STRATIGRAPHY OF THE McALESTER FORMATION (BOOCH SANDSTONES) IN THE EUFAULA RESERVOIR AREA, EAST-CENTRAL OKLAHOMA

By

CLINTON RANDALL BISSELL

Bachelor of Science

University of Southern Mississippi

Hattiesburg, Mississippi

1982

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the degree of
Master of Science
July, 1984

STRATIGRAPHY OF THE McALESTER FORMATION

(BOOCH SANDSTONES) IN THE

EUFAULA RESERVOIR AREA,

EAST-CENTRAL OKLAHOMA

Thesis Approved:

Arthur W. Cleaves
Thesis Adviser

Zuhair al-Shaieb

Allan P. Bennison

Gary F. Stewart

Norman N. Durham
Dean of the Graduate College

PREFACE

This thesis represents a surface and subsurface geologic study of the stratigraphy, including sedimentology and petrography, of the McAlester Formation (Booch) Sandstones. The area covered includes Haskell, Muskogee, and McIntosh Counties with parts of Okmulgee and Pittsburg Counties, Oklahoma. Recent hydrocarbon discoveries in the Booch Sandstone encouraged the development of this project and the opportunity to work with a classic ancient delta example was personally challenging.

I would like to thank my thesis committee; Dr. Arthur W. Cleaves (adviser), Dr. Gary F. Stewart, and Dr. Zuhair Al-Shaieb for their assistance and interest in this study. Deepest appreciation is expressed to Mr. Allan P. Bennison for his sincere interest, valuable comments and suggestions, and financial support. I also thank the Oklahoma Geological Survey for financial aid and access to cores and cuttings used in this study. The Oklahoma Well Log Library and the Oklahoma City Geological Society Log Library were kind enough to allow free access to geophysical logs used in subsurface mapping. The many suggestions of other faculty and my fellow graduate students are gratefully acknowledged.

Most of all I wish to thank my family. My parents, Mr. and Mrs. Allen H. Bissell, have given me a lifetime of opportunities. Special thanks to my wife, Dawn, whose loving understanding and support made this project possible.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure | Page

Figure | Page

LIST OF PLATES

Plate

CHAPTER I

ABSTRACT

The McAlester Formation of Desmoinesian (Pennsylvanian) age is a dominantly shale lithostratigraphic unit in the Arkoma Basin geologic province of East-central Oklahoma and Western Arkansas. Five named sandstone members are regionally persistent within the area of study. They are (in ascending order): the Warner, Lequire, Cameron, Tamaha, and Keota. In the subsurface, these units are known as the Booch Sands; the Lower Booch locally produces large amounts of oil and gas.

The Warner (Lower Booch) and other members of the McAlester Formation all appear related to the typically deltaic regressive episodes that punctuate the overall transgression that occured during the Desmoinesian. Upper and lower delta plain deposits, channels, delta front sandstones, and prodelta shales were observed and measured in outcrops of McAlester members, with an emphasis on the Warner Sandstone. The two cores obtained for the study were useful in similar environmental interpretations and a petrographic study. Five sets of well cuttings were utilized to aid in the subsurface stratigraphic aspect of the study and in petrography of wells that produce from the Booch.

Subsurface mapping of the Warner cycle, an informal subdivision of the McAlester Formation used to illustrate a regressive phase of sedimentation, revealed a southeast extension of The Booch Delta as originally mapped by D. A. Busch (1953). The net sand map prepared explained both

apparent production trends in the area under Eufaula Reservoir and the proximal deltaic facies identified in the outcrop aspect of this study. By utilizing small scale maps of producing Booch fields, the Lower Booch (Warner) net sand map, a previously published structure map, and a location map of major Booch production, conclusions on trapping mechanisms could be drawn. It appears that the best hydrocarbon production in the Eufaula Reservoir area is associated with the interaction of major channel facies and large scale anticlines, synclines, or faults.

All sandstones within the McAlester Formation may be classified as sublitharenites, typically dominated by monocrystalline quartz, and containing small amounts of feldspar, detrital clay, and fragments of metamorphic rock. Authigenic cements and clays usually include siderite, an indicator of deltaic sedimentation itself, calcite, hematite, kaolinite, illite, and chlorite. Productive porosity in the Booch Sandstone is classified as 'hybrid' intergranular, a combination of several events of precipitation of authigenic cements and dissolution of these minerals. The dissolution of detrital constituents such as feldspar and clay clasts (and matrix) contribute to overall porosity which usually ranges from 8 to 15 percent.

The persistent character of the members allowed correlations from the surface to the subsurface, within the framework of cycles identified by the overall transgressive or regressive nature of the sediments. With such correlations, information presented on depositional environments, investigations of trapping mechanisms, maps prepared, and identification of porosity controls for the Booch sands chances for success in exploration for oil and gas in the Lower Booch (Warner) Sandstone may be enhanced.

CHAPTER II

INTRODUCTION

Location of Study

This thesis study involves the surface and subsurface analysis of the sandstone members (Booch Sandstones) in the McAlester Formation, a lower Desmoinesian (Pennsylvanian) lithostratigraphic unit in the Arkoma Basin geologic province of East-central Oklahoma (Figure 1).

Surface work involved the examination and measurement of the sandstone and intervening shale members of the McAlester Formation. In ascending order, these include: McCurtain Shale, Warner Sandstone, Lequire-Cameron Sandstone, Tamaha Sandstone, and Keota Sandstone. Exposures were studied in McIntosh, Muskogee, and Haskell Counties, Oklahoma.

Subsurface geological mapping involved all of McIntosh County and parts of Haskell, Okmulgee, Muskogee, and Pittsburg Counties. The exact area is defined by Township(s) 8 through 14 North, Range(s) 13 through 19 East, Oklahoma. The northern two-thirds of Eufaula Reservoir lies within this 1764 $mi.^2$ area. No McAlester cores were available within the area outlined above. However, cores were obtained from wells located at Sec. 3, T. 12 N., R. 11 E., and Sec. 17, T. 11 N., R. 12 E., short distances outside the mapping areas.

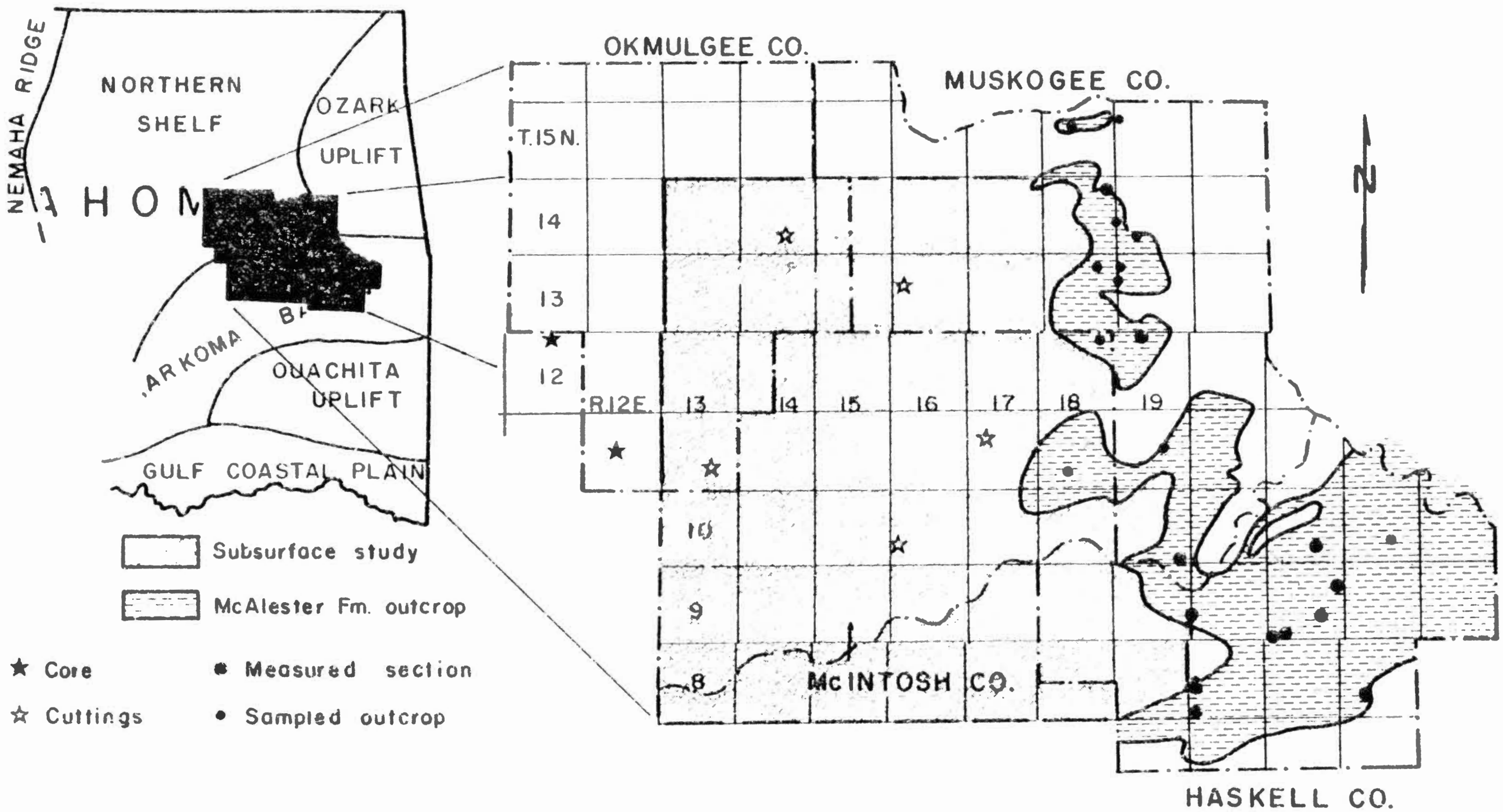


Figure 1. Index Map of the Thesis Study Area.

Objectives

The major objectives of this study include:

1. Delineation of probable regressive and transgressive sedimentation episodes and cycles in the McAlester Formation.
2. Correlations of members in the McAlester Formation to the subsurface equivalent geophysical log responses.
3. Recognition of specific depositional facies in McAlester sandstone outcrops and cores.
4. Generation of subsurface maps illustrating the sand body geometry, depositional framework, and construction of cross-sections illustrating the correlation of important reservoir sandstone members of the McAlester Formation.
5. Development and illustration of basic explanations of oil and gas entrapment in McAlester sandstones.
6. Evaluation of petrographic and diagenetic characteristics of McAlester sandstones.

Methods of Investigation

Data collection for this study involved several forms. First, outcrops in McIntosh, Muskogee, and Haskell Counties were examined and measured for the purpose of determining depositional environments and petrographic character, and for familiarization with overall stratigraphic relationships of members. Twelve approximately 30 feet thick sections were measured; these are described in Appendix A. Twelve other outcrops were examined and sampled within the three-county study area to provide additional precision in defining specific depositional environments (Table II, Chapter IV).

No cores were available within the subsurface map area. However, two cores from west of this area were obtained and measured to evaluate depositional environments, petrographic character, and hydrocarbon reservoir possibilities within the sandstones. Core descriptions appear in Appendix A. In addition to cores, five sets of well cuttings were examined and compared to available geophysical logs for the purpose of understanding the relationships between log responses and lithology within the McAlester Formation (Table III, Chapter VI).

More than 134 thin sections were prepared from surface and subsurface sandstone samples. Thin sections were utilized to study the petrography and diagenetic history of the McAlester sandstones, as outlined in Chapter VII. Basically, diagenetic history was determined by the apparent cross-cutting relationships among authigenic minerals in the sandstones.

One thin section from each measured section and core was stained with sodium cobaltnitrate for detection of feldspars; feldspar values were corrected accordingly. Thin sections containing significant (more than 5%) carbonate cements were stained with alizarin red/potassium ferricyanide solution to distinguish between ferroan and non-ferroan calcite and dolomite. To further aid in determining mineralogy, powder x-ray diffraction was also utilized. The clay mineral fraction was removed from twenty powdered samples, heated and glycolated, and run on a 2-14 2θ x-ray diffraction to investigate the composition and degree of crystallinity. Scanning electron microscopy and cathode illuminescence were used to examine textural relationships among authigenic and detrital minerals.

Correlations between surface members of the McAlester Formation and subsurface geophysical log responses were accomplished by stripping out geophysical logs with probable lithology and comparing these stratigraphic sequences to complete outcrop sections. County bulletins were invaluable in this approach. From the easternmost wells (those nearest outcrops), a network of geophysical log cross-sections was developed to aid in correlation of units throughout the study area.

Finally, subsurface data were collected from geophysical and driller's logs available at log libraries. Three regional subsurface maps were prepared with this data for the purpose of illustrating the sand geometry of the Warner Member, thickness of the total format cycle that includes the Warner Sandstone, and thickness of the McAlester Formation. Format cycles utilized in this report follow the ideas of Brown (1979), wherein, a cycle represents constructive (regressive) through destructive (transgressive) sedimentation episodes. Similarly, Busch's (1974) genetic increment of strata, "GIS", represents a single sedimentation episode delineated by marker beds such as coal or limestones.

Previous Investigations

Literature research was an important part of this study. During early stages of the research, county geological bulletins were utilized to locate many of the McAlester outcrops examined. Perhaps more important, these works demonstrated the very types of stratigraphic correlations lacking in the subsurface. The Muskogee-Porum District was mapped by Wilson and Newell in 1937. Muskogee County was re-mapped by Oakes, et al. in 1977. Haskell County was mapped by Oakes and Knechtel in 1948. The surface geology and petroleum resources of McIntosh County were described in a bulletin written by Oakes (1966), with subsurface work by Koonz. Stratigraphic descriptions of the McAlester Formation, its members, and associated strata were utilized from the texts of all these Oklahoma Geological Survey publications.

More detailed petrographic and stratigraphic studies of McAlester sandstones were included in Master's theses. Scruton (1949) evaluated the petrography and depositional environment of the Warner Sandstone in outcrops generally north of Warner, Muskogee County. An analysis of the Stigler Coal and collateral McAlester strata in Haskell and parts of adjacent counties was written by Karvelot (1972). Karvelot's report included several useful measured section descriptions. Strata of the Hartshorne and McAlester formations were correlated by Catalano (1978) in eastern Haskell County.

The Booch Sandstone (Warner Member) of the McAlester Formation was mapped in the subsurface by Reed (1923) and Busch (1953). Dr. Busch's famous Booch sandstone isolith map has been published in many text books and reports since 1953 (Figure 2). However, no recent maps have been published on Booch (McAlester) sandstones within Busch's area or in adjacent areas.

The McAlester Formation has been included in broader studies of Desmoinesian strata in East-central Oklahoma. Visher et al., (1971) illustrated a regional geophysical log correlation including the McAlester (Booch). Another important source of information on McAlester stratigraphy has been Bennison (1979a, 1979b, 1984 personal communication). His articles on Desmoinesian coal cycles (including the McAlester) demonstrate many correlations utilized in this study.

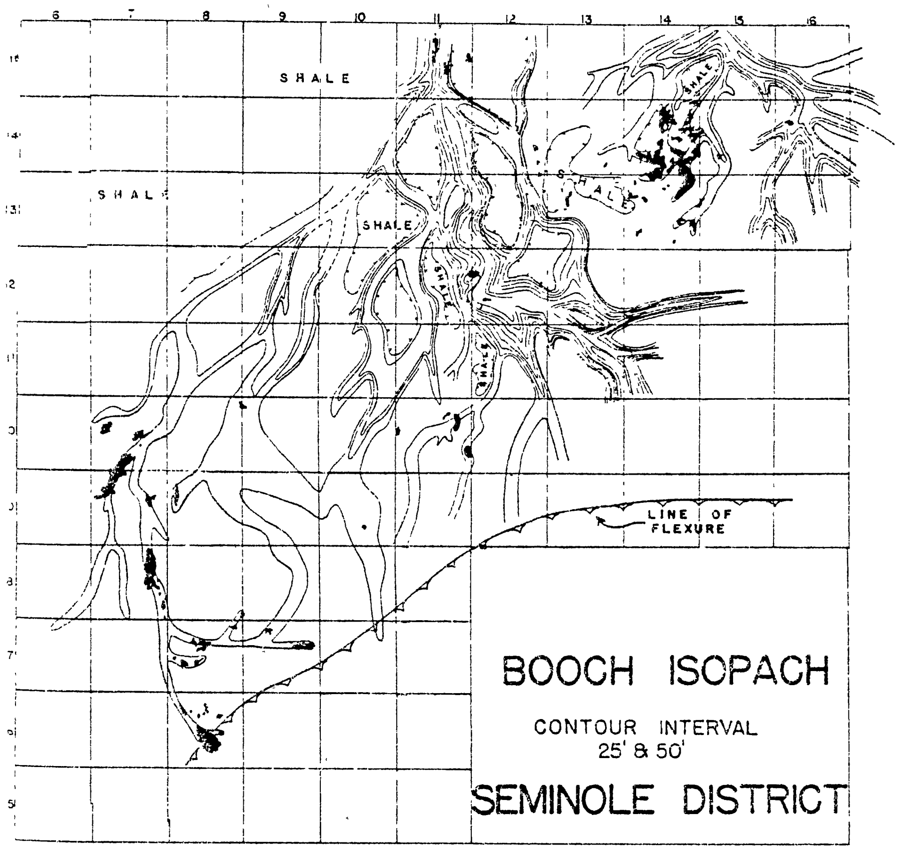


Figure 2. D. A. Busch's (1974, p. 75) Booch Sand Isolith Map, Seminole District, Oklahoma.

CHAPTER III

STRATIGRAPHY

Pennsylvanian System

Desmoinesian Series

In Oklahoma, the Lower and Middle Pennsylvanian are subdivided, in ascending order, into the Morrow, Atoka, and Desmoines Series (Table I). Strata involved in the present study are all of Desmoinesian age. Desmoinesian rocks in the Arkoma Basin are shales and siltstones, a minor amount of sandstone, and very little impure limestone. The Desmoinesian sediment wedge thickens from north to south from the Northern Shelf province (Cherokee Shelf of older usage) into the Arkoma foreland basin. Bennison (1979a) developed models to explain sedimentation cyclicity and illustrated the nearly eight fold thickening in the Desmoinesian sequence north to south from Kansas to the Ouachita Mountain province (Figure 3).

Several deltaic and fan-delta regressive sedimentation episodes provide the sandstones in the Desmoinesian of East-central Oklahoma. Dark marine shales and several regionally extensive limestones record the major transgressive events of the Desmoinesian (Cherokee) Sea. The lensatic and regionally extensive sandstones, underclays, and coals record similarly important regressive events. The source of terrigenous clastic detritus in the Arkoma Basin was from the north, with the sea

TABLE I

LOWER AND MIDDLE PENNSYLVANIAN STRATIGRAPHIC NOMENCLATURE

Desmoinesian Series	Marmaton Group	Holdenville Sh. Wewoka Fm. Wetumka Sh. Calvin Fm.
	Cabanis Group	Senora Fm. Stuart Sh. Thurman Ss.
	Krebs Group	Boggy Fm. Savanna Fm. *McAlester Fm. Hartshorne Fm.
Atokan Series	U. Dornick Hills Group	Atoka Fm.
Morrowan Series	L. Dornick Hills Group	Wapanucka Ls. Union Valley Ls. Cromwell Ss. Jefferson Ss.

* Subject of this study

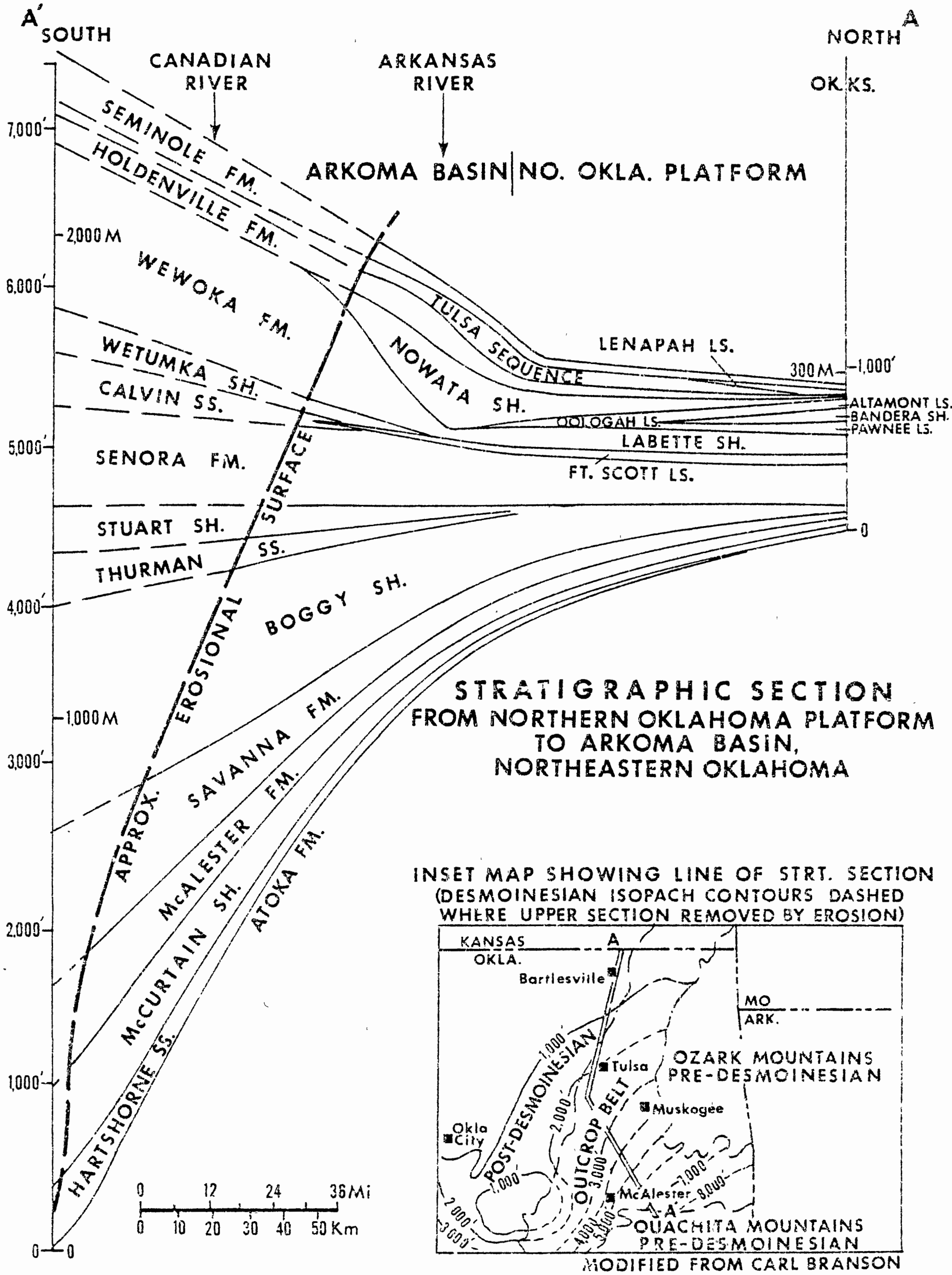


Figure 3. North to South Thickening of Desmoinesian Strata in Eastern Oklahoma (Bennison, 1979a, p. 285).

transgressing from the south, through the lower and middle Desmoinesian (Krebs, Cabaniss Groups). However, later Desmoinesian (Marmaton Group) sediments indicate a source reversal due to the growing Ouachita orogen to the south (Krumme, 1975).

Krebs Group

The Desmoinesian Series is divided into the Krebs, Cabaniss, and Marmaton Groups. In earlier literature concerning Oklahoma and in present usage in Kansas, the Krebs and Cabaniss are represented by the single "Cherokee Group". The Krebs Group is conformable upon Atokan sediments, and except for channel sands scoured into lower units, formations within the Krebs Group may be considered conformable. In the study area the Krebs Group contains, in ascending order, the Hartshorne, McAlester, Savanna, and Boggy Formations.

McAlester Formation

The McAlester Formation is a shale dominated lithostratigraphic unit. It thickens from north to south ranging from 150 feet north of Muskogee, Oklahoma to about 1200 feet in southern Haskell County (Oakes, 1977; Oakes and Knechtel, 1948). The McAlester Formation was named by J. A. Taff in 1899 for exposures around McAlester, Pittsburg County, Oklahoma (Oakes, 1977).

The term McAlester Formation is applied to the strata between the top of the Hartshorne Formation and the base of the Savanna Formation. While this application is consistent with the most recent studies in Muskogee, McIntosh, and Haskell Counties, it is not specific enough for correlations from surface to subsurface.

The Hartshorne Formation contains the following sequence: Lower Hartshorne (Tobucksy) Sandstone, coal, Upper Hartshorne Sandstone, Upper Hartshorne Coal (Catalano, 1978). In Arkansas, the Upper Hartshorne Sandstone and coal are considered part of the McAlester Formation (Haley, 1981). However, in Oklahoma, the base of the McAlester Formation is considered conformable with the Upper Hartshorne Coal. Where the coal is absent, the Upper Hartshorne Sandstone provides the basal contact.

The upper limit of the McAlester Formation has been changed since the first application of the formation name. It was previously considered to be the base of the Tamaha Sandstone (Wilson and Newell, 1937). Presently, the contact is considered to be the base of the Spaniard Limestone, a fossiliferous, sideritic, biomicrite, identifiable as the lowest consistent limestone in the overlying Savanna Formation. Locally, a thin coal may underlie this limestone (Oakes,1977).

The McAlester Formation contains six named members and several intervening coals. In ascending order these are: the McCurtain Shale, Warner Sandstone (Warner coals), Lequire Sandstone, Cameron Sandstone (Stigler Coal), Tamaha Sandstone (Tamaha Coal), and Keota Sandstone (bituminous siltstone). Commonly, a shale is between the Keota Sandstone and Spaniard Limestone. When the Spaniard is absent or indistinguishable, the base of the lowest sandstone in the Savanna is considered as the top of the McAlester Formation. Stratigraphic nomenclature and correlations used in this report are summarized by Table I and Figure 4.

Cycles of Sedimentation

Introduction

Besides illustrating the stratigraphic positions of the sandstone members in the McAlester, Figure 4 demonstrates cyclicity of the units by generalizing the transgressive or regressive nature of units within the formation. Bennison (1979a) named Desmoinesian coal cycles, delineating a cycle as that sediment between and including a coal at the base, upward to the next underclay in the sequence and naming the cycle for the coal at the base. In a sense, this type of cycle represents maximum regression to maximum regression. Problems with using this approach in subsurface mapping include discounting the possibility of redistribution of a regressive sandstone over the coal or paleosol during the next encroachment of the sea. Also, nomenclature may become confusing. For example, the readily recognizable Tamaha Sandstone is not contained within the Tamaha Coal Cycle.

For the purpose of illustrating and emphasizing regressive episodes, cycles have been proposed in this study which include an upward regressive through transgressive sequence: phosphatic marine shale, impure fossiliferous limestones and rippled siltstones, prodeltaic shales and delta front siltstones, channel or prograded shoreline sandstones, underclay, coal, and transgressive sandstone or limestone. Basically, what is attempted is a maximum transgressive (or "deepest water facies") to maximum transgressive cycle from which various subsurface maps may be constructed to illustrate paleobathemetry, sand geometry, etc., of each regressive episode ("GIS" of Busch, 1974; "format" of Brown, 1979). Informal names of cycles are proposed, derived from either the prominent

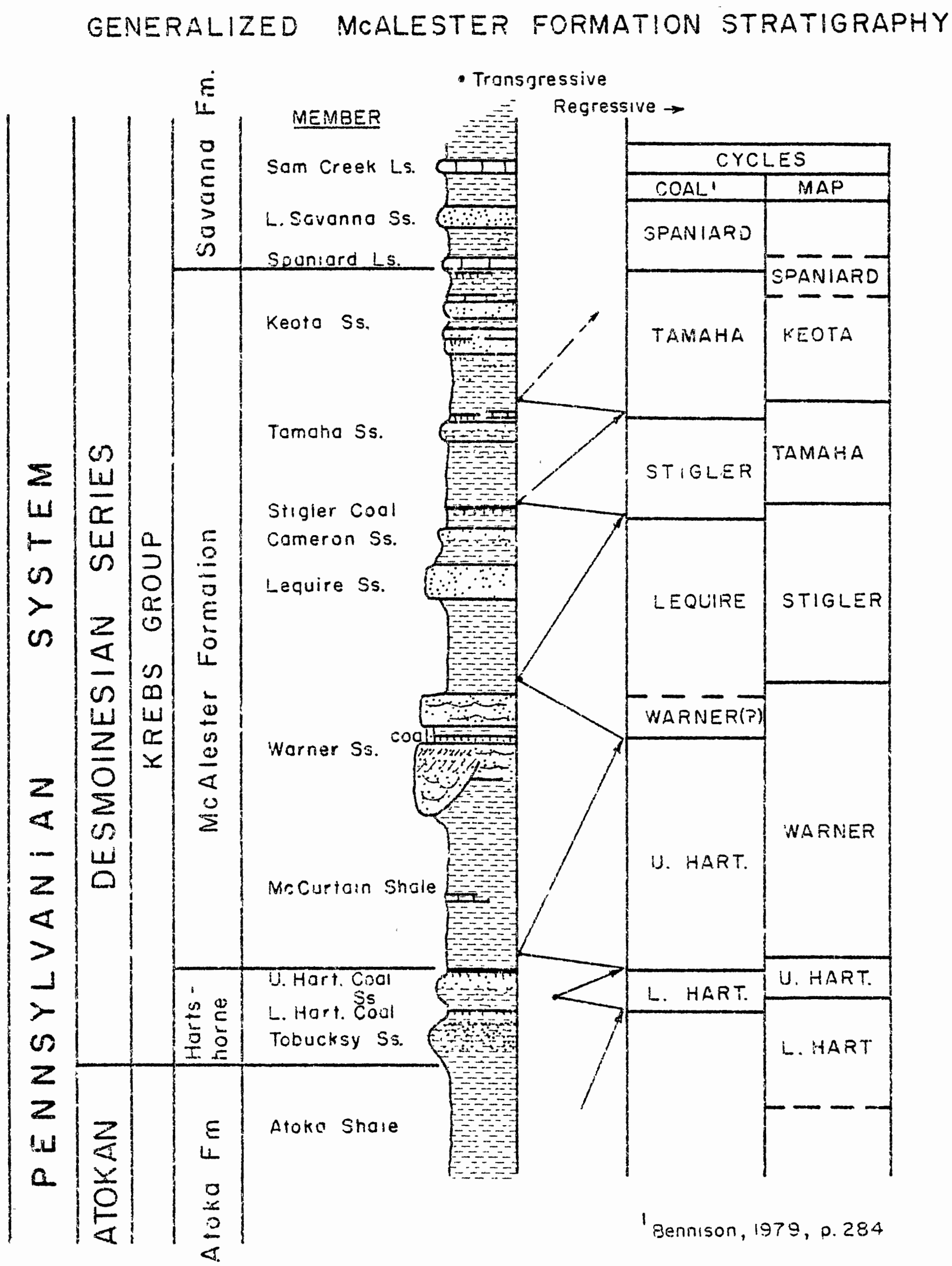


Figure 4. Generalized Stratigraphic Section for the McAlester Formation.

sandstone or coal within the cycle. Within the McAlester Formation, four complete cycles are distinguished in ascending order: the Warner, Stigler, Tamaha, and Keota. Smaller cycles may be recognized within each cycle by slight changes in lithology, or by the presence of coals.

Warner Cycle

The informal Warner Cycle contains the McCurtain Shale Member and Warner Sandstone Member (and coal) of the McAlester Formation. Functionally, the base of the cycle is the top of the Upper Hartshorne Coal, whereas the cycle ends at the top of the upper Warner Sandstone.

The McCurtain Shale is a black to dark-gray fissile shale with phosphatic and sideritic septarian nodules in the lower part, becoming more silty and sandy in the upper part. The McCurtain typically contains a few thin sideritic limestones and rippled sandstones and siltstones. It is present through the study area and thins from about 500 feet in Haskell County northward to 80 feet near Muskogee (Oakes, 1977; Oakes and Knechtel, 1948).

The Warner Sandstone overlies the McCurtain Shale, thickening locally at the underlying shale's expense. The Warner is actually two sandstones. The lower Warner is typically a fine to medium grained sandstone, coarsening upwards, that contains plant debris and abundant iron in the form of siderite or hematite. It is usually gray to tan, cross-bedded, contorted, or massive (Figure 5). There also may be a five foot shale containing a locally important coal seam separating the lower and upper sandstone bodies (Oakes, 1977). The upper Warner is best described as a tan to brown, thinly bedded, rippled, very-fine to medium sandstone that commonly contains flaser beds, burrow mottles, and ironstone.

The Warner varies in thickness from 0 to nearly 60 feet within the study area (Oakes, 1977). The thickest Warner Sandstone observed was 50 feet of cross-bedded, friable, ferrugenous medium sand at Brushy Mountain (Sec. 29, T. 14 N., R. 19 E.). However, most Warner outcrops observed were finer-grained sandstones, 20 to 30 feet thick. The Warner Sandstone correlates with the 'Lower' Warner of Kansas and Missouri usage, and is regionally extensive (Ebanks, 1979).

Stigler Cycle

The Stigler Cycle contains the unamed shale above the Warner, the Lequire Sandstone Member, the Cameron Sandstone Member (when present), through the Stigler Coal (Figure 6). The shale above the Warner was described by (Oakes, 1977) as dark gray to green, commonly silty, sometimes containing thin, fossiliferous limestones, thin sandstones, and very thin coaly beds. The thickness of the shale is highly variable from 0 to 60 feet in Muskogee County, and to 300 feet in Haskell County (Oakes and Knechtel, 1948). The shale commonly grades upwards into the Lequire Sandstone.

The Lequire and Cameron Sandstone Members are considered by Oakes (1977) as one member (Lequire-Cameron) in Muskogee County. The lower, Lequire unit is a gray to buff, 8 to 40 feet thick, rippled, mixed cross-bedded very fine to fine sandstone. The Cameron is discontinuous, 0 to 30 feet thick, silty- or sandy-shale zone or lensatic sandstone, located above the Lequire and below the economically important Stigler

Figure 5. Contorted and Friable Medium-sand at the Type-locality of the Warner Sandstone at Warner, Oklahoma.

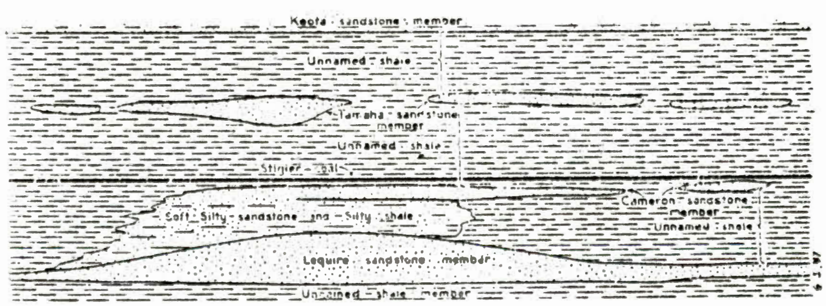


Figure 6. Typical Stratigraphic Relationship of McAlester Members Between the Warner Sandstone and the Keota Sandstone (from Oakes and Knechtel, 1948, p. 39.

