

**KANSAS GEOLOGICAL SURVEY
OPEN-FILE REPORT 87-36**

**THE AREAL DISTRIBUTION AND DEPOSITIONAL SETTING
OF THE MCLOUTH SANDSTONE IN JEFFERSON AND
LEAVENWORTH COUNTIES, KANSAS**

by

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COUNTIES, KANSAS

A Thesis
Presented to
The Graduate Faculty of
The University of Southwestern Louisiana
In partial fulfillment of the
Requirements for the Degree
Master of Science

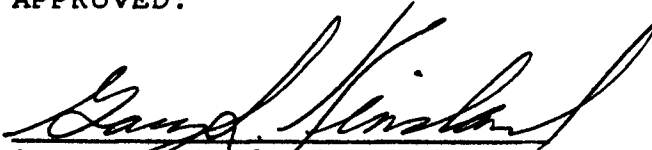
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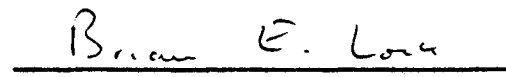
Fall 1987


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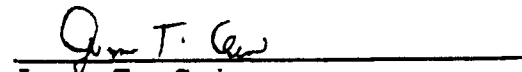
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"The task is by no means a hopeless one"

- Rachel Carson in Silent Spring

Dedication

I am dedicating this thesis to my parents, John and Sunnye Strickland, without whom this thesis would not have been possible. Their constant support, both emotionally and financially, kept me moving forward even when the idea of finishing this thesis seemed to be a hopeless task. Additionally, I would like to thank my dad for suggesting this thesis topic as well as providing advice and expertise during its completion. Credit for much of the regional work outside the study area, including Plate 4, should go to him.

ACKNOWLEDGMENTS

I would like to thank a number of people who have contributed in various ways towards the completion of this report. A special thanks is extended to Dr. E.J. Webb for his advice and encouragement during the initial phases of this study. Special thanks are also extended to G.M. Hertel for his time and generosity in providing data and insight. I also would like to thank Dr. G.L. Kinsland, greatly, for his time and advice in reviewing the manuscript and providing valuable comments. Additionally, thanks are extended to the members of my thesis committee, Dr. B.E. Lock and Dr. R.U. Birdseye. Finally, I am indebted to the following individuals, in no particular order, who have given advice or assistance too diverse to list: computer whiz Peter Bahrs; Supervising Drafter Tina Huerta (Conoco, Inc.); the late George Reed (Sampson Oil Co.); Jeanne Flanagan and Mary Lou Coltharpe (Fairway Petroleum, Inc.); consulting geologist John Hickox; Bill Iverson for well data; Tom Stander for providing cores; W. Lynn Watney and others of the Kansas Geological Survey; Rusty Peacher and Sam Broussard (Core Analysis Inc.); palynologist Dr. Carol Williams; and the Kansas Geological Society for allowing me access to their well files.

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ABSTRACT

The revival of hydrocarbon exploration in the Forest City basin over the past decade has been driven largely by discoveries made in basal Pennsylvanian sandstones within northeastern Kansas. The McLouth sandstone has been one such target. However, confusion surrounding the nature of the McLouth stratigraphic interval has precluded efficient development of its resources and inhibited understanding the Early Pennsylvanian depositional history of northeastern Kansas. This confusion has arisen from erroneous interpretations of the depositional environments responsible for the McLouth sandstone and from erroneous correlations of the McLouth section to younger strata. Such spurious correlations of the McLouth interval have invoked the usage of several ambiguous terms which have only served to perpetuate the confusion.

Detailed stratigraphic correlations coupled with lithologic evidence and supported by palynologic study (Williams, in preparation) have resulted in redefinition of the areal distribution of the McLouth sandstone from a localized sand body to a basinwide deposit and confirmation that the McLouth strata are the product of fluvial deposition on a relatively low-lying aggrading coastal plain. In addition, evidence is presented outlining an anomalous clastic section found in apparent sinkholes subjacent to the

McLouth interval (proposed Bower formation, Morrowan/Atokan).
A proposed revision of the Lower Cherokee Group (Pennsylvanian) in northeastern Kansas by recognizing two members (McLouth sandstone member and Burgner Limestone member) of the Riverton formation (Atokan) is also presented. The interpretations are displayed by regional and local cross sections, isopach and structure maps, paleotopographic and paleogeologic maps, as well as by lithofacies maps.

INTRODUCTION

This report documents the results of a study on the "McLouth sand" (Lee and Payne, 1944) which is an important petroleum producing horizon within the Carboniferous System in the southwestern portion of the Forest City basin in northeastern Kansas. This stratigraphic interval comprises the basal section of the Cherokee Group and consists of interbedded, dominantly non-marine sandstones, siltstones, shales, and sporadic coal deposited over a karst surface of Mississippian limestone. These sandstones have produced over 1.5 million barrels of oil (cumulative through 1985) and over 6 billion cubic feet of gas (cumulative through 1986, although some estimates place this figure at roughly 8-10 Bcf) in Jefferson and Leavenworth counties, and continue to play an ever increasing role as an exploration target within the Forest City basin.

The primary objectives of this study were 1) to delineate the areal distribution of the McLouth sand in Jefferson and Leavenworth counties, and 2) to interpret the depositional setting responsible for the genesis of these heterogeneous clastics. Achievement of these objectives sheds some light on possible trends for exploration and Pennsylvanian geologic history in the immediate vicinity and the Forest City basin. During the pursuit of these goals, several corollary objectives became apparent and subsequently

were added to this study. These secondary objectives were 1) to delineate the regional extent of the McLouth sand throughout eastern Kansas and perhaps into western Missouri, southeastern Nebraska, and southwestern Iowa and 2) to determine the appropriate stratigraphic position (Atokan, Desmoinesian, etc.) and rank (member, formation) of the McLouth sand. The first idea developed as a result of recent work by Ravn (1986) and to a lesser extent the work by Deason (1984), while the second came about as a result of the tremendous amount of confusion concerning the proper age and stratigraphic position of these strata. The recognition of this stratigraphic interval in the subsurface throughout the Forest City basin may play a pivotal role in the development of oil and gas prospects in relatively pristine areas of northernmost eastern Kansas and northwestern Missouri.

AREA OF INVESTIGATION

The study area encompasses nine townships (324 square miles) centered in the eastern half of Jefferson County and the western half of Leavenworth County, in northeastern Kansas (Figure 1). The stratigraphic interval under investigation is entirely in the subsurface of northeastern Kansas though there may be correlative lithologies exposed elsewhere (i.e. Iowa). Surface geology of the area is dominated by Kansan glacial till that has been eroded in places by numerous small streams, thus exposing the underlying Late Paleozoic strata including the Wabaunsee

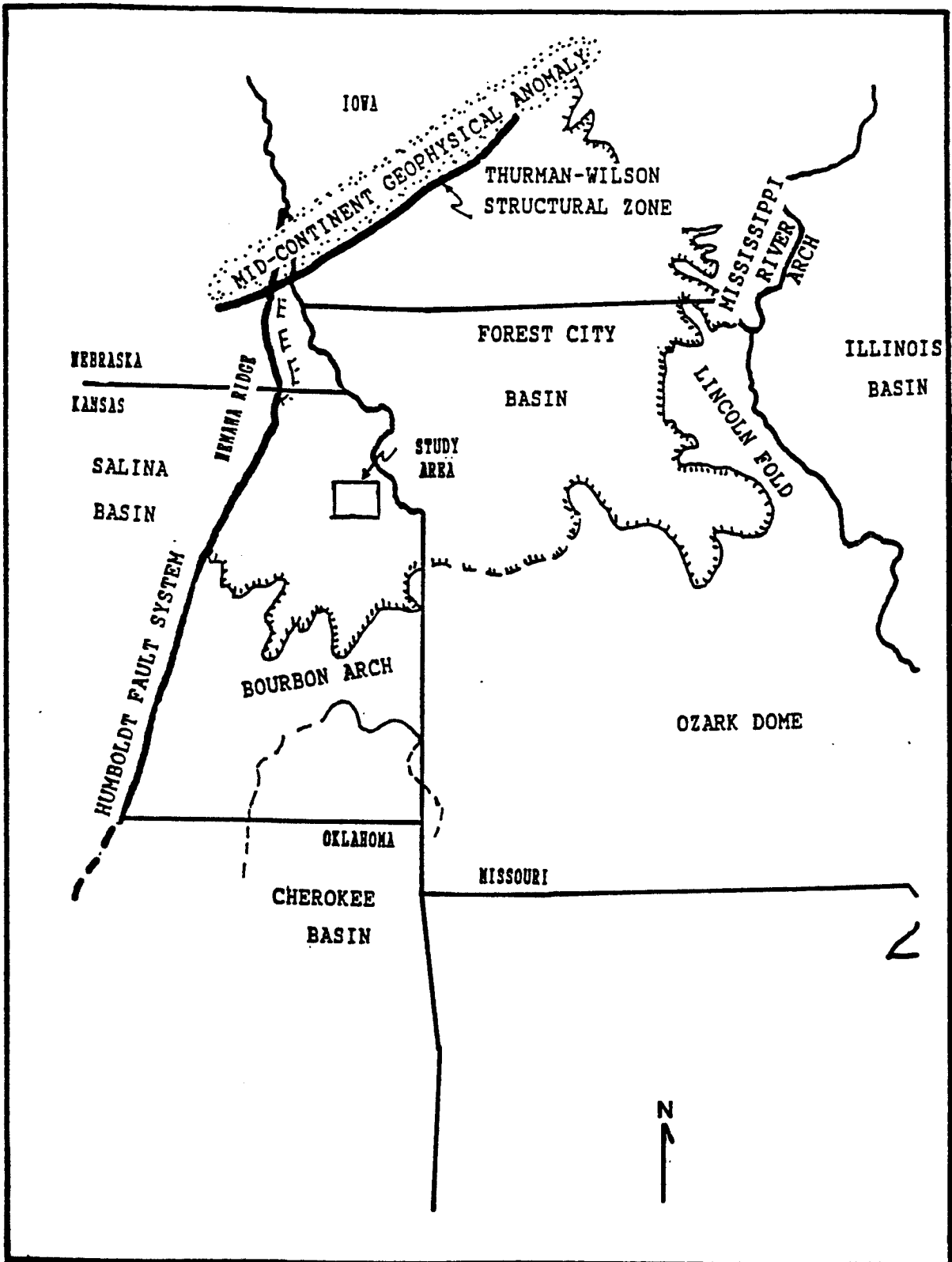


Figure 1 - Map of study area within the Forest City basin. Major structural elements of the area are also depicted (after Lee, 1943; Lee and Payne, 1944; Branson, 1962; Gregory, 1982).

and Shawnee Groups (Frye and Walters, 1950; Frye and Leonard, 1952). The resulting dissected glacial plain is now characterized by low rolling hills, with relief approaching 250 feet, and numerous shallow lakes.

METHODS OF INVESTIGATION

Detailed correlations of electrical logs from over 350 wells in T8S-T10S and R19E-R21E form the body of data used in this study. In addition, numerous driller's logs and sample descriptions were incorporated to provide information where electric logs were unavailable and to provide lithologic control when correlated or tied to nearby electric logs. Various other geologic data from previous investigations (Lee and Payne, 1944; Harris, 1984; Deason, 1984; Ravn et al., 1984; Dubois, 1985; Ravn, 1986) were also incorporated. Well cuttings were examined from a few key wells to help define the lithology and its correlation with electric log signatures. Conventional cores from two wells were also examined for sedimentary structures and lithology. Samples were taken from the cores for palynological study (Carol Williams, Houston, Tx., in preparation). In all, close to 800 wells were used within the study area while additional wells were utilized outside the study area to obtain regional control. Acquisition of data was primarily from the Kansas Geological Society Library, the Kansas Geological Survey, the Kansas Corporation Commission, and various local operators. It should be noted that numerous

difficulties were encountered during the acquisition of this data. The failure of local operators to disclose accurate well information to the Kansas Corporation Commission and its subsequent failure to enforce disclosure requirements led to several problems. In numerous cases inaccurate well locations, elevations, horizon depths, and production information were reported by operators and the KCC.

Following detailed study and correlation of available data a north-south cross section was constructed tying wells within the study area to wells throughout eastern Kansas and into Missouri. Wells along the southern portion are discussed by Harris (1984) while the northern-most ties in with a study by Deason (1984). This was done to establish regional control for correlations made within the McLouth study area. Once this control was established, various subsurface maps were prepared. Interval isopach maps and net sandstone isolith maps were constructed to aid in determining paleo-sand dispersal patterns and depositional environments. Structure contour maps were prepared to determine structural influence and relationships to this dispersal pattern. Paleogeologic maps were also generated to serve as a potential aid in defining the depositional setting. Various cross-sections were constructed to illustrate the multiple lateral facies changes and to show structural relations within selected oil and gas fields.

An important aspect of this study is the regional control and detailed correlation made possible through the

use of large scale (5"=100') electric logs. The Gamma Ray curve (GR) has also proven to be vital for regional correlations. The quality and quantity of the data are such that correlations locally, and to some extent regionally, can be made with confidence in the Lower Cherokee section. Drilling activity during the late 1970's and through the present has provided greater well control, which combined with improvements in geophysical logging have made this study feasible. The electric logs utilized in this study are primarily gamma ray-neutron-density (Dual Porosity log) and gamma ray-neutron short normal (R A Guard log). The GR curve detects the natural radioactivity of a given horizon (Schlumberger, 1972; Rider, 1986) and thus is crucial for correlation since coals, organic-rich shales and relatively shale-free lithologies (sandstone, limestone) are readily distinguished. Watney (1985) has used the magnitude of the GR deflection to successfully identify black phosphatic shales, commonly associated with cyclothems, in the midcontinent. These organic-rich shales often provide excellent correlation markers. They are easily recognized and generally traceable over large areas. The spontaneous potential (SP) curve was also used but only where the GR curve was unavailable since its parameters are not as reliable for correlation in this area. Various combinations of electric logs have proven useful in locating key horizons, identifying lithology and establishing stratigraphic correlations. The Dual Porosity log is vital

for distinguishing coal from black shale while the R A Guard log or resistivity curve aid in the recognition of limestone facies. By correlating these curves to sample descriptions of the well or nearby wells, it is possible to tie lithology directly to the log motif for facies recognition.

Upon completion of log correlation, map preparation, and cross-section construction, a depositional model was developed. Lateral and vertical facies relationships were considered in the context of Walther's Law to construct a representative model of the depositional setting. This model was then compared with several published models of both ancient and modern environment of sandstone (Rich, 1923; Bass, 1934; Lins, 1950; Wanless et al., 1970; Shelton, 1978; Selley, 1978; Ebanks, 1979; Coleman and Prior, 1980; Klein, 1980; Gregory, 1982; Weimer et al., 1982; McCubbin, 1982; Fernandez, 1982; Galloway and Hobday, 1983; Harris, 1984; Ravn et al., 1984; Busch and Link, 1985) and coal deposition (White, 1925; Landis and Van Eck, 1965; Frazier and Osanik, 1969; Horne et al., 1978; Nuelle, 1985).

