	0.0	---	---	---	4.0
E-7	22.0	79.0	1.8	1.3	0.0	0.0	1.5	---	0.0	0.0	0.0	---	---	12.0
E-8	24.5	86.8	2.8	0.0	0.0	0.0	1.8	---	0.0	0.0	0.3	---	---	3.3

DIAGENETIC CONSTITUENTS
BATESVILLE SANDSTONE
OUTCOPR 'E'
INDEPENDENCE COUNTY, ARKANSAS
NW/COR NW/4 NW/4 SEC. 16-T13N-R6W

SLIDE	DEPTH	KAOL	ILL	CHLR	HEM	PYR	SID	SER	DOLO	DEAD	CEMENT		
NUM.	(FEET)								OIL		CARB	QTZ	FSP
E-1	1.5	1.5	---	---	0.8	---	0.5	---	---	---	---	4.5	---
E-2	6.5			BAD DATA									
E-3	9.0	3.3	---	---	3.0	---	2.0	---	---	---	---	3.8	---
E-4	13.5	3.8	---	---	0.8	---	1.5	---	---	---	---	2.5	---
E-5	17.5	2.5	---	---	0.3	0.0	0.3	---	---	---	---	3.0	---
E-6	21.0	2.5	---	---	2.0	---	2.5	---	---	---	---	3.5	---
E-7	22.0	1.0	---	---	0.5	0.3	---	---	---	---	0.3	2.8	---
E-8	24.5	0.0	---	---	1.5	---	---	---	---	---	0.0	3.8	---

0.0% = TRACE AMOUNTS NOTED IN THIN SECTION EXAMINATION.
--- = CONSTITUENT NOT SEEN IN THIN SECTION EXAMINATION.

DETRITAL CONSTITUENTS
BATESVILLE SANDSTONE/
HINDSVILLE LIMESTONE
OUTCROP 'G'
INDEPENDENCE COUNTY, MISSISSIPPI
C SW/4 SW/4 SE/4 SEC34-T15N-R12W

SLIDE NUM.	DEPTH (FEET)	MQTZ	PQTZ	FELD	MRF	SRF	CHRT	CHL	MUSC	TOUR	ZIRC	RUTL	POROSITY PRI	SEC
G-1	0.5	45.5	0 8	1.5	0.8	0.5	1.3	0.0	0.3	0.0	0.0	---	---	11.0
G-2	3.5	37.3	1.3	2.5	0.3	0.5	0.3	---	0.3	0.3	0.0	---	---	12.0
G-3	6.5	7.5	0.0	0.0	1.5	---	---	---	---	---	---	---	---	0.0
G-4	8.0	72.5	1.5	0.5	0.0	---	3.3	---	0.0	0.0	0.0	---	---	11.8
G-5	9.5	63.0	0.5	---	---	---	0.0	---	0.0	0.0	0.0	---	---	0.0
G-6	11.0	75.0	1 3	2.3	---	0.0	0.0	---	0.3	0.0	0.0	0.0	---	5.8
G-7	20.0	61.0	4.5	2.3	0.5	---	0.0	0.0	0.0	0.0	0.0	0.0	---	0.8
G-8	22.5	68.3	3.5	3.3	0.0	1.0	0.0	---	0.0	0.0	0.0	---	---	4.3

DIAGENETIC CONSTITUENTS
BATESVILLE SANDSTONE/
HINDSVILLE LIMESTONE
OUTCROP 'G'
INDEPENDENCE COUNTY, ARKANSAS
C SW/4 SW/4 SE/4 SEC. 34-T15N-R12W