Coal. The Lequire-Cameron contains carbonized wood fragments and plant impressions.

The Stigler Coal overlies the Lequire-Cameron throughout the area, reaching a thickness of two feet. Typically, a thin coal or "rider vein" exists several feet above the Stigler Coal in Haskell County.

Upper McAlester Cycles

Because of the discontinuous nature of the many sandstones, limestones, and coals above the Stigler Coal, the recognition of strict transgressive or regressive cycles in the upper McAlester Formation is difficult. However, the general patterns or succession of lithologies may suggest three or more cycles in the upper McAlester: Tamaha, Keota, and Spaniard (Figure 4). Each would be named for recognized members and the shales below.

The shale between the Stigler Coal and Tamaha Sandstone varies in thickness between 50 to 80 feet in Muskogee County, and thickens southward into the Arkoma Basin (Oakes, 1977). In Haskell County it is dark gray to black, fissile shale, that is silty near the top. The Tamaha Sandstone appears as a 3 to 20 foot, rippled, olive green to brown, coarse silt to fine sand. In northern Haskell County, it is very bioturbated at the top. When locally absent, the Tamaha interval can be identified within the study area as a silty shale. A very thin coal and limestone were observed above the Tamaha Member near Keefeton, Muskogee County.

The shale between the Tamaha and Keota Members is brown and silty. The shale thickens north to south in the study area, reaching a Thickness of about 150 feet in Haskell County. The overlying Keota Sandstone

Member is present throughout Muskogee and Haskell County, and is represented by numerous, very fine sandstone lenses in a silty zone. This zone varies in thickness from 5 to 200 feet. The Keota is easily distinguished from other units in the McAlester by its numerous green to buff sand lenses, abundant Calamites fossils, leaf impressions, and regional persistence (Oakes, 1977).

The top of the McAlester Formation is the base of the Spaniard Limestone Member of the Savanna Formation. The shale between the Keota and Spaniard strata is silty, gray to brown and contains a thin coal (Spaniard) just below the top. This shale varies in thickness north to south from about 5 to 25 feet.

Surface to Subsurface Correlations

Introduction

Wilson (1935) attempted correlations between the surface Atoka, Hartshorne, McAlester, Savanna, and Boggy Formations with their subsurface counterparts. Much of the subsurface usage has been derived from local, or functional usage (i.e. the Brown Lime appears brown in well cuttings). Bennison (1979a, 1979b) illustrated similar correlations between the surface and subsurface. Common surface-to-subsurface correlations for lower Krebs Group strata include (in descending order): Bluejacket (Boggy Formation) Sandstone - Bartlesville; Doneley, Sam Creek, and Spaniard (Savanna Formation) Limestones - Brown Limes; McAlester sandstone members - Booch Sands; Warner Sandstone - Lower Booch (also Middle Booch); and Hartshorne Sandstones - Hartshorne (sometimes Basal Booch); Atoka sands are called 'Dutcher' or 'Gilcrease'.

McAlester Formation

Plates I, II, and III (in pocket), and Figure 7, illustrate correlations of the McAlester utilized in the subsurface mapping presented with this study. Outcrop stratigraphy was studied and compared to nearby well data to develop correlations. Composite stratigraphic sections from the Muskogee, McIntosh, and Haskell County Bulletins of the Oklahoma Geological Survey were valuable in this approach, especially since these sections were prepared in a vertical scale of 1 inch equals 100 feet, the common geophysical log vertical scale (Wilson and Newell, 1937, Plate III; Oakes, et al. 1967, Plate II; Oakes, 1977, Plate II).

These composite sections, like the electric log cross sections, illustrate the southward and eastward thickening of the section. The Warner Sandstone Member of the McAlester Formation correlates with the Lower Booch Sandstone (most common usage), a known oil and gas producer. The Lower Booch log response illustrated in Figure 7 matches the average thickness and stratigraphic character of the Warner (Upper and Lower) in outcrop. In the subsurface the Warner may attain a thickness of over 250 feet and show apparent scouring into the Hartshorne. Neither the great thickness nor the downcutting of the Warner into the Hartshorne Formation are seen on the surface. To summarize, the electrically resistant shale, coal, and siltstone below the Lower Booch represent the McCurtain Shale, Upper Hartshorne Coal, and Upper Hartshorne Sandstone. McAlester Formation black shale facies provide a likely source for hydrocarbons. The first sand above the Warner would, of course, be the Lequire-Cameron, commonly called the Upper Booch Sandstone. The

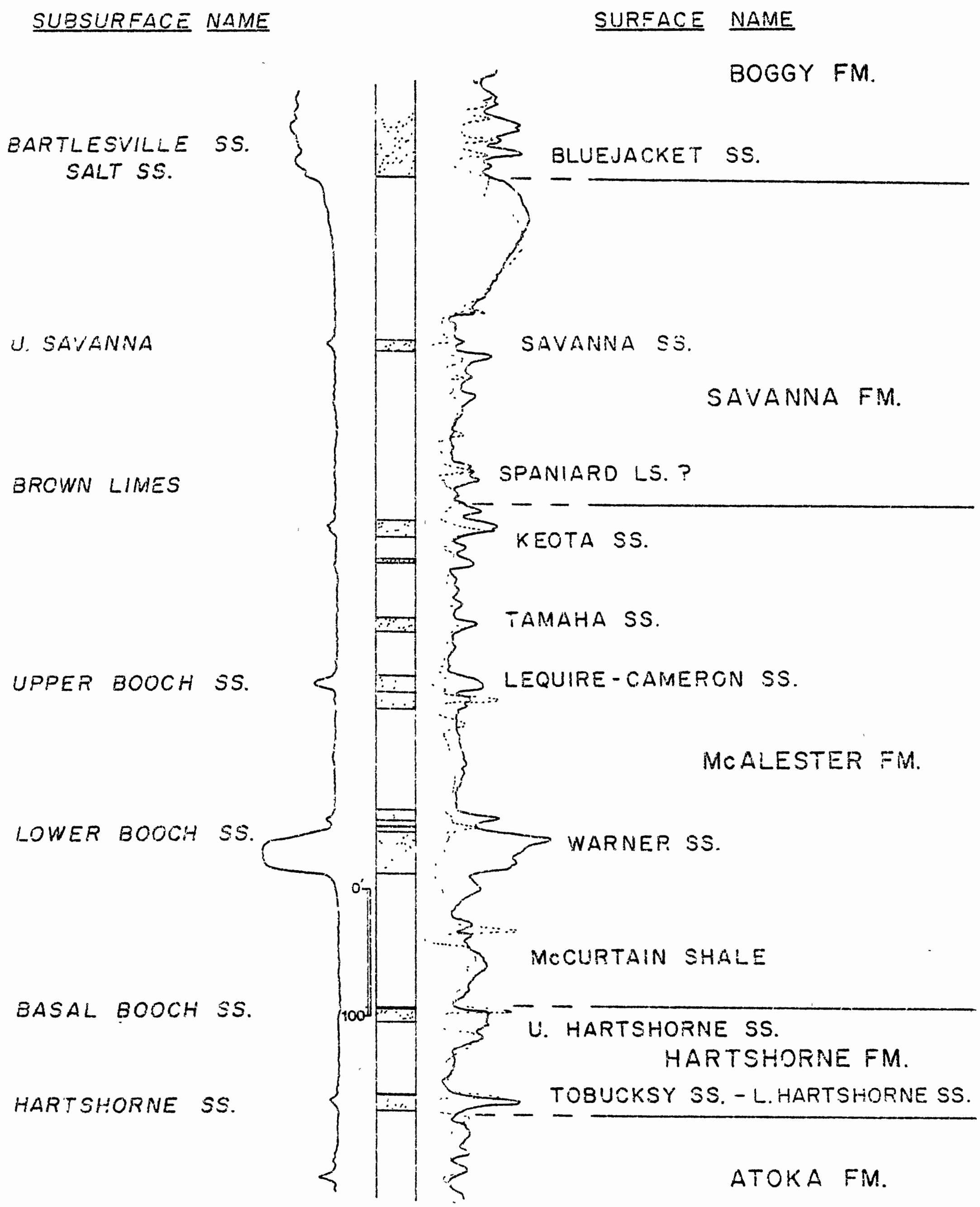


Figure 7. Surface and Subsurface Nomenclature.

Stigler Coal may be identified above the Upper Booch by a 'spike' in the short normal resistivity.

Correlation of McAlester strata above the Upper Booch is more difficult and somewhat arbitrary. The Tamaha is correlated with the next highest sandy or silty subsurface zone. The numerous sandstone lenses of the Keota respond quite well above the Tamaha zone on logs. Above the Keota Sandstone lies a shale and numerous "Brown Limestones". The lowest of these limestones (Spaniard Limestone) is very thin and generally present on logs. Also, the "Brown Limestones" appear not as three continuous markers, but regionally as a 'zone' where three or more limestones, siltstones, and sandstones may develop. For these reasons, the functional top of the McAlester Formation in the subsurface was designated as the top of the Keota zone, as correlated into the subsurface from the easternmost logs used in the study. The top was determined by the highest sandstone lens in the Keota sequence. A difference of 5 to 25 feet between the subsurface and outcrop or roughly 2% error in isopach thickness of the McAlester Formation can be anticipated in this correlation.

A remarkable consistency in the vertical positions of sandstone members in the McAlester Formation was observed in the construction of cross-sections and subsurface maps. Except for the Warner (Lower Booch), even the individual thicknesses of these sand members show little variation as seen along strike. Like the intervening shales, the sandstones tend to thicken southward. The consistency in stratigraphy and basinward thickening of the entire sequence aided in identifying cycles of area wide transgressions and regressions.

Busch (1953, 1974) illustrated correlations of the Booch Sand and McAlester Formation. The westernmost log (11 N., 12 E.) on Plate II was compared with this correlation and a major discrepancy was found. It appears that the top of the McAlester Formation was placed above the Lequire-Cameron Member (Upper Booch) and the base approximately 100 feet into the Atoka Formation. These differences probably arise from changes in the boundaries of the McAlester by various authors (Wilson and Newell, 1937; Oakes and Knechtel, 1948) and the previous lack of wireline electric logs such as those now available to permit the correlations provided in this study.

Regional Correlation

The stratigraphic equivalents of the Warner Sandstone Member of the McAlester Formation are recognized on the surface and in the subsurface throughout the Arkoma Basin and Northern Shelf of Oklahoma, as well as in parts of Arkansas, Kansas, and Missouri (Haley, 1961; Moore, et al., 1951; Howe, 1961). Other members of the McAlester are absent or rarely recognized. Regionally the Warner Sandstone is known as the Little Cabin, Booch, Taneha, Tucker or Burgess Sandstone.

CHAPTER IV

DEPOSITIONAL FRAMEWORK

Evolution of the Arkoma Basin

The Arkoma Basin and Ouachita Mountain regions of Oklahoma have a complex geologic history. Many articles have been written on the tectonic and sedimentary characteristics of these features and adjacent regions in Oklahoma, Arkansas, and Texas. Houseknecht (1983) summarized current ideas on the evolution of the Arkoma Basin. He discussed the tectonic history by emphasizing evidence in the sedimentary record.

The Arkoma Basin history began with the development of a rift system or divergent plate boundary during the late Precambrian. A young (Ouachita) ocean basin developed with the opening of a proto-Atlantic. The southern margin of North America evolved into a passive, Atlantic-type margin (Houseknecht, 1983). Upon this south-facing shelf, thermal subsidence influenced the early and mid-Paleozoic (Cambrian-Silurian) accumulations of mostly shallow marine carbonates and sandstones. The interval is punctuated by numerous unconformities. In the deeper part of the Ouachita orthogeosynclinal basin, the time-equivelant sediments were very different in character. Deep marine shales, sandstones, and limestones of this facies are now exposed in the Ouachita Mountain Province, the result of the Ouachita orogeny.

The ocean began to close during the Late Devonian or Mississippian (Houseknecht, 1983). As North America and "Llanoria" converged, a subduction zone and volcanic arc developed within the basin. Through the earliest Atokan (Pennsylvanian) time normal shelf sedimentation continued. During Atokan time, detritus poured into the remnant ocean basin from the east, north, and south. Subduction resulted in flexure of the North American continental crust and the development of normal faulting.

Collision of the continents caused the uplift of the subduction complex, forming the Ouachita mountains and the Arkoma foreland basin (Houseknecht, 1983) by late Atokan time. During the earliest Desmoinesian (McAlester) some sediment was being shed from the south into the Arkoma Basin. However, in Oklahoma, the Ozark mountain and Nemaha Ridge sourcelands continued to provide sediment from the north (Figure 8). By middle Desmoinesian time, southerly derived sedimentation dominated the Arkoma Basin (Houseknecht, 1983).

Depositional Setting of the McAlester Formation

Source and Basin Characteristics

Many workers have recognized the probable northerly source of McAlester sandstones. Busch's (1953) isolith map of the Booch sandstone (Figure 2) clearly demonstrates a northerly derived distribution system of deltaic-type sediments. Agterberg and Briggs (1963) determined paleocurrent directions from ripple marks in Desmoinesian outcrops. They recognized a dominantly south-southeast current direction in Krebs group strata, and suggested an Ozark source for sediments studied.

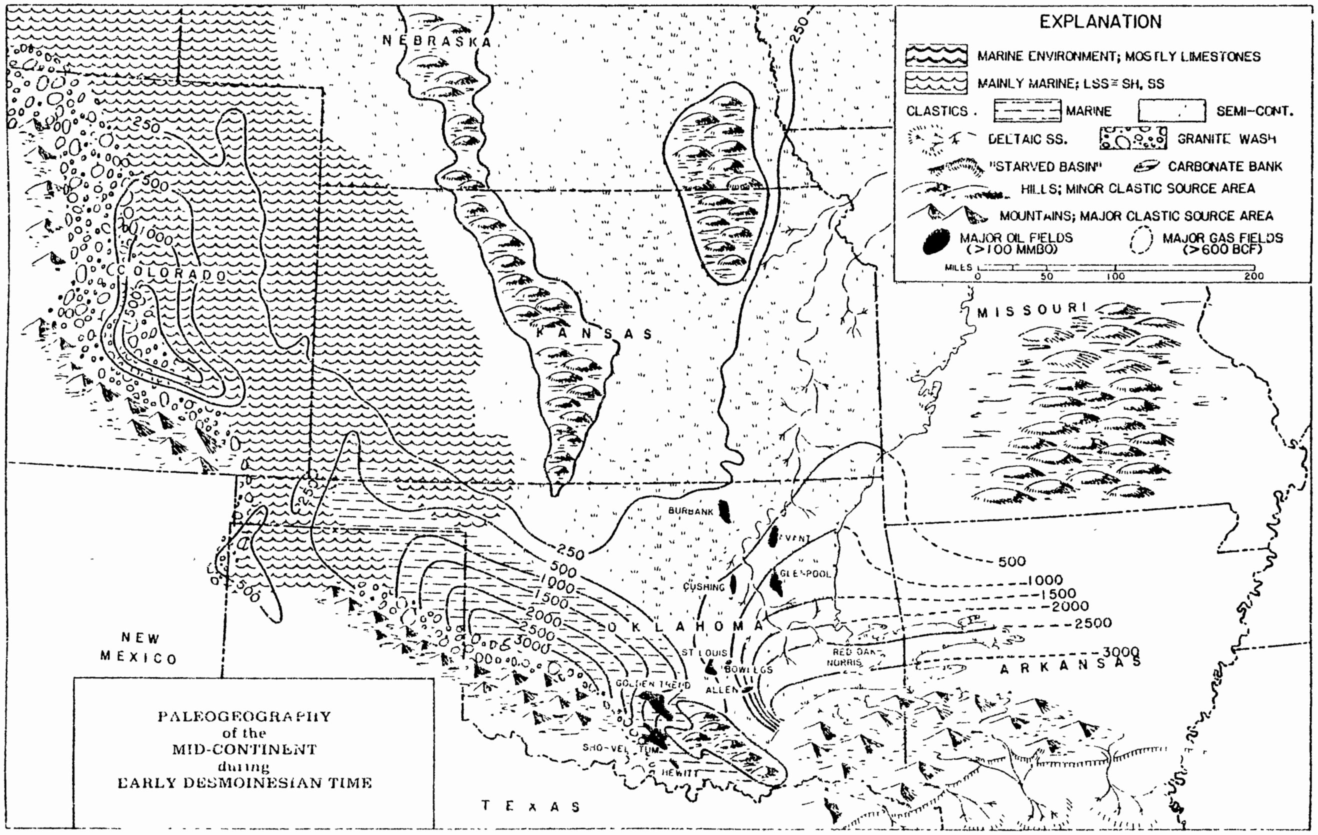


Figure 8. Lower Desmoinesian Paleogeography (from Rascoe and Adler, 1983, p. 991).

Karvelot (1972) mapped paleocurrent directions of McAlester sandstones in Haskell County. The apparent northwestern source direction for outcrops examined matched the general framework of Busch's (1953) isolith map. In an earlier study, Scruton (1949) concluded based on petrography and outcrop character that the Warner Sandstone represented northerly (Ozark) derived deltaic sediment. No observation made in the surface or subsurface aspects of this study conflicted with an ultimate northerly source for McAlester sandstones.

The shape of the Arkoma foreland basin during McAlester deposition was probably a trough that trended east-west, fed from the north by rivers and from the south by fan sediments off the Ouachita highlands. In Arkansas, two McAlester Formation troughs have been identified, both northeast-southwest trending, which contain a maximum of 1800 feet of McAlester sediment (Haley, 1961). Busch, (1974) illustrated an isopach map of the McAlester Formation in East-central Oklahoma (also Plate VI, in pocket). As demonstrated before, while Busch's correlations of the McAlester were not correct, this map does generally demonstrate the shelf-to-basin character of the unit during McAlester deposition.

The thickening of the McAlester Formation to the south represents a transition from shelf to basin. This thickening is probably associated with differential subsidence due to crustal loading; the result of the previously described Pennsylvanian continental collision and subsequent Ouachita orogeny in early Desmoinesian time (Houseknecht, 1983).

The McAlester Formation also thickens abruptly on the south side of several northeast-southwest trending faults, regardless of the location of the downthrown side. Koonz (and Oakes, 1967, Plate III) mapped the subsurface structure of McIntosh County and delineated several major fault systems. Cohen (1982) modeled the structural characteristics of a passive to active continental margin. He explained reversals and reactivations of prexisting listric, normal faults, that develop during later periods of basinal extension. It is possible that this model may be applicable to faults in East-central Oklahoma (see Figure 25).

Paleoclimate

Paleoclimatic reconstructions of North America during Pennsylvanian time generally place East-central Oklahoma near the equator (Heckel, 1977; Habicht, 1979, Foldout 5). Partial evidence for this interpretation is the large number of coals, and accompanying *Calamites* and *Lepidodendron* (tropical-type) plant debris, indicating swamps and marshes in a humid, tropical climate. Furthermore, Habicht (1979) utilized the locations of other climate-sensitive sedimentary rocks and paleomagnetism to suggest paleolatitude.

Heckel (1977) discussed the origin of the phosphatic black shales common to the Pennsylvanian cyclothems in Kansas and Oklahoma (Figure 9). Interaction between oxygen-starved, phosphate-rich upwelling bottom water and warm water circulating above the thermocline encouraged phosphorite development within the black muds during transgressive phases of cyclic sedimentation.

Booch Delta

Surprisingly, it was not D. A. Busch (1953) who first published an isolith map of the Booch Sandstone and postulated a deltaic origin based upon sand geometry. R. D. Reed (1923) prepared and published such a map. Reed concluded that:

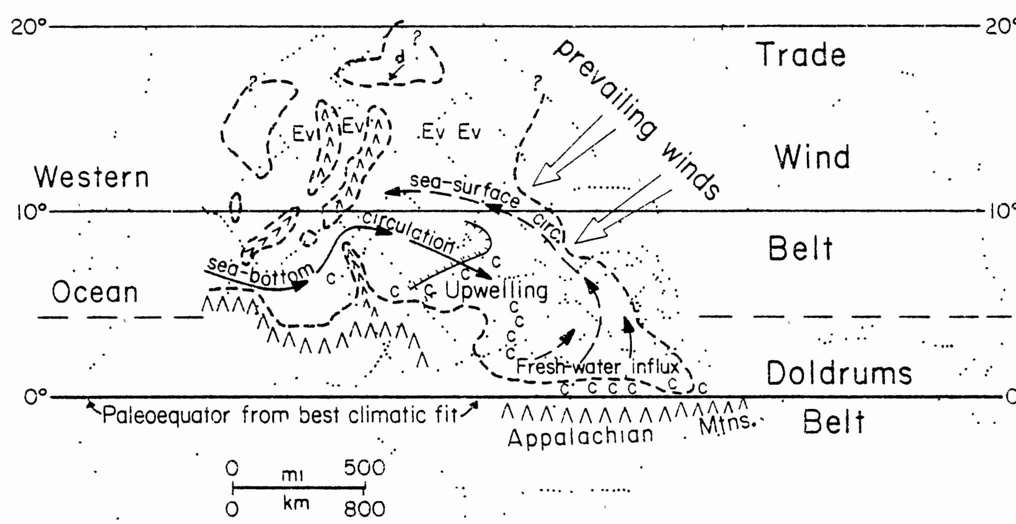


Figure 9. Probable Orientation of North America During Middle to Late Pennsylvanian Time. "Ev" = Evaporites, "c" = Coals, "d" = Dune Sands (from Heckel, 1977, p. 1056).

> The peculiar Booch sand promises, albiet in a somewhat doubtful manner, to fit nicely into the scheme of things which a Pennsylvanian delta would require us to assume in the Henreyetta district (p. 57).

He erroneously theorized southern source for the Booch Delta prograding into a more northerly epicontinental sea.

Scruton (1949) recognized that the myriad of environments that he observed in the Warner could only exist within the framework of:

> ...that most complicated of sedimentary environments, the region where a river...flowing generally southwest...entered the sea. At some place within the (study) area every characteristic feature of the deltaic environment can be found...the interpretation is unavoidable (p. 67).

Most of the work on the Booch-Warner Sandstone since 1953 has been guided by Busch's (1953) well publicized isolith map of the Booch Sandstone. This exceptional map clearly demonstrates the bifurcating sand geometry observed in modern, high constructive deltas (Fisk, 1961; Brown, 1979).

There is little doubt that the Warner Sandstone Member and other McAlester sandstones (Booch Sands) represent phases of a single deltaic episode or several deltaic episodes. However, a more exact determination of depositional environments from outcrops and cores measured in this study is desired. For that reason, current ideas on specific depositional models and environments within deltas will now be presented.

Depositional and Facies Models

Fisk (1961) studied the Mississippi Delta and outlined the sand geometry, facies associations, and sediment character of 'bar-finger' sandstones. The criteria applied to the recognition of bar-finger sandstones in ancient deltaic deposits (Figure 10) are summarized as

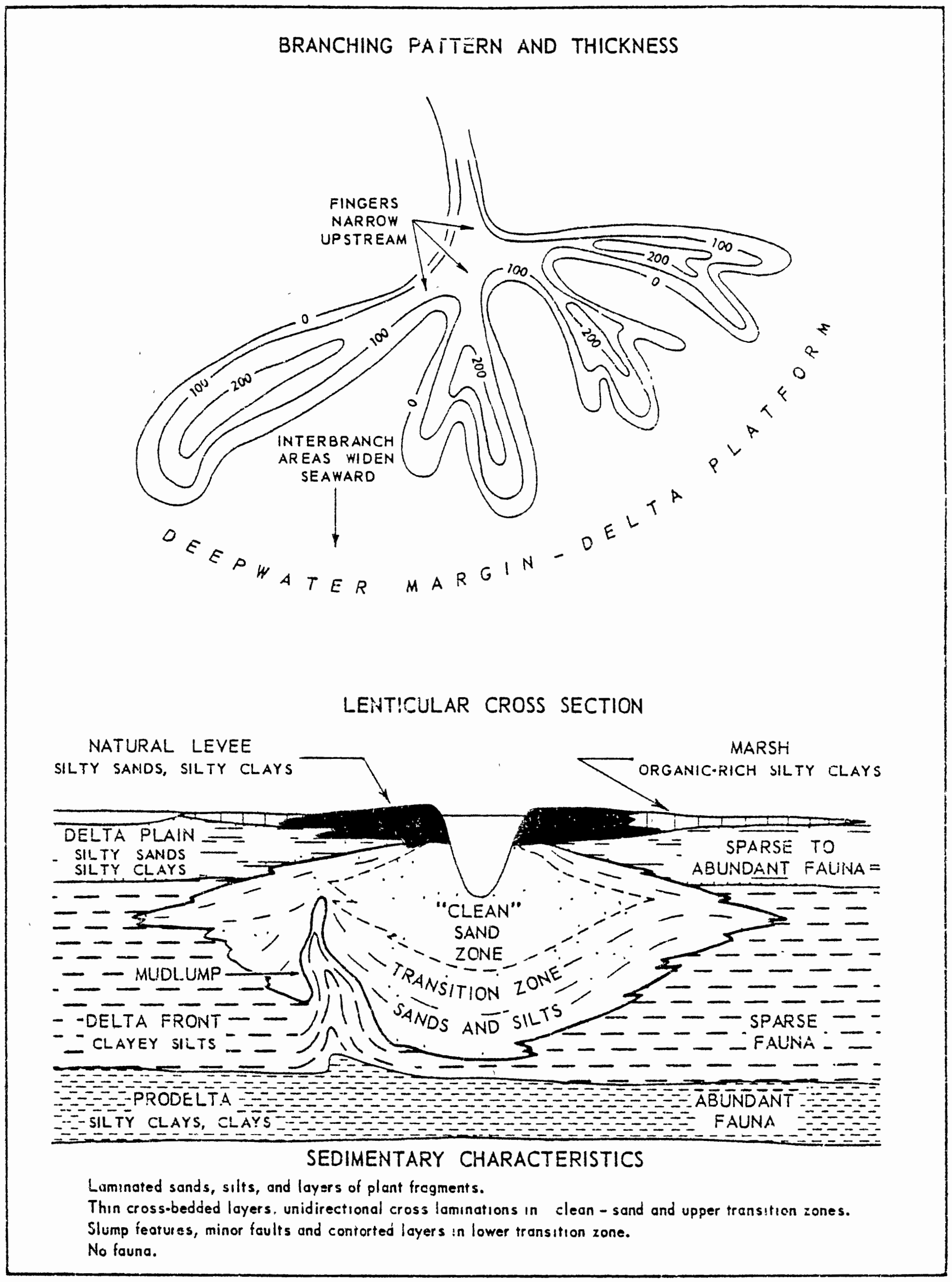


Figure 10. Distinguishing Characteristics of Bar Finger Sandstones (from Fisk, 1961, p. 49).

follows. Elongate and lenticular sands thin upstream and bifurcate downstream. Boundaries with surrounding finer-grained, marine fauna-bearing facies are transitional. The central portions of the bodies are composed of clean, well-sorted sand that contains laminated and unidirectionally cross bedded sands. Festoon cross beds, plant fragments, and laminae of silts and clayey-silts occur within the bar-finger. Minor faults, contortions, and mud lump 'stocks' are developed during deposition. Furthermore, Fisk applied these criteria to Busch's Booch Delta and concluded (based on evidence available) that the thick elongate sand bodies represented ancient bar fingers.

Depositional models associated with Appalachian coals were the focus of a report by Horne, et al. (1978). Criteria for the recognition of five types of specific depositional environments were outlined. Landward subdivisions of their Pennsylvanian deltaic facies tract include: barrier, back barrier, lower delta plain, transitional lower delta plain, and upper delta plain-fluvial elements (Figure 11). Measured sections were presented to illustrate common vertical sequences of lithologies and sedimentary structures.

Brown (1979) identified two basic models for cratonic deltas: the high-constructional lobate (Figure 12) and the high-constructional elongate (Figure 13), within which many local depositional environments can be identified. The basis of the identification and subsurface mapping of individual deltas was the 'delta cycle' genetic interval, a vertical subdivision of the stratigraphic section very similar to the mapping cycle put forth earlier in this report.

The most important hydrocarbon reservoirs within delta systems are "delta-front" sandstones, those sandstones deposited during initial

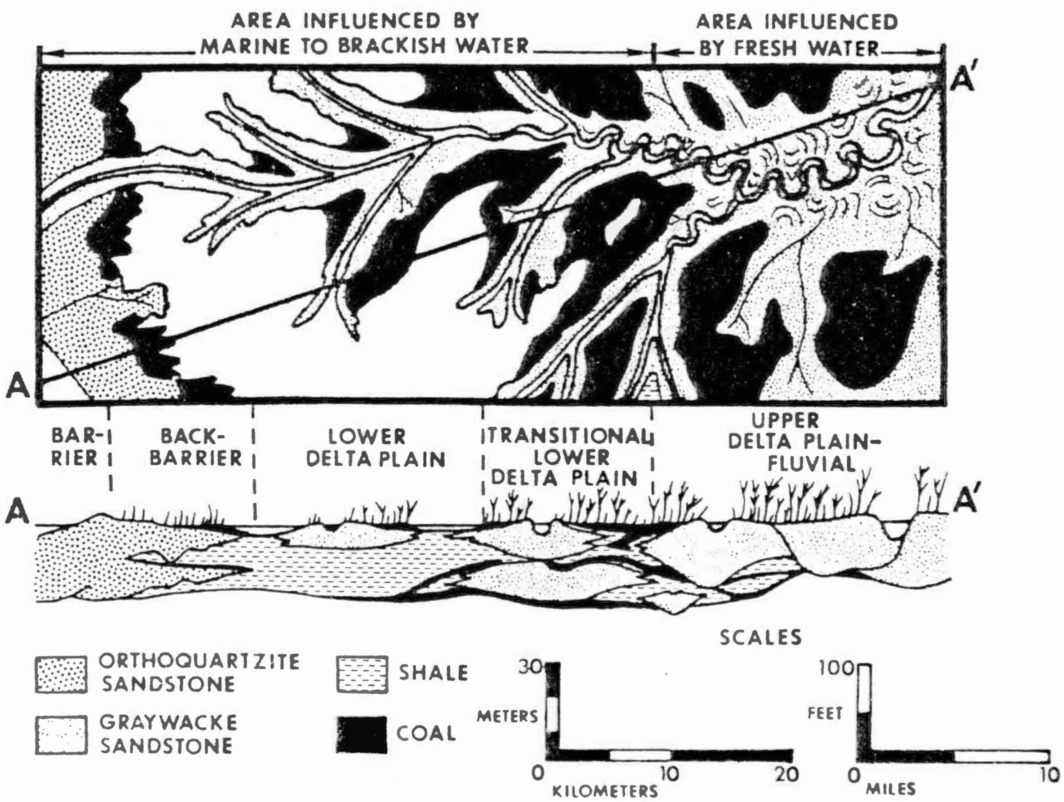


Figure 11. Depositional Environments Associated with Coal Developments in Coastal Areas (from Horne, et al., 1978, p. 2382).

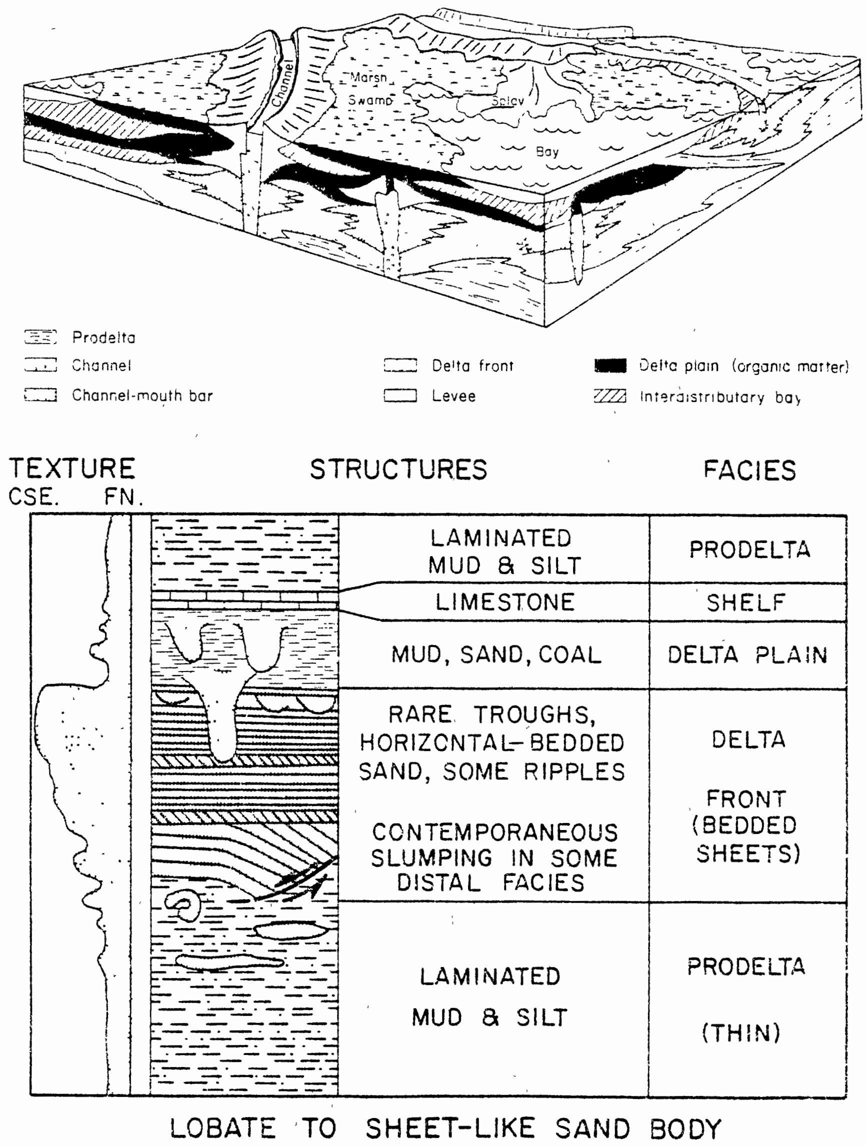


Figure 12. Cratonic, Lobate Delta Model (from Brown, 1979, p. 51).

