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**STRATIGRAPHY, PETROGRAPHY, AND DEPOSITIONAL  
ENVIRONMENTS OF THE PAWNEE LIMESTONE  
MIDDLE PENNSYLVANIAN (DESMOINESIAN),  
MIDCONTINENT NORTH AMERICA**

by

R. C. Price

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Rex Clayton Price

An Abstract

Of a thesis submitted in partial fulfillment  
of the requirements for the degree of  
Doctor of Philosophy in Geology  
in the Graduate College of  
The University of Iowa

December, 1981

Thesis supervisor: Professor Philip H. Heckel

## ABSTRACT

The Pawnee Limestone represents a major cyclic depositional sequence in which rapid transgression deposited thin carbonate (Childers School Limestone) and shale (Anna Shale Member), and slower interrupted regression deposited both thicker carbonate (Myrick Station Limestone and Laberdie-Coal City Limestone) and clastic (Mine Creek Shale) sequences. Maximum transgression culminated in deposition of the widespread marine black, fissile, and phosphatic Anna shale, which accords better with the model of Heckel (1977) than the nearshore model of Merrill (1975). The Pawnee regressive sequence is interrupted by a second, though minor, transgression at the end of Mine Creek Shale deposition. Increase conodont abundances are associated with both transgressive shales.

In addition to sea level oscillations, sea floor topography, including the "Shelf Edge Rise," Bourbon Arch, Saline County Arch, Lincoln Fold Complex, and intervening basins, strongly affected sedimentation patterns during Pawnee time. Algal mounds are generally restricted to topographic highs whereas significant coal formation is restricted to basins.

Newly defined beds are 1) Joe shale bed above Mine Creek and below Laberdie-Coal City representing the second transgressive phase; 2) "Lower Laberdie Limestone," which formed on the Bourbon Arch and is laterally equivalent to the Mine Creek Shale; and 3) Frog limestone bed, laterally equivalent to both Myrick Station and "Lower Laberdie" limestone, which pinches out southward into the Cherokee Basin between the Anna and Joe Shales.

The Sageeyah Limestone, a member of the Labette Shale below the Pawnee, makes up the lower half of the Oologah Formation of Oklahoma, whereas the Pawnee makes up the upper half. This corrects previous miscorrelations which had Pawnee Limestone forming the lower half of the Oologah and the overlying Altamont Limestone forming the upper half.

Diagenetic trends show bladed rim cement lining interior voids of skeletal grains deposited on topographic highs or northward in the more shoreward direction. Adjacent to black shales, which are interpreted as deeper water deposits, interior bladed rims are absent. Dolomitization, generally ferroan, commonly occurs within argillaceous carbonates or in carbonates adjacent to black shales and probably reflects clays as a source of  $Mg^{++}$ .

Abstract approved:

Philip D. Heckel  
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CERTIFICATE OF APPROVAL

PH.D. THESIS

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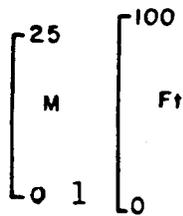
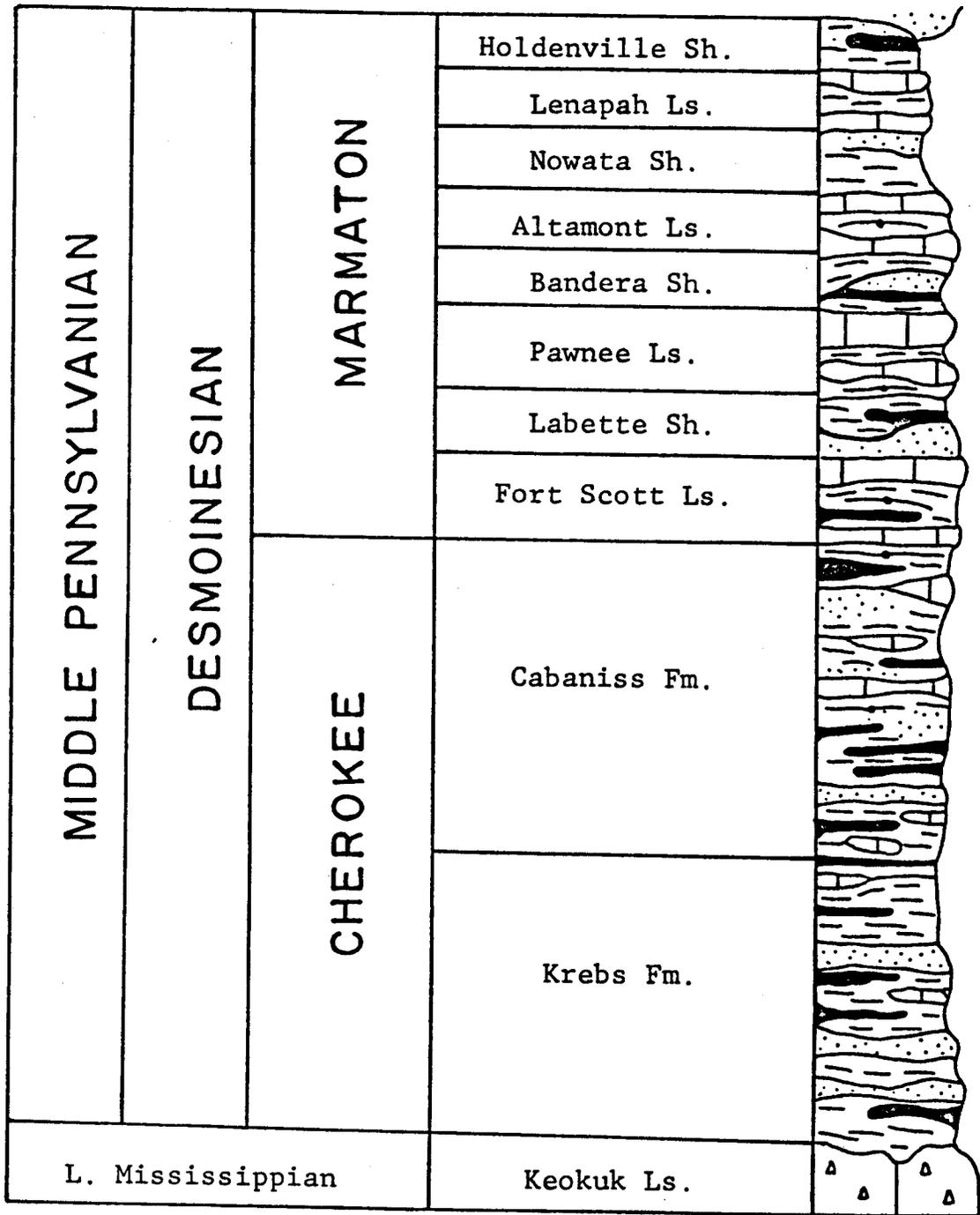
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CHAPTER I  
INTRODUCTION

Pennsylvanian cyclic sequences in Midcontinent North America have been known for a long time, with most recent work on Upper Pennsylvanian units. The present work is the first detailed study of a Middle Pennsylvanian unit since that of Schenk (1967).

The Pawnee Limestone of Middle Pennsylvanian (Desmoinesian) Age, is one of four limestone formations constituting the Marmaton Group (Figure 1). It is exposed along 960 kilometers of outcrop extending from northeastern Oklahoma across southeastern Kansas, central Missouri, southwestern Iowa and into east-central Nebraska. The Iowa and Nebraska outcrop areas represent deposition around the northeastern edge of the Forest City Basin whereas units in north central Missouri were deposited across part of the Lincoln Fold System and the Saline County Arch. Units in southeastern Kansas were deposited across the Bourbon Arch and the Cherokee Basin, which extends into northeastern Oklahoma. At the southernmost limit of the limestone outcrop in the Tulsa area, units were deposited across the "Shelf Edge Rise," which separates the shallow Cherokee Basin from the deeper Arkoma Basin to the south.

Figure 1. Stratigraphic position of Pawnee Limestone in Middle Pennsylvanian sequence of Kansas. (From Heckel, et al., 1979, p. 10.)



EXPLANATION

- Limestone
- Shale, gray, green, or red
- Shale, black, phosphatic
- Sandstone
- Coal

Figure 1

The strike of the Pawnee outcrop belt changes from northeast across Oklahoma, Kansas, and Missouri to due north at the Missouri-Iowa border and ultimately to northwest across southwestern Iowa into Nebraska (Figure 2). This progressive westward bending of the outcrop belt reflects deposition around the eastern and northern margin of the Forest City Basin. Along the southern portion of the outcrop belt the regional dip is approximately 30-40 feet per mile (5.1-7.5 m/km) to the northwest. In Iowa the beds dip essentially the same amount to the southwest toward the center of the basin.

Topography along the outcrop belt in Kansas and Oklahoma is characterized by eastward facing escarpments or cuestas formed by the limestone resistance to erosion. Although the Pawnee Limestone is generally poorly exposed along its outcrop belt, these eastward facing escarpments can expose weathered but nearly continuous outcrop for miles. The backslope commonly weathers at the angle of dip and is generally quite weathered, with outcrops exposed only by occasional stream or artificial cuts. The top of the limestone formation is usually eroded, slumped, and difficult to find because of the lack of a resistant overlying unit. Strike ridges are more pronounced where streams are more youthful and downcutting is common, as in northern Oklahoma within the drainage basin of the Verdigris River and along the Kansas-Missouri border within

Figure 2. Location map of Pawnee exposures (black dots) and cores (bullseyes) studied. Open circles refer to reference sections taken from other sources. See Appendix A for exact location of localities.

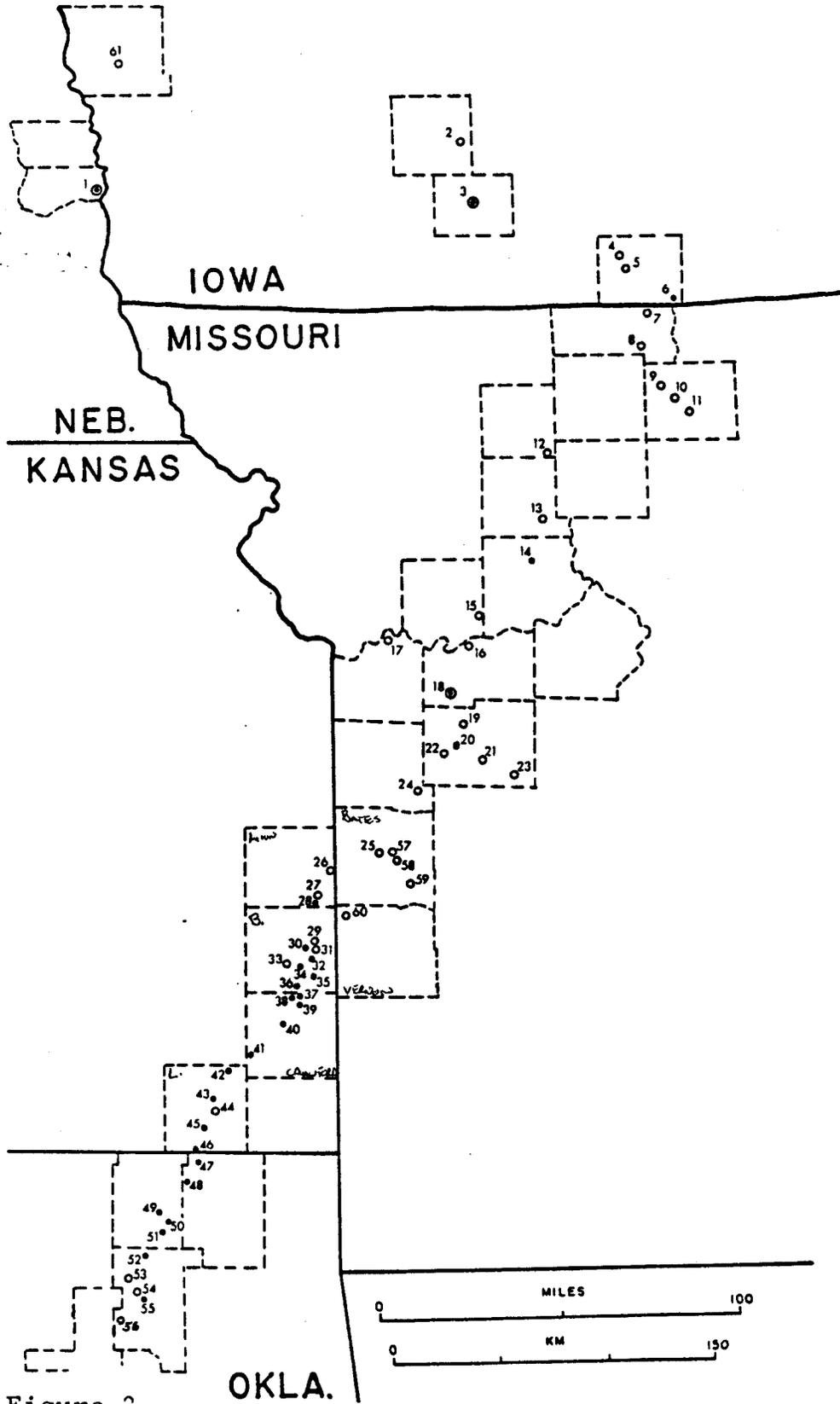


Figure 2

OKLA.

the drainage basin of the Marais des Cygnes (Osage) River. These two drainage basins are separated in southern Kansas, adjacent to the Oklahoma border, by the drainage system of the Neosho River (Figure 3), which has not downcut as deeply, leaving topography characterized by flat land with gently rolling hills. Outcrops and surface exposures are rare in this area. Most complete sections in both southeastern Kansas and northern Oklahoma are found in quarries and along artificial highway and railroad cuts. Outcrops are rare in northern Missouri, Iowa, and Nebraska because of the cover of Pleistocene glacial deposits.

In the vicinity of the type locality of the Laberdie Limestone Member in Linn County, Kansas, the Pawnee Limestone consists of the following stratigraphic sequence in ascending order: 1) Anna Shale Member, 2) Myrick Station Limestone Member, 3) Mine Creek Shale Member, 4) Laberdie Limestone Member (see Figure 4). It is underlain by the Labette Shale and is overlain by the Bandera Shale.

#### Purpose

The Pawnee Limestone of the Midcontinent area is one of the few limestone formations of Middle Pennsylvanian age that has not received recent detailed study. The purpose of this study is 1) to thoroughly map the Pawnee Limestone across its outcrop belt, 2) work out the detailed stratigraphy in order to solve longstanding correlation

Figure 3. Location of drainage systems. Marais des Cygnes, Neosho, and Verdigris Rivers (dotted) cut across and expose rocks along outcrop belt of Marmaton Group (solid wavy line).

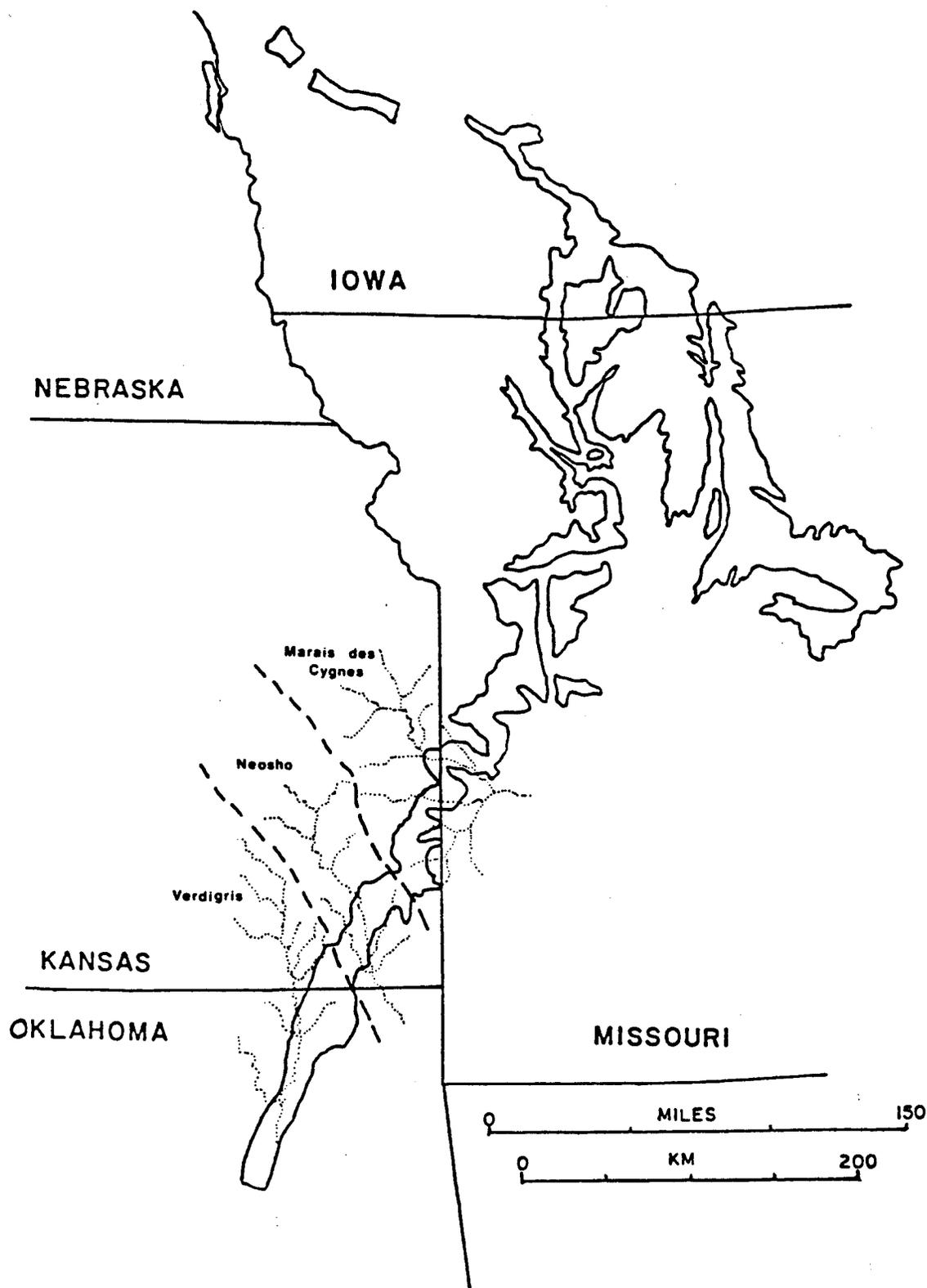


Figure 3

Figure 4. Measured section near type locality of Laberdie Limestone Member of Pawnee Limestone. Shows typical cyclic succession north of Bourbon Arch in southeastern Kansas. Standard lithologic symbols used, except convex-upward curves within limestone pattern represent abundant phylloid algae and triangles within limestone represent an abundance of chert. Solid black lines with blackened circles represent black, fissile, and phosphatic shale. See Appendix A (#28) for location of section.

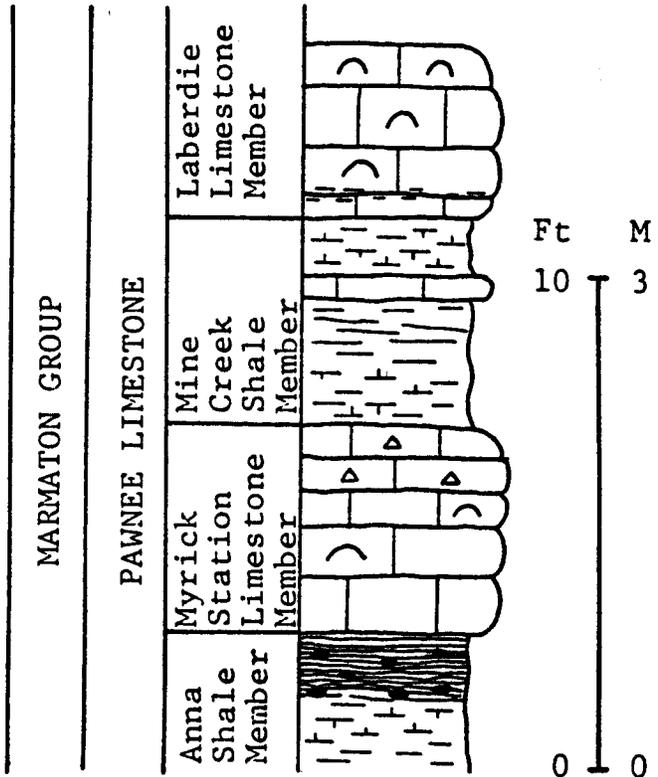


Figure 4

problems, 3) study petrography of the limestones, and 4) ultimately determine the environment of deposition and establish patterns of diagenesis related to positions within the stratigraphic sequence. Aside from Schenk (1967), no detailed regional work on the Middle Pennsylvanian has yet been undertaken.

Differences in regional paleogeography between Middle and Upper Pennsylvanian time affected the facies distribution now seen along outcrop in southern Kansas and northern Oklahoma. In Middle Pennsylvanian time, the carbonate shelf edge extended southward to the Tulsa region in Oklahoma and dropped off into the Arkoma Basin where clastic deposition prograded from the south (Moore, 1979). By late Pennsylvanian time the basin to the south was filled, and clastics spilled over onto the shelf and into southern Kansas (Heckel, 1980). Paleogeographic effects have commonly been overlooked by many workers when studying other Midcontinent Pennsylvanian units. However, Ravn (1981) and Mitchell (1981), studying Missourian units (Upper Pennsylvanian), and Schenk (1967) and Gentile (1967), studying Desmoinesian units (Middle Pennsylvanian), have noted subtle geologic structures that caused topographic variation within the basin, which have had a profound effect on depositional patterns. An explanation of the detailed stratigraphy of the Pawnee and of facies and diagenetic changes within the carbonates, which are

based primarily on petrographic analysis, will be related to both paleogeography and sequence of depositional environments.

#### Method of Study

Initial work consisted of field mapping of the Pawnee Limestone. Twenty-five sections have been measured, and detailed samplings of fifteen of these sections have been made. One of these sections was processed for pollen and spores to determine if any trends might be environmentally significant. Complete petrographic analysis was conducted on the limestones from ten of the collected sections. The limestones were studied to determine variation in major fossil groups and grain-size characteristics, which form the basis of depositional interpretation. Diagenetic changes such as compaction and cement history were also studied. Both limestone and shale members from eight of the collected sections have been processed for conodonts. Conodonts were identified to genus and to species when possible in order to determine if they follow the same distributional trends described by Heckel and Baesemann (1975) for Missourian conodonts. Petrographic analysis and conodont studies were also conducted on key intervals from the remaining collected sections. To supplement outcrop data, cores from Missouri, Iowa, and Nebraska were studied. In addition to the twenty-five measured sections, a total

of thirty-six sections from the literature were studied for the purpose of constructing a cross section for regional correlation. Only twenty-nine from this total of sixty-one sections were actually used as control for construction of this cross section.

Synthesis of all detailed analyses should allow determination of the best depositional model for the Pawnee Limestone. The consideration of paleogeographic variations as part of the depositional model should prove important in explaining broad stratigraphic changes along the outcrop belt and also in explaining more subtle facies and diagenetic changes. This depositional model should be an important predictive tool when studying other Midcontinent Middle Pennsylvanian units deposited under similar paleogeographic conditions.

#### Previous Work

Middle and Upper Pennsylvanian rocks of the Midcontinent consist of laterally persistent sandy shale formations alternating with laterally persistent limestone formations containing thin shales. Cyclothems, or vertically repeating sequences of beds, were first noted in Middle Pennsylvanian rocks in Illinois by Weller (1930) and in Upper Pennsylvanian rocks in Kansas by Moore (1931). Most units in Kansas were classified into cyclothems by Moore (1936, 1949) and were considered to have resulted

from sea level oscillations. Based on the work of Elias (1937), Moore considered the fusulinid-bearing limestones to represent maximum transgression. More recently, Schenk (1967) and Heckel (1977) considered the black phosphatic shale member within the limestone formation to represent maximum transgression. The basic vertical cyclic pattern referred to as a "Kansas-type cyclothem" (Heckel, 1977, p. 1046) is, in ascending order: sandy "outside" nearshore shale formation - "middle" or transgressive limestone member - "core" offshore shale member - "upper" or regressive limestone member - sandy "outside" nearshore shale formation (Figure 5). The middle and upper limestones and intervening black (commonly phosphatic) shale constitute the marine formation for which the cyclothem is named. The term "core" (Heckel and Baesemann, 1975) refers to the position of the black shale member between the limestone members within the limestone formation, whereas the "outside" shale formation is outside of this limestone formation.

The depositional model proposed by Heckel (1977) suggests that the outside shale was deposited under near-shore marine to nonmarine conditions. The ensuing transgression resulted in deposition of the middle (transgressive) limestone. At maximum transgression, the water depth was great enough for development of a

Figure 5. Basic vertical sequence of individual "Kansas cyclothem." This transgressive-regressive depositional unit characterizes, with only minor modification, most of the Marmaton, Kansas City, Lansing and Shawnee Groups of the Midcontinent Pennsylvanian. Positional terms derived from Moore (1936) for limestones and Heckel and Baesemann (1975) for shales. Conodont faunas conspicuously differentiate the two shale members. (From Heckel, 1977, Fig. 2.)

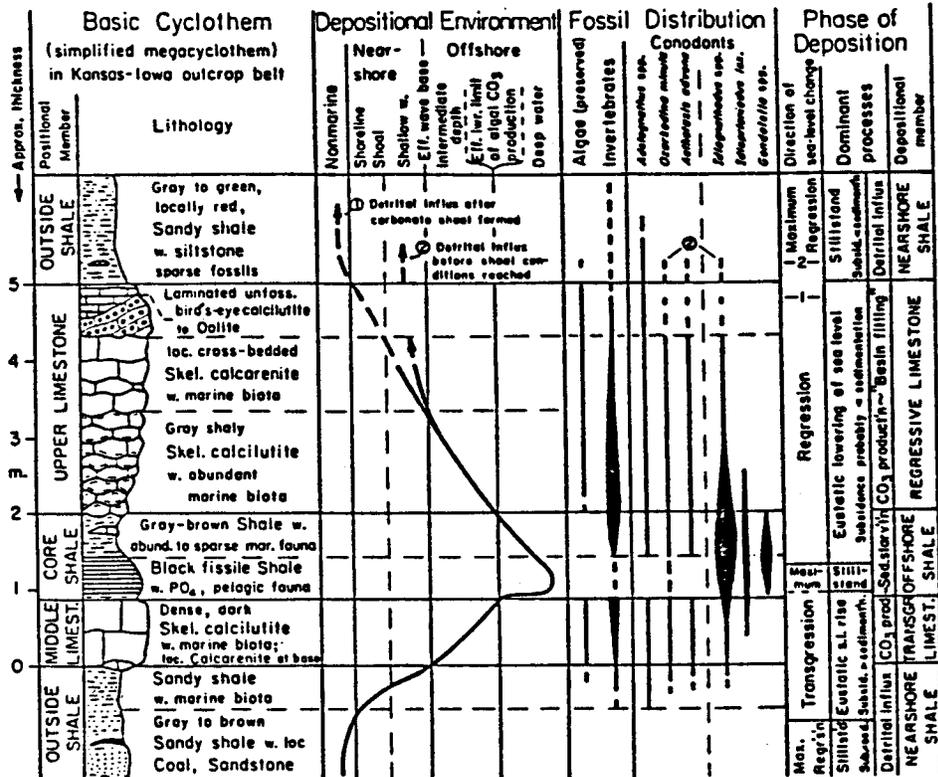


Figure 5

thermocline, which led to anoxic bottom conditions. Quasi-estuarine circulation upwelled nutrient-rich waters and resulted in deposition of the black phosphatic shale facies (Heckel, 1977). Subsequent regression re-established bottom oxygenation, and the upper (regressive) limestone was deposited. Encroachment of detritus associated with continued regression allowed nonmarine to marine prodeltaic muds to inundate the area, forming the overlying "outside" shale formation.

Although in some areas the Pawnee Limestone shows elements of the "Kansas-type cyclothem," along much of its outcrop it lacks the middle (transgressive) limestone and, therefore, is more like an Illinois cyclothem (Figure 6), which had been interpreted differently by Weller (1956) and Zangerl and Richardson (1963). Zangerl and Richardson (1963) described the Middle Pennsylvanian Mecca Quarry Shale in the Illinois Basin and considered this fissile black shale to have been deposited extremely rapidly beneath an algal flotant in a nearshore shallow-water environment. Merrill (1975) and Merrill and Martin (1976), based also on work in the Illinois Basin, considered the black fissile shales of the Midcontinent area to have been deposited beneath this type of flotant in nearshore to lagconal environments. Ravn (1981) thoroughly reviewed the nearshore - maximum transgression controversy for deposition of Midcontinent black fissile shales and

Figure 6. Basic Illinois cyclothem. Shows close resemblance to Pawnee cyclic sequence where "middle" limestone is absent.

## 'TYPICAL' ILLINOIS CYCLOTHEM

(Weller, 1930)

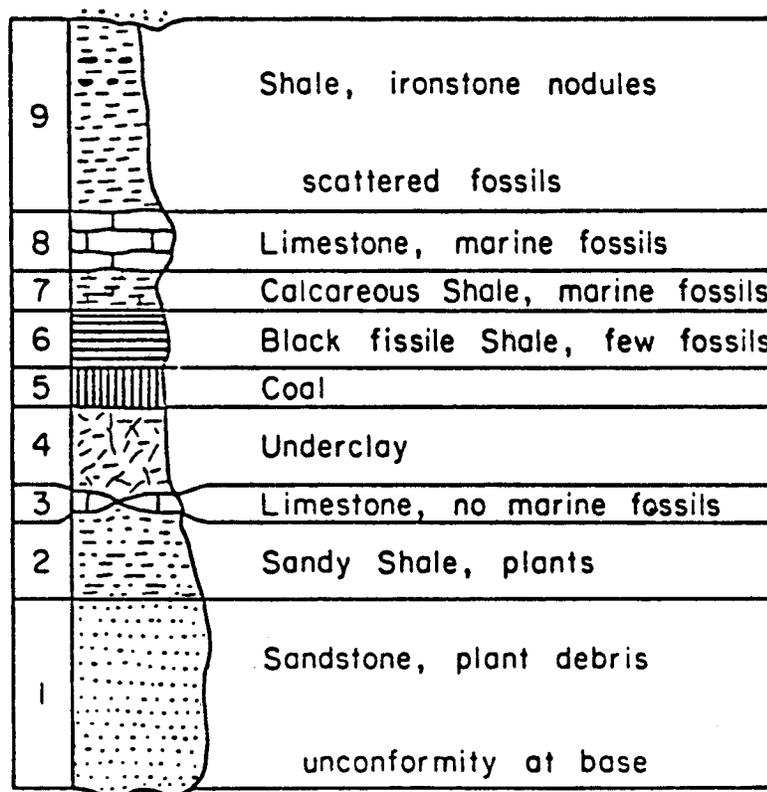


Figure 6

stressed the problems of applying depositional models developed in one area to different geographic and depositional settings as has been done by Merrill (1975).

Previous stratigraphic studies that included the Pawnee Limestone were conducted by Ohern (1910), Alcock (1942), Travis (1942), Oakes (1952), Cade (1952), Faucette (1954), Sparks (1955), Schmidt (1959), Cole (1965), Chenoweth (1966), and Gamble (1967) in northern Oklahoma, by Jewett (1941, 1945), Jungmann (1964), and Gamble (1967) in Kansas, by Cline (1941), Greene and Searight (1949), Cline and Greene (1950), Jefferies (1958) and Bowman (1963) in Missouri, and by Cline (1941), Wilcox (1941), Cline and Stookey (1943), Hershey, et al. (1960), Stark (1973) and O'Brien (1977) in Iowa. Foraminifers have been studied in Oklahoma by Alexander (1954) and Laukel (1956), in Kansas by Laukel (1956) and in Missouri by Bebout (1963). Palynological studies were conducted in Missouri by Weiser (1960), and the Pawnee megafauna of Adair County, Missouri, was studied by Bridges (1957). Conodonts were studied in Missouri by Burnley (1938) and in Iowa by Chamblin (1956). Currently, J. W. Swade (manuscript in preparation) is studying conodonts of the Marmaton Group from cores in Iowa.

Early works on the Pawnee Formation relied mainly on outcrop description and gave member names to most of the lithologies, but did not undertake a complete regional

analysis utilizing modern depositional interpretations. Several different workers studied small portions of the entire outcrop belt and produced questionable correlations of the members within the Pawnee. Also, the basal Oologah Formation of Oklahoma has traditionally been correlated with the Pawnee Limestone, whereas the upper half has been correlated with the Altamont Formation (Oakes, 1952; Chenoweth, 1966). Results of the present study, however, do not corroborate these correlations.

## CHAPTER II

### STRUCTURAL FEATURES AND INFLUENCE

#### Influence

In tectonically active areas the influence of structural movements on sedimentation patterns has been well documented (Dickinson, 1974). Also, control of sedimentation patterns in the relatively stable mid-craton has been noted along structures such as the Nemaha Uplift and Bourbon Arch (Moore and Jewett, 1942; Jewett, 1951). These structural features seem to have been associated with the Ozarks to the east and the more tectonically active Ouachitas to the south. Structural features like the Nemaha Uplift and Bourbon Arch tend to evolve from time of maximum activity to ultimate quiescence and go through the stages of 1) exposure, 2) initial inundation, 3) late inundation, and 4) buried topography. Since several hundred million years may elapse before structures cease to exert an influence upon sedimentation, the rocks deposited during this span of time may represent a wide variety of depositional settings and numerous sea level oscillations.

### Exposure

The exposure stage is characterized by maximum tectonic activity associated with faulting and possibly folding. Sedimentary rocks thin toward the feature, are commonly upturned along the margins, and ultimately pinch out over the top. Older rocks exposed along the crest show evidence of erosion and subaerial exposure.

### Initial Inundation

The initial inundation stage suggests decreased tectonic activity, which is no longer capable of maintaining the structure above sea level as in the exposed stage. Structural relief, still relatively high, allows thick sedimentary sequences to form in deeper portions of the basin where sedimentation rates are greater. These sedimentary deposits thin toward the structure but extend over the crest. Deposition over the crest indicates the structure was no longer subaerially exposed, but thinning of the deposit illustrates the structure's persistent, though diminished, control on sedimentation. This stage is readily recognized because thick sedimentary sequences of up to 100 meters or more are affected by the high structural relief. If the feature was lower with little structural relief, thick sedimentary sequences would extend over the crest with minimal thinning. Thinner sedimentary deposits, however, would be affected by features of both high or low relief.

### Late Inundation

The late inundation stage is characterized by low relief, which causes only subtle topographic expression on the sea floor. Major clastic influxes override the structure with little effect on thickness of the stratigraphic sequence. However, some thinning over the crest occurs in thinner clastic sequences.

Although major wedging of sediments normally does not occur across these structures, distinct facies changes in both carbonate and clastic sequences have been recognized in the Midcontinent Pennsylvanian by Schenk (1967), Gentile (1967), Ravn (1981), Mitchell (1981), and this study (see Depositional Environments section). Nevertheless, these broad gentle features are not easily recognized because 1) beds deposited over the structure exhibit little if any reversal of dip and 2) thinning of major stratigraphic sequences is minor. In the absence of the above two characteristics, most previous workers did not consider sea floor topography, controlled by buried structure, as a cause for lateral facies distribution of midcontinent sedimentary rock units. Rocks deposited higher in the stratigraphic sequence, under even less local structural influence, would probably exhibit no definitive evidence for the existence of sea floor topography. Nevertheless, even minor surface irregularities could still control facies distribution. Although these facies distributions

alone could not be considered evidence of topographic relief, an evaluation of basin history, by studying older rock units, should determine whether this area was previously occupied by an active structure. Epeirogenic movements along buried fractures associated with major cratonic structures might result from continued sediment loading in the basin and would enable the features to exist as a minor topographic high for an extended length of time.

#### Buried Topography

The buried topography stage is characterized by a relatively flat depositional surface with no more structural control on topography.

It should be noted that these stages are arbitrary subdivisions and that transitional features with characteristics of two different stages can occur between categories in the sequence.

#### Plate Tectonics and Regional Structural Development

Because distribution of geologic structures seems to exert a control on major depositional patterns and also on more subtle facies changes, an understanding of the regional distribution and structural history of major orogenic belts is needed to better interpret the development of local structure. The existence of major Precambrian rift features is commonly accepted (Burke and

Dewey, 1973a; Dewey and Burke, 1973). These features are believed to be associated with continental fragmentation that shaped the North American continent (Burke and Dewey, 1973b) or with extensional events (Stewart, 1976). In contrast to younger rocks, these Precambrian epicratonic rifts are not confined to margins of the craton (Stewart, 1976). The Ouachita-Marathon complex apparently formed along Precambrian zones of weakness reactivated during Pennsylvanian continental collision (Hill, 1970; Walper, 1977; Kluth and Coney, 1981). Contrary to Irving (1977) who thought that during the Carboniferous South America collided with the eastern coast of North America, Burges (1976), Walper (1977), Ross (1979), and Kluth and Coney (1981) concluded that South America collided with the southern margin of the North American craton forming the Ouachita-Marathon complex. The general northerly component of stress (Hills, 1970; Kluth and Coney, 1981) resulted in both vertical and strike-slip components of movement (Kluth and Coney, 1981). According to Burgess (1977) the stresses were oriented to the northwest during the Pennsylvanian but were oriented more to the northeast during Permian time. This probably corresponds to continental collision which occurred initially along the Ouachitas during Middle Pennsylvanian time with ultimate collision along the Marathon belt in Late Pennsylvanian and Permian time. This

indicates clockwise rotation of the South American plate upon collision with the North American continent.

#### Local Structure Development

The predominant northwest-southeast structural trend in Kansas and Missouri is probably a result of the continental collision forming the Ouachita-Marathon Complex. Positive structural features affecting the sedimentation patterns of the Pawnee Limestone (Figure 7) are 1) Nemaha Uplift, 2) Kirksville-Mendota Anticline of the Lincoln Fold System, 3) Saline County Arch, 4) Bourbon Arch, and 5) Shelf Edge Rise. The Pawnee outcrop crosses each of these structures except the Nemaha Uplift.

The Ozark uplift, a pre- and post-Pennsylvanian structure centered in southeastern Missouri, which has undergone intermittent movement since the Precambrian (Moore and Jewett, 1942), was considered a landmass of low relief during Desmoinesian time (Wanless, 1975). The Chautauqua Arch is a pre-Mississippian structure that represented the westward extension of the Ozarks into southeastern Kansas. By Pennsylvanian time the southern portion of the area previously occupied by the Chautauqua Arch was structurally depressed to form the Cherokee Basin. The northern part, however, continued to be an area of positive structural relief known as the Bourbon Arch. Farther to the south the Arkoma Basin, also structurally

Figure 7. Major structural features affecting Middle Pennsylvanian sedimentation patterns.