SLIDE NUM.	DEPTH (FEET)	KAOL	ILL	CHLR	HEM	PYR	SID	SER	DOLO OIL	DEAD	CEMENT CARB	QTZ	FSP
G-1	0.5	---	---	---	38.3	---	---	--	---	---	---	0.3	---
G-2	3.5	---	---	---	44.8	---	---	---	---	---	---	0.8	---
G-3	6.5	---	---	---	---	---	---	---	---	---	46 8	---	---
G-4	8.0	0.0	---	---	5.0	---	---	---	---	---	0.0	5.5	---
G-5	9.5	---	---	---	2.8	---	---	---	---	---	11.8	3.5	---
G-6	11.0	0.3	4.8	---	6.0	---	3.5	---	---	---	---	1.0	---
G-7	20.0	---	5.5	---	20.8	---	4.0	0.0	0.0	0.0	0.3	0.5	---
G-8	22.5	0.5	---	---	13.5	---	---	---	---	---	0.0	5.8	---

SLIDE NUM.	ELEV (FEET)	BRACH	BRY	ECHI	CRIN	PELE	OOID	PEL	INTR	MOLL
G-3	6.5	1.8	12.5	14.3	0.0	1.0	1.5	0.0	3.3	3.3
G-5	9.5	0.0	5.0	9.0	---	1.0	1.5	0.0	3.3	3.5

0.0% = TRACE AMOUNTS NOTED IN THIN SECTION EXAMINATION.
--- = CONSTITUENT NOT SEEN IN THIN SECTION EXAMINATION

APPENDIX B

WELLS USED IN CROSS-SECTIONS

AND EXPLANATIONS

NW-SE STRIKE-OTIENTED STRATIGRAPHIC CROSS SECTIONS

A-A'

LOCATION	WELL NAME	COMPANY
Sec 7-10S-4E	#1 T. R. Hall	O W Killiam
Sec 8-11S-5E	#1 Anderson-Homan	Moon-Hines-Tigrett
Sec. 25-11S-5E	#1 West	Pruet Prod. Co
Sec 29-12S-6E	#1 Murphree	Texas Oil & Gas Corp
Sec 36-12S-6E	#1 Beasley	Louisiana L & E. Co
Sec 27-13S-7E	#1 Hobson L Sanderson Jr	Triad Oil and Gas Co
Sec 1-14S-19W	#1 Airport	Triad Oil and Gas Co
Sec. 28-14S-18W	#1 Smith Estate	Centennial Explor
Sec 17-15S-17W	#1 Boyette Smith	Moon-Hines
Sec 3-16S-17W	#1 Ralph Thomas	Elf Aquitaine Oil & Gas

B-B'

LOCATION	WELL NAME	COMPANY
Sec 16-11S-1E	#1 James W Miller	Florida Gas & Expl
Sec 19-12S-2E	#1-A J W Clarke	Justice Mears
SEc 22-13S-2E	#1 Fowler-Langley	Carter Oil Co
Sec 11-14S-3E	#1 S A Farr	Pruet Prod Co
Sec 28-14S-4E	#1 Dexter	Pruet Prod Co
Sec 25-15S-4E	#1 David Wade	Meridian Oil, Inc
Sec 25-16S-5E	#1 Jarrett	Shell Oil Co
Sec 17-17S-6E	#5 Simmons	Grace Pet Co
Sec 34-17S-6E	#2 Edward E Seitz	Baria & Mason

SN-NE DIP-ORIENTED STRATIGRAPHIC CROSS SECTIONS

C-C'

LOCATION	WELL NAME	COMPANY
Sec 34-13S-1E	Unit 34-7	Stack Land & Expl
Sec 22-13S-2E	#1 Fowler-Langley	Carter Oil Co
Sec 28-12S-3E	#1 Houston Hospital	Michigan Oil Co
Sec. 9-12S-4E	#1 U.S.A.	Vaughy & Vaughy
Sec 5-12S-5E	#1 Dallas	Louisiana L & E Co
Sec 25-11S-5E	#1 West	Pruet Prod Co
Sec 17-11S-6E	#1 Mary Rutherford	Ensource, Inc
Sec 20-10S-7E	#1 Hill	R L Burns Corp
Sec 22-9S-7E	#1 Leslie	Dr. J W Bailey
Sec 33-8S-9E	#1 Bon Adams	O W William

D-D'