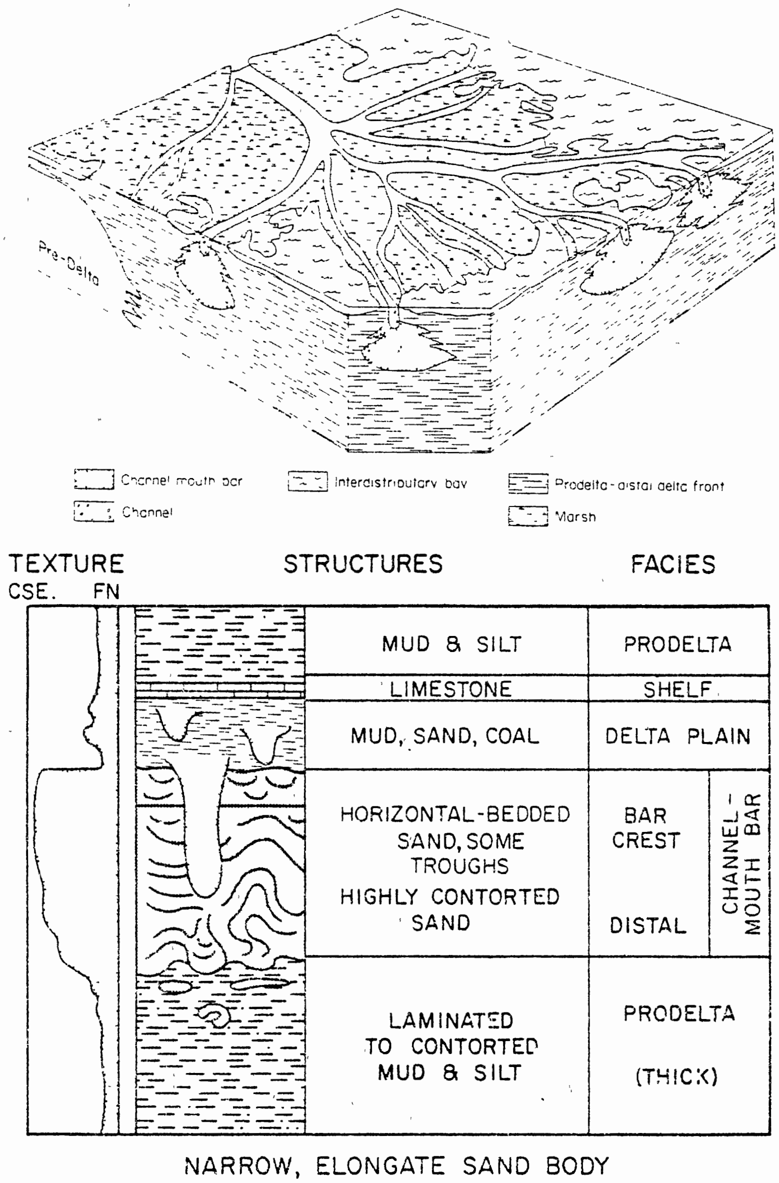


Figure 13. Cratonic, Elongate Delta Model (from Brown, 1979, p. 52).

progradation (advancement) of the delta system (Brown, 1979). Other reservoirs of lesser importance that may develop within a constructive, cratonic delta system are strike-oriented barrier sandstones, destructive barrier sandstones, and crevasse splay deposits. Source rocks for hydrocarbons in delta systems include adjacent shales.

The character of delta front sands varies depending upon the overall lobate or elongate geometry of the delta. Lobate delta-front sandstones exhibit digitate electric log patterns, which generally may be distinguished from massive, blocky elongate sandstone electric log patterns (Brown, 1979).

Lobate deltas are characterized by marine-reworked delta-fringe sandstones, lobate geometry, thin preserved channel mouth bar sandstones, and contemporaneous growth faults. In contrast, elongate deltas exhibit narrow, elongate delta front sandstones composed of the channel mouth bar and distributary channel-fill sandstones (bar fingers of Fisk, 1961). Elongate channels were rapidly deposited in relatively deep water and involved contemporaneous subsidence into thick, water saturated prodelta mud. These sand bodies are frequently deformed by rapid subsidence and injection of mud and sand diapirs (Brown, 1979).

Reservoir facies within lobate systems frequently include growth faulted delta front sandstones, distributary channel fill, delta-front sheet sandstone and bar fingers. The fact that elongate, bar finger sands are enclosed in prodelta shales increases their stratigraphic trap potential (Brown, 1979).

Straight distributary channels, usually in distal parts of the delta complex, may be abandoned and filled vertically by bedload sands, then muds. Generally narrower than bar finger sands, distributary channel sands are also distinguished by their box-like geometry on geophysical logs (Figure 24). These channel-fill sandstones frequently grade upwards into fluvial-type meander belt sandstones, characterized by an upward decrease in grain size, permeability, and scale of sedimentary structures (Brown, 1979).

This overview of various types and characteristics of cratonic deltas provides a framework for evaluating measured sections and cores of sandstones within the McAlester Formation with respect to variations in lithology, sedimentary structures, and apparent sedimentary facies.

CHAPTER V

OUTCROP STUDY

Introduction

The outcrop zone of the McAlester Formation in Haskell, McIntosh, and Muskogee Counties is characterized by ridges and valleys where the resistant sand members crop out in the dominantly shale sequence. Throughout eastern Oklahoma, regional dip is to the west and the gently dipping sandstone units create a large number of east-facing escarpments. In the study area, sandstone outcrops are commonly exposed on the limbs of folds, generally synclines. These occurences of sandstone outcrops, along with several "fresh" roadcuts and excavations provided the opportunity to study the McAlester sandstone members in outcrop.

The primary objectives of the outcrop study were:

1. To interpret depositional environments in the sandstone members, for the purpose of understanding the depositional framework of the McAlester Formation.
2. To establish an outcrop vertical stratigraphic sequence of rock units that can be compared to the subsurface McAlester section as seen in electric logs.
3. To investigate the petrographic and diagenetic characteristics of the sandstones for later comparison with samples of the same units in the subsurface.

Geologic maps and measured sections obtained primarily from Oklahoma Geological Survey county bulletins aided in the identification of outcrops suitable for measurement and/or sampling. Before beginning data collection a reconnaissance survey was made using available geologic maps to identify probable exposures. Outcrops for measurement and/or sampling were selected based upon quality of exposures and distance between sampling points for the same member. From this approach two types of sampling localities were distinguished in this study:

1. Measured Sections - represent 20 foot or thicker sandstone and shale outcrops that are exposed sufficiently to display sedimentary structures and permit an environmental interpretation. These localities were examined, measured, and sampled for petrographic analysis (see Appendix A).
2. Sampled Outcrops - are those localities that in some way did not meet the above criteria (perhaps the target rock unit was very poorly exposed) and were only sampled for petrographic analysis.

A total of 12 measured sections (Figure 14) and several sampled outcrops were utilized in this study (Table II). At least one section of each member of the McAlester was measured, six of the measured sections are Warner Sandstone. As mentioned earlier the Warner is the hydrocarbon producing Lower Booch Sandstone in the subsurface and merits the greatest attention of the McAlester rock units.

Measured Sections

McCurtain Shale

The McCurtain Shale is the basal member of the McAlester Formation; it overlies the Upper Hartshorne Coal. The McCurtain Shale was observed

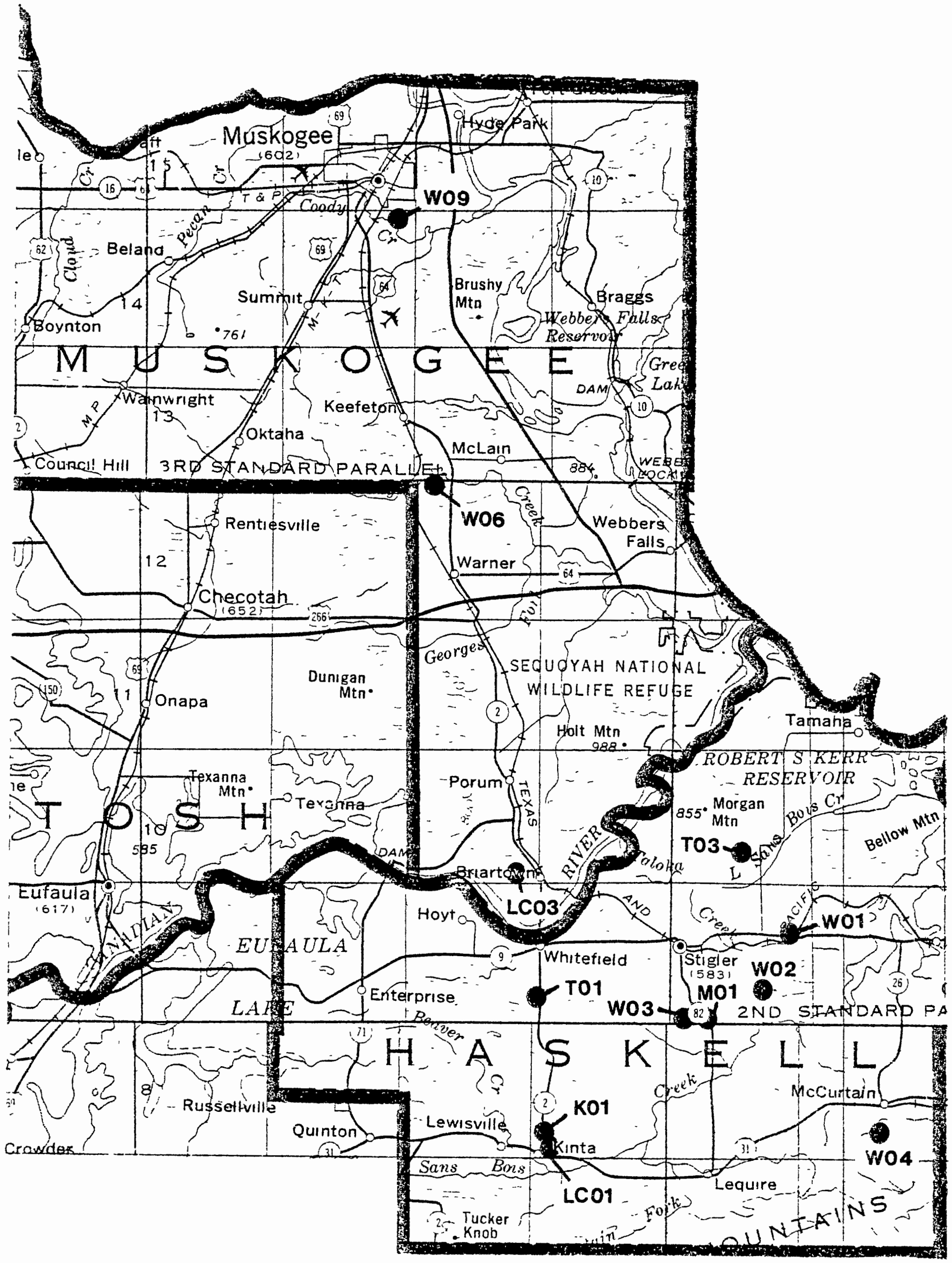


Figure 14. Locations of Measured Sections (U.S.G.S. Base, Oklahoma, 1:500,000).

TABLE II

MEASURED SECTION AND SAMPLED OUTCROP LOCATIONS

	Measured Sections: Appendix A			
M01	McCurtain Shale	C	SW	Sec. 32, T. 9 N., R. 21 E.
W01	Warner Sandstone	C	SL	Sec. 12, T. 9 N., R. 21 E.
W02	Warner Sandstone	C	NW	Sec. 27, T. 9 N., R. 21 E.
W03	Warner Sandstone	SW	SE	Sec. 31, T. 9 N., R. 21 E.
W04	Warner Sandstone	SE	NW	Sec. 28, T. 8 N., R. 22 E.
W06	Warner Sandstone	SW	NW	Sec. 5, T. 12 N., R. 19 E.
W09	Warner Sandstone	SE	SE	Sec. 2, T. 14 N., R. 18 E.
LC01	Lequire-Cameron Ss.	N	N	Sec. 31, T. 8 N., R. 20 E.
LC03	Lequire-Cameron Ss.	NW	SW	Sec. 36, T. 10 N., R. 19 E.
T01	Tamaha Sandstone	C	EL	Sec. 25, T. 9 N., R. 19 E.
T03(4)	Tamaha Sandstone		C	Sec. 27, T. 10 N., R. 21 E.
K01	Keota Sandstone	SE	SW	Sec. 19, T. 8 N., R. 20 E.
	Sampled Outcrops			
W05	Warner Sandstone	SW	NE	Sec. 27, T. 10 N., R. 22 E.
W08	Warner Sandstone	SW	NW	Sec. 7, T. 15 N., R. 19 E.
W10	Warner Sandstone	C	WL	Sec. 18, T. 13 N., R. 19 E.
W11	Warner Sandstone	SW	SW	Sec. 16, T. 12 N., R. 19 E.
W12	Warner Sandstone		NW	Sec. 19, T. 14 N., R. 19 E.
W13/K02	Warner Sandstone		SL	Sec. 2, T. 12 N., R. 18 E.
W14	Warner Sandstone		SE	Sec. 29, T. 14 N., R. 19 E.
LC02	Lequire-Cameron Ss.	SE	NE	Sec. 28, T. 11 N., R. 18 E.
K03	Keota Sandstone	SW	NW	Sec. 7, T. 13 N., R. 19 E.
K04	Keota (Shale)	C	EL	Sec. 17, T. 15 N., R. 18 E.
S01	Spaniard Limestone	SW	NE	Sec. 11, T. 13 N., R. 18 E.
S02	Spaniard Limestone	SE	SW	Sec. 19, T. 8 N., R. 20 E.

throughout the study area, however, only one section was measured. The McCurtain Shale (M01) is exceptionally well exposed in a roadcut on S.H. 82 south of Stigler, C SW 1/4 Sec. 32, T. 9 N., R. 21 E. This section was measured previously by Oakes and Knechtel (1948), however not for the purpose of environmental interpretation.

The 140 foot exposure of black and dark gray marine shale contains a few ripple marked siltstone layers and very fine sandstones (Figure 15), also two thin sideritic biomicritic carbonate layers containing brachiopods, bryozoans, crinoid fragments and other obviously marine fauna elements were also noted. There is a 2 inch coal and underclay near the base of the exposure, probably the Upper Hartshorne Coal unit.

The McCurtain Shale typically is silty and sandy near the base of the overlying Warner Sandstone. Because of the marine character of the lower and middle McCurtain, and its coarsening upward relationship to the Warner, it is believed to represent marine shelf and prodeltaic sedimentation associated with the Warner (or Lower Booch) deltaic episode.

Warner Sandstone

Six sections of Warner Sandstone were measured (W01, W02, W03, W04, W06, and W09) and many outcrops were examined and sampled throughout the study area. The Warner was typically distinguished from other sandstone members by is coarser grain size and stratigraphic position above the McCurtain Shale.

Outcrop W01, Sec. 12, T. 9 N., R. 21 E., was first measured by Karvelot (1972). This roadcut is well exposed and illustrates two distinctly different bedding types within the Warner Sandstone. The lower fifteen feet of gray to maroon, moderately well sorted, medium sandstone contains large and medium scale unidirectional tabular cross-beds: siderite cement is present on the bedding surfaces (Figure 16). The consistency of the nearly due east dipping surfaces give a distinct sense of paleocurrent directions. In several places the tabular beds are deformed, contorted, and even folded over to form "recumbent forsets" (Karvelot, 1972).

The upper sands in the Warner are also medium-grained and moderately well sorted but differ distinctly in appearance from the basal beds. The upper, brown, trough cross-bedded sands scour the upper surface of the tabular sands. Troughs are usually contorted by both penecontemporaneous deformation and iron diagenesis, and the upper sandstone is much more friable than the lower.

Just a few miles south, measured sections W02 (Sec. 27, T. 9 N., R. 21 E.) and W03 (Sec. 31, T. 9 N., R. 21 E.) exhibit characteristics similar to W01. Section W02 shows medium-scale trough cross-bedded Warner Sandstone scoured into silty McCurtain Shale. Numerous plant fragments and clay clasts are in this layer. Higher in the section, the reddish sand is very deeply weathered and friable. Sedimentary structures are difficult to distinguish; however mixed trough and tabular cross bedding and small recumbent forsets were recognized. The upper surface of this section contained symmetrical ripples.

Section W03 illustrates a contorted, trough cross-bedded lensatic sandstone body scoured deeply into a horizontally bedded, rippled, silt and very fine sandstone. The Warner contains abundant iron in the form of siderite, limonite, or hematite.

The close proximity of the three measured sections requires that environmental interpretations for each section fit with the interpretation

Figure 15. Bioturbated Siltstone Layer in the McCurtain Shale (Sec. 32, T. 9 N., R. 21 E.).

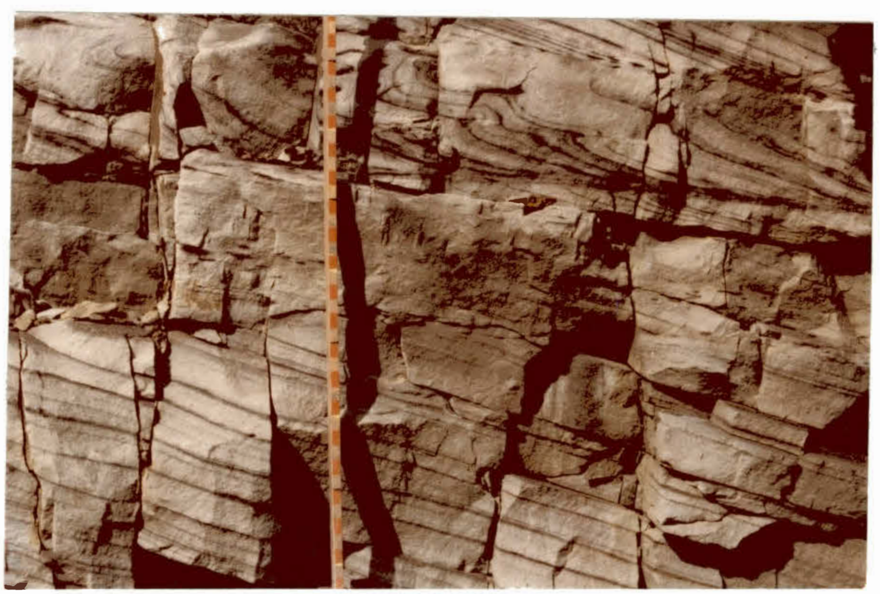


Figure 16. Unidirectional, Tabular Cross-bedding in a Warner Sandstone Channel (Sec. 12, T. 9 N., R. 21 E.

of the others. The northerly (W01) section represents stacked, rapidly prograding distributary channels. The initial progradation is marked by the unidirectional tabular cross-beds and recumbent forsets. This lower unit has been scoured into by an upper channel containing trough cross-bedded sandstone. The two measured sections to the south are smaller channels, resulting from the bifurcation of the main-distributary channel seen in W01. The silty-sand and sandy- to silty-shale of the upper McCurtain seem to indicate a poorly developed 'delta front' sand.

Farther southeast (Sec. 28, T. 8 N., R. 22 E.), another outcrop of Warner Sandstone (W04) was measured. Several three to six foot thick, gray, siderite cemented, medium-sand lenses had scoured into dark-gray, marine shale (Figures 17 and 18). Numerous plant fragments were observed in this zone. The upper fifteen feet of this forty-two foot measured section contained brown to gray, assymmetrically rippled, slightly burrowed sandstone, interbedded with silt and clay.

This outcrop represents the progradation and lateral migration of a small distributary channel in a distal portion of the delta complex. The delta front facies is absent, either removed by scour or never deposited. The upper rippled sand is the destructive facies developed after abandonment of that portion of the delta complex. Sand would be marine reworked over the regressive facies as the complex subsides.

Nearly 46 miles to the north (Sec. 2, T. 14 N., R. 18 E.), a very similar transgressive sand is directly above a well developed coal and the lower Warner sandstone. This lower sandstone is five feet thick, sideritic and contorted at its basal contact, becoming rippled at the top. There is a well developed paleosol below the 8 inch coal and a one foot silty clay just above. This sequence illustrates a transgression over a upper transitional delta plain deposit (Horne, et al., 1978).

West of Warner, on the north bluff of the escarpment formed by the Rattlesnake Mountain syncline (Sec. 5, T. 12 N., R. 19 E.), twenty feet of Warner Sandstone is well exposed (Figure 19). The contact with the greenish-gray, horizontally laminated and flaser bedded silty and sandy shale below is gradational and the sandstone coarsens upward to medium-grained sandstone containing tabular cross-bedding sets. The middle, fine-sand zone contains rippled layers and mixed, small-scale, multidirectional, cross beds. Locally, a thick coal and rippled sandstone are above this sequence. The lower deltaic plain facies of Pennsylvanian deltas in the central Appalachians as described by Horne, et al. (1978) included a very similar vertical sequence. This outcrop probably represents that facies nearest the channel mouth bar.

Above this section stratigraphically, and almost everywhere within the study area, the upper Warner sandstone appears as a rippled, reworked sand, interbedded with silt and mud. This regionally persistent upper sandstone is believed to denote an area wide transgression (destructive phase) during the Warner deltaic episode.

Several other Warner outcrops were sampled for petrographic studies. However, many were very poorly exposed and exhibited no distinguishable sedimentary structures. The type locality of the Warner (Figure 5), although very poorly exposed, did exhibit contortions and large scale (trough) cross-bedding. Similar (but thicker) friable, medium-grained, iron cemented (limonite, hematite) sandstones are found at Brushy Mountain (Sec. 29, T. 14 N., R. 19E.), and the east end of Rattlesnake Mountain (Sec. 3, T. 12 N., R. 19 E.) north of Warner. These

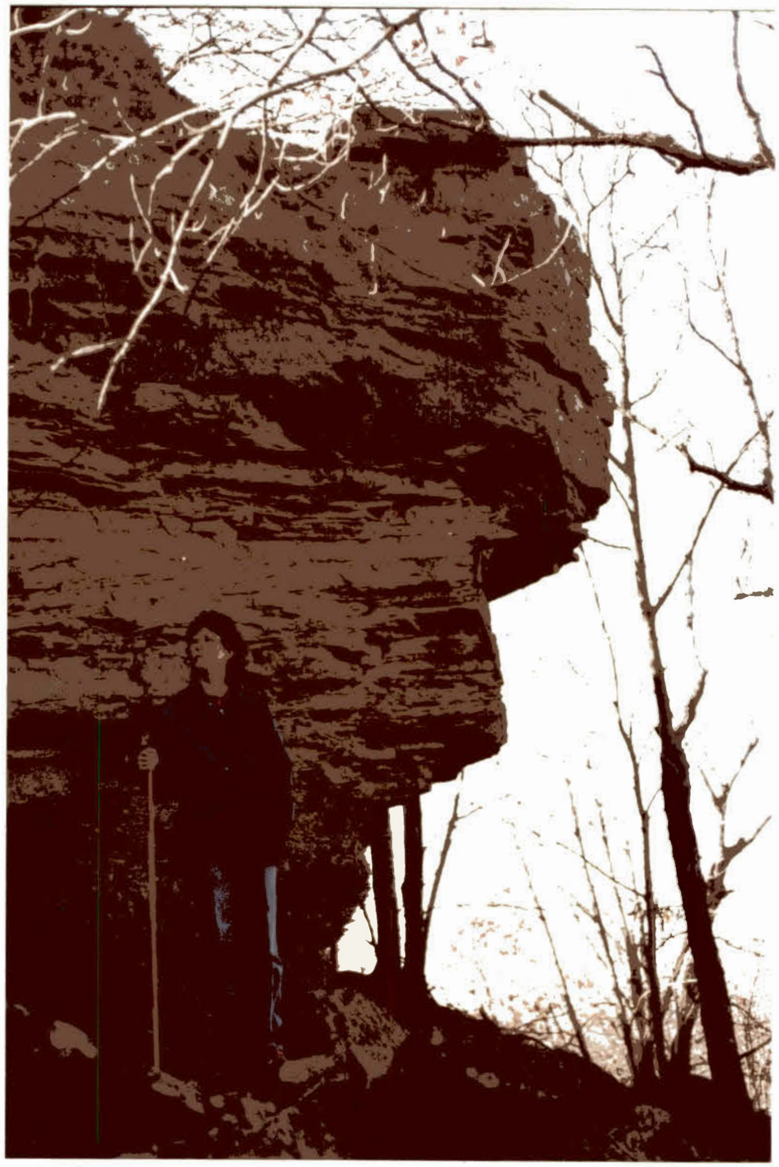


Figure 19. Coarsening Upwards Lower Deltaic Plain Deposit in the Warner Sandstone (WO6) at Sec. 5, T. 12 N., R. 19 E.

exposures probably represent Warner distributary facies in Muskogee County.

The Warner Sandstone was the only member of the McAlester observed to exhibit grain size and porosity generally associated with hydrocarbon reservoir sandstones. With the exception of a few very thin sand layers within the Lequire-Cameron, porosity rarely exceeded 5% in other sandstone members. Thus they are not considered to possess hydrocarbon reservoir quality.

Other Sandstone Members

Two outcrops of the combined Lequire-Cameron Member were measured in detail and sampled for petrographic evaluation. The first, LC01 (Sec. 31, T. 8 N., R. 21 E.) crops out in a road cut north of Kinta, in Haskell County. Two generally coarsening upwards sequences overlie a gray, unnamed shale. This outcrop was described by Oakes and Knechtel (1948) and Karvelot (1972). At this locality numerous interesting sedimentary structures may be observed in the very-fine and fine sands: dewatering structures, assymetric ripples, flaser bedding, tracks, trails, and burrows. Large Calamites fossils were found in the gray, more massive bedded sandstone layers. This 40 foot section is overlain by about 15 feet of very poorly exposed siltstone and the Stigler Coal. Section LC03 was exposed at a quarry approximately ten miles north of LC01, Sec. 36, T. 10 N., R. 19 E. It was very similar in grain size and sedimentary structures, yet differed in thickness (only 15 feet of sand).

Karvelot (1972) identified coarser grained channel facies of Lequire sandstone in Haskell County and Catalano (1978) recorded a 95 foot maximum thickness for the Lequire Sandstone. This information suggests thinning of the Lequire to the north and west. A channel mouth bar facies interpretation for these two measured sections is compatible with the conclusion that a Lequire distribution system must have existed to the immediate northeast.

A well exposed section of Tamaha Sandstone (TO3-4) was measured at a strip pit at Sec. 27, T. 10 N., R. 21 E. (also measured by Karvelot, 1972). The vertical sequence included gray silty-shale with a pair of very thin coaly layers at the base and coarsened upward to thin, gray, lensatic, calcareous very-fine sands interbedded with silty-shale and sandy-silt (Figure 20). Above this lower 15 foot sequence, the section is dominated by about 10 feet of flaser bedded and rippled very-fine sandstone. The sequence is capped by a few extremely bioturbated layers of gray, very fine sand. Another Tamaha outcrop of almost exactly the same vertical sequence was observed along the Canadian River at Section 7, T. 9 N., R. 20 E.

A poorly exposed Tamaha section (TO1) was measured at Sec. 25, T. 9 N., R. 19 E. It consists of thirty feet of sandy shale containing four flaser bedded silty layers in the lower and middle part. Above an abrupt and possibly erosional contact the sequence coarsens and contains a four foot very fine sand lens and siltstone.

The Tamaha Sandstone is rarely well exposed; therefore study of sedimentary structures for environmental interpretation is difficult and any conclusion speculative. The specific facies models of Horne, et al. (1978) may be applied with difficulty to some sequences. The Tamaha appears to be a bay-fill sequence associated with some upper McAlester deltaic distributary system.

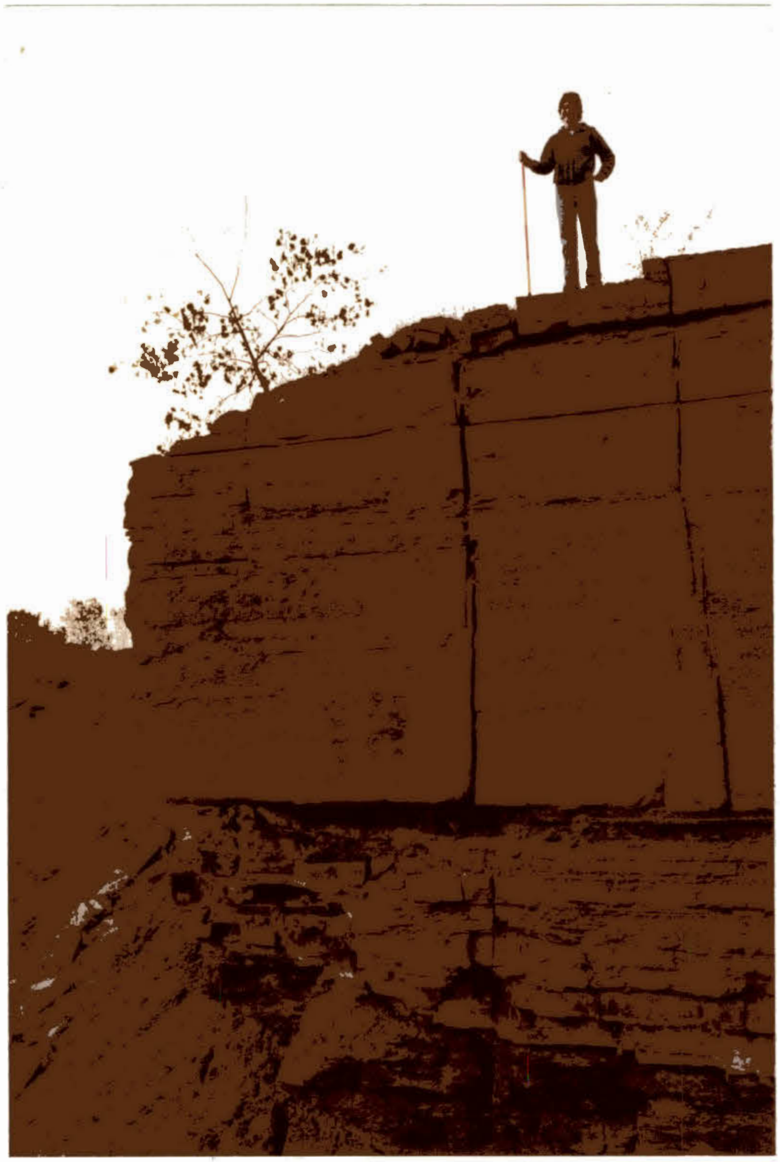


Figure 20. Tamaha (T04) Sandstone at Strip Pit North of Stigler (Sec. 27, T. 10 N., R. 21 E.).

The Keota Member is also poorly exposed and difficult to classify environmentally. One section of the Keota (K01) was measured at a road-cut on S. H. 2, north of Kinta. Numerous very-fine sand lenses were observed in nearly thirty feet of silty shale. Abundant Calamites fossils and fern imprints are present in the lower part of the section. The sand lenses are not individually persistent but, as mentioned before, the Keota 'zone' is present over almost the entire study area. Like the Tamaha, the Keota may represent a prograded shoreline, possibly more tidally influenced, as indicated by the lens-like nature of the sandstones.

The Spaniard Limestone was examined at several localities within the study area. It was very fossiliferous in southern Muskogee and Haskell Counties, appearing almost marginally marine to the north. The Spaniard is generally sideritic, and thinly bedded with the dark shales of the lower Savanna. It appears to represent the initial transgression for marine dominated Savanna Formation deposition.

CHAPTER VI

SUBSURFACE STUDY

Introduction

The major hydrocarbon producing Lower Booch Sandstone has been correlated with the Warner Sandstone Member of the McAlester Formation. While hydrocarbon "shows" are not unusual in other McAlester Sandstones, especially the Upper Booch (Lequire-Cameron), these sands are virtually non-productive. For this reason, the Lower Booch (Warner) has been studied in much more detail.

The subsurface area of this study includes McIntosh County and parts of adjacent Haskell, Muskogee, Okmulgee, and Pittsburg Counties. Specifically, the area defined by T. 8-14 N., R. 13-19 E., was mapped based upon data interpreted from more than 550 geophysical logs and driller's strip logs. Two cores were available from immediately outside this study area and will be discussed in detail later in this chapter.

The primary objectives of the subsurface aspect of this study were:

1. To interpret Lower Booch depositional facies from cores available.
2. To investigate petrographic and diagenetic characteristics of the Lower Booch Sandstone (as seen in the core).
3. To prepare subsurface maps illustrating Lower Booch sand geometry (net sandstone isolith), Warner Cycle depositional framework (Warner isopach), and McAlester Formation thickness within the

TABLE III

CORE AND WELL CUTTING LOCATIONS

		Core Descriptions: Appendix A		
BO1	L. Booch Sandstone	SE	NW	Sec. 3, T. 12 N., R. 11 E.
BO2	McAlester Fm.	NW	NE	Sec. 17, T. 11 N., R. 12 E.
		Well Cuttings		
BA	L. Booch Sandstone	SE	SE	Sec. 27, T. 14 N., R. 14 E.
BB	L. Booch Sandstone	SE	SE	Sec. 17, T. 11 N., R. 17 E.
BC	L. Booch Sandstone	SE	NW	Sec. 27, T. 11 N., R. 13 E.
BD	McAlester Fm.		SE	Sec. 18, T. 13 N., R. 16 E.
BE	McAlester Fm.	NW	SW	Sec. 30, T. 10 N., R. 16 E.

study area (total formation isopach).

4) To analyze major (known) hydrocarbon producing areas with the depositional framework developed by the maps.

Study of Cores

Hemisphere Drilling, No. 1 Ryals-Pine (B01)

This well was temporarily completed as a gas well. Unfortunately, other information and geophysical logs were not available. The interval cored included 2234-2243 feet and 2252-2276 feet, roughly 33 feet of Lower Booch sand.

The well is located at SW NE SE NW, Sec. 3, T. 12 N., R. 21 E., in the Morgan Pool, Okfuskee County. Oil and gas production in the Morgan Pool is from the Lower Booch or basal Atoka Formation (Dutcher Sands). Figure 21 illustrates the distribution of permeable Lower Booch sand in the Morgan Pool as interpreted from spontaneous potential logs.