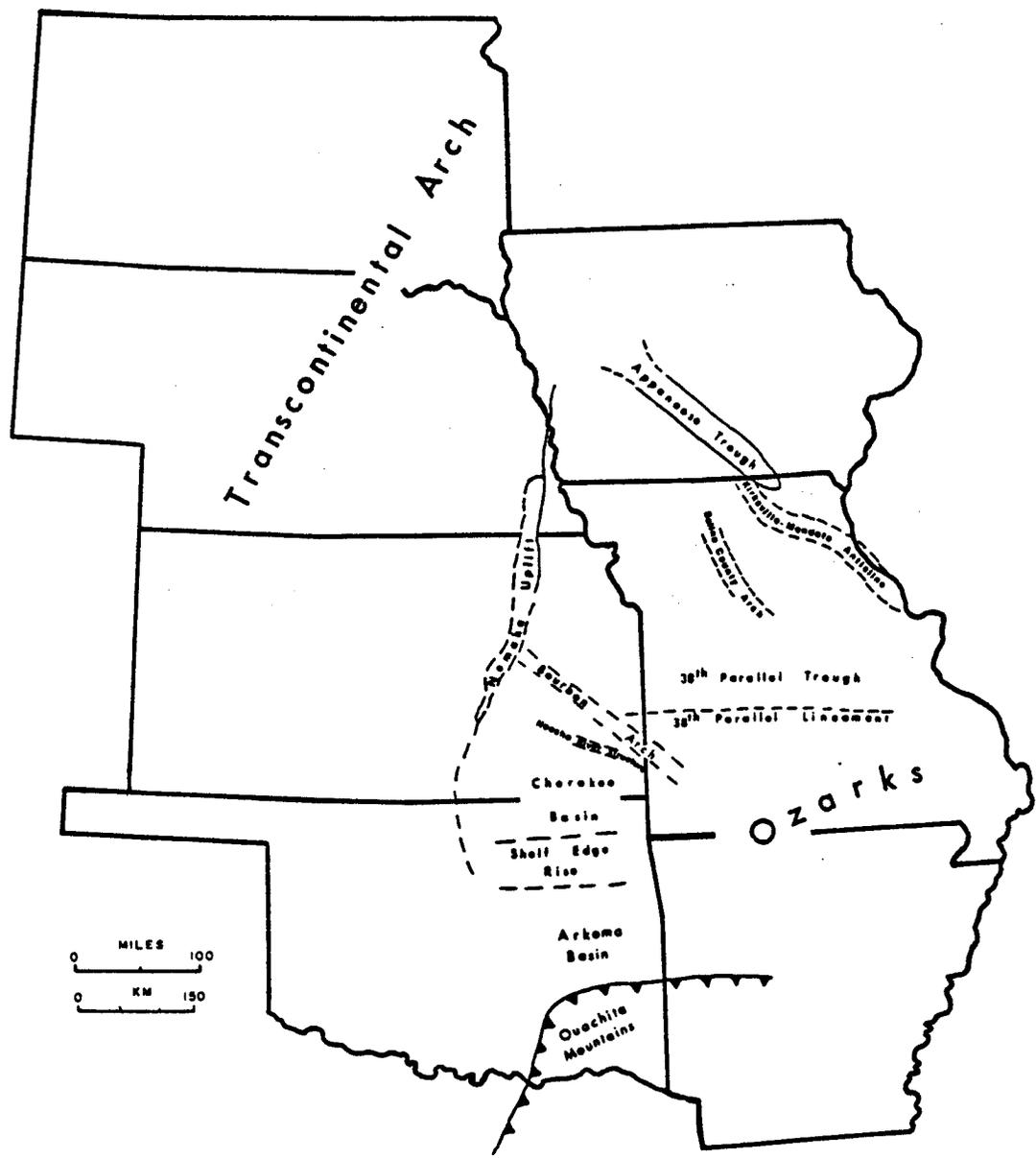


Figure 7

depressed, apparently was separated from deeper portions of the Cherokee Basin by an intervening high. This relative high is herein termed the Shelf Edge Rise, which will be defined further in a later section.

The Bourbon Arch, exposed during Early Pennsylvanian time, was covered by sediments during Middle and Late Pennsylvanian time (Jewett, 1951). The Nemaha Uplift, a north-south oriented structure bordering the west side of the Forest City Basin, remained active longer and was not covered until Missourian time.

In Missouri the northwest-southeast-trending Lincoln Fold System and Saline County Arch also affected sedimentation in Middle Pennsylvanian time. The Saline County Arch is located in northeastern Saline County (Searight and Searight, 1961), and its trend can be extended northward into Carroll and Livingston Counties.

The Lincoln Fold System as illustrated by Bunker (1981) is a series of anticlines and synclines occupying a 50-kilometer-wide belt in northeastern Missouri and south-central Iowa. The westernmost anticline (Kirksville-Mendota [McCracken, 1973]) and associated negative area to the east (informally called the "Appanoose Trough" by the Iowa Geological Survey [personal communication, Bill J. Bunker and Brian J. Witzke]) is the only portion of the Lincoln Fold System crossed by the Pawnee Limestone. Both the Kirksville-Mendota Anticline and the

Appanoose Trough strongly affected depositional patterns of the Pawnee.

The Bourbon Arch will be discussed in detail because 1) the term has been used in several different ways and needs to be defined and 2) since it was an exposed positive structure controlling sedimentation during Early Pennsylvanian time, its structural development and history should aid in understanding Midcontinent sedimentation patterns across Middle and Upper Pennsylvanian structures that were no longer subaerially exposed but were going through the initial or late inundation stages.

The Bourbon Arch, first noticed by Lee (1939) as an "anticlinal divide," was named by Moore and Jewett (1942) who showed it separating the Forest City Basin to the north from the Cherokee Basin to the south. The Bourbon Arch trends northwest-southeast and crosses Bourbon, Allen, and Coffey Counties, Kansas (Lee, 1943). Both Moore and Jewett (1942) and Jewett (1951) show the Arch as a broad structural feature approximately 40 kilometers in width. At the Kansas-Missouri border, Moore and Jewett (1942), Jewett (1951), and Wanless (1975) showed the Arch bending due east, whereas Merriam (1963) showed the Arch continuing in a southeasterly trend (Figure 8). In Missouri, McCracken (1971) considered an east-west linear feature, which is a westward extension of the Ozarks across southern Missouri into Kansas, as the Bourbon Arch. This trend

Figure 8. Various locations given for Bourbon Arch.  
Location of Wanless (1975) represented by alternating  
dots and dashes, McCracken (1971) by long dashes,  
Merriam (1963) by short dashes, and Moore and Jewett  
(1942) and Jewett (1951) between solid lines.

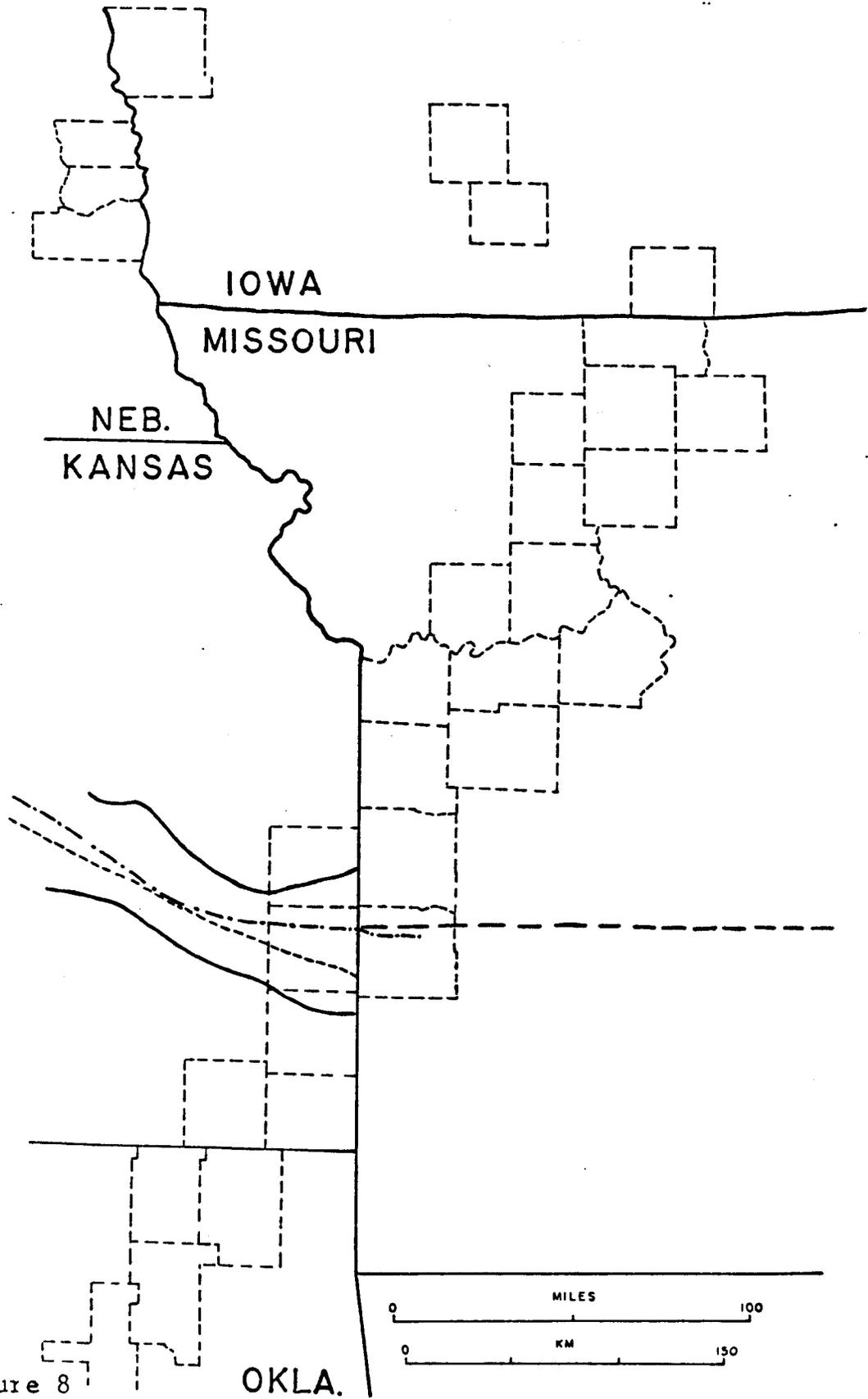


Figure 8

OKLA.

(Figure 8), determined by following a discontinuous series of east-west trending faults, is the dominant east-west structural zone in Missouri and cuts across the more common northwest-southeast oriented structures (McCracken, 1971). Denison (1966) shows Precambrian change along this same trend, which has subsequently been termed the 38th Parallel Lineament by Heyl (1972).

In southeastern Kansas two parallel northwest-southeast trending fault zones predominate which apparently controlled development of positive structures in the vicinity of the Bourbon Arch. These fault zones represent down-faulted grabens where sediment thickening occurred (Merriam, 1963). The northernmost fault (Chesapeake Fault Zone), developed near the end of Mississippian time and cuts Mississippian rocks, but Pennsylvanian rocks show no evidence of fracture (Merriam, 1963; McCracken, 1971). The upthrown southwestern side of the Chesapeake Fault Zone corresponds with the geographic position of the Bourbon Arch, which according to Jewett (1951) is a post-Mississippian structure. Timing of fault activity closely coincides with the appearance of the Bourbon Arch as a structural high (Figure 9). The upthrown northeastern side of the southern unnamed fault zone roughly corresponds with the geographic position of the Neosho River Structure, which was delineated by Ravn (1981) (Figure 9). These two fault zones are also illustrated on Precambrian structure

Figure 9. Location of Bourbon Arch (B) along upthrown southwestern margin of the Chesapeake Fault Zone (C). The Neosho River structure (A), location from Ravn (1981), roughly parallels the upthrown northeastern margin of a more southerly unnamed fault zone. These two parallel fault zones apparently controlled positive structural development along the entire area between them, which is herein collectively referred to as the Bourbon Arch Complex (BAC). Note continuation of Chesapeake Fault trend into Missouri and probable continuation of associated Bourbon Arch. The east-west 38th Parallel Lineament (L) intersects Chesapeake and southern unnamed fault zones in southeastern Kansas, increasing the structural complexity within the Bourbon Arch Complex. Solid line represents faults and the symbols U & D represent upthrown and downthrown sides respectively.

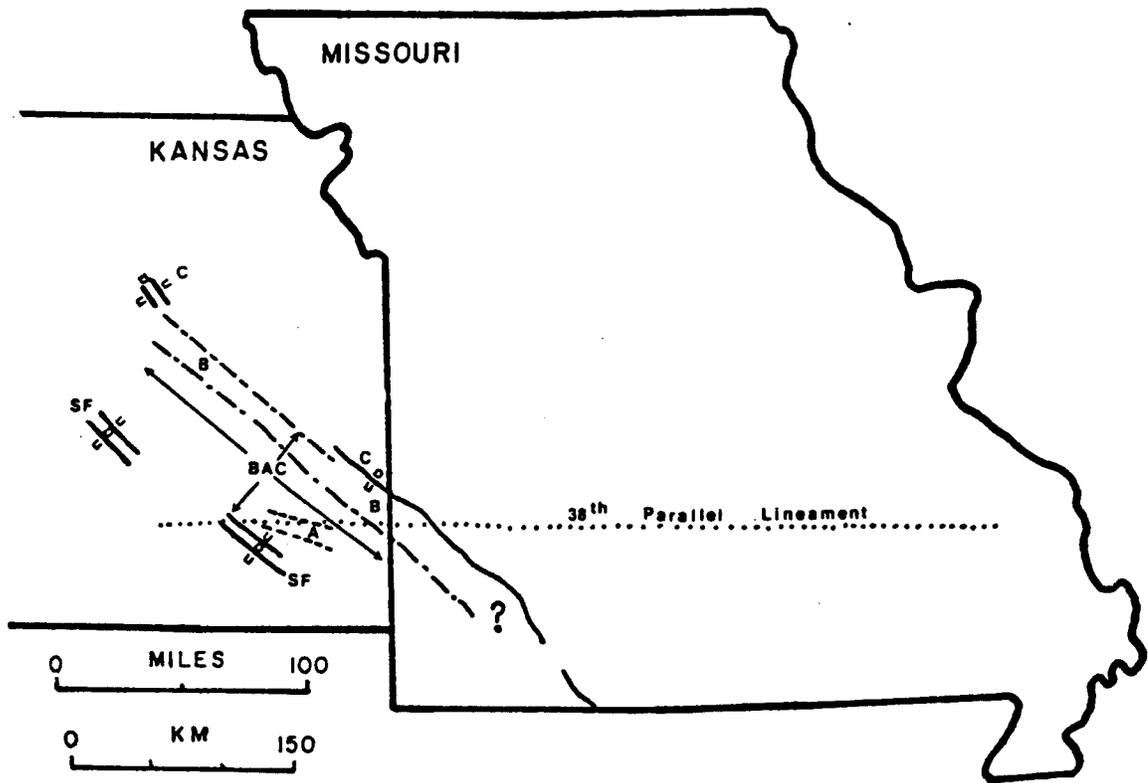


Figure 9

maps and probably reflect late Mississippian movements along Precambrian zones of weakness. The area between these two reactivated fault zones apparently represents a horst block and is reflected in the positive structural development of the Bourbon Arch and the Neosho River Structure during Pennsylvanian time. Since the structural features within this area appear to be genetically related, it is proposed that the term "Bourbon Arch Complex" is used for the entire area between these fault zones (Figure 9). The Neosho River Structure shall be restricted to the area north of the south fault zone and the Bourbon Arch shall be considered the positive area south of the Chesapeake Fault Zone. It should be noted that positive areas also lie outside of the Bourbon Arch Complex (Schell City-Rich Hill Anticline to the northeast and the Fredonia Dome to the southwest) and are possibly associated with upthrown blocks peripheral to these two graben fault zones.

The Bourbon Arch in Kansas, based on structural development and location, is genetically different from the Bourbon Arch of Missouri (38th Parallel Lineament). The east-west trending Bourbon Arch of Missouri (38th Parallel Lineament) cuts across northwest-southeast trending structure. The Bourbon Arch of Kansas has been shown to be a northwest-southeast trending structure and continuation of the Bourbon Arch into Missouri might be expected to be along the trend of the Chesapeake Fault Zone, which extends

southeastward across Missouri into northern Arkansas (McCracken, 1971) (Figure 9). Continuation of the east-west structural trend from Missouri is reflected in Precambrian rocks of Kansas. Based on the Precambrian structural map of Cole (1976), this trend intersects and cuts across the Kansas Bourbon Arch in eastern Allen County, and continues due west across Allen, Woodson, and Greenwood Counties (Figure 9). This east-west structural trend, east of Allen County, was apparently considered a continuation of Bourbon Arch of southeast Kansas by Moore and Jewett (1942), Jewett (1951), and Wanless (1975), and it accounts for their showing the Bourbon Arch bending to the east at the Kansas-Missouri border. This east-west trend, intersecting the Bourbon Arch, increases the structural complexity within the Bourbon Arch Complex. However, since it is not genetically related to the Bourbon Arch of Kansas and it is recognized as a separate structure, the name 38th Parallel Lineament will be used for the remainder of this study. To the north, an east-west trending trough borders this positive structure and is herein called the 38th Parallel Trough.

### CHAPTER III STRATIGRAPHY

The Pawnee Formation is part of the Marmaton Group named by Haworth (1898) for exposures along the Marmaton River in southeastern Kansas. The Marmaton Group is characterized by sandstone, shale, and coal sequences interbedded with limestones. Moore and Haynes (1917) subdivided the Marmaton, in ascending order, into the Fort Scott Formation, Labette Formation, Pawnee Formation, Bandera Formation, Altamont Formation, Nowata Formation, and Lenapah Formation. The Pawnee Limestone, named by Swallow (1866), was considered a single limestone ledge. However, Moore (1936) noted a thin limestone below a 0.6 meter black platy shale as constituting the base of the Pawnee. Jewett (1941) divided the Pawnee Formation of southeastern Kansas into four members, in ascending order: 1) Anna Shale Member, 2) Myrick Station Limestone Member (named by Cline [1941] for exposures in Missouri), 3) Mine Creek Shale Member, and 4) Laberdie Limestone Member. The Anna Shale Member included a thin slabbly limestone at its base that had been recognized from southwestern Missouri into southeastern Kansas (Jewett, 1941). Alcock (1942) noted thickening of this limestone bed to exceed 1.0 meter

in northern Oklahoma and considered it a separate member, which he designated as the Childers School Limestone Member. Farther south near Oologah, Oklahoma, Schmidt (1959) recognized several limestone beds below the Anna, which thickened to form a massive limestone. This was designated the Sageeyah Limestone Member of the Pawnee Formation (Schmidt, 1959) and included the Childers School Limestone of Alcock (1942).

Contrary to Ohern (1910), Oakes (1952) and Alexander (1954) who felt the Oologah Formation consisted of the Pawnee Formation at its base and the Altamont at the top, Schmidt (1959), Moore (1944, 1949), and Jewett (1941, 1945) considered the Pawnee to constitute most of the Oologah. Results of this study corroborate their conclusion.

#### Correlation of Units

The basis for determining correlations of units along the Pawnee outcrop belt is a study of twenty-five sections measured from outcrops and an additional thirty-six sections taken from previous works (see Appendix A for location of sections). These additional sections, from inaccessible cores or badly weathered and slumped outcrops that no longer can be measured accurately, give more control in areas where measured sections are widely spaced. The type section of the Oologah Formation (from Chenoweth, 1966) was used to clarify miscorrelations from the Kansas

outcrop area southward into Oklahoma. To ensure reliable correlation, sections were used only if they included key marker beds such as the Lexington Coal bed of the Labette Shale or the black phosphatic Anna Shale Member.

Figures 10 and 11, generalized cross-sections constructed from twenty-nine of the sixty-one sections that were studied, show facies relationships and gross lithologies of members of the Pawnee Limestone. Figure 12 is a generalized column showing correlations of members of the Pawnee and adjacent formations along the outcrop belt. The following summary refers to the facies relationships noted on the above figures.

The Anna Shale, the most laterally persistent member, is recognized along the entire outcrop area. In Oklahoma, the thickening of the Sageeyah Limestone Member (considered in this study to be a member of the Labette Shale) below the Anna and also of the Laberdie Limestone Member of the Pawnee Formation above the Anna make up most of the Oologah Formation. The Myrick Station Limestone Member overlies the Anna Shale and attains maximum thickness in southwestern Missouri. It is overlain by the Mine Creek Shale as recognized in Missouri, but to the north the upper Myrick Station interfingers with the lower Mine Creek Shale of Iowa. Toward the south the Mine Creek Shale interfingers with the "Lower Laberdie Limestone," which can be separated into a lower chaetetid facies and an upper

Figure 10. Generalized north-south cross-section of Pawnee Limestone showing names of different members and beds along outcrop belt. Datum is middle of black phosphatic Anna shale. Solid vertical lines indicate sections used as control for developing cross-section. A \* by section number indicates measured and described sections. If no \* by section number, then section is from the literature. See Appendix A for key to location codes and numbers.



Figure 11. Generalized north-south cross-section of Pawnee Limestone showing lithologic variation along outcrop belt. Lithologic symbols are as follows:

- Solid black = coal
- Continuous solid horizontal lines with circles = black, fissile shale with phosphate nodules
- Horizontal dashes = gray shale
- Horizontal dashes with vertical lines = calcareneous shale
- Brick pattern = limestone
- Convex-upward curves = phylloid algae
- Convex-upward quartermoons with vertical lines = chaetetids
- Brick pattern with horizontal dashes = argillaceous limestone
- Stippled with horizontal dashes = siltstone
- Stippled = sandstone

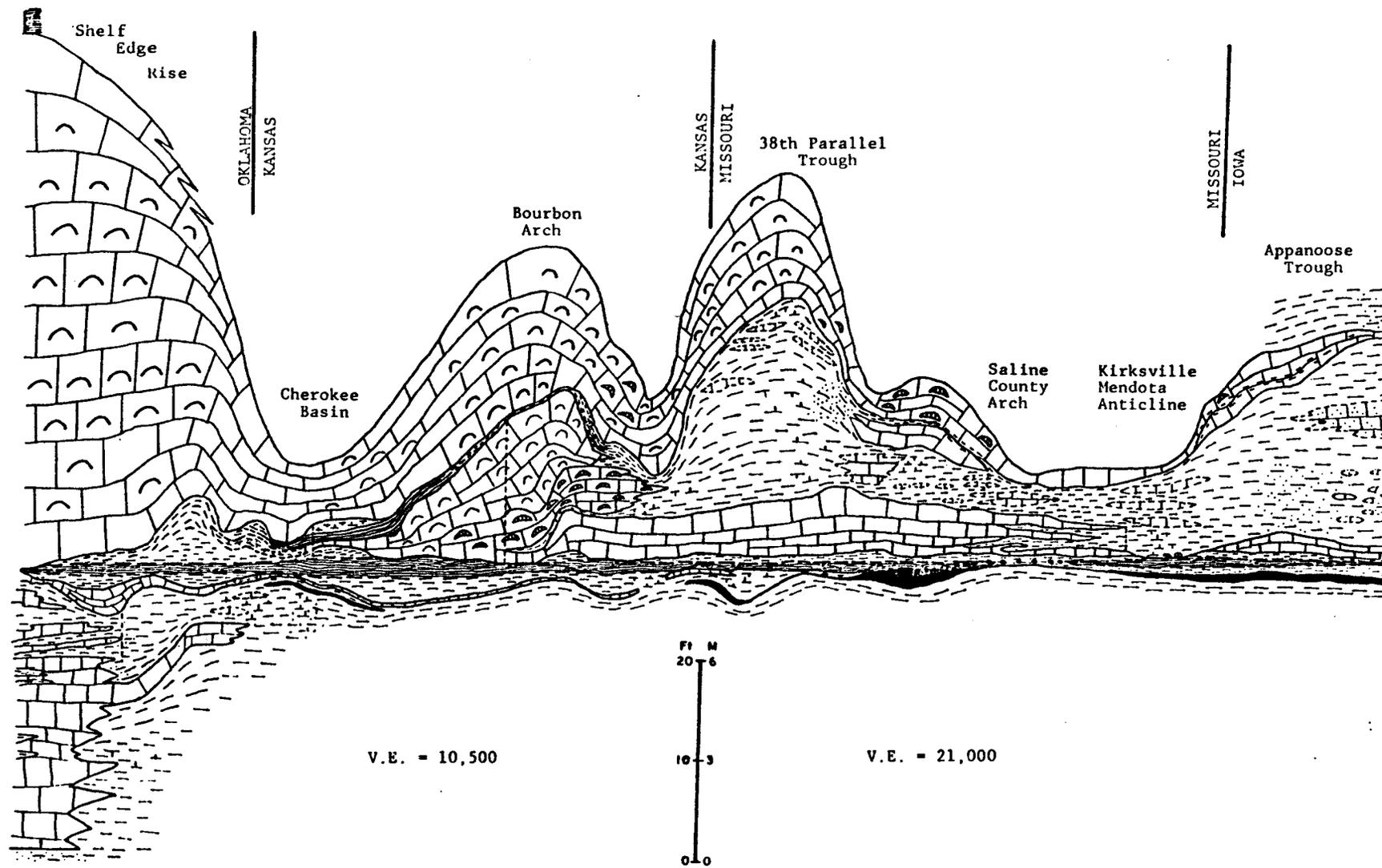


Figure 11

Figure 12. Generalized column showing correlation of  
Members of Pawnee Limestone and adjacent formation  
along outcrop belt.

SHELF EDGE RISE		CHEROKEE BASIN	BOURBON ARCH	38th PARALLEL TROUGH	APPANOOSE TROUGH	
OOLOGAH LIMESTONE	Laberdie Limestone Member	BANDERA SHALE	BANDERA SHALE	BANDERA SHALE	BANDERA SHALE	
	Anna Shale Member	Laberdie Limestone Member	Laberdie Limestone Member	Coal City Limestone Member	Coal City Limestone Member	
		Joe shale bed	Joe shale bed	Joe shale bed	Joe shale bed	
	Anna Shale Member	Frog limestone bed	"Lower Laberdie" limestone bed	Algal facies --- Chaetetid facies	"Missouri" Mine Creek Shale	"Iowa" Mine Creek Shale
		Anna Shale Member	Myrick Station Ls. Mbr.	Myrick Station Ls. Mbr.	Myrick Station Ls. Mbr.	Myrick Station Ls. Mbr.
		Childers Sch. Ls. Mbr.	Childers Sch. Ls. Mbr.	Childers Sch. Ls. Mbr.	Lexington Coal	Mystic Coal
	Sageeyah Limestone Member	Wimer Sch. Ls. Mbr.	LABETTE SHALE	LABETTE SHALE	LABETTE SHALE	
		LABETTE SHALE				

LABETTE SHALE  
Figure 12

algal mound facies (Figure 13). Farther south these facies cannot be separately identified, and they converge with the Myrick Station Limestone where the lower bed of the Mine Creek Shale pinches out. The massive limestone unit formed by this convergence is called herein the Frog limestone bed. It can be traced southward for about 35 kilometers to the Oklahoma-Kansas border where it pinches out between the Anna and the overlying dark shale bed. This upper shale bed, herein termed the Joe shale bed, is stratigraphically equivalent to the upper Mine Creek but is considered a separate unit because it is lithically different and formed under quite different sedimentological conditions from most of the Mine Creek. To the south the Joe shale bed converges with and forms the upper part of the Anna Shale Member. Northward the Joe shale bed correlates with an extremely fossiliferous calcareous shale horizon in the upper Mine Creek and possibly also with the base of the Laberdie proper. The Anna Shale of Oklahoma thus is laterally equivalent to the Anna Shale, Myrick Station Limestone, and Mine Creek Shale of Missouri and Iowa. The Laberdie Limestone Member, originally described near the Kansas-Missouri border, overlies the Mine Creek Shale of Missouri and is laterally equivalent to the Coal City Limestone of Iowa. In southeastern Kansas, the Laberdie Limestone, as originally defined, is restricted to the interval above the Joe shale. Southward into Oklahoma

Figure 13. Lower tongue of Mine Creek Shale. Separates underlying Myrick Station Limestone from overlying chaetetid (massive limestone) and algal mound (slabby limestone) facies of "Lower Laberdie Limestone." Location is Jubilee Quarry section (see #34, Appendix A for exact location).



Figure 13

the Laberdie correlates with the entire limestone sequence above the Anna Shale Member. The "Lower Laberdie" is a limestone unit which has traditionally been considered part of the Laberdie, but which is actually a carbonate facies of the Missouri Mine Creek Shale and which overlies type Laberdie.

To better understand stratigraphic relationships of the Pawnee and adjacent formations in northern Oklahoma, Kansas, Missouri, Iowa and Nebraska, the following units will be discussed in detail: 1) Labette Shale, 2) Childers School Limestone Member, 3) Anna Shale Member, 4) Myrick Station Limestone Member, 5) Mine Creek Shale Member, 6) Lower Laberdie limestone bed, 7) Frog limestone bed, 8) Joe shale bed, 9) Laberdie Limestone Member-Coal City Limestone Member, and 10) Bandera Shale. Detailed stratigraphic relationships of the Pawnee in Oklahoma will be discussed under the heading of Oologah Formation.

### Labette Shale

#### Definition

Haworth (1898) originally described the Labette Shale as a series of beds between the Pawnee and Fort Scott Limestones and assigned the town of Labette in Labette County, Kansas, as the type locality. Jewett (1941) designated an exposure of gray silty shale "near the middle of the north line and extending to a point near the

northeast corner of sec. 22, T. 33S., R. 20 E.," as a pro tempore type exposure.

The top of the Labette originally was marked by a thin black limestone overlain by approximately a meter of gray to black shale (Haworth, 1898). However, Jewett (1941) considered this black shale and underlying limestone to be the basal Anna Shale Member of the Pawnee Formation. Subsequently Moore (1949) correlated a thin limestone below the Lexington coal of Missouri with the limestone at the base of the Anna Shale. This correlation corroborated Jewett's assumption that the Lexington was part of the Pawnee Formation. However, workers in Missouri (Cline and Greene, 1950; Bridges 1957) felt Moore had insufficient evidence for this correlation and concluded that the marine limestone below the coal belonged in a preceding cycle not related to the Pawnee. Therefore, they included the Lexington Coal within the Labette Shale.

The thin limestone at the base of the Anna Shale is commonly absent in Iowa, therefore Cline and Stookey (1943) included the Anna Shale with the Labette. The difficulty of picking an upper contact for the Labette shale across the outcrop belt exists 1) because the contact is gradational and 2) because the base of the Pawnee and top of the Labette can be one of several lithologies. The base of the Pawnee can be a black fissile and phosphatic shale, a gray-black flakey shale, a thin slabbly black calcarenitic

to calcilutitic limestone, an indurated gray-brown calcarenitic limestone, or a fossiliferous gray shale. The top of the Labette can be a gray silty shale, a fossiliferous gray shale, or a coal (Lexington). The Lexington Coal does not always form the top of the Labette, but can be 2.4 to 3.0 meters below the contact with the Pawnee. In the intervening shales, several fossiliferous marine gray shale horizons can be interbedded with the gray silty shales and can be confused with the fossiliferous shale sometimes forming the base of the Pawnee. It is recommended that, when present, the base of the limestone underlying the Anna Shale should be considered as the contact with the Labette. In absence of the limestone, the contact shall be considered the base of the fossiliferous marine shale immediately below the black Anna Shale. Underlying fossiliferous gray shale horizons that are not contiguous with the black phosphatic Anna Shale are considered lenses in the upper Labette. If no limestone or fossiliferous shale zone is present below the black facies of the Anna, then the base of the black shale is chosen as the contact. Although in Iowa the contact is commonly gradational, the black facies can be differentiated from the underlying unfossiliferous gray-silty Labette Shale.

### Description and Lateral Variation

The Labette Shale consists of clayey and silty shale, sandstone, and minor amounts of limestone and coal. Four major areas of thickening are noted along the outcrop belt in 1) south-central Iowa, 2) Kansas-Missouri border, 3) Kansas-Oklahoma border, and 4) north-central Oklahoma. The Labette thins from 6.6 meters in Dallas County, Iowa, to 1.8 meters of gray shale at the Iowa-Missouri border. The Labette Shale is generally less than 3 meters thick across north-central Missouri but thickens to more than 30 meters in west-central Missouri southeastern Kansas (Jewett, 1941; Gamble, 1967) near the state line. Across Kansas, the Labette averages 12 meters in thickness (Moore, 1949). In northern Oklahoma near the Kansas border, Gamble (1967) shows the Labette thickening to 60 meters. Southward into Oklahoma the Labette thins to less than 30 meters in the Tulsa region but farther south it thickens to a maximum of 75 meters in the Arkoma Basin (Oakes, 1952; Gamble, 1967). Thickness variation in northern Oklahoma will be discussed in more detail under the heading "Oologah Formation." The area of increased thickness of the Labette is associated with major occurrences of sandstone. Cline and Stookey (1943) documented that eastward thickening of sandstone in the Labette was more prominent in southwestern Missouri and in Oklahoma than in Kansas.

The distribution of coal in the upper Labette also corresponds with areas of thickening of the unit. A 2 to 5 centimeter coal covers a three-county area along the Kansas-Oklahoma border. Near the Kansas-Missouri border the Lexington coal attains approximately 1 meter in thickness where it is commonly mined. This coal disappears southward in southeastern Kansas, and thins to a 0.6 centimeter smut across north-central Missouri. In southern Iowa the Mystic Coal at the top of the Labette also attains mineable thicknesses of 0.9 meters (Hershey, et al., 1960).

#### Correlation

Moore (1944) correlated the Labette Shale with the upper Wetumka Shale and the lower Wewoka Formation of central Oklahoma. The Lexington Coal of Missouri has been correlated by Jewett (1945) with the thin 2 to 5 centimeter coal found near the Kansas-Oklahoma border. The Lexington Coal is also correlated with the Mystic of Iowa (Moore, 1944; Searight, 1955), which in turn is correlated with the Herrin (No. 6 Coal) of Illinois. Limestone of the lower Oologah in Oklahoma is herein correlated with the upper part of the Labette Shale.

#### Summary

Regional thinning in the Labette Shale is accompanied by a reduction in detrital grain size and thinning of sandstone and also of coal. These areas generally

correspond to positive structural features (Bourbon Arch in southeastern Kansas and the Saline County Arch and Kirksville-Mendota anticline of north-central Missouri). The thinning in Oklahoma is associated with facies change above the shelf margin and will be explained in more detail with the Oologah Formation. The location and direction of thickening of the thick sequences of the Labette can be explained, in part, by assuming multiple detrital source areas. In Iowa, thickening is northwestward toward the Transcontinental Arch, while eastward thickening along the Kansas-Oklahoma border suggests the Ozarks as a possible source area (Gamble, 1967). In the Kansas City area Gamble (1967) considered the Nemaha Uplift as a local source. Thickening in the Arkoma Basin to the south suggests the Ouachita orogenic uplift as a source area. Apparently the Transcontinental Arch, Nemaha, Ozarks, and Ouachitas all contributed sediments to the Labette, whose depositional pattern was complicated even further by topographic variations across the Bourbon Arch, Saline County Arch, and Kirksville-Mendota Anticline.

#### Childers School Limestone Member

##### Definition

The Childers School Limestone Member of the Pawnee Formation was originally named by Alcock (1942) for the limestone at the base of the black fissile Anna Shale

Member. The type exposure designated by Alcock (1942) as the road cut in the southwest corner of sec. 6, T. 26 N., R. 17 E. is actually located in the southeast corner of sec. 1, T. 26 N., R. 16 E. Jewett (1941) originally included this limestone bed as the lower part of the Anna Shale Member. However, because the limestone is well developed in northern Oklahoma and is a key marker bed, Alcock (1942), amended the definition of the Anna Shale Member to exclude this limestone bed, which he designated as the Childers School Limestone Member. In the original description, the Childers School Limestone referred to a single limestone bed below the Anna Shale Member.

#### Description and Lateral Variation

The Childers School Limestone becomes a calcareous shale to the north and is generally missing in north-central Missouri and in Iowa. However, in southeastern Kansas it is a black slabby calcarenite to calcilutite that extends into west-central Missouri (Jewett, 1941). The limestone, locally missing in southeastern Kansas, ranges from 2 to 5 centimeters thick (Figure 14). Near the Kansas-Oklahoma border it is underlain by a 5-centimeter coal, but is generally underlain by unfossiliferous gray shale. Both the lower and upper contact, in the Kansas-Missouri area, are

Figure 14. Five-centimeter coal at top of Labette Shale. Contact is transitional with overlying 10-centimeter carbonaceous gray shale, which grades into 15-centimeter Childers School Limestone Member at top. Location is Ellis School section (see #45, Appendix A for exact location).



Figure 14

gradational (Figure 15). The lower part of the limestone, especially where overlying coal, commonly contains plant debris (Figure 16). The upper part characteristically contains fossil groups such as echinoderms, brachiopods, trilobites, bryozoans, and corals, which reflect open marine conditions.

Southward from the Kansas-Oklahoma border, the Childers School Limestone changes from a dark gray calcilutite to a dense massive skeletal calcarenite which ranges up to a meter thick. In Nowata County, Oklahoma, it is commonly underlain by sandstone and siltstone of the Labette Shale and overlain by the black phosphatic Anna Shale Member. Both the lower and upper contacts are usually sharp. Farther south, the Childers School is underlain by limestone lenses in the upper Labette (discussed in section on Oologah Limestone).

#### Summary

The Childers School Limestone, usually absent in north-central Missouri and in Iowa, changes from a thin black slabby calcilutite to calcareous <sup>in</sup> calcareous in southeastern Kansas to a massive skeletal calcarenite in northern Oklahoma. It is recognized as the lowermost member of the Pawnee Limestone and should be defined as the first limestone bed immediately below the black fissile facies of the Anna Shale Member.

Figure 15. Horizontal view of Childers School Limestone Member showing preserved tree stump penetrating up into it. A 5 centimeter coal is approximately 25 centimeters lower in sequence. Note base of blocky, fissile, and phosphatic Anna Shale Member at top of photograph. Location is Ellis School section (see #45, Appendix A for exact location).



Figure 15

Figure 16. Blocky, fissile, and phosphatic Anna Shale Member (behind and above upper half of hammer). Base of hammer rests on thin lenticular Childers School Limestone Member. Location is Jubilee Quarry section (see #34, Appendix A for exact location).



Figure 16

## Anna Shale Member

### Definition

The type section of the Anna Shale Member, the same as that of the Pawnee Limestone, is located a little north of the center of sec. 7, T. 27 S., R. 24 E., in Bourbon County, Kansas (Jewett, 1945). The Anna originally included both the Childers School Limestone and the Lexington Coal. The Lexington Coal is now considered a bed in the upper Labette Shale and the Childers School Limestone, lying below the base of the Anna Shale, is defined as the lowermost member of the Pawnee Limestone.

### Description and Lateral Variation

The following lithologies generally characterize the Anna Shale Member, in ascending order: 1) gray fossiliferous shale, 2) dark gray to black flakey shale, 3) black indurated chippy shale, 4) black, phosphatic, and fissile shale, 5) black indurated chippy shale, 6) dark gray to black flakey shale, and 7) gray fossiliferous shale. The lithologies both above and below the black, phosphatic, and fissile shale facies are mirror images of one another and reflect progressive gradations into the overlying Myrick Station Limestone and the underlying Childers School Limestone (when present). Any or all of the gradational facies are locally absent. Presence or

absence of these facies along with the southward convergence of the Anna Shale with the Joe shale bed, cause the Anna Shale to vary in thickness along outcrop, from 7.5 centimeters to 2.85 meters. Individual gradational facies range in thickness from a few centimeters to as much as 1 meter. Workers in Kansas (Jewett, 1945), Missouri (Gentile, 1976), and Iowa (Cline and Stookey, 1943) commonly described the Anna as containing a coal. Frequently the coal, now placed in the Labette Shale, immediately underlies the Anna Shale. Results of this study show that, in all cases, a demonstrably marine horizon separates the black, phosphatic, and fissile facies of the Anna from the coal. Commonly the marine horizon is the Childers School Limestone Member, but northward into northern Missouri and Iowa it is a thin fossiliferous shale. This fossiliferous shale horizon, occasionally less than 2 centimeters thick, can be a gray shale or can even be the base of the black shale facies. In Missouri, Burnley (1938) noted that a zone of pyritized fossils commonly marks the base of the black shale where it is in contact with the coal. In Iowa, O'Brien (1977, p. 64) recognized two facies in the Anna Shale. The lowermost facies was described as a black shale with "sparse benthic marine fauna" separating the underlying coal from the overlying phosphatic black shale facies. In the Nebraska Offutt core a 50 centimeter interval is missing at the base

of the Pawnee Limestone. This missing interval apparently corresponds to the Anna Shale Member, which is identified in the Logan core 60 kilometers to the north in Harrison County, Iowa, as a dark gray fossiliferous shale.