PREVIOUS INVESTIGATIONS

Previous studies of the McLouth sandstone have been intermittent and closely parallel interest generated by explorationists for petroleum and to a lesser extent for coal. Haworth and Kirk (1894) were among the first to recognize the economic value of the Cherokee shales (later Cherokee Group) both for the sand lenses which provided

petroleum reservoirs and for the numerous coal seams. Most of the subsequent interest was focused in southeastern Kansas. It was about forty years later that the surface work of H. Haworth and C.B. Taylor led to the 1939 discovery well in the McLouth area (Lee and Payne, 1944). Early investigation of this new field and producing horizon was reported by Lee (1941). The productive zone, termed "McLouth sand", was stated to be Desmoinesian in age and placed in the Lower Cherokee section (Lee, 1943; Lee and Payne, 1944). Drillers encountering this sandy interval in the basal Pennsylvanian section called it by various terms in addition to McLouth sand including Burgess Sandstone, Bartlesville Sandstone, and Squirrel sandstone. This practice produced tremendous confusion for stratigraphers. Lee (1943, p.82) stated " the Burgess sand should not be confused with the McLouth..." and later " the McLouth sand is frequently referred to as Bartlesville sand with which it has nothing in common..." (Lee and Payne, 1944, p.51). The term "Squirrel sand" for the McLouth was short lived and has since come to denote a lenticular sand lens variably positioned in the Upper Cherokee. These early workers relied exclusively on well cuttings, sample descriptions, and driller's logs for data since electric logging was in its infancy and a reliable correlative outcrop for the McLouth had not been established. Thus considerable difficulties were encountered when correlating well to well within a given field, let alone on a regional scale.

The McLouth sandstone was interpreted as a widespread blanket deposit that exhibited a cyclic nature suggesting to early workers repeated inundation by marine waters. The concept of cyclothems (Weller, 1931; Moore, 1936; Abernathy, 1937) was new and dominated the thinking of many early geologists in the midcontinent. It has had considerable influence since, both positive and negative. Ebanks (1979, p.297) made note of one negative aspect:

"Classification of the Cherokee Group in Kansas has suffered because of this [cyclothem ideology]. That is, the hypothesis that certain types of rock units succeed and precede others in a predictable and repeating fashion throughout a specified vertical interval, is useful in describing portions of the Middle and Upper Pennsylvanian rock succession of the Mid-Continent; this idea, when taken to an extreme and applied to rock units like the Cherokee Group of Kansas, may lead to confusion".

The brackets and underline were provided by this author to add emphasis. However, the idea when presented, allowed geologists to describe the cyclic nature they observed and consequently provided a means of correlating intervals of strata in a systematic manner on a regional basis. The recognition of the role of the depositional environment responsible for the cyclic sedimentation also allowed for more widespread correlation, both intrabasinally and interbasinally. Apparently, it was with these relatively new ideas that Lee and Payne (1944) and numerous other investigators in the midcontinent studied and interpreted the McLouth sandstone.

Interest in the McLouth area and petroleum exploration in the Forest City basin waned during the late 1940's

through the early 1950's. However, during this time, confusion mounted concerning the Desmoinesian correlations leading ultimately to a midcontinent conference to resolve this issue. Representatives from Kansas, Iowa, Missouri, Nebraska, and Oklahoma were in attendance. Searight et al., (1953) decided that coal beds showed the greatest lateral persistence and these beds formed the basis for dividing the Cherokee Group into eighteen formations. This marked the first formal attempt to establish widely recognizable interstate formational boundaries within the Cherokee Group. The McLouth stratigraphic interval was left off of the new classification either due to oversight, assumed correlation with the Warner Formation, or possibly because it was viewed as Atokan although the later explanation is doubtful. Howe (1956) applied the results of the 1953 conference to revise the Desmoinesian stratigraphy of the Cherokee Group in southeastern Kansas. He recognized the Krebs and Cabaniss Subgroups, further dividing these into numerous (18) formations based on the continuity of coal beds and the concept of cyclicity. Each formation was bounded above and below by a coal bed and thus formed a "cycle" of sediment.

In Missouri, Searight and Palmer (1957) reported the first substantiated claim of Atokan rocks in the eastern Kansas-Missouri-Iowa region. This interval of limestone, shale, coal, and clay sink deposits was designated the Burgner Formation. The age determination was based on the identification of the primitive Fusulinella. The first

indication that the McLouth sandstone was Atokan was presented by Searight and Howe (1961) when they correlated a limestone above the McLouth with the Burgner. This led to a revision by the Missouri Geologic Survey of the pre-Desmoinesian strata. They designated the McLouth, Burgner, and Riverton, in ascending order, as formations within the Atokan Series (Figure 2). The McLouth Formation was defined only in the subsurface. This classification system was not accepted by all workers in the midcontinent. Branson (1962) briefly mentions the possibility of Atokan rocks in the Forest City basin while Anderson and Wells (1968) and Wells (1971) confirmed the existence of Atokan rocks within the basin but questioned the correlation of the McLouth as Atokan. Their work correlating electric logs indicated the McLouth Formation may be younger, "...This sandstone, however may be as young as the Warner Formation (early Desmoinesian)..." (Anderson and Wells, 1968, p.273). The confusion surrounding the appropriate stratigraphic position for the McLouth and other rocks of early Middle Pennsylvanian age is due largely to correlation difficulties arising from extreme lateral facies variation and general lack of macrofossils. Accurate chronostratigraphy is nearly impossible under these conditions. "The stratigraphy of the Lower Cherokee in Iowa is virtually unknown, both because stratigraphic relations are very complex and because data are insufficient in several critical areas..." (Landis and Van Eck, 1965, p.36).

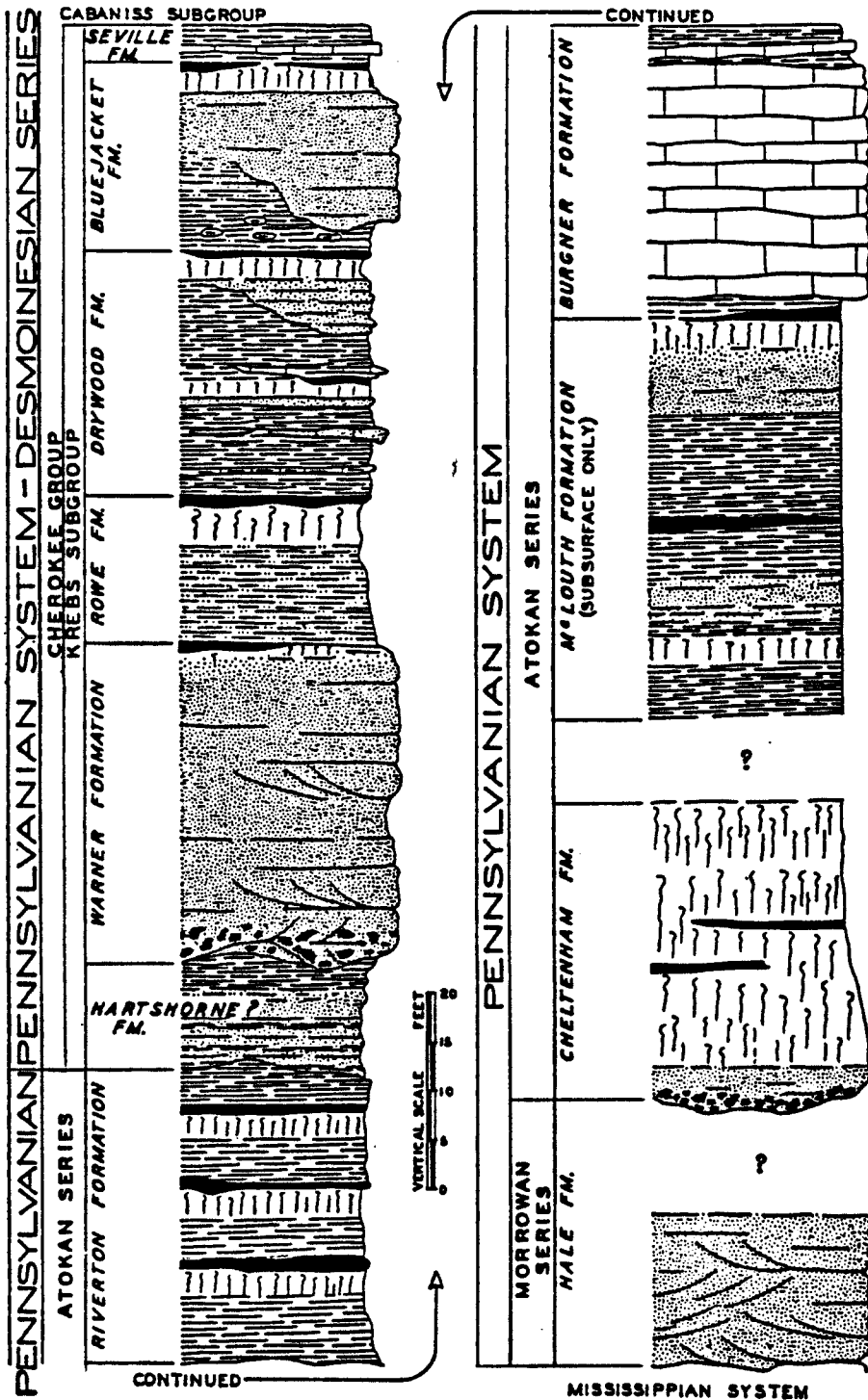


Figure 2 - Pennsylvanian System in Missouri; Morrowan, Atokan, and Desmoinesian Series. (Cherokee Group, Krebs Subgroup). (From Searight and Howe, 1961)

The above quote was cited by Gregory (1982) and restated here because it accurately reflects the state of stratigraphic classification of the Lower Cherokee, not only in Iowa, but throughout the midcontinent at that time.

The United States Geological Survey (USGS) in conjunction with various state geological surveys investigated the Pennsylvanian System of the United States during the late 1960's and early 1970's. Results concerning the Forest City basin were presented by Stewart (1975) and Wanless (1975a). Their work utilized intervals of strata (i.e. interval A, interval B, etc.) rather than the chronostratigraphic or lithostratigraphic terminology that was currently being used. In general interval B represents Atokan rocks and interval C represents Desmoinesian strata, yet these divisions remained somewhat imprecise (Stewart, 1975, table 3, p.131). Both authors recognized the McLouth Formation as possibly Atokan (Figure 3). Wanless (1975a) projected the interval B-C boundary from Missouri into the subsurface of Kansas, Iowa, and Nebraska using records from deep wells and thereby recognizing Atokan strata in the Forest City basin.

Interest in the economic potential of the Middle Pennsylvanian section of the Forest City basin has increased over the past decade, yet the confusion surrounding the appropriate stratigraphic divisions within this section remain. Recent work on the related Cherokee basin in southeastern Kansas and the Iowa portion of the Forest City

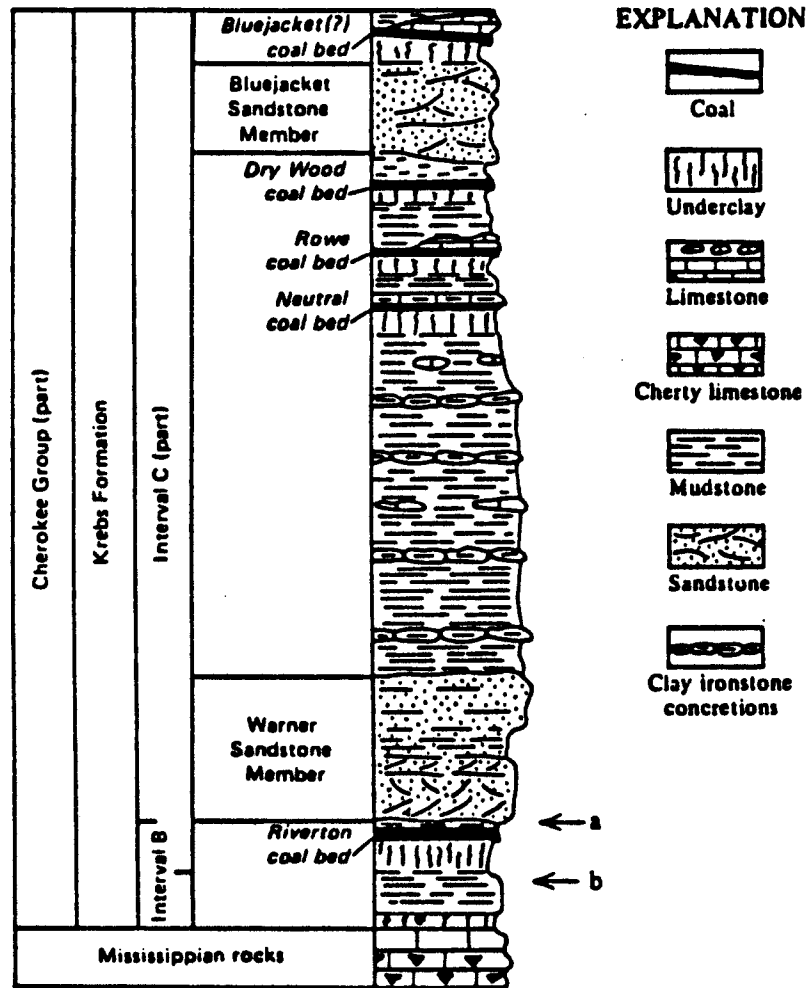


FIGURE 3 - Stratigraphic relations of interval B and the lower part of interval C in eastern Kansas. Base of Warner Sandstone Member of Krebs Formation (a) is contact of intervals B and C throughout most of eastern Kansas. Contact is located approximately at position b in parts of southeastern Kansas. Section not drawn to scale.

(From Stewart, 1975)

basin has contributed significantly to resolving the ambiguities in the stratigraphic nomenclature and in understanding the geologic history of each area. Harris (1984, 1985a, 1985b) studied conventional core, electric logs, and outcrop descriptions of the Cherokee Group in southeastern Kansas and southwestern Missouri. His results demonstrated the good lateral continuity of several coal beds in both the Upper and Lower Cherokee section. This allowed for more detailed correlation of the strata and enabled him to revise the stratigraphy of the Cherokee Group in southeastern Kansas (Figure 4). Several new coal horizons were designated within the Krebs Formation. Staton et al. (1987) also studied the Cherokee Group in central southeast Kansas and found that several black shales are crucial marker beds for the detailed correlation of this section. The Tebo and Weir-Pittsburg black shales were shown to be key markers in the Middle Cherokee section and widely traceable throughout his study area.