The lower contact of the sandstone was not present in the core, but the grain size obviously coarsened upward. Rippled flaser bedding dominates the lower 15 feet of fine- and very fine-sand. Thin intervals in this lower zone contain soft-sedimentary contortion and bioturbation. Strata between 2256 and 2260 feet contained oil-stained, fine- and medium-grained, cross-bedded sand. Petrographic studies of this zone revealed a peculiar silica-after-sulphate replacement cement. Immediately above this zone calcite cemented very fine sand contains plant rootlets. A 9-foot missing interval separates this zone from the upper 9 feet of core. This upper portion includes interbedded very fine sands with mud at the base, two very thin coaly layers in the middle, and dark shales

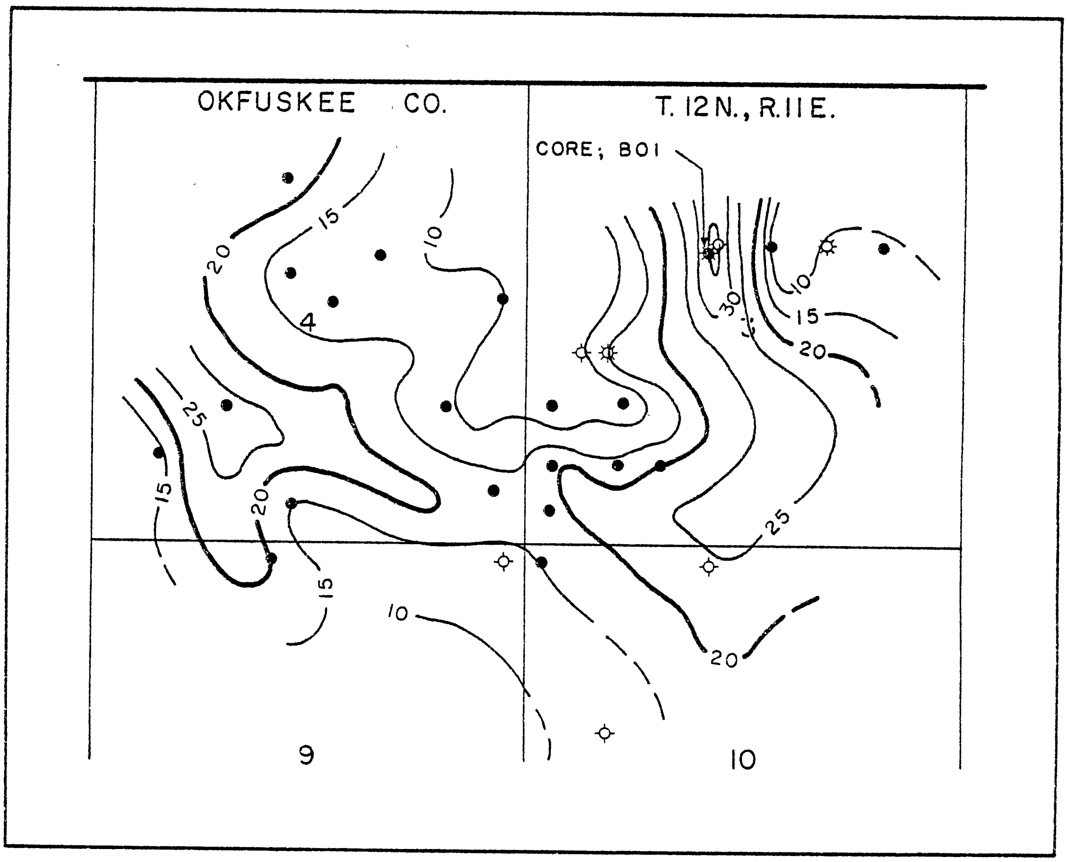


Figure 21. Lower Booch Sand Distribution (in Feet) in the Morgan Pool, Okfuskee County, Oklahoma.

interbedded with slightly burrowed very fine sands at the top (Figure 22).

This core appears to represent a crevasse splay or small, lower deltaic plain channel mouth bar deposit. When compared with the models put forth by Horne, et al. (1978) either interpretation may be applied. Location of the core and comparison with sandstone geometry (Figures 21 and 22) illustrate its proximal relationship to a north to south trending distributary sand body. Rootlets in the calcareous fine sand at the top of the lower cored interval suggests an interdistributary bay-fill deposit. The lower sands contain glauconite, siderite, and phosphatic cements, whereas the cross-bedded sands are cemented by calcite and poikilotopic quartz (after sulphates). This sequence indicates a small-scale marine regression involving the development of a thin channel mouth bar or crevasse splay deposit on the lower deltaic plain. The cross-bedded, (replaced) sulphate cemented, medium sand may represent a brief subaerial exposure of sands, before complete subsidence and infilling of inter-distributary bays occurred.

Tamarack Petroleum, No. 2 Kerr (B02)

This second cored well, located at NW NW NE Sec. 17, T. 11 N., R. 12 E., was completed as an oil well in the "Wilcox Sand" (Ordovician). No log for this well was available, however nearby wells typically contain several feet of both Upper and Lower Booch Sandstone. The core received was from depths of 2041 through 2071 feet. Because no log was obtained for this well and no distinctive sandstone appears in this core, it can only be assumed to represent some sequence within the McAlester Formation.

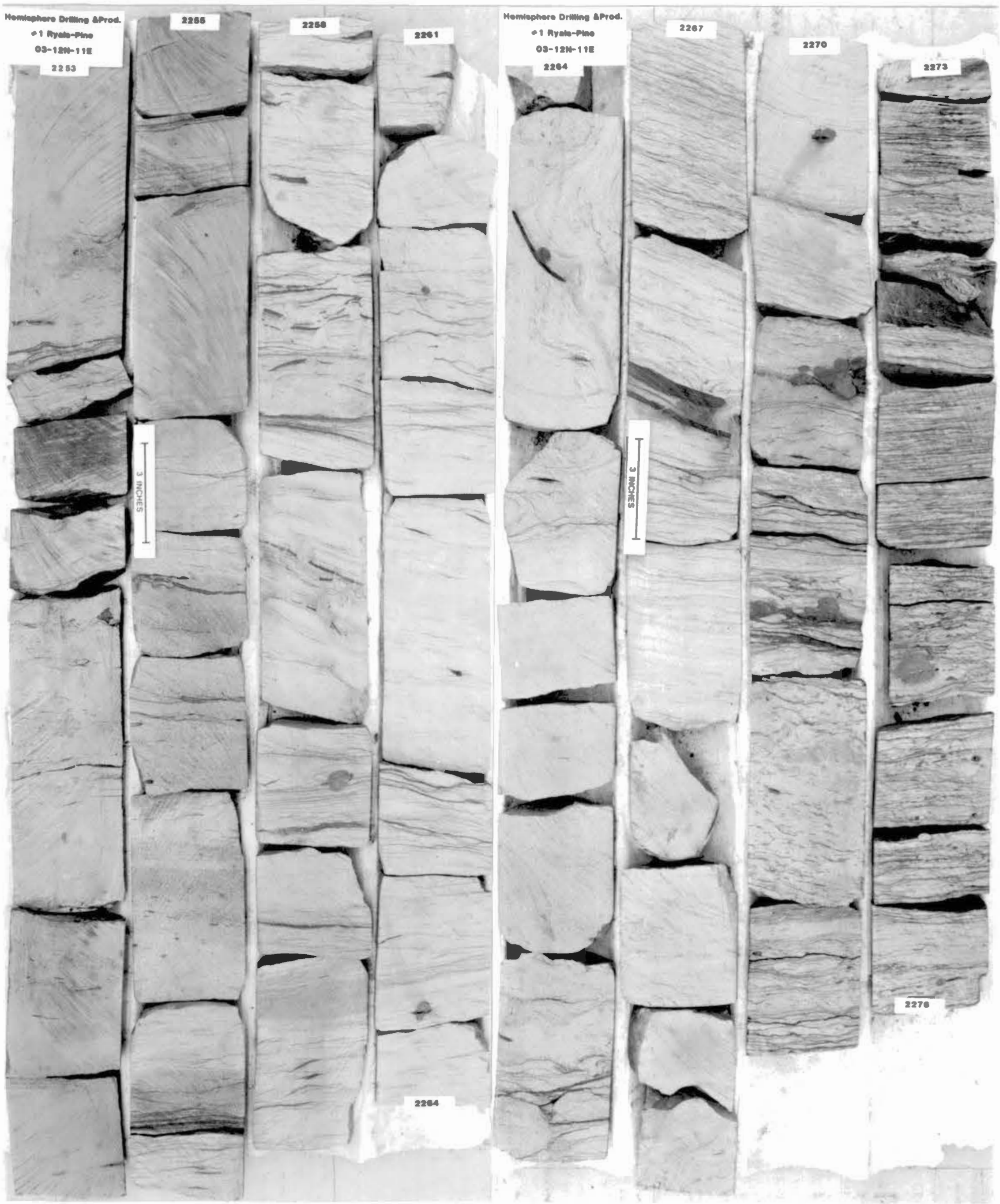


Figure 22. Core B01, Sec. 3, T. 12 N., R. 11 E., Interval from 2253 feet to 2276 feet.

The well was drilled in the Aztec pool, a small area of Bartlesville oil production in Okmulgee County. One mile east (Sec. 16), gas is produced from the Booch in the Summers Pool.

It is possible that the core represents the shaley interval between the Lower and Upper Booch sandstones. The flaser-bedded very fine-sand and interbedded mud at the base strongly resemble the upper portion of the previously described Lower Booch. The 20 foot dark shale interval above contains a highly fossiliferous, iron rich, marine carbonate. There is a five foot thick silty sand zone at the top of the sequence. Plant fragments and a few burrows are throughout the core. Two small, low angle faults are in the core, both indicated by slickensided surfaces on bedding planes. The upper fault zone was also distinguished by micro-faulting in the sand immediately above (Figure 23).

If the assumed stratigraphic position of this core is correct, it probably shows evidence of a destructive and transgressive phase at the end of the Lower Booch episode and initial prodeltaic sedimentation for the progradation of the Upper Booch Sandstone.

Subsurface Mapping

Introduction

Three regional subsurface maps (Plates IV, V, VI, in pocket) and seven field maps were prepared for this study. Most of the field maps were sketches used to develop explanations of correlations, and oil and gas production control. Figures 21 (Morgan Pool) and 26 (Texanna Field) are two such maps.

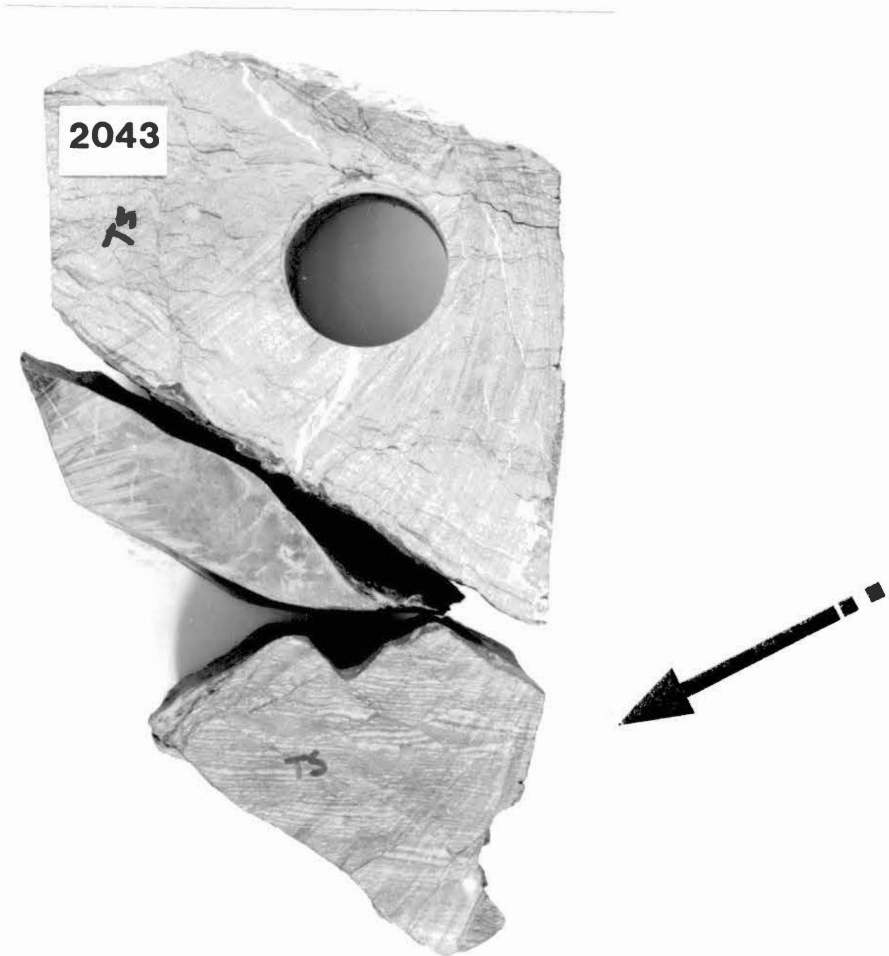


Figure 23. Microfaulting in the Upper Sandstone Zone (2043 feet) of Core BO2 (Sec. 17, T. 12 N., R. 11 E.).

Warner Cycle (Lower Booch) Sand Isolith

Plate III is a geophysical log cross-section illustrating the correlation of the Warner Cycle. Plate IV illustrates net sand thickness (S.P. response) within the Warner Cycle, the top of the Upper Hartshorne Coal to the top of the Warner (Lower Booch) Sandstone. The two major channels have scoured into the underlying (McCurtain) shale; the westernmost channel incised nearly 100 feet into the Hartshorne Formation.

Net sandstone thickness is highly variable and increases at the expense of the underlying shale. All wells examined for this study contained some sand in the Warner Cycle; this varies from as little as 8 feet in the extreme northwest part of the map area to greater than 350 feet in the extreme southeast. In many wells the Lower Booch is two sands, an upper marine transgressive sheet sand and a lower sand that includes thick channel fill sands. The upper sheet sand typically accounts for the presence of some Lower Booch sand in every well examined (Figure 24, item T).

The westernmost channel is an extension of Busch's (1953; see also Figure 2) eastern distributary system. The presence of a more easterly distributary channel paralleling the Warner outcrops measured in this study explains the deltaic facies observed. The lower delta plain deposits northeast of Warner (Sec. 5, T. 12 N., R. 11 E.), the highly contorted sands at the type locality in Warner, abrupt thickening of sands at Brushy Mountain and Rattlesnake Mountain in Muskogee County, and the west and south directed Warner channels in Haskell County indicate a cratonic, probably elongate delta system (Brown, 1979). In the subsurface, the channels bifurcate southward and some smaller sand bodies

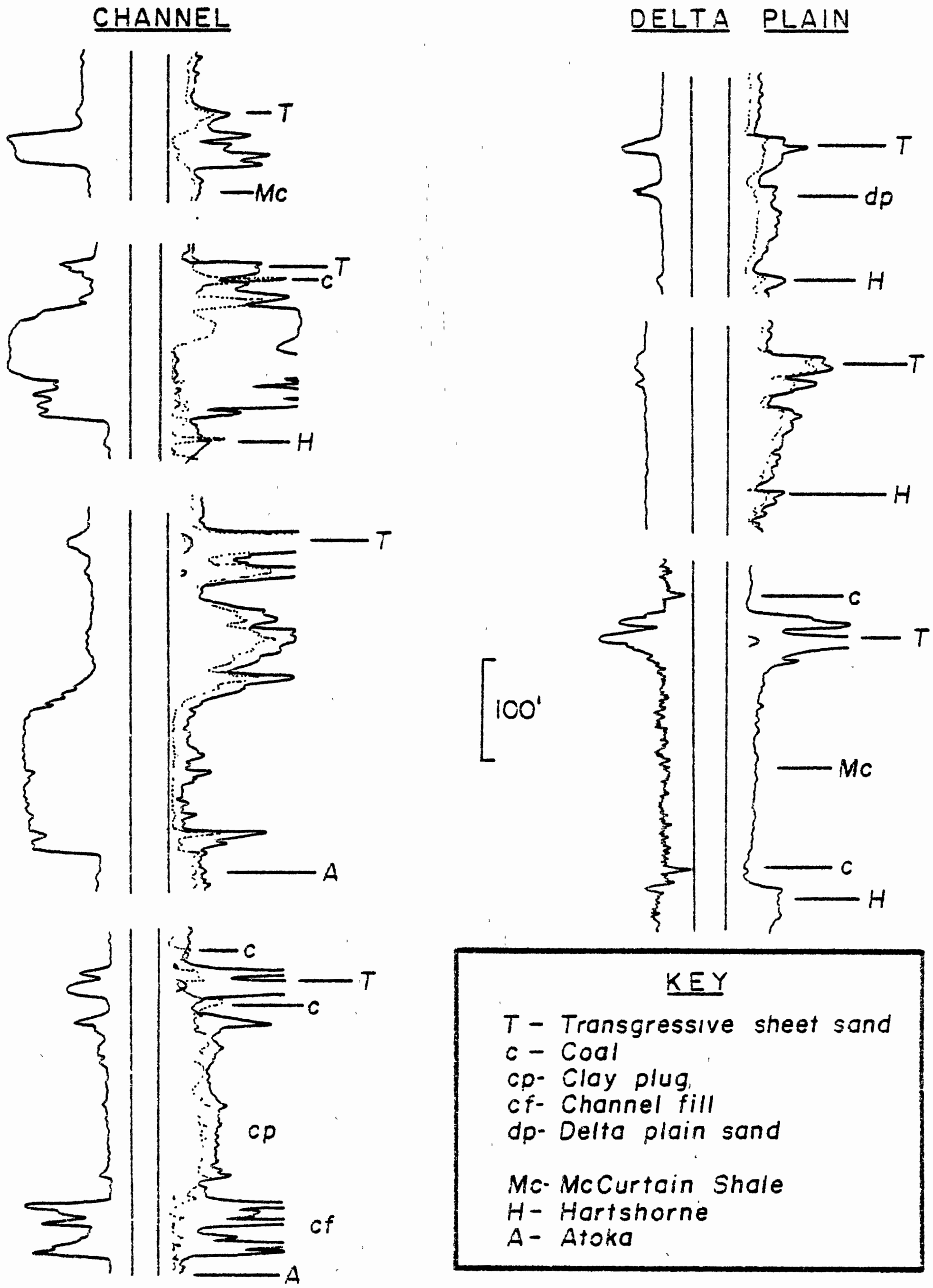


Figure 24. Typical Lower Booch (Warner) Sandstone Geophysical Log Responses.

appear to have paralleled the shoreline, having become strike oriented due to marine reworking. The eastern channel fans out in the southeast almost merging with the eastward-prograded west channel. The abrupt change in direction of the western channel probably reflects progradation into the axis of the basin to the south. In any case, the distribution of sands in the subsurface completely agrees with and corresponds to deltaic depositional facies identified in Warner measured sections and the paleocurrent directions observed in outcrop exposures of the Warner Sandstone.

Warner Cycle Isopach

Further insight into the Lower Booch (Warner) depositional framework can be obtained from examining the Warner Cycle Isopach Map (Plate V). The deep incision of channels into the shelf and differential compaction of sandstones in shales (Busch, 1953) can easily be recognized by anomalous isopach thicknesses.

This interval isopach map is considered a general reconstruction of the depositional basin as present in the study area. The distributary channels intersect the basin axis almost at 90°. These channels bifurcated down dip, especially at the basinal hinge line (or shelf edge), turned eastward and prograded down the axis of the basin. The shelf edge was oriented N. 60-70° E. (T. 9 N.).

By projecting sandstone facies observed in outcrop into the subsurface along strike and considering the rate of section thickening to the south, three broad depositional subdivisions may be identified: upper deltaic plain, transitional to lower deltaic plain, and distal delta to slope. The upper deltaic plain corresponds to interval isopach contour values less than 100 feet. The transitional to lower deltaic plain likely existed in the area covered by the contour values between 100 feet and 225 feet. This zone generally corresponds to the best developed Warner coal area in outcrop. The thickness of the interval increases markedly south of the 225 feet contour. This pronounced increase indicates an area of rapid subsidence, probably associated with sediment loading of the basin and tectonic overburden in the Ouachitas due to thrusting associated with the growing orogeny (Houseknecht, 1983).

McAlester Isopach

The isopach map of the McAlester Formation (Plate VI) was prepared to demonstrate correlation and variation in total thickness within the study area. Like the Warner Cycle isopach, it also illustrates the effects of differential compaction in sandstone and shale sequences. A minor northward shift in the basinal hingeline developed through the time represented by McAlester deposition.

Petroleum Occurence

Numerous small fields produce oil and gas from the Lower Booch Sand within the study area. The Southeast Salem Field, located at Sec. 17, T. 10 N., R. 14 E., reportedly produced a small amount of gas from 4 feet of Upper Booch Sand (Oakes, et al., 1966).

Figure 25 illustrates major distributary channels, large-scale structural features (from Oakes, et al., 1966), and locations of several Booch fields. Some local occurrences of oil and gas in the Booch certainly are controlled by stratigraphic trapping mechanisms such as differential compaction and sandstone pinch outs. Minor structural

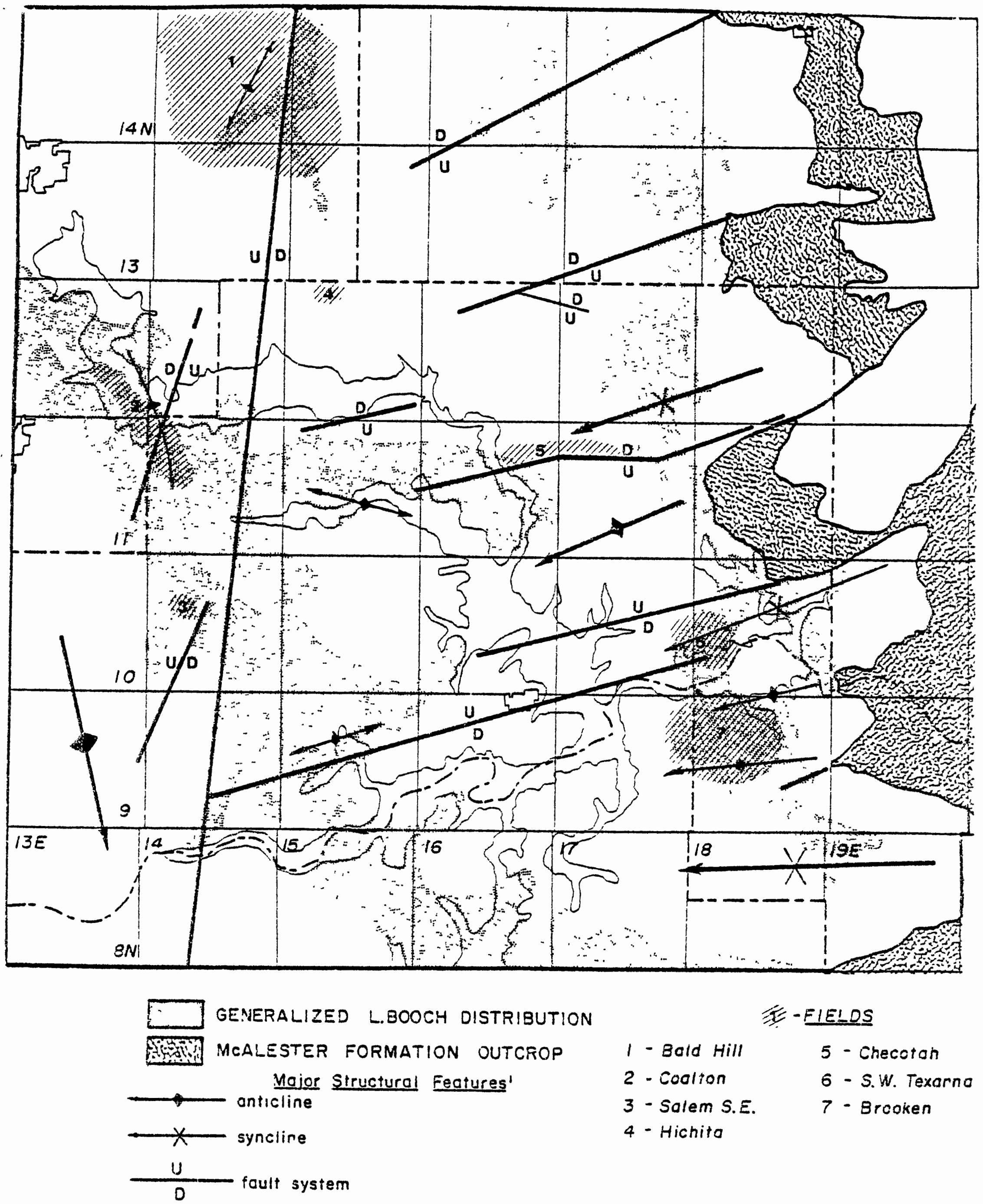


Figure 25. Stratigraphic and Structural Controls on Petroleum Occurrence in the Lake Eufaula Area (after Oakes, et al., 1967, Plate III).

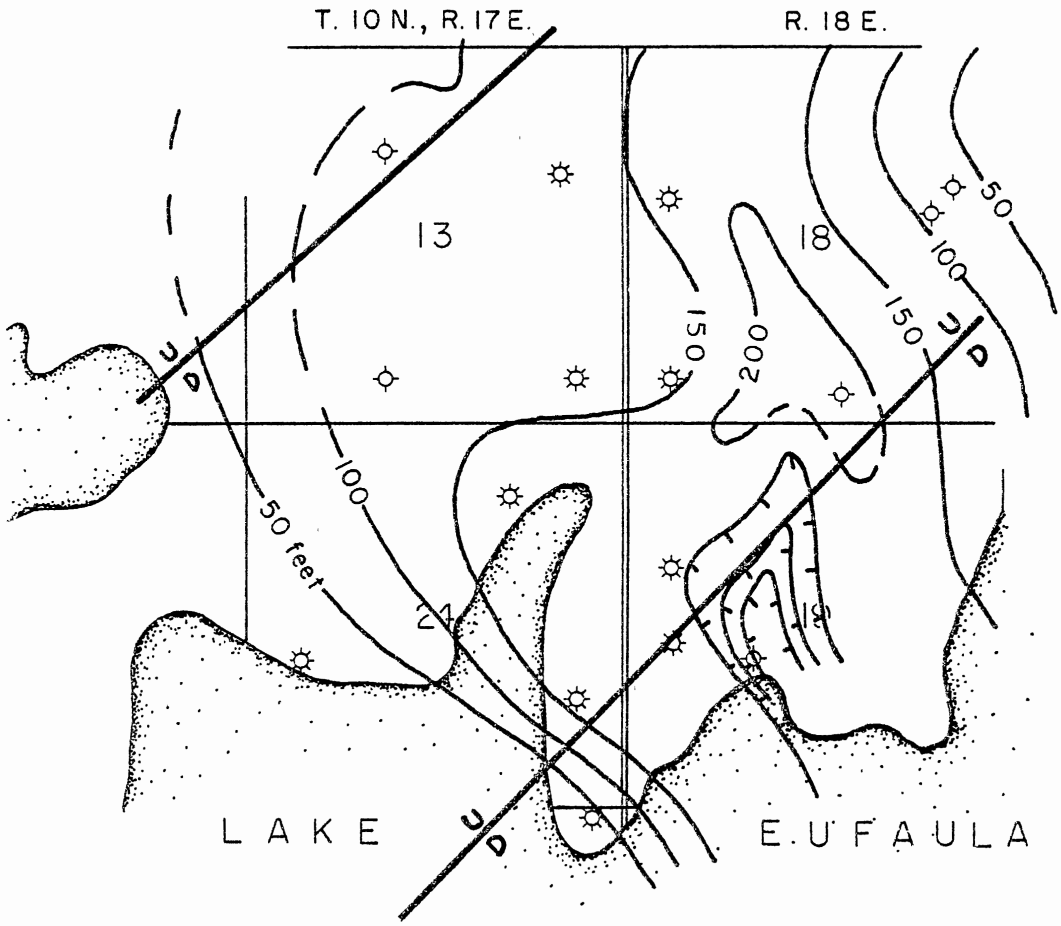


Figure 26. Sketch Map of the S. W. Texanna Field, Illustrating Lower Booch Sand Distribution and Major Faults.

features may also be involved in other local Booch production. However, it is obvious that notable occurrences of petroleum in the Booch are associated with the interaction of regional faults and folds with major Booch sand distribution systems.

The Southwest Texanna field (Figure 26) is an example of such an interaction. Gas was discovered in 1981 when Cities Service Company, Nixon A No. 1, was drilled on the north shore of Lake Eufaula, at S 1/2 S 1/2 NE 1/4 SE 1/4, Sec. 24, T. 10 N., R. 17 E. The trap involved the south fault system of the Warner uplift and the east channel of the Lower Booch Sandstone.

An active exploration effort for Lower Booch Sand traps in the study area would involve developing highly detailed sand maps and structural maps to determine the coincident locations of porous sands (of almost any thickness) and structure. This is not to say that pure stratigraphic traps are not present in Booch sands; however no such traps have been satisfactorily demonstrated.

CHAPTER VII

PETROGRAPHY AND DIAGENESIS

Composition

Detrital Constituents

The composition of detrital constituents remains generally consistant throughout the sands of the McAlester Formation. Local compositional differences seem more a product of grain size variation than stratigraphic position. Average compositions of Warner and upper McAlester sandstones are shown in Figure 27.

Monocrystalline quartz is the most abundant constituent regardless of grain size. Grains typically are angular due to overgrowths, but appear to have been round or subround during deposition. Original quartz grain shapes may be preserved by illite dust rims and early carbonate cements. Polycrystalline quartz is seen as recrystallized or sutured composite grains, appearing metamorphic in origin.

Feldspar is not abundant in these sandstones, especially in outcrop, where weathering removes unstable constituents. Plagioclase (albite) is the common feldspar in finer sands with potassium feldspars prominent as sediments coarsen. Plagioclase grains were distinguished by twinning, while orthoclase grains were commonly cloudy and showed evidence of dissolution along cleavage planes. Feldspar overgrowths were observed on a few grains, but these are poorly developed.

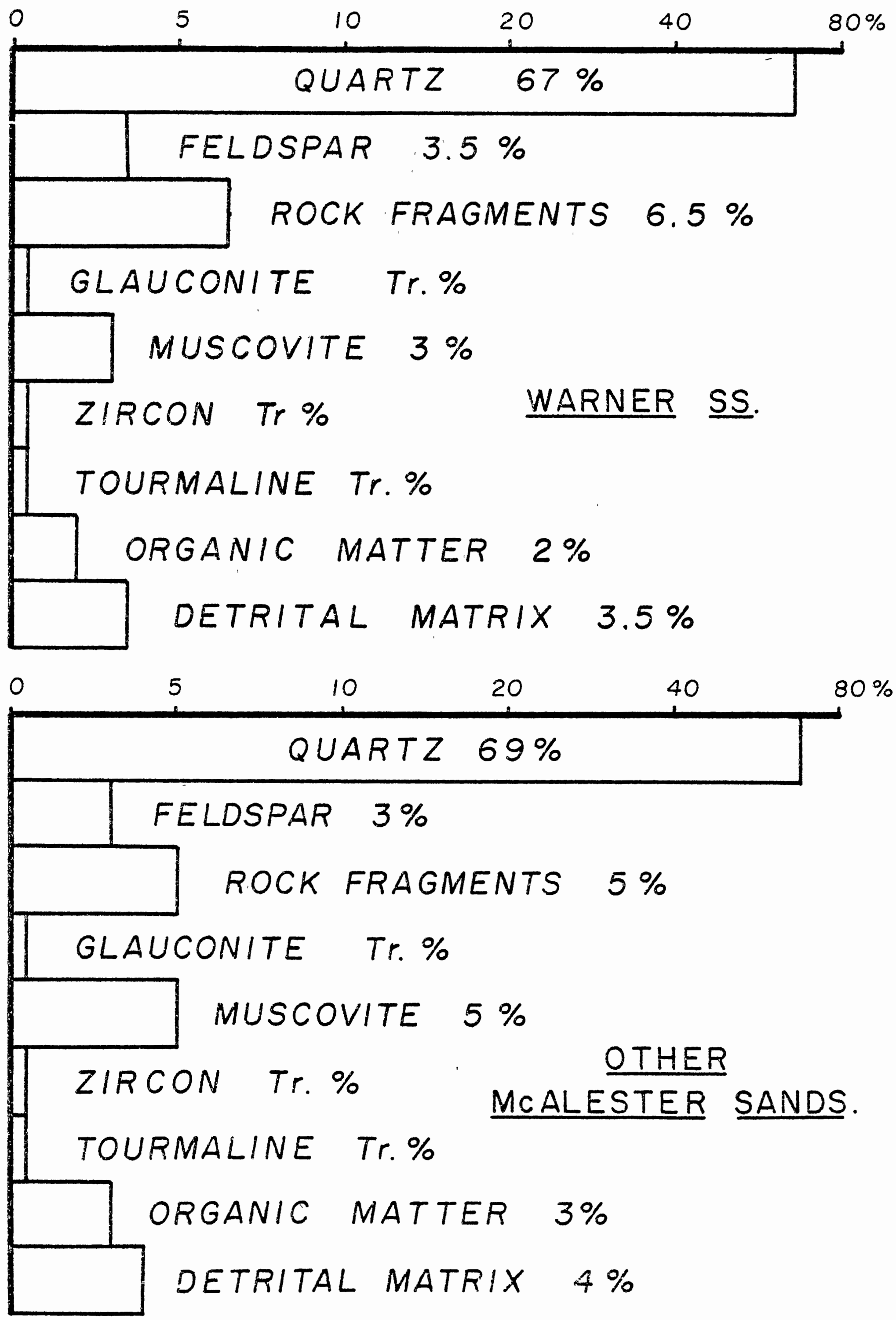


Figure 27. Average Composition of Major Detrital Constituents in McAlester Sandstones.

Rock fragments typically include organic rich illitic and chloritic mudstone and siltstone clasts that are squeezed and that appear as recrystallized pseudomatrix. Distinctive, rounded chert grains are also seen but are not common. Fragments of metamorphic rock, such as schistose quartz with muscovite and biotite, or schistose muscovite-staurolite are common.

Muscovite is more abundant in finer sands, composing as much as 14% of detrital constituents. Biotite occurs with muscovite and is usually altered to chlorite. Glauconite is a very minor constituent of McAlester Sands; only a few grains were seen in thin sections. Zircon, tourmaline, leucoxene, and magnetite (?) are the most common heavy minerals, but are only comprise a trace percentage of these sands.

Dispersed detrital matrix includes illite, chlorite, and granular organics. The organics are usually found along bedding or in phosphatic laminae. Granular crystals of siderite are dispersed in all sands. The grain to grain relationship of siderite to detrital constituents seemed to suggest a detrital origin. Siderite is an early diagenetic product resulting from the alteration of colloidal iron compounds in rapidly deposited sediments having neutral pH, negative Eh, high-carbonate and low sulphur activities (Curtis and Spears, 1975).