The most conspicuous lithology of the Anna Shale Member is the black phosphatic shale facies (Figure 16). It is a black, fissile, and hard shale that lacks benthic organisms, but contains common fish debris and high abundancies of conodonts (approximately 1,000/kg). It commonly is vertically jointed and weathers into rectangular blocks. The black phosphatic shale facies is the most laterally persistent unit and displays the most uniform thickness (0.075-0.75 meters) of any facies of the Pawnee across the outcrop belt. Workers in Oklahoma (Alcock, 1942; Faucette, 1954; Schmidt, 1959), Kansas (Jungmann, 1964), Missouri (Gentile, 1976), and Iowa (Hershey, et al., 1960) have all noted the lateral persistence of the Anna Shale. Northward across the outcrop belt, the black phosphatic facies gradually thickens from only 7.5 centimeters at Oologah, Oklahoma, to a maximum of 75 centimeters thick in southern Crawford County, Kansas. Continuing northward, it thins to 30 centimeters on the Bourbon Arch but thickens again to almost 60 centimeters at the Kansas-Missouri border. Once again, a gradual thinning occurs until it is represented by only a 0.6 centimeter thick pebbly phosphate horizon in

northern Missouri along the Saline County Arch and Kirksville-Mendota Anticline. From northern Missouri to the Iowa-Missouri line, it thickens to 45 centimeters of black shale. From that point, it thins northward to less than 30 centimeters in Madison County, Iowa, and disappears northwestward in Harrison County, Iowa, (Logan Core) and if present in Nebraska is in the missing interval in the Offutt core (see Appendix B).

Phosphate nodules, characteristic of this facies, are generally spherical in shape and range from 0.6 to 7.5 centimeters in diameter. North of Crawford County, Kansas, the phosphate nodules usually have a crystalline core. These nodules are extremely durable and whole nodules, weathered from the shale, commonly litter the outcrop. Southward the phosphate nodules frequently nucleate around orbiculoid brachiopods and phosphatic skeletal material. In addition to Petrodus denticals, both a cranium and a shoulder girdle of a paleoniscoid fish have been found inside these nodules. (These specimens have been repositied in the Museum of Natural History, University of Kansas.) The skeletal nuclei act as planes of weakness, and nodules found on weathered exposures, south of Crawford County, Kansas, are frequently broken in half.

### Correlation

The Anna Shale, widespread throughout the Midcontinent, is also recognized in Illinois (Moore, 1944). Results of this study show that the Anna Shale converges southward with the overlying Joe shale in southeastern Kansas. The intervening Frog limestone, laterally equivalent to the "Lower Laberdie" (which is in turn equivalent to the Mine Creek Shale) and the Myrick Station Limestone, shales out to the south. Southward from the Wimer School section (Oklahoma), the Anna Shale Member is laterally equivalent to the Anna Shale, Myrick Station Limestone, and the Mine Creek Shale of Missouri. This correlation will be discussed in more detail in the sections on the "Lower Laberdie Limestone" and on the Joe shale bed.

### Summary

The black phosphatic shale facies of the Anna Shale Member is the most easily recognized and the most persistent of any facies within the Pawnee Limestone. General areas of thinning or disappearance of the black shale facies correspond with the shelf edge in northern Oklahoma, the Bourbon Arch, Saline County Arch-Kirksville-Mendota Anticline, and Nemaha Uplift. An anomalous thickening of the entire Anna Shale Member in northern Oklahoma (Wimer School section) corresponds with

the convergence of the Anna and Joe shale and associated shaling out of the intervening Frog limestone bed, thereby forming one mappable unit.

### Myrick Station Limestone Member

#### Definition

The type Myrick Station Limestone crops out in ravines along the south bluff of the Missouri River west of Lexington, Lafayette County, Missouri (Cline, 1941). It overlies the Anna Shale Member and is, in turn, overlain by the Mine Creek Shale (Figure 17). Since the Childers School Limestone is either absent or poorly developed in this area, the Myrick Station Limestone is the first prominent limestone above the Lexington Coal and is commonly called "Lexington Cap Rock" by workers in Missouri.

#### Description and Lateral Variations

The Myrick Station Limestone, a dense brownish-gray massive limestone, ranges from 0.3 to 2.25 meters in thickness. It is relatively uniform along the outcrop belt from southeastern Kansas to west-central Missouri with an average thickness of 0.9 to 1.2 meters. The lower part, adjacent to the Anna Shale Member, is the most massive and most lithologically uniform. Fossil groups such as

Figure 17. Massive Myrick Station Limestone Member (lower part of photograph). Limestone at top is base of chaetetid facies of "Lower Laberdie" limestone. Break between these limestone beds is 5-centimeter thick lower Mine Creek Shale tongue. Location is Jubilee Quarry section (see #34, Appendix A for exact location).

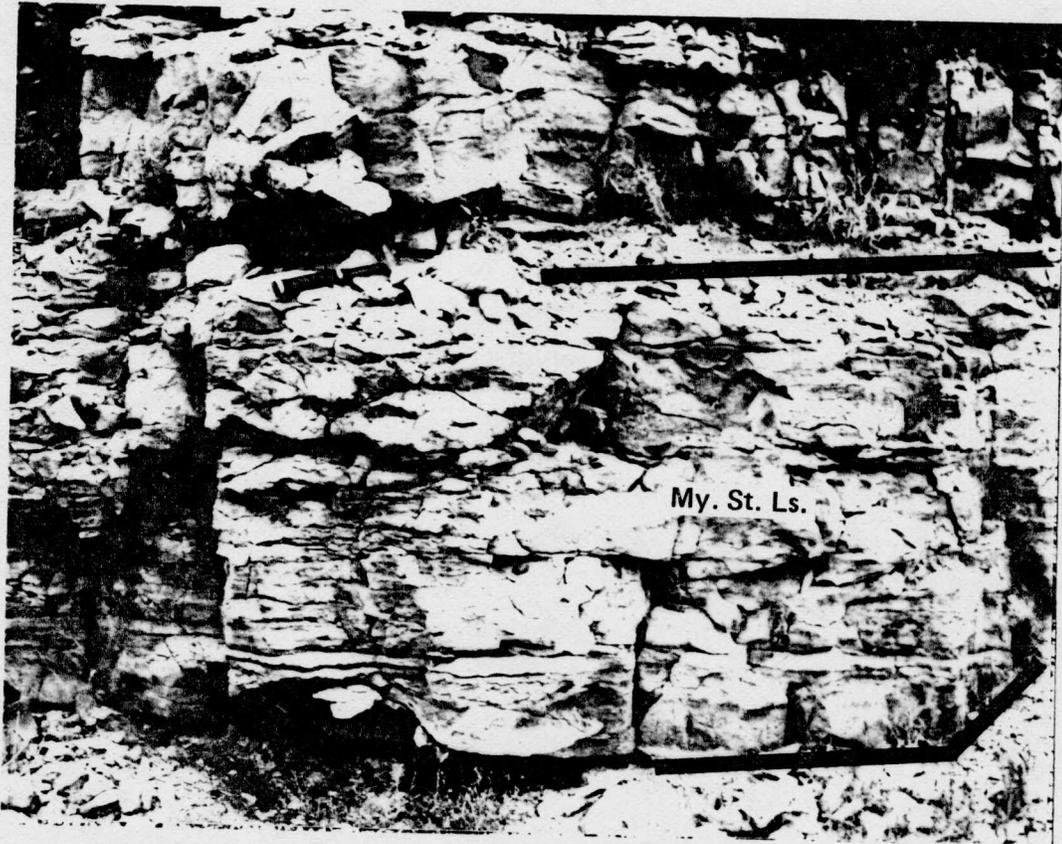


Figure 17

echinoderms, corals, bryozoans, and brachiopods are common, with algae increasing in abundance toward the top. Argillaceous zones, more common in the upper part in west-central Missouri, apparently become shale partings farther north in the vicinity of the Saline County Arch and Kirksville-Mendota Anticline. Cline (1941, p. 71) noted that "as the massive limestone is traced north of the Missouri River it dissipates into calcareous shale with discontinuous stringers of limestone." This apparent interfingering with the Mine Creek Shale occurs in north-central Missouri just south of the Iowa-Missouri state line. In southern Iowa, the Myrick Station is a massive 0.6 to 1.2 meter limestone that decreases in thickness, northwestward, to only 0.3 meters in Guthrie County (Cline and Stookey, 1943).

Southward from the type section, across southeastern Kansas, the Myrick Station Limestone thins to about 0.3 meters before the overlying "Lower bed of the Mine Creek Shale" pinches out. The Myrick Station Limestone converges with and cannot be differentiated from the overlying "Lower Laberdie Limestone" and forms what will be informally designated the Frog Limestone bed.

#### Correlation

Based on stratigraphic position above the Anna shale and lithologic similarity, the Brereton Limestone of

Illinois has been correlated with the Myrick Station Limestone of the Midcontinent (Weller, et al., 1942).

In southeastern Kansas, Jewett (1945) showed an anomalous thickening of the Myrick Station Limestone in the vicinity of the Bourbon Arch. He ascribed these local thickenings (up to 2.7 meters) to Chaetetes biostromes in the upper part of the member. However, this study shows the "Chaetetid Facies" to be separated from the Myrick Station Limestone by the "Lower Mine Creek Shale," therefore establishing the chaetetid horizon as the lowermost facies within the "Lower Laberdie Limestone" (refer to Figure 11). This study also shows the Myrick Station Limestone converging with the "Lower Laberdie Limestone," forming the "Frog limestone bed." To the south, the "Frog limestone bed" shales out between the "Joe shale bed" above and the Anna Shale Member below. Since this entire southern shale sequence is recognized as the Anna Shale Member, the Myrick Station Limestone is correlative with the middle to upper part of the Anna Shale Member of Oklahoma.

Earlier workers considered the Myrick Station Limestone to extend into Oklahoma. Faucette (1954) felt that the Myrick Station limestone was present, but could not be separated from the Laberdie Limestone Member. However, Alcock (1942), Travis (1942), Cade (1952) and Schmidt (1959), based on lithologic similarity with the

Myrick Station Limestone of Kansas, considered the massive limestone bed immediately overlying the black shale as the Myrick Station Member. Travis (1942) pointed out, however, that correlation over a broad geographic area is tenuous when based exclusively on similar lithologies. The reason for this lithologic similarity of the limestones is probably due to the relationship of the two different limestone horizons with the underlying black phosphatic shale. Since both limestones immediately overlie a black fissile shale, they probably formed under similar conditions.

#### Summary

The Myrick Station Limestone is extremely uniform between the Bourbon Arch of Kansas and the Saline County Arch-Kirksville-Mendota Anticline of Missouri. It is also relatively uniform across south-central Iowa. In the vicinity of the Saline County Arch-Kirksville-Mendota Anticline, the Myrick Station Limestone interfingers with the overlying Mine Creek Shale. In the vicinity of the Bourbon Arch, the limestone thins, converges with the "Lower Laberdie Limestone," and then ultimately shales out to the south. The Myrick Station Limestone is not present in Oklahoma.

## Mine Creek Shale Member

### Definition

The type exposure of the Mine Creek Shale is 1.6 kilometers west of the Kansas-Missouri border in Linn County, Kansas (sec. 23, T 21 S., R 25 E.), on a tributary of Mine Creek (Jewett, 1941). This area has been extensively mined for coal and the type exposure can no longer be located. The Pittsville, Missouri, section (P. Mo. section in Appendix C) located about 64 kilometers to the northeast in southwestern Johnson County, Missouri, is a good reference section for the Mine Creek Shale Member (Figure 18).

### Description and Lateral Variations

The Mine Creek Shale extends from southeastern Kansas (just north of the Bourbon Arch), across Missouri and into south-central Iowa. It consists of the following lithologies: 1) black, gray, greenish gray, brown, yellow, and red shale, 2) brownish gray siltstone, 3) sandstone, 4) limestone, and 5) minor amounts of coal. This study shows that the Mine Creek Shale consists of two different clastic wedges; one centered in west-central Missouri in the vicinity of the type locality and the other centered in south-central Iowa (Figure 19). Both clastic wedges thin in north-central Missouri across the Saline County

Figure 18. Myrick Station Limestone Member (along road) separated from Coal City-Laberdie Limestone Member (top of photograph) by 3.6 meters of Mine Creek Shale. This well developed clastic Mine Creek sequence, deposited in 38th Parallel Trough, is designated as a reference section. Location is Pittsville, Missouri, section (see #20, Appendix A for exact location).

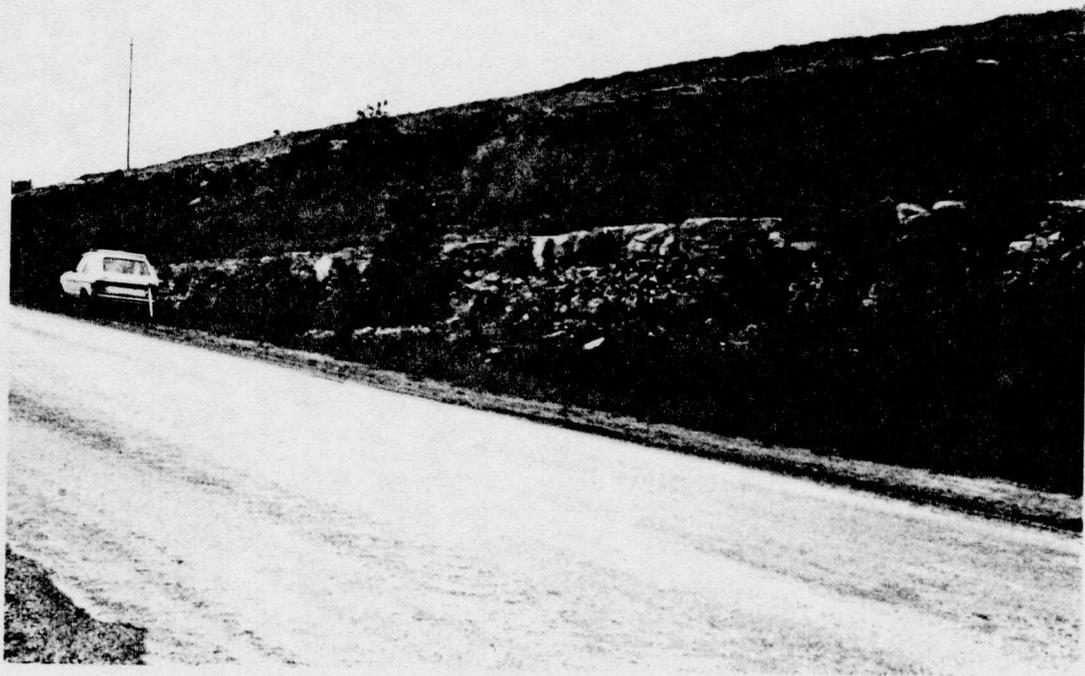


Figure 18

Figure 19. Isopach map of clastics within Mine Creek Shale Member. Contour interval = 5 feet. Dots are control points. East-west thickening in Missouri represents clastics from direction of Ozarks filling 38th Parallel Trough. Northwest-southeast thickening in Iowa represents clastics from direction of Transcontinental Arch filling Appanoose Trough.

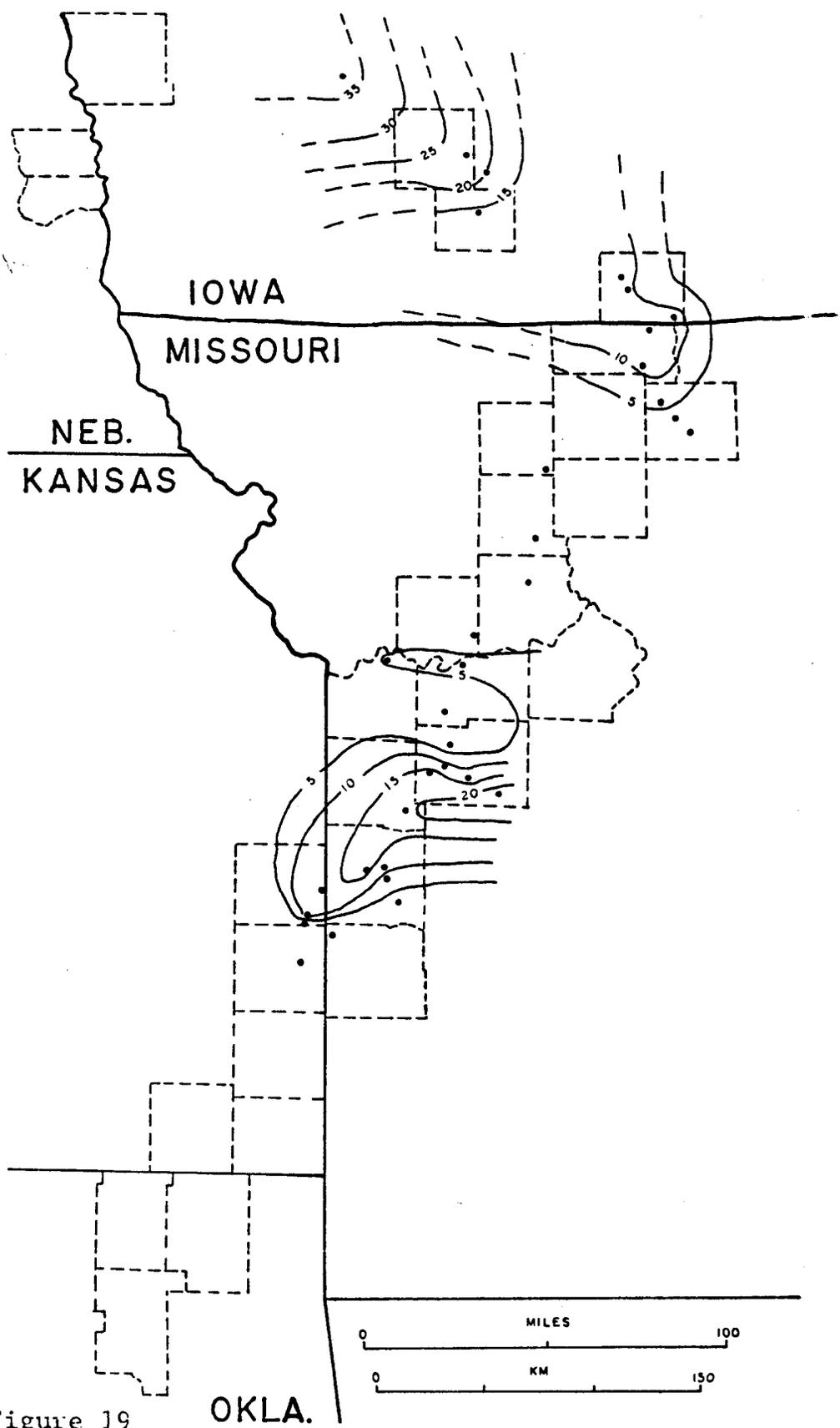


Figure 19

OKLA.

Arch-Kirksville-Mendota Anticline area. The Mine Creek Shale will be discussed under separate headings of 1) Iowa, 2) north-central Missouri transition, and 3) Kansas-Missouri.

#### Iowa Mine Creek Shale

In Iowa, the Mine Creek Shale increases from 1.95 meters at the Iowa-Missouri border to 11.7 meters in Guthrie County, Iowa (Cline and Stookey, 1943). This northwestward thickening (see Figure 19) is toward the Transcontinental Arch, which is a likely source area. Thicker sections of Mine Creek Shale are due to the presence of sandstone (Landis, 1965), which, however, is of minor importance in the Kansas-Missouri Mine Creek shale. Occasional sandy limestone lenses are present (O'Brien, 1979), and a coal smut commonly occurs in the upper part (Cline and Stookey, 1943). The top becomes increasingly calcareous, is interbedded with thin limestone lenses, and appears gradational with the overlying Coal City Limestone Member.

#### North-central Missouri Transition

Across north-central Missouri, between the two major clastic wedges, the Mine Creek Shale ranges from 0.6 to 1.8 meters thick. This area of abrupt thinning is across the Lincoln Fold system (Cline and Green, 1950) and Saline

County Arch. The sequence consists of alternating limestones and calcareous shales with carbonates commonly contributing up to sixty percent of the total thickness (Figure 20). In this area, the Myrick Station Limestone also consists of alternating limestones and shales and apparently interfingers with the Iowa Mine Creek Shale (see Figure 11). Cline (1941, p. 39) stated, "There is such complete gradation between the upper [Coal City Limestone Member] and lower limestone [Myrick Station Limestone Member] members of the Pawnee through the calcareous shale and marl [Mine Creek Shale] that it is difficult to determine the exact boundaries of each member."

#### Kansas-Missouri Mine Creek Shale

This clastic wedge of the Mine Creek Shale lies in an east-west linear trend across southern Johnson County, Missouri, bends southwestward and extends into Kansas (Figure 19). It thins westward from a maximum thickness of 6.3 meters in Johnson County, Missouri, over a distance of 105 kilometers, to 3 meters in Linn County, Kansas. Eight kilometers farther south, it thins abruptly to approximately 1.2 meters thick. Southward it interfingers with the "Lower Laberdie Limestone." The basal persistent shale tongue, the "Lower Mine Creek," separates the "Lower Laberdie Limestone" from the Myrick Station Limestone (Figure 21) and pinches out in northern Crawford County,

Figure 20. Contour map of percentage of carbonates within Mine Creek Shale Member. Contour interval = 20 percent. Dots are control points. Increased carbonate percentage delineates high area of Saline County Arch-Kirksville Mendota Anticline.

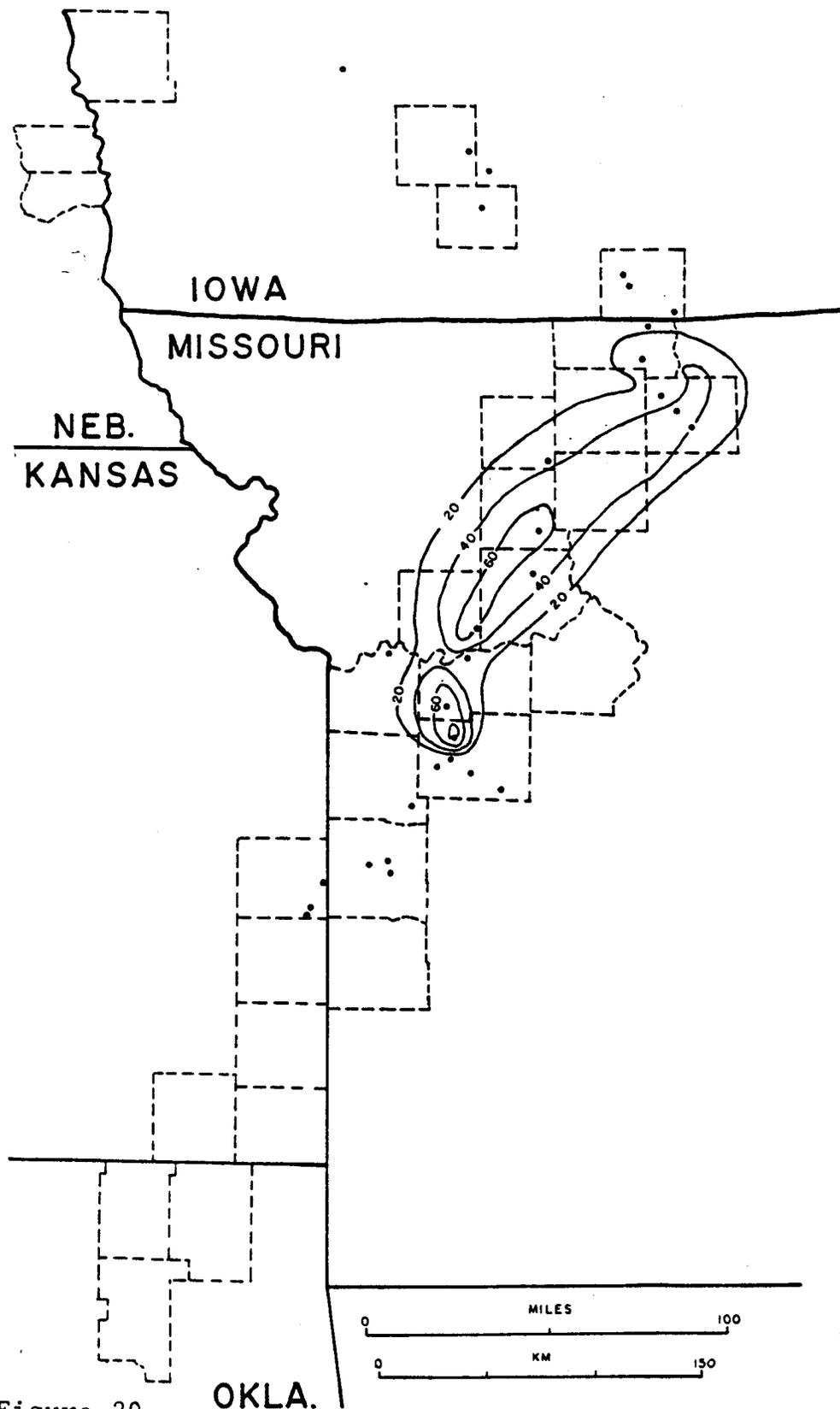


Figure 20

Figure 21. Basal persistent shale tongue of "Lower Mine Creek." This tongue separates Myrick Station limestone below from "Lower Laberdie" limestone above. Location is Jubilee Quarry (see #34, Appendix A for exact location).

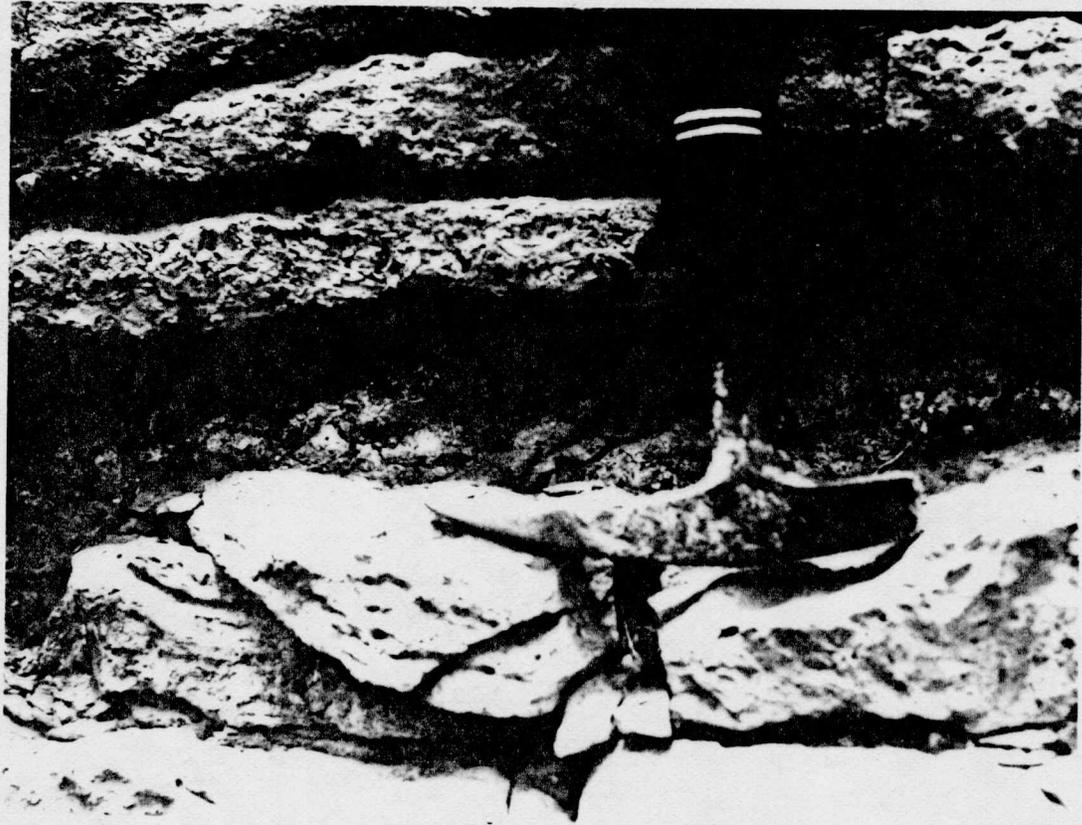


Figure 21

Kansas, where the 38th Parallel Lineament intersects the Bourbon Arch of Kansas. Along the northern margin of the Bourbon Arch, another tongue, the "Upper Mine Creek Shale," grades into a black and platy shale that overlies the "Lower Laberdie." This black platy shale may represent the northernmost extent of the "Joe shale bed" to be described later.

Both Jewett (1945) and Moore (1949) considered the Mine Creek Shale to extend into northeastern Oklahoma. However, workers in Oklahoma (Travis, 1942); Cade, 1952); Faucette, 1954; Schmidt, 1959) have not recognized the Mine Creek Shale. The lithologic unit, south of the Bourbon Arch, that Jewett (1945) identified as Mine Creek Shale, is a "black platy shale." This shale bed is neither exactly stratigraphically equivalent (see Figures 10 and 11) nor genetically related to the bulk of the Mine Creek Shale, and is herein called the "Joe shale bed," which will be discussed in more detail in a later section.

The Kansas-Missouri Mine Creek Shale is dominated by brownish-yellow, green and gray shale. Root cast are rare, and sandstone and siltstone lenses, present only in thicker sections, are generally of minor importance. Occasional limestone lenses occur in the middle of the shale. Upper portions generally consist of calcareous gray shales alternating with thin limestone lenses, but black platy shales are occasionally present. A brachiopod horizon exists in

the upper part, which according to Jewett (1945) and Gentile (1976) is correlatable across west-central Missouri.

#### Correlation

The Kansas-Missouri Mine Creek Shale, in the vicinity of the type locality, overlies the Myrick Station limestones and is laterally equivalent to the upper part of the Iowa Mine Creek Shale. The lower part of the Iowa Mine Creek Shale interfingers with and is laterally equivalent to the upper part of the Myrick Station Limestone. In southeastern Kansas, the Kansas-Missouri Mine Creek Shale is correlative with the "Lower Laberdie Limestone" and the overlying Joe shale bed. However, in Oklahoma it is correlative with the upper part of the Anna Shale Member.

#### Summary

Two distinct clastic wedges with different source areas constitute what is called the Mine Creek Shale. These two clastic wedges are referred to, herein, as the Iowa Mine Creek Shale and the Kansas-Missouri Mine Creek Shale. The Iowa Mine Creek Shale thickens to the northwest toward the Transcontinental Arch and was deposited within the Appanoose Trough. However, the Kansas-Missouri Mine Creek Shale thickens to the east toward the Ozarks and was deposited within the 38th Parallel Trough. Both of these clastic wedges drastically thin and interfinger in

north-central Missouri across the positive structural area of the Saline County Arch and Kirksville-Mendota Anticline. The lower part of the Iowa Mine Creek, which interfingers with the Myrick Station Limestone, is older than the Kansas-Missouri Mine Creek, which overlies the Myrick Station. To the south, the Kansas-Missouri Mine Creek shale grades into limestone and eventually pinches out across the Bourbon Arch in Crawford County, Kansas, and is absent in Oklahoma.

### "Lower Laberdie Limestone"

#### Definition

The limestone overlying the "Lower Mine Creek Shale" tongue in the area of the Bourbon Arch, is separated from the stratigraphically higher type Laberdie Limestone Member by the overlying "Joe shale bed" and is herein termed the "Lower Laberdie Limestone." The term "Lower Laberdie Limestone" is used for this sequence because 1) it has been previously considered part of the Laberdie, 2) much of it is lithologically similar, although not correlative with the type Laberdie-Coal City, and 3) it is separated from the type Laberdie only by the thinnest development of the Joe shale bed. The "Lower Laberdie" comprises two facies: 1) lower Chaetetid facies and 2) upper Algal Mound facies. The upper algal facies of the "Lower Laberdie Limestone" and the algal facies of the Laberdie Limestone Member are

lithologically similar and can be separated only if the Joe shale is exposed.

#### Description and Lateral Variation

The "Lower Laberdie Limestone" extends for approximately 30 kilometers from northern Crawford County, Kansas, to northeastern Bourbon County, Kansas. Restricted to the area of the Bourbon Arch, it undergoes rapid facies changes off the Arch, both northward and southward.

Although the Chaetetid Facies ranges from 0.6 to 1.35 meters thick, it generally displays a uniform thickness of 1.2 meters. It is a calcilutite with laminated and encrusting chaetetids common throughout the sequence (Figure 22). Jewett (1945) and Moore (1949) considered this facies as part of the upper Myrick Station Limestone, however, this study shows the Chaetetid Facies to be separated from the Myrick Station Limestone by the "Lower Mine Creek Shale." The Algal Mound Facies, ranging from 0.3 to 2.7 meters thick, reaches maximum thickness in northern Crawford County. It is a light gray to tan phylloid algal calcilutite (Figure 23) with an abrupt lower contact with the Chaetetid Facies. A good reference section showing both facies of the "Lower Laberdie Limestone" is exposed in a quarry in the SW $\frac{1}{4}$ , sec. 31, T. 27 S., R. 24 E., in northern Crawford County, Kansas (see Mid-west Minerals Lake Crawford section in Appendix C).

Figure 22. Chaetetid facies of "Lower Laberdie" limestone. Note laminated and encrusting habit of chaetetids distributed throughout skeletal calcilutite. Location is Jubilee Quarry section (see #34, Appendix A for exact location).

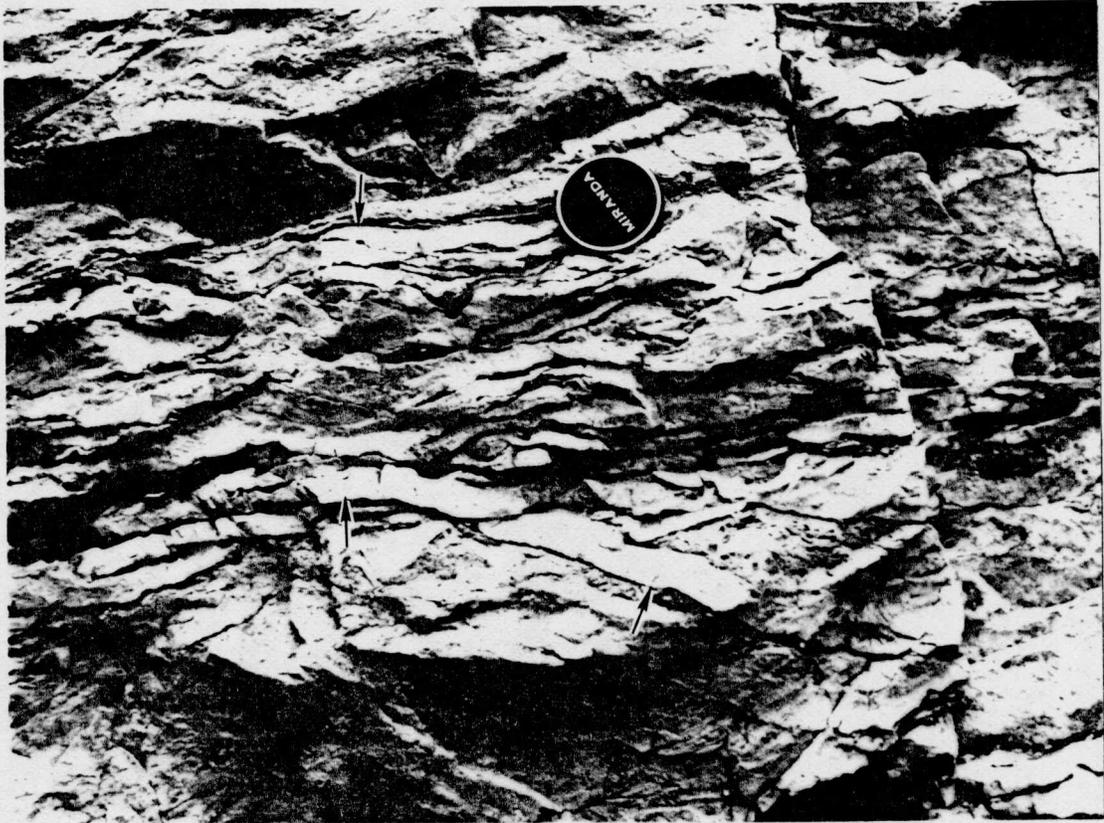


Figure 22

Figure 23. Algal mound facies of "Lower Laberdie" limestone. Dark streaks are phylloid algal blades distributed throughout algal calcilutite. Location is Jubilee Quarry section (see #34, Appendix A for exact location).



Figure 23

### Correlation

To the north, the "Lower Laberdie Limestone" inter-fingers and is correlative with the Mine Creek Shale. South of the Bourbon Arch where both the Chaetetid and Algal Mound Facies thin and cannot be differentiated, the "Lower Laberdie Limestone" converges with the Myrick Station Limestone Member. Southward from the point of convergence, the limestone sequence is referred to as the Frog Limestone Bed, which will be discussed in more detail in the next section. In Oklahoma, this bed is correlative with the middle to upper part of the Anna Shale Member.

### Summary

The "Lower Laberdie Limestone" is restricted to the area of the Bourbon Arch, and consists of a lower Chaetetid Facies and an upper Algal Mound Facies. It undergoes rapid lateral facies change to shale, off the Arch, both to the north and, through equivalent limestone, to the south.

### Frog Limestone Bed

### Definition

The name, Frog limestone bed, is informally applied to the limestone that overlies the black, fissile, and phosphatic Anna Shale Member and is overlain by the black, platy to fissile Joe shale bed in western Crawford, Neosho, and Labette Counties. The type and reference section,

approximately 0.8 kilometers south of Frog Cemetery in southwestern Crawford County, Kansas, is located along the north bank of Hickory Creek in the SW corner of SE $\frac{1}{4}$ , sec. 14, T. 30 S., R. 21 E.

#### Description and Lateral Variation

The Frog limestone bed is recognized across approximately 40 kilometers of outcrop from southern Crawford County to southern Labette County, Kansas. Although this is the area of the Neosho River Valley where outcrops are rare, the Frog limestone bed was noted to thin southward from a maximum of 1.5 meters at the reference section to only 15 centimeters thick about 24 kilometers north of the Oklahoma border.

In the north, the base and top of the Frog limestone bed, adjacent to the black shales, is a dense skeletal calcilutite. Algae, absent in the dense skeletal calcilutite, increase toward the center of the bed where they reach maximum abundance. To the south where the Frog limestone is only about 15 centimeters thick, it is entirely dark gray skeletal calcilutite lacking algae.

#### Correlation

In the vicinity of the Bourbon Arch, the upper part of the Frog limestone bed is correlative with the "Lower Laberdie Limestone," while the lower part is correlative

with the Myrick Station Limestone. To the south, in southeastern Kansas, the Frog limestone shales out between the Anna Shale Member and the Joe shale bed. Farther south, in Oklahoma, it is correlative with the middle to upper part of the Anna Shale Member.

#### Summary

The Frog limestone bed, formed by the convergence of the Myrick Station Limestone and the "Lower Laberdie Limestone," thins southward off the edge of the Bourbon Arch into the Cherokee Basin. Deeper into the basin to the south, the Frog limestone shales out between the Anna Shale Member and the Joe shale bed.

#### Joe Shale Bed

#### Definition

The name, Joe shale bed, is informally applied to the black flakey to fissile shale that overlies the Frog limestone bed and is overlain by the Laberdie Limestone Member. The reference section (#42, Figure 10) is approximately 1.6 kilometers northwest of the Joe bench mark in northeastern Labette County, Kansas, located along the south side of the section line road in the NW $\frac{1}{4}$ , NE $\frac{1}{4}$ , sec. 7, T. 31 S., R. 21 E.

### Description and Lateral Variations

The Joe shale bed extends northward from southern Kansas near the Oklahoma border to the vicinity of the Bourbon Arch. South of the reference section it maintains a relatively uniform thickness of 0.3 to 0.6 meters while northward it thins to approximately 5 centimeters over the top of the Bourbon Arch. Along the northern edge of the Bourbon Arch, Jewett (1945) reported a black platy shale, about 0.3 meters thick, above the Chaetetid Facies of the "Lower Laberdie Limestone." In southern Bates and northern Vernon Counties, Missouri, where the Mine Creek Shale thins to only about 0.6 meters thick along the northern edge of the 38th Parallel Lineament, Gentile (1976) reported the upper half as a black platy facies. These might represent the northernmost extent of the black facies of the Joe shale where it grades into calcareous shale at the top of the Upper Mine Creek Shale in Missouri. South of the Bourbon Arch, the Joe shale bed resembles the Anna Shale Member and is black, fissile to flakey, and lacks benthic fossils. Abundance of conodonts and vertebrate remains is high. Detrital silt and clay are common but detrital sand is rare. Where the Joe shale thins over the Bourbon Arch, it changes to a dark gray color, but conodont abundances remain high. Northward, off the edge of the Bourbon Arch, it once again becomes black and platy but immediately

merges with the upper part of the coarse-grained clastic wedge of the Mine Creek Shale.