LOCATION	WELL NAME	COMPANY
Sec. 32-21N-13E	#1 Davis	Grace pet. Corp
Sec. 6-16S-5E	#1 Scott	Southland Royalty Co
Sec 3-15S-5E	#1 Henley	Ladner & Gilbraltar Co
Ssec 25-14S-6E	#1 Minnie Plant Whitaker	Louisiana L & E Co
Sec 1-14S-19W	#1 Airport	Triad Oil and Gas Co
Sec. 20-13S-17W	#1 Mary Lou Lann	Energy Three, Inc
Sec 13-12S-17W	#1 Weyerhauser	TXO Prod Corp

NW-SE STRIKE-ORIENTED STRUCTURE CROSS SECTIONS

A'-A"

LOCATION	WELL NAME	COMPANY
Sec. 7-10S-4E	#1 T R Hall	O W Killiam
Sec 8-11S-5E	#1 Anderson-Homan	Moon-Hines Tigrett
Sec 25-11S-5E	#1 West	Pruet Prod Co
Sec 29-12S-6E	#1 Murphree	Texas Oil and Gas Co
Sec 36-12S-6E	#1 Beasley	Louisiana L & E Co
Sec 27-13S-7E	#1 Hobson L Sanderson Jr	Triad Oil and Gas Co
Sec 1-14S-19W	#1 Airport	Triad Oil and Gas Co
Sec 28-14S-18W	#1 Smith Estate	Centennial Exp
Sec. 17-15S-17W	#1 Boyette Smith	Moon-Hines
Sec 3-16S-17W	#1 Ralph Thomas	Elf Aquitaine Oil & Gas

SW-NE DIP-ORIENTED STRUCTURE CROSS SECTION

B'-B"

LOCATION	WELL NAME	COMPANY
Sec. 33-14S-2E	#1-C Crawford	Phillips Pet Co
Sec 11-14S-3E	#1 S A Farr	Pruet Prod. Co
Sec 34-13S-4E	#1 Mabel Real	Louisiana L & E Co
Sec. 16-13S-5E	#1 McCain	Morrow Oil & Gas Co
Sec 29-12S-6E	#1 Murphree	Texas Oil & Gas Co
Sec. 12-12S-6E	#2 C. P Coggin	Louisiana L & E. Co
Sec 35-11S-uE	#2 Young	Puret Prod Co
Sec 10-11S-8E	#1 Gilmore-Puckett	Walter E Sistrunk
Sec 10-10S-9E	#1 O R Smith - H Benson	C Dale Armour
Sec 26-9S-10E	#1 Barrett	Moon-Hines-Tigrett

Stratigraphic cross-sections A-A', B-B', C-C', and D-D' were constructed using dual induction logs consisting of a spontaneous potential curve with deep, medium and short or laterolg resistivity curves. The correlations and "tops" of formations were based on the resistivity and spontaneous potential curves. Correlation and/or "tops" of formation where there is little to no spontaneous potential curve development is based on the resistivity curves for continuity of the correlations on each cross-sections. The stratigraphic cross section are hung on the base of the "Millerella" Limestone as a datum line using the Neal Black Shale (below) to aid in consistency of correlations.

The zip-zag nature of the lines defining the sand bodies was done in this fashion simply to show a gradual change in thickness laterally. This is not intended to suggest time equivalency between sands or shales at any given point or that these sands are either influenced by marine and/or fluvial depostion. The "floating" sand bodies observed between wells on certain cross sections are sands which appear on the isolith maps. They have been included on the cross sections to indicate the sands encountered moving along the line of cross section on the isolith maps.

VITA

Stephen Wayne Witt

Candidate for the Degree of

Master of Science

Thesis: COMPARATIVE PETROGRAPHY OF THE CHESTERIAN BATESVILLE DELTA AND EQUIVALENT SUBSURFACE DEPOSITIONAL SYSTEMS ON THE NORTHERN SHELF OF THE BLACK WARRIOR BASIN

Major Field: Geology

Biographical:

Personal Data: Born in Bartlesville, Oklahoma, November 25, 1956, the son of Donald R. and Joyce A. Witt.

Education: Graduated from Sooner High School, Bartlesville, Oklahoma, in May, 1975; received Bachelor of Science degree in Geology from Oklahoma State University in May, 1988; completed requirements for the Master of Science degree at Oklahoma State University in December, 1990.