Mason (1980) and Gregory (1982) investigated the Cherokee section in central and south central Iowa, respectively. Both studies again noted the significant role coal beds play in lithologic correlation as well as the frequent facies changes. Gregory (1982) used palynological evidence to correlate coal seams and provide chronologic data on the coal beds. Ravn et al. (1984) and Ravn (1986) also utilized this palynological method of analyzing spore

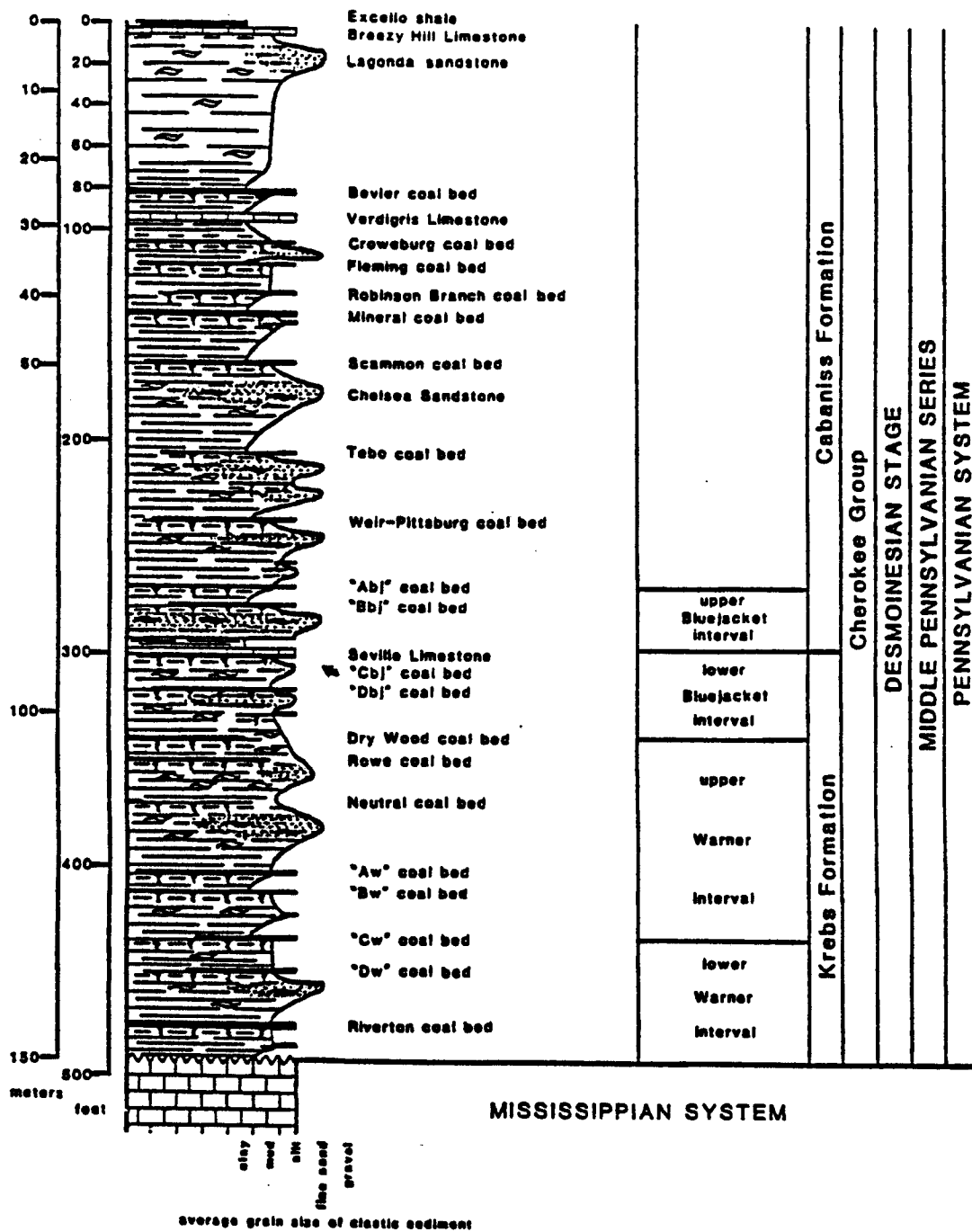


FIGURE 4 - Composite section of the Cherokee Group in southeastern Kansas from description of 24 cores.
(From Harris, 1985b)

assemblages of individual coal beds to accurately define the chronostratigraphy of the Cherokee Group in Iowa.

This technique permitted a revision of the nomenclature of the Pennsylvanian stratigraphy in Iowa (Figure 5). Ravn et al. (1984) decided to add the designation of "Supergroup" in addition to "Series" for the Morrow, Atoka, and Des Moines, etc. because these divisions were primarily lithologic divisions as originally defined. Their work demonstrated that some parts of in the Des Moines Series are really Atokan in age. Also, the possible existence of Morrowan rocks in the Forest City basin of Iowa was recognized (Gregory, 1982, p.128; Ravn et al., 1984; Ravn, 1986).

The correlations and nomenclature of the Cherokee Group in northeastern Kansas are still uncertain. In fact, there is still disagreement throughout the midcontinent on the appropriate terminology for Lower Cherokee strata. Figure 6 shows the accepted Lower to Middle Pennsylvanian section in southeastern Kansas, Missouri, and northern Oklahoma. The southeastern Kansas section is representative of the current view of the northeastern Kansas section as well. This study, in addition to examining the areal distribution and depositional setting, hopes to provide some insight into the Lower Cherokee section in northeastern Kansas. This study demonstrates the presence of Pennsylvanian strata unaccounted for in the current nomenclature for northeastern Kansas.

SYSTEM	SERIES (Time)	SUPERGROUP (Rock)	Stratigraphic Nomenclature				
			Western Interior Basin			Eastern Interior Basin, Scott & Muscatine Counties	
			GROUP	FORMATION	Named Member	FORMATION	Named Member
PENNSYLVANIAN	DES MOINESIAN	DES MOINES	MARMATON	"LOST BRANCH"	Cooper Creek Ls unnamed Sh. Sw Mills Ls		
				UNNAMED SH.			
				LENAPAH Ls			
				NOWATA SH.			
				ALTAMONT	Worland Ls. Lake Neecho Sh. Amoret Ls.		
				BANDERA SH.			
				PAWNEE	Coal City Ls. Mine Creek Sh. Myrick Sta. Ls. Anna Sh.		
				LABETTE SH.	Mystic Coal Marshall Coal		
				STEPHENS FOREST	Higginsville Ls. unnamed sh. Houx Ls. Little Osage Sh.		
				MORGAN SCHOOL SH.	Summit Coal		
			MOUSE CREEK	Blackjack Creek Ls. Excebo Sh.			
			CHEROKEE	SWEDE HOLLOW	Mulky Coal	"SPOON"	
					Bevier Coal Wheeler Coal		
					Ardmore Ls. Oakley Sh. Whitebreast Coal		
				FLORIS	Carruthers Coal unnamed coal		
KALO	Cliffland Coal Blackeak Coal						
KILBOURN	unnamed coals						
MORROWAN	ATOKAN	MORROW	CASEYVILLE	Wyoming Hill Coal Wildcat Den Coal			

FIGURE 5 - Early and Middle Pennsylvanian stratigraphy in Iowa (after Landis and Van Eck, 1965; Ravn et al., 1984).

Consequently, a stratigraphic chart was constructed which this author feels is representative of the strata under investigation (Figure 7). The nomenclature is informal at this time.

There have been few studies that have tried to interpret the depositional environments of the McLouth interval. Lee and Payne (1944) were the first, speculating as mentioned before, that the McLouth was deposited on a coastal plain periodically inundated by marine waters yielding a blanket-type deposit of interstratified sand and shale. Dubois (1985) reported on the McLouth sandstone of Leavenworth Field in Kansas. In his study, three distinct sand intervals were recognized and isopachous maps of each were prepared from electric log study. In addition, a small cross-section was constructed to show the relationships among the three sand bodies. A nearshore marine bar environment was postulated for the upper sand while the lower sand was viewed as the result of point-bar deposition by a fluvial system. The middle sand was least understood, yet was viewed to be possibly of crevasse-splay origin.

The early studies, which relied on well cuttings and sample descriptions to categorize the heterogeneous Cherokee section, combined with recent studies, using innovative biostratigraphy and refined lithostratigraphy, have provided a foundation for understanding the complex nature, and the depositional systems responsible for the genesis, of the Cherokee Group in the midcontinent.

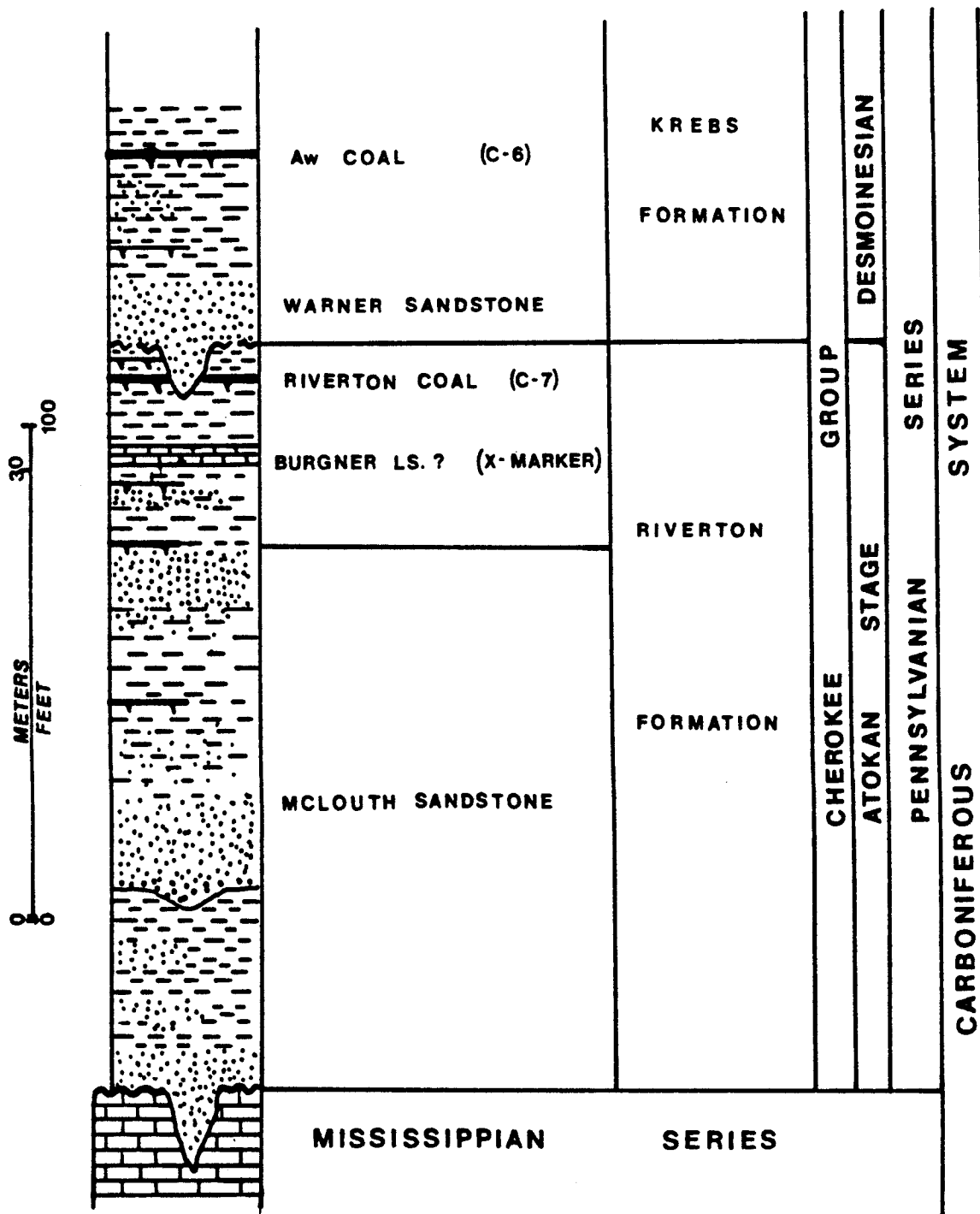


FIGURE 7 - Composite stratigraphic column of the Lower Cherokee Group in northeastern Kansas used in this report.

REGIONAL STRATIGRAPHY

The stratigraphy of the Forest City basin consists of deposits of Cambrian through Permian age sitting nonconformably upon Precambrian igneous rock. Although a complete lithologic section may have been deposited, structural uplift and subsequent erosion have removed nearly every formation below the Desmoinesian strata in one place or another (Lee, 1943). This report will describe only those rocks involved in the interpretation of the McLouth i.e. portions of the Upper Mississippian and Middle Pennsylvanian. In addition, only the stratigraphy of the McLouth section will be described in detail. For a complete description of the entire stratigraphic section present, the reader is referred to papers by other authors (Lee, 1943; Moore, 1949; Howe and Koenig, 1961; Merriam, 1963; Zeller, 1968; Ravn et al., 1984; Harris, 1985a).

Mississippian Series

Osagian Stage

Burlington and Keokuk Limestone (undifferentiated)- These limestones are distinguishable lithologically and faunally at their type locality in Iowa (Lee, 1943; Zeller, 1968) yet are virtually indistinguishable in the subsurface of northeastern Kansas. Therefore, they are generally referred to as the Burlington-Keokuk (B-K) section. The lower portion of the B-K sequence is often cherty, sucrosic

dolomite. The chert is opaque or semi-opaque and gray or white (Lee, 1943). The upper portion is generally a fossiliferous, crinoidal limestone containing pockets of chert. The top of the B-K section is placed at the base of the microfossiliferous chert belonging to the overlying Warsaw Limestone (Lee, 1943). Recognition of this division between the B-K and Warsaw is not possible on wireline logs. However, the "B-K porosity zone" is readily apparent and provides stratigraphic control within these zones (see Figure 8). This porous zone is typically 130-135 feet below the top of the Warsaw Limestone. It is composed of coarsely crystalline cherty dolomite and may be traced throughout most of eastern Kansas, wherever sufficiently deep well control is available: operators typically drill 10-15 feet into the top of the Mississippian surface and stop. Thickness of the B-K is typically 100-170 feet in northern Kansas except across the Nemaha Uplift where it is generally eroded off.

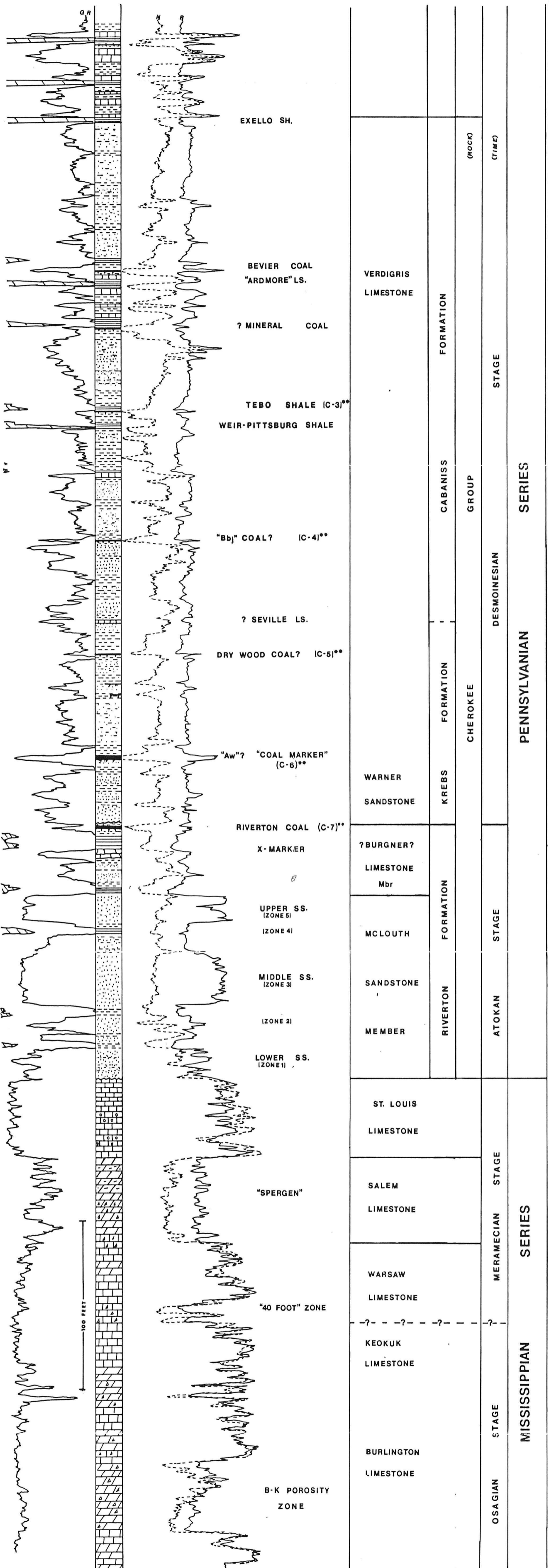
Merimecian Stage

Warsaw Limestone - The Warsaw Limestone rests disconformably over the Burlington-Keokuk (Zeller, 1968). This limestone is composed of chert typically enclosing silicified remains of microfossils and spicules (Lee, 1943). In the study area, the Warsaw is typically a granular to semi-granular cherty limestone with zones of cherty dolomite.

FIGURE 8 - Composite stratigraphic column and electric log signatures of the Cherokee Group and Upper Mississippian strata in northeastern Kansas discussed in this report.