### Correlation

To the south in Oklahoma the Joe shale bed converges with and makes up the top of the Anna Shale Member. North of the Bourbon Arch it is equivalent to the top of the Mine Creek Shale and/or possibly the basal Laberdie Limestone.

### Summary

The Joe shale, only a 5-centimeter thick gray shale on the Bourbon Arch, thickens off the Arch both to the north and south to a black platy shale over 0.3 meters thick. Northward, off the edge of the Arch, it is not as readily recognized where it becomes a calcareous shale either at the top of the Mine Creek Shale clastic sequence or within the lower part of the Coal City Limestone Member. To the south in Oklahoma, where the intervening Frog Limestone pinches out, it merges with and forms the top of the Anna Shale.

Laberdie Limestone Member-

Coal City Limestone Member

### Definition

The Laberdie Limestone member, the uppermost member of the Pawnee Limestone of Kansas, overlies the Mine Creek Shale Member and is overlain by the Bandera Shale. Jewett

(1941) designated the section located in a quarry in the southwestern part of sec. 6, T. 23 S., R. 25 E., 1.6 kilometers west of Prescott, Linn County, Kansas, as the type exposure. A few months earlier, Cline (1941, p. 64) named the Coal City Limestone as the uppermost member of the Pawnee in Iowa. This is the same limestone that Bain (1896) called the "Seventeen-foot limestone," a term used to indicate its approximate position above the Mystic Coal in Appanoose County, Iowa. Earlier Missouri Survey reports called this bed the "Water rock" in Putnam County, Missouri. Cline (1941) designated outcrops in the east bluff of the River in the SE $\frac{1}{4}$ , sec. 16, T. 67 N., R. 16 W., near Coal City in Appanoose County, Iowa, as the type section. However, Cline and Stookey (1943) stated that the type section, erroneously reported as being in the SE $\frac{1}{4}$ , is actually in the S $\frac{1}{2}$  of the SW $\frac{1}{4}$ . Several inconsistencies by Cline (1941) suggest that he was uncertain of the stratigraphic relationship of the Coal City Limestone with the uppermost member of the Pawnee of Kansas-Missouri. 1) He stated (p. 37) that "Moore and Jewett have agreed to select an appropriate name for this limestone [the uppermost member in Kansas and Missouri] and designate as a type section some locality in southeastern Kansas." 2) He stated (p. 59) that "on the basis of stratigraphic position the Coal City Limestone would appear to correlate with the upper limestone member of the Pawnee of west-central

Missouri." 3) However, his cross sections show the Coal City Limestone of north-central Missouri and Iowa as an additional limestone member above the uppermost limestone member of west-central Missouri and Kansas. Subsequent workers (Greene and Searight, 1949; Cline and Greene, 1950) have shown the Laberdie Limestone Member and the Coal City Limestone Member to be lateral equivalents. Since the term Coal City had priority, they suggested suppressing the term Laberdie. Although this study corroborates their correlations (Figures 10 and 11), the term Laberdie should also be retained since it is ingrained in the Kansas literature. Usage of the term Laberdie is generally restricted to the Kansas-Oklahoma outcrop while usage of the term Coal City is generally restricted to the Missouri-Iowa outcrop.

#### Description and Lateral Variation

The Laberdie-Coal City Limestone is a light gray, thin bedded limestone ranging in thickness from less than 0.3 meters in Iowa to approximately 4.5 meters in Kansas. Exact thicknesses were difficult to determine because of weathering back of the top of the unit along the dip slope. Maximum thickening of over 15 meters occurs in northern Oklahoma where the Laberdie Limestone Member makes up most of the upper portion of the Oologah Formation, which will be discussed in more detail in a later section. This

observation is contrary to traditional correlations into Oklahoma (Oakes, 1952), which show the Laberdie Limestone making minor contributions to the total Oologah thickness and occurring only at its base. Three distinct areas of thickening were observed across the outcrop belt: 1) In northern Oklahoma, shelf edge algal mound thickenings in excess of 15 meters make up the top of the Oologah Formation. 2) In southeastern Kansas, algal mound thickening of approximately 4.5 meters occurs across the Bourbon Arch. This algal mound thickening overlies the Chaetetid and algal mound facies of the "Lower Laberdie" and results in total carbonate thicknesses (with only a 5 centimeter Joe shale parting) of 7.5 to 9 meters above the Myrick Station Limestone. The upper few centimeters in the vicinity of the Bourbon Arch is a skeletal calcarenite. 3) In west-central Missouri, algal-mound thickening of approximately 3.6 meters occurs over the Kansas-Missouri Mine Creek clastic wedge. Between these algal mounds, the limestone thins to generally less than 3 meters. Algae decrease in abundance in the thin areas, where other fossil groups become more dominant. The Coal City Limestone thins northward across Missouri and does not exceed 0.6 meters in thickness across the Saline County Arch-Kirksville-Mendota Anticline area. The top of the Coal City in this area is badly weathered and appears brecciated. Northward into Iowa it thickens to a maximum of 1.35 meters. Across

Missouri, Gentile (1976) and Cline (1941) recognized that the upper part of the Mine Creek Shale consists of alternating limestone and shale and is gradational with the overlying Coal City. In Putnam County, Missouri (Cline and Greene, 1950) and at the type exposure in Appanoose County, Iowa (see Coal City section in Appendix C), the Coal City consists of two limestone beds and an intervening thin shale. Locally in Iowa the Coal City is calcarenitic. Chaetetids, although generally common in the Laberdie-Coal City, are rare both in the algal mound facies and in facies across the Saline County Arch and Kirksville-Mendota Anticline. In Nebraska, the Coal City Limestone appears to be absent (see Appendix B).

#### Correlation

The Coal City Limestone of Iowa is correlative with the Laberdie Limestone of Kansas as described at the type exposure. Southward across the Bourbon Arch, the Laberdie proper is restricted to the limestone above the Joe shale bed. In Oklahoma, the Laberdie Limestone of Kansas is correlative with the entire sequence above the Anna Shale Member and makes up the upper part of the Oologah Formation. The Coal City of Iowa is correlated with the Bankston Fork Limestone of southern Illinois (Weller, et al, 1942).

### Summary

The Coal City Limestone of Iowa is correlative with the Laberdie Limestone of Kansas and is recognized from southern Iowa to northern Oklahoma. The Coal City thins conspicuously across the Saline County Arch-Kirksville-Mendota Anticline and only slightly thickens northward into Iowa. To the south, three areas of thickening lie across 1) the Kansas-Missouri Mine Creek clastic wedge, 2) the Bourbon Arch, and 3) the Shelf Edge Rise.

### Bandera Shale

#### Definition

The Bandera Shale, named by Adams (1903) for exposures near the former railroad station at Bandera, in Bourbon County, Kansas, lies above the Pawnee Limestone and below the Altamont Limestone.

#### Description and Lateral Variation

The Bandera Shale consists of clayey and sandy shale, sandstone and minor amounts of coal and limestone (Jewett, 1945). Cline and Greene (1950) stated that lithologically it is quite variable across the outcrop belt and it cannot be easily characterized. Red to green shale generally forms the top of the formation. A thin bedded flaggy sandstone, which was designated the Bandera Quarry Sandstone by Jewett (1941), occurs near the middle to upper part in

southeastern Kansas. In Kansas the Mulberry coal occurs in the lower part of Bandera Shale and ranges from a few centimeters to about 1.8 meters above the base of the formation (Jewett, 1945). It pinches out southward across the Bourbon Arch, but Schoewe (1955) reported thicknesses of 1.2 meters near the Kansas-Missouri line in the 38th Parallel Trough. North of the Missouri River it thins and becomes a mere smut (Cline, 1941). Cline and Stookey (1943) state that the Lonsdale Coal of Iowa occupies the approximate stratigraphic position of the Mulberry Coal of Kansas and Missouri but "...information is too meager to permit a precise correlation." The Lonsdale Coal is thickest in Guthrie County (Cline and Stookey, 1943) in the Appanoose Trough. Both the Lonsdale Coal of Iowa and the Mulberry Coal of Kansas-Missouri seem to be associated with increased thicknesses of the Bandera, which can be attributed to an increase in the amount of sandstone. In Iowa, the Bandera thickens northwestward from approximately 9 meters in Appanoose County to over 15 meters in Guthrie County (Cline and Stookey, 1943). The thickening, accompanied by an increase in sandstone, is toward the Transcontinental Arch. Southward, Cline (1941) showed the Bandera ranging from 3 to 6 meters thick across north-central Missouri. Across southeastern Kansas thicknesses range from 10.5 to 22.5 meters (Moore, 1949). The Bandera reaches a maximum thickness of 40.5 meters in

the Cherokee Basin along the Kansas-Oklahoma border (Gamble, 1967). Schmidt (1959) concluded that the source of the Bandera in this area was to the east in the direction of the Ozarks. An isopach map of the Bandera by Gamble (1967) supports this hypothesis. Southward into Oklahoma, the Bandera pinches out on the Shelf Edge Rise, as discussed in detail under the Oologah Formation.

### Correlation

In northern Oklahoma, the Bandera Shale is correlative at least in part with part of the upper Oologah Formation. Farther south it is equivalent to the Wewoka Shale.

### Summary

The Bandera Shale, like the Labette Shale reflects a complex detrital depositional pattern with multiple source areas. Source areas seem to have been in the direction of the Ozarks for the thickening in the Cherokee Basin and the Transcontinental Arch for the thickening in the Appanoose Trough. To the south, in northern Oklahoma, the Bandera pinches out toward the Shelf Edge Rise.

## Oologah Formation

### Definition

Drake (1897) first applied the term Oologah Limestone to the rock sequence "exposed in Oologah" (Rogers County, Oklahoma), "along Four Mile Creek at the west edge of

Oologah, and in an escarpment some 3 miles to the east of that place." In the subsurface, the Oologah is often referred to as the Big Lime (Jordan, 1957). Adams (1903) first attempted to differentiate the Oologah Limestone. He inferred that the lower member of the Parsons Limestone (now the Altamont Limestone) correlated with the upper part of the Oologah. Ohern (1910) correlated the Oologah with the Pawnee, Bandera, and Altamont Formations of southeastern Kansas. Subsequent workers in Oklahoma (Gould, 1927; Oakes, 1952; Cade, 1952; Alexander, 1954; Faucette, 1954; Bennison, 1973) have accepted this correlation and generally consider the Pawnee correlative with the lower half of the Oologah, with the Altamont correlative with the upper half. However, stratigraphic sections by Moore and Dott (1937) and Branson (1964) show the Altamont contributing only a minor amount of the total thickness at the very top of the Oologah. Jewett (1941, 1945), working southward from the Kansas outcrop area into northern Oklahoma, noted thickening of the limestone below the Anna Shale and postulated that the Pawnee Limestone "comprises the greater part of the thick Oologah Limestone." While correlating Pennsylvanian formations of North America, Moore (1944) states that, "it is now known that the formation called Oologah Limestone is chiefly, if not exclusively, an expanded development of the Pawnee Limestone." Other workers (Travis, 1942; Sparks, 1955;

Cole, 1965) also noted this limestone thickening below the Anna Shale. Schmidt (1959), studying the convergence of the Altamont and Pawnee Limestones, and Gamble (1967) came to the same general conclusions as Moore and Jewett. Field correlations in the present study, from southeast Kansas into northern Oklahoma, also corroborate these correlations (see Figures 10 and 11) and suggest that the key to making reliable correlations is based on an understanding of the black phosphatic shale members from the Kansas outcrop area.

#### Description and Lateral Variations

The Labette Shale, Pawnee Limestone, and Bandera Shale-Altamont Limestone in Oklahoma will be discussed separately in order to clarify the contribution of each individual unit to the total thickness of the Oologah.

#### Labette Shale

In Oklahoma, the Labette Shale reaches maximum thickness of over 60 meters in both the Cherokee basin and the Arkoma Basin. Between these basins, in central Rogers County, sandstone is conspicuously absent and the shale thins to approximately 12 meters in two different areas about 9.6 kilometers apart (Cole, 1965). Between these zones the shale is over 30 meters thick. These areas of shale thinning correspond to an equivalent increase in

thickness of carbonate lenses in the upper Labette (Cole, 1965; Schmidt, 1959) and are therefore caused mainly by facies change. These carbonates in the upper Labette are commonly reported to exceed 12 meters in thickness (Sparks, 1955; Schmidt, 1959; Cole, 1965), and Gamble (1967) reported maximum thicknesses of up to 21 meters.

Alcock (1942) noticed a thickening in northern Oklahoma of the single thin limestone bed that commonly occurs below the Anna Shale in southeastern Kansas, and named the bed the Childers School Limestone Member of the Pawnee Formation. In northern Oklahoma this limestone bed becomes a calcarenite and might be difficult to separate from the limestones in the upper Labette Shale. Schmidt (1959) apparently overlooked the work of Alcock (1942) and named the entire limestone sequence below the Anna Shale Member and above the shale of the Labette Formation as the Sageeyah Limestone Member of the Pawnee Limestone. He designated a roadcut near the center of the west line of the SW $\frac{1}{4}$ , sec. 22, T. 22 N., R. 15 E., approximately 4.8 kilometers west of Sageeyah in Rogers County, Oklahoma, as the type section. Although he recognized portions of this limestone as part of the upper Labette Shale, he also considered it the same as the thin limestone below the Anna Shale in southeastern Kansas. Since Alcock (1942) considered the lowermost member of the Pawnee Limestone as a single bed below the Anna Shale Member and also since his

work has priority, it is recommended that the term Childers School Limestone be retained for this member at the base of the Pawnee. In Oklahoma, the term Childers School Limestone should be restricted to the first limestone bed below the Anna Shale. It is also recommended herein 1) that the term Sageeyah be restricted to those limestones below the Childers School Limestone Member of the Pawnee, and 2) that the Sageeyah be considered a member of the Labette Shale.

The Sageeyah Limestone Member refers to the limestones below the Childers School Limestone Member of the Pawnee limestone and above the shales in the lower part of the Labette Shale Formation. It is the uppermost member of the Labette Shale in Rogers County. An exposure just south of the railroad track in an artificial waterline cut in the NW $\frac{1}{4}$ , sec. 11, T. 22 N., R. 15 E. (O.K. section #55, Appendix C), is designated as a new reference section because it is more complete and better exposed than the type section described by Schmidt (1959).

The Sageeyah ranges from a series of alternating silty limestones and shales to massive algal limestone. The alternating limestone and shale sequence occurs north of the major algal limestone thickenings and represents an interfingering with the clastics of the Labette Shale. The Sageeyah interval reaches maximum thickness of 21 meters

and makes up the lower half of the Oologah Limestone of the Tulsa region.

The Wimer School Limestone, a massive dark gray to yellow-brown marine limestone, was originally described by Cade (1952) from an exposure "one-fourth mile west of the southwest corner of sec. 19, T. 28 N., R. 18 E." According to Cade (1952) this limestone member of the Labette Shale, approximately one meter thick, occurs anywhere from 0.6 to 9.0 meters below the Anna.

If the limestone below the Anna becomes massive and individual beds are not readily differentiated, then both the Wimer School Limestone Member in the middle to upper part of the Labette Shale and the Childers School Limestone at the base of the Pawnee may be included within the Sageeyah.

#### Pawnee Limestone

The key to mapping and correlation of both the Pawnee and Altamont Limestones in northern Oklahoma is the recognition of the associated black phosphatic shale members. The black phosphatic facies of the Anna Shale Member of the Pawnee Formation is the most laterally persistent facies within the entire formation. Although both limestone and coarser detrital sequences undergo numerous facies change across the outcrop belt, the black phosphatic facies of the Anna Shale Member, was traced from

Iowa across Missouri and Kansas and into northern Oklahoma. Most of the early workers in Oklahoma were apparently unaware of the lateral persistence of these black shales and did not recognize their importance as key marker beds. The black phosphatic facies of the Anna Shale thins to only 7.5 centimeters thick in central Rogers County, Oklahoma, about 3.2 kilometers south of Oologah. Although according to Sparks (1955) it pinches out several kilometers to the south, it is as much as 1.1 meters thick in quarries in the SE $\frac{1}{4}$ , sec. 9, T. 20 N., R. 14 E., northeast of Tulsa. In the vicinity of Oologah, below the black phosphatic shale of the Anna, the Sageeyah Limestone of the Labette Shale thickens to over 9 meters. The Laberdie Limestone Member of the Pawnee, which overlies the black phosphatic Anna Shale, thickens from approximately 4.5 meters at the Kansas-Oklahoma border to over 9 meters in northern Rogers County. Both Alcock (1942) and Cole (1965) reported thicknesses of approximately 12 meters for the Laberdie Limestone in Rogers County. The Laberdie Limestone seems to make up the upper part of the Oologah.

#### Bandera Shale-Altamont Limestone

The Bandera Shale, described in an earlier section, reaches maximum thickness of over 30 meters in northern Oklahoma and separates the Pawnee Limestone from the

overlying Altamont Limestone. In ascending order, the Altamont Limestone consists of the Amoret Limestone Member, Lake Neosho Shale Member, and Worland Limestone Member. The Lake Neosho Shale, a black phosphatic shale, seems to bear the same relationship to the Altamont as the Anna does to the Pawnee (Cole, 1965). Schenk (1967) noted that this black phosphatic shale was the most laterally persistent unit of the Altamont and extended from northern Oklahoma into Iowa. The Amoret Limestone, below the black shale, undergoes facies changes across subaqueous topographic highs and becomes a calcareous shale in places (Schenk, 1965). Absence of the Amoret Limestone results in a continuous shale sequence from the Bandera up through the Lake Neosho. However, the Lake Neosho can be recognized at the top by its black, fissile, and phosphatic character.

Southward from the Kansas-Oklahoma border the Amoret becomes very shaly in places. Concurrently, the Bandera thins over a distance of 9.6 kilometers in central Nowata County from 37 meters thick to only 5 meters thick (Alcock, 1942). Continuing southward this combined shale interval of the Bandera, Amoret, and Lake Neosho thins to less than a meter thick where it is lithologically a black phosphatic shale. Both Sparks (1955) and Cole (1965) suggested that the Bandera had totally pinched out and the black shale is a continuation of the Lake Neosho Member of the Altamont. Black shale in the creek bed north of the intersection of

31st and Garnett Streets in Tulsa, lying upon the Oologah limestone, is identified as Lake Neosho Shale because it contains a distinctive conodont fauna characteristic of the Lake Neosho Shale at many localities to the north.

The Worland Limestone overlying the black shale of the Lake Neosho Member also thins considerably to the south. Alcock (1942, p. 61) states that the Altamont Limestone averages 3.9 meters thick in southern Nowata County, while to the south, in northern Rogers County, Cole (1965, p. 23) reported thicknesses of only 1.5 meters.

#### Correlation

The convergence of the Bandera and Lake Neosho Shales as the Amoret disappears is recognized in northern Rogers County as a mostly black, phosphatic shale sequence. In central Rogers County, where the Oologah is well developed, a black phosphatic shale is commonly found in the middle of the limestone sequence. Earlier workers considered this shale as the Bandera-Lake Neosho and therefore correlated the upper half of the Oologah with the Altamont Limestone and the lower half with the Pawnee Limestone. Lateral tracing of beds from the Kansas-Oklahoma border now demonstrates that this medial shale in the limestone sequence is the Anna Shale Member of the Pawnee Limestone. The lower half of the Oologah thus is formed by limestone thickenings in the upper part of the Labette Shale, which

are formally named the Sageeyah Limestone Member. The Pawnee Limestone makes up the upper half of the Oologah. The black phosphatic shale that overlies the Oologah was considered the Nowata Shale by Chenoweth (1966) and Bennison (1973). However, based on field correlations, this black shale overlying the Oologah is recognized as the Lake Neosho Shale of the Altamont Formation. Since the Amoret Limestone Member of the Altamont Limestone, below this black shale, pinches out southward in Nowata County, the Altamont does not contribute to the Oologah thickness. The calcareous shale and thin bedded limestone overlying this black shale represents the southernmost extension of the Worland Limestone Member, but based on the type section described by Chenoweth (1966) is not considered part of the Oologah.

#### Oologah Type Section

Sparks (1955) noticed two black fissile shales within the Oologah sequence. Chenoweth (1966), describing a core that he designated as the type Oologah, recognized a black phosphatic shale in the middle of the Oologah and a second black phosphatic shale, which he considered as the base of the overlying formation. Chenoweth (1966) followed the traditional correlations of Ohern (1910) and Oakes (1952) for the Oologah, and he considered the medial black shale as the Bandera with the Pawnee Limestone below and the

Altamont Limestone above. Based on his correlations, the upper black phosphatic shale overlies the Altamont and, therefore, by stratigraphic position had to be the base of the Nowata Shale. However, lithologically the Nowata Shale does not have a black phosphatic shale facies anywhere else (personal communication, P. H. Heckel). See Figure 24 for a proposed revision of the Oologah type section. Refer to Chenoweth (1966) for detailed lithologic descriptions.

### Summary

A revision of the Oologah shows correlation of the lower half below the medial black phosphatic Anna Shale with the Sageeyah Limestone Member of the Labette Shale. The upper half correlates with the Pawnee Limestone. The upper black phosphatic shale is considered the Lake Neosho Member of the Altamont and immediately overlies the top of the Oologah. The 1.2 to 1.5 meters of limestone that overlies the Lake Neosho Shale is considered the Worland Member of the Altamont Limestone.

The Oologah Limestone, attaining maximum thickness in southern Rogers and Tulsa Counties, is geographically located between the Arkoma Basin to the south and the Cherokee Basin to the north. The Oologah is interpreted to have been deposited between these two basins on the relative high of the Shelf Edge Rise. The postulated existence of the Shelf Edge Rise is based upon the

Figure 24. Revised correlation of formations from Kansas outcrop area to type section of the Oologah Formation of northern Oklahoma. This correlation shows top of Laberdie Limestone equivalent to top of Oologah and base of Sageeyah Limestone equivalent to base of Oologah. Recognition of Childers School Limestone Member is tentative pending analysis of core.

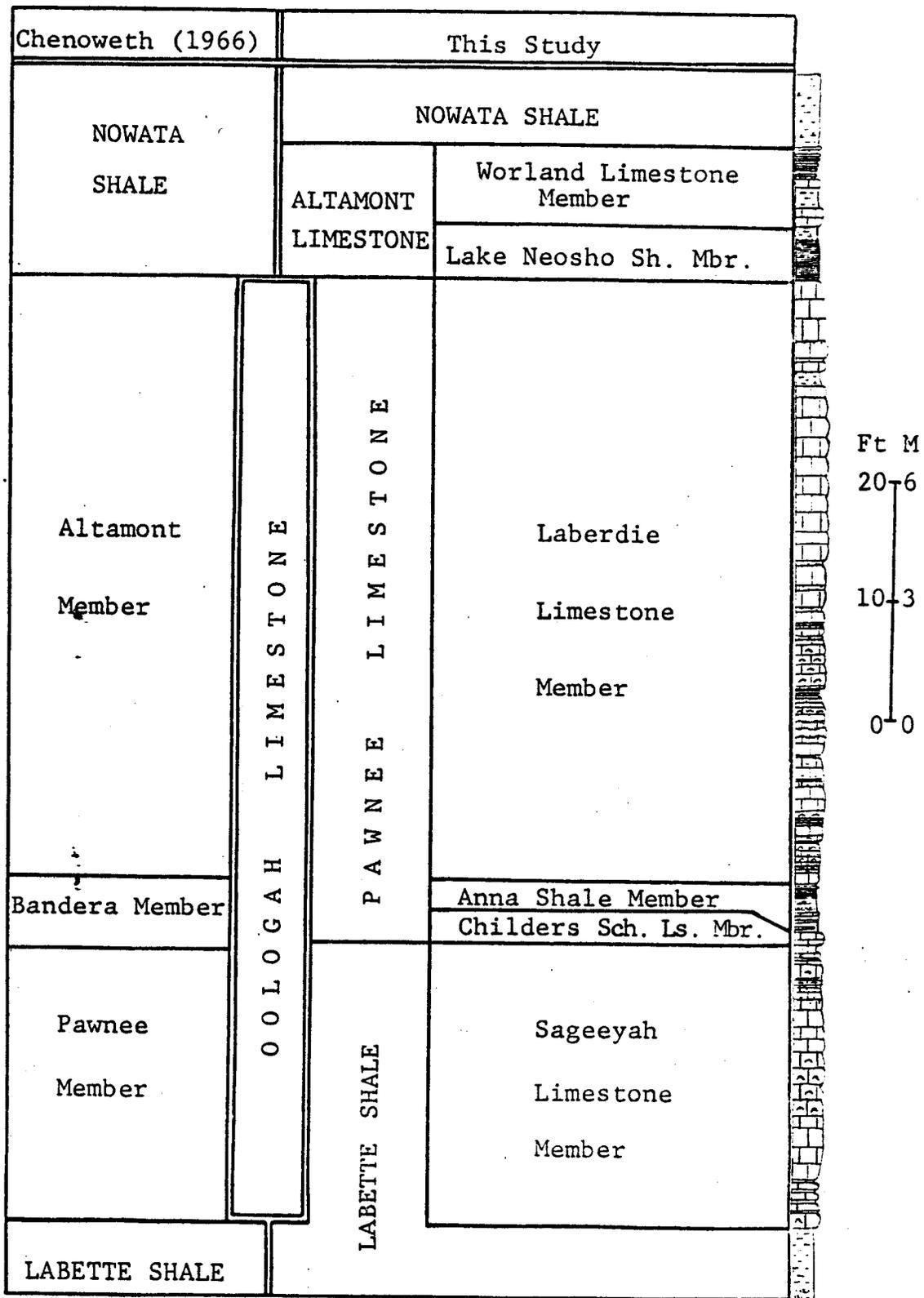


Figure 24

following trends in Desmoinesian sedimentation: 1) thinning and ultimately pinching out of the Bandera Shale; 2) shaling out of the Amoret Limestone Member of the Altamont, which in Kansas and Missouri was noted by Schenk (1967) to become a calcareous shale over positive structures; 3) thickening of clastics of the Labette Shale into both the Cherokee Basin and Arkoma Basin, with upper portions interfingering with and becoming a massive carbonate over the postulated high; if this were a low, the influx of clastics would have overwhelmed carbonate production; and 4) absence of sandstone in the lower part of the Labette Shale below the massive carbonate buildup. Where the clastics thicken both to the north and to the south, sandstone is present in the lower Labette Shale.

Collectively, these sedimentary trends are best explained by the existence of a subaqueous topographic high. The Shelf Edge Rise eventually became covered by clastics that filled the Arkoma Basin and prograded northward into southern Kansas, and thus it apparently had little effect on sedimentation during Missourian time.

CHAPTER IV  
PETROGRAPHY

Study of petrography of the members of the Pawnee Limestone using thin sections stained with Alizarin red-S and potassium ferrocyanide, enables determination of both depositional and diagenetic fabrics from which facies can be interpreted (Figures 25 and 26). Members to be discussed in ascending stratigraphic order: 1) Childers School Limestone Member, 2) Anna Shale Member, 3) Myrick Station Limestone Member, 4) "Lower Laberdie Limestone" - Frog Limestone Bed, 5) Mine Creek Shale Member, and 6) Laberdie Limestone-Coal City Limestone Member. Discussion of the Sageeyah Member of the Labette Shale will be included with the Childers School Limestone.

Childers School Limestone Member

Observations

In northern Oklahoma, south of the Wimer School section, the Childers School Limestone is a massive, strongly indurated, and tannish to light brown skeletal calcarenite, ranging in thickness from approximately 0.2 meters to 1.0 meters. Northward, across southeastern Kansas, the Childers School is a slabby dark gray to black

Figure 25. Depositional facies of carbonates along outcrop belt of Pawnee Limestone. Convex upward curves indicate abundance of phylloid algae and convex upward quarter moons with vertical lines indicate abundance of chaetetids. Refer to Figure 10 for names of members and beds.

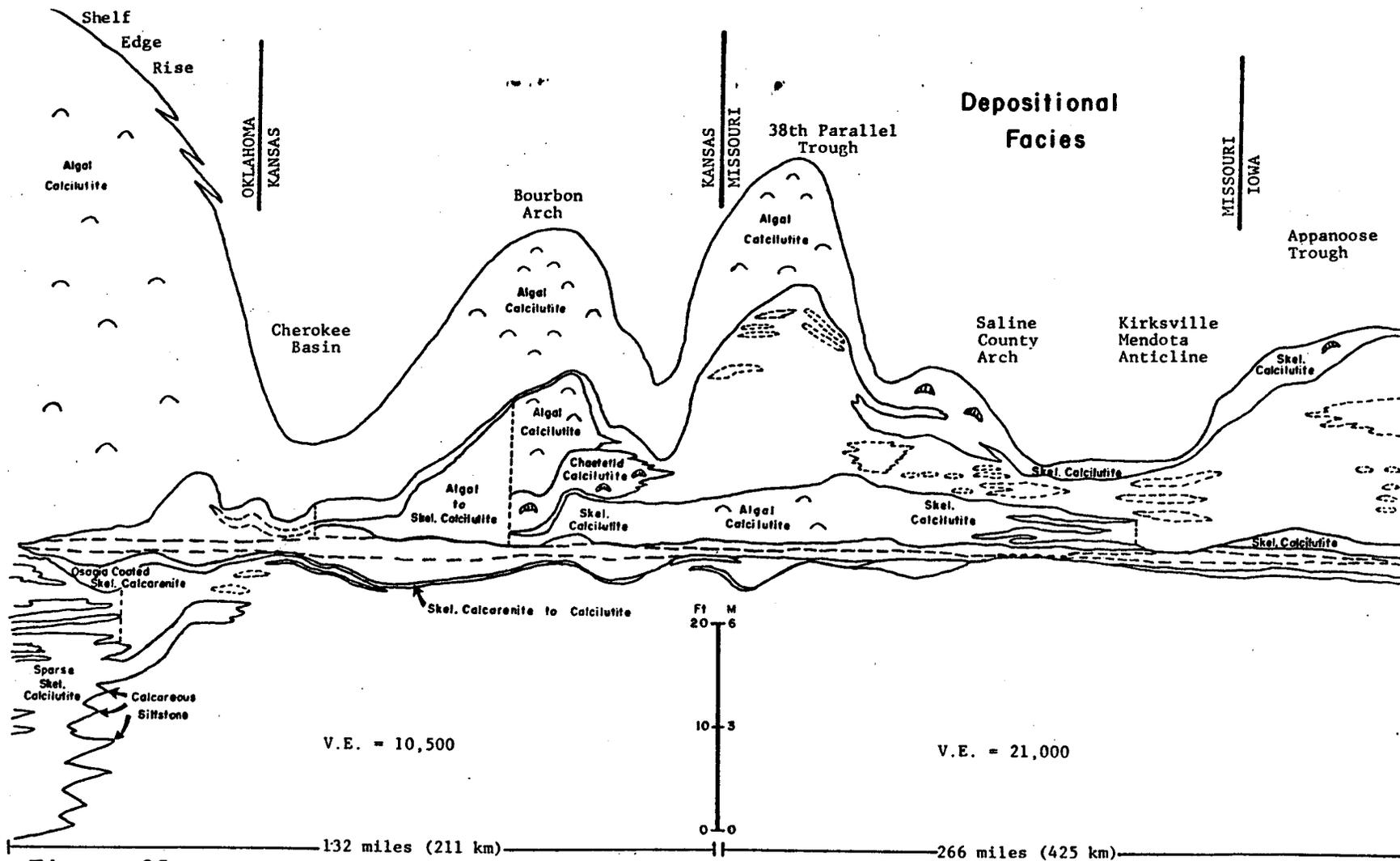


Figure 25

Figure 26. Diagenetic facies of carbonates along outcrop belt of Pawnee Limestone. Refer to Figure 10 for names of members and beds.

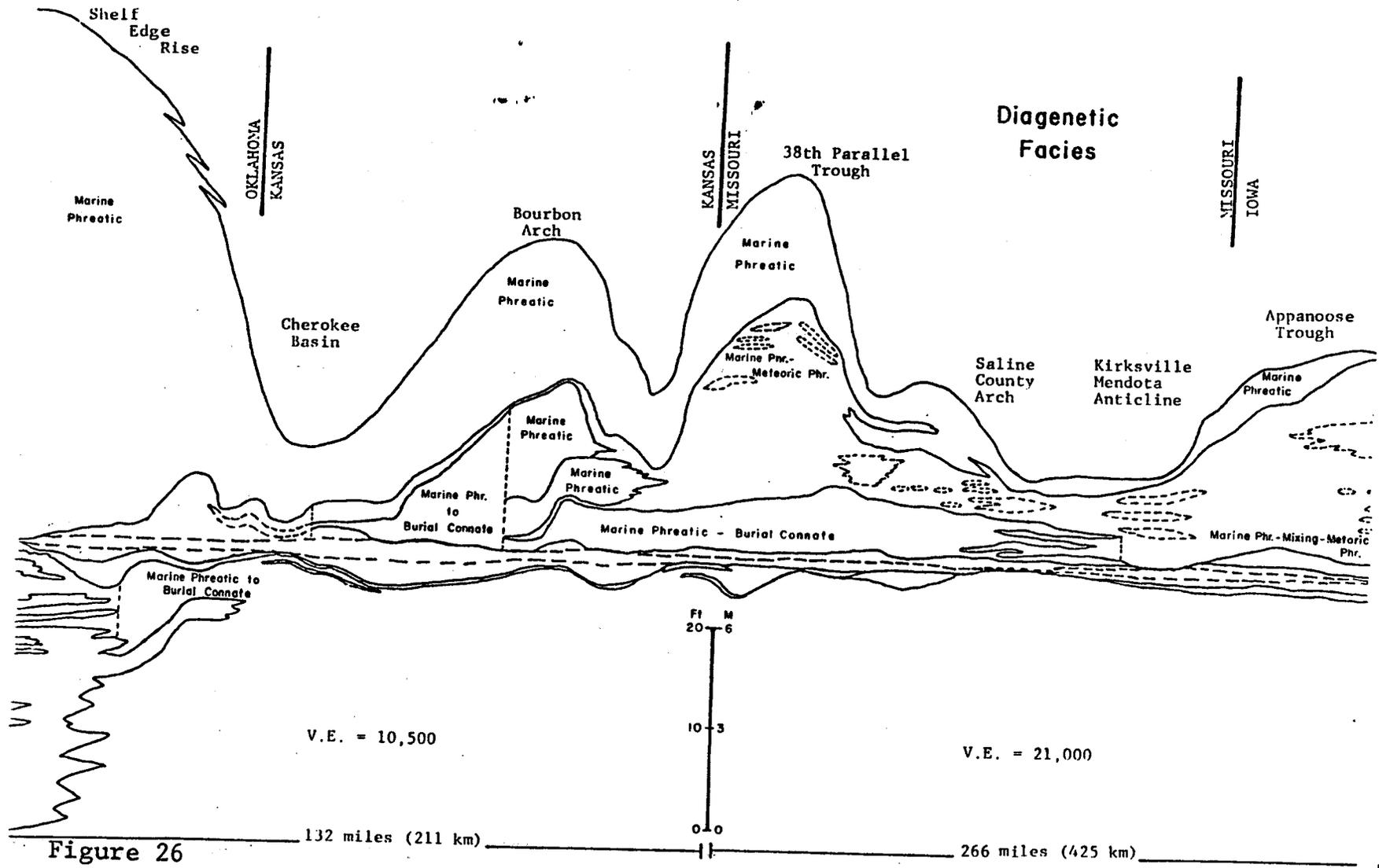


Figure 26

skeletal calcilutite to calcarenite, which is lenticular and does not exceed 0.2 meters thick.

Petrographically, the Childers School of Oklahoma is generally a well-sorted skeletal calcarenite. Minor amounts of fine-grained detrital quartz sand occur throughout, but decrease in abundance toward the top. When less than 0.4 meters thick, the limestone lacks micritic matrix. When thicker, the base of the limestone also lacks matrix material, but grades upward into a calcarenite with as much as 20% of the total rock volume consisting of micritic matrix. At the top, the calcite matrix is completely dolomitized to rhombic dolomite microspar. Ten to fifteen centimeters from the top, the calcite matrix is only partially dolomitized and only a few centimeters lower it is almost totally calcite mud.

High organic diversity, as well as abundance, is indicated by the presence of skeletal grains representing the following fossil groups: echinoderms, brachiopods, bryozoans, foraminifers, red algae (Archaeolithophyllum) and green algae (dasycladacian) molluscs, ostracodes, and trilobites. These skeletal grains, 60 to 80 percent of the total rock volume, are tightly packed (Figure 27) but differ from the Childers School Limestone in Kansas (Figure 28) by not exhibiting parallel orientation, crushing, or grain interpenetration. Good preservation of the internal structure of Archaeolithophyllum and

Figure 27. Tight packing of Childers School Limestone deposited on Shelf Edge Rise in Oklahoma. Noticeably lacking is any early rim cements. Scale is 1 mm long.

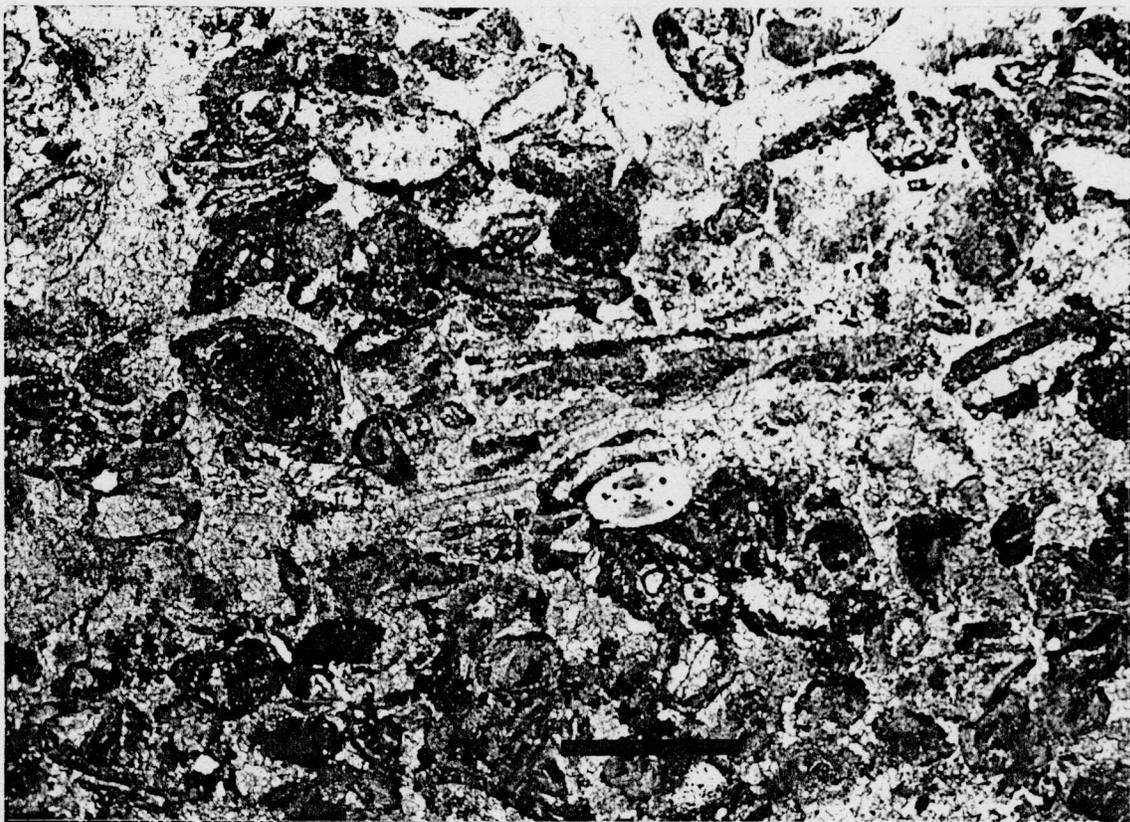


Figure 27

Figure 28. Extreme overpacking of Childers School Limestone deposited in Cherokee Basin in Kansas. Complete lack of early rim cements apparently resulted in grain crushing, interpenetration and parallel orientation during subsequent burial and compaction. Scale is 1 mm long.