Professional Experience: Summer geologist for Union Oil of California, Mid-Continent Region, Oklahoma City, Oklahoma, May to August, 1989; Graduate Teaching Assistant, Department of Geology, Oklahoma State University, August, 1988 to May, 1989 and from August, 1989 to May, 1990.

DIP-ORIENTED STRATIGRAPHIC CROSS-SECTION B-B′

DIP-ORIENTED STRATIGRAPHIC CROSS-SECTION D-D′

BLACK WARRIOR BASIN

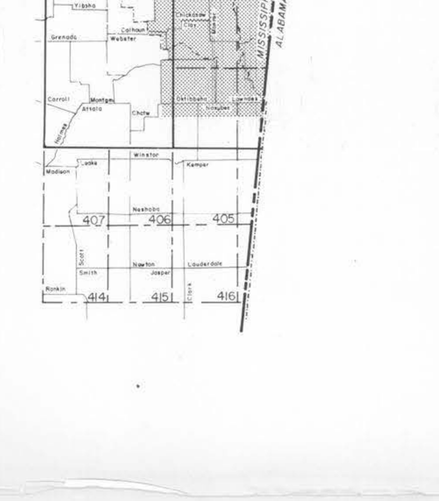
MISSISSIPPI

STRUCTURE MAP
BASE/MILLERELLA LIMESTONE
C.I. = 100'

STEPHEN W. WITT M.S. THESIS, 1990
OKLAHOMA STATE UNIVERSITY

SCALE: 1" = 8000'

PLATE I



BLACK WARRIOR BASIN

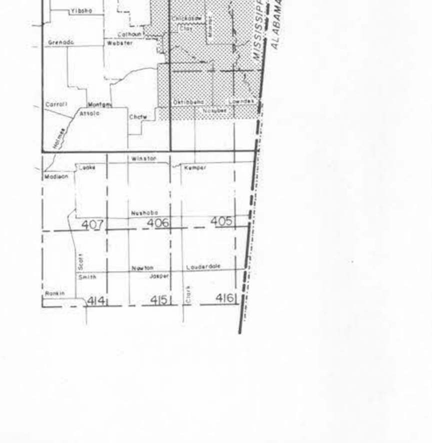
MISSISSIPPI

NET SAND ISOLITH MAP
MILLERELLA SANDSTONE
C.I. = 10'

STEPHEN W. WITT M.S. THESIS, 1990
OKLAHOMA STATE UNIVERSITY

SCALE: 1" = 8000'

PLATE 2



BLACK WARRIOR BASIN

MISSISSIPPI

NET SAND ISOLITH MAP
CARTER 'A' SANDSTONE
C.I. = 20'

STEPHEN W. WITT M.S. THESIS, 1990
OKLAHOMA STATE UNIVERSITY

SCALE: 1" = 8000'

PLATE 3

BLACK WARRIOR BASIN

MISSISSIPPI

NET SAND ISOLITH MAP
CARTER 'B' SANDSTONE
C.I. = 20'

STEPHEN W. WITT M.S. THESIS, 1990
OKLAHOMA STATE UNIVERSITY

SCALE: 1" = 8000'