COMPOSITE LOG OF CHEROKEE AND UPPER MISSISSIPPIAN

STRATIGRAPHY* IN STUDY AREA



EXPLANATION OF SYMBOLS

- GRAY SHALE
- BLACK SHALE
- SILTSTONE
- SANDSTONE
- ARGILLACEOUS SANDSTONE
- LIMESTONE
- OOLITIC LIMESTONE
- CHERTY LIMESTONE
- DOLOMITE
- ARGILLACEOUS DOLOMITE
- CHERTY DOLOMITE
- COAL
- UNCONFORMITY

*LOWER CHEROKEE (RIVERTON INTERVAL) PROPOSED THIS STUDY
 **COAL DESIGNATION FOR CORRELATION ONLY THIS STUDY

Thickness in this area averages 35 feet. Determination of the top of Warsaw is accomplished by recognizing the first clean (low gamma ray) and resistive response below the Salem Limestone on wireline logs. Also helpful in recognizing the Warsaw Limestone is the presence of a porous zone (the 40 foot zone) a few tens of feet below the Warsaw's top (see Figure 8).

Salem (Spergen) Limestone - The Salem Limestone conformably overlies the Warsaw and consists predominantly of dolomite to gray, silty dolomite. This dolomite often becomes quite argillaceous with abundant sponge spicules in northeastern Kansas. Sparse chert is light gray to brown with microfossils including the foraminifera "Endothyra baileyi" (Zeller, 1968). Typical thickness in the study area is 20-30 feet with maximum observed thickness about 50 feet. Recognition of the Salem Limestone on electric logs is facilitated by higher gamma ray and lower resistivity readings than the formations above and below.

The interval resembles a "shaley" limestone (see Figure 8).

St. Louis Limestone - The St. Louis Limestone is noncherty, gray to tan, dense lithographic to sublithographic limestone that conformably overlies the Salem limestone. Interspersed beds of oolitic limestone and calcarenite are locally present. Thickness in the study area is often less than 20 feet yet may reach 36-40 feet in some wells. Identification from electric log is generally definite and facilitated by the low GR response coupled with

a high resistivity. This combination is usually sufficient to distinguish the St. Louis from the underlying Salem Limestone and the overlying unit (see Figure 8). In the study area the overlying unit is always of Pennsylvanian age, the Chesterian Stage apparently having been eroded away.

Mississippian rocks underlie the Pennsylvanian strata throughout the entire study area. However, this boundary forms an interregional unconformity reflecting extensive post-Mississippian erosion. As a consequence, variable age Mississippian carbonates were exposed at this erosional surface. The paleogeology of this pre-Pennsylvanian surface is depicted in Plate 1. This erosional surface has long been viewed as essentially an extensive peneplain. Within the study area, a contour map of this surface reveals significant topography (Plate 2). The Mississippian surface is better characterized as a karst surface with numerous hills and valleys. Local relief changes of a hundred feet over less than a mile are not uncommon. The extent of sediment removed and the amount of time involved in this lacuna is unknown. However, north of the study area, St. Genevieve Limestone (Chesterian) is present indicating less extensive erosion to the north, or lack of deposition to the south. This situation requires further investigation for the resolution of this anomaly.

Pennsylvanian Series

In eastern Kansas, the Pennsylvanian section is incomplete due to the previously mentioned lacuna, while the understanding and classification of these strata are incomplete due to the previous lack of adequate subsurface geologic data. Although this interval has been studied extensively since the late 1800's, it is only over the last two decades that sufficient data have become available to study the Lower Cherokee section in northeastern Kansas. The Cherokee nomenclature has primarily been devised from studies in southeastern Kansas and Missouri and then applied, somewhat blindly, to the Middle Pennsylvanian section in northeastern Kansas. This has been done because of the availability of surface exposures and conventional cores in southeastern Kansas. The Cherokee section of northeastern Kansas, and of the Forest City basin in general, has been shown to be very similar to that of the Cherokee basin to the south. Numerous key correlation markers are traceable throughout both basins; the Verdigris Limestone, the Bevier, Croweburg, Mineral, Scammon, and Riverton coals, as well as the Excello, "V", Mineral, and Scammon black shales. Staton et al. (1987) has shown that the Tebo and Weir-Pittsburg black shales are valuable as correlation markers in southeastern Kansas and this study has found them to be equally valuable as key markers within northeastern Kansas. Figure 8 shows the log character of these horizons within the study area. This author has found

additional coals described by Harris (1984) to be of value in correlations within the study area and on a regional basis. It should be noted that these basin to basin correlations are to a large degree based purely on stratigraphic position and have yet to be studied biostratigraphically to determine whether the coals are, in fact, exactly equivalent. Is the Riverton coal of southeastern Kansas really the same coal bed as that in northeastern Kansas? In Missouri? This problem requires further study and the techniques utilized by Ravn (1986) should be sufficient to resolve it.

Although there is a definite similarity between much of the Cherokee section in the Cherokee basin and that of the Forest City basin, the Lower Cherokee section of the later basin is much thicker. Lee (1943) was one of the first to recognize this thickening Pennsylvanian section. It is this stratigraphic interval, found only in the subsurface in Kansas although it may be correlative with the Kilbourn Formation of Iowa, that needs additional study. Lee (1943) and Lee and Payne (1944) investigated this interval of rock and coined the term McLouth sand to describe the generally sandy strata. This interval comprises the lowermost section of the Pennsylvanian in northeastern Kansas, except possibly for the "pre-McLouth" which is discussed in the following section. The basal contact of the Pennsylvanian is the interregional unconformity previously mentioned. The upper boundary is considerably more obscure and is viewed as

conformable with the overlying strata. Because there is apparently no distinct break in deposition between the McLouth sandstone and the overlying shales, along with other factors mentioned later in the text, this author is proposing that the McLouth sandstone be given member status within the Riverton formation. The Riverton Formation (as originally defined) is more established as a stratigraphic unit and a discernable contact between it and the McLouth sandstone, while locally distinct, is regionally obscure. This classification is based primarily on lithologic evidence. However, palynological evidence (Carol Williams, 1987, Houston, Tx., personal communication) indicates the McLouth is definitely pre-Desmoinesian, possibly Atokan or Morrowan. Additionally, the so-called "x-marker" locally used by operators in the area, is tentatively correlated with the Burgner Formation (Searight and Palmer, 1957). This correlation was previously suggested by Searight and Howe (1961). Again, the correlation is largely based on lithostratigraphic evidence and needs to be confirmed by biostratigraphic evidence. However, in this study the "x-marker" is included as a limestone member of the Riverton Formation. The age of the Riverton Formation is also disputed. The Kansas Geological Survey has viewed it as Desmoinesian based primarily on its inclusion as part of the Riverton Cyclothem, which contains the overlying Warner Sandstone, as defined by Moore (1949).

The Missouri Geologic Survey lists the Riverton Formation as Atokan (Searight and Howe, 1961). This study indicates that the Riverton is of Atokan age.

Morrowan/Atokan Stage (?)

Bower Formation (proposed new formation) - Detailed correlation of the well data in this study revealed the presence of an anomalous clastic section, apparently below the Riverton Formation, but above the Mississippian strata. The occurrence of this section is erratic, having been found in just eight wells thus far. Table I lists the wells containing this "pre-McLouth" (strictly speaking this strata is "sub-McLouth" because the distinction is lithologic) section. The name Bower formation has informally been used by this author to describe the pre-McLouth section after the well (Petro-Tech Inc., Bower #1, section 35, T10s-R20E) in which it was first recognized. The formation consists of interbedded sand and shale. The shale occasionally has carbonaceous streaks; reworked limestone may also be present. The thickness is highly variable ranging from 50-120 feet. The age and origin of the Bower formation is open to speculation. The eroded Mississippian beneath this formation is older than that beneath the Riverton in other areas of this investigation. This suggests deep erosion into the Mississippian carbonates prior to Bower deposition. This erosion combined with the sporadic occurrence of the sequence (see Plate 1) appears to be the result of infilling

TABLE I - Listing of wells containing pre-McLouth (Bower formation) section.

<u>Location</u>	<u>Operator</u>	<u>Lease</u>
39-9S-19E SW NE NW	Jerry Lutz	Vanderwiede #5
14-10S-19E C NW NE	Petro-Tech Inc.	Rhodes #1
4-10S-20E W/2 NW SE	Hamm Quarry	Wells-Rayburn #1
4-10S-20E W/2 NW NW	Petro-Tech Inc.	Willits #5
5-10S-20E SW NE NE	Petro-Tech Inc.	Bower #1
5-10S-20E SE SW NE	Petro-Tech Inc.	Bower #6
5-10S-20E NE SE NW	Petro-Tech Inc.	Turner #1
8-10S-20E NW NW NE	Sherrod Co.	Benne #1

of the scoured cavities in the karst surface prior to Riverton deposition. Bretz (1950) studied sink deposits in Missouri north and west of the Ozark Uplift. He concluded that the various associated deposits resulted from slow subsidence under the load of overlying strata and thus the "cavity-making and fill-making" were contemporaneous. This idea is not completely adequate to explain the occurrence of the Bower formation. Figures 9 and 10 show wells with Bower strata in relation to the typical McLouth section in surrounding wells. The anomalous section is clearly seen on comparing the Bower #1 well with other wells in its immediate vicinity (Figure 9) which typically only contain upper McLouth sandstone. Figure 10 shows the pre-McLouth strata as they occur in T9S-R19E. Notice that the section here lies below the middle McLouth sandstone and that the contact appears to be unconformable. In all eight wells that contain pre-McLouth strata, the section appears to be anomalously thick when compared with nearby wells and the underlying Mississippian formation is inevitably older than that underlying basal Pennsylvanian rock in surrounding wells. This underlying Mississippian strata is Burlington-Keokuk limestone. The occurrence of the Bower strata in association with underlying Mississippian anticlines is noteworthy, yet the significance of this association is unclear at this time, as is the extent of the unconformable contact. The age of the Bower formation is unknown although it appears to be older than Riverton. However, it is

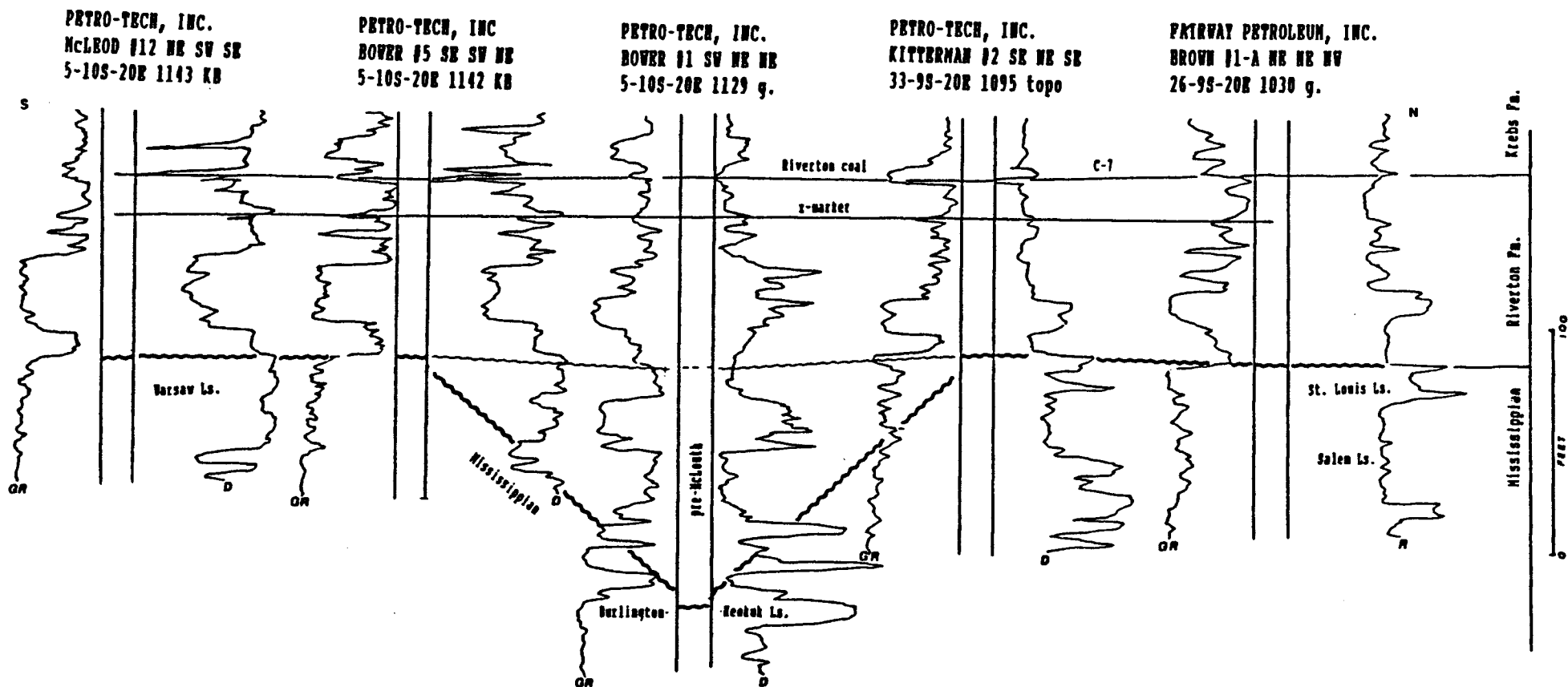


FIGURE 9 - Cross-section showing relationship of pre-McLouth (Bower formation) section to nearby wells with typical Riverton section for the area.

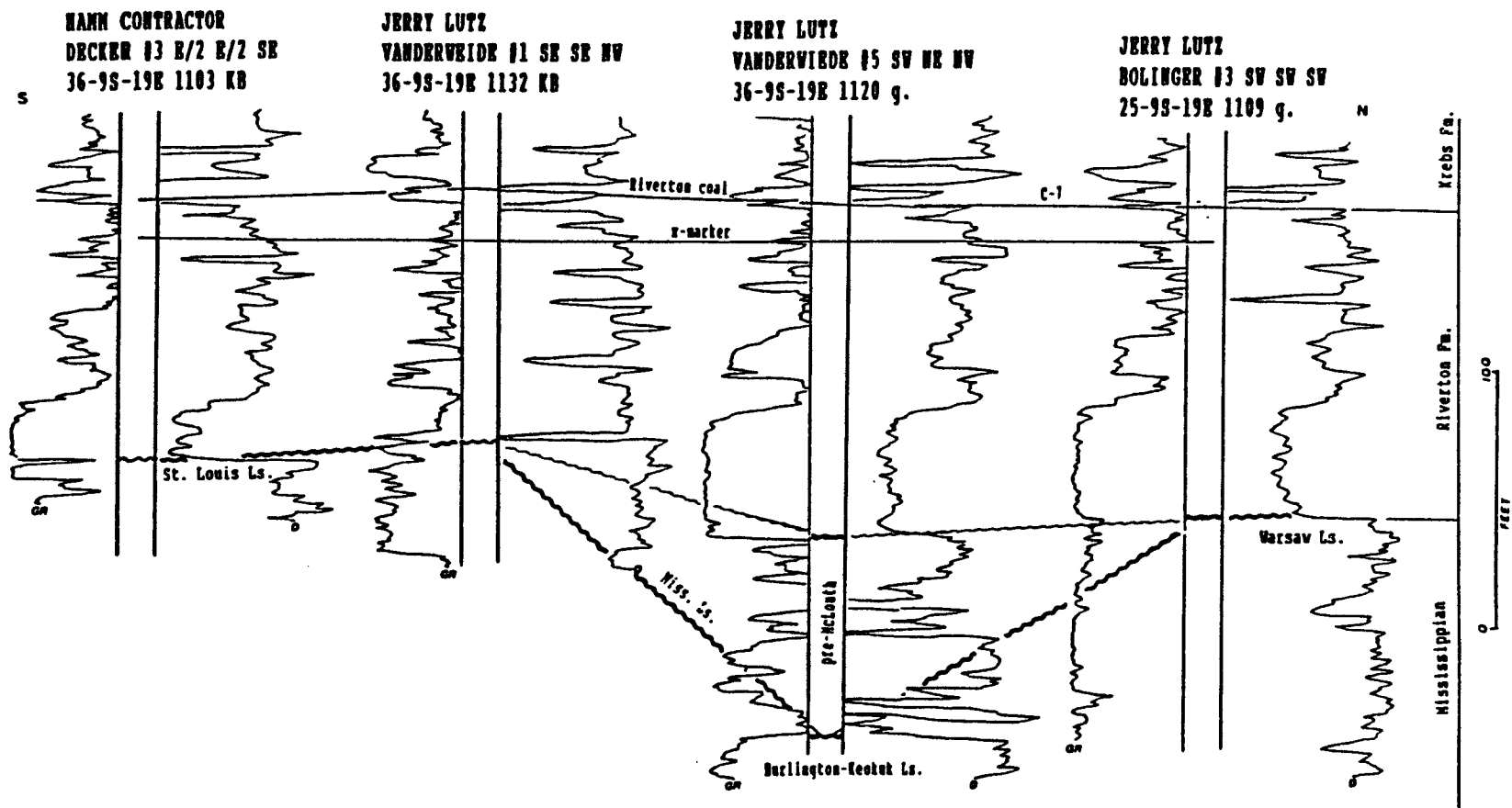


FIGURE 10 - Cross-section showing pre-McLouth section in relation to nearby wells in T9s-R19E. Note thickened section of Vanderwiede #5 well and unconformable contact of Riverton strata with underlying pre-McLouth.

possible that it represents remnants of early Riverton deposition across the area, preserved in sinkholes.