Figure 28 illustrates compositional plots for individual McAlester sandstone members based on relative abundance of quartz (monocrystalline and polycrystalline), rock fragments (including chert), and feldspars. Most samples are plotted as sublitharenites, due to detrital mud clasts and metamorphic rock fragments. Some samples plotted as quartz arenites, usually finer grained sands and silts; a few samples were leached completely of metastable constituents. One Lequire-Cameron sample

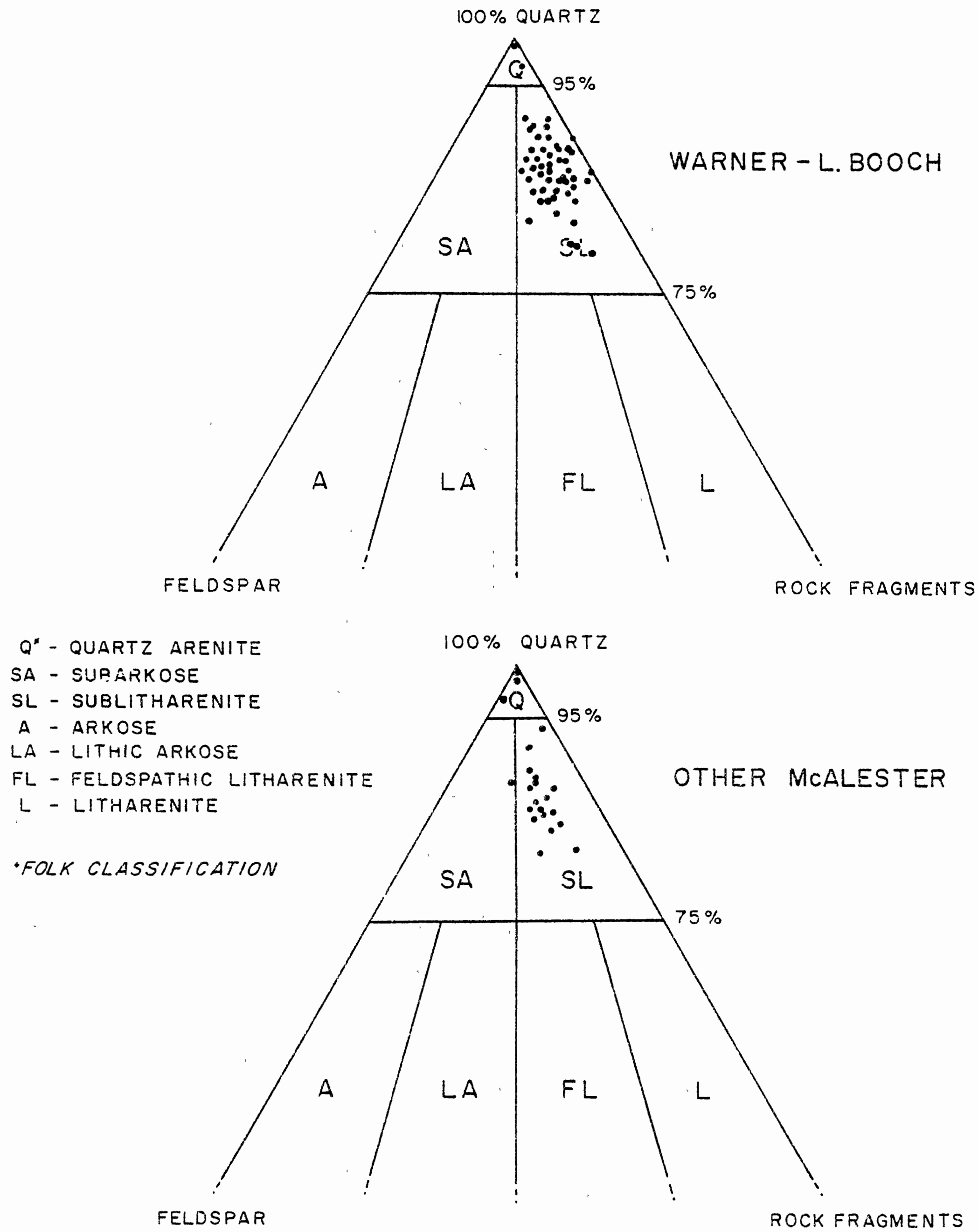


Figure 28. Classification of McAlester Sandstones.

plotted as a subarkose. The average McAlester sandstone contains 85-90% quartz (mostly the monocrystalline variety), 3-5% plagioclase and potassium feldspars, and 5-15% rock fragments in the form of mudclasts, metamorphic rock fragments, and chert.

Diagenetic Constituents

Quartz overgrowths and microquartz are the dominant cementing agents in fine sands and silts (Figure 29). These cements also dominate in coarser sands where early carbonate cements and well developed illite coatings are absent (Figures 30, 31, and 32). Overgrowths are interlocked, suggesting pressure solution and suturing. Evidence of pressure solution was observed in samples collected south of the Canadian River (Haskell County).

Siderite is present as highly birefringent granular masses and spherulitic siderite cement and is commonly associated with calcite cements. Replacement of quartz grains and solution embayments are common where siderite is in contact with quartz. The preservation of round quartz grains lacking overgrowths suggests that siderite cementation was an early diagenetic event, and that porosity-reducing mechanical compaction in well cemented, coarser grained samples was minimal (Figure 33). However, siderite and ferroan calcite developments within overgrowth reduced pores and on microquartz indicate at least one other event of carbonatization. Iron carbonates typically display telodiagenetic (late diagenetic) alteration to hematite and limonite. In many outcrop samples iron-bearing minerals such as siderite, ferroan calcite, biotite, and iron illite (detrital matrix) are completely altered to limonite and hematite.

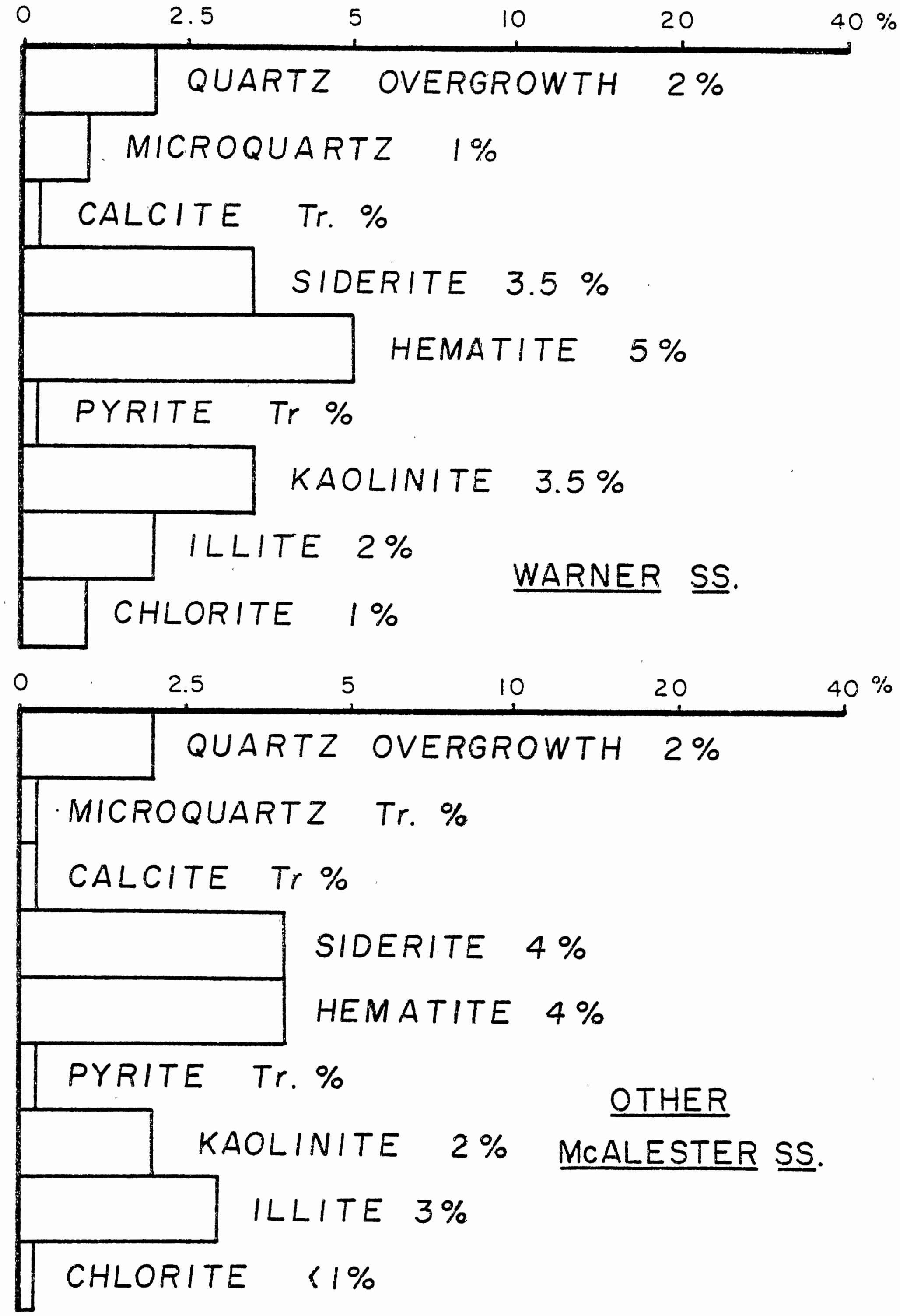


Figure 29. Average Composition of Major Authigenic Constituents in McAlester Sandstones.

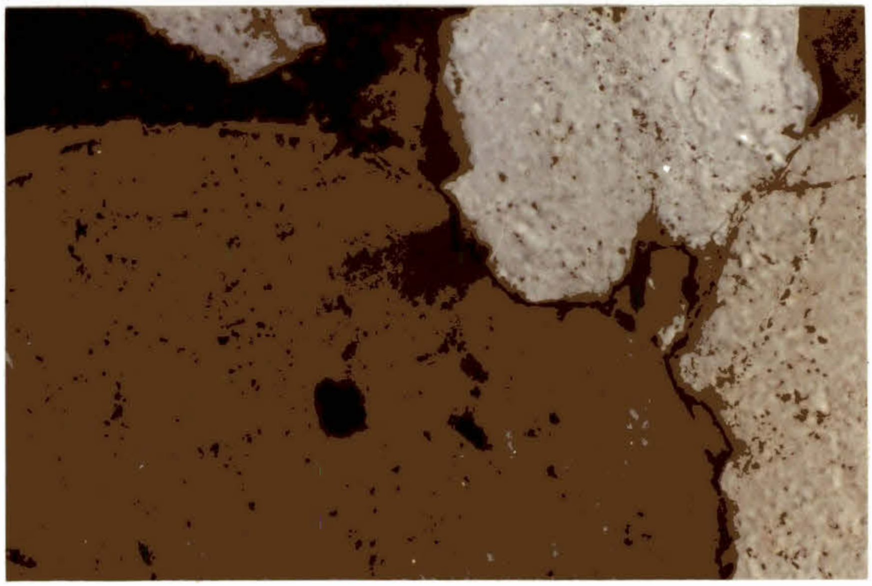


Figure 30. Photomicrograph of Effects of Pressure Solution and Quartz Overgrowth in the Warner Sandstone (W02, 200X, XN).

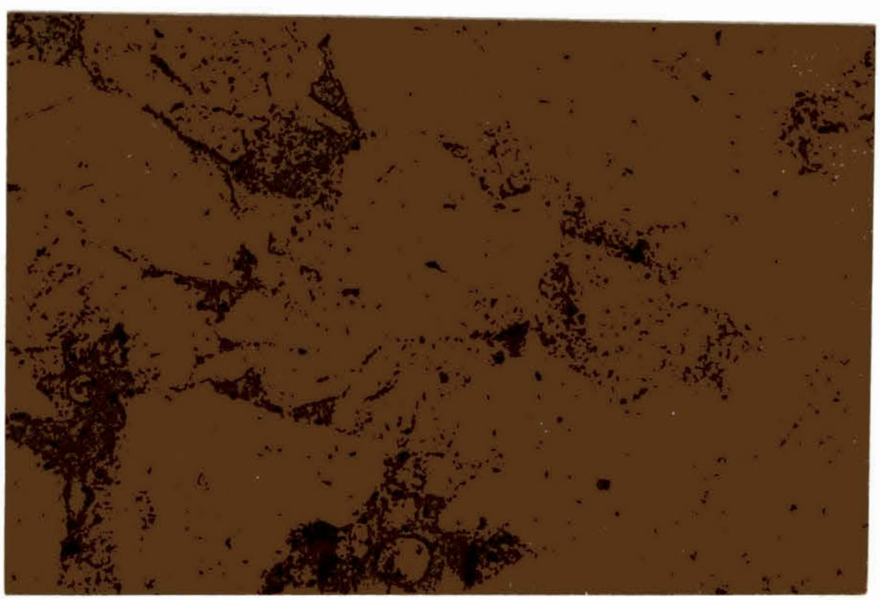
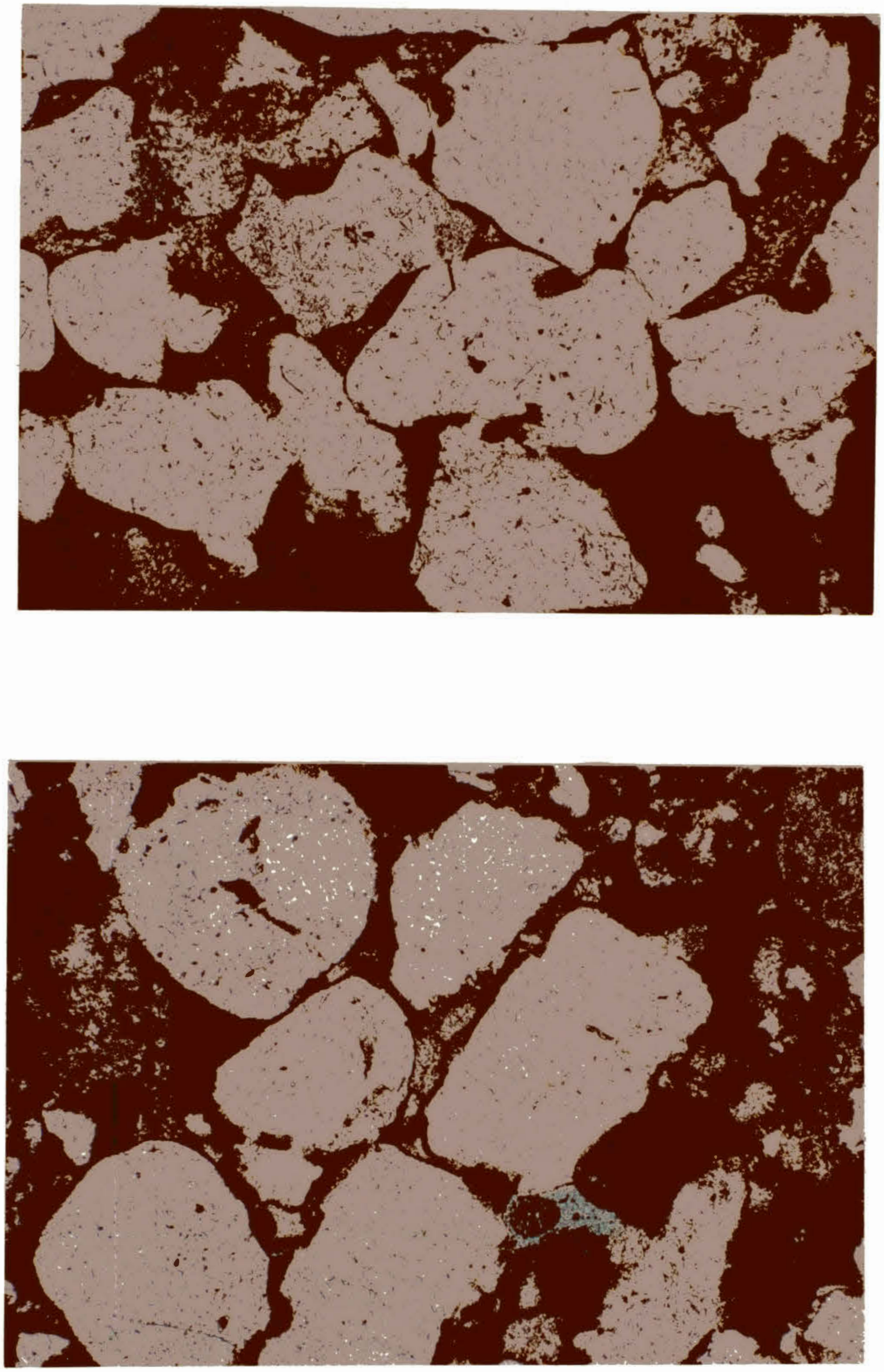


Figure 31. Photomicrograph of Microquartz Cementation in the Warner Sandstone (W01, 100X, PPL).



A

B

Figure 32. Photomicrographs Illustrating Original Quartz Grain Shapes Preserved by Detrital Illite (A) and Early Siderite (B) Cements (W04, 100X, PPL).

A

B

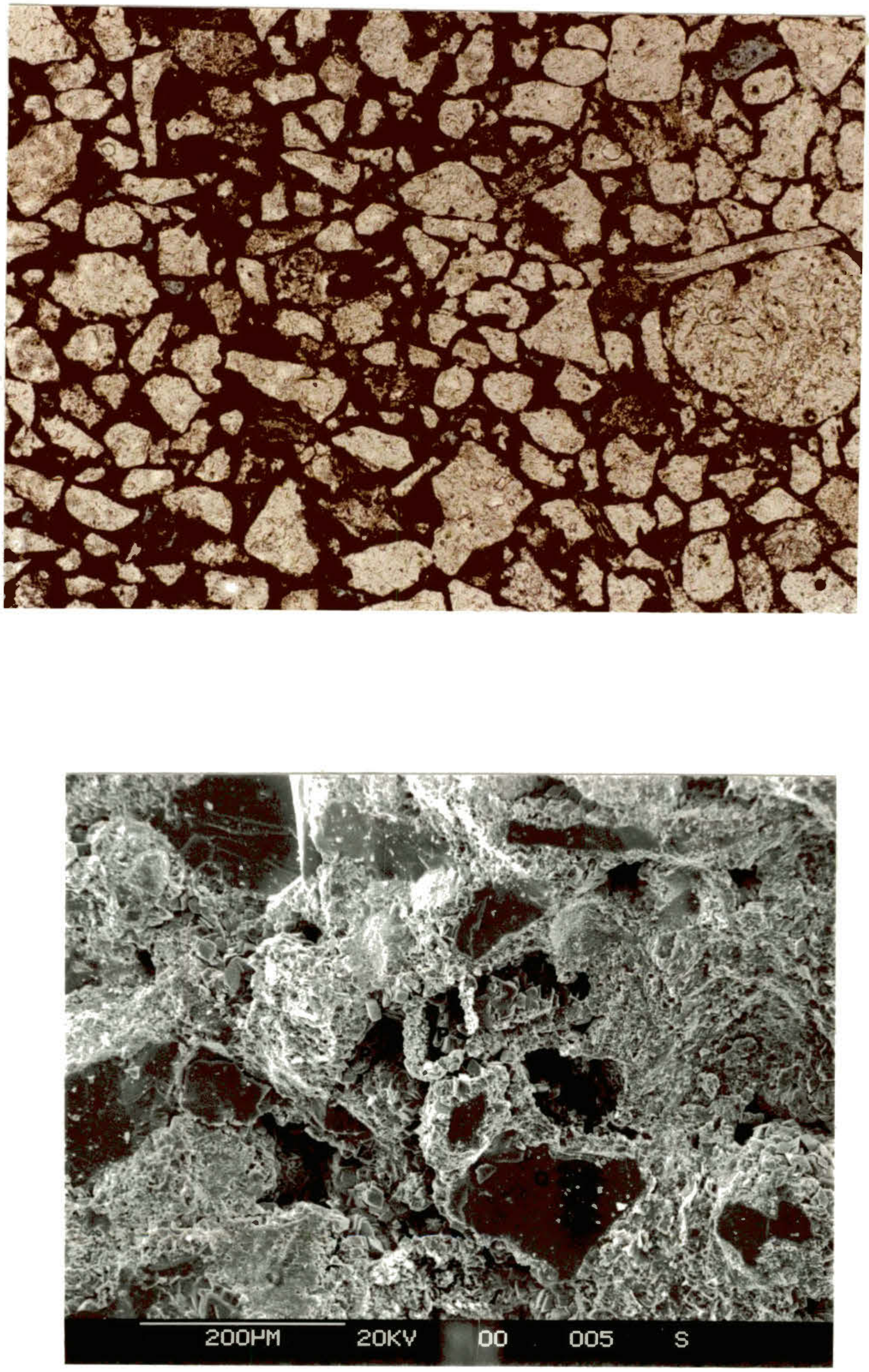


Figure 33. Photomicrograph (A) and SEM Image (B) of Siderite-cemented Warner Sandstone (W04, 40X, PPL, SEM - 150X).

Samples from cores contained both siderite and ferroan calcite cement, with only minor amounts of pyrite. Core B01 - Hemisphere Drilling No. 1 Ryals-Pine (Sec. 3, T. 12 N., R. 11 E.) contained a peculiar, poikilotopic low-birefringent cement with cleavage traces at 90°. Cathode illuminescence studies of this sample suggested quartz replacement of a sulphate (Figure 34). Minor sulphate cements could have developed within a periodically subaerial environment. Beaches, berms, levees, or crevasse splays could have been such an environment.

Major authigenic clay minerals observed in McAlester sands include kaolinite, illite, and chlorite. Sericite (coarse illite) was a common replacement of quartz and feldspar grains. Kaolinite is the dominant authigenic clay mineral in coarser-grained sandstones, particularly in the Warner. The common kaolinite growth form involves pore-filling or pore-packing, low birefringent booklets that result from feldspar breakdown. In many outcrop samples large, silt-sized, kaolinite booklets pack obviously oversized pore spaces (Figure 36 and 37). Illite and sericite are in all samples, but dominate the clay mineral assemblage in the upper McAlester sands. Illite is distinguished by its highly birefringent laths, lining and bridging pores.

Authigenic chlorite, a dominant clay mineral, is difficult to identify (Figure 38 and 39). The common growth forms for chlorite are isopachous rims on grains and 'house of cards' aggregates dispersed in pore throats. X-ray diffraction of clay extraction samples agree with most petrograhic observations. In samples where variations in percentages were great, chlorite was unidentified in thin section, due to its low birefringence and delicate nature. SEM inspection of McAlester

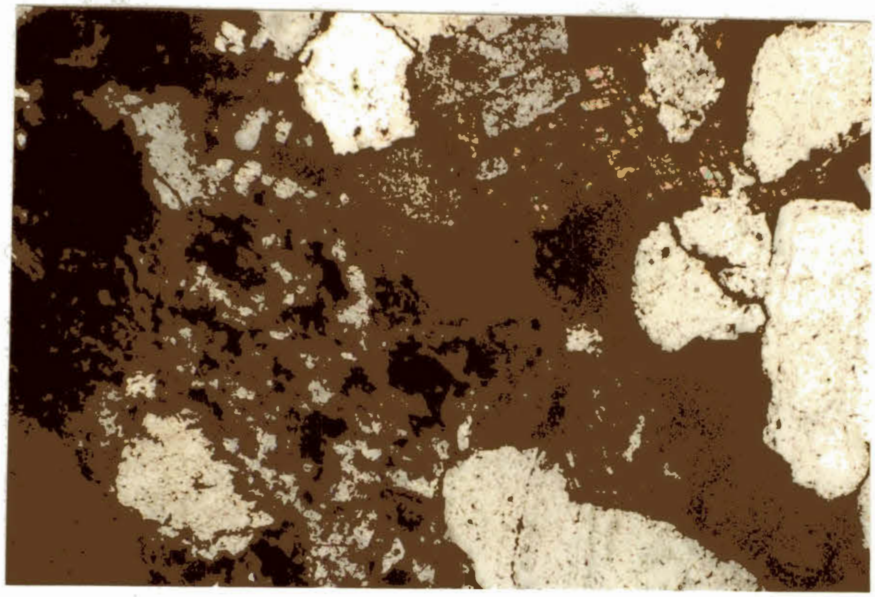


Figure 34. Photomicrograph of Quartz-after-sulphate Poikiotopic Cement in Core B01 (100X, XN).

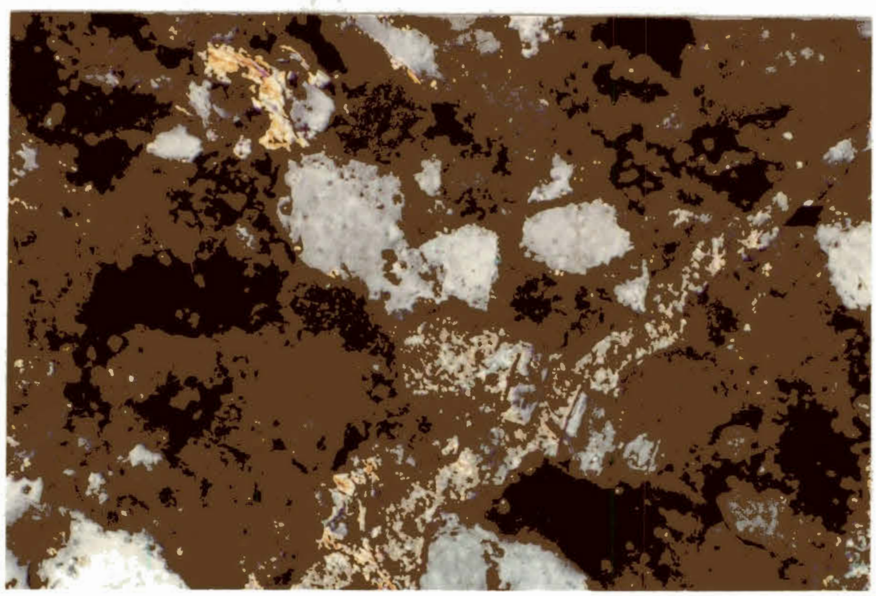


Figure 35. Photomicrograph Illustrating Granular Siderite and Displacive Calcite Cements (T04, 100X, XN).

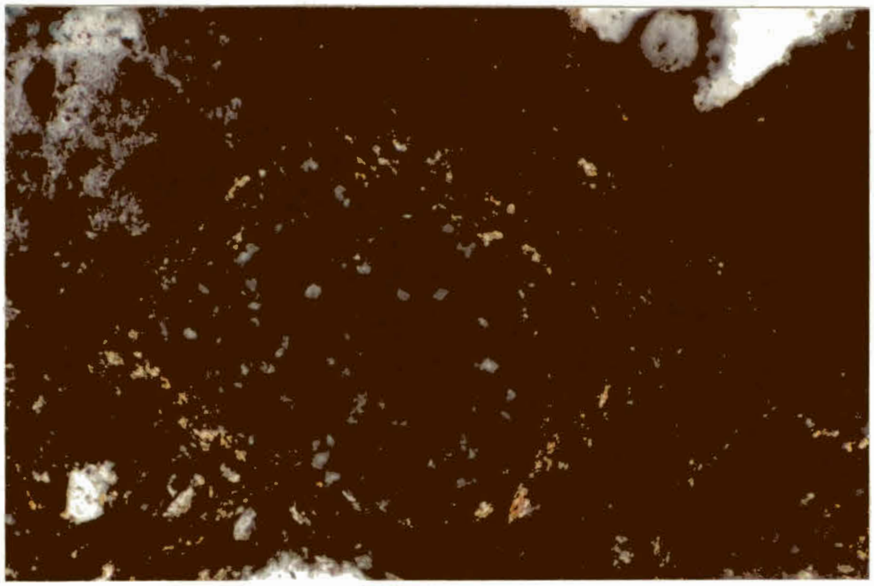


Figure 36. Photomicrograph Illustrating Authigenic Kaolinite Development in a Dissolution Pore (W01, 200X, XN).

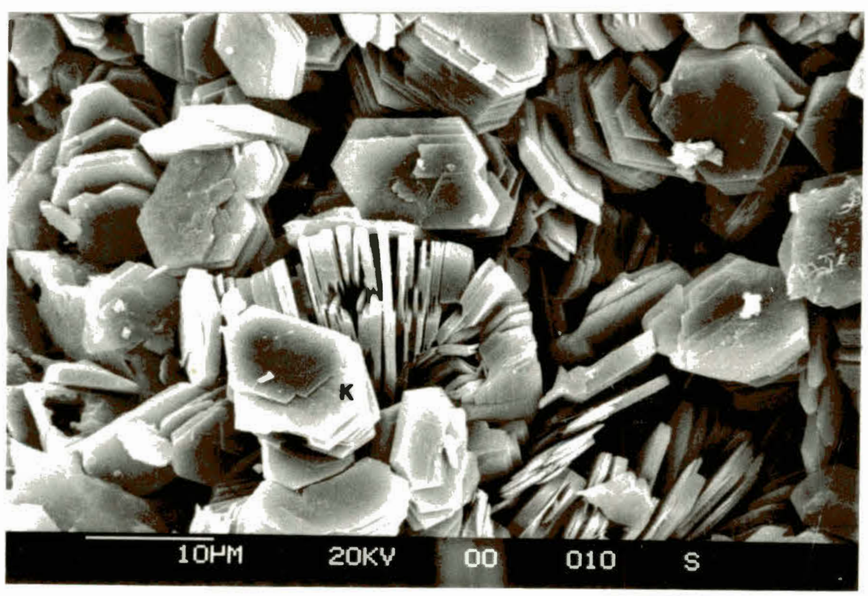


Figure 37. SEM Image of Pore-filling Kaolinite in the Warner Sandstone (W01, 1500X).

sandstone samples confirmed authigenic chlorite in some samples thought to contain very little or none (Figure 39).

Porosity

Because of the lack of subsurface petrographic data from cores, conclusions about the evolution of porosity in the subsurface are speculative. Besides the two cores previously discussed, thin sections were prepared from the Lower Booch well cuttings of five wells within the study area. Subsurface data, when combined with "fresh" outcrop samples, provides useful information about development of porosity. Hayes (1979) discussed the usefulness of outcrop data in sandstone porosity studies:

> (Subsurface to surface) comparisons show similar kinds and amounts of solution porosity in subsurface and outcrop samples, demonstrating that solution porosity in these outcrop samples predated modern weathering (p. 30).

Various types of secondary porosity are observed in McAlester Sandstones. One important texture is reduced intergranular, the result of pore reduction by quartz overgrowth. Secondary porosity also developed by dissolution of metastable detrital framework constituents, dissolution of detrital matrix and squeezed pseudomatrix, and dissolution of authigenic carbonate cements.

Intergranular porosity is important in subsurface samples and appears as "hybrid pores". These are formed by the reduction of porosity and partial cementation by quartz overgrowth, cementation and slight replacement of overgrowths by calcite, and partial or complete dissolution of this calcite before hydrocarbon migration (Schmidt and McDonald, 1979b) (Figures 40 and 41). Otherwise, dissolution secondary porosity

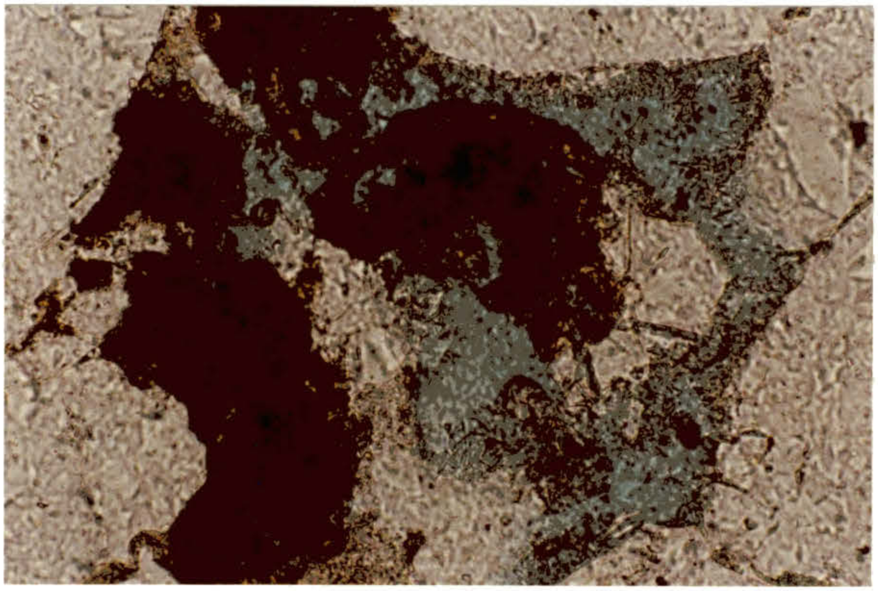


Figure 38. Photomicrograph of Authigenic Chlorite and Siderite Cements. Note the Pore-lining Nature of Chlorite (W01, 200X, PPL).

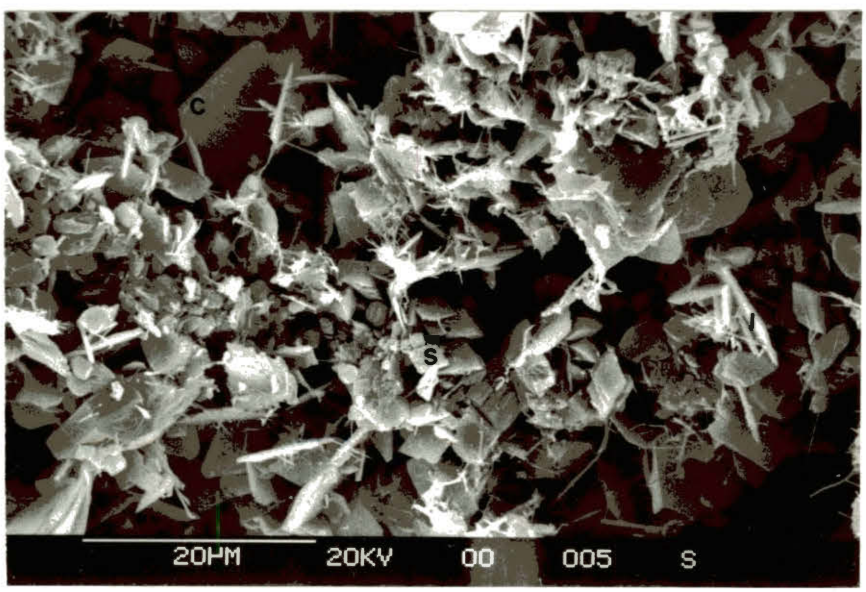


Figure 39. SEM Image of Authigenic Chlorite (C) and Illite (I) in a Siderite-cemented (S) Sandstone (W01, 1500X).

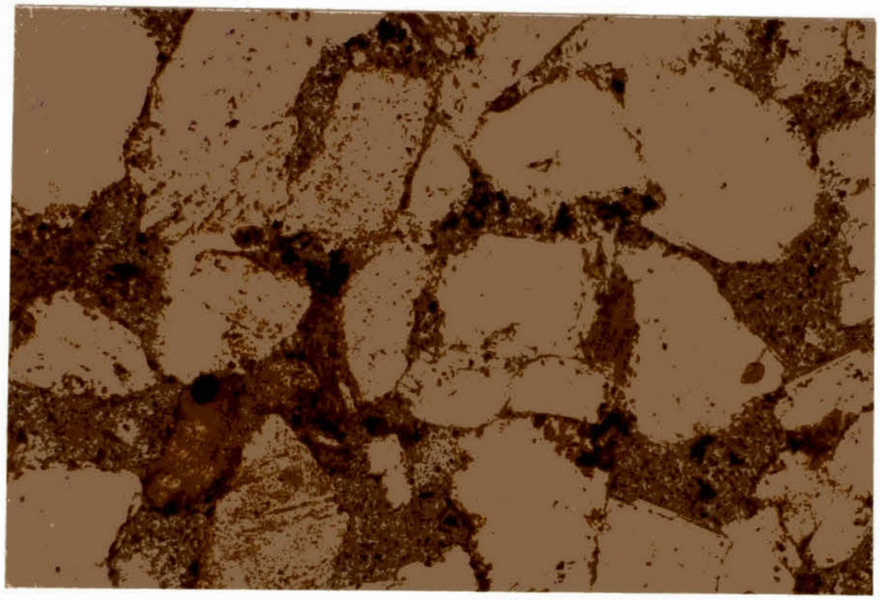


Figure 40. Photomicrograph of "Hybrid" Porosity, Lower Booch Sandstone, Bald Hill Field (BA, 100X, PPL).