PLATE 4

BLACK WARRIOR BASIN

MISSISSIPPI

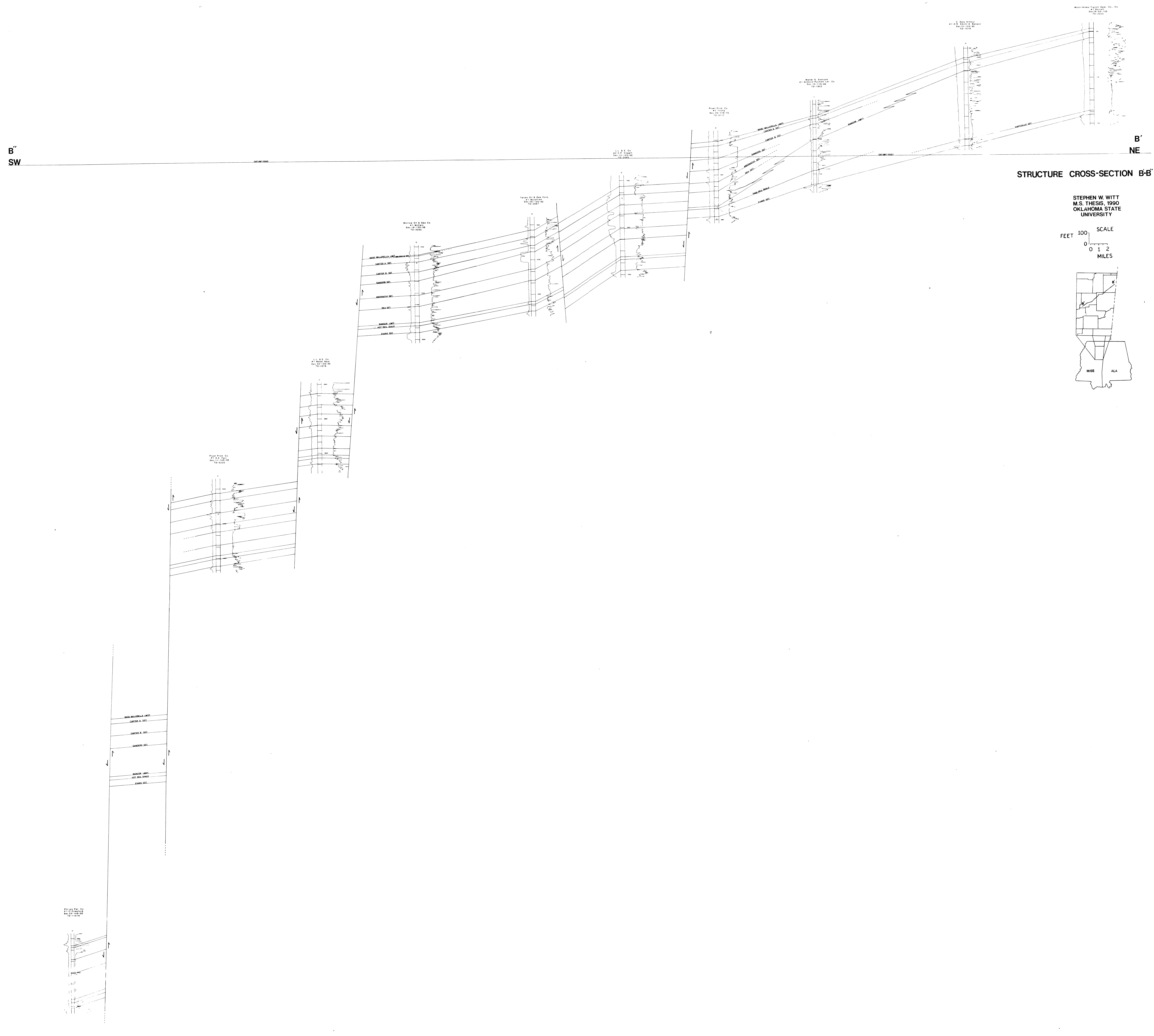
NET SAND ISOLITH MAP
TOTAL CARTER SANDSTONE
C.I. = 20'

STEPHEN W. WITT M.S. THESIS, 1990
OKLAHOMA STATE UNIVERSITY

SCALE: 1" = 8000'

PLATE 5


A′
NW
A″
SE
STRUCTURE CROSS-SECTION A′-A″
STEPHEN W. WITT
M.S. THESIS, 1990
OKLAHOMA STATE
UNIVERSITY
BASE MILLERELLA LMST
CARTER A SST
CARTER B SST
SANDERS SST
ABERNATHY SST
REA SST
BANGOR LMST
HIGH RES. SHALE
EVANS SST
MISS
ALA



STRUCTURE CROSS-SECTION B-B''

STEPHEN W. WITT
M.S. THESIS, 1990
OKLAHOMA STATE
UNIVERSITY