Figure 11 is a composite stratigraphic column depicting typical thickness and position of the Bower formation with respect to the overlying Riverton Formation. It bears a resemblance to the lower portion of the Riverton interval shown in Figure 7 except that the Bower formation is thicker and rests upon older Mississippian as discussed. Perhaps the Bower formation, as described here, should actually be included as part of the Riverton. Perhaps the lower portion of the McLouth sandstone member of the Riverton Formation (see Figures 7 and 8) should be taken out of the Riverton and included in the Bower formation. The lack of data and sporadic occurrence of this pre-McLouth section precludes any final conclusions at this time. Biostratigraphic study of the lower McLouth sandstone within the Riverton Formation and of the Bower formation is needed to resolve this ambiguity since wireline log evidence. For these reasons, the Bower formation was left off of the composite log (Figure 8) and the composite stratigraphic column (Figure 7) pending further investigation.

Atokan Stage

Riverton Formation - The Riverton Formation rests upon the eroded Mississippian surface throughout the entire study area except as previously noted. The type locality for the Riverton is in Missouri where it consists of dark gray to

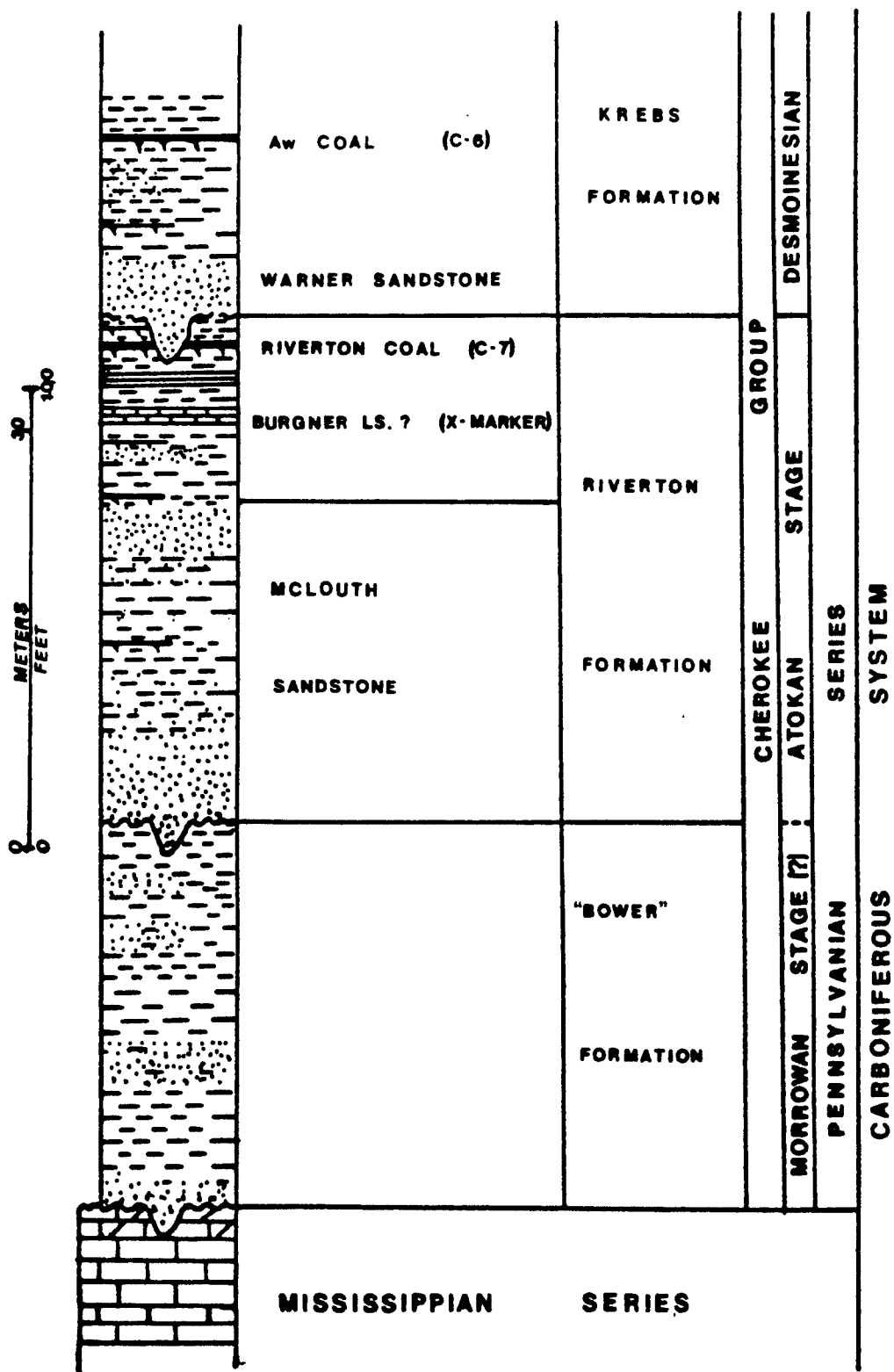


FIGURE 11 - Composite stratigraphic column showing proposed stratigraphy of the Bower formation in relation to overlying Riverton Formation. The underlying Mississippian carbonate in all wells identified as containing Bower strata is Burlington-Keokuk Limestone.

black, fine grained shale with infrequent coal beds (Searight and Howe, 1961). In northeastern Kansas, this stratigraphic interval is comprised of a lower nonmarine section (McLouth sandstone member) overlain, apparently conformably, by an increasingly marine section (Burgner limestone member).

McLouth sandstone member - This investigation indicates that the McLouth strata are presently located only in the Forest City basin. Previously, the McLouth section was thought possibly to correlate with the Warner sandstone of southeastern Kansas which comprises the basal Pennsylvanian strata in that region (Anderson and Wells, 1968). However, the McLouth sandstone member clearly does not correlate with the Warner sandstone, and in fact, underlies the Warner typically by 30-40 feet in northeastern Kansas (Plate 3). Additionally, recent palynological work by Carol Williams (in preparation) confirms that the McLouth is indeed older than the Desmoinesian Warner interval. Regional mapping of the Cherokee Group throughout eastern Kansas and into the Forest City basin shows that the McLouth sandstone member and part of the Burgner limestone member are absent south of the Bourbon Arch (Plate 4). The Bourbon Arch is a broad, structural feature found in central eastern Kansas and will be discussed in the section on regional structure. The upper portions of the Riverton Formation (Riverton coal bed and commonly a thin section of shale) does extend across the Bourbon Arch into southeastern Kansas and is found between

the Warner sandstone and the Mississippian surface in numerous wells. Plate 4 shows the distribution of the McLouth sandstone as currently mapped by the author. The western limit is the Nemaha Uplift which provided a depositional barrier as well as a post-depositional erosional barrier as suggested by the tight isopach lines found in Nemaha and Pottawatomie counties, Kansas. The change of over 700 feet in thickness over a distance of less than six miles suggests to this author an erosional barrier rather than a depositional, onlapping relationship. The McLouth strata thin to a "feather-edge" along the eastern edge of the Forest City basin in Putnam, Sullivan, Linn, Charitan, Lafayette, Clay, and Platte counties, of Missouri (Searight and Howe, 1961). The McLouth section appears to extend northward to south central Iowa as the equivalent of the Kilbourn and of the lower portion of the Kalo Formations. Gregory (1982) reports that the Kilbourn Formation generally consists of the Basal Cherokee strata and ranges upward to the base of the Blackoak coal. These deposits, like the McLouth, are mainly non-marine, consisting of shales, siltstones, sandstones, and occasional coals. The Kilbourn and Blackoak coal of the Kalo Formation are Atokan age (Ravn et al., 1984; Ravn, 1986).

The overall thickness of the McLouth sandstone member varies due principally to the influence of paleotopography of the Mississippian surface during deposition and to differential compaction following deposition. This thickness

is typically 100-110 feet. A broad thinning of the McLouth strata occurs throughout T9S-R20E where only the upper sandstone zone is present. To the northeast and southwest, the section thickens.

Burgner limestone member - The increasing marine influence upon the Cherokee became evident for the first time during Burgner deposition. The Burgner limestone member is predominantly a marine unit composed of black shales, siltstones, and the Burgner limestone. This member overlies the McLouth sandstone member without a significant break in deposition yet is overlain unconformably by the Desmoinesian age Warner sandstone member of the Krebs Formation.

The Burgner member is distinguished from the McLouth member by its marine character and the presence of the Burgner limestone (x-marker on wireline logs). This key signature found on numerous electric logs throughout the study area, and apparently in surrounding counties, provides a reliable horizon for mapping. In this study, the x-marker (a term utilized by local operators) has proven to be a more reliable marker than the top of the McLouth sand, which was cited by Lee and Payne (1944) to be a reliable marker for structural mapping.

A dark, often black marine shale overlies the McLouth strata. The thickness varies from 8-16 feet although greater thickness has been recorded. The shale appears to be laterally persistent and recognizable on wireline logs by a relatively high gamma ray (GR) reading. Directly above this

shale is commonly a white, tightly cemented siltstone which is sandy in some wells. Thickness is typically 4 feet. Lee and Payne (1944, p.31) reported the presence of this "persistent white siltstone bed a short distance above the McLouth sand" and further "its top is 15-25 feet, usually 20 feet, above the top of the McLouth sand". A short distance (2-10 feet) above this siltstone is a thin fossiliferous limestone. This limestone is identified on wireline logs by a clean gamma ray (GR) kick coupled with a high resistivity kick and is the "x-marker" identified in this study. The distinction between these two (thin siltstone and x-marker) on electric logs is apparent locally but may become blurred on a regional basis. This limestone was mentioned by Lee and Payne (1944, p. 31) as a very persistent reference bed composed of "medium to dark gray fossiliferous argillaceous limestone". It is this limestone that is tentatively correlated with the Burgner Limestone of Missouri (Searight and Palmer, 1957). Thickness of this limestone within the study area reaches only a few feet. The type section in Jasper County, Missouri consists of a fossiliferous limestone about 16 feet thick surrounded by dark shales and coals. Brachiopods and abundant crinoid stems are found in the strata. This is quite similar to the limestone found in this study. It should be noted that the correlation of the two is not definite and needs further investigation, but for this study the Burgner correlation appears valid and is also useful in relating midcontinent stratigraphy.

Directly above the Burgner limestone is a dark gray to black shale generally 6-10 feet thick. Near the top of this shale is a coal bed identified as the Riverton Coal. It is widespread, being found in most of the wells studied, and readily identified on wireline logs. This coal is the oldest widespread coal traceable throughout the study area. In a few wells the Riverton Coal is absent, having apparently been eroded away by the fluvial system associated with the overlying channel sands of the Warner stratigraphic interval. The coal bed is typically overlain by a thin shale unit. The presence and thickness of this unit is irregular also due to the erosional nature of the contact with the overlying Warner strata. This unconformable contact is apparent within the study area and has been recognized elsewhere. Howe (1956) noted that the thickness of the Riverton strata in southeastern Kansas is about 15 feet and the shale between the Riverton coal and the Warner is generally absent due to erosion prior to the deposition of the Warner sandstone.

Desmoinesian Stage

Krebs Formation - The Krebs Formation throughout much of eastern Kansas, specifically south of the Bourbon Arch, is the basal Pennsylvanian unit. This stratigraphic interval is correspondingly the lowermost unit of Cherokee strata in those regions. The Krebs Formation consists of dominantly terrigenous shales, siltstones, sandstones and coals. The sandstones generally exhibit a channel geometry and approach

70 feet in thickness. The numerous coals are typically lenticular, yet a few are laterally persistent and can be used as reliable correlation markers. Harris (1984) recognized seven coals within the Warner stratigraphic interval, four of which he designated informally as Aw, Bw, Cw, etc. This author has tentatively recognized the Aw coal as a prominent coal bed in northeastern Kansas. The Aw coal is often designated "coal marker" by local operators and is valuable as drilling marker as well as a mapping horizon. The top of the Krebs Formation is the Seville Limestone. In the study area of this investigation, it is difficult to distinguish with certainty. This author doubts the lateral persistence of this bed and feels it is a poor horizon, stratigraphically, to mark the division of the Krebs Formation and the overlying Cabaniss Formation. Other authors have also questioned the lateral persistence of this limestone and its use as a key bed in dividing formations (Harris, 1984; Ravn et al., 1984; M.D. Staton, 1987, Kansas Geological Survey, personal communication). Perhaps a better division based on lithostratigraphy in the absence of accurate age data, is the Bbj coal bed named by Harris (1984) and correlated into northeastern Kansas in this study as the C-4 coal.

Several authors have studied the Desmoinesian section of southeastern Kansas and have provided a much more extensive description of the stratigraphy. Ebanks (1979) and Harris (1984, 1985a, 1985b) have written recent reports.

The Desmoinesian section of northeastern Kansas and the Forest City basin has been studied considerably less. Ravn et al. (1984) and Ravn (1986) document recent investigations in Iowa.

LITHOLOGY OF THE MCLOUTH SANDSTONE MEMBER

The McLouth sandstone member of the Riverton Formation is composed chiefly of non-marine sandstone, siltstone, shale and minor coal. The following lithologic description of these strata is based largely on a combination of the previous work by Lee and Payne (1944) and various core and sample descriptions by local operators and this author.

Table II depicts the relative abundance of the various lithologies present within the McLouth section. It is evident that many facies are present and variations within individual units exist. However, for the purposes of correlation and general understanding of the depositional framework, these lithologies were grouped according to stratigraphic position and composition into five lithofacies. Lacking adequate biostratigraphic data, one must anticipate that these lithofacies, treated as zones, may overlap and be time-transgressive to some extent. Lee and Payne (1944) divided the McLouth strata into seven such lithologic zones based on cable-tool cuttings. The present study, utilizing detailed correlation of geophysical logs, driller's logs, and sample descriptions, has reduced the

Table II - Classification of generalized lithologic types of the McLouth sand based on composition and grain size.

(The quantitative importance of the lithologic varieties is indicated by the asterisks: *** abundant; ** common; * uncommon, but not rare; no asterisk indicates rare.)