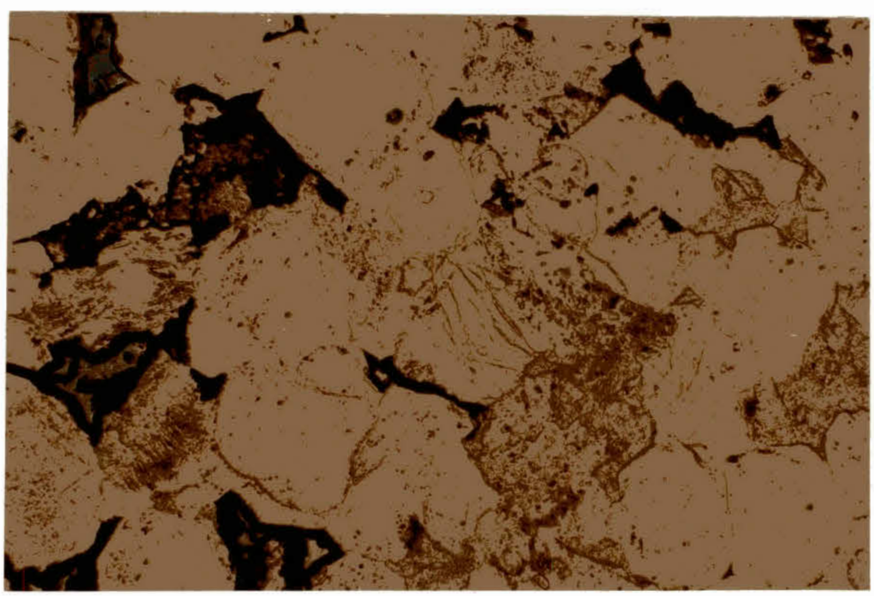
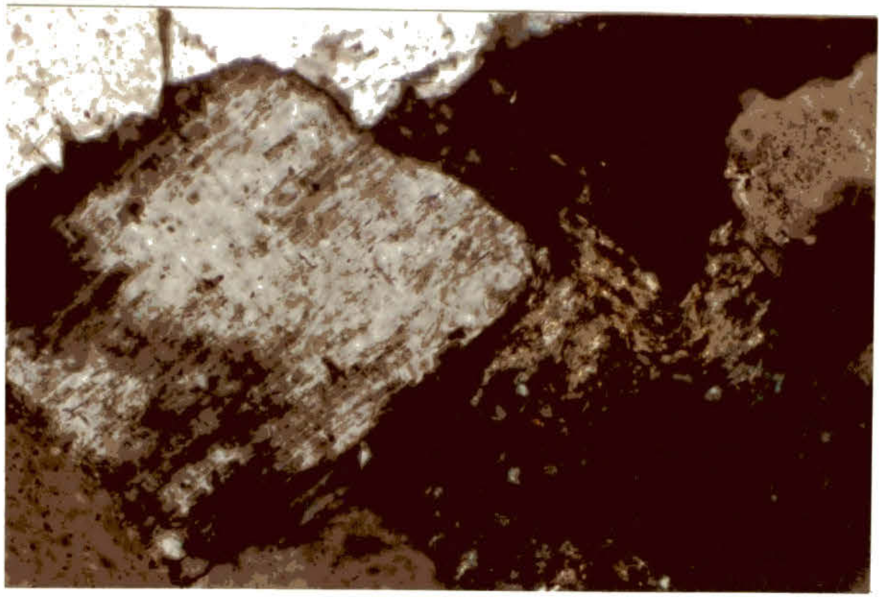


Figure 41. Photomicrograph Illustrating Oil Stained Porosity Owing to the Dissolution of Calcite Cement (B01, 100X, PPL).

development in McAlester sandstones is typically a function of grain size. Consequently any coarse grained facies may contain reservoir quality sands. Feldspar and detrital matrix compose 2-7% each of total detrital grain composition in all samples. Porosity in very fine-grained sands and silts rarely exceeds 5%. It is owing to the dissolution of feldspar and to a lesser extent detrital matrix (Figure 42). Intergranular porosity in finer grain sands and silts may be completely occluded by quartz overgrowths and illitic authigenic minerals.

Fine- to medium-grained sands of the Warner exhibit significant porosity ranging from 3% to 20%. A great variety of secondary porosity textures are exhibited in Warner samples. These include intergranular pores, oversized pores, grain and cement molds, and intraconstituent dissolution textures (Schmidt and McDonald, 1979b). All of these textures result from dissolution of detrital and authigenic constituents. Dissolution of carbonate cements results in oversized pores and apparent inhomogeneity of packing. Feldspars typically dissolve to form intragranular porosity and are seen as honeycombed grains. Detrital matrix may dissolve to form intraconstituent porosity. Simultaneous dissolution of all metastable constituents will form tremendously oversized pores (Figure 43).

Primary porosity was reduced by siderite, quartz overgrowth, microquartz, and calcite (Figure 44). As secondary porosity developed it was partially to completely occluded by clay minerals, late stages of carbonatization, and quartz overgrowths (Schmidt and McDonald, 1979a). In outcrops, porosity is occluded by the late precipitation of kaolinite as anomalously large pore-packing booklets. Siderite and ferroan calcite cements oxidize to insoluble iron minerals like hematite



XN

PPL

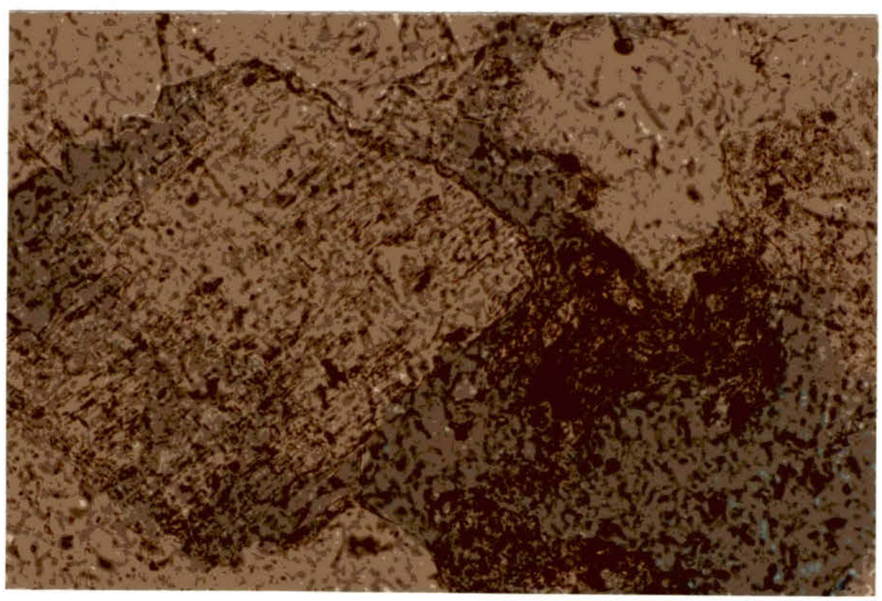


Figure 42. Photomicrographs Illustrating Porosity Owing to the Dissolution of Feldspar, Left, and Detrital Matrix, Right (W01, 200X, XN-top, PPL-bottom).

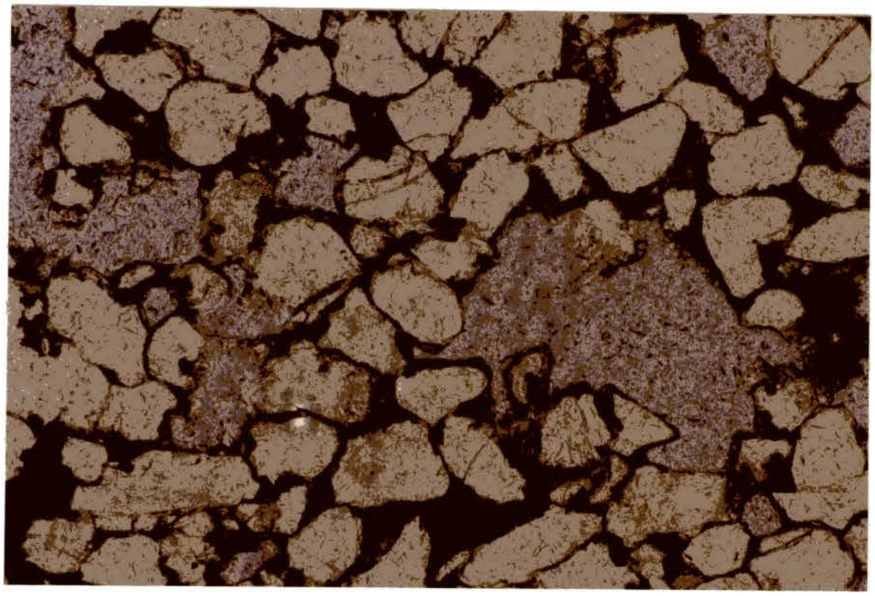


Figure 43. Photomicrograph of Hematite (Formed after Siderite) Cemented Quartz Arenite (W02, 40X, PPL).

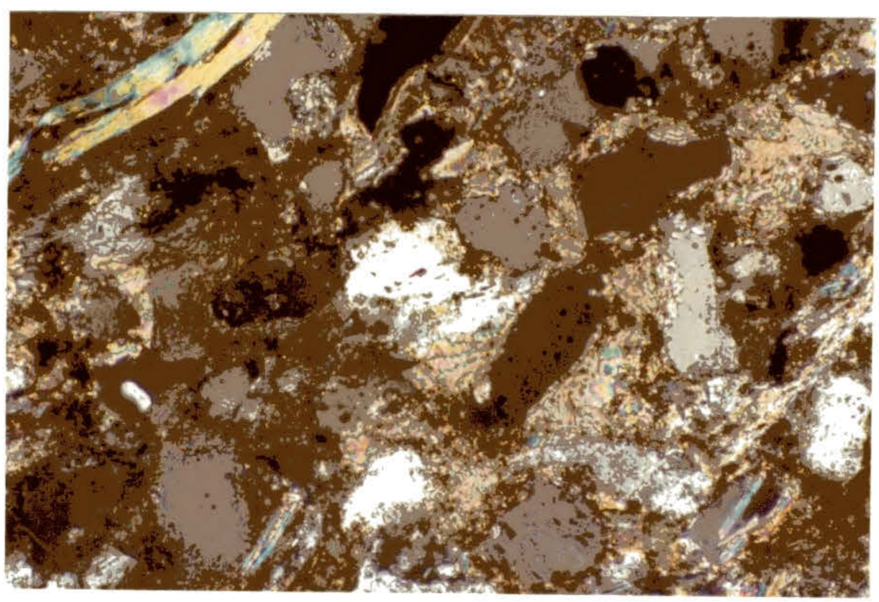


Figure 44. Photomicrograph Illustrating Complete Cementation by Siderite and Calcite (B02, 200X, XN).

and limonite. Some Warner outcrops exhibited the complete leaching of all unstable constituents due to diagenesis. Sandstones of this type are classified as hematite cemented quartz arenites.

Diagenetic History

Figure 45 summarizes the complete diagenetic history of the McAlester sandstones. The sequence of events was determined by cross-cutting relationships observed in thin sections. Variations in the intensity of an event within a sample was more a function of grain size than stratigraphic position. Subsurface samples were less mature (diagenetically) than outcrop samples, thus not all meso-diagenetic and no telodiagenetic effects commonly observed in the more basinward outcrop samples were seen in core and cutting thin sections (Schmidt and McDonald, 1979a).

Siderite is granular, flattened rhombic crystal aggregates or dispersed crystals throughout all McAlester samples. It is an important cementing agent in some medium sands, especially those from distributary channel facies. It is suggested that colloidal iron compounds were detrital constituents that altered to siderite shortly after deposition. The normal (neutral) pH, low Eh, and low sulphur activity necessary for this process are all present in a rapidly developing delta system. Carbonate activity would increase as organic and plant material decayed in the sediment (Curtis and Spears, 1975). The preservation of rounded quartz grains by granular siderite provides the best evidence for early post depositional development. Quartz overgrowths, then microquartz, precipitated during a period of low pH in pore spaces that were reduced in siderite cements. Generally, siderite and calcite replace

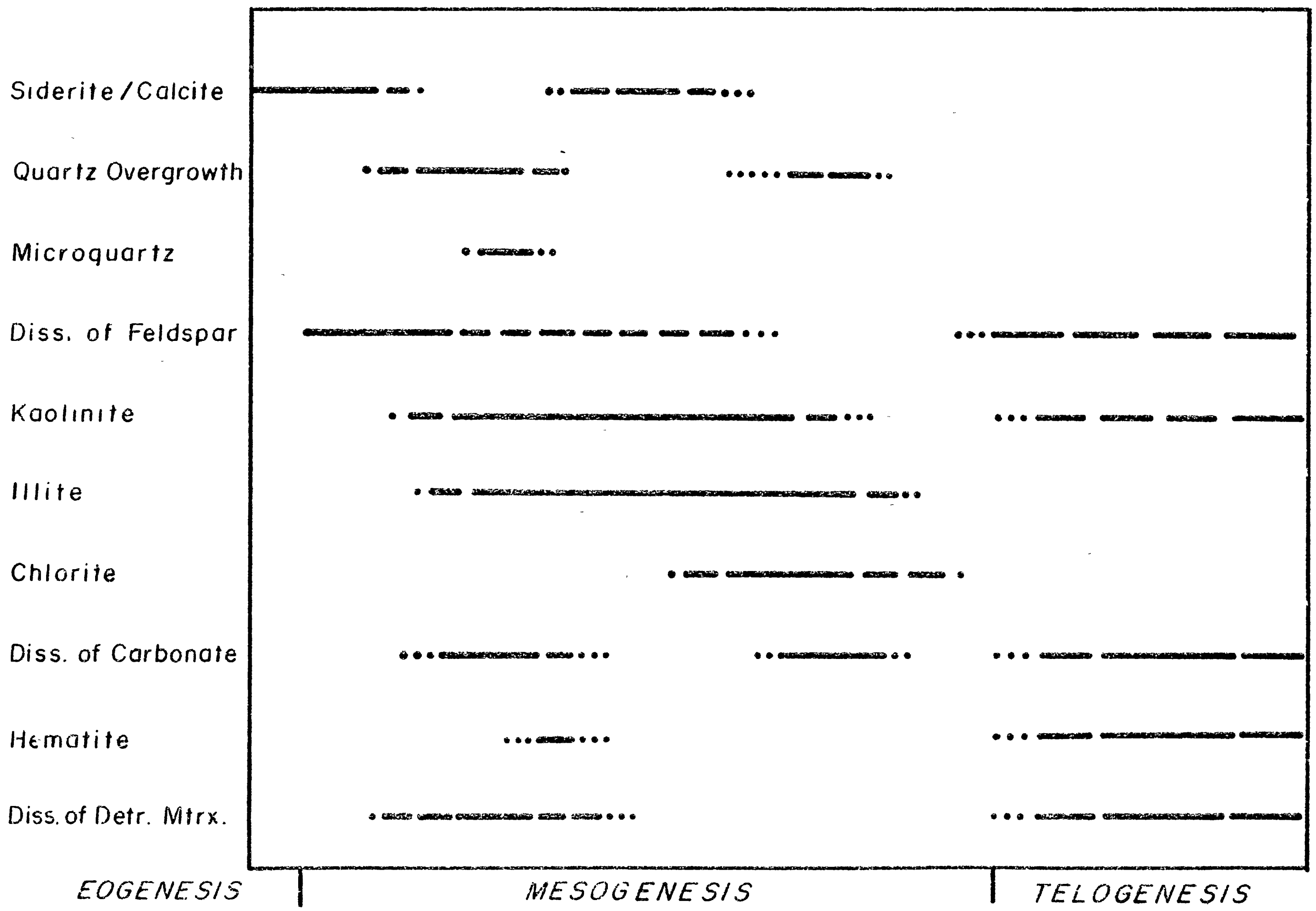


Figure 45. Paragenetic Sequence for McAlester Sandstones.

authigenic quartz. This suggests at least one later state of carbonatization or carbonitization occurred as a continuous process (Schmidt and McDonald, 1979a). Dissolution of feldspars, dissolution of carbonates, and dissolution of detrital matrix takes place locally any time the pH lowers to acidic conditions.

Kaolinite and illite appear to be early diagenetic minerals, probably derived from the dissolution and replacement of feldspars. Precipitation of either is a function of salinity and permeability, where kaolinite tends to form in open pores and illite in pore throats. Authigenic chlorite was typically a later precipitant that coated open pores and clogged pore throats. This is most commonly noted in basinward samples.

Outcrop samples display evidence of late-stage diagenesis. In subsurface samples secondary porosity appeared to be on the increase, whereas in outcrop samples all porosity seemed to be decreasing due to quartz overgrowths and the development of authigenic clay minerals (before surface exposure). In some instances surficial leaching (telodiagensis) had removed all feldspar, detrital matrix, and carbonate cements from samples and thus giving anomalously large porosity values.

CHAPTER VIII

SUMMARY AND CONCLUSIONS

The Lower Desmoinesian McAlester Formation is divided into six named members. In ascending order these members are McCurtain Shale, Warner Sandstone, Lequire Sandstone, Cameron Sandstone, Tamaha Sandstone and Keota Sandstone. Sandstones and coals within the McAlester generally represent regressive deltaic sedimentation events. The intervening shales are typically dark, contain marine faunas, and represent marine transgressive events. From this, cycles may be delineated to illustrate major transgressive-regressive couplets (format units).

Regressive episodes in the McAlester appear related to ancient deltaic sedimentation with a northerly source. Specific depositional environments may be identified in outcrops and cores of McAlester members, each representing variations in facies elements of the overall high-constructional deltaic system. The thickest cycle present within the study area, the Warner Sandstone, is the hydrocarbon producing Lower Booch Sandstone of the Eufaula Reservoir area. Warner outcrops and Booch cores help identify likely hydrocarbon reservoir and non-reservoir quality sandstone facies.

Subsurface mapping of regional sand geometry for the Warner (Lower Booch) Cycle corroborates the high constructive, elongate delta origin postulated by Busch (1953), Fisk (1961), and Brown (1979). The mapping of local occurrences of hydrocarbons in the McAlester sands, along with a regional comparison of Warner sandstone geometry, major structural features, and large hydrocarbon discoveries, together suggests that trapping circumstances are combinations of structure and stratigraphy in the study area.

The hydrocarbon reservoir potential of McAlester sands vary based upon porosity and permeability. The medium-grained sublitharenites of the Warner Sandstone provide ideal reservoir quality porosity development. Finer, tight sands in other McAlester members are similar in composition, but virtually unproductive. Porosity in the Warner typically developed by the dissolution of unstable detrital framework grains, detrital matrix, and authigenic cements. Combinations of precipitation and dissolution events creates intergranular "hybrid" pores, the most common reservoir quality porosity. A sequence of diagenetic activity with time can be derived by petrographic observations of mineralogic cross-cutting relationships.

Overall, there are five major conclusions made in this report.

1. Each sandstone and shale member in the McAlester Formation represents a regressive and transgressive phase of sedimentation. Cycles are delineated by the following vertical sequence: phosphatic marine shale, impure fossiliferous limestones, prodeltaic silty-shale, delta-front siltstone, channel or prograded shoreline sandstones, underclay, coal, transgressive (destructional) sandstone or limestone. Major cycles in the McAlester include: Warner, Stigler, Tamaha, Keota, and part of the Spaniard.
2. Members (and related cycles) of the McAlester Formation can be correlated to subsurface geophysical log responses. Thus, these

responses can be directly correlated with surface lithologies and vertical sequences.

3. Evidence from outcrops, cores, and sand geometry in the subsurface indicate that the Warner Cycle (Lower Booch and Warner Sandstone) represents a high constructive, elongate delta. Upper McAlester sands represent facies associated with separate deltas. However, the major distribution system of these sands is not present in the study area.

4. The Warner (Lower Booch) Sandstone contains the most likely hydrocarbon reservoir facies. Present occurrences of hydrocarbons in the Warner indicate that combination (structural and stratigraphic) traps are responsible for major accumulations.

5. Sandstone members in the McAlester Formation are typically sublitharenites, with very little variation in composition strati-graphically. Reservoir quality porosity development is restricted to coarser-grained sands (Warner). Porosity developed through a series of diagenetic events, but mainly from the dissolution of detrital framework grains, detrital matrix, and authigenic carbonate cements. It is occluded by authigenic cements and clay minerals such as kaolinite, illite, and chlorite.

SELECTED REFERENCES

Agterberg, F. P., and Briggs, G., 1963, Statistical Analysis of Ripple Marks in Atokan and Desmoinesian Rocks in the Arkoma Basin of East-central Oklahoma: Jour. Sed. Petrology, Vol. 33, No. 2, pp. 393-410.

Al-Shaieb, Z., and Shelton, J. W., 1981, Migration of Hydrocarbons and Secondary Porosity in Sandstones: Amer. Assoc. Petroleum Geologists Bull., Vol. 65, No. 11, p. 2433-2436.

Bennison, A. P., 1979a, Mobile Basin and Shelf Border Areas in Northeastern Oklahoma During Desmoinesian Cyclic Sedimentation: in Hyne, N. J., ed., Pennsylvanian Sandstones of the Mid-Continent, Tulsa Geol. Soc. Spec. Publication No. 1, pp. 283-294.

Bennison, A. P., 1979b, A Guidebook to the Desmoinesian Coal Cycles and Associated Sands of East Central Oklahoma: Tulsa Geol. Society, 41 p.

Bennison, A. P., 1984, Personal Communication.

Borchert, H., 1975, Genesis of Marine Sedimentary Iron Ores in Lepp, H., ed., Geochemistry of Iron, Benchmark Papers in Geology, Vol. 18, pp. 294-312.

Branson, C. C., 1956, Pennsylvanian History of Northeastern Oklahoma: Tulsa Geol. Soc. Digest, Vol. 24, pp. 83-86.

Brown, L. F., Jr. 1979, Deltaic Sandstone Facies of the Mid-Continents: in Hyne, N. J., ed., Pennsylvanian Sandstones of the Mid-Continent, Tulsa Geol. Soc. Spec. Publication No. 1, pp. 35-63.

Busch, D. A., 1953, The Significance of Deltas in Subsurface Exploration: Tulsa Geol. Soc. Digest, Vol. 21, pp. 71-80.

Busch, D. A., 1959, Prospecting for Stratigraphic Traps: Amer. Assoc. Petroleum Geologists Bull., Vol. 43, No. 12, pp. 2829-2843.

Busch, D. A., 1971, Genetic Units in Delta Prospecting: in Ancient Deltas, Amer. Assoc. Petroleum Geologists Reprint Series No. 19, pp. 209-226.

Busch, D. A., 1974, Stratigraphic Traps in Sandstones - Exploration Techniques: Amer. Assoc. Petroleum Geologists, Tulsa, Oklahoma, 174 p.

Busch, D. A., 1983, Personal Communication.

Catalano, L. E., 1978, Geology of the Hartshorne Coal, McCurtain and Lafayette Quadrangles, Haskell and LeFlore Counties, Oklahoma: Unpub. M. S. Thesis, Oklahoma State University, 61 p.

Cline, L. M., 1968, A Guidebook to the Geology of the Western Arkoma Basin and Ouachita Mountains, Oklahoma: Oklahoma City Geol. Society, 126 p.

Cohen, C. R., 1982, Model for Passive to Active Continental Margin Transition: Implications for Hydrocarbon Exploration: Amer. Assoc. Petroleum Geologists Bull., Vol. 66, No. 6, p. 708-718.

Curtis, C. D., and Spears, D. A., 1975, The Formation of Sedimentary Iron Minerals: in Lepp, H., ed., Geochemistry of Iron, Benchmark Papers in Geology, Vol. 18, pp. 91-96, 274-282.

Dickenson, W. R., and Suzek, C. A., 1978, Plate Tectonics and Sandstone Composition: Amer. Assoc. Petroleum Geologists Bull., Vol. 63, No. 12, pp. 2164-2182.

Dickey, P. A., and Rohn, R. E., 1955, Facies Control on Oil Occurrence: Amer. Assoc. Petroleum Geologists Bull., Vol. 39, No. 11, p. 2306-2320.

Ebanks, W. J., 1979, Correlation of Cherokee (Desmoinesian) Sandstones of the Missouri - Kansas - Oklahoma Tri-State Area: in Hyne, N. J., ed., Pennsylvanian Sandstones of the Mid-Continent, Tulsa Geol. Soc. Spec. Publication No. 1, pp. 295-312.

Fisk, H. N., 1961, Bar Finger Sands of Mississippi Delta: in Peterson, J. A., and Osmond, J. C., eds., Geometry of Sandstone Bodies, Amer. Assoc. Petroleum Geologists, Tulsa, Oklahoma, pp. 29-52.

Frezon, S. E., 1962, Subsurface Paleozoic Rocks of the Arkoma Basin: Oklahoma Geol. Survey Circular No. 58, 53 p.

Habicht, J. K. A., 1979, Paleoclimate, Paleomagnetism, and Continental Drift: Amer. Assoc. Petroleum Geologists, Study in Geology No. 9, 31 p.

Haley, B. R., 1961, Thickness Trends in the Hartshorne Sandstone and the McAlester Formation in Northwestern Arkansas: in Short Papers in the Geologic and Hydrologic Sciences, U. S. Geol. Survey Prof. Paper 424-C, pp. C80-C81.

Hayes, J. B., 1979, Sandstone Diagenesis - The Hole Truth: in Scholle, P. A., and Schluger, P. R., eds., Aspects of Diagenesis: Soc. Econ. Paleontologists and Mineralogists Spec. Publication No. 26, pp. 127-139.

Heckel, P. H., 1977, Origin of Phosphatic Black Shale Facies in Pennsylvanian Cyclothems of Mid-Continent North America: Amer. Assoc. Petroleum Geologists Bull., Vol. 61, No. 7, pp. 1045-1068.

Horne, J. C., Ferm, J. C., Caruccio, F. T., and Baganz, B. P., 1978, Depositional Models in Coal Exploration and Mine Planning in Appalachian Region: Amer. Assoc. Petroleum Geologists Bull., Vol. 62, No. 12, pp. 2379-2411.

Houseknecht, D. W., 1983, Tectonic - Sedimentary Evolution of the Arkoma Basin: Soc. Econ. Paleontologists and Mineralogists Mid-Continent Section, Vol. 1, 119 p.

Howe, W. B., and Koeng, J. W., eds., 1961, The Stratigraphic Succession in Missouri: Missouri Geological Survey and Water Resources Vol. XL, pp. 80-83.

Karvelot, M. D., 1972, The Stigler Coal and Collateral Strata in Parts of Haskell, LeFlore, McIntosh, and Muskogee Counties, Oklahoma: Unpub. M. S. Thesis, Oklahoma State University, 93 p.

Koinm, D. N., and Dickey, P. A., 1967, Growth Faulting in McAlester Basin of Oklahoma: Amer. Assoc. Petroleum Geologists Bull, Vol. 51, No. 5, pp. 710-718.

Krumme, G. W., 1975, Mid-Pennsylvanian Source Reversal on the Oklahoma Platform: Unpub. Ph.D. Dissertation, University of Tulsa, 146 p.

Larese, D., 1983, The Role of Diagenesis in Porosity and Permeability Development within Sandstones, a Brief Study: Lecture notes, Oklahoma State University.

Levorsen, A. I., 1927, Convergence Studies in the Midcontinent Region: Amer. Assoc. Petroleum Geologists Bull., Vol. 11, No. 7, pp. 657-682.

Moore, G. E., 1979, Pennsylvanian Paleogeography of the Mid-Continent: in Hyne, n. J., ed., Pennsylvanian Sandstones of the Mid-Continent, Tulsa Geol. Soc. Spec. Publication No. 1, pp. 2-12.

Moore, R. C., Frye, J. C., Jewett, J. M., Lee, W., and O'Connor, H. G., 1951, The Kansas Rock Column: State Geological Survey of Kansas Bull. No. 89, pp. 98-101.

Oakes, M. C., and Knechtel, M. M., 1948, Geology and Mineral Resources of Haskell County, Oklahoma: Oklahoma Geol. Survey Bull. No. 67, 136 p.

Oakes, M. C., and Koonz, T., 1967, Geology and Petroleum of McIntosh County, Oklahoma: Oklahoma Geol. Survey Bull. No. 111, 88 p.

Oakes, M. C., 1977, Geology and Mineral Resources (Exclusive of Petroleum) of Muskogee County, Oklahoma: Oklahoma Geol. Survey Bull. No. 122, 78 p.

Pittman, E. D., 1979, Porosity, Diagenesis and Productive Capability of Sandstone Reservoirs: in Scholle, P. A., and Schluger, P. R., eds., Aspects of Diagenesis, Soc. Econ. Paleontologists and Mineralogists Spec. Publication No. 26, pp. 159-173.

Rascoe, B., Jr., and Adler, F. J., 1983, Permo-Carboniferous Hydrocarbon Accumulations, Mid-Continent, U.S.A.: Amer. Assoc. Petroleum Geologists Bull, Vol. 67, No. 6, pp. 979-1001.

Reed, R. D., 1923, Some Suggestions in Regard to Pennsylvanian Paleogeography in the Henreyetta District, Oklahoma: Amer. Assoc. Petroleum Geologists Bull., Vol. 7, pp. 50-57.

Schmidt, V., and McDonald, D. A., 1979a, The Role of Secondary Porosity in the Course of Sandstone Diagenesis: in Scholle, P. A., and Schluger, P. R., eds., Aspects of Diagenesis, Soc. Econ. Paleontologists and Mineralogists Spec. Publication No. 26, pp. 175-207.

Schmidt, V., and McDonald, D. A., 1979b, Texture and Recognition of Secondary Porosity in Sandstones: in Scholle, P. A., and Schluger, P. R., eds., Aspects of Diagenesis, Soc. Econ. Paleontologists and Mineralogists Spec. Publication No. 26, pp. 209-225.

Scholle, P. A., and Spearing, D., eds., 1982, Sandstone Depositional Environments: Amer. Assoc. Petroleum Geologists, Tulsa, Oklahoma, 410 p.

Scruton, P. C., 1949, The Petrography and Environment of Deposition of the Warner, Little Cabin, and Hartshorne Sandstones of Northeastern Oklahoma: Unpub. M. S. Thesis, University of Tulsa, 77 p.

Sutter, L. J., Basu, A., and Mack, G. H., 1981, Climate and the Origin of Quartz Arenites: Jour. Sed. Petrology, Vol. 51, No. 4, pp. 1235-1246.

Thomas, W. A., 1975, Evolution of the Ouachita - Appalachian Continental Margin: Jour. Geology, Vol, 84, pp. 323-342.

Visher, G. S., 1969, How to Distinguish Barrier Bar and Channel Sands: World Oil, Vol. 168, No. 6, pp. 106-114.

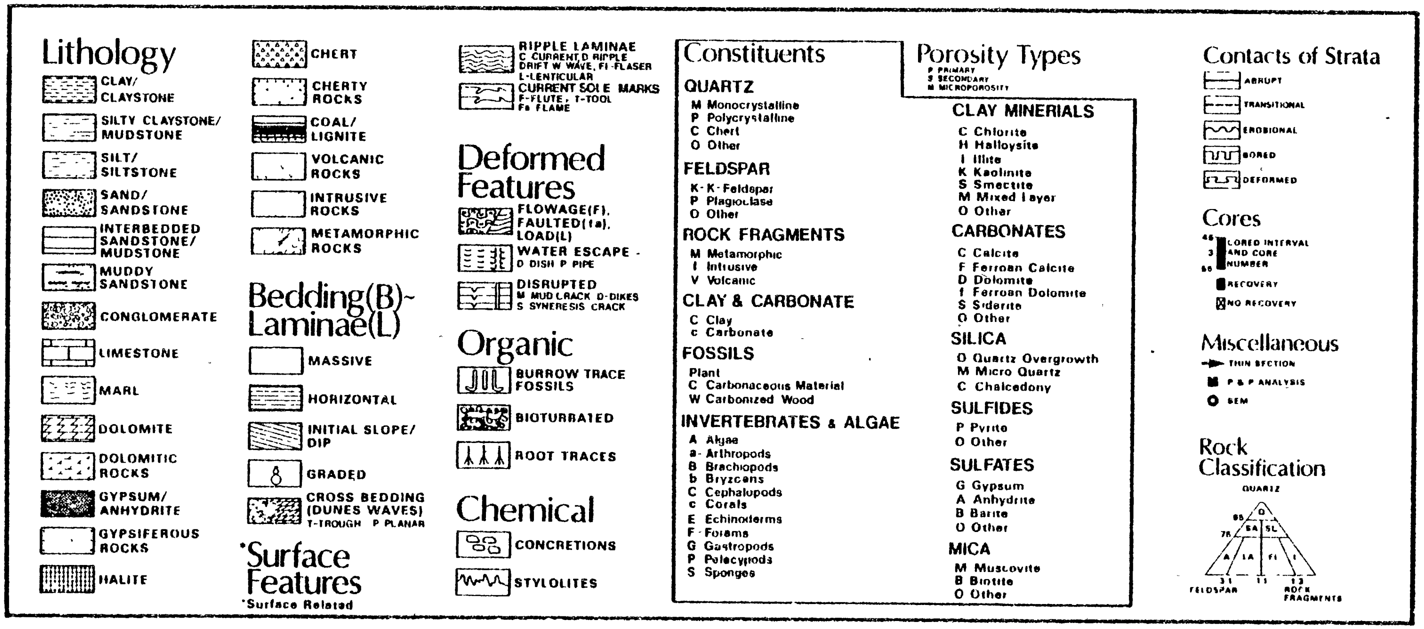
Visher, G. S., Saitta, S. B., and Phares, R. S., 1971, Pennsylvanian Delta Patterns and Petroleum Occurrences in Eastern Oklahoma: Amer. Assoc. Petroleum Geologists Bull., Vol. 55, No. 8, pp. 1206-1230.

Wilson, C. W., Jr., 1935, Age and Correlation of Pennsylvanian Surface Formations, and of Oil and Gas Sands of Muskogee County, Oklahoma: Amer. Assoc. Petroleum Geologists Bull., Vol. 19, No. 4, pp. 503-520.