Figure 28

dasycladacean green algae and also of microstructural layering of molluscs grains is common. However, edges of echinoderm grains are commonly replaced by dolomitic microspar. Rounding and abrasion of skeletal grains is common, as is the development of micrite envelopes. A common characteristic is osagia coatings (Henbest, 1963) of encrusting forams and algae on outer grain surfaces (Figure 29). Commonly, several grains are encrusted and matted together forming spherical masses up to 1 millimeter in diameter. Like the carbonate mud matrix, these coatings and micrite envelopes are replaced by dolomitic microspar at the top of the unit (Figure 30), but become progressively less altered downward from the top.

Intergranular void filling spar makes up approximately 20 to 30 percent of the total rock volume. Early bladed or drusy isopachous rims are absent. Initial blocky void filling spar is ferroan calcite, which fills almost all available pores. Any remaining pores are rare, but are filled by ferroan dolomite.

The Childers School Limestone of extreme northern Oklahoma and Kansas is a poorly to well sorted skeletal calcarenite to skeletal calcilutite with local occurrences of detrital quartz silt. Either the skeletal calcarenite or the skeletal calcilutite can occur at any one locality but both are commonly present. When both are present, the

Figure 29. Osagia coatings on outer grain surfaces of Childers School Limestone deposited on Shelf Edge Rise in Oklahoma. Although, early rim cements are absent, osagia coatings apparently imparted some rigidity to the grains and prevented extreme overpacking. Scale is 1 mm long.

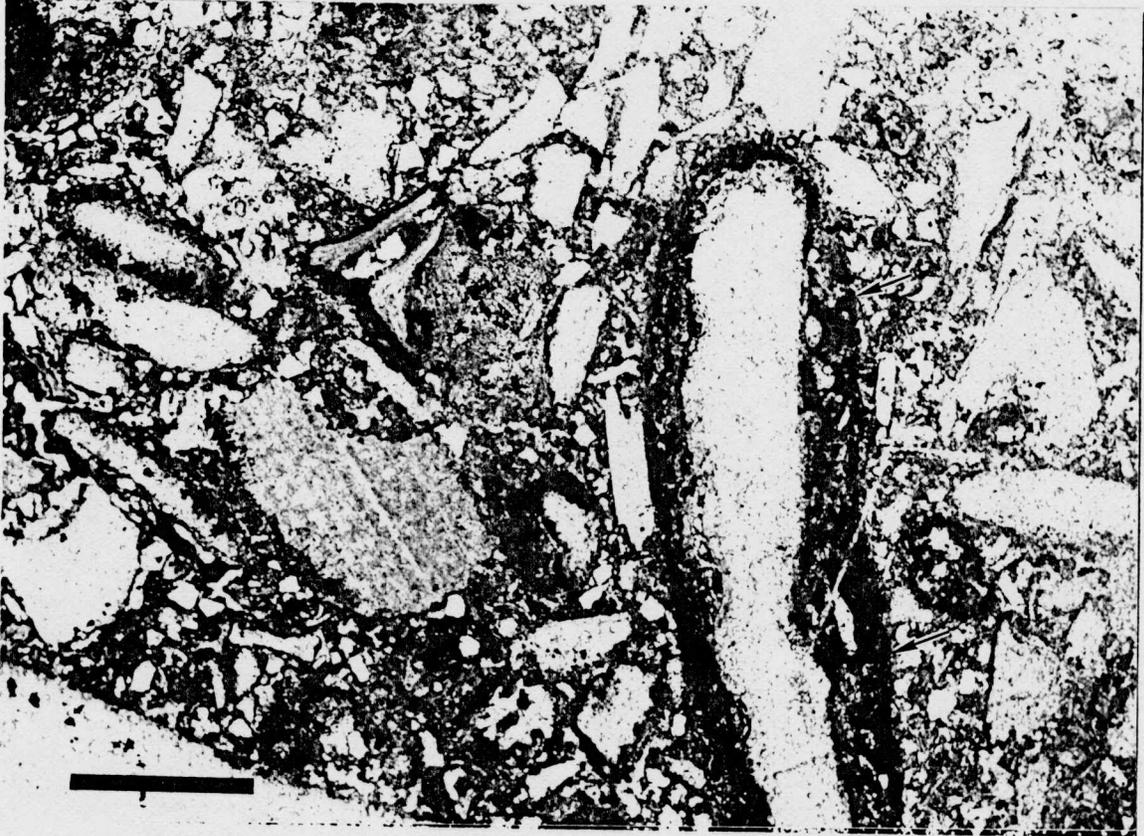


Figure 29

Figure 30. Dolomitic microspar replacing micrite envelopes  
and osagia coatings on grains of Childers School  
Limestone deposited on Shelf Edge Rise in Oklahoma.  
Scale is 1 mm long.



Figure 30

calcarenite is not restricted to the top or bottom of the unit but can occur anywhere within the sequence.

The matrix of the calcilutite, both carbonate and detrital mud, can constitute up to 60 to 70 percent of the total rock volume. If carbonate mud matrix occurs at the top, it is altered to dolomitic microspar, but as with matrix in the calcarenites, alteration decreases with increasing downward distance from the top.

Grains representing essentially the same previously mentioned fossil groups, except red and green algae, are present. *Osagia* coatings and micrite envelopes are rare to absent, and parallel orientation, crushing, and grain interpenetration result in a tightly packed fabric. Most grains are broken, disarticulated, and show little evidence of rounding due to abrasion. In tightly packed areas, echinoderms are commonly replaced by several cloudy calcite spar crystals which display different extinction angles. However, grains are generally well preserved, and molluscs commonly show relict layering. Toward the top, skeletal grains are partially dolomitized, phosphatized, pyritized and silicified. Zones of thin calcarenite at places in Kansas are nearly totally pyritized.

Void-filling spar is less abundant in rocks from the Kansas outcrop, because the overpacked nature of the calcarenite effectively reduced original porosity. However, like the Childers School in Oklahoma, no

isopachous rims are present and void filling proceeded from initial blocky ferroan calcite spar to final ferroan dolomite.

### Interpretation

#### Depositional Facies

The Childers School Limestone can be divided into an "osagia-coated skeletal calcarenite facies" in Oklahoma and a "skeletal calcarenite to calcilutite facies" in Kansas. Based on the presence of the previously mentioned fossil groups, both facies are interpreted as forming under normal marine salinities. Abrasion and common osagia coatings on grains in the "osagia-coated skeletal calcarenite facies" suggest that current activity was capable of rolling and tumbling skeletal grains. This, in conjunction with the presence of both red and green algae and fine-grained detrital quartz sand suggest that water depths were relatively shallow and well within the photic zone.

The skeletal calcarenite to calcilutite of Kansas generally consists of angular skeletal grains lacking osagia coating and probably represents deposition under quieter water conditions at or below effective wave base.

#### Diagenetic Facies

Although the Childers School Limestone has been divided into two separate depositional facies,

diagenetically it is relatively consistent across its area of outcrop. Overpacking of grains that lack early rim isopachous cement, discernible neomorphism with preservation of structure of original aragonitic grains (molluscs and green algae), and blocky ferroan calcite and dolomite cement indicate movement from the marine phreatic depositional and diagenetic environment into the deeper burial connate zone (Heckel, manuscript in review). These characteristics generally apply to the Childers School Limestone and have also been noted for other mid-continent Pennsylvanian limestones below black phosphatic shales (Watney, 1980; Heckel, manuscript in review). Absence of early rim cements apparently allowed substantial compaction prior to cementation. Uneven stress on grains associated with this overpacked grain fabric probably resulted in degrading neomorphism of echinoderm grains in certain Kansas samples. Although early rims are absent, in Oklahoma as well, the osagia coatings that are common there apparently imparted a greater rigidity to the grains (Scholle, 1978) inhibiting extensive overpacking due to compaction.

Ferroan calcite is common throughout as cement, but ferroan and non-ferroan dolomite concentrated at the top of the unit replaces matrix and less commonly grains and also commonly fills voids. Distribution and characteristics of this dolomite also conform to deep-burial late stage

diagenetic alteration of clays and associated limestones as postulated by McHargue and Price (manuscript in review). They noted that both selective dolomitization of calcite mud to rhombic microspar and blocky ferroan dolomite void-filling spar commonly occur adjacent to shales, and they postulated that diagenetic alteration of montmorillonitic clays supplied  $Mg^{++}$  for this late stage dolomitization. Selective dolomitization of osagia coatings and micrite envelopes illustrates this preferential dolomitization of fine-grained material, while the ferroan dolomite spar fills the last remaining voids and fractures. Pyritization and silicification also are most common near the contact with the overlying shale and could also be controlled by ion-rich fluids expelled from the clay lattice during burial diagenesis.

#### Sageeyah Limestone Member of Labette Shale

The Sageeyah Limestone grades northward from an algal calcilutite at the latitude of Tulsa to a sparse skeletal calcilutite with restricted fauna eventually to calcareous siltstone. The algal calcilutite of the Sageeyah Limestone was not studied petrographically. However, petrographic study of the sparse skeletal calcilutite indicate that it is composed of approximately 99 percent matrix material. Calcite mud, which is occasionally clotted and pelleted, predominates, and detrital mud is rare. All skeletal

grains are rare, but grains representing echinoderms, bryozoans, forams, and ostracodes were identified. Interior voids within skeletal grains were thinly rimmed by bladed calcite spar and were followed by blocky calcite spar mosaics.

Depositionally this skeletal calcilutite facies seems to represent somewhat restricted marine conditions, which were transitional between the normal marine salinities of the more fossiliferous algal calcilutite to the south and the presumably fresh-water influenced detrital facies in the Cherokee Basin to the north.

#### Anna Shale Member

The most conspicuous lithology of the Anna Shale is the black phosphatic facies, which is a laminated blocky to fissile shale composed of fine-grained detrital quartz silt, detrital clay and organic material. This black phosphatic shale lacks definitely marine benthos, but remains of probable pelagic marine organisms such as conodont, fish, and probable epiplanktonic orbiculoid brachiopods are abundant. In addition to phosphatic skeletal material, phosphate nodules contain well preserved radiolarians (Berendsen and Nodine-Zeller, 1978), which also represent a pelagic fauna. In addition to phosphate nodules, lenticular phosphatic lamina are common and also seem to displace depositional detrital laminations. This

suggests that they formed diagenetically after initial deposition. Humic organic material, probably transported in colloidal suspension, is common throughout the Anna, but increases in abundance to the north (Joe E. Hatch, personal communication, 1981). Heavy metals also are concentrated in the black shale facies (Hyden and Danilchik, 1962; Brown, Bailey, and Cline, 1977).

Gray shale both above and below the black phosphatic facies is transitional to the adjacent limestones and contains a diverse benthic and pelagic marine fauna. These gray shale facies are interpreted to form under normal marine conditions in the absence of carbonate mud production.

The black phosphatic facies of the Anna Shale Member is interpreted, as are other black phosphatic shales in the Midcontinent (Merrill and Martin, 1976; Heckel, 1977), to have been deposited under anoxic marine conditions with the bottom unsuitable for benthic organisms. Probable causes for anoxic bottom conditions are elaborated in a later section.

#### Myrick Station Limestone Member

The Myrick Station Limestone exposed from southeastern Kansas to Iowa is a thick-bedded dense skeletal to locally algal calcilutite, which is partially dolomitic. Matrix material forms 85 to 98 percent of the rock, and varies

from pelleted and homogeneously textured micrite to homogeneously textured rhombic dolomitic microspar. Burrows are relatively common throughout the skeletal calcilutite. In Kansas and Missouri, dolomitized matrix is generally restricted to the base of the unit adjacent to the underlying black shale, but is locally present along argillaceous zones within the unit, along stylolites (Figure 31), and occasionally at the top. In Iowa, the matrix is dolomitized throughout the entire unit.

Fragmented and whole brachiopods and fusulinids dominate skeletal grains, except in west-central Missouri where algal blades are locally abundant. Echinoderm, bryozoan, ostracode, mollusc, coral, sponge, and trilobite fragments, though relatively rare, are typically associated with the brachiopod and fusulinid facies. In Kansas, micrite envelopes resulting from algal borings are conspicuously absent at the base, but are found occasionally at the top. Coarse borings by gastropods or sponges are relatively common. In Iowa, micrite envelopes are also rare, but have been identified throughout the unit. Partial dolomitization of echinoderms by rhombic microspar is common. Silicification, grading from chalcedony along the margins to chert in the centers, is rare and is generally restricted to brachiopods and occasionally echinoderms. Pyritization of grains occurs locally at the base. The pelleted micritic matrix,

Figure 31. Myrick Station Limestone showing rare dolomitization associated with stylolites. Scale is 1 mm long.

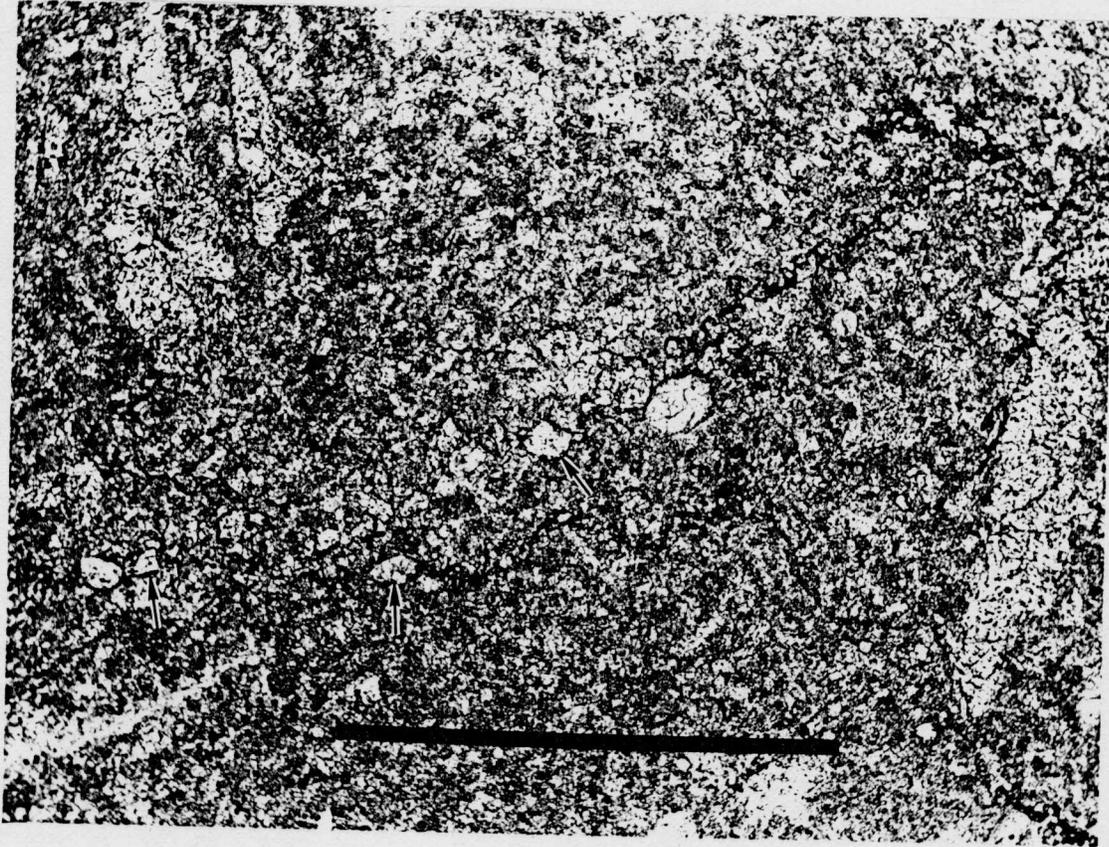


Figure 31

generally restricted to those areas of greatest diversity of fossil groups, is absent in areas where algal blades predominate.

In west-central Missouri, algal blades are the dominate skeletal grain. Possible preservation of utricles (Figure 32) suggests the presence of codiacian green algae. In Missouri, algae occur at the base but increase in abundance toward the middle of the unit. A reduction in algae in upper portions of the unit coincides with increased shaliness at the top. In north-central Missouri, where the Myrick Station is thinner and argillaceous, algae are present but rare. In zones where algae are most abundant, both walled and unwalled calcispheres are common (Figure 33). At the top, both algal blades and calcispheres are occasionally replaced by ferroan dolomite. Voids beneath algal blades are rare because blades are generally flattened and crushed. Fractured carbonate mud commonly separates the algal blades.

Because algal blades are flattened and voids are not readily preserved, void-filling spar is relatively rare and generally constitutes less than 5.0% of the total rock volume. Interior rim cement within skeletal grains occurs as poorly developed coarse blades (Figure 34) except in Iowa where well developed bladed to fibrous rims are common (Figure 35). Also in Iowa, rare fibrous rims grow outward into the dolomitic matrix (Figure 36). Interior calcite

Figure 32. Possible preservation of utricles. These suggest presence of codiacian green algae in algal facies of Myrick Station Limestone in Missouri. Scale is 1 mm long.

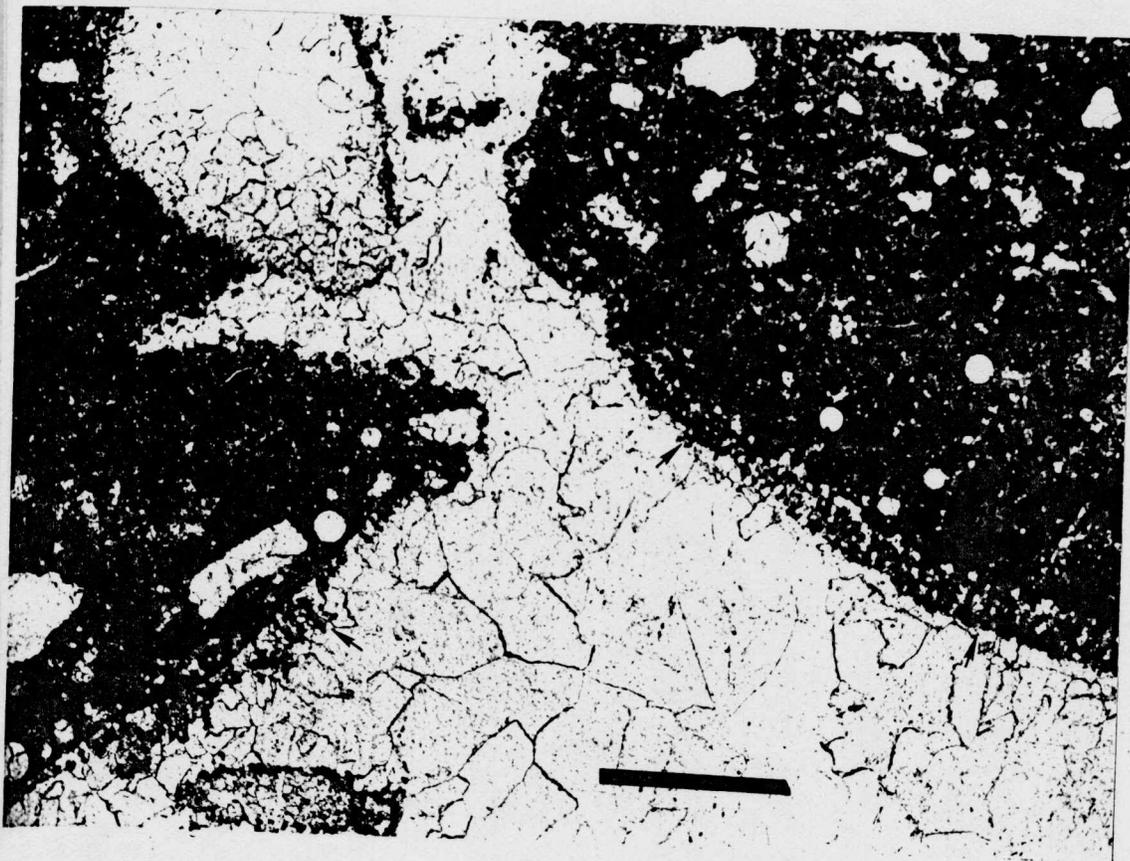


Figure 32

Figure 33. Walled and unwalled calcispheres. These are associated with increased abundance of algae in algal facies of Myrick Station Limestone in Missouri. Scale is 1 mm long.

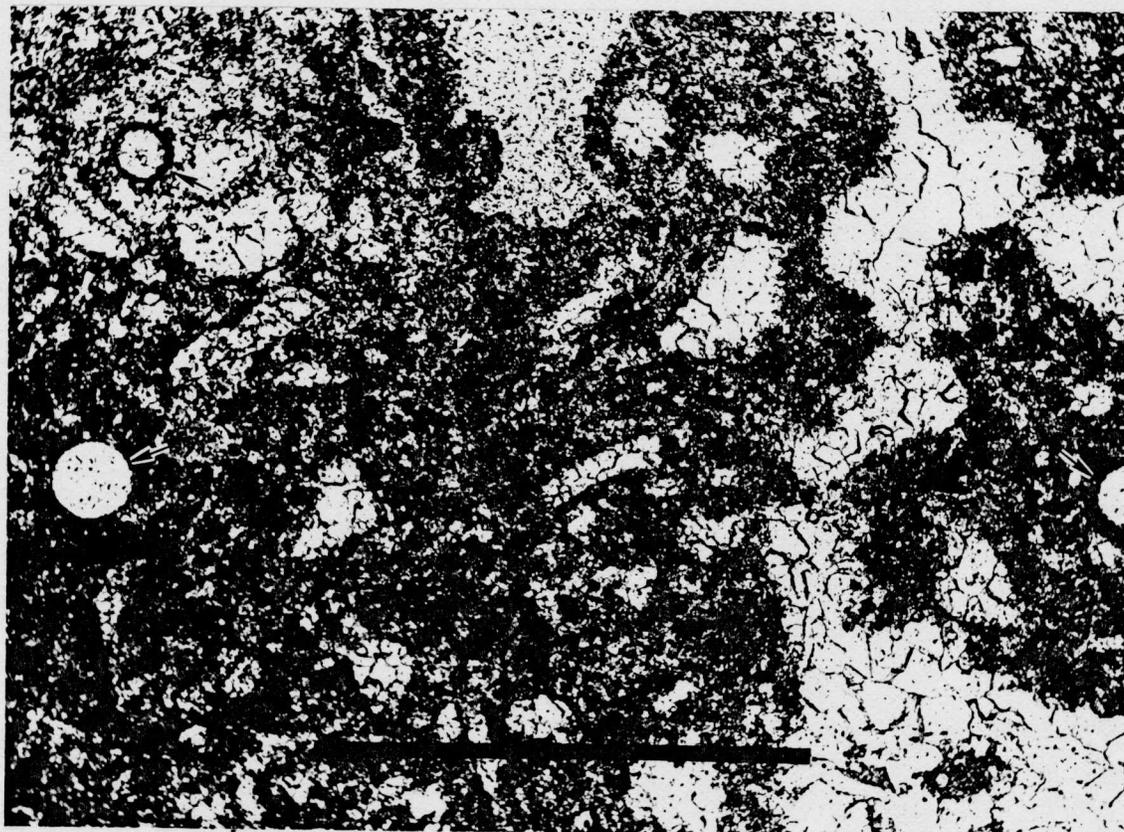


Figure 33

Figure 34. Poorly developed coarse bladed cement. These line interior margins of voids within skeletal grains and grade into coarse blocky calcite in center. Sample from Myrick Station Limestone in Missouri. Scale is 1 mm long.

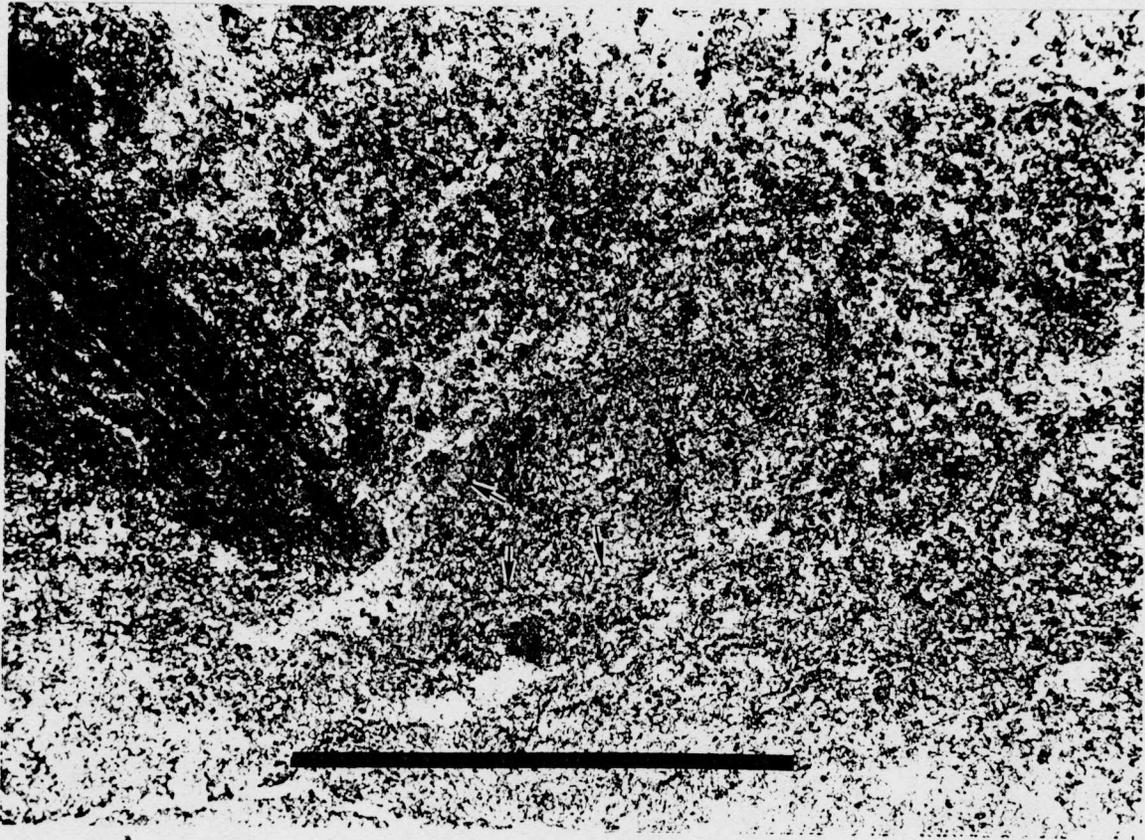


Figure 34

Figure 35. Well developed bladed cement rims. These line interior margins of voids within skeletal grains and grade into coarse blocky calcite in center. Sample from Myrick Station Limestone in Iowa. Scale is 1 mm long.

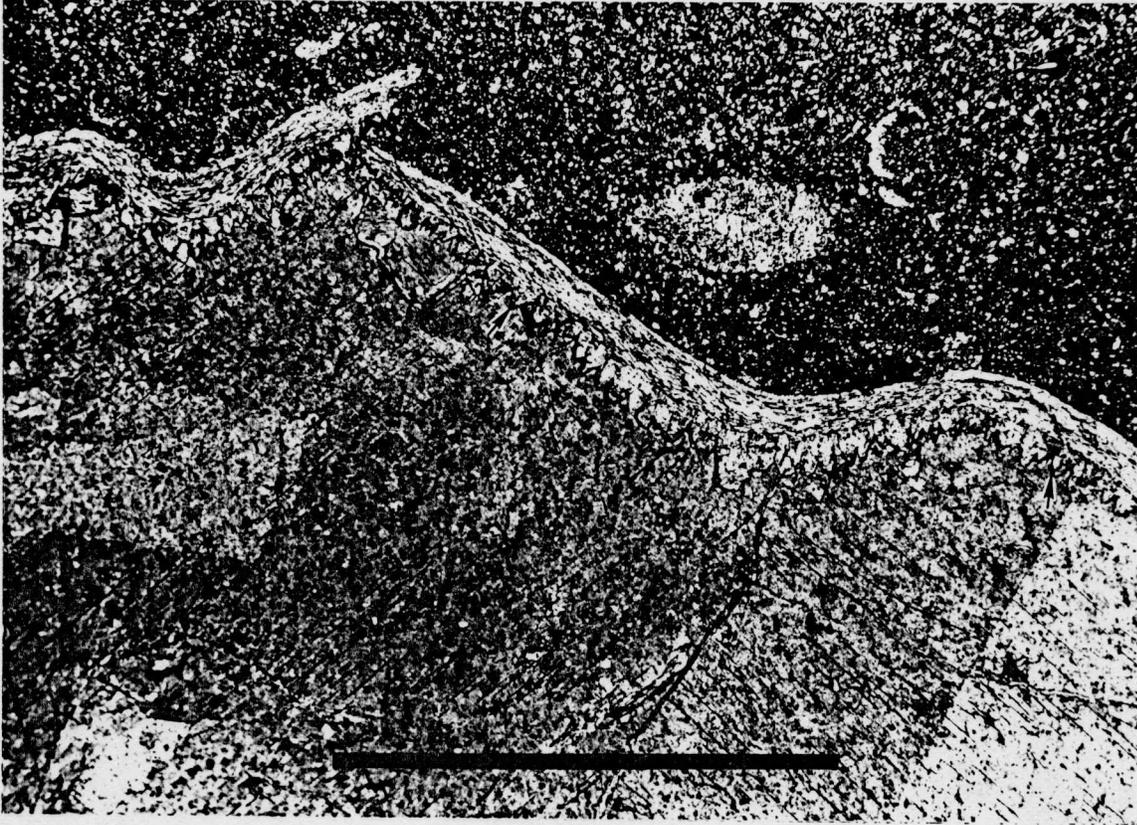


Figure 35

Figure 36. Fibrous exterior rims. These coat skeletal grains and grow into dolomitized matrix. Sample from Myrick Station Limestone in Iowa. Scale is 1 mm long.

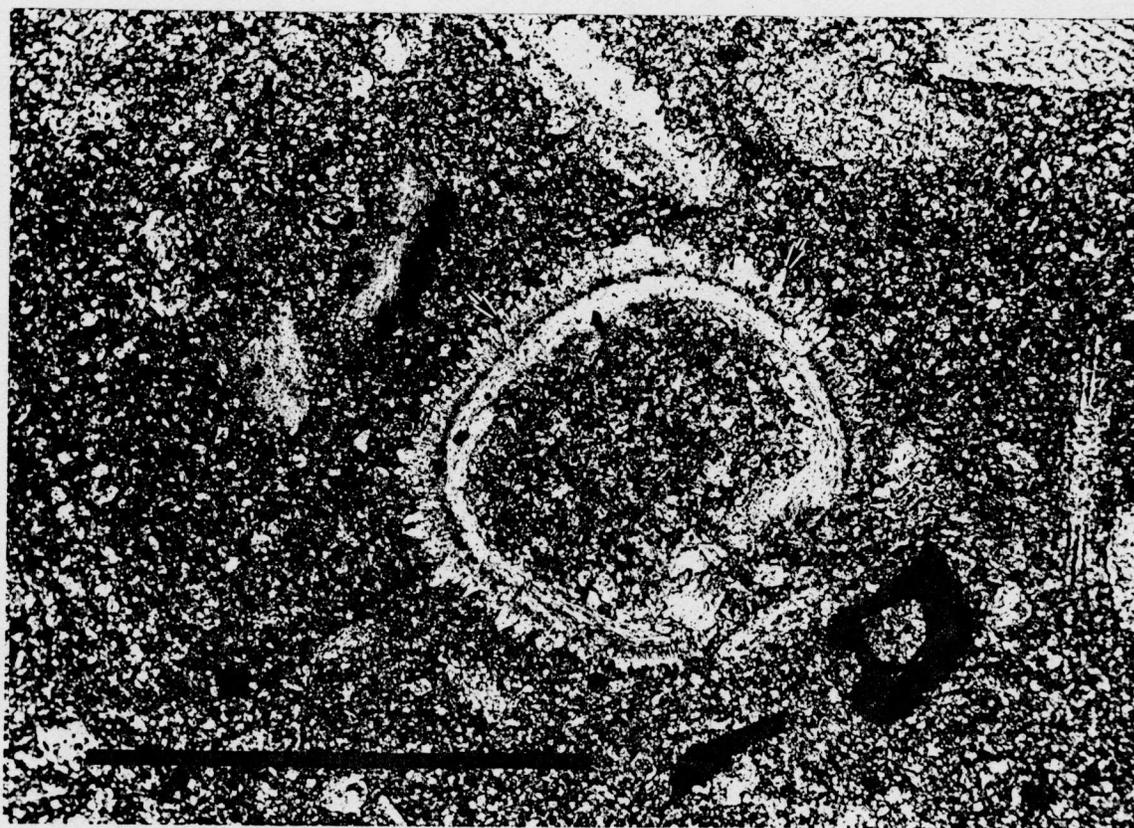


Figure 36

rims grade into blocky calcite spar and ultimately to ferroan calcite or dolomite in the center of voids. Void-filling ferroan dolomite, like the rhombic dolomitic microspar, is generally restricted to argillaceous horizons within the carbonate or to the top or bottom of the unit adjacent to shales.

### Interpretation

#### Depositional Facies

The Myrick Station Limestone can be divided into 1) a skeletal calcilutite facies in Kansas and in north-central Missouri and Iowa and 2) an algal calcilutite facies in west-central Missouri. Both facies were deposited below effective wave and/or winnowing base. In Kansas, the absence of boring algae (micrite envelopes) at the base of this non-shaly carbonate, suggests that water depths were too great for adequate light penetration and algal growth. More shoreward, in west-central Missouri, water depths were apparently shallow enough for algal proliferation. The absence of algae in argillaceous horizons at the top of the algal calcilutite and also in the more argillaceous facies to the north, suggests that increased turbidity may have contributed to the loss of the algal calcilutite facies in north-central Missouri and Iowa. Although the causes of the absence of algae from the skeletal calcilutite facies

of north-central Missouri and of Kansas appear to differ, the limestones in these two areas are very similar.

### Diagenetic Facies

The skeletal calcilutite of Kansas and the algal calcilutite facies of west-central Missouri are very similar diagenetically. Skeletal grains are relatively well preserved, interior rim cements are poorly developed and exterior isopachous rims are absent. Apparently, marine interior rim cement began to develop prior to burial. The rhombic dolomitic microspar and ferroan dolomite late stage void filling is generally associated with clays and according to McHargue and Price (manuscript in review) reflect burial late-stage alteration. A minor amount of dolomite is associated with stylolites, and according to Wanless (1979) is also a late stage compactional event.

Apparently initial alteration of these facies were in the marine phreatic diagenetic environment but subsequent burial resulted in later alteration in the burial connate diagenetic environment.

The skeletal calcilutite of Iowa seems to have undergone a different diagenetic history than either facies of the Myrick Station to the south. The extremely well developed fibrous rims should reflect the marine phreatic or marine vadose diagenetic environments (Longman, 1980).

Because of the presence of fine-grained matrix, which signifies little winnowing, and the absence of shoal water facies, this cement is believed to have formed in the marine phreatic environment below effective wave base. Complete dolomitization of the fine-grained matrix suggests subsequent migration of the mixing zone into the area. Dolomitization controlled by mixing of meteoric and marine water was hypothesized by Badiozamani (1973) in his study of Ordovician rocks in Wisconsin and verified by Land (1973) in his study of Pleistocene rocks of Jamaica. Following dolomitization, blocky calcite spar grew outward from the early fibrous rims into the dolomitic matrix. This suggests migration of the saturated meteoric phreatic zone (Longman, 1980; Heckel, manuscript in review) into the area.

In west-central Missouri and Kansas the Myrick Station seems to have undergone initial marine phreatic cementation followed by burial connate diagenesis, whereas in Iowa it went from marine phreatic to meteoric-marine mixing to saturated meteoric phreatic diagenetic environments.

"Lower Laberdie Limestone" -

Frog Limestone Bed

Observations

The "Lower Laberdie Limestone" consists of a lower chaetetid calcilutite facies and an upper algal calcilutite

facies. Both facies contain a diverse marine invertebrate fauna of relatively low abundance like that of the previously described Myrick Station Limestone. Sponge spicules and associated silicified gastropods and pelecypods are common at the base of the chaetetid facies. At the top, both phylloid algal blades and unwalled calcispheres are common and apparently represent a transition into the overlying algal facies. Laminated chaetetids encrusted by bryozoans and foraminifers are common throughout. Micritic matrix material makes up to 75 to 95% of the total rock volume. Although generally homogeneous, the matrix is locally heavily pelleted. Fibrous rim cement coats interiors of skeletal grains and grades inward into coarse blocky calcite mosaics in the center of voids.

The algal calcilutite facies is dominated by phylloid algal blades and unwalled calcispheres. Algal blades are commonly encrusted by bryozoans and foraminifers. Like the algal calcilutite facies of the Myrick Station, algal blades and fractured mud are generally flattened and crushed into underlying voids. Micritic matrix makes up 85 to 95 percent of the rock volume and is homogeneously textured. As in the chaetetid calcilutite, fibrous isopachous cement coats interiors of skeletal grains and grades into coarse blocky spar in the centers of voids.

The Frog limestone bed, which is laterally equivalent to both the Myrick Station Limestone and the "Lower Laberdie Limestone" is mainly dense gray skeletal calcilutite with diverse invertebrate fauna of low abundance closely resembling the Myrick Station Limestone of southeastern Kansas. Algae are presented only in the center of the unit. Where algae are absent the limestone lacks both interior rim cement and micrite envelopes. Ferroan dolomite commonly fills voids. Within the algal horizon, on the other hand, both micrite envelopes and interior rims lining skeletal voids are common, with blocky calcite spar filling final voids.

#### Interpretations

##### Depositional Facies

Both the chaetetid calcilutite facies and the algal calcilutite facies of the "Lower Laberdie limestone" are interpreted to have been deposited under normal marine conditions below effective wave base, based on the presence of carbonate mud and absence of any shoal-water indicators, but within the photic zone, based on presence of micrite envelopes and algal blades.

The algal portion of the Frog limestone appears to have been deposited under conditions similar to those of the "Lower Laberdie limestone," whereas the dense gray calcilutite seems to have been deposited under conditions

more like those of the Myrick Station Limestone in southeastern Kansas. The dense gray calcilutite lacks both algal blades and micrite envelopes and is interpreted to have been deposited below both the zone of effective light penetration for these types of algae as well as effective wave base.

#### Diagenetic Facies

Both the chaetetid calcilutite facies and the algal calcilutite facies underwent initial cementation within the marine phreatic diagenetic environment. This early cementation imparted some coherence and rigidity to both the mud and skeletal grains, but subsequent burial and associated compaction resulted in the flattening of most primary sheltered voids originally preserved beneath blades. The coarse blocky calcite spar that fills final voids is characteristic of either the burial connate or meteoric phreatic diagenetic environment (Heckel, manuscript in review). Since this facies lacks solution vugs, abundant overgrowths or other diagnostic characteristics of meteoric diagenesis, it is interpreted to have undergone burial connate diagenesis. These facies also overlie and are more closely associated with the burial connate diagenetic facies of the Myrick Station Limestone rather than the meteoric phreatic diagenetic facies of the Myrick Station in southern Iowa.

The Frog limestone bed, where algal-rich, is diagenetically similar to the "Lower Laberdie limestone" and is interpreted to have undergone marine phreatic and subsequent burial connate diagenesis. The dense gray skeletal calcilutite with relatively well preserved skeletal grains and absent to rare interior or exterior rims apparently underwent early diagenetic alteration in deeper perhaps colder water where little calcite precipitation takes place. Subsequent burial transferred the unit into the burial connate diagenetic environment.

#### Mine Creek Shale Member

##### Observations

The Mine Creek Shale Member in north-central Missouri is essentially alternating limestone and shale beds with occasional siltstone layers.

Siltstone horizons consist predominantly of angular detrital quartz with minor amounts of both orthoclase and plagioclase feldspars, chert, and mica. Matrix material generally contributes less than 10 percent of the total volume of the cleaner siltstones and is predominantly detrital clay. Carbonate cement locally fills intergranular voids.

Several limestone lenses commonly occurring toward the top of the Mine Creek include the uppermost brachiopod shell horizon, generally only a few centimeters thick,

which is laterally persistent across west-central Missouri (Jewett, 1945; Gentile, 1976). This brachiopod shell horizon is petrographically similar to the Childers School Limestone of Oklahoma, in that it is a tightly packed abraded-grain skeletal calcarenite, which contains echinoderm, brachiopod, bryozoan, foraminifer, green (dasycladacean) algae, mollusc, and trilobite skeletal grains. Also, similar to the Childers School, the grains are highly micritized and are osagia coated. However, noticeable differences are 1) the presence of bladed isopachous rim cement on skeletal grains in the shell beds, 2) absence of dolomitization of either micrite envelopes and osagia coatings on the shells, and 3) blocky calcite spar, instead of ferroan dolomite, as final void filling.

### Interpretations

#### Depositional Facies

The siltstone lenses, because of gradational nature with adjacent marine carbonates, probably represent detrital influx, which temporarily interrupted carbonate production in the marine environment. Because of the angularity of quartz and chert grains and the presence of feldspars, the source area was probably not too distant.

The brachiopod shell horizon is an abraded-grain and osagia-coated skeletal calcarenite. It is postulated to

have formed under normal marine salinities, above effective wave base, and well within the photic zone.

### Diagenetic Facies

The presence of early rim cement indicates that the brachiopod shell horizon remained long enough in the marine phreatic environment where waters were shallow and sufficiently warm to develop an isopachous cement coating. The absence of the early rim in the Childer School of Oklahoma, suggests that the water was incapable of carbonate precipitation and therefore probably colder and deeper. The absence of both fine-grained replacive dolomite and coarse blocky ferroan dolomite void filling is apparently due to the absence of an overlying shale, which McHargue and Price (manuscript in review) considered as a common source of  $Mg^{++}$  for dolomitization of many Midcontinent Pennsylvanian limestones. Since the coarse blocky void filling spar is non-ferroan, it is suggested that the marine phreatic diagenetic environment was followed by saturated meteoric phreatic conditions.

### Laberdie-Coal City Limestone Member

#### Observations

Lithologies of the Laberdie Limestone are similar to those previously described for the "Lower Laberdie Limestone" and the Myrick Station. In west-central

Missouri, Kansas, and Oklahoma, the Laberdie is a dense gray skeletal calcilutite at the base and grades upward into an algal calcilutite. The top is locally an osagia-coated skeletal calcilutite to calcarenite. Northward in Kansas and Missouri, the algal calcilutite occurs closer to the base of the member.

The dense gray skeletal calcilutite of the Laberdie resembles the base of the Myrick Station (see earlier section for detailed description). Interior rim cements on skeletal grains are poorly developed to absent, micrite envelopes are rare and algal blades are generally missing. Northward along the outcrop belt, micritized grains and interior rim cements become more common at the base.

Well developed algal mounds occur 1) on the Shelf Edge Rise in Oklahoma, 2) over the Bourbon Arch in Kansas, and 3) upon the Mine Creek clastic wedge in west central Missouri. Lithologically these algal mounds resemble the algal calcilutite facies of the "Lower Laberdie Limestone" (see earlier section for detailed description). Phylloid algae also are common in the thinner offmound facies between major thickenings. The main difference between algal calcilutites of the mound facies and those of the offmound facies is that the moundrock contains more abundant algal blades, most of which are inclined at some oblique angle, with spar-filled protected voids below. In the offmound facies, the algal blades are more commonly

flattened and chaetetids dominate the offmound facies north of the northernmost algal mound.

The top of the Laberdie-Coal City is generally an osagia-coated skeletal calcilutite containing approximately 90 percent micritic matrix. On the Bourbon Arch, however, it is locally calcarenitic with well preserved skeletal grains (including Archaeolithophyllum). Interior fibrous rims within voids in skeletal grains and micritization of grains are common.

In north-central Missouri and Iowa the equivalent Coal City limestone is commonly split by an abundantly fossiliferous gray marine shale only a few centimeters thick. Detrital quartz silt is rare to absent within the shale. The Coal City Limestone is a skeletal calcilutite with a diverse marine biota of low abundance. Matrix material commonly makes up 80 to 90 percent of the total rock volume. Algal blades are rare in north-central Missouri and absent in Iowa. Laminated chaetetids are commonly conspicuous on outcrop in areas where algae decrease in abundance. Micrite envelopes and interior rim cement that coats grain voids are common throughout the entire sequence and decrease toward the intervening gray marine shale. Partial dolomitization of the micritic matrix and ferroan dolomite filling late-stage voids occurs adjacent to this shale horizon. Osagia coating of grains is common at the top of the unit. The top of the Coal City

across the Saline County Arch is calcilutitic, but is intensely weathered and brecciated.

### Interpretations

#### Depositional Facies

The dense gray skeletal calcilutite at the base of the Laberdie is interpreted to have formed under normal marine condition near the lower limits of effective light penetration because it lacks algal grains, and micrite envelopes are either absent or poorly developed.

The algal calcilutite also was deposited under normal marine conditions but in shallower water well within the photic zone. The predominance of carbonate mud suggests quiet water conditions below effective wave base.

Abundance of chaetetids increases with an associated reduction in abundance of algae and apparently reflect the chaetetids ability to colonize in areas that are not ideal for algal proliferation. The algae apparently out-competed the chaetetids under ideal conditions for algal proliferation, thereby explaining the absence of chaetetids from algal facies.

Across Missouri and Iowa, extensive micritization of grains floating in carbonate mud matrix is common in the Coal City. This suggests slow deposition within the photic zone but below effective wave base. The loss of micrite envelopes toward the fossiliferous gray marine shale and

the absence of detrital quartz silt in it suggests a possible deepening of water for its deposition.

Lithologies of the top of the Laberdie-Coal City, which are calcarenitic across the Bourbon Arch and locally brecciated over the Saline County Arch, suggest that on subaqueous topographic highs the upper portion was deposited above effective wave base or was subjected eventually to subaerial exposure respectively.

#### Diagenetic Facies

Poorly developed interior rim cements lining skeletal grain voids occur within the dense gray calcilutite at the base of the unit and also occur adjacent to the intervening gray shale. This suggests slower rates of precipitation in cooler and probably deeper water and corroborates previously discussed depositional conditions.

The well developed interior fibrous rims lining skeletal grains of the algal calcilutite suggest early cementation in shallow warm water, which is conducive for precipitation. Early marine cementation apparently was more pervasive on the subaqueous topographic highs where algal mounds are thickest and sheltered voids are commonly preserved beneath algal blades. Off the topographic highs, in deeper water between mounds, cementation was not as pervasive as is evidenced by the flattening of algal blades and coherent mud into underlying voids.

Diagenetic alterations of the Laberdie-Coal City Limestone are the type that take place within the marine phreatic diagenetic environment.

#### Summary of Patterns

Although the Childers School Limestone in Oklahoma is interpreted to have initially formed under relatively shallow water marine conditions, northward it appears to have been deposited in water both below effective wave base and limits of effective light penetration for algal growth. Lack of early interior and exterior isopachous rims on skeletal grains and common grain crushing and interpenetration all suggest alteration only after extensive compaction in the burial connate diagenetic environment with no evidence of meteoric invasion.

The base of the Myrick Station Limestone and the Frog limestone bed generally lack shallow water indicators and probably formed in deeper open marine water. On topographic highs and more shoreward in Iowa, fibrous interior rim cements and matrix dolomitization are common with algae occasionally present, and are suggestive of shallower water conditions. The deeper water carbonates apparently underwent cementation in the marine phreatic diagenetic environment whereas the near-shore carbonates were cemented in the marine phreatic to meteoric phreatic diagenetic environments.

The Laberdie and Coal City Limestones commonly contain algae and interior fibrous rim cements that line skeletal grain voids and apparently formed under relatively shallow open marine conditions below effective wave base. Calcarenites occur over the Bourbon Arch and brecciated carbonates over the Saline County Arch. The Laberdie-Coal City apparently underwent early diagenetic alteration in the marine phreatic environment, but was invaded by unsaturated meteoric vadose environments at least on the Saline County Arch, which caused limestones to brecciate there.

CHAPTER V  
RECOGNITION AND DISTRIBUTION  
OF MICROFOSSILS

Ostracodes, encrusting and arenaceous foraminifers, holothurian sclerites, scolecodonts, fish debris, conodonts and palynomorphs have all been recognized in residues from the Pawnee Limestone. However, systematic studies were made only of palynomorphs from one section (Jubilee Quarry) to determine trends of vertical distribution, and of conodonts from 11 vertical sections along the outcrop belt to determine trends of vertical and lateral distribution.

Palynomorphs

The main purpose for processing for palynomorphs was to determine their occurrence and concentration within the black phosphatic shale member. Since these shales formed within an anoxic environment, they should represent ideal conditions for palynomorph preservation. The Jubilee Quarry section was chosen for sampling because the Childers School Limestone is lenticular and locally absent and a complete sequence of samples grading from the underlying gray Labette shale into the black phosphatic Anna Shale could be obtained.

Standard processing procedures were used for concentrating palynomorphs (Gray, 1965). Ten slides of each sample were prepared and studied for pollen and spores.

The lowermost sample, approximately two feet below the top of the Labette Shale, contained abundant palynomorphs. Palynomorphs then decrease in abundance toward the top of the Labette and are completely absent from the Anna Shale Member. Although extremely rare, palynomorphs at the top of the Labette Shale are nevertheless well preserved.

This continued well preservation accompanying the upward decrease in abundance suggests that the absence of palynomorphs from the black phosphatic shale is due to non-deposition rather than to alteration and removal by corrosive fluids during diagenesis.

#### Conodonts

The purpose of the conodont study of the Pawnee Limestone is to determine both vertical and lateral distribution trends for comparison with the trends determined by Heckel and Baesemann (1975) for Upper Pennsylvanian (Missourian) units. This is only a generalized study to show gross distributional trends, not a rigorous taxonomic study. Similar, but more detailed distributional studies (Wood, 1977; Mitchell, 1981) have been conducted on certain Missourian units.

### Methods

Samples from eleven different sections along the outcrop belt were processed for conodonts (Figure 37). Depending upon lithology of the sample, processing was by one of three methods. Limestones were dissolved in 10 percent formic acid for 18 to 36 hours. Gray shales were 1) oven dried, 2) placed in Stoddards Solvent for 24 hours, 3) drained, and 4) finally immersed in water for 24 hours. Organic-rich black fissile shales were placed in a 5 percent solution of sodium hypochlorate (bleach). When the solution turned dark (approximately 10-14 days) it was decanted off and replaced by fresh bleach. Most organic-rich samples (500 grams) took six to twelve months before completely disaggregating. Disaggregated sample residues were wet-sieved through 120 (125 micron) and 230 (63 micron) mesh screens. Large residues from the 120-mesh screen, were reduced in size by heavy-liquid separation (tetrabromoethane) and were subsequently picked for conodonts. Detailed conodont data are presented in Appendix C. Since most samples were only 300 to 500 grams, both the number of conodonts per sample and the extrapolated number of conodonts per kilogram is given for each identified species.

Figure 37. Generalized cross-section of Pawnee Limestone showing 10 of the 11 sections (vertical lines) processed for conodonts. Horizontal lines show approximate sample location within each section. Refer to Appendix A for location codes. One additional section (NOC) processed for conodonts is discussed in Appendix B.

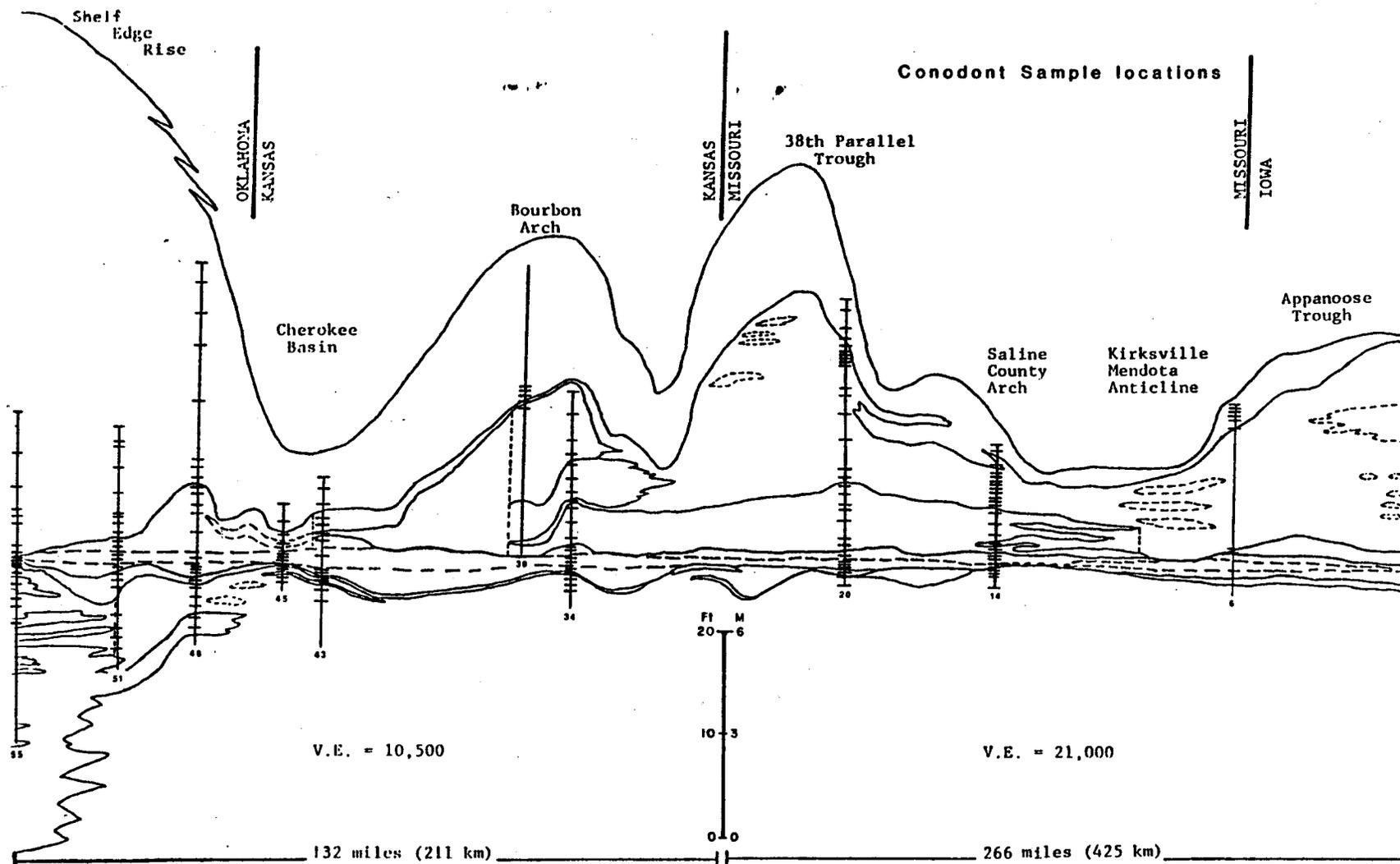


Figure 37

## Identification

Conodonts representing seven different genera have been identified and placed in the following categories: 1) Adetognathus gigantus, 2) Aethotaxis sp., 3) Anchignathodus minutus, 4) Diplognathodus spp., 5) Idiognathodus delicatus, 6) Idioprioniodus conjunctus, 7) Neognathodus spp., and 8) ramiform elements undifferentiated. Only platform elements were included in abundance counts of Adetognathus gigantus, Anchignathodus minutus, Diplognathodus spp., Idiognathodus delicatus, and Neognathodus spp. However, all elements of Aethotaxis sp. (5 elements) and of Idioprioniodus conjunctus (7 elements) were included in respective abundance counts and would partly explain anomalously high counts. Each of the above categories will be defined and discussed individually.

Adetognathus gigantus

Adetognathus gigantus, based on dimorphic platform elements, has been recognized in Missourian rocks by Baesemann (1973) and also in Desmoinesian rocks by J. W. Swade (personal communication). Adetognathus identified in this study are assigned to the species gigantus because of the presence of dimorphic platform elements.

Aethotaxis sp.

Baesemann (1973) described Aethotaxis advena from Missourian rocks. Since Aethotaxis recognized in

Desmoinesian rocks has not been adequately studied and may or may not be the same species as that of Baesemann (1973), it will be considered Aethotaxis sp. for this study.

Anchignathodus minutus

Ozarkodina minuta of Baesemann (1973) is presently considered Anchignathodus minutus by J. W. Swade (personal communication) whose terminology is used for this study.

Diplognathodus spp.

J. W. Swade (personal communication) has recognized two different previously undescribed species of Diplognathodus from the Pawnee interval. Since only nine specimens of Diplognathodus were identified from all processed samples, they are collectively grouped under Diplognathodus spp.

Idiognathodus delicatus

Extensive morphological variation exists for Idiognathodus, and according to Merrill (1975) the group has never been satisfactorily speciated. Idiognathodus identified from the Pawnee are assigned to the species delicatus in the same sense as that of Merrill (1975) and therefore represent form species.

Idioprioniodus conjunctus

Idioprioniodus typus, commonly found in Missourian rocks, contains six different elements, whereas,

Idioprioniodus conjunctus, commonly found in Desmoinesian rocks, contains 7 different elements (Merrill and Merrill, 1974). All 7 elements are identified in the Pawnee samples and therefore represent Idioprioniodus conjunctus in the sense of Merrill and Merrill (1974).

#### Neognathodus spp.

Merrill (1975) speciated Neognathodus on the basis of morphological variations. These variations include arrangement of nodes, number of nodes, and presence of a parapet. The biostratigraphic implications of Merrill's speciation are far too complex for this study, therefore all Neognathodus are grouped together under Neognathodus spp.

#### Ramiform Elements Undifferentiated

Ramiform elements of Adetognathus gigantus, Anchignathodus minutus, Diplognathodus spp., Idiognathodus delicatus, and Neognathodus spp. are grouped together and counted as ramiform elements undifferentiated.

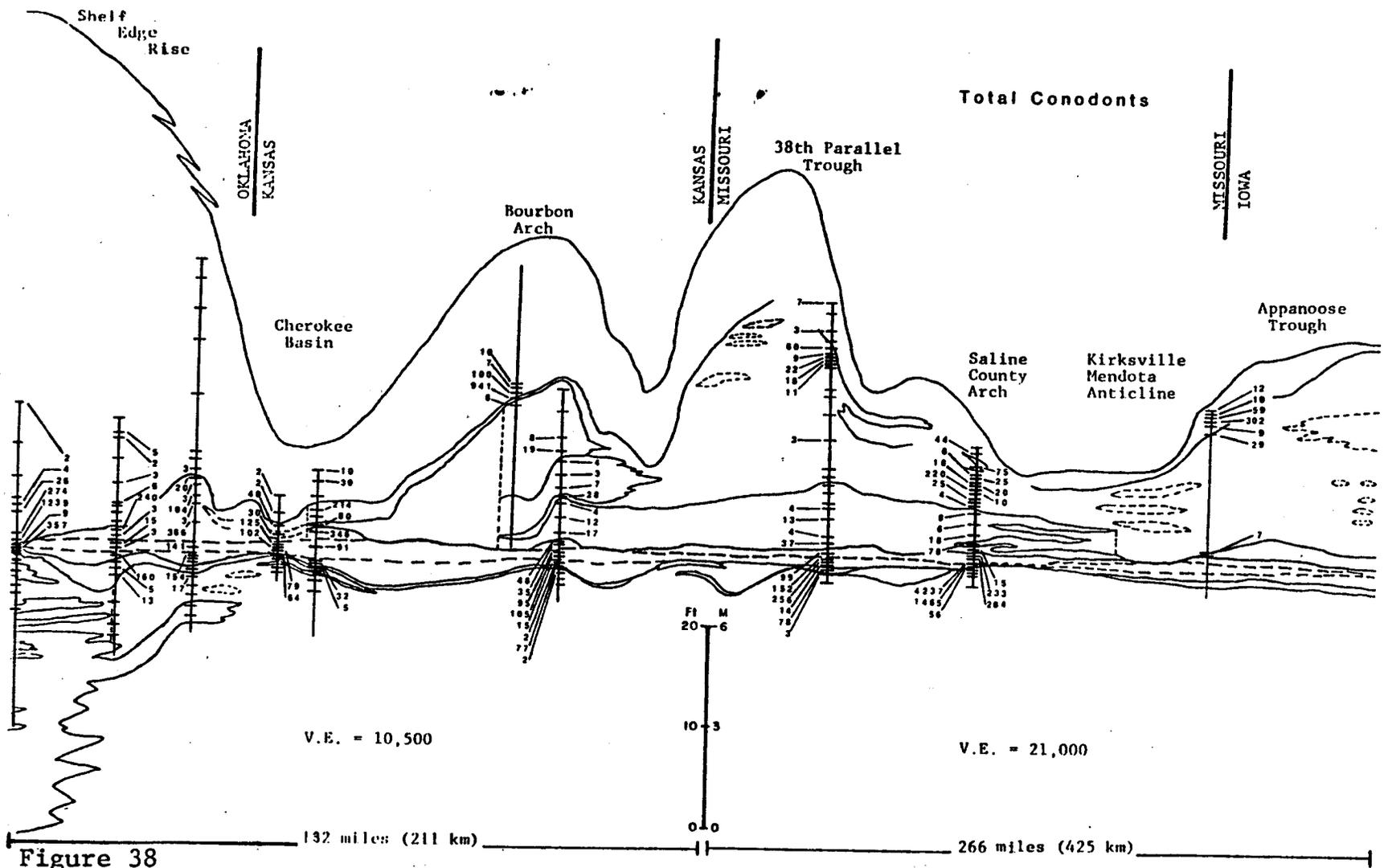
#### Distribution Along Outcrop Belt

Maximum conodont abundance in the Pawnee occurs within the Anna Shale Member in samples from both the black fissile phosphatic portion and from the black flakey to gray transitional portion. Anomalously low conodont abundances within some black fissile shale samples

(particularly from No. Ok. and O.Ok. sections) is attributed to leaching and removal of conodonts after deposition. This conclusion is based on the presence of conodont molds on bedding planes and also on the weathered nature of the few conodonts recovered from samples of abnormally low counts. Low abundance within the black flakey and gray transitional portion is attributed to decreased abundance during deposition and not to leaching, because no molds are found on bedding planes and conodonts are well preserved even when counts are low. The black phosphatic portion is apparently more susceptible to fluid flow and subsequent leaching because of the blocky fracture and the fissility, whereas the black to gray transitional portion is more impermeable.

Conodont counts from the Anna Shale generally range from several hundred to over a thousand per kilogram of processed sample (Figure 38). Maximum abundance of over four thousand conodonts was recorded from the Anna at the Coloma section (Co. Mo.), where thickness of the rock sequence is greatly reduced because of deposition across the Saline County Arch. Similar to the trends of Heckel and Baesemann (1975) for conodonts in Missourian cyclothem, abundances generally decrease in both directions away from the black shale. However, an anomalous horizon of increased conodont abundance occurs stratigraphically above the Anna. This horizon apparently persists from

Figure 38. Generalized cross-section of Pawnee Limestone showing total abundance of combined conodont taxa. All elements are included in count. Vertical lines show sections processed for conodonts and horizontal lines show approximate sample location within each section; those with no numbers indicate barren samples. Abundances are listed for a kilogram sample. See Appendix C for actual abundances and detailed lithologic sections.



southeastern Kansas to Iowa and is represented by the Joe shale across the Bourbon Arch and in the Cherokee Basin to the south, by a calcareous shale separating limestones at the top of the Mine Creek Shale across the Saline County Arch, and by a shale parting within the Coal City Limestone in the Appanoose Trough. Although lithically, this shale in Missouri and Iowa is not readily recognized in the field, as is the Anna Shale, it is believed to represent a continuous but thin horizon. Southward from the Bourbon Arch, the Joe shale becomes black and fissile to flakey and converges with the top of the Anna. South of this convergence the Joe shale cannot be lithically separated from the Anna. However, a zone of low conodont abundance, apparently corresponding to the Frog limestone interval of the north, separates the high conodont abundance of the Joe shale at the top from the high conodont abundance of the Anna Shale at the base at sections Lab SW, E.S., W.S., and No.Ok. (Figure 38).

Just as Wood (1977), Wood and Heckel (1977), and Mitchell (1981) found with Stanton and Iola (Missourian) conodont distribution, this study shows that vertical variation in both distribution and abundance is more dominant than lateral change. Furthermore, similar trends of distribution of individual genera are apparent.

Lateral variation does exist, however, in the distribution of Adetognathus gigantus (Figure 39). In

Figure 39. Generalized cross-section of Pawnee Limestone showing abundance and distribution data for Adetognathus gigantus. Only platform elements are included in abundance counts. Abundances are listed for a kilogram sample. See Appendix C for actual abundances and detailed lithologic sections. Symbols are same as those used in Figure 38.

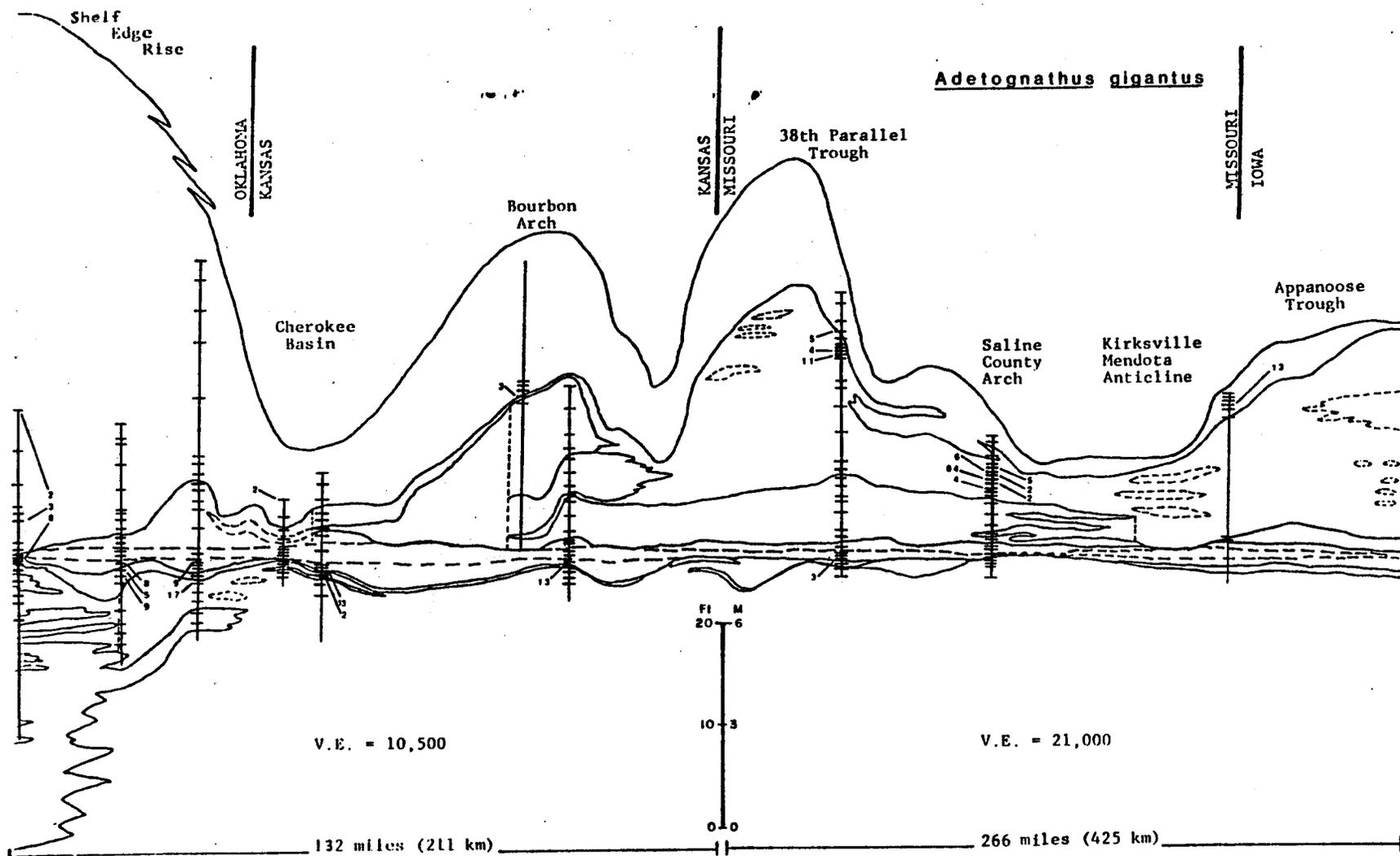


Figure 39

southern Kansas and in Oklahoma Adetognathus gigantus is common below the Anna Shale, whereas northward it is relatively rare at this stratigraphic position. In Missouri, Adetognathus gigantus is most common above the Anna Shale in the upper part of the Mine Creek Shale and is rare to absent in the overlying limestone. Both the carbonates of the Mine Creek Shale in Missouri and the Childers School Limestone of Oklahoma commonly contain Adetognathus gigantus. These two carbonate horizons are petrographically very similar and were interpreted to have formed under relatively shallow conditions (see section on petrography). Adetognathus gigantus is absent from the black fissile shale throughout the entire outcrop belt. Heckel and Baesemann (1975) noted this same pattern of distribution in Missourian rocks and considered Adetognathus lautus to be restricted to more nearshore environments.

Swade (1977) studied conodont distribution in the Cherokee and Marmaton Groups of Iowa and considered Diplognathodus as ubiquitous. In this study, however, Diplognathodus spp. was identified from only two samples in the lower part of the Laberdie and the Coal City (Figure 40). Because of its rarity no conclusions were drawn concerning its distribution.

Figure 40. Generalized cross-section of Pawnee Limestone showing abundance and distribution data for Diplognathodus spp. Only platform elements are included in abundance counts. Abundances are listed for a kilogram sample. See Appendix C for actual abundances and detailed lithologic sections. Symbols are same as those used in Figure 38.

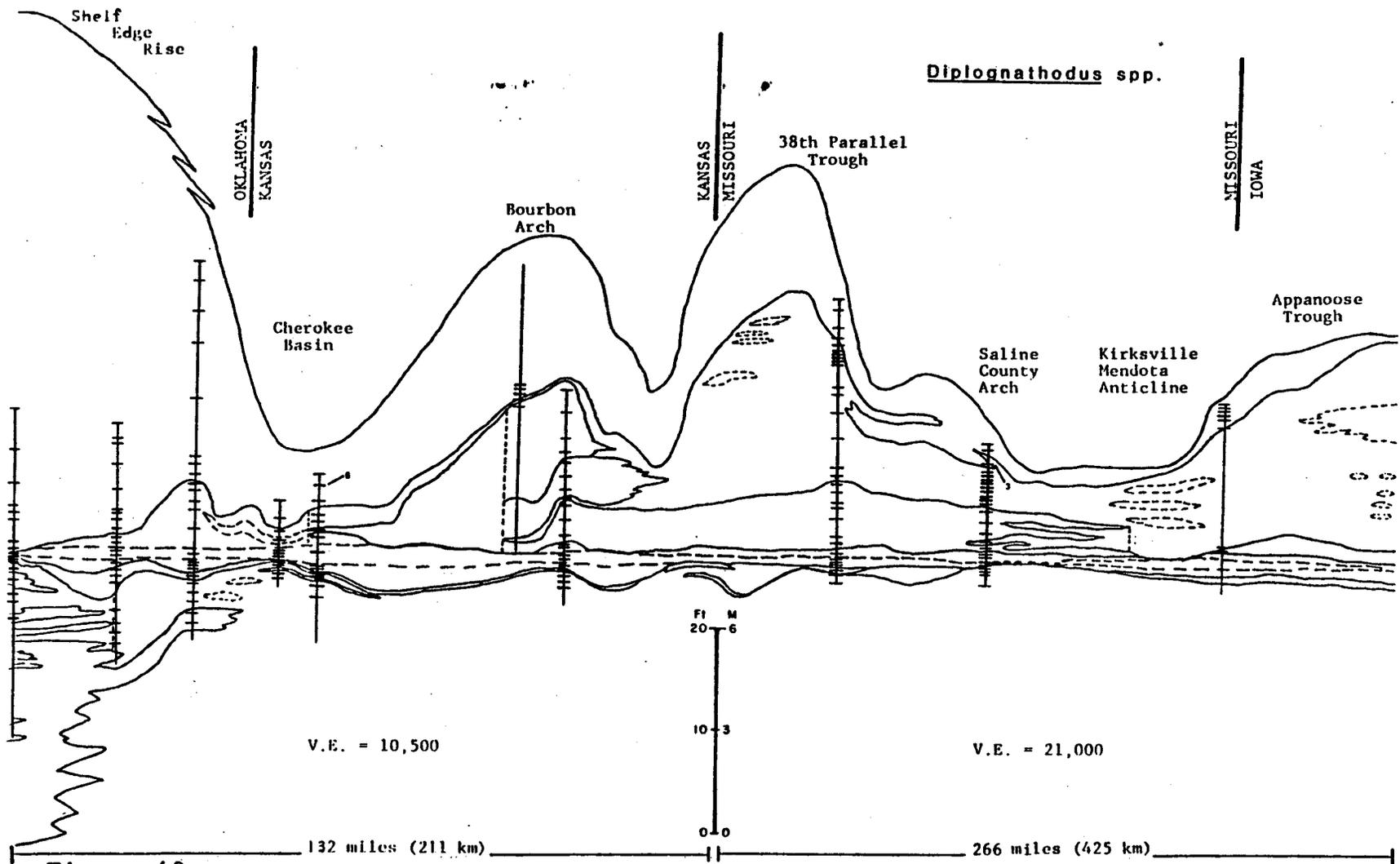


Figure 40

Both Aethotaxis sp. (Figure 41) and Anchignathodus minutus (Figure 42) are more commonly found in carbonates, though occasionally in calcareous shales, which stratigraphically overlie the black phosphate shale. Although Anchignathodus minutus is rarely found below the black shale, the distribution of these taxa above the Anna is similar to the distribution reported by Swade (1977) in Desmoinesian cyclothem and by Heckel and Baesemann (1975) in Missourian cyclothem. Both taxa are absent from the black phosphatic shale.

Distributions of Idiognathodus delicatus (Figure 43) and Neognathodus spp. (Figure 44) are very similar. Idiognathodus delicatus has the most ubiquitous distribution of all identified conodonts as Heckel and Baesemann (1975) found in Missourian cyclothem. Both taxa exhibit maximum abundance in the Anna Shale and also in the upper shale horizon (Joe-upper Mine Creek) where total abundance also showed a substantial increase. Both taxa decrease in abundance away from these two horizons. Where Idiognathodus delicatus is rare, Neognathodus spp. is generally absent. From all samples, abundance of Idiognathodus delicatus either equals or is greater than that of Neognathodus spp. In contrast, J. W. Swade (personal communication) noted that the ratio of Neognathodus to Idiognathodus is approximately 3:1 for the black shale of the Altamont Formation, whereas the

Figure 41. Generalized cross-section of Pawnee Limestone showing abundance and distribution data for Aethotaxis. All five elements are included in abundance counts. Abundances are listed for a kilogram sample. See Appendix C for actual abundances and detailed lithologic sections. Symbols are same as those used in Figure 38.

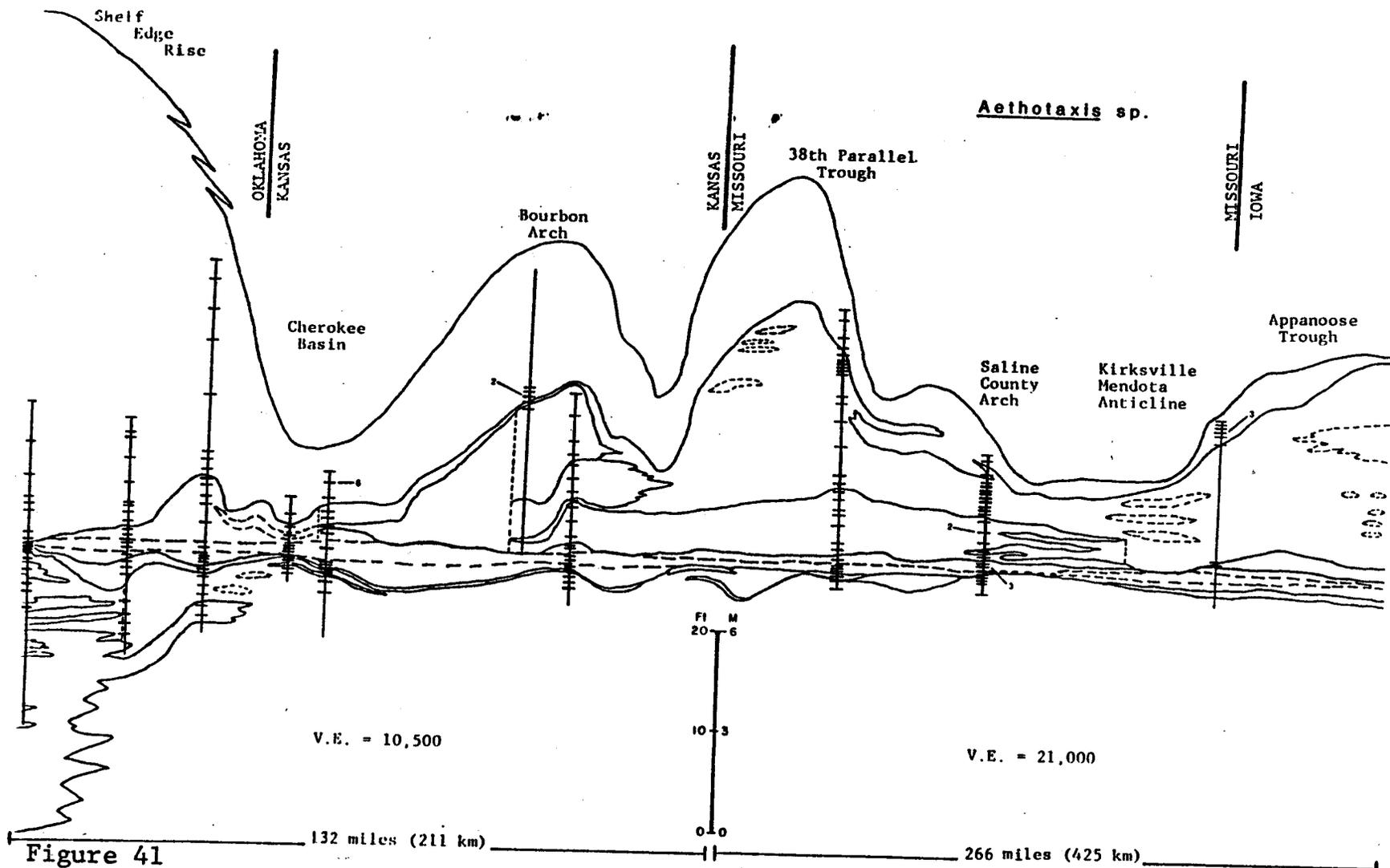


Figure 41

Figure 42. Generalized cross-section of Pawnee Limestone showing abundance and distribution data for Anchignathodus minutus. Only platform elements are included in abundance counts. Abundances are listed for a kilogram sample. See Appendix C for actual abundances and detailed lithologic sections. Symbols are same as those used in Figure 38.

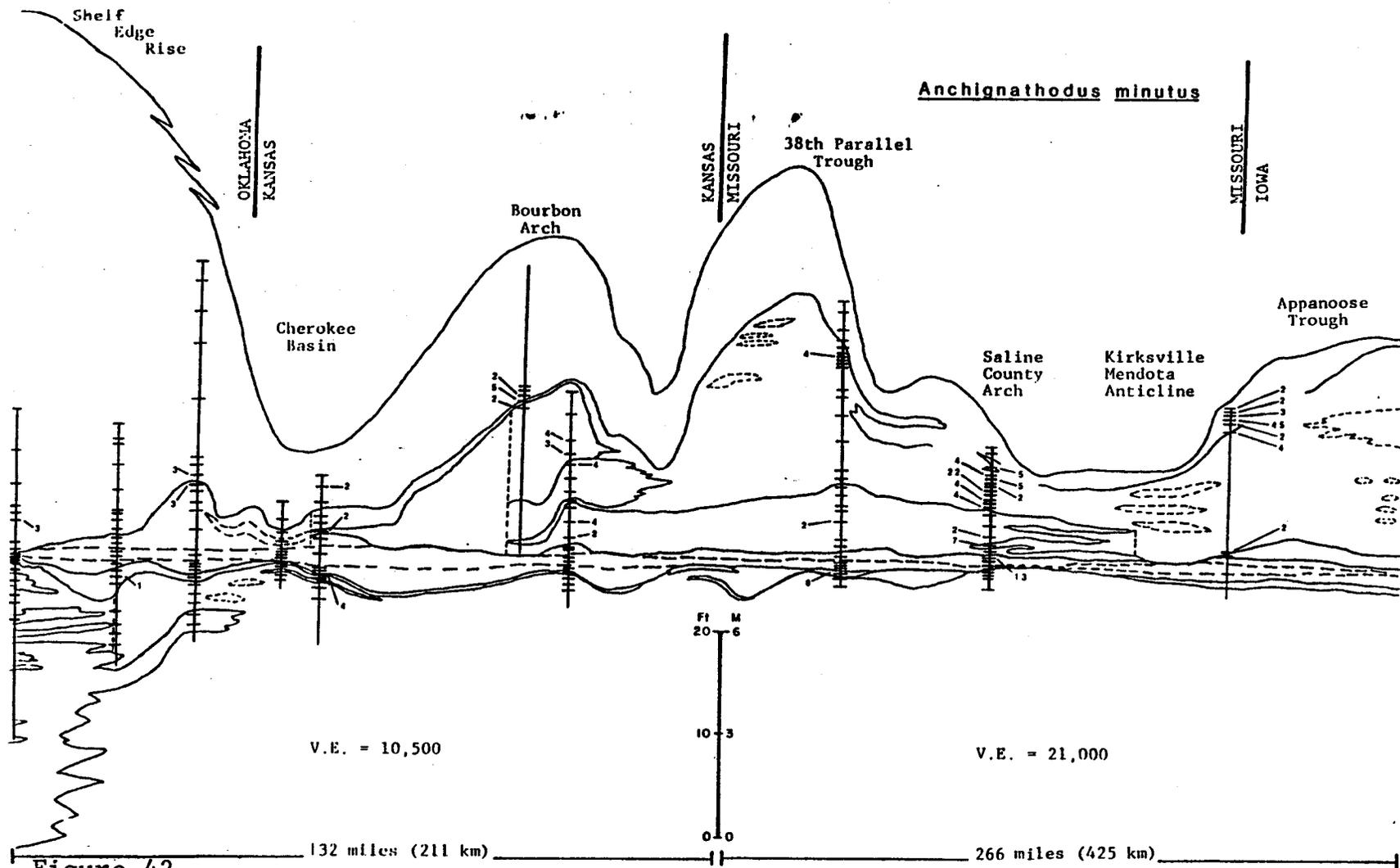


Figure 42

Figure 43. Generalized cross-section of Pawnee Limestone showing abundance and distribution data for Idiognathodus delicatus. Only platform elements are included in abundance counts. Abundances are listed for a kilogram sample. See Appendix C for actual abundances and detailed lithologic sections. Symbols are same as those used in Figure 38.



Figure 44. Generalized cross-section of Pawnee Limestone showing abundance and distribution data for Neognathodus spp. Only platform elements are included in abundance counts. Abundances are listed for a kilogram sample. See Appendix C for actual abundances and detailed lithologic sections. Symbols are same as those used in Figure 38.

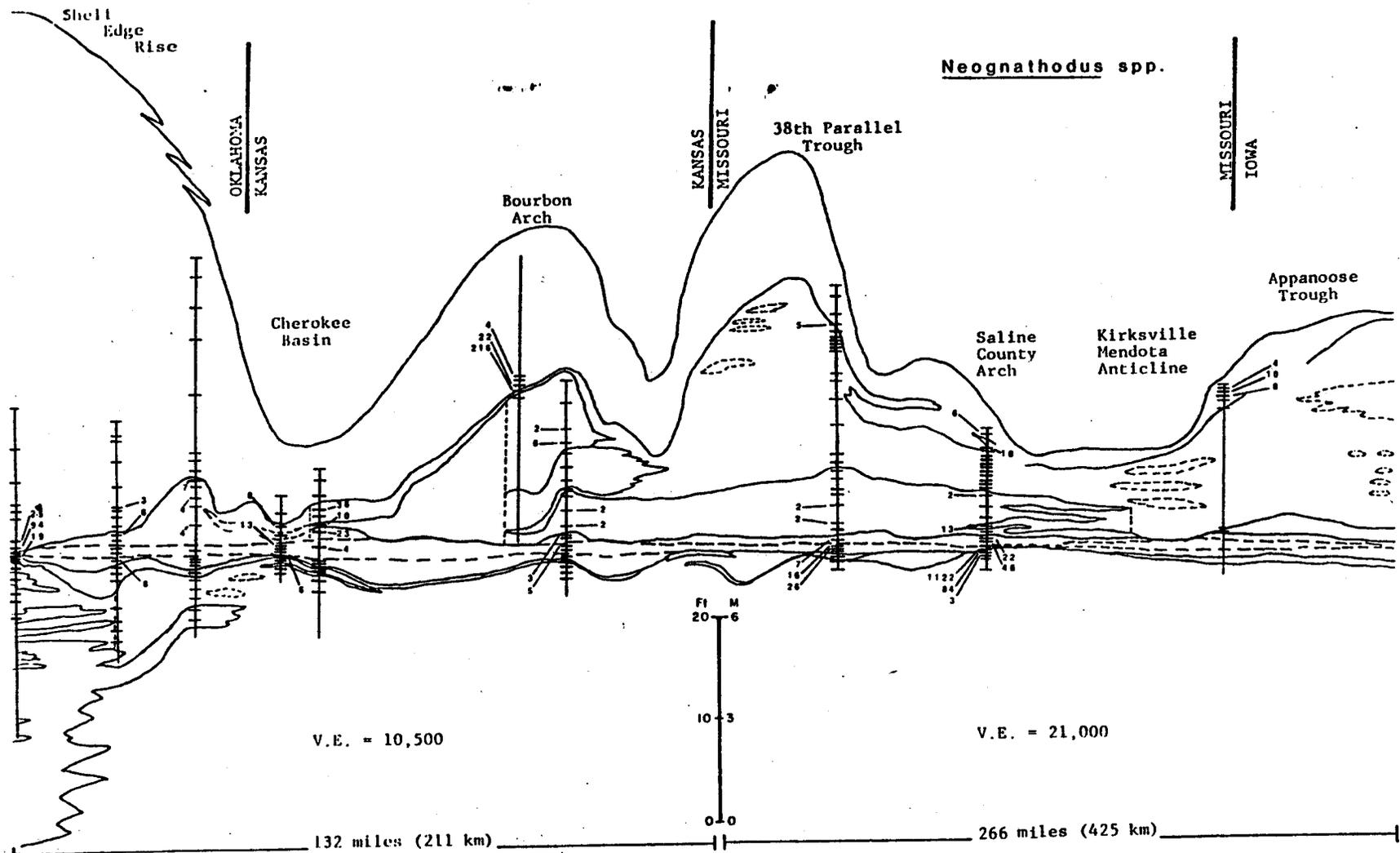


Figure 44

abundance of Idiognathodus is greater than or equal to that of Neognathodus from the black shale of the Pawnee. He considers these conodont ratios as important criteria for differentiating these two cyclothems.

Idioproniodus conjunctus is concentrated in two distinct horizons (Figure 45); 1) The Anna Shale Member and 2) the upper shale horizon (Joe-upper Mine Creek) where total conodont abundance increases. Abundances rapidly decrease in surrounding shale and limestones. This distribution in dark laterally continuous shale horizons is similar to that found by Heckel and Baesemann (1975) in Missourian cyclothems, where they considered Idioproniodus as characterizing more offshore deposits.

#### Distribution within the Oologah

From the Oologah Formation in the vicinity of Tulsa, Oklahoma, samples were taken from both the medial and the overlying black phosphatic shales. Field correlations of this study indicate that the medial black shale is the Anna Shale Member of the Pawnee and that the overlying black shale is the Lake Neosho Shale of the Altamont Limestone. Based on these correlations the lower half of the Oologah is made up of the Sageeyah Limestone whereas the upper half is made up of the Pawnee Limestone. Traditional correlations, however, show the Pawnee equivalent to the lower half and the Altamont equivalent to the upper half

Figure 45. Generalized cross-section of Pawnee Limestone showing abundance and distribution data for Idioprioniodus conjunctus. All seven elements are included in abundance counts. Abundances are listed for a kilogram sample. See Appendix C for actual abundances and detailed lithologic sections. Symbols are same as those used in Figure 38.



(see the earlier chapter on stratigraphy for a more detailed explanation of the stratigraphic significance of these shales).

In the sample of the medial black shale, abundance of Idiognathodus exceeds that of Neognathodus, and J. W. Swade (personal communication) recognizes this pattern as characteristic of the Anna Shale Member of the Pawnee. In the sample of the overlying black shale, however, the Neognathodus to Idiognathodus ratio was approximately 3:1, and J. W. Swade (personal communication) recognizes this pattern as characteristic of the Lake Neosho Member of the Altamont Limestone. Therefore, conodont distribution and abundance corroborate previous conclusions based on field observation of stratigraphic relationships of these two black shales and on the correlation of the Oologah Limestone with Kansas formations.

#### Summary

From the previous data, the following generalizations can be made: 1. Adetognathus gigantus, completely absent from the black phosphatic shale, is associated with both shale and carbonate facies that are considered to have formed under relatively shallow conditions. 2. Idiognathodus delicatus is the most ubiquitous taxa in the Pawnee interval. 3. Although Neognathodus spp. are commonly associated with Idiognathodus delicatus,

abundances of Idiognathodus delicatus always equal or exceed those of Neognathodus spp. in the Pawnee. 4. Conodont distribution within the medial black shale of the Oologah Limestone of Oklahoma and within the overlying black shale corroborates field observations and suggests that the Pawnee, not the Altamont, is equivalent to the upper half of the Oologah. 5. Aethotaxis sp. and Anchignathodus minutus are rare to absent below the Anna Shale Member. Both taxa are absent from the black phosphatic shale but are present in the overlying shales and limestones. 6. Idioprioniodus conjunctus is concentrated in two different horizons of high abundance: a) the Anna Shale Member and b) the Joe shale bed and its equivalents. 7. The presence of Idioprioniodus conjunctus, Idiognathodus delicatus, and Neognathodus spp. within the anoxic black phosphatic shale suggests a pelagic mode of life for these taxa.

CHAPTER VI  
DEPOSITIONAL ENVIRONMENTS

Interpretation of Cyclic Sequence

The thin, dense, and dark Childers School Limestone, continuous at the base of the Pawnee in northern Oklahoma and for some distance into southern Kansas, is a typical "middle limestone" of a "Kansas cyclothem." Overlying the nonmarine to marine detrital Labette Shale, it is the transgressive limestone of the Pawnee cycle. Although, the Pawnee Limestone lacks the Childers School Limestone northward where it thus resembles the typically "Illinois Cyclothem," the characteristics of both the gray and black fissile facies of the overlying Anna Shale Member are even there more compatible with the depositional model of Heckel (1977), which suggests that these shales formed offshore in deeper water. These characteristics include: 1) their position as the most persistent and laterally extensive facies along the entire outcrop belt; 2) absence of coarse-grained terrigenous detritus, which is found abundantly in the underlying Labette Shale and the overlying Bandera Shale, both readily recognized as nearshore shales; 3) position of the black phosphatic facies generally sandwiched between marine gray shale facies that are

abundantly fossiliferous and transitional into adjacent carbonates; 4) absence of palynomorphs, which should be common in nearshore lagoonal environments; and 5) lack of shallow water indicators in contiguous portions of adjacent limestones (except the Childers School Limestone in northern Oklahoma where it was deposited on the Shelf Edge Rise). These characteristics preclude the interpretation of Merrill (1975) of black shale deposition in a nearshore lagoonal environment. Conodont abundance and distribution were not used as criteria for this depositional interpretation, but patterns are very similar to those shown by Heckel and Baesemann (1975) in Missourian cyclothem and tend to corroborate their conclusions (see section on conodont distribution).

Within the framework of the depositional model of Heckel (1977), the black phosphatic Anna Shale Member is interpreted to have formed during maximum transgression when water depth became great enough for a thermocline to form and quasi-estuarine circulation to develop. This circulation cell upwelled nutrient-rich waters, formed a nutrient trap, depleted bottom oxygen and concentrated phosphatic material in the sediment. The term "offshore shale facies" will be used for the Anna in this study instead of the positional term "core shale" or the interpretive term "deep-water black shale." The term "core shale" is inappropriate when discussing the Pawnee

Limestone because the Anna lies at the base of the cyclothem where the underlying Childers School Limestone is absent. Also, on and south of the Bourbon Arch, a second black fissile shale (Joe shale bed) occurs above the Anna. The term "deep-water black shale" is avoided because other workers (e.g., Merrill, 1975) have made erroneous comparisons with Black Sea depths of 2000 meters. "Offshore shale facies" refer to rocks deposited during maximum transgression, which are commonly though not necessarily black, fissile, and phosphatic. Throughout the remainder of this study the term "black shale" will be given genetic significance by referring to rocks of the offshore shale facies.

The early regressive phase of deposition of the Pawnee is represented by the dense, gray, and massive Myrick Station Limestone Member and the overlying "Lower Laberdie Limestone." The Mine Creek Shale represents detrital wedges prograding basinward during this early regressive phase. This regressive phase was interrupted by a second, though minor, transgressive phase culminating in deposition of the Joe shale bed, and then continued with the subsequent deposition of the Laberdie-upper Coal City Limestone.

Although the basic depositional model of Heckel (1977) does apply to the Pawnee Limestone, the Pawnee differs from the general sequence (in which maximum transgressive black

shale deposition is followed by a continuous regression sequence) by containing an upper black shale (Joe shale bed), which represents a second transgressive phase.

#### Controls for Cyclic Deposition

Two general hypotheses, presented to explain Pennsylvanian cyclic deposition, are eustatic sea level change controlled by Gondwanan glaciation (Wanless and Shepard, 1936; Wanless and Cannon, 1966; Crowell, 1978; Heckel, 1980) and intermittent tectonic movements and subsequent subsidence (Weller, 1930, 1956). A detailed discussion of these two ideas is not warranted for this study, as the writer accepts glacial eustatic sea level changes as most plausible and refers the reader to Heckel (1980).

The duration of each individual cyclic interval during Middle and Upper Pennsylvanian time closely approximates the frequency of Pleistocene glaciation (Heckel, 1980). Also, the rate of glacial buildup, which is much slower than deglaciation (Broecker and VanDonk, 1970) should result in thicker regressive sequences compared with transgressive sequences. Rapid deglaciation should result in a transgressive sequence with evidence of a relatively rapid transgression. The Limestone members of the Pawnee Limestone generally conform to the above characteristics. The Laberdie-Coal City Limestone is a relatively thick

regressive sequence. In contrast, the characteristics of the Childers School Limestone that suggest rapid transgression are 1) thinness of the unit where it is present, 2) presence of well preserved plant material in the lower part but open marine fauna at the top (at one locality, Ellis School, a tree stump was found preserved within the Childers School Limestone), and 3) lack of any limestone deposition during transgression to the north, where the offshore gray and black open marine Anna shale directly overlies coal, and evidence of progressive deepening of water is absent, replaced by a surface of nondeposition.

Pawnee Paleogeography and  
Environments of Deposition

To adequately understand facies distribution and environments of deposition, both sea level oscillations (depositional model of Heckel [1977]) and effects of sea floor topography must be considered. Structures controlling sea floor topography, already discussed, are listed from south to north along the outcrop belt: 1) Shelf Edge Rise, 2) Cherokee Basin, 3) Bourbon Arch Complex, 4) 38th Parallel Trough, 5) Saline County Arch, and 6) Kirksville-Mendota Anticline, and Appanoose Trough (see Figure 46).

Figure 46. Generalized north-south cross-section showing generalized paleotopography that affected sedimentation during Pawnee deposition. Not drawn to scale.

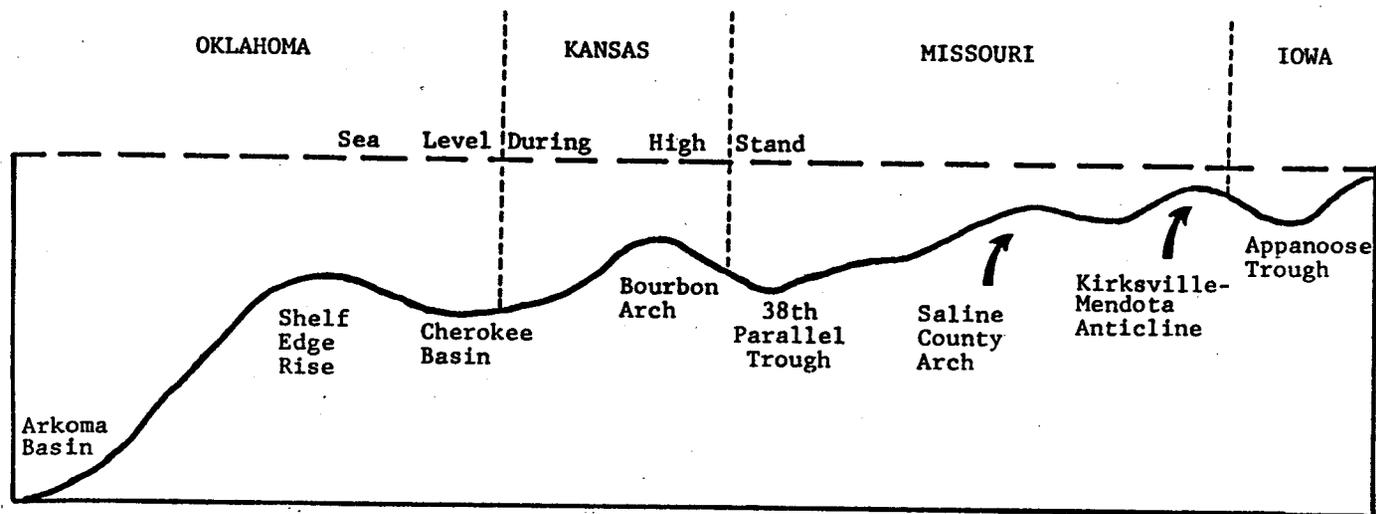


Figure 46

## Depositional History of the Pawnee Sequence

Discussion of depositional history of the Pawnee interval is based upon recognition of lateral facies equivalents along the outcrop belt at eight different stratigraphic positions within the sequence. Two of these stratigraphic positions follow stratigraphic units that are apparently time lines: 1) the black phosphatic facies of the Anna shale and 2) the Joe shale bed and lateral equivalents, which are the basis for constructing six additional time lines showing lateral facies equivalents (Figure 47). The phases of deposition delineated by the eight different time lines will be discussed separately under the following headings: 1) Sageeyah-Upper Labette, 2) Childers School Limestone, 3) Anna Shale, 4) lower Frog-Myrick Station-Iowa Mine Creek, 5) upper Frog-"Lower Laberdie"-Missouri Mine Creek, 6) Joe Shale-lateral equivalents, 7) basal Laberdie-upper Coal City, and 8) upper Laberdie-Bandera.

### Sageeyah-Upper Labette

The Sageeyah Limestone Member of the Labette Shale was deposited during a low stand of sea level in northern Oklahoma on the south side of the Shelf Edge Rise. The well developed phylloid algal mound facies suggests

Figure 47. Generalized cross-section of Pawnee Limestone showing position of eight different time lines. Paleogeographic maps constructed from these time lines are 1) Sageeyah-upper Labette (pre-transgressive phase), 2) Childers School Limestone (early transgressive phase), 3) black phosphatic Anna shale (maximum transgressive phase), 4) lower Frog-Myrick Station-Iowa Mine Creek (early first-regressive phase), 5) upper Frog-"Lower Laberdie"-Missouri Mine Creek (late first-regressive phase), 6) Joe shale-lateral equivalent (maximum, second transgressive phase), 7) basal Laberdie-upper Coal City (early second-regressive phase), 8) upper Laberdie-Bandera (late second-regressive phase). Above numbers correspond with numbered time lines.

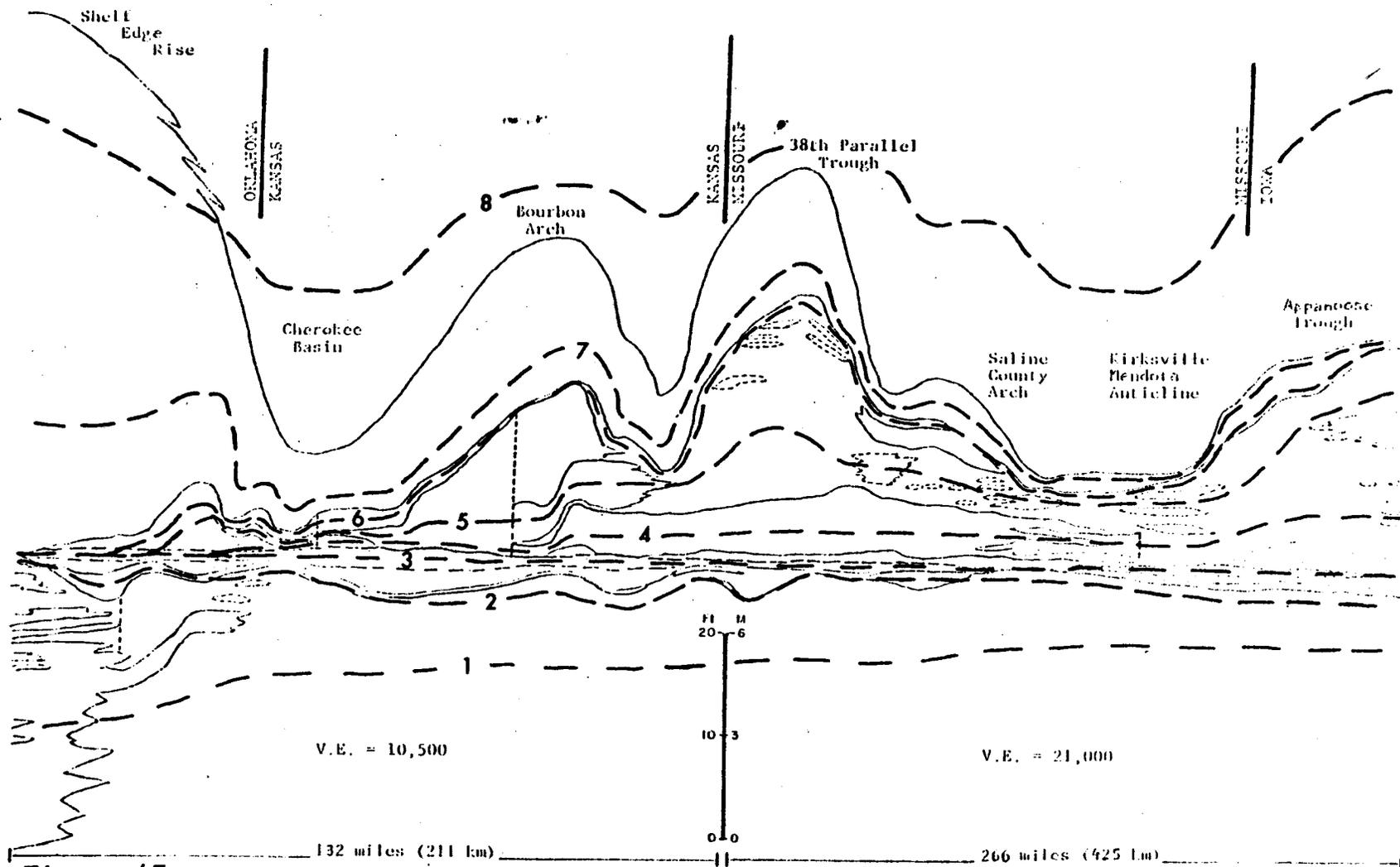


Figure 47

relatively shallow conditions mostly below effective wave base but well within the photic zone. Clastics of the upper Labette Shale, apparently representing prograding deltaic deposits, were deposited concurrently to the north and interfinger with Sageeyah Limestone along the north side of the Shelf Edge Rise (Figure 48).

Carbonate production was continuous on the Shelf Edge Rise throughout Sageeyah deposition, but low-lying coastal swamps in several lower places to the north became conducive to coal formation, probably at the time that initial transgression impounded flowing water and stranded detrital influx farther to the north and east.

#### Childers School Limestone

The Childers School Limestone of Oklahoma is an osagia-coated skeletal calcarenite, which almost exclusively contains the conodont Adetognathus gigantus. Petrographically it is interpreted to represent shallowing conditions, above effective wave or current base, compared with the underlying Sageeyah algal mound. This shallowing could have been caused by continued carbonate buildup on the Shelf Edge Rise just prior to the beginning of major transgression, or to a minor regression for which there is no other evidence to the north. If the Pawnee sequence had not been studied along the entire outcrop belt, workers in the Tulsa, Oklahoma, area might erroneously conclude that

Figure 48. Generalized distribution and relationships of Sageeyah-upper Labette facies throughout study area during pre-transgressive phase of deposition. Standard lithologic symbols used, except convex-upward curves within limestone pattern represent abundant phylloid algae. Paleolatitude base from Heckel (1977).

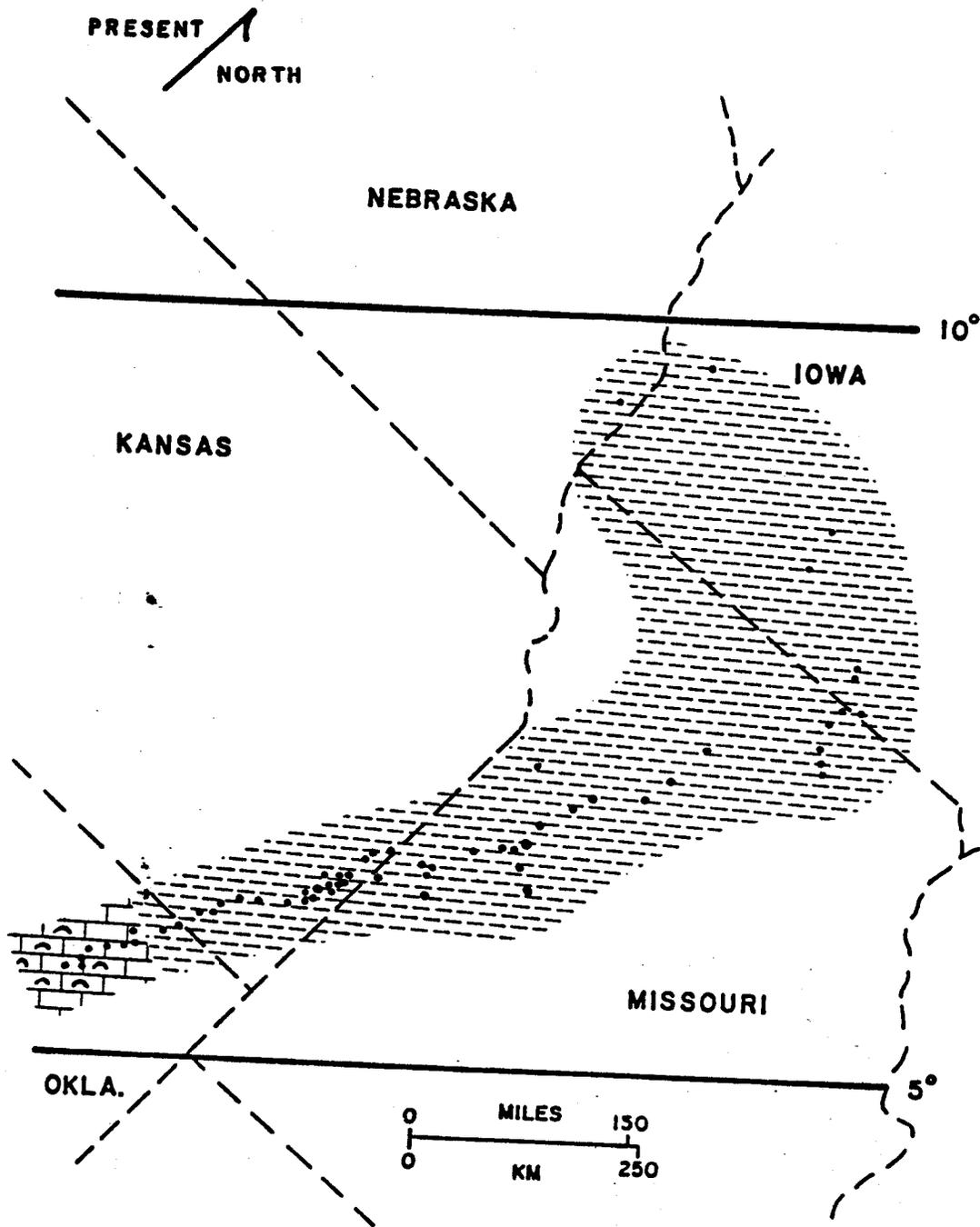


Figure 48

this shallowing culminated in the formation of a nearshore black lagoonal mud suggested by the overlying Anna shale. However, regional study of the Anna, as previously discussed, suggests that on the contrary, the Anna is an offshore marine shale.

The calcarenitic Childers School Limestone on the Shelf Edge Rise apparently formed prior to the thin lenticular Childers School to the north (Figure 49) which petrographically suggests deeper water conditions. The calcilutitic Childers School and northward equivalent horizons record the major transgressive phase of the Pawnee cycle. This rapid transgression caused the Childers School to become progressively thinner northward and to override the coal swamps of the Cherokee Basin. Transgression became rapid enough that little carbonate formed above the Lexington coal swamp in the 38th Parallel Trough, but it pushed the shoreline farther to the north and produced swamplike conditions in the Appanoose Trough in Iowa, which formed the Mystic Coal. Continued transgression halted coal formation in Iowa and resulted in deposition of the gray base of the Anna shale. The coal swamp in the Cherokee Basin, which is farther downslope, existed only for a brief time prior to inundation, and the resulting coal is thin, rarely exceeding 5.0 centimeters in thickness. The more shoreward coal swamps in the 38th Parallel Trough and the Appanoose Trough existed for a

Figure 49. Generalized distribution and relationships of Childers School Limestone facies during early transgressive phase of deposition. Standard lithologic symbols used, except double vertical lines in limestone pattern indicate calcarenites and swamp symbols indicate coal formation. Shale in northern Missouri and Iowa possibly represents subaerial exposure. Paleolatitude base from Heckel (1977).

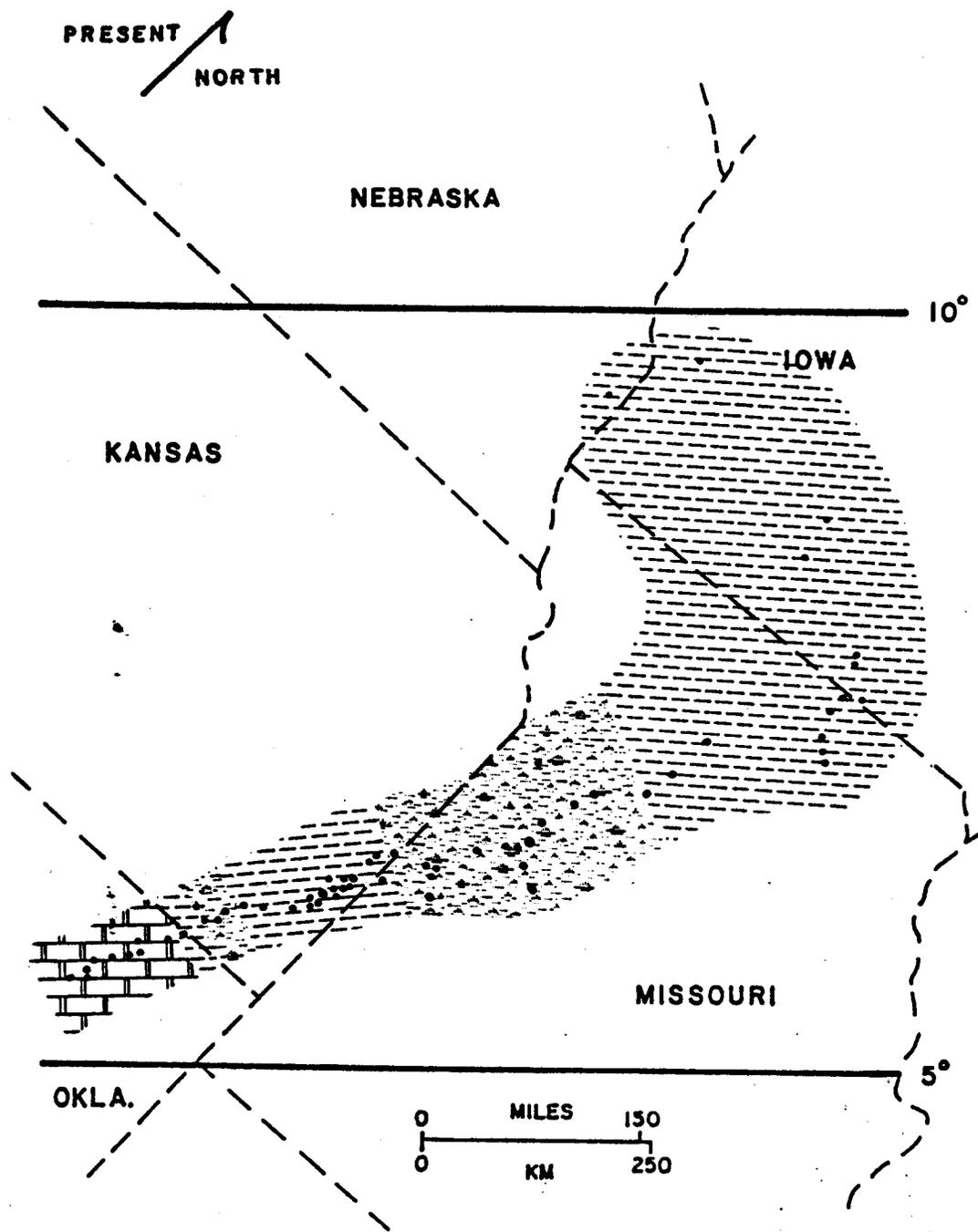


Figure 49

longer period of time and the resulting coals (Lexington, Mystic) commonly exceed one meter in thickness.

Coal swamps were restricted to topographic low areas and were absent from the intervening high areas of the Bourbon Arch and the Saline County Arch-Kirksville Mendota Anticline, which apparently remained too well drained for swamp conditions to last long enough for coal formation.

### Anna Shale

The basal gray facies of the Anna Shale was deposited in deepening water in which carbonate production was inhibited and coarse detritus was stranded far away near distant, clastic sources. The black phosphatic facies of the Anna Shale Member also lacks coarse-grained terrigenous detritus and is laterally continuous from Tulsa, Oklahoma, to southern Iowa. The entire black phosphatic facies is considered to have formed at maximum transgression under extremely slow rates of deposition, thus is less diluted by detrital sediments and therefore contains the highest concentrations of pelagic microfossils (particularly conodonts) in the entire Pawnee. Deposition is considered to have been extremely slow under conditions of even greater sediment starvation across the subaqueous topographic high of the Saline County Arch-Kirksville Mendota Anticline, where adjacent to the pebbly phosphate horizon, conodonts are well preserved and abundances exceed

4000/kg. Nevertheless, no scouring or undulose contacts were noted, which would suggest that any winnowing and lag concentration that may have occurred was by extremely gentle currents. Earliest regression destroyed the thermocline which allowed bottom reoxygenation and deposition of the gray marine shale facies of the upper Anna over the entire sea bottom.

Since the black phosphatic facies of the Anna Shale Member is interpreted to have formed at time of maximum transgression (Figure 50), the center of this black phosphatic would shale, therefore, closely approximate a time line.

#### Lower Frog-Myrick Station- Iowa Mine Creek

The Myrick Station Limestone formed during early regression after water depths shallowed sufficiently for both bottom reoxygenation and carbonate production. In the vicinity of the Bourbon Arch, the Myrick Station is thin (less than 1.0 meter thick), lacks algal blades, and petrographically is interpreted to have formed earliest in relatively deep water. Northward in the 38th Parallel Trough, algal blades are more abundant and the Myrick Station was considered to have formed later under shallower water conditions. Farther to the north in Iowa, the Myrick Station Limestone is thin and correlates with only the lower part of the Myrick Station of Missouri (Figure 51).

Figure 50. Generalized distribution and relationships of Anna facies during maximum transgressive phase of deposition. Dashed lines represent gray shale, solid black lines represent black, fissile shale. Paleolatitude base from Heckel (1977).

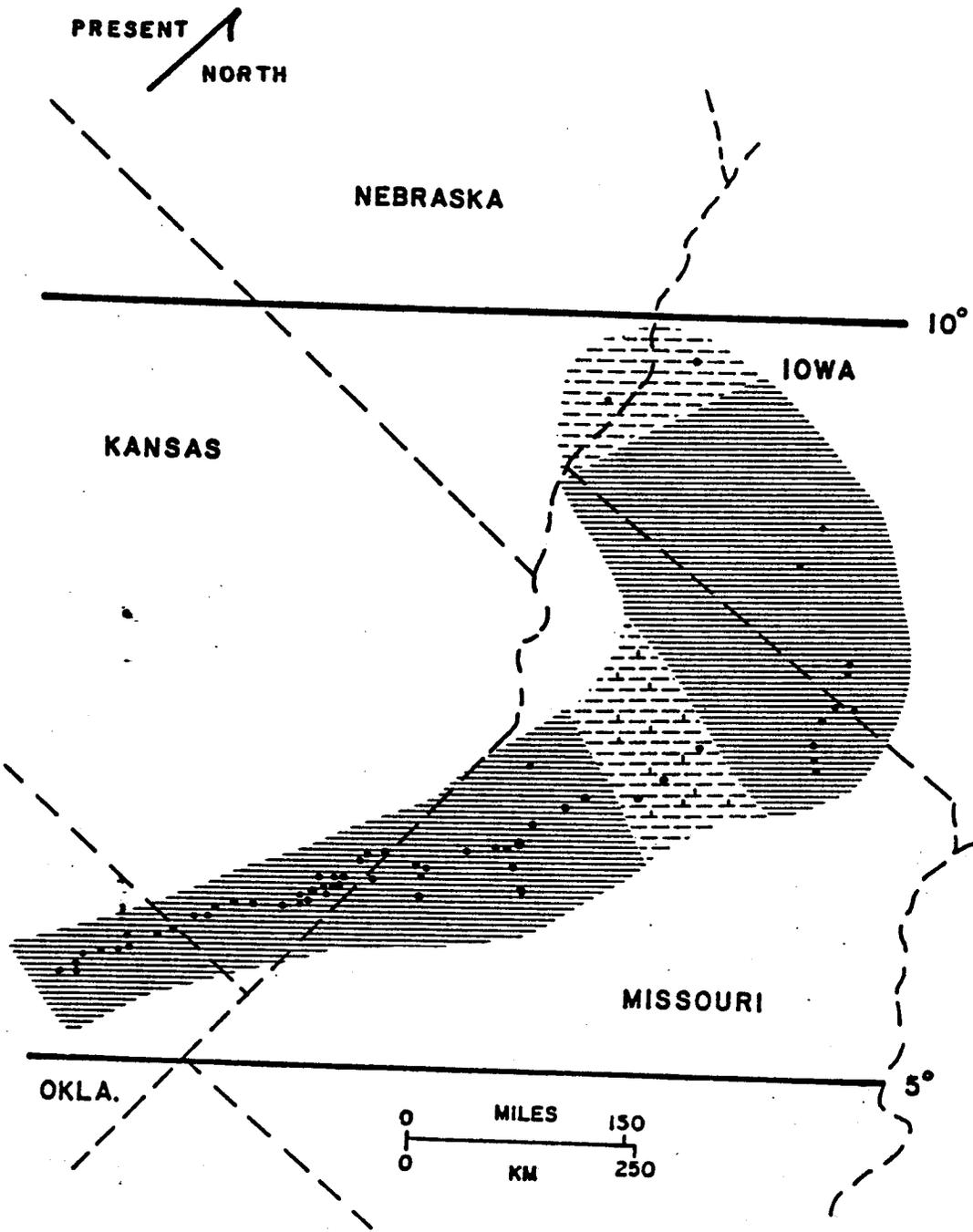


Figure 50

Figure 51. Generalized distribution and relationships of lower Frog-Myrick Station-Iowa Mine Creek facies during early, first regressive phase of deposition. Standard lithologic symbols used, except convex-upward curves within limestone pattern represent abundant phylloid algae and solid black lines represent black, fissile shale. Paleolatitude base from Heckel (1977).

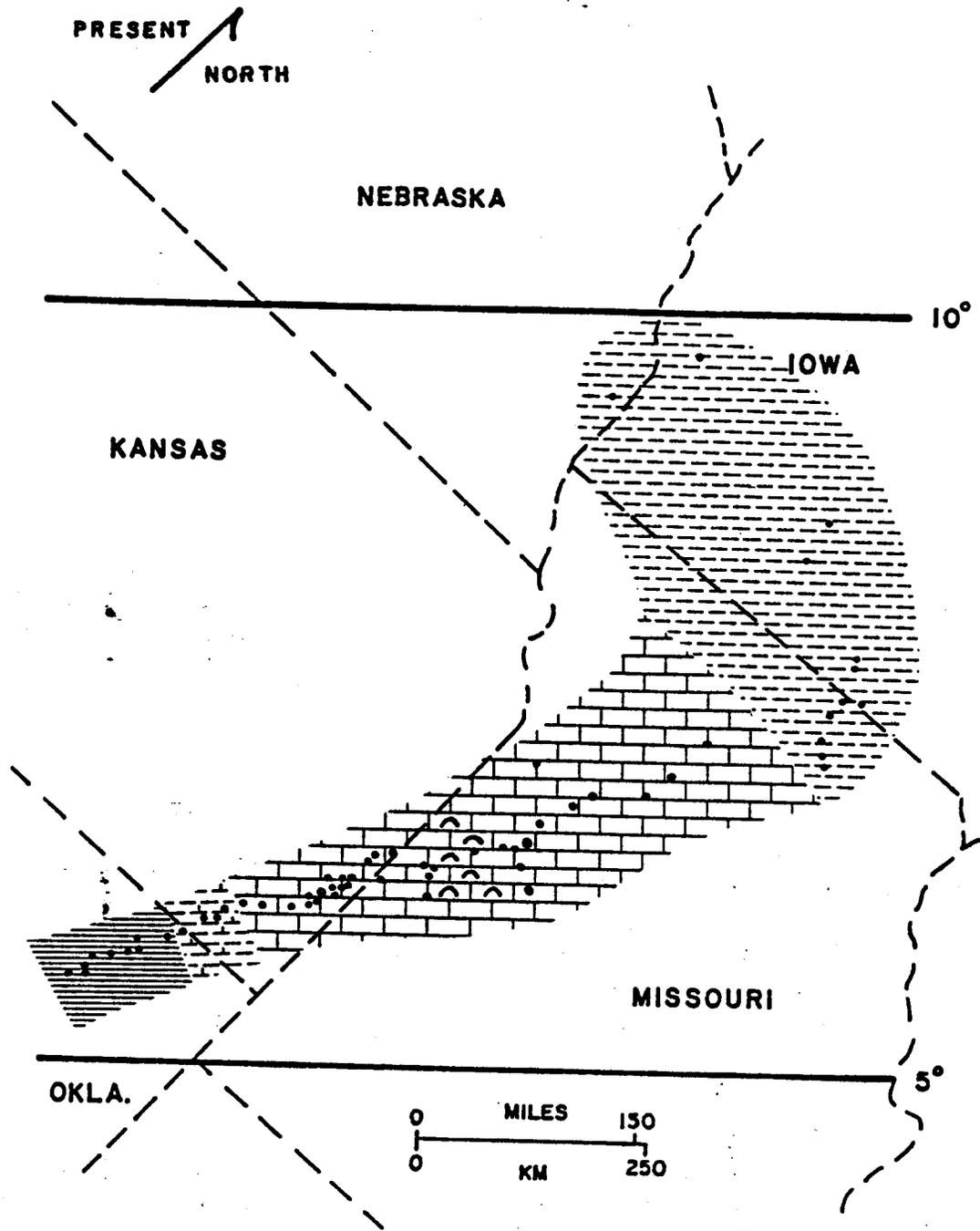


Figure 51

With continued regression, the prodeltaic wedge of the Iowa Mine Creek Shale prograded down the Appanoose Trough, covered the Myrick Station in Iowa, and interfingered with the upper part of the Myrick Station in Missouri, across the Saline County Arch-Kirksville Mendota Anticline.

South of the Bourbon Arch, in the Cherokee Basin, initial carbonate production that started during early regression continued uninterrupted as the Frog limestone bed (discussed in more detail in the next section).

Upper Frog-"Lower Laberdie"-  
Missouri Mine Creek

Further regression allowed clastic deposits to extend farther basinward as the Missouri Mine Creek prodeltaic wedge, which filled the 38th Parallel Trough. This detrital influx overrode the Myrick Station in Missouri and interfingered with the upper portion of the Iowa Mine Creek across the Saline County Arch-Kirksville Mendota Anticline. Since the Saline County Arch-Kirksville Mendota Anticline was more nearshore and thus periodically overwhelmed by clastics, carbonates are poorly developed as thin lenticular beds across the structure. Southward, clastics of the Missouri Mine Creek Shale were unable to prograde across the Bourbon Arch except for an initial distal prodeltaic basal Mine Creek wedge. Afterwards, carbonate production continued, forming the "Lower Laberdie," which

started as chaetetid calcilutite and continued as algal calcilutite as water became shallower and more sunlit (Figure 52).

Southward, in the Cherokee Basin, where there was no Mine Creek detrital influx, carbonate production continued uninterrupted as the Frog limestone bed while the Myrick Station, Mine Creek, and "Lower Laberdie" were deposited to the north. The Frog is interpreted to have been deposited under increasingly deeper water conditions toward the south because algae, restricted to the middle of the unit, decrease southward along outcrop.

#### Joe Shale-Lateral Equivalents

The overlying Joe shale bed is lithologically similar to the Anna Shale Member. Although it lacks phosphate nodules, it is black, locally fissile, lacking coarse-grained detritus and is interpreted to have formed under deep-water conditions representing a second transgressive phase during which carbonate production ceased for a while even over the Bourbon Arch. This interpretation is based not only on the above mentioned characteristics of the shale itself but also upon its stratigraphic relationship, to the south, with the Anna Shale.

Southward, in the deeper part of the Cherokee Basin the Frog limestone thins and ultimately shales out between the Joe and Anna Shales. Near the Kansas-Oklahoma border

Figure 52. Generalized distribution and relationships of upper Frog-"Lower Laberdie"-Missouri Mine Creek facies during late, first regressive phase of deposition. Standard lithologic symbols used, except quarter moons with vertical lines within limestone pattern represent abundant chaetitids and solid black lines represent black, fissile shale. Paleolatitude base from Heckel (1977).

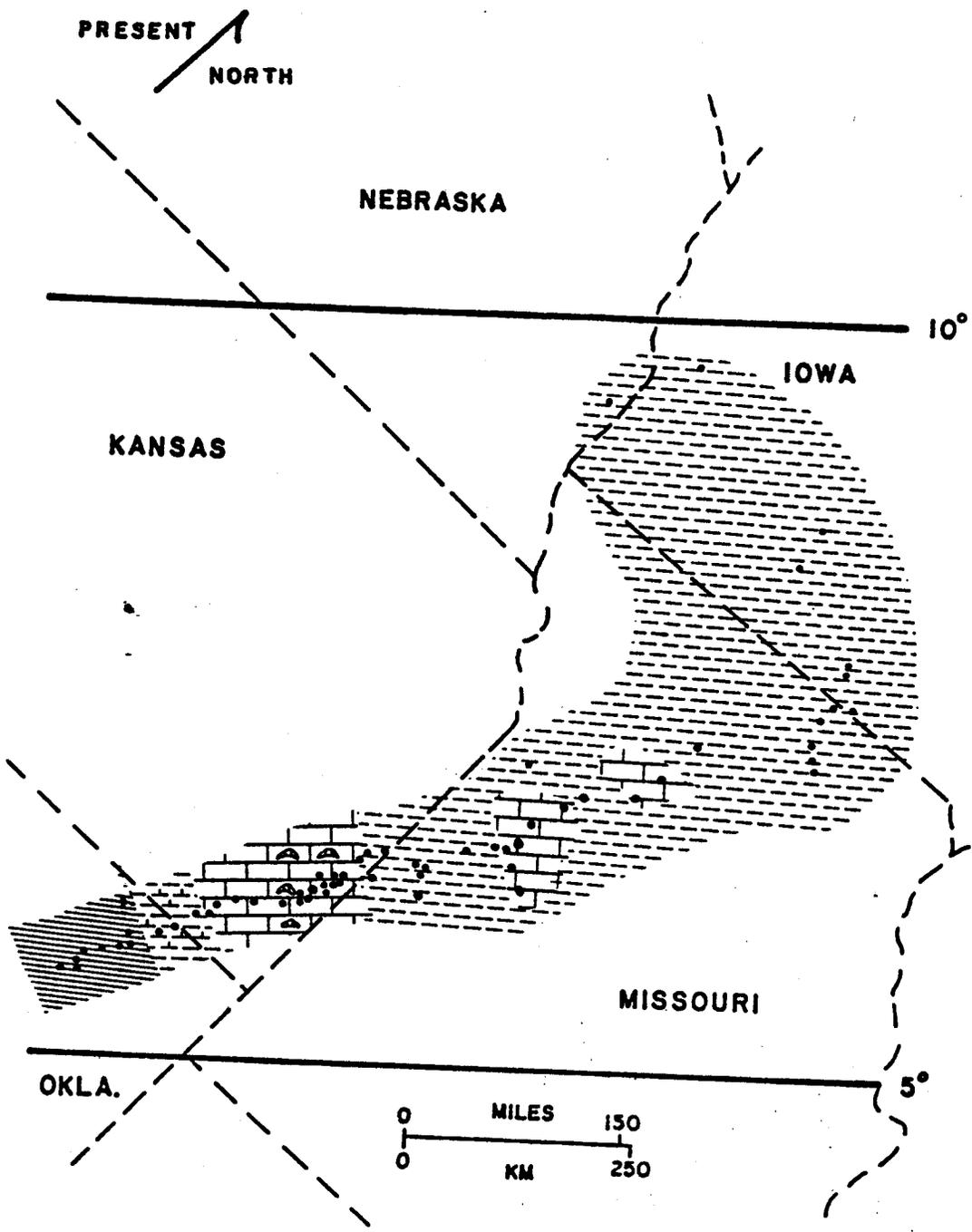


Figure 52

the two shales cannot be separated and to the south are collectively called the Anna Shale. The Frog limestone apparently represents the southernmost limit of carbonate production associated with the Myrick Station-"Lower Laberdie"-Mine Creek regressive phase. This regressive phase is well developed as carbonate on the Bourbon Arch, but farther southward into the basin, water depths were great enough for continuous low-oxygen bottom conditions to persist and preclude carbonate production during this initial phase of regression. The second transgression was not nearly as extensive as the Anna transgression, as is evidenced by the absence of anoxic conditions in the Joe shale bed over the Bourbon Arch, where it thins to several centimeters of gray marine shale with an abundant and diverse fauna. Although both north and south of the Bourbon Arch the Joe shale is black, farther northward, it loses its black character altogether and occurs as an abundantly fossiliferous calcareous gray shale near the top of the Missouri Mine Creek. This gray shale horizon apparently splits the Coal City Limestone in northern Missouri and southern Iowa. Recognition and tracing of this gray shale horizon in the northern outcrop area is facilitated by locating the high-abundance conodont zone, which, like that of the Anna Shale, can be traced along the entire outcrop belt. The maximum transgressive phase of

the Joe shale and its lateral equivalents to the north likewise apparently closely approximate a time line (Figure 53).

Reminiscent of the calcarenitic Childers School Limestone underlying the maximum transgressive Anna shale is the development of an osagia-coated calcarenite on the top of the Missouri Mine Creek prodeltaic wedge. This osagia-coated calcarenite represented shallow water conditions on a topographic high prior to culmination of the second transgressive phase.

The occurrence of two transgressive phases in the Pawnee was suggested earlier by Cline and Stookey (1943) in Iowa, who recognized the Myrick Station and Coal City as two separate cycles separated by thick Mine Creek Shale which contains non-marine intervals.

#### Basal Laberdie-Upper Coal City

The basal Laberdie and roughly equivalent upper Coal City (Figure 54) represent reestablishment of carbonate production over the entire outcrop belt southward to Tulsa during early regression following the Joe transgressive phase. Algae are relatively common in lowermost portions of the Laberdie on the Bourbon Arch and also on the Missouri Mine Creek Shale prodeltaic wedge further indicating that the Joe transgression was relatively minor compared to the Anna. During regression, the sea bottom

Figure 53. Generalized distribution and relationships of Joe shale facies during maximum, second transgressive phase of deposition. Dashed lines represent gray shale, solid black lines represent black, fissile shale. Paleolatitude base from Heckel (1977).

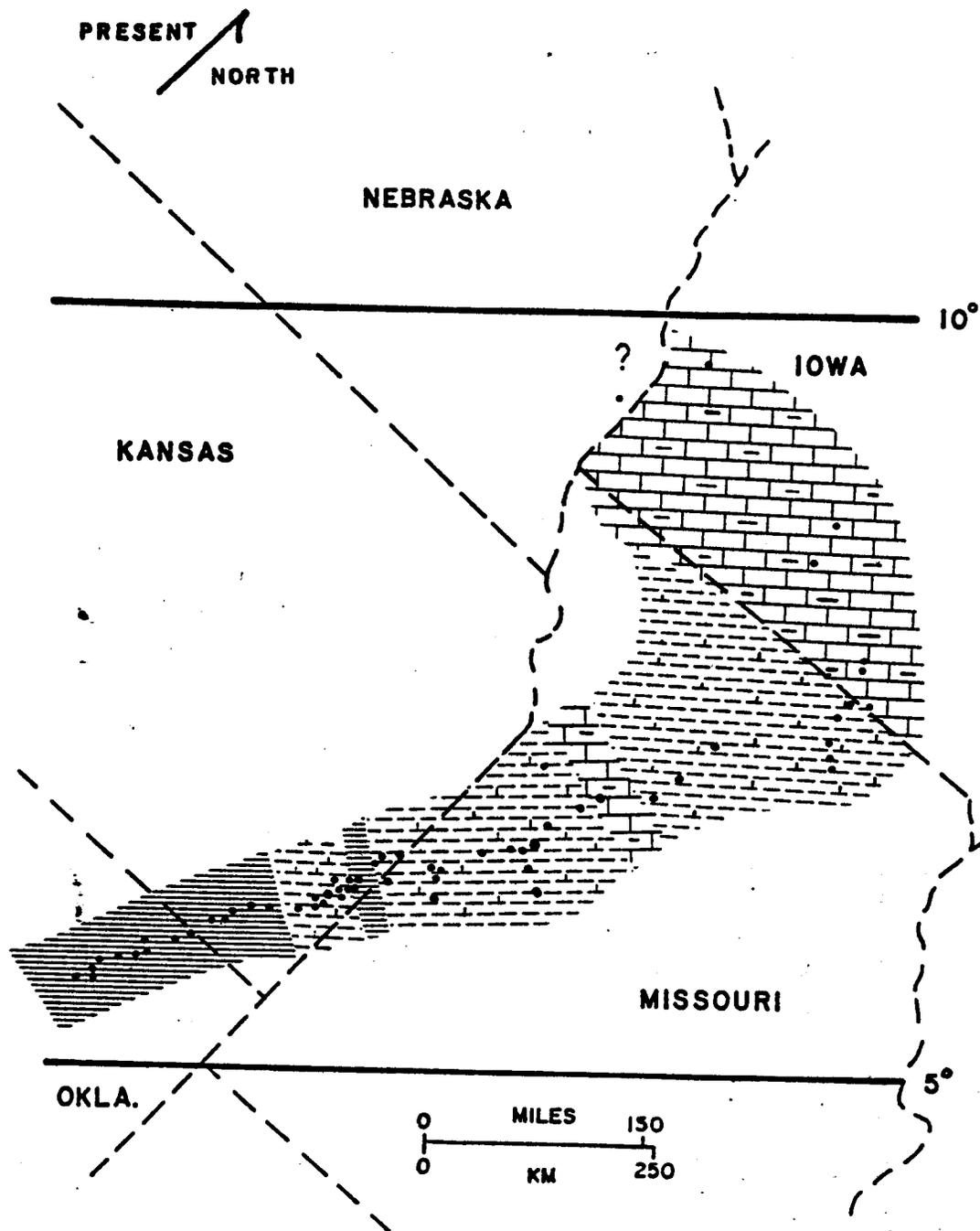


Figure 53

Figure 54. Generalized distribution and relationships of basal Laberdie-upper Coal City facies during early, second regressive phase of deposition. Standard lithologic symbols used, except convex-upward curves within limestone pattern represent abundant phylloid algae. Paleolatitude base from Heckel (1977).

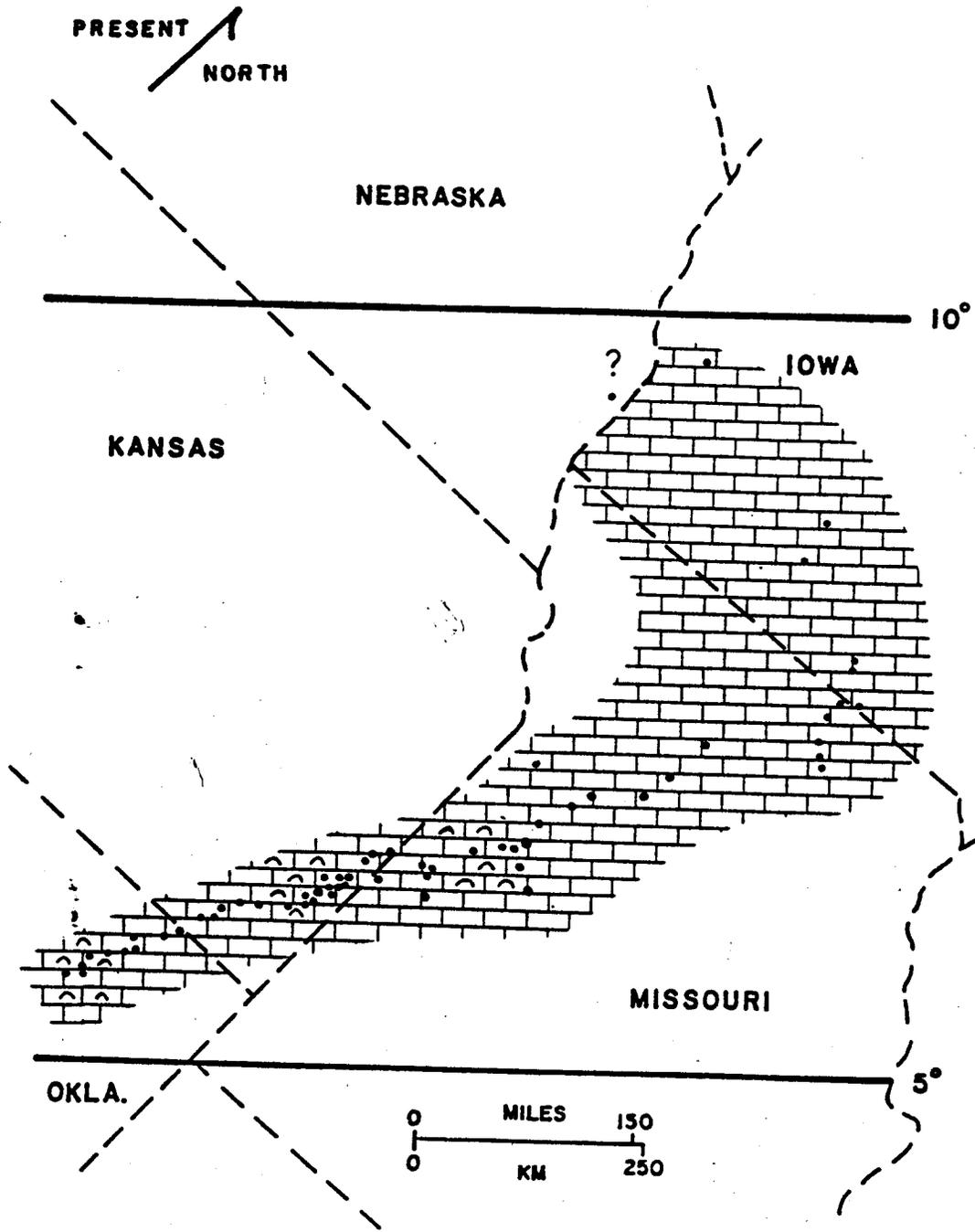


Figure 54

stayed long enough in increasingly sunlit water for well developed phylloid algae mounds to form in the Laberdie on the positive areas of the Shelf Edge Rise, Bourbon Arch, and the Missouri Mine Creek prodeltaic wedge, which had previously filled the 38th Parallel Trough.

#### Upper Laberdie-Bandera Shale

With continued regression and shallower water conditions, clastics of the Bandera prograded from both the north and the east into the Midcontinent area and overwhelmed carbonate production of the Laberdie everywhere except on the Shelf Edge Rise. This progradation occurred prior to complete regression and exposure because shoal-water and shoreline carbonates are generally absent from the top of the Laberdie. Thin calcarenites formed at the top of the Laberdie only on the Bourbon Arch and in the Logan, Iowa, area and indicate that the Bourbon Arch and the northernmost area were above effective wave base prior to covering by the Bandera Shale. Possible brecciation at the top of the Laberdie (Coal City), across the Saline County Arch, also suggests shallowing and possibly exposure prior to Bandera deposition. Elsewhere, in the previously mentioned topographic lows, the top of the Laberdie is a skeletal to algal calcilutite and was probably below effective wave base when covered by the Bandera shale.

The Bandera Shale thins south of the Cherokee Basin and ultimately pinches out, as it does not extend over the Shelf Edge Rise. Schmidt (1959) showed the thin Bandera sequence on the northern margin of the Shelf Edge Rise, as consisting of several alternating limestone and shale beds. This sequence suggests a possible interfingering with upper portions of the Laberdie. If this is the case, the upper Laberdie, on the Shelf Edge Rise, formed during latest stages of regression and is contemporaneous with the Bandera (Figure 55) that had already covered the Laberdie to the north. This facies relationship, occurring during regression, resembles that of the underlying Sageeyah Limestone which interfingers with the Labette Shale. Together these facies relations help explain why the Oologah Limestone is so thick and why it has been considered erroneously to represent the Altamont as well as the Pawnee Limestone in Oklahoma.

#### Lateral Facies Belts in Regressive Limestone

Heckel (1975), based on the well developed Missourian regressive limestones described a succession of lateral facies belts along outcrop. The Pawnee Limestone also can be divided into similar distinct though more complex, facies belts (Figure 56). The terrigenous detrital facies is restricted to the Arkoma Basin and grades northward into

Figure 55. Generalized distribution and relationships of uppermost Laberdie-upper Bandera facies during late, second regressive phase of deposition. Standard lithologic symbols used, except convex-upward curves within limestone pattern represent abundant phylloid algae. Paleolatitude base from Heckel (1977).

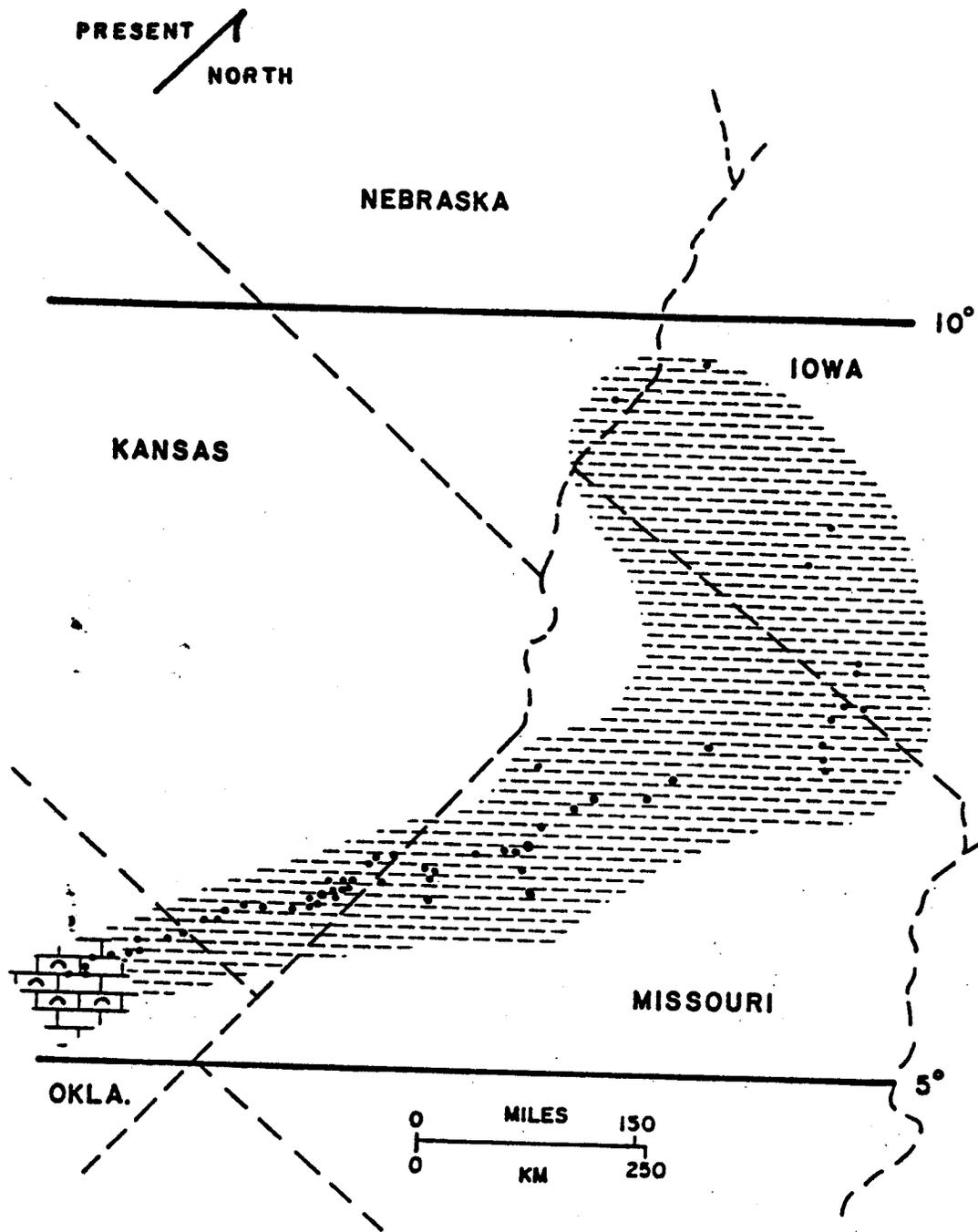


Figure 55

Figure 56. Major facies belts developed during regressive phase of deposition of Pawnee Limestone. Facies are separated by dashes. Open marine facies occur between algal mound facies and also between algal mound and nearshore facies. Line of outcrop shows entire Marmaton Group (Desmoinesian).

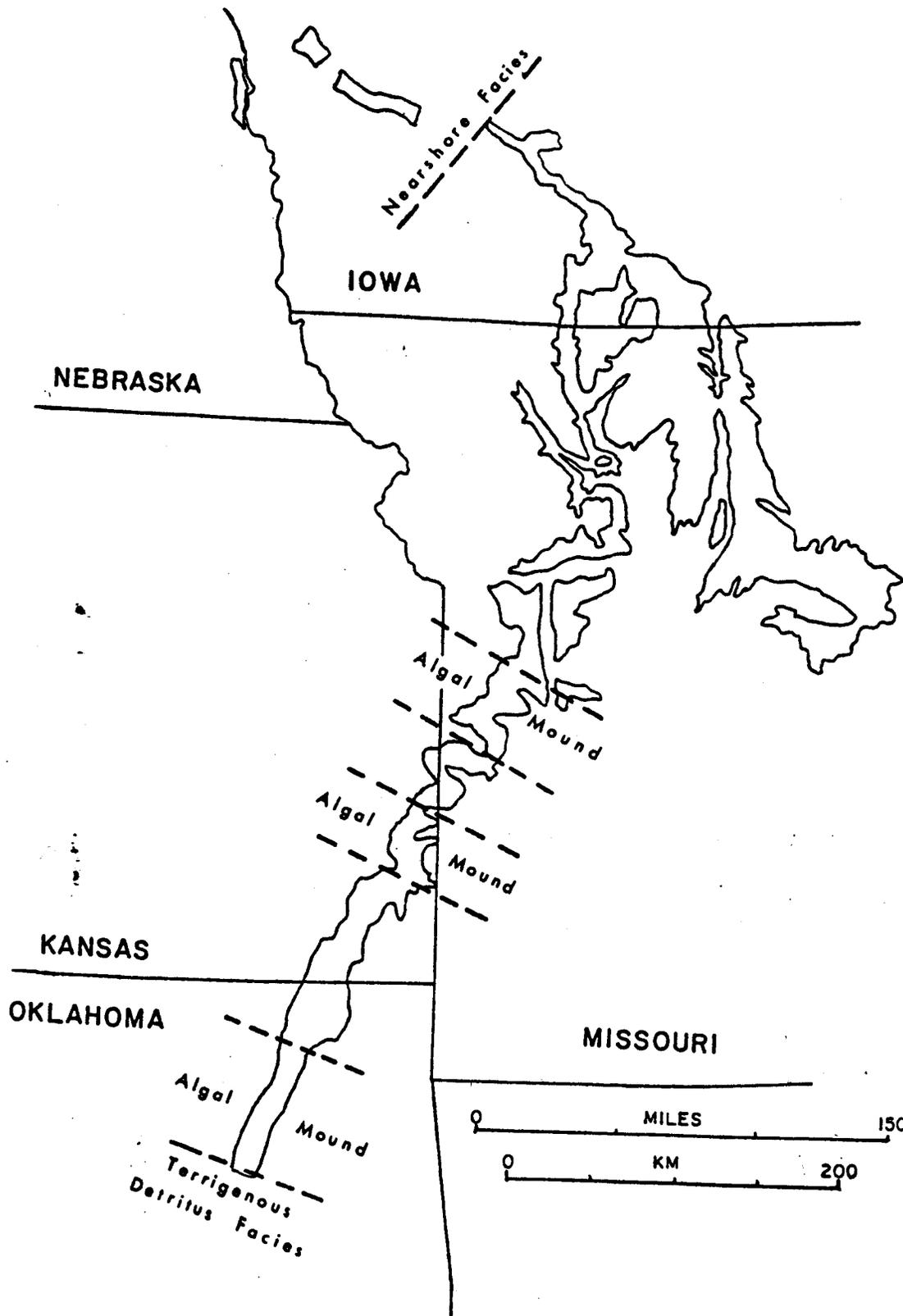


Figure 56

an algal mound facies on the Shelf Edge Rise. Algal mound facies also exist on the Bourbon Arch and on the prodeltaic lobe of the Missouri Mine Creek Shale. In lower basins between these algal mounds and also to the north in Iowa are the less algal open marine facies belts. Shallow-water carbonate features suggestive of exposure were recognized over the Saline County Arch and in the Nebraska Offut core (see discussion in Appendix B) and represent nearshore facies during regression. Even though Pawnee facies belts conform to persistent features of depositional topography, shoal-water facies are more common toward the north and basinal facies are better developed to the south.

#### Summary

An understanding of the significance of the black phosphatic Anna Shale Member is the key for determination of depositional environments. The Anna shale formed during maximum transgression and extends along the entire outcrop area. Subsequent regression resulted in nearly continuous Myrick Station-"Lower Laberdie"-Frog carbonate production on the Bourbon Arch as prodeltaic wedges prograded and filled successively the Appanoose and 38th Parallel Troughs with the Mine Creek Shale. A second transgression, represented by the Joe shale, again pushed back the shoreline and halted delta encroachment. This transgression was not as extensive as the Anna

transgression and water depths became great enough only for anoxic conditions to extend past the Bourbon Arch into west central Missouri. In the Cherokee Basin, water depths remained great enough during the minor regression between the Anna and Joe transgression for anoxic bottom condition to persist and resulted in continuous black shale deposition, as is shown by the Anna and Joe Shale convergence to the south. Continued regression after the Joe transgression resulted in deposition of the Laberdie-Coal City Limestone all the way from Iowa to Oklahoma. This limestone, subaerially exposed in only a few places, was mostly buried by the prograding Bandera shale prior to much withdrawal of the sea. Evidence suggests that on the Shelf Edge Rise in Oklahoma, carbonate production persisted and interfingered with the Bandera influx from the north.

Sea floor topography played an important role in facies distribution during rise and fall of sea level. During the minor regression between the Anna and Joe transgressive phases, prograding clastics of the Mine Creek advanced basinward down both the Appanoose and then the 38th Parallel Troughs. Positive areas in the north, the Saline County Arch and Kirksville-Mendota Anticline, were periodically covered by pulses of clastics at this time which stifled carbonate production and resulted in thin-bedded alternating limestone and shale sequences. The entire Pawnee sequence thins greatly over this positive

region. Farther southward the Bourbon Arch was rarely covered by clastic pulses, and the chaetetid and algal carbonates formed a thick sequence during this minor regressive phase. During the regressive phase that followed the Joe transgression, thick carbonate algal mound sequences once again coincided with (and are restricted to) the more basinward topographic highs. Thick carbonate algal mound sequences occur on the Shelf Edge Rise, the Bourbon Arch, and also on the prodeltaic wedge of the Missouri Mine Creek, which apparently raised the sea bottom in the 38th Parallel Trough. Factors that made these positive areas more conducive to algal proliferation are 1) relatively clear water of low turbidity as clastics were trapped within surrounding negative areas, 2) position higher in the photic zone and therefore better lighted, and 3) probably better water circulation and nutrient replenishment.

Coal in the underlying Labette Shale also reflects the previously discussed topographic variations by forming only within the negative areas of the Cherokee Basin, 38th Parallel Trough and Appanoose Trough. The coal is also thicker and better developed in the two more shoreward negative areas, but drastically thins or disappears across intervening highs.

## CHAPTER VII

## CONCLUSIONS

1. Lithologic and stratigraphic considerations of the Pawnee Limestone support the basic model of Heckel (1977) that the vertical sequence of the "Kansas-type Cyclothem" represents a transgressive-regressive event with maximum transgression culminating in deposition of a black phosphatic shale. Nevertheless, the Pawnee cycle differs from the typical "Kansas-type Cyclothem" by the common absence of the transgressive limestone and by the occurrence, during the regression, of a upper dark, sediment-starved, and conodont-rich shale recording a second, though minor, transgression.

2. The black phosphatic Anna Shale Member represents maximum transgression, based on the lateral continuity, absence of coarse-grained terrigenous detritus, absence of palynomorphs and association with fossiliferous gray shales that are transitional to adjacent open marine limestone lacking shallow-water indicators.

3. The Joe shale bed represents a second, less extensive transgressive phase, based on lateral continuity of conodont-rich and sediment-starved shales which are black in more southerly topographic lows.

4. Nearshore, in Iowa, two separate regressive carbonates (Myrick Station and Coal City) are recognized. The Myrick Station formed during a minor regression between the two transgressions and is not developed farther offshore in the Cherokee Basin and southward where deep water anoxic conditions persisted. The Coal City and equivalent Laberdie to the south represent major regression after the second minor transgression.

5. The Pawnee Limestone is equivalent to the upper half of the Oologah Formation of Oklahoma, with the greatly thinned Altamont Limestone occurring above the top of the unit. The Sageeyah Limestone Member of the Labette Shale constitutes the lower half of the Oologah. The black shale in the middle of the Oologah is the Anna Shale Member of the Pawnee, not the Bandera, and the black shale above the top of the Oologah is the Lake Neosho Member of the Altamont, not basal Nowata.

6. Lack of early rim cements along with overpacking and crushing of skeletal grains in the Childers School Limestone suggests deposition during transgression and subsequent burial and compaction before any cementation, as described by Heckel (manuscript in preparation) for other transgressive calcarenites.

7. Common distribution of late-stage ferroan dolomite within carbonates adjacent to black shales suggest that  $Mg^{++}$ -rich fluids for dolomitization were derived from

surrounding clays during late-stage burial diagenesis (McHargue and Price, manuscript in review).

8. Increased conodont abundances coincide with both the Anna and Joe transgressive phase. Trends in both abundance and distribution of genera are similar to those reported by Heckel and Baesemann(1975) for Missourian rocks, with Idioproniodus concentrated in horizons representing the maximum transgressive phases. Adetognathus is absent from the black phosphatic facies and is concentrated in horizons that are readily interpreted to represent shallow-water conditions.

9. An understanding of both sea level fluctuations and sea floor topography is essential to understanding lateral facies distribution.

10. The Bourbon Arch complex of southeastern Kansas, a positive area of low relief, profoundly affected facies distribution as it promoted nearly continuous carbonate production after Anna deposition, and blocked Mine Creek regressive clastic influx from entering the Cherokee Basin.

11. During regression between the Anna and Joe transgressive phases, clastics of the Iowa Mine Creek Shale prograded southward from the Transcontinental Arch area and filled the Appanoose Trough. With continued regression, clastics of the Missouri Mine Creek Shale prograded westward from the Ozark area, filled the 38th Parallel

Trough and interfingered with the "Lower Laberdie Limestone," which was forming on the Bourbon Arch.

12. Algal mounds were restricted to topographic highs and formed on the Shelf Edge Rise, Bourbon Arch, and Missouri Mine Creek prodeltaic wedge.

13. Later during Missourian time, the Shelf Edge Rise of northern Oklahoma was apparently covered by deltaic clastics from the south and no longer exerted much control on sedimentation patterns. Nevertheless, the southeastern Kansas phylloid algal mound facies belt for Missourian rocks (Heckel and Cocke, 1969) coincides with the geographic position of the Bourbon Arch Complex, which apparently continued to control mound distribution for some time.

14. Coals formed in the lows of the Cherokee Basin, 38th Parallel Trough, and Appanoose Trough and are thin to absent over intervening highs, which apparently remained too well drained even during transgression for coal development. The 38th Parallel Trough and Appanoose Trough, which were more shoreward and therefore exposed to coal swamp conditions for a longer period of time, accumulated the greatest coal thicknesses as the mineable Lexington and Mystic coals respectively.

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APPENDIX A

LOCATION OF SECTIONS

Section numbers correspond with number localities of Figure 2. Number is followed by symbol code and location. An \* denotes studied sections and \*\* denotes studied cores. Underlined sections are illustrated in Appendix C, except section #1 which is in Appendix A and section #28 which is Figure 4. If no \* or \*\* follow number, then section is from the literature with reference following detailed location.

1. \*\*NOC (Nebraska Offutt Core) S $\frac{1}{2}$  SE $\frac{1}{4}$  SE $\frac{1}{4}$  NW $\frac{1}{4}$ , Sec. 11, T. 13 N., R. 13 E. Core stored at Nebraska Geological Survey.
2. SK (Stark) Sec. 14, T. 75 N., R. 26 W. (Stark, 1973).
3. CP-37, NE $\frac{1}{4}$  SE $\frac{1}{4}$  NE $\frac{1}{4}$ , Sec. 2, T. 72 N., R. 26 W. Core stored at Iowa Geological Survey. See also O'Brien, 1977.
4. CP-22, SE $\frac{1}{4}$  SW $\frac{1}{4}$  SE  $\frac{1}{4}$ , Sec. 36, T. 70 N., R. 19 W. Core stored at Iowa Geological Survey.
5. CXI (Cline XI) SE $\frac{1}{4}$  NE $\frac{1}{4}$ , Sec. 19, T. 69 N., R. 18 W. Cline (1941).
6. \*CC (Coal City) NW $\frac{1}{4}$ , Sec. 21, T. 67 N., R. 16 W.
7. CIX (Cline IX) Secs. 25, 34, 36, T. 67 N., R. 18 W. Cline (1941).
8. CVIII (Cline VIII) Secs. 20, 27, 28, T. 65 N., R. 18 W. Cline (1941).
9. C&G#5 (Cline and Greene #5) NE $\frac{1}{4}$  SE $\frac{1}{4}$ , Sec. 10 and NW $\frac{1}{4}$  Sec. 11, T. 63 N., R. 17 W. Cline and Greene (1950).
10. C&G#8 (Cline and Greene #8) NE $\frac{1}{4}$  SW $\frac{1}{4}$ , Sec. 32, T. 63 