A. Quartz sandstone

1. Well-sorted, porous sandstone **
2. Argillaceous sandstone ***

Subvarieties formed by cementation of above varieties

- a. Quartzitic sandstone *
- b. Sideritic sandstone
- c. Pyritiferous sandstone
- d. Asphaltic sandstone *

B. Quartz siltstone

1. Well-sorted siltstone **
2. Sandy siltstone *
3. Clayey siltstone **

Subvarieties formed by cementation of above varieties

- a. Siliceous siltstone *
- b. Sideritic siltstone *

C. Massive clay (fire clay)

1. Well-sorted, homogeneous clay **
2. Silty clay
3. Sandy clay

D. Shale

1. Micaceous silty shale **
2. Clay shale **

E. Clay ironstone

1. Clay ironstone *
2. Red sideritic limestone

F. Coal *

G. Intraformational breccia phase of argillaceous sandstone**

(From Lee and Payne, 1944, p. 84)

seven zones to five. These zones consist of vertically alternating sandstone and shale sequences which show great lateral variation. The various lithologies often grade laterally into one another over relatively short distance making correlation difficult and grouping of the strata into lithologic zones somewhat arbitrary. Compounding this situation is the common absence of an individual zone in any particular area due to a hiatal or erosional contact. The lithologic zones are designated from the bottom to the top as 1 to 5. Zones 1, 3 and 5 are generally characterized by sandstone and correspond to A, C, and E (G), respectively, of Lee and Payne (1944). Zone F of Lee and Payne (1944) is often absent allowing Zones E and G to appear as a single sandstone. Because this distinction is difficult to resolve from electric logs, Zone 5 of this study is a composite of Zones E, F, and G. This zone is commonly referred to by local operators as the upper McLouth sandstone. Dubois (1985), as previously mentioned, recognized three McLouth sandstone zones: lower, middle, and upper. The upper sandstone is the same as that just mentioned. However, the middle and lower zones recognized by Dubois are represented by Zone 3 in this study. Zone 5 of this study is referred to as the Burgess Sandstone by Dubois.

There are several generalities concerning the strata within the McLouth section which are important and deserve mention. First, the various sandstone bodies are often intricately interbedded and interlaminated by shale. Second,

plant fragments, spores, leaf imprints, and an overall high carbonaceous content within the McLouth is common. Third, the sand grains often appear angular to subangular in hand specimen yet are actually rounded grains with silica overgrowths giving the appearance of angularity. These characteristics, combined with the great lateral variation in lithology, are important indicators for depositional origin and reservoir quality.

Zone 1 - The sandstone of zone 1 forms the basal unit overlying the eroded Mississippian surface throughout most of the northeastern side of the study area. It is interpreted to be the oldest McLouth bed, though many local operators prefer to call this unit the Burgess Sandstone. This author is opposed using the term Burgess for reasons previously discussed. The Zone 1 sandstone is generally absent over anticlinal features and most of the western limits of the study area. This unit is typically a coarse grained argillaceous sandstone. Grain size is fairly uniform though the interstices are commonly filled with clay and silt. In addition, thin streaks of gray to black shale occur irregularly throughout the sand body. Angular chert, probably of Mississippian age, is commonly found near the base of the zone suggesting reworking of eroded material from the Mississippian surface.

Zone 2 - Shale and siltstone are the dominant lithologies present in Zone 2, although an occasional sand streak may be found. In various places within the study area this zone is

the basal unit. In these instances, angular chert fragments are often found near the base. Otherwise, Zone 2 rests above the sandstone of Zone 1. The siltstone and shale are micaceous with both muscovite and biotite present. The silt is usually a quartz-mica combination. Dark gray to black shale may be present and often contains carbonized plant fragments and pyrite. Zone 2, as well as Zone 4 (stratigraphically higher), regularly exhibit a laminated appearance due primarily to the alternation of light gray and dark gray laminae, and to the presence of microscopic partings caused by mica flakes and carbonized particles.

Zone 3 - The sandstone of Zone 3 occurs throughout the study area. On the western side it is typically the basal McLouth sandstone lying directly on the Mississippian carbonates or other pre-McLouth strata. However, in most of the wells studied it is underlain by Zones 1 and 2 and is the middle McLouth sandstone. This sandstone is generally the thickest of the three sand zones and exhibits the most clearly defined channel-sand characteristics. The sandstone ranges from a thick well-sorted, porous body such as that on the west side of the study area to a highly laminated, argillaceous sand body in other areas. Thin beds of silt and shale are commonly present which create vertical permeability barriers within individual sand bodies. The sandstone is typically weakly cemented by silica, although pyrite and siderite cements may be present. Grain size in any one field or local area is uniform, yet may vary

considerably within the fine to coarse range across the study area. Accessory detrital minerals include feldspar, muscovite, and biotite. Heavy minerals commonly present are zircon, magnetite, tourmaline, and ilmenite. Leucoxene is also present as are chert fragments. The feldspar fraction is composed of fine to medium sand sized particles of microcline and orthoclase.

Zone 4 - This zone is composed of clay, shale, and siltstone. It is lithologically similar to Zone 2. However, there are some important differences. The percentage of black shale is much higher, and pyrite is more common. Linguloid shells have been reported from strata of this zone. Also, reddish brown siderite spherulites are commonly present within the shale. Light colored micaceous siltstone may be present which also contain the spherulites. These spherulites range in size from about 1/8 to slightly over 1 millimeter in diameter. They are found in aggregates as well as individually. The thickness of zone 4 is variable, though it rarely exceeds 15 feet. In the absence of an upper McLouth sandstone (Zone 5), distinction between the shales of Zone 4 and overlying shales of Zone 5 is difficult.

Zone 5 - This upper McLouth unit is generally composed of clean, porous to argillaceous sandstone which locally may grade into siltstone or shale. The sandstone is mostly fine grained, subrounded, and well sorted. Grain size varies over the study area from fine to medium. Average porosity for this upper sandstone is 23 percent. Plant fragments and coal

debris may be present in the argillaceous facies of this zone. Minor amounts of glauconite have been reported in this sandstone. Upper and lower contacts often exhibit strong resistivity characteristics on wireline logs possibly reflecting complete cementation of these contacts. This sandstone is widespread throughout the central portion of the study area. In numerous wells in this study, the upper McLouth sandstone is absent, which makes it difficult to pick the top of the McLouth sandstone member.

Overlying the McLouth sandstone member is the tentatively designated Burgner limestone member of the Riverton Formation. The lower portion of this member is a dark gray to black shale which is similar to that of zone 4 within the McLouth member; this creates difficulty in accurately dividing the two in the absence of an upper McLouth sandstone, as mentioned above. The author has used a resistive kick within this shale interval of lower Burgner and upper McLouth to divide the two members in these instances.

GEOLOGIC SETTING AND HISTORY

The Forest City basin is an elongate, shallow Late Paleozoic interior cratonic basin of both structural and depositional origin with a generally north-northeast trend (Lee, 1943; Lee et al., 1946; Anderson and Wells, 1968). The basin is located in northeastern Kansas, northwestern

Missouri, southwestern Iowa, and the southeastern tip of Nebraska (Figure 12). The Forest City basin covers approximately 33,000 square miles with an average depth of 3000 feet. The basin has a sediment volume of about 19,000 cubic miles (Rapoport and Grender, 1986). The regional dip of strata in the study area is to the west-northwest at about 15 feet per mile. While the Forest City basin itself is a Carboniferous basin, its origins may be traced back to the North Kansas basin of "pre-Nemaha ridge" time. Numerous structural movements have influenced the midcontinent throughout the Precambrian and Paleozoic and helped form the North Kansas basin and ultimately the Forest City basin (Figure 13). Only a brief review of major influences responsible for the creation of the North Kansas and later Forest City basins will be given in this report.

The structural and stratigraphic evolution of the Forest City basin began during the Late Cambrian and culminated with the uplift and subsequent beveling of Permian strata prior to Cretaceous deposition. During the Late Cambrian and Early Ordovician, the central Ozark region of Missouri was subsiding while southeastern Nebraska was rising (Lee, 1943; Lee et al., 1946). This structural warping permitted the accumulation of sediment to the east and exposure of the Nebraska arch to the west. The axial orientation of the basin during this time was essentially northwest-southeast. The study area during this tectonic phase was approximately midway between these extremes and

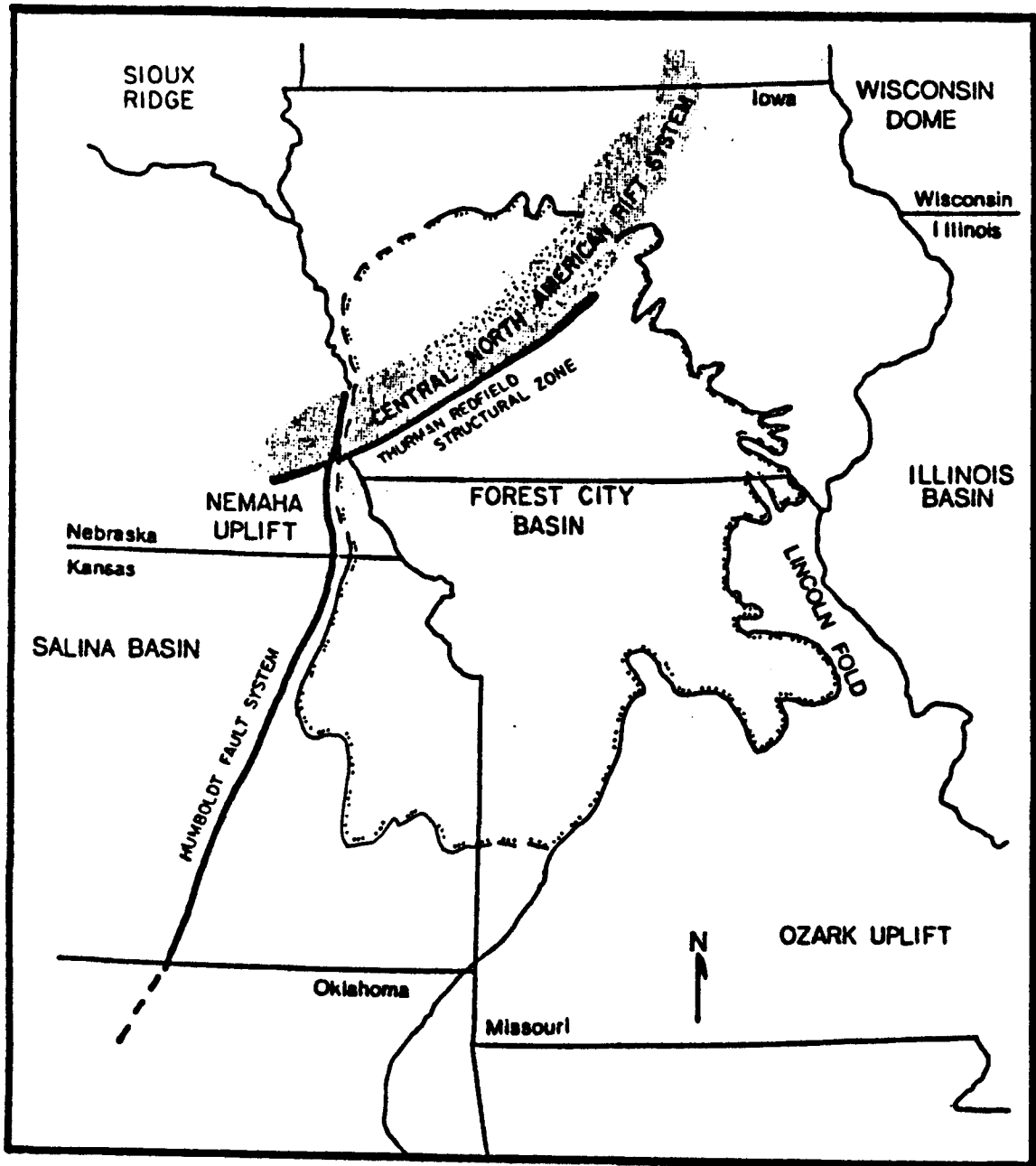


FIGURE 12 - Map of Pennsylvanian structural features of the area and current configuration of the Forest City basin. (modified from Ravn *et al.*, 1984)

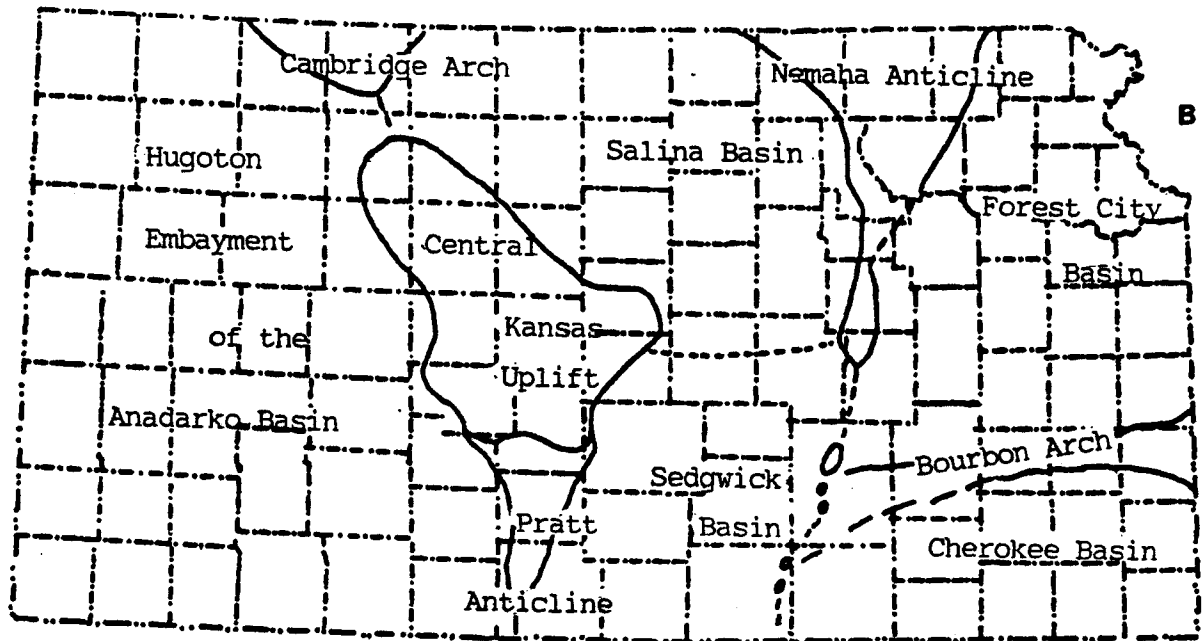
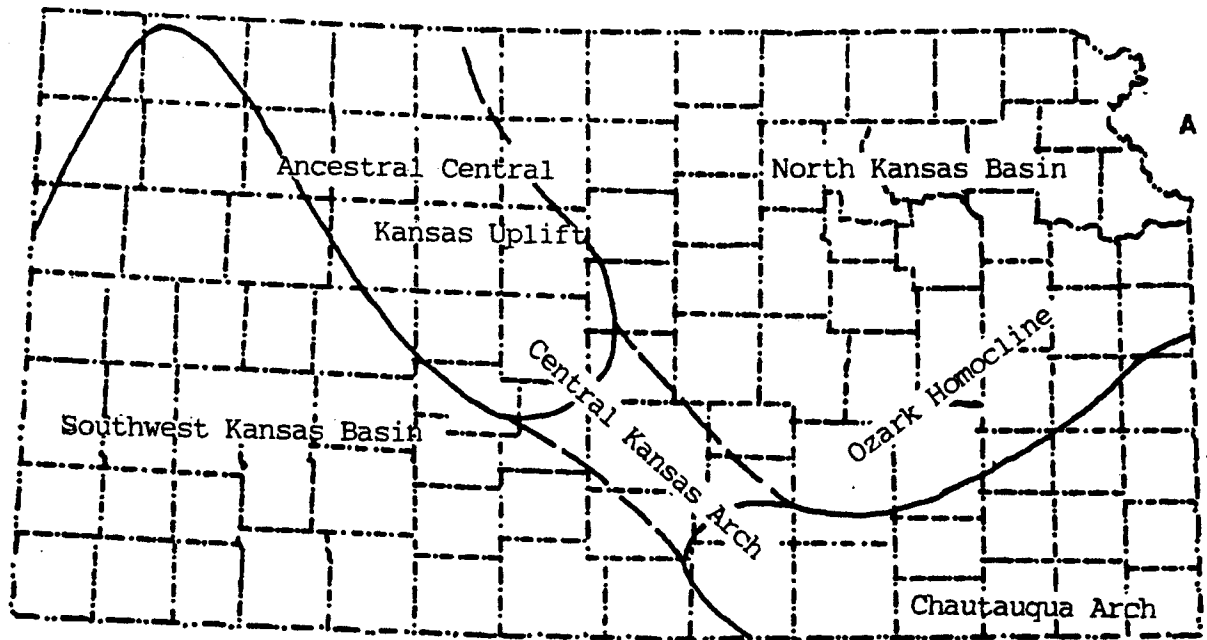


FIGURE 13 - Major structural feature of Kansas during A) pre-Mississippian post-Devonian; and B) pre-Desmoinesian post-Mississippian. Note dissection of the North Kansas basin by the Nemaha Anticline and the development of the Forest City basin. (modified from Merriam, 1963)

consequently had only a moderate amount (about 700 feet) of Late Cambrian-Early Ordovician sediment accumulation.