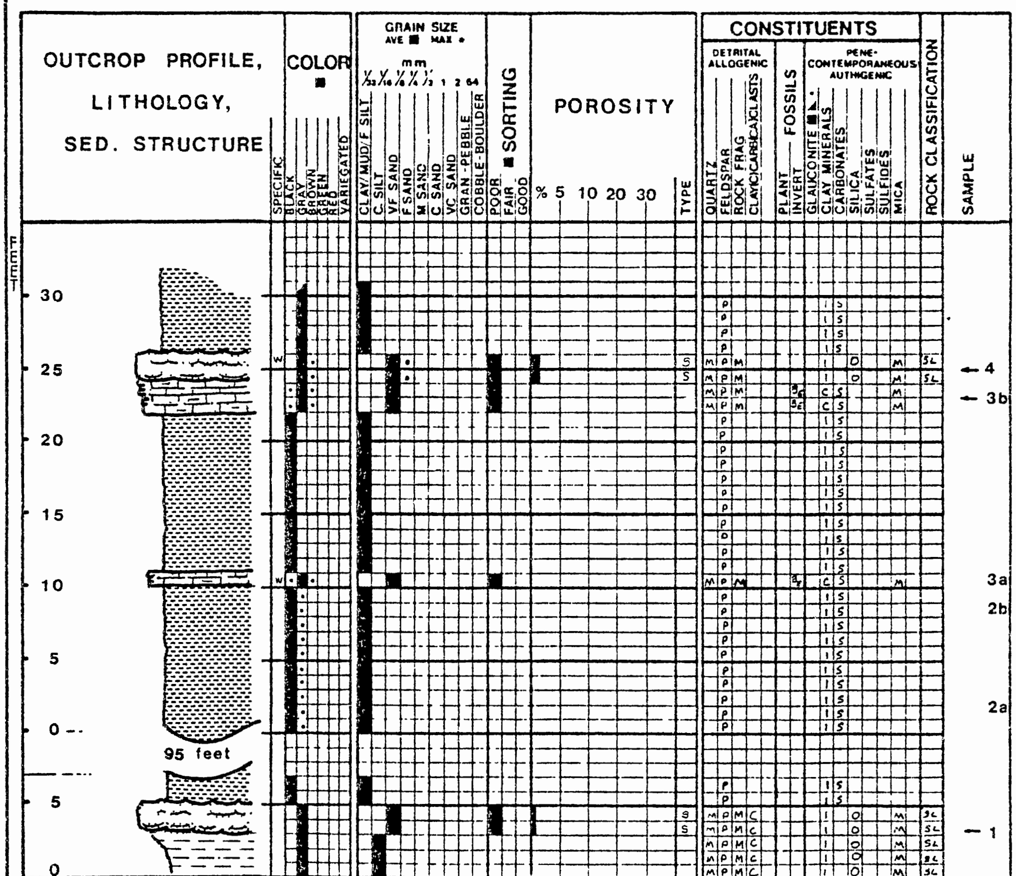
Wilson, C. W., and Newell, N. D., 1937, Geology of the Muskogee-Porum District, Muskogee and McIntosh Counties, Oklahoma: Oklahoma Geol. Survey Bull. No. 57, 184 p.

APPENDIX A

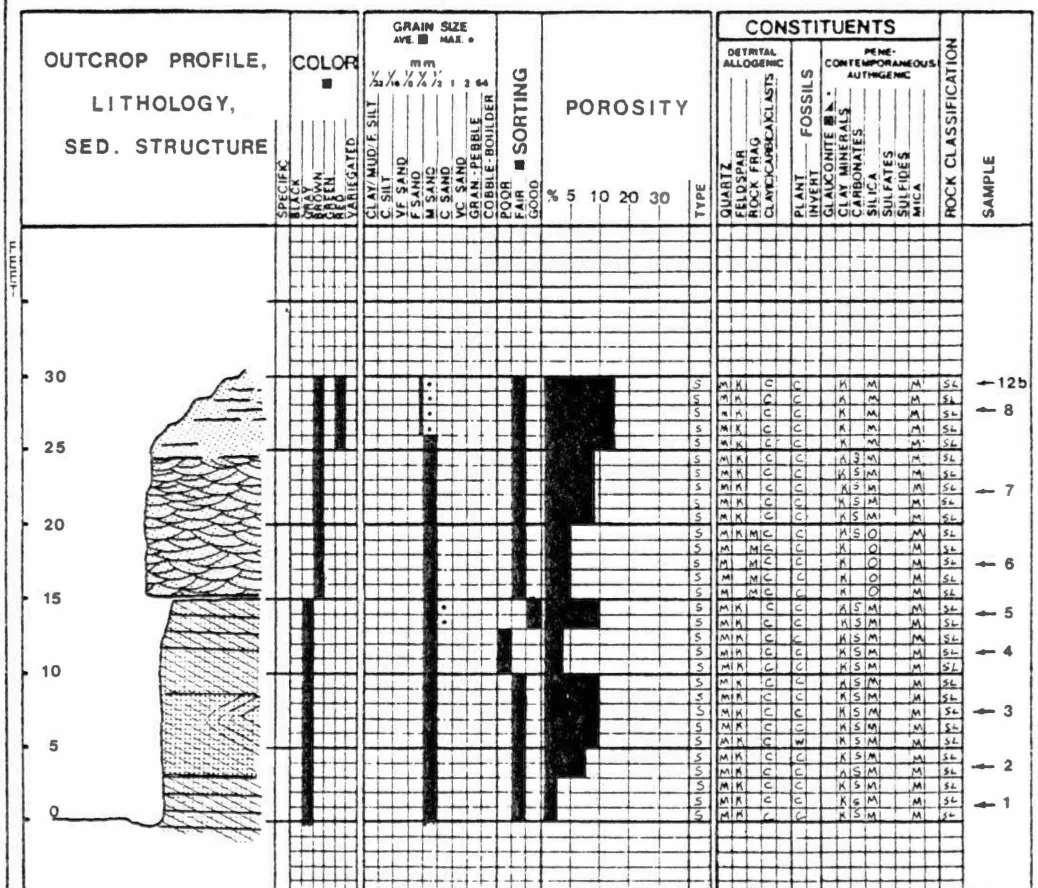
MEASURED SECTIONS AND CORE DESCRIPTIONS


Lithology
CLAY/ CLAYSTONE
SILTY CLAYSTONE/ MUDSTONE
SILT/ SILTSTONE
SAND/ SANDSTONE
INTERBEDDED SANDSTONE/ MUDSTONE
MUDDY SANDSTONE
CONGLOMERATE
LIMESTONE
MARL
DOLOMITE
DOLOMITIC ROCKS
GYPSUM/ ANHYDRITE
GYPSIFEROUS ROCKS
HALITE
CHERT
CHERTY ROCKS
COAL/ LIGNITE
VOLCANIC ROCKS
INTRUSIVE ROCKS
METAMORPHIC ROCKS
Bedding(B)~ Laminae(L)
MASSIVE
HORIZONTAL
INITIAL SLOPE/ DIP
GRADED
CROSS BEDDING (DUNES WAVES)
T-TROUGH P PLANAR
*Surface Features
*Surface Related
RIPPLE LAMINAE
C CURRENT D RIPPLE DRIFT W WAVE, FI-FLASER L-LENTICULAR
CURRENT SOLE MARKS
F-FLUTE, T-TOOL Fe FLAME
Deformed Features
FLOWAGE(F), FAULTED(fa), LOAD(L)
WATER ESCAPE - D DISH P PIPE
DISRUPTED
M MUD CRACK D-DIKES S SYNERESIS CRACK
Organic
BURROW TRACE FOSSILS
BIOTURBATED
ROOT TRACES
Chemical
CONCRETIONS
STYLOLITES
Constituents
QUARTZ
M Monocrystalline
P Polycrystalline
C Chert
O Other
FELDSPAR
K-K-Feldspar
P Plagioclase
O Other
ROCK FRAGMENTS
M Metamorphic
I Intrusive
V Volcanic
CLAY & CARBONATE
C Clay
c Carbonate
FOSSILS
Plant
C Carbonaceous Material
W Carbonized Wood
INVERTEBRATES & ALGAE
A Algae
a- Arthropods
B Brachiopods
b Bryzcans
C Cephalopods
c Corals
E Echinoderms
F-Forams
G Gastropods
P Pelecypods
S Sponges
Porosity Types
P PRIMARY
S SECONDARY
M MICROPOROSITY
CLAY MINERIALS
C Chlorite
H Halloysite
I Illite
K Kaolinite
S Smectite
M Mixed Layer
O Other
CARBONATES
C Calcite
F Ferroan Calcite
D Dolomite
f Ferroan Dolomite
S Siderite
O Other
SILICA
O Quartz Overgrowth
M Micro Quartz
C Chalcedony
SULFIDES
P Pyrite
O Other
SULFATES
G Gypsum
A Anhydrite
B Barite
O Other
MICA
M Muscovite
B Biotite
O Other
Contacts of Strata
ABRUPT
TRANSITIONAL
EROSIONAL
BORED
DEFORMED
Cores
45
3
55
CORED INTERVAL AND CORE NUMBER
RECOVERY
NO RECOVERY
Miscellaneous
THIN SECTION
P & P ANALYSIS
SEM
Rock Classification
QUARTZ
Q
95
SA
SL
75
A
LA
FI
I
3 1
1 1
1 3
FELDSPAR
ROCK FRAGMENTS

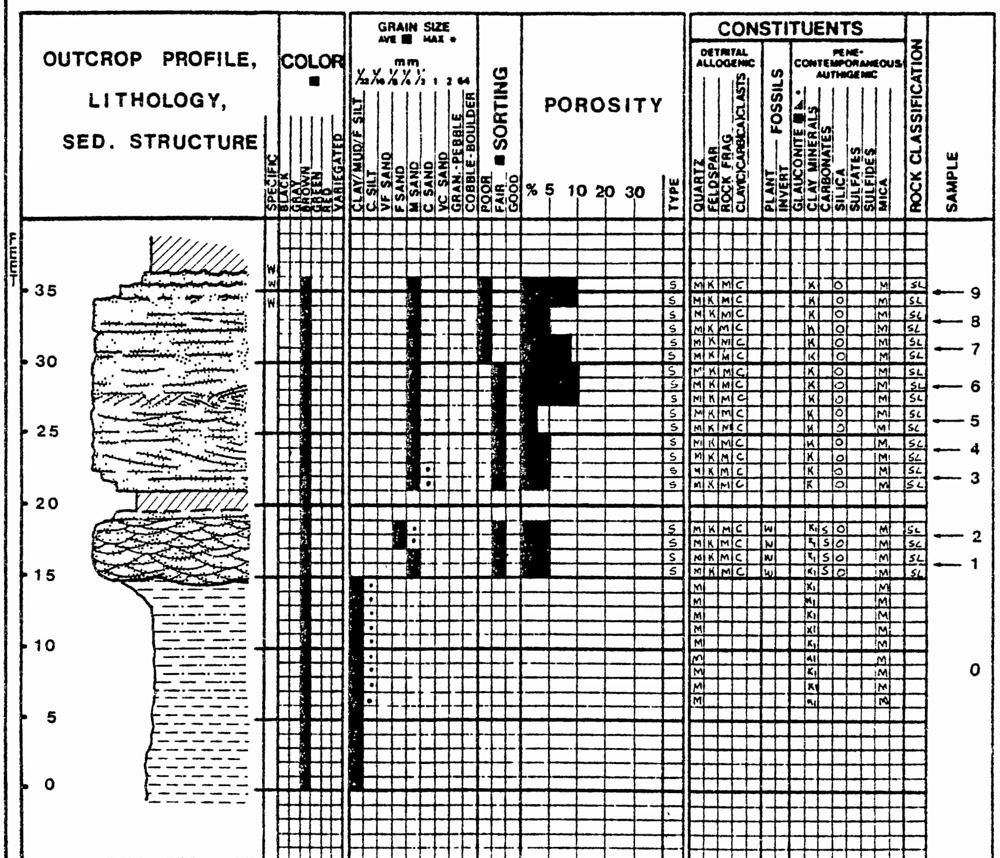
MEAS. SEC.: **MO1**	UNIT: **McCurtain Shale**
LOC.: **Roadcut south of Stigler, OK**	REF.: **Sampled after Oakes and**
C SW Sec. 32, T.9N., R.21E.	**Knechtel, 1948, p. 131**



MEAS. SEC.: **W01**	UNIT: **Warner Sandstone**
LOC.: **Roadcut 4.5 miles east of**	REF.: **Karvelot, 1972, p. 75**
Stigler, OK C SL Sec.12, T.9N., R.21E.	



MEAS. SEC.: **W02**	UNIT: **Warner Sandstone**
LOC.: **Bluff on north side of**	REF.:
Shropshire Valley Sec. 27, T.9N.,R.21E.	

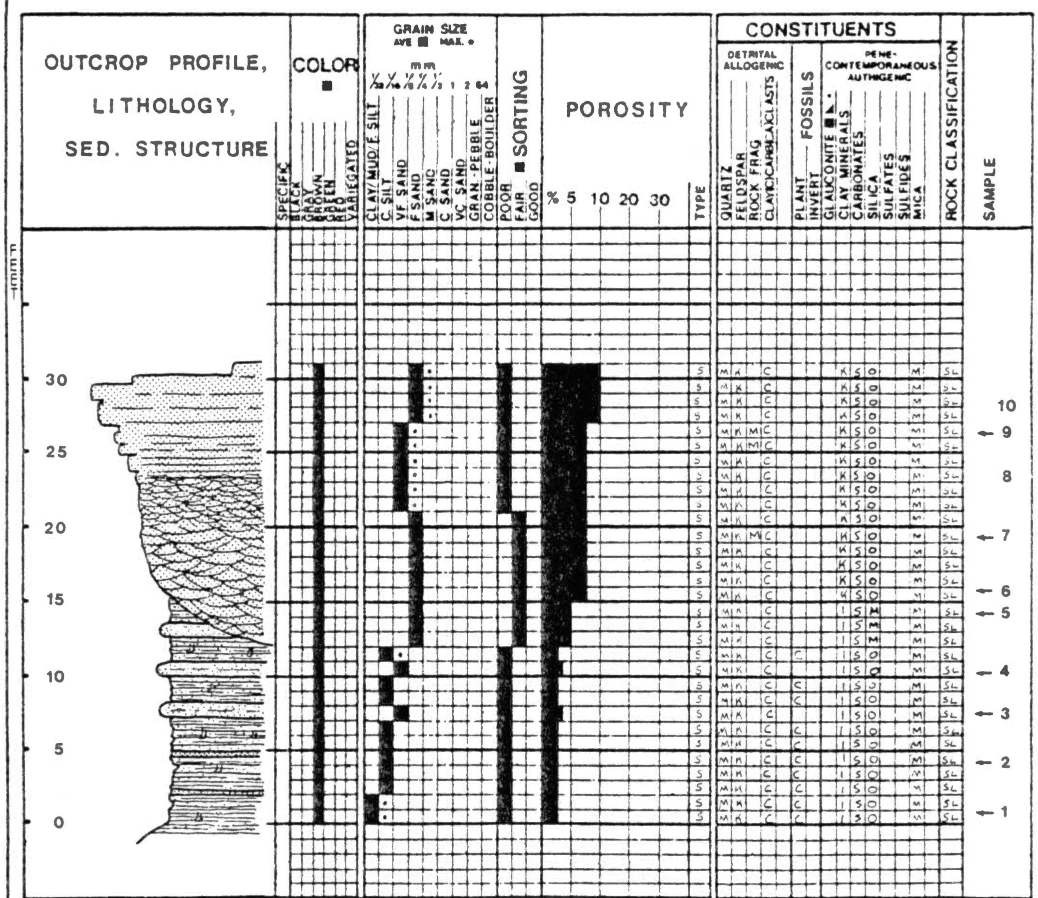


MEAS. SEC.: **W03**

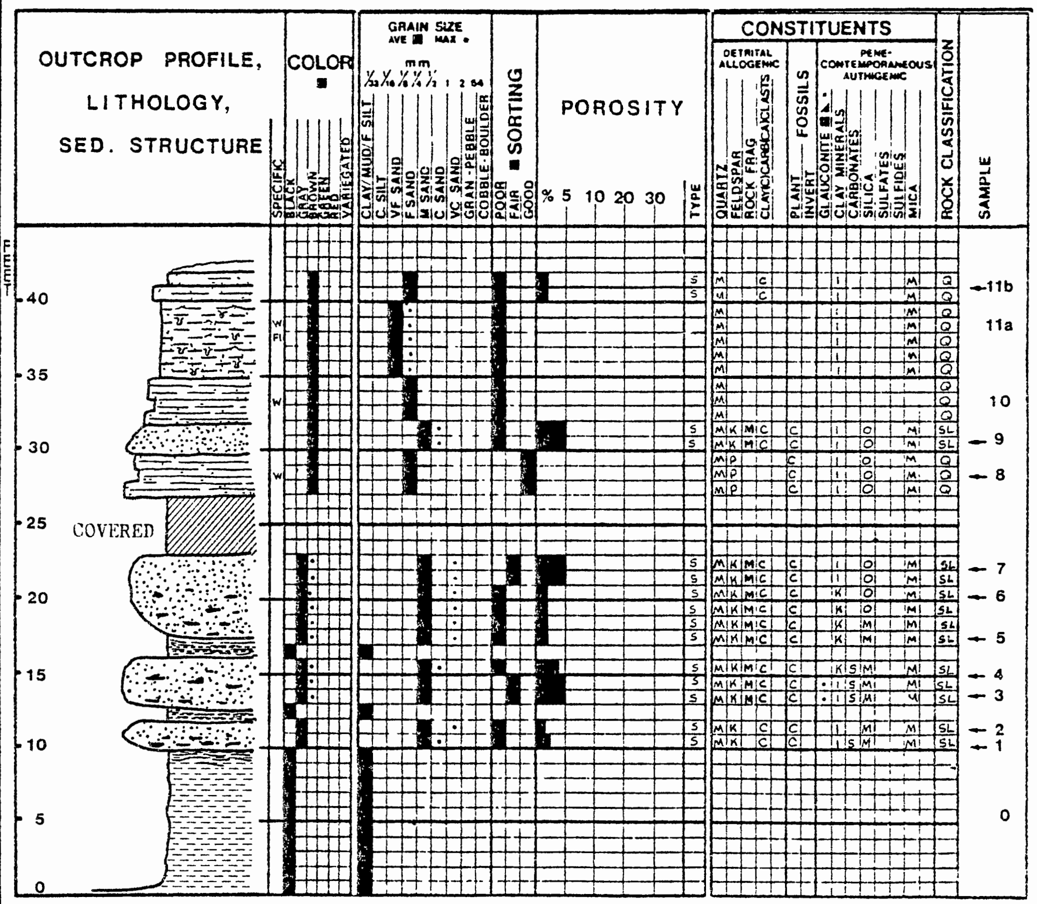
UNIT: **Warner Sandstone**

LOC.: **Bluff at SW SE Sec.31,T.9N,R.21E.**

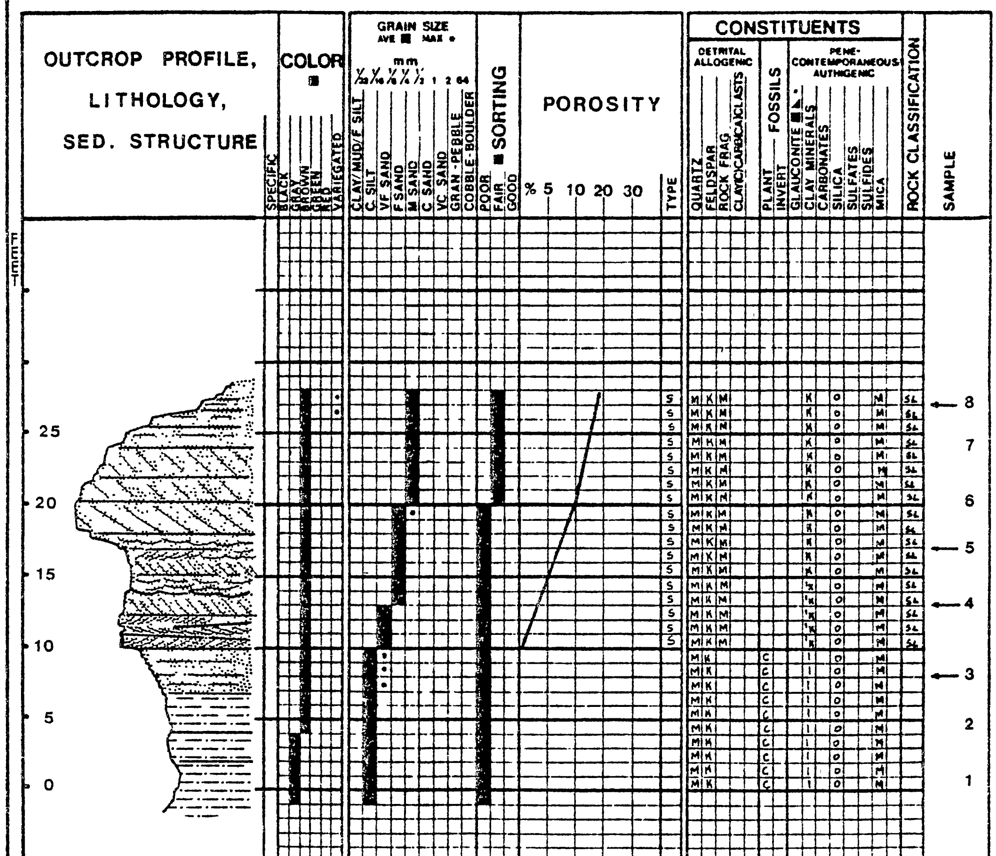
REF.:



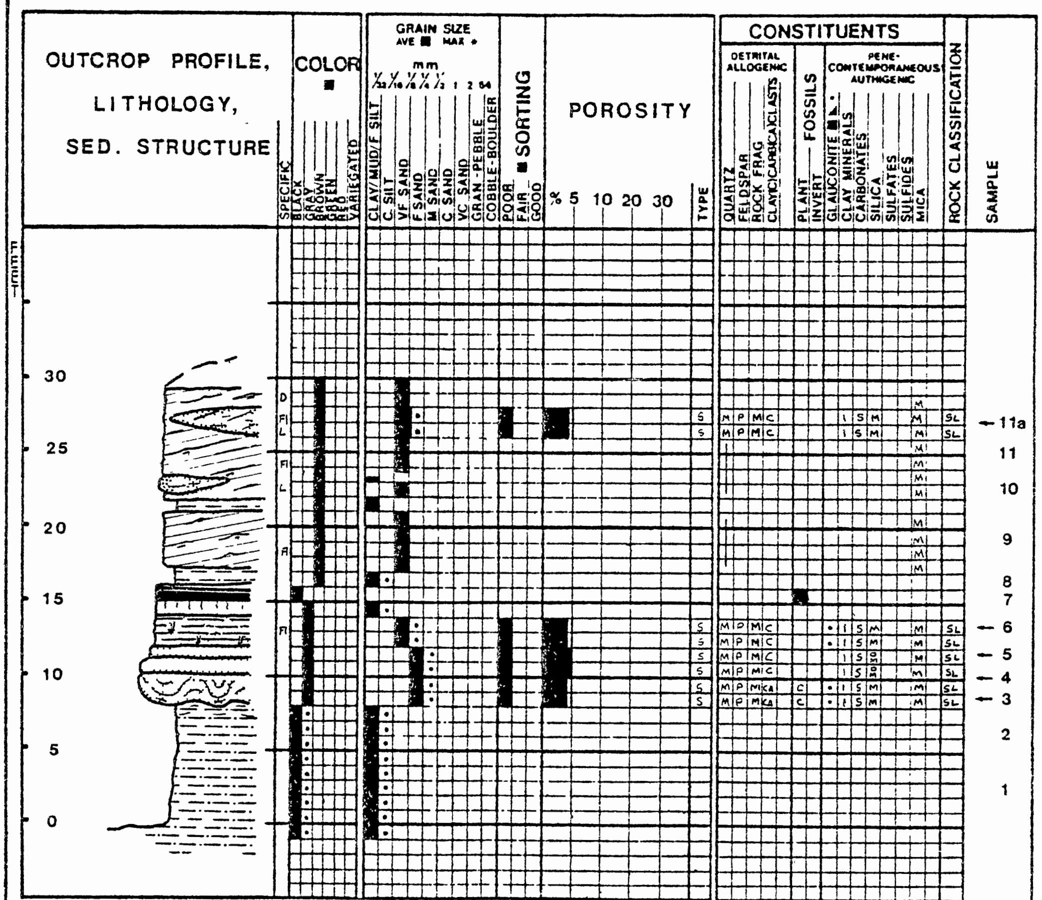
MEAS. SEC.: **W04**	UNIT: **Warner Sandstone**
LOC.: **Wellsite excavation near McCurtain, OK Sec. 28, T.8N., R.22E.**	REF.:



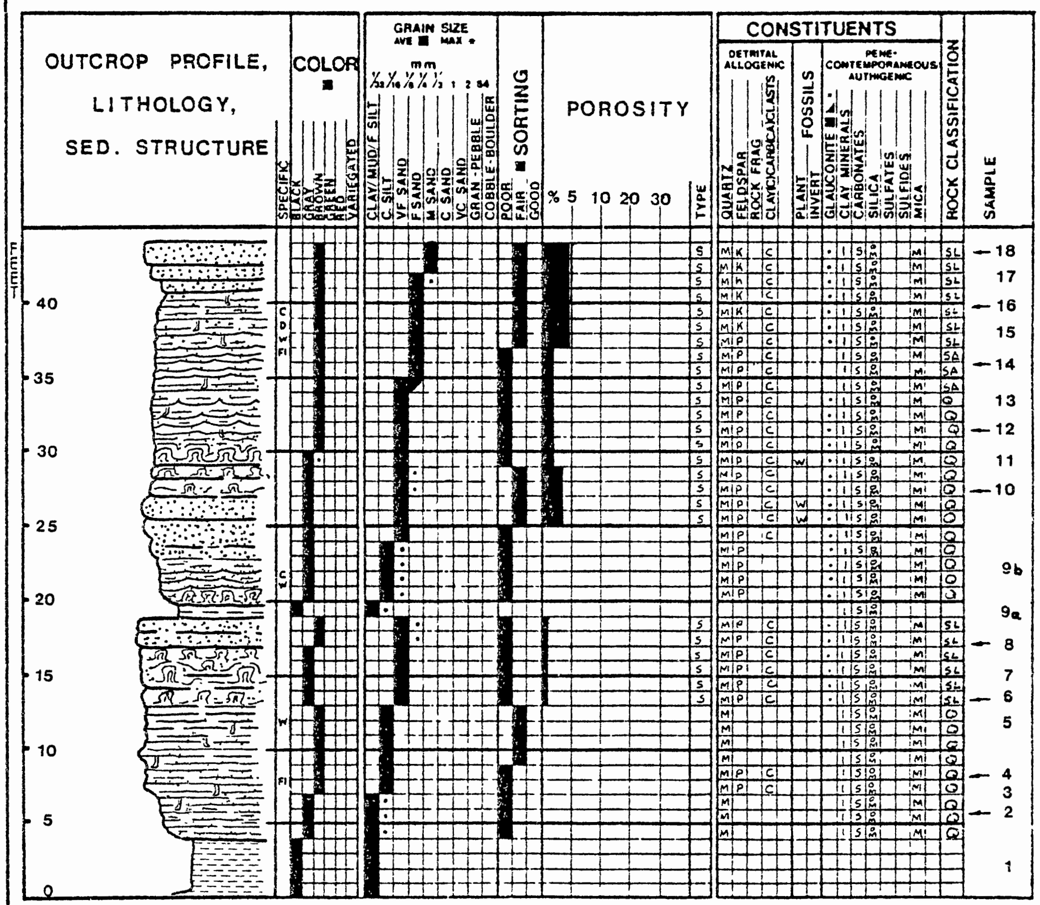
MEAS. SEC.: **W06**	UNIT: **Warner Sandstone**
LOC.: **North of Warner, OK**	REF.:
SW NW Sec. 5, T.12N., R.19E.	



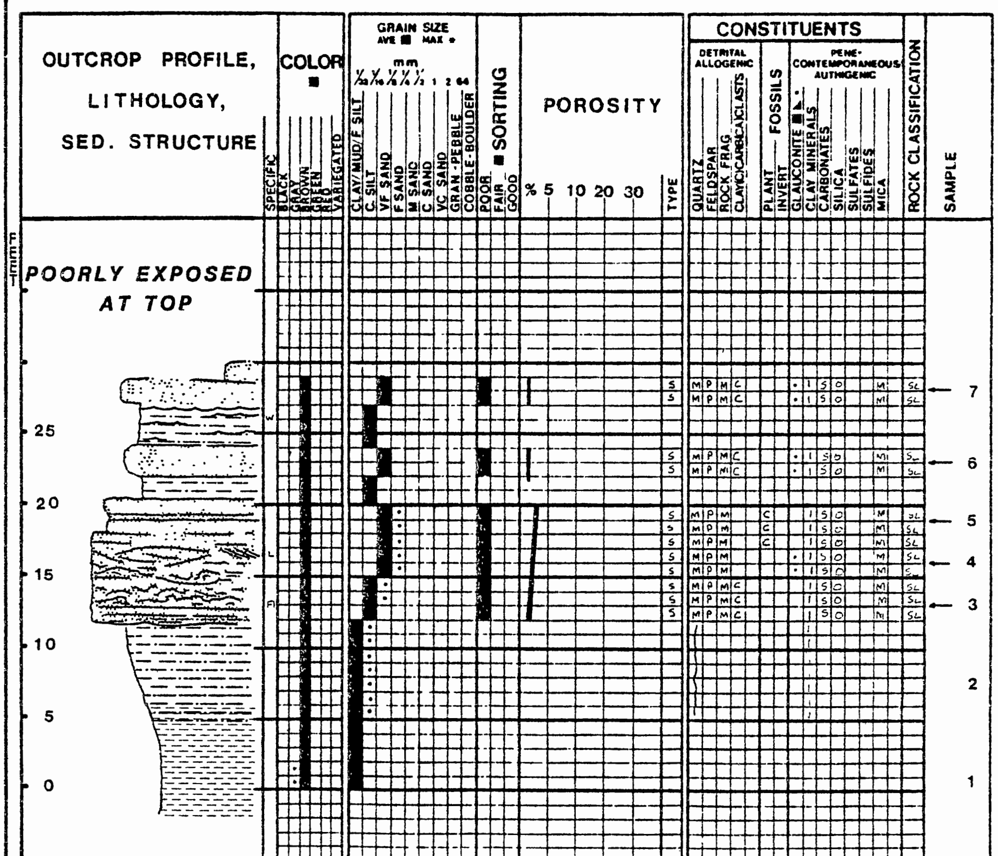
MEAS. SEC.: **W09**	UNIT: **Warner Sandstone**
LOC.: **Roadcut on U.S. 64 in Muskogee, OK SE SE Sec. 2, T.14N., R. 18E.**	REF.:



MEAS. SEC.: **LC01**	UNIT: **Lequire-Cameron SS.**
LOC.: **Roadcut 2 miles north of Kinta,**	REF.: **Karvelot, 1972, p. 74**
OK N N Sec. 31, T.8N., R.20E.	**Oakes and Knechtel, 1948,p. 125**



MEAS. SEC.: **LC03**	UNIT: **Lequire-Cameron SS.**
LOC.: **Quarry at Sec. 36, T.10N.,R.19E.**	REF.:

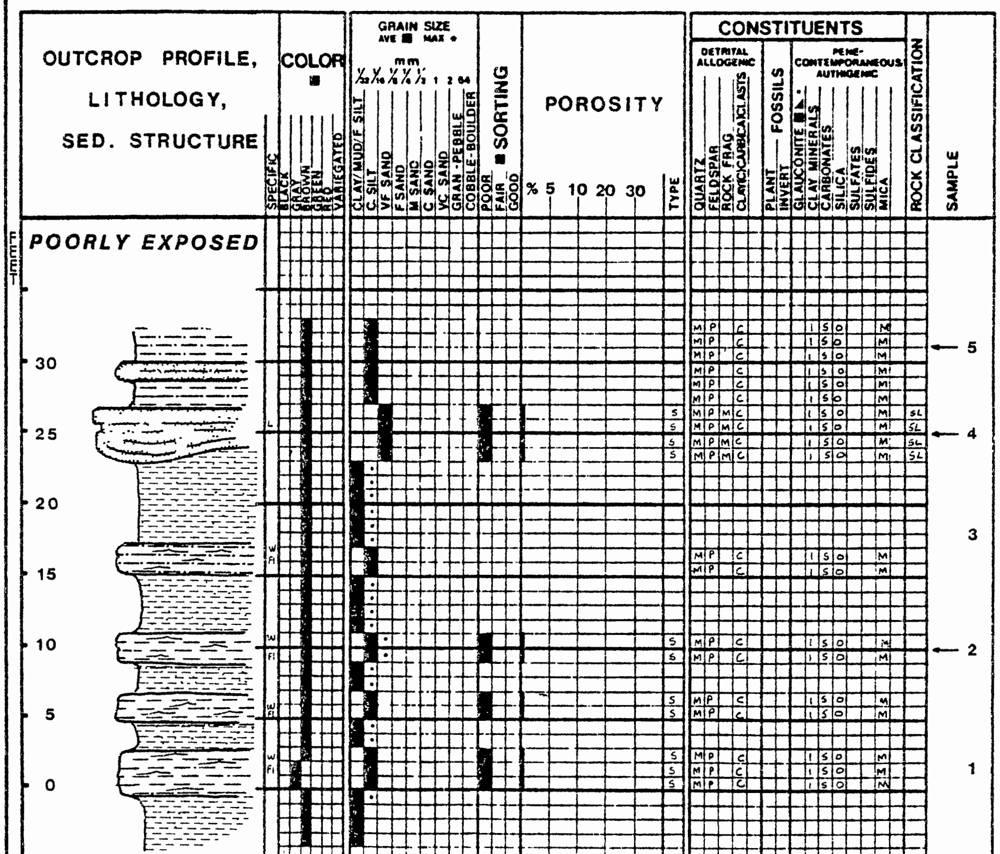


MEAS. SEC.: **T01**

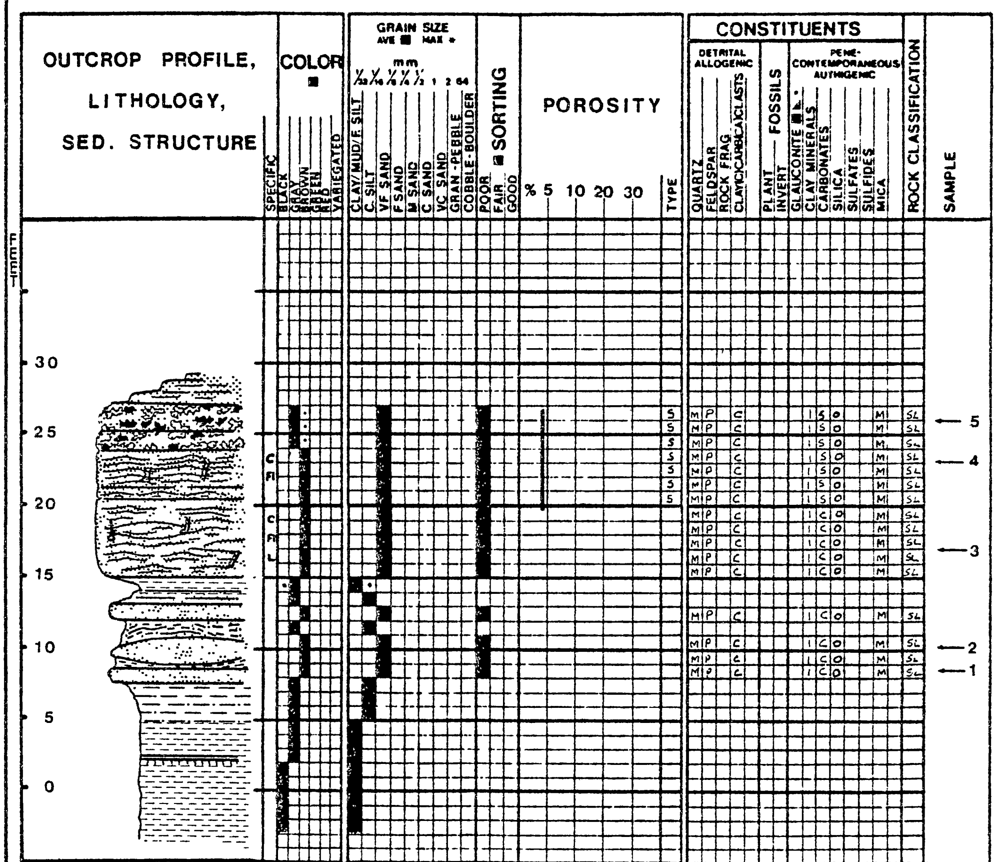
UNIT: **Tamaha Sandstone**

LOC.: **C EL Sec. 25,T.9N.,R.19E.**

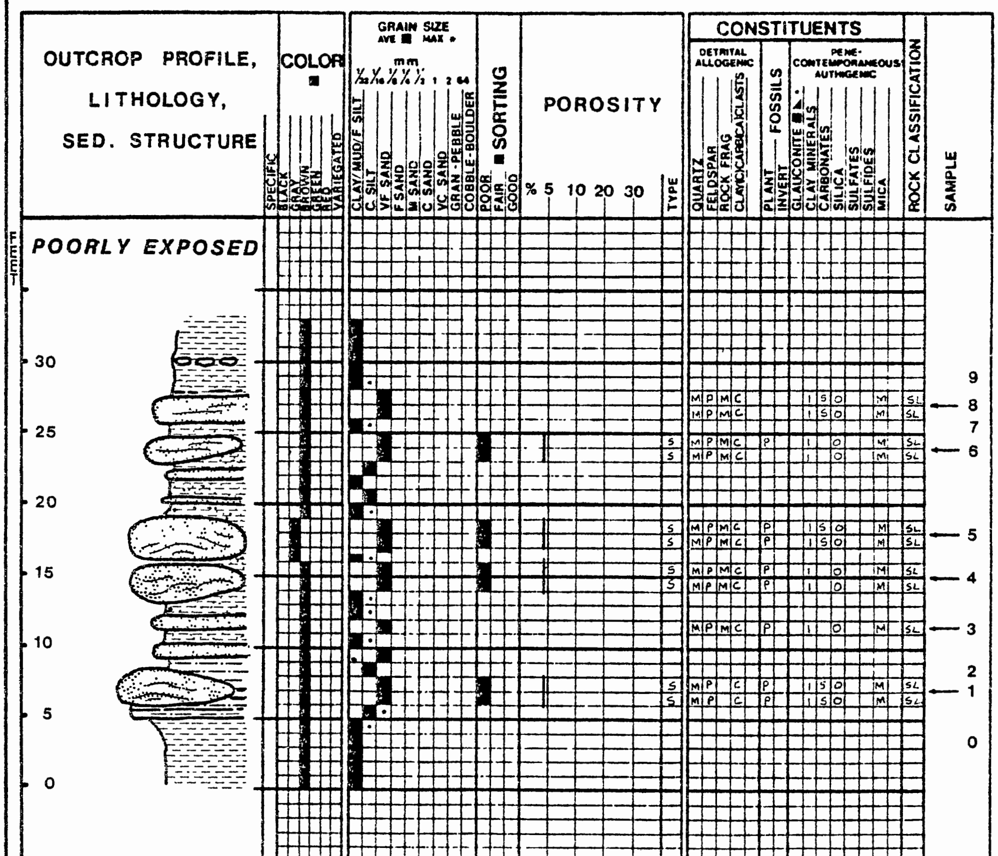
REF.:

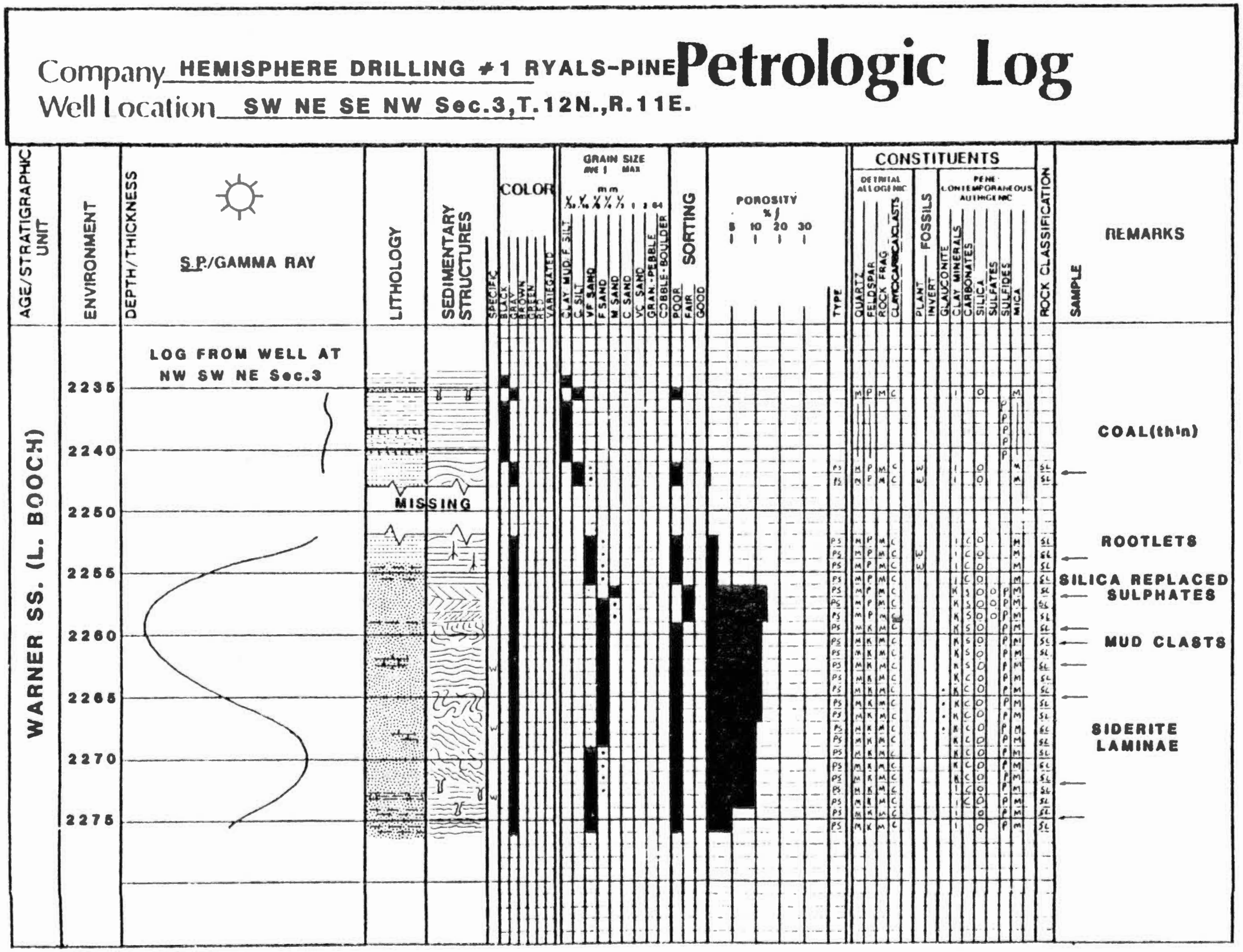


MEAS. SEC.: **T03-4**	UNIT: **Tamaha Sandstone**
LOC.: **Strip pit at**	REF.: **Karvelot,1972,p.76**
C Sec.27,T.10N.R.21E.	



MEAS. SEC.: **K01**	UNIT: **Keota Sandstone**
LOC.: **SE SW Sec. 19, T.8N., R.20E.**	REF.: **Oakes and Knechtel,**
	1948, p. 125

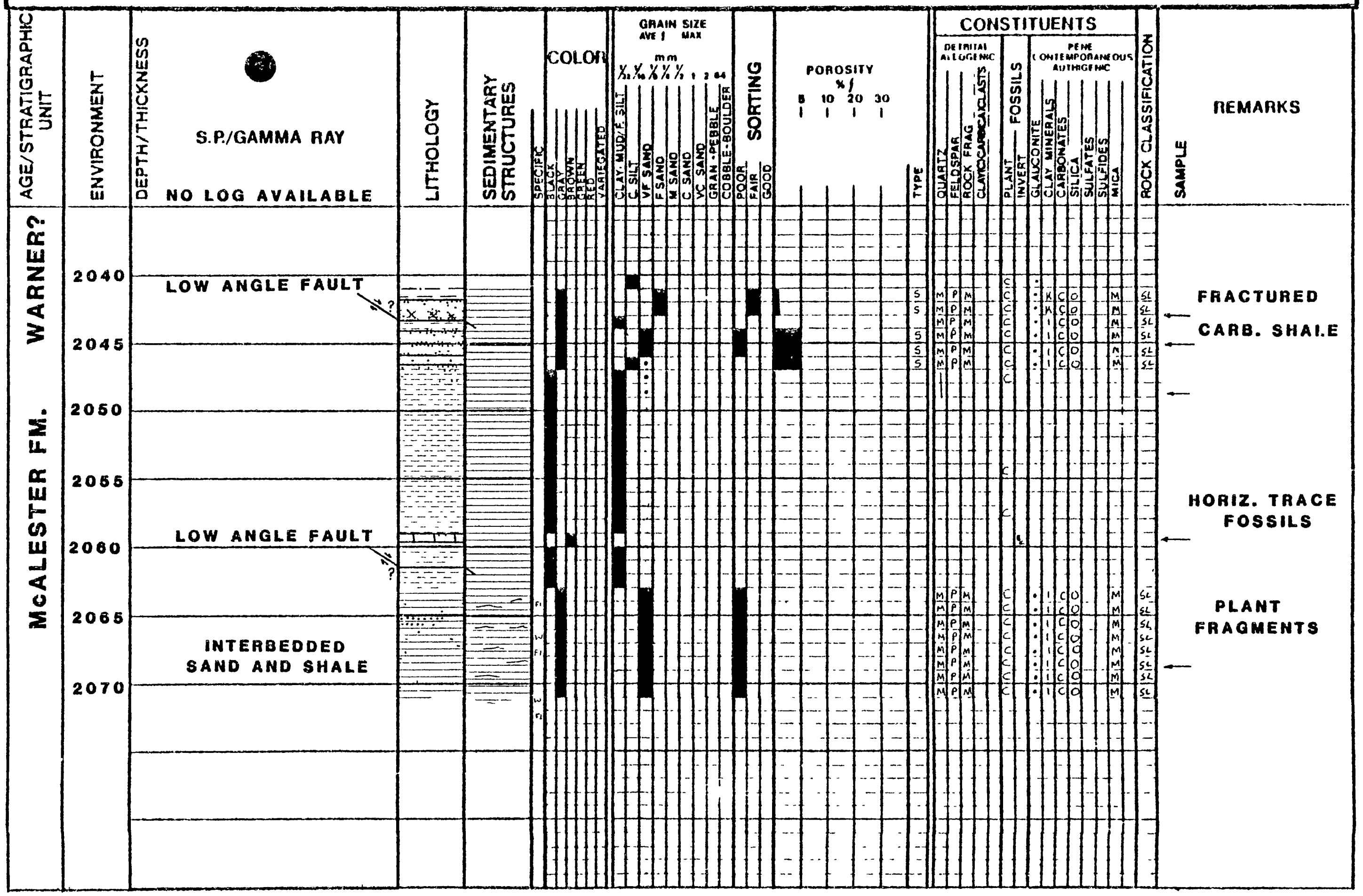



Company HEMISPHERE DRILLING #1 RYALS-PINE
Petrologic Log
Well Location SW NE SE NW Sec.3,T.12N.,R.11E.
AGE/STRATIGRAPHIC UNIT
ENVIRONMENT
DEPTH/THICKNESS
S.P./GAMMA RAY
LITHOLOGY
SEDIMENTARY STRUCTURES
COLOR
GRAIN SIZE
SORTING
POROSITY
CONSTITUENTS
ROCK CLASSIFICATION
SAMPLE
REMARKS
LOG FROM WELL AT NW SW NE Sec.3
WARNER SS. (L. BOOCH)
2235
2240
2250
2255
2260
2265
2270
2275
MISSING
COAL(thin)
ROOTLETS
SILICA REPLACED SULPHATES
MUD CLASTS
SIDERITE LAMINAE

Company TAMARACK PETROLEUM #2 KERR

Well Location NW NW NE Sec.17,T.11N.,R.12E.

Petrologic Log



APPENDIX B

PHOTO-REDUCTIONS OF PLATES

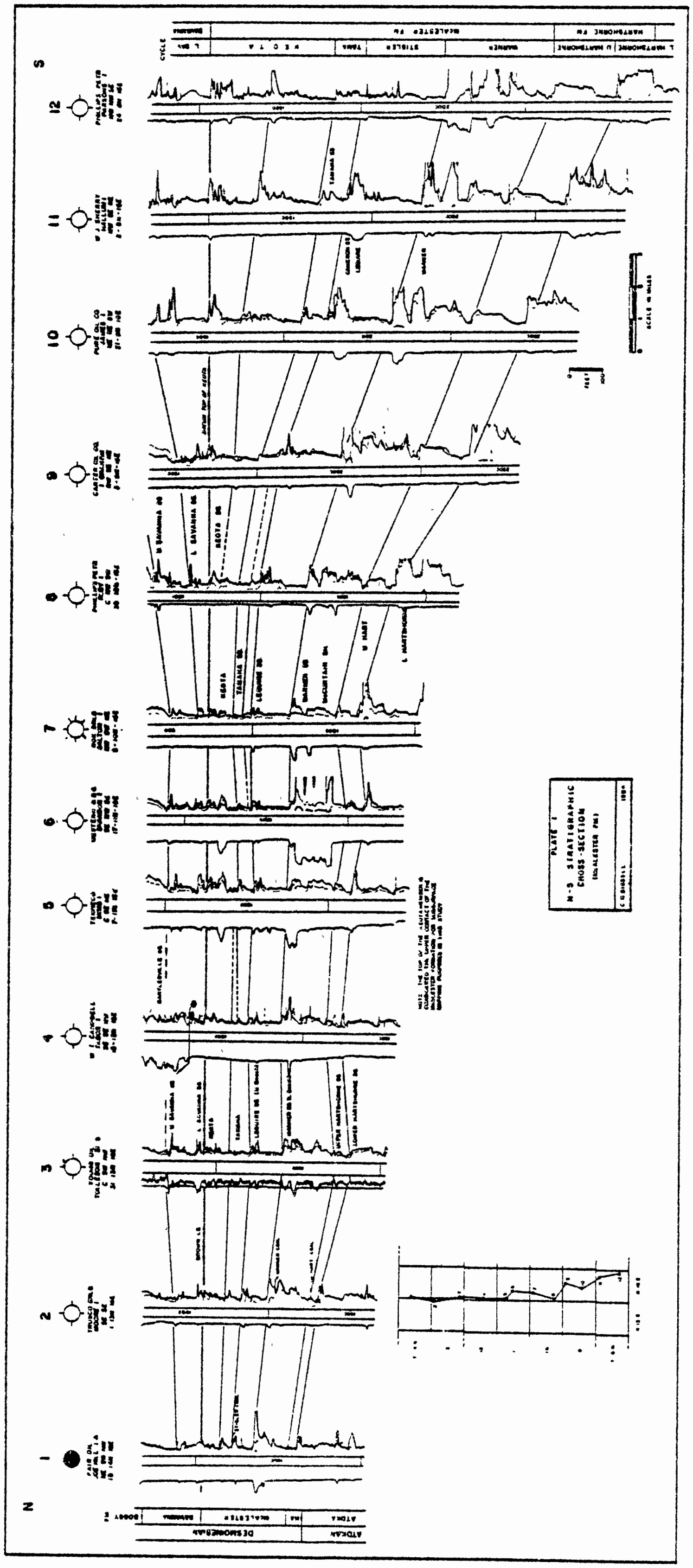
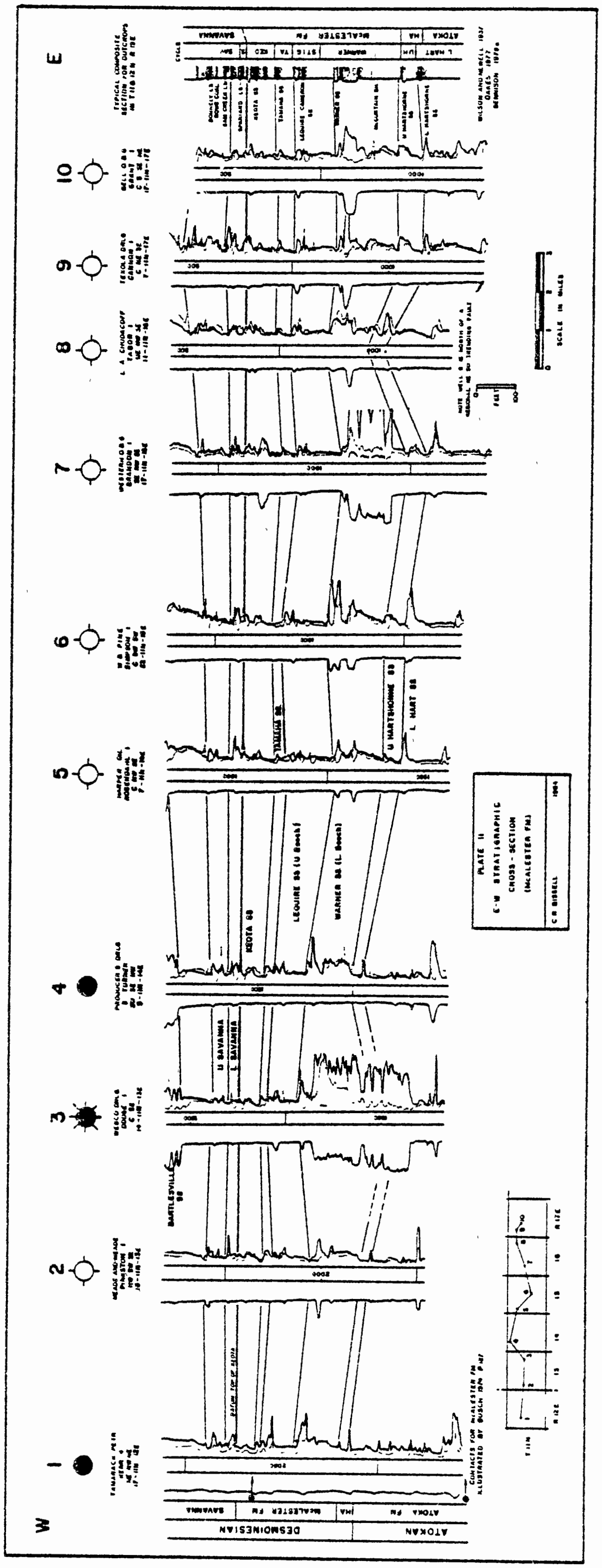
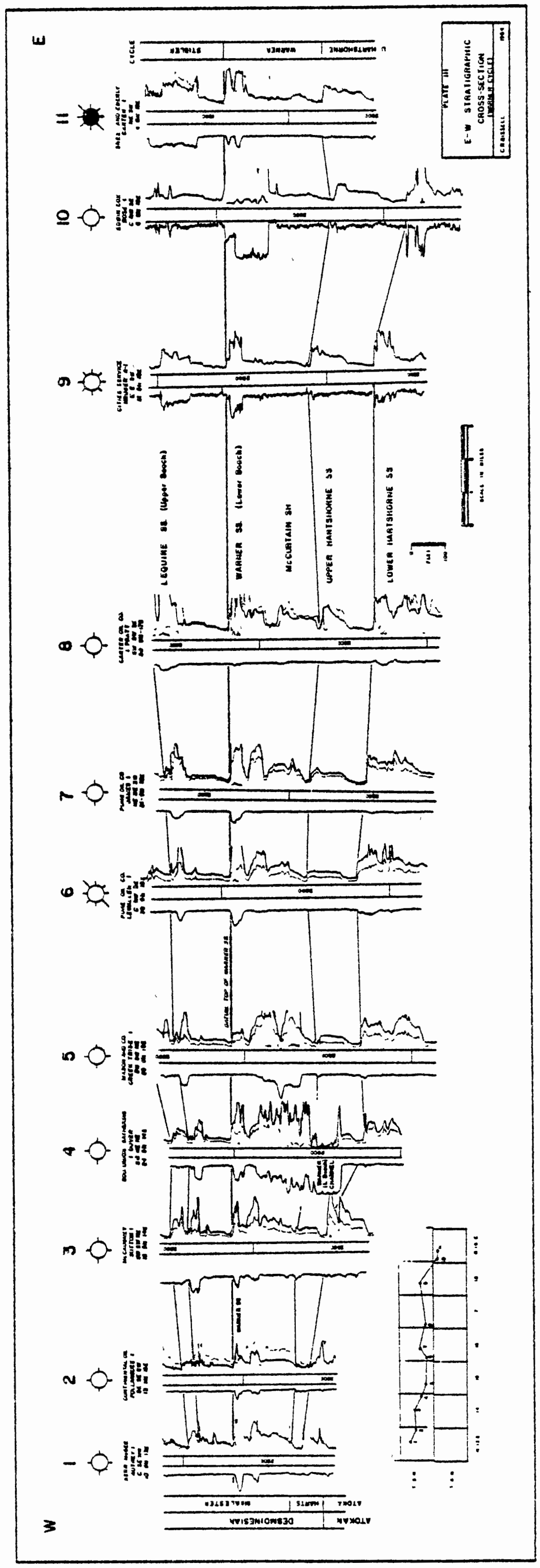
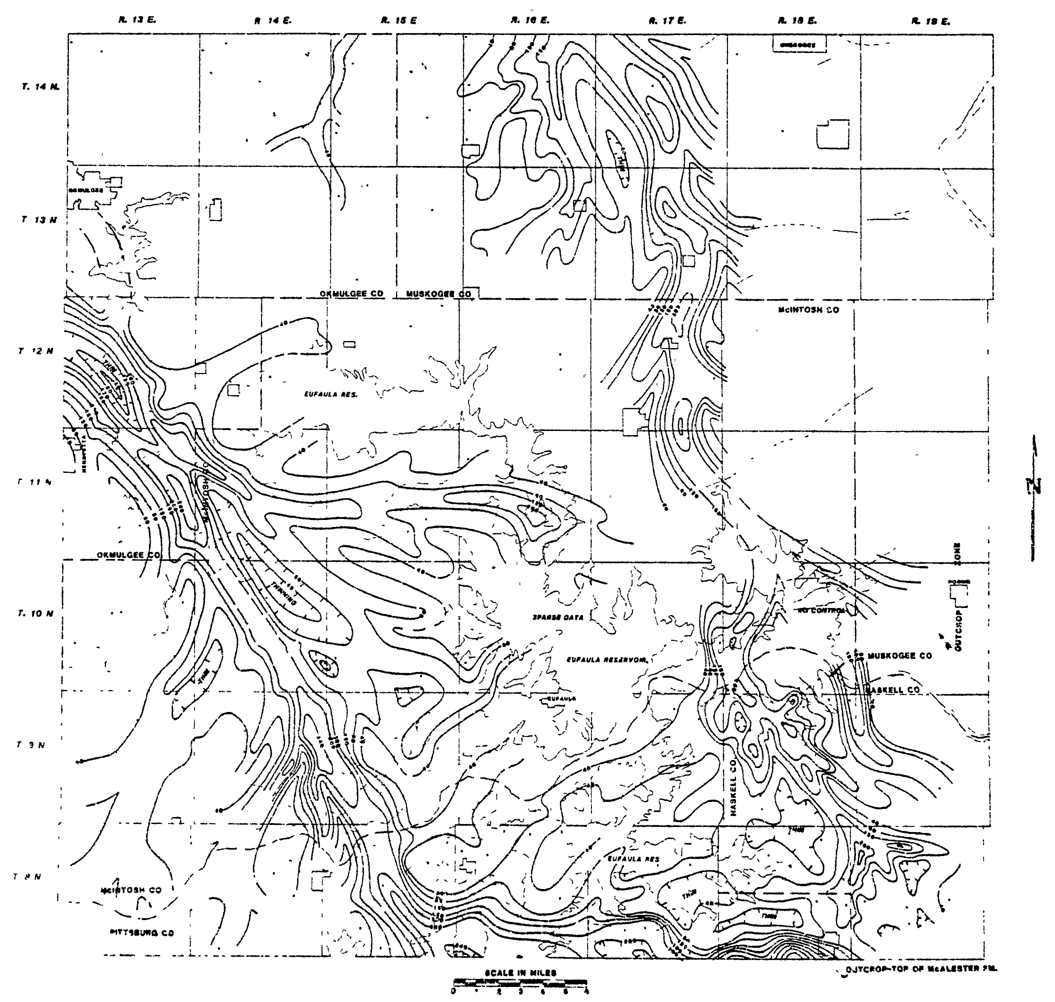


PLATE I
N-S STRATIGRAPHIC CROSS-SECTION
(McALESTER FM.)


W
E
DESMOINESIAN
ATOKAN
BARTLESVILLE SS
U SAVANNA
L SAVANNA
KEOTA SS
LEQUIRE SS (U Booch)
WARNER SS (L. Booch)
TAMAHA SS
U HARTSHORNE SS
L. HART SS
PLATE II
E-W STRATIGRAPHIC
CROSS-SECTION
(McALESTER FM)
C R BISSELL
SCALE IN MILES


W
E
PLATE III
E-W STRATIGRAPHIC
CROSS-SECTION
LEQUIRE SS. (Upper Booch)
WARNER SS. (Lower Booch)
McCURTAIN SH
UPPER HARTSHORNE SS
LOWER HARTSHORNE SS
DESMOINESIAN
ATOKAN
CYCLE
1
2
3
4
5
6
7
8
9
10
11



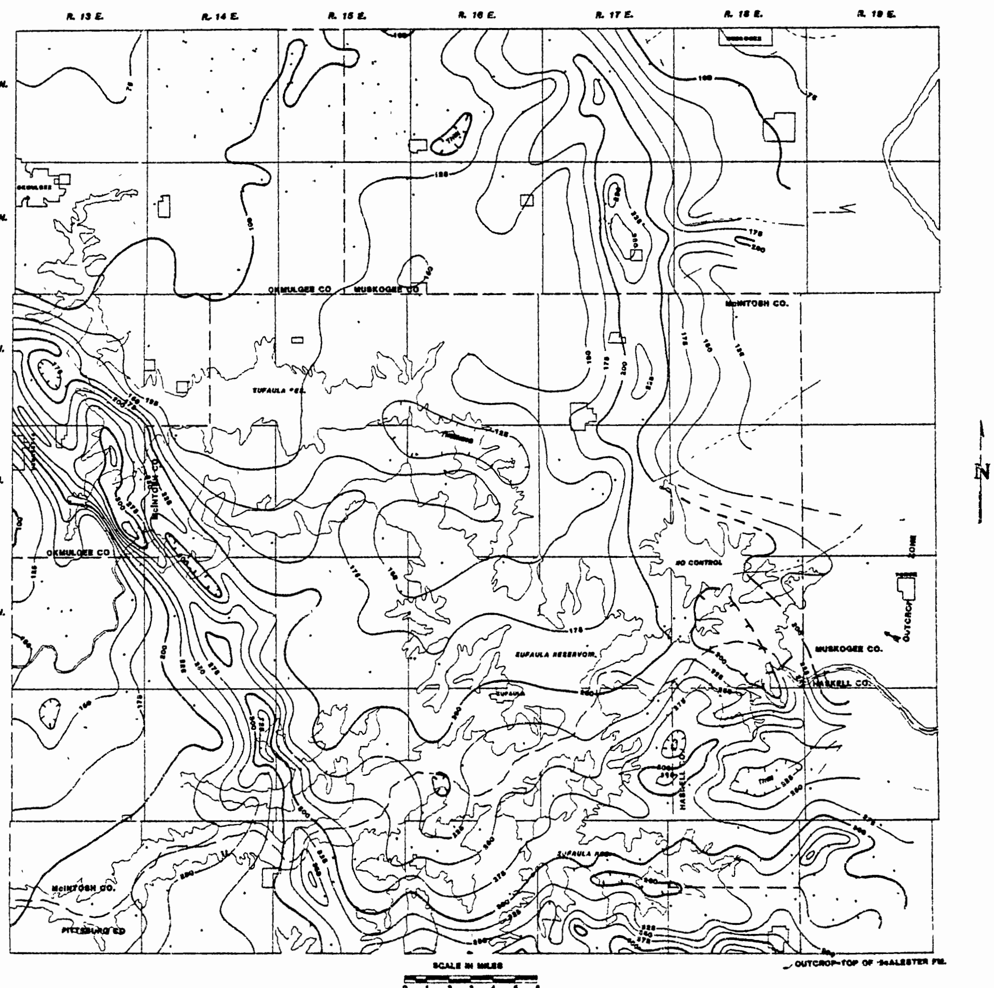
CONTOUR INTERVAL, 40 FEET

PLATE IV

NET SANDSTONE ISOLITH
WARNER CYCLE
(Lower Booch)

LAKE EUFAULA AREA, OKLAHOMA

C. R. BISSELL 1984



CONTOUR INTERVAL 25 FEET

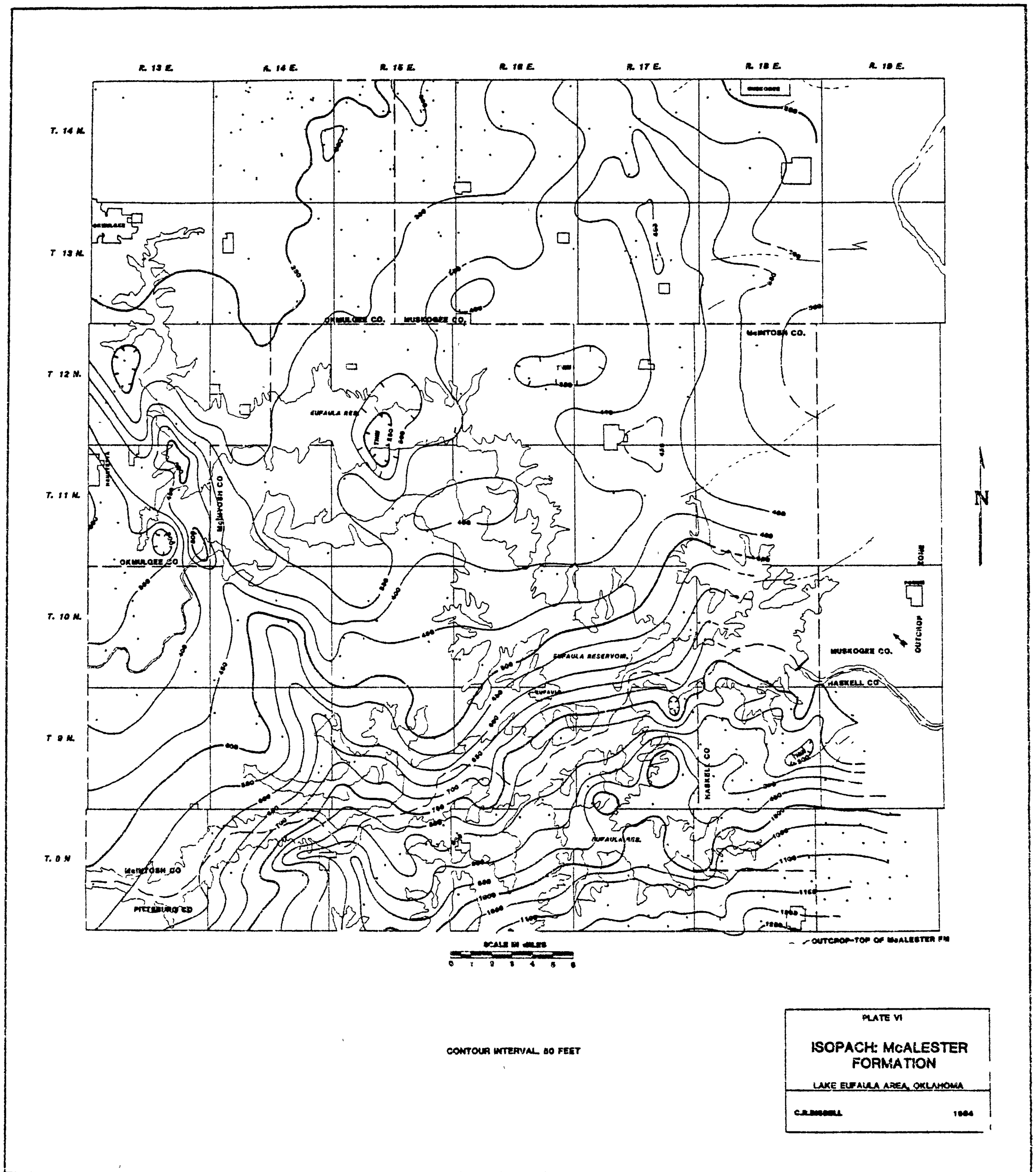
PLATE V

ISOPACH: WARNER CYCLE

UPPER HARTSHORNE COAL TO TOP OF WARNER SS.

LAKE EUFAULA AREA, OKLAHOMA

C.R.C.DELL 1984


R. 13 E.
R. 14 E.
R. 15 E.
R. 16 E.
R. 17 E.
R. 18 E.
R. 19 E.
T. 14 N.
T. 13 N.
T. 12 N.
T. 11 N.
T. 10 N.
T. 9 N.
T. 8 N.
OKMULGEE CO.
MUSKOGEE CO.
McINTOSH CO.
EUFAULA RES.
OKMULGEE CO
McINTOSH CO
EUFAULA RESERVOIR
MUSKOGEE CO.
HASKELL CO.
HASKELL CO
OUTCROP ZONE
EUFAULA RES.
McINTOSH CO
PITTSBURG CO
N
OUTCROP-TOP OF McALESTER FM
SCALE IN MILES
0 1 2 3 4 5 6
CONTOUR INTERVAL 50 FEET
PLATE VI
ISOPACH: McALESTER FORMATION
LAKE EUFAULA AREA, OKLAHOMA
1984

VITA

CLINTON RANDALL BISSELL

Candidate for the Degree of

Master of Science

Thesis: STRATIGRAPHY OF THE McALESTER FORMATION (BOOCH SANDSTONES) IN THE EUFAULA RESERVOIR AREA, EAST-CENTRAL OKLAHOMA.

Major Field: Geology

Biographical:

Personal Data: Born in Jackson, Mississippi, July 24, 1960, the son of Mr. and Mrs. Allen H. Bissell.

Education: Graduated from R. M. Callaway High School, Jackson, Mississippi, in May, 1978; received the Bachelor of Science degree in Geology from the University of Southern Mississippi, in May, 1982; completed requirements for Master of Science degree at Oklahoma State University in July, 1984, with a major in Geology.

Professional Experience: Summer employee, Mississippi Bureau of Geology, Summers, 1978-1979; Teaching Assistant, University of Southern Mississippi, 1982; Hydrologic Technician, United States Geological Survey, Summer, 1982; Teaching Assistant, Oklahoma State University, 1982-1984. Junior Member of the American Association of Petroleum Geologists.