By Middle Ordovician time the structural regime had shifted as the Ozark region began to rise while the previously high Nebraska arch to the west slowly subsided (Lee, 1943). The axial orientation of the North Kansas basin also shifted to a more north-south trend. The Chautauqua arch evolved during this tectonic phase in southeastern Kansas and combined with the Ozark highlands to form the southern barrier of the North Kansas basin (Wells, 1971). This basin became the dominant feature in the four state area until Carboniferous time. Throughout the Middle and Late Ordovician, the basin received dominantly terrigenous clastic sediment. The Thebes Sandstone and Orchid Creek Shale are preserved remnants of these early clastics in southeast Missouri (Anderson and Wells, 1968). Additionally, it is the Middle Ordovician Simpson Group and overlying shales of the Decorah Formation that may be the source rocks for the hydrocarbons found in the Simpson, Viola, and "Hunton" horizons and perhaps the productive Cherokee sandstones as well (Newell et al., 1987).

Two major pulses of tectonic movement have been recognized to have occurred during Silurian and Devonian time: one preceding the deposition of Devonian rocks, and the other preceding the deposition of the Late Devonian Chattanooga Shale (Lee, 1943). The first event uplifted the southeastern portions of the North Kansas basin and

subsequently caused extensive erosion of Silurian strata throughout the basin. Within the study area, the Silurian section is absent (Lee, 1943). The other prominent movement also created a re-elevation of the surface to the southeast and was followed by the removal of Devonian as well as some earlier rock (Lee, 1943; Lee et al., 1946; Anderson and Wells, 1968). Following this tectonic event, basin-wide subsidence ensued resulting in the deposition of the Chattanooga Shale. This phase of basin submergence marked the final broad tectonic movement affecting the North Kansas basin prior to the first recognizable effects of the emerging Nemaha uplift. The study area during this time interval was again peripheral to major deposition and is characterized by moderate sediment accumulation; the aggregate thickness of the Late Ordovician-Devonian section is 430-450 feet (Lee et al., 1946).

Following the uplift, erosion, and peneplanation of the Devonian strata, the North Kansas basin subsided and deposition of the Kinderhook clastic section ensued, marking the base of the Carboniferous System in the four state region. The earliest evidence of the emerging Nemaha uplift is found in Lower Mississippian strata as demonstrated by the crestal thinning of the Fern Glen Limestone (Osagian) beneath the Burlington carbonates (Lee, 1943). The midcontinent during most of the Mississippian can be characterized by extensive marine deposition in shallow

seas. This resulted in the deposition of a great thickness of marine limestone.

Widespread uplift and erosion took place during the Late Mississippian pre-Morrowan time creating the widely recognized pre-Pennsylvanian unconformity. The Cambridge arch and Central Kansas uplift also developed during this period of activity (Rascoe and Adler, 1983). This pre-Morrowan epeirogeny continued to reactivate the Nemaha uplift as it progressively divided the North Kansas basin into two separate entities (see Figure 13). The westerly down-warped region developed into the Salina basin. The eastern flank of the Nemaha anticline was sharply down-dropped along the Humboldt fault resulting in the development of a synclinal region that directly preceded the Forest City basin (Lee, 1943; Lee and Payne, 1944). It should be pointed out that the division of the North Kansas basin by the Nemaha uplift did not simply create two basins where there was previously one (Lee, 1943; Lee, Leatherock, and Botinelly, 1948). The two basins (Salina and Forest City) probably would have developed whether the North Kansas basin was already present or not (Lee, Leatherock, and Botinelly, 1948).

By Early Pennsylvanian time the North American and South American plates were colliding, probably as an "arc-continent" collision (Walper and Rowett, 1972; Wickham, Roeder, and Briggs, 1976; Rascoe and Adler, 1983). This tectonism possibly provided the impetus for many of the

tectonic features which developed in the midcontinent throughout the Carboniferous. This event, resulted in the Wichita Orogeny, and was responsible for the folding and faulting associated with the Ouachita Orogeny; the Arbuckle-Wichita uplifts; the Ancestral Rockies; and the rapid subsidence of the Arkoma basin (Harris, 1984; Rascoe and Adler, 1983). In the four state region mentioned in this study, the orogeny was reflected by the rejuvenation of Ozark and Nemaha uplifts; the Bourbon arch; and the numerous anticlines and domal structures such as the "McLouth Dome" found in T9S-R20E in northeastern Kansas. The structural trend of the Forest City basin during this period was northeast, which contrasts with the northwest trend prevalent throughout most of the region's history. Anderson and Wells (1968) and Wells (1971) have stated that these two opposing trends may have been responsible for the development of numerous domal features possibly providing areas of hydrocarbon accumulation. Recent analysis of lineaments detected by remote sensing methods reveals that these two trends are still prominent (Figure 14) and have influenced the stratigraphy to the present (Callen, 1983).

The Bourbon arch is a broad, somewhat indistinct feature trending northeast-southwest through portions of Bourbon, Allen Woodson, Greenwood, and Elk counties, Kansas. The arch provided a barrier between the Forest City basin to the north and the Cherokee platform to the south during most of Riverton deposition. However, the Bourbon arch was



FIGURE 14 - Lineament map of Atchison, Jefferson, and Leavenworth counties, Kansas. Note prominent NW-SE and opposing NE-SW trends of lineaments.
(From Callen, 1983)

apparently inundated by marine and paralic waters during late Riverton deposition as evidenced by the presence of a thin shale overlain by the Riverton coal extending across the arch. The onset of Krebs deposition throughout eastern Kansas marked the end of the influence on deposition by the Bourbon arch. The Forest City and Cherokee basins are depositionally indistinct during the Desmoinesian because this barrier had effectively been removed and there is little evidence of any rejuvenation of this feature (McMillan, 1956; Gentile, 1968).

DEPOSITIONAL SETTING

The Cherokee Group of eastern Kansas has historically been considered to be of marine origin. However, recent work by various authors (Visher et al., 1971; Shelton, 1978; Ebanks, 1979; Gregory, 1982; Ravn et al., 1984; Harris, 1984, 1985a; Ravn, 1986; O'Brien, 1987) on the Cherokee Group in southeastern Kansas, Oklahoma, Missouri, and Iowa have shown the Cherokee strata to be dominantly non-marine. These investigations have all indicated the heterogeneous clastics of the Cherokee to be the result of aggrading fluvial systems, prograding deltaic systems, or a combination of the two.

The depositional environments responsible for generating the McLouth sandstone member, and more generally, the Riverton Formation are difficult to pinpoint due to: the

numerous and rapid facies changes; the lack of biostratigraphic data for establishing time markers; the lack of conventional core and/or outcrop exposures for analysis of sedimentary structures (the McLouth sandstone member is a subsurface unit). However, recognition of a general depositional setting for this interval of strata is possible through analysis of the facies (and lithologic composition) and their relationships to each other, establishing the dispersal patterns of the sandstone bodies from wireline log correlations, and by comparing individual and suites of log motifs with modern analogs.

Lee and Payne (1944, p. 121-122) stated that the McLouth was deposited "on a flat, slowly subsiding plain of aggradation, at times partly inundated and occupied by shallow bodies of brackish to marine water and marshlands, and at other times at or slightly below sea level and occupied by numerous shifting and aggrading streams, flood plains, and associated lakes and swamps". Since that interpretation, various local operators and geologists have viewed the McLouth strata as resulting from varying depositional settings ranging from turbidity currents to offshore bars to an agglomeration of sand termed a chernalith (churnolith?). More recently Dubois (1985) studied the McLouth strata in the Leavenworth oil and gas field. He interpreted the "lower" McLouth sandstone (zone 3 sandstone of this report) to be a fluvial point bar deposit. The "middle" McLouth sandstone (not distinguished from zone

3 in this study) was stated to be of levee or crevasse splay origin. The upper McLouth sandstone (zone 5 sandstone) is interpreted to be the result of marine bar deposition.

Walther's Law states that a conformable vertical sequence of facies is the result of progradation and aggradation of a lateral sequence of environments. This idea plays an integral part in recognizing ancient sedimentary environments and is particularly apropos in studying the Lower Cherokee section of northeastern Kansas. The complex facies relationships of the McLouth strata pose problems for detailed environmental studies but aid in general depositional setting studies. While it is futile at this time to state that an individual sandstone body within the McLouth sandstone member resulted from point-bar deposition, for example, it is reasonable to conclude that the McLouth strata are the result of deposition associated with fluvial systems. Plate 6 is a map showing lithofacies relationships within Zone 3. The map was constructed by recognizing the lithology present in zone 3, seventy feet (70 feet), below the x-marker. While this map does not reflect the true relationships at the time of deposition due to post-deposition structural movements that may have obscured these relations, the author believes these structural movements were sufficiently minor to preserve the overall nature of these relationships. The map clearly shows an interlacing channel geometry for the sandstone. An isopachous map of this sandstone in the western portion of the study area

shows a low sinuosity channel trending north-south with sandstone thicknesses reaching 50 feet (Plate 7). Plate 10 shows a stratigraphic and structural cross section through a portion of this channel. The stratigraphic cross section demonstrates the "channel-fill" nature of the sand body deposited within an erosional Mississippian valley about 2.5 miles across. The structural cross section shows present day structure. Though the section is not to true horizontal scale, the relationship of the surface of the Mississippian and the x-marker is demonstrated for these wells. They appear to parallel one another in this region, as is the case commonly. However, this is not always true because the surface of the Mississippian incorporates erosional topography which may distort the true structural picture. A comparison of the contour maps of the Mississippian and x-marker surfaces demonstrates this principal (Plates 2 and 5, respectively). A lithofacies map similar to that described above was also prepared for the upper sandstone (Zone 5) of the McLouth sandstone member (Plate 8). Instead of the interlacing sandstone geometry of Zone 3, it shows a broad belt of sandstone trending northeast-southwest with peripheral, isolated pods of sandstone. Complete isopaching of this genetically related package of sediment was not feasible due to the heavy reliance on driller's logs, which lack accurate thickness information, in the construction of Plate 8.

Lithologic composition and grain parameters may also be indicative of depositional setting. The high carbonaceous content (dominated by plant material) throughout the strata suggests a low energy environment. The thin coal beds found erratically within the McLouth sandstone member are lenticular; coal deposits of this type have been attributed to flood plain settings (backswamp) peripheral to major fluvial channels (White, 1925; Frazier and Osanik, 1969; Horne et al., 1978). The Riverton coal bed, which is the oldest Pennsylvanian coal in eastern Kansas to show great lateral persistence, is the result of a different depositional setting. This coal, like other widespread coal seams characterizing the Pennsylvanian of the midcontinent, was deposited on a relatively flat, low-lying coastal plain. The environments of deposition of the numerous Pennsylvanian coals have been studied by various authors. Wanless (1975b) and Schopf (1975) summarized recent thinking on the Pennsylvanian climate and coal deposition in the United States. There are few, if any, modern analogs for the depositional setting responsible for the extensive coal deposits of this time period. Regions such as the Florida Everglades, the Amazon delta, or perhaps the Okefenokee Swamp in Georgia approximate the environments in which thick, laterally extensive coals may develop (Conybeare, 1979).

Besides the abundance of carbonaceous detritus, a general lack of marine fossils is also characteristic of the

McLouth strata and suggests terrestrial deposition. Paralic environmental influences become recognizable in Zones 4 and 5 with the appearance of minor, but significant, amounts of glauconite and the presence of linguloid shells. This suggests that brackish to marine waters at least partially inundated the study area. The siderite spherulites also indicate terrestrial conditions because they are thought to be derived from soil forming processes (B.E. Lock, University of Southwestern Louisiana, personal communication). A common textural feature of the McLouth sandstone member is the association of rounded to subrounded sand grains in a clay matrix. This textural inversion may represent an immature sandstone and Folk (1974) has found that textural inversions may be indicative of low energy environments of deposition.

Wireline log signatures, particularly the gamma ray (GR) and spontaneous potential (SP) motifs, have been utilized to define clastic depositional environments (Coleman and Prior, 1980; Galloway and Hobday, 1983; Busch and Link, 1985). Within the study area, a variety of log signatures for any given sand body may be found, Zone 3 sandstone for instance, depending upon the site of well penetration within the sand body. Coleman and Prior (1980) have expounded on this situation of multiple log signatures within a depositional setting by indexing log signatures of subenvironments for many clastic depositional settings. Though multiple log signatures are present for any

individual sand body of the McLouth sandstone member, two generalized motifs are frequently encountered, the "bell" shaped curve and the "blocky or cylindrical" shape. Both of these motifs are suggestive of channel fill deposits (Fernandez, 1982; Busch and Link, 1985). Selley (1978) has found that the presence or absence of glauconite and carbonaceous detritus combined with electric log signatures is indicative of sedimentary environments. These ideas when applied to the McLouth sandstone member suggest a fluvial/deltaic setting for sandstones of Zones 1 and 3, while that of Zone 5 is a tidal sand ridge or marine bar deposit.

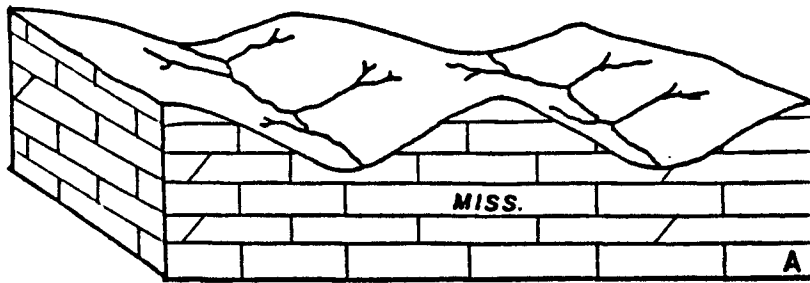
The McLouth section is similar to the overlying Warner and Bluejacket-Bartlesville sandstone sequence, with the exception of a widely traceable coal facies. The lithologies, log characteristics, vertical and lateral facies relations, and overall north-south sand trend are similar. The Bluejacket-Bartlesville sandstone in northeastern Oklahoma has been interpreted as a Desmoinesian fluvio-deltaic complex trending basically north-south (Visher et al., 1971; Shelton and Rowland, 1978). This same stratigraphic sequence has been traced throughout Missouri and southeastern Kansas where a more east-west component of the sandstone geometry is evident (Ebanks, 1979). The Warner strata have also been viewed as the result of a fluvio-deltaic system prograding southwestward through Missouri and southeastern Kansas (Ebanks, 1979; Harris, 1984). These

stratigraphic intervals have yet to be defined in the subsurface of northeastern Kansas.

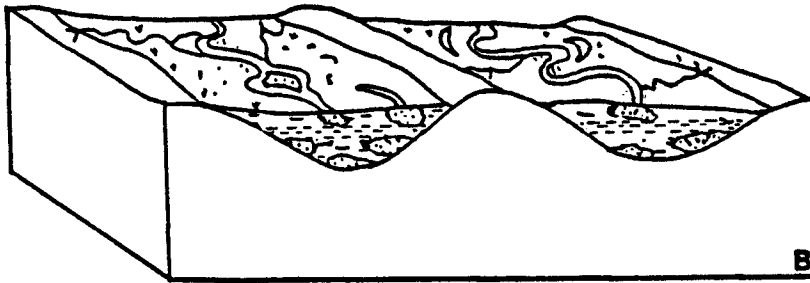
Gregory (1982) investigated the Desmoinesian Kalo Formation in Iowa. Again, the lithology of this formation resembles that of the McLouth strata with the exception of widespread coal facies in the Kalo. The evidence cited indicates that the heterogeneous clastics of the Kalo Formation are the product of a deltaic system prograding southward across south central Iowa into the Forest City basin. Ravn et al. (1984) found that the Lower Cherokee in Iowa (Kilbourn Formation) appears to be the result of major infilling of the karst Mississippian surface by dominantly fluvial processes. Numerous similarities exist between the Kilbourn Formation of Iowa and the McLouth sandstone member of the Riverton Formation in northeastern Kansas. First, both record periods of infilling of the Mississippian surface within the Forest City basin and appear to be of similar age (Atokan). Sediments of the Kilbourn, like those of the McLouth, are dominantly non-marine sandstones, shales, siltstones, and thin, discontinuous coals. It is this author's opinion, as previously mentioned, that the Kilbourn Formation is correlative with the McLouth section. Further, the Riverton Formation as defined in this report may be correlative with the Kilbourn Formation and Kalo Formation up to and including the Blackoak Coal.

Interpretation of McLouth Deposition

The three sandstone units (Zones 1, 3, and 5) within the McLouth sandstone member record three distinct phases of deposition within the confines of a larger depositional cycle (Riverton) of fluvial deposition in northeastern Kansas. The overall trend of the fluvial complex appears to be northeast-southwest, with individual river channels variably exhibiting a more north-south or east-west component. The facies of Zone 1 records the major period of sediment infilling of the irregular Mississippian surface (Figure 15). The intermittent shifting and aggrading of individual fluvial channels filled the erosional valleys characterizing the underlying surface. The facies of Zone 2 probably represent flood plain silts and shales deposited peripherally to the active channels as well as reflecting a rise in base level which effectively drowned the existing fluvial system. This created a low energy depositional setting conducive to clay and silt buildup. The sandstone characteristic of Zone 3 facies reflect increased tectonism, lowering of base level, and resumption of fluvial domination within the study area. The gray to black shale and siltstone common in Zone 4 again probably mark a period of rising base level and reduction of fluvial influence. As mentioned previously, this facies contains linguloid shells and organic-rich shale, which possibly reflect minor influences of a marine transgression creating brackish, stagnant waters in localized areas. The sandstone characterizing Zone 5



Depiction of pre-Pennsylvanian surface



Depiction of infilling phase (Zones 1 and 2)

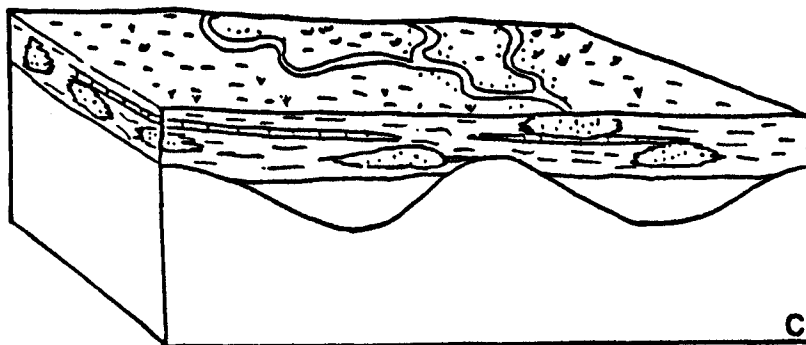


FIGURE 15 - Schematic representation . depicting the depositional setting of the McLouth sandstone member of the Riverton Formation. Lower diagram C depicts Zone 3 facies.

possibly owes its origin to one of two processes, or a combination of the two. The electric log signatures, sand body geometry, and presence of glauconite suggests that the sandstones are the result of marine bar deposition of some sort. Perhaps tidal sand ridges, offshore bars, or sand waves. However, it is also possible that the observed geometry and marine characteristics result from marine reworking of a fluvial sand body. The sandstone could have been originally deposited as fluvial sequence which upon being transgressed by marine waters was subsequently reworked to its present configuration. The lithology of the overlying Burgner limestone member attests to the increasing marine influence that dominated upper Riverton deposition in the study area.

Although the McLouth strata resemble the overlying Desmoinesian section as mentioned previously, the presence of a prominent delta in the study area has not been recognized. The great thickening of sedimentary strata (sediment lobes) associated with deltaic processes has not been observed, nor have the typical log signatures. An isopachous map of the interval between the x-marker and the Mississippian surface shows no clear sand trends one would expect in a deltaic setting (Plate 9). Additionally, cross sections prepared across this region do not show what one would expect on wireline log signatures in a deltaic setting (Plates 11 and 12). Thus, although the stratigraphy and log signatures are somewhat similar to those of an upper deltaic

plain, there is no evidence that the McLouth strata were associated with a delta, at least within the study area. McCabe and Shenck (1982) described a similar setting for the Pennsylvanian Port Hood Formation of Canada. They envisioned a meandering fluvial system to account for the observed Port Hood strata. A simple meandering river system cannot fully account for the McLouth section.

The apparent lack of distinctive sand trends mentioned above coupled with the observed facies of the McLouth section can be interpreted to be the result of an anastomosing system of channels. O'Brien (1987) has studied the Cherokee Group in north-central Oklahoma and stated that "the Cherokee genetic sequence of strata are, for the most part, a complex maze of anastomosing fluvial channels generally trending north-south. This picture is further complicated by many isolated pods, splays, and partially preserved minor channels between and outside of the main channels". Smith and Smith (1980) suggests that anastomosing fluvial systems are commonly on low-gradient alluvial plains. These systems may be common in flood plain settings (Galloway and Hobday, 1983; Mial, 1987). The envisioned topographical relief during McLouth deposition fits this criteria. The lithofacies map of Zone 3 shows evidence of an anastomosing fluvial complex (Plate 6).

CONCLUSIONS

In essence, results from this study have confirmed the depositional setting of the McLouth strata to be that envisioned by Lee and Payne (1944), although the areal extent of the interval is found to be considerably more widespread than was originally thought. The evidence presented suggests that the McLouth stratigraphic interval within the study area is the product of numerous shifting and aggrading stream channels associated with a major fluvial system oriented essentially northeast-southwest. The exact nature of these fluvial channels and the source of their alluvium is open to speculation but there is evidence that the channels may have been anastomosing. The Nemaha uplift has been cited by several authors as the primary source of sediment (Lee and Payne, 1944; Krumbein, 1948; Anderson and Wells, 1968). However, the notable lack of an appreciable feldspar component in the McLouth sandstone and the proximity of the Nemaha uplift argues against this interpretation. A more distant source is suspected by this author, possibly the Canadian Shield to the north or even the Ozark uplift to the east. It is further suggested that deposition occurred at or near base level, with occasional minor inundation by marine waters, possibly under estuarine conditions. The overlying black shales and thin limestone probably indicate marine transgression and a temporary cessation of fluvial dominance within the study area.

The areal distribution of the McLouth sandstone member is far greater than initially recognized by most authors. The evidence presented suggests it occurs throughout eastern Kansas north of the Bourbon arch and probably extends throughout the Forest City basin.

Regional correlations across eastern Kansas and into the Forest City basin demonstrate that the McLouth strata occur stratigraphically below the oldest recognized Desmoinesian-aged strata (Warner interval). The tentative correlations of a prominent coal bed (C-7) and crinoidal limestone (x-marker) with the Riverton Coal and the Burgner Limestone, respectively, suggest an Atokan age for the McLouth strata. In addition, palynologic evidence (Carol Williams, Houston, Tx., in preparation) confirms the pre-Desmoinesian age of the McLouth section.

Regional mapping of the Cherokee Group throughout eastern Kansas has demonstrated that the Bourbon arch played a prominent role in restricting McLouth deposition to the Forest City basin. Evidence suggests that the arch effectively divided the Forest City and Cherokee basins until late Riverton deposition, at which time these sediments were deposited across the arch and buried it. It is also apparent that the orientation of the Bourbon arch is east northeast-west southwest; contrary to most previous depictions of the arch.

The regional correlations and tentative nomenclature presented in this study provide a useful framework which

should facilitate the further investigation of the Cherokee Group, particularly the lower section, in northeastern Kansas. The proposed Riverton Formation is believed to represent an overall transgressive-regressive cycle masked by extensive fluvial overprinting. The numerous multistory and laterally complex sand bodies within the McLouth sandstone member record a period of non-marine deposition and appears to be indicative of autocyclic (stream avulsion, crevassing of levees, etc.) mechanisms masking the allocyclic (tectonic pulses, climatic fluctuations, etc.) mechanisms apparently influencing Riverton deposition in northeastern Kansas. The Burgner limestone member reflects the marine period of deposition during the transgressive phase of the overall cycle. The Riverton Coal bed capping the sequence probably records regression of the marine influence and resumption of terrestrial influence throughout the study area. The Riverton sedimentary cycle is not the classic "cyclothem" prevalent throughout much of the Pennsylvanian of the midcontinent. There is no "core shale" or "upper limestone". However, there is cyclicity, and there is a remarkable resemblance to the Cherokee cyclothem model (Figure 16) of Heckel (1978, p. 10, fig. 3).

Cherokee Cyclothem

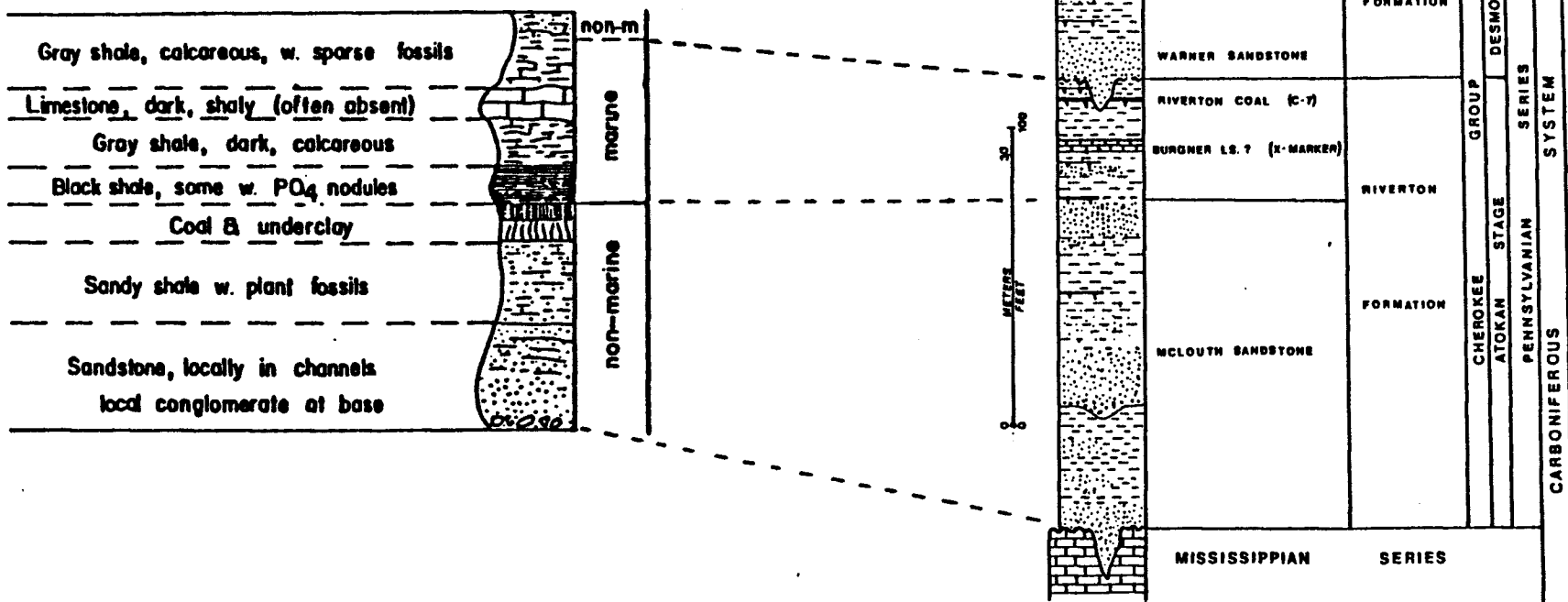


FIGURE 16 - Comparison of the Cherokee cyclothem model of Heckel (1978) to the proposed Riverton Formation.

SUGGESTIONS FOR FURTHER STUDY

The recognition of widespread stratigraphic units within the Lower Cherokee strata of northeastern Kansas useful in regional correlation work should provide the means by which additional study of this section in the Forest City basin is possible. The biostratigraphic techniques utilized by Ravn (1986) need to be broadly applied to revise the Cherokee Group of northeastern Kansas. Furthermore, the geological societies of the four state region bounding the Forest City basin need to unify the terminology applied to the various stratigraphic intervals within the basin.

Recommendations of a more localized interest would be:

- 1) to investigate the relationship of the Lower Cherokee section (Riverton Formation) to the Nemaha uplift in northeastern Kansas
- 2) To investigate the proposed Bower Formation for age determination and relationship to the overlying McLouth strata. Is the Bower correlative with the lower McLouth (Zone 1) interval? If so, what does this suggest for early Pennsylvanian deposition in northeastern Kansas? These questions need to be answered.

A sufficient geological data base is currently available as well as the methodologies necessary to resolve the considerable confusion surrounding the Cherokee Group in northeastern Kansas. The elimination of this confusion will greatly contribute to understanding the Forest City basin and midcontinent geology in general.

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BIOGRAPHICAL SKETCH

Matthew Owen Strickland was born December 29, 1960 in Casper, Wyoming. After attending primary school in Connecticut and New Jersey, he moved to Houston and graduated with honors from Memorial High School.

Matt received a four-year Conoco, Inc. scholarship with which he attended the University of Texas at Austin. He received a Bachelor of Science degree in geology in 1983. Scholastic interests focused on a broad spectrum of geologic curricula and selected petroleum engineering courses. Strickland joined the American Association of Petroleum Geologists (AAPG), the Society of Petroleum Engineers (SPE), and the student geological society. Matt attended geology field camp in Switzerland and Germany. Professional experience during this period included working with seismic and gravimeter field crews in Barbados and east Texas. He was also a research assistant for both Lacoste and Romberg, Inc. and Richard Nehring in Austin, Texas.

Enrolling at the University of Southwestern Louisiana in the graduate geology program in 1984, Strickland's scholastic interests focused on courses in sedimentary geology and geophysics while working as a teaching assistant. He received grants in aid from the Graduate Student Organization where he served as departmental representative, and from the Pennzoil Company.

Matt plans to pursue professional employment in the petroleum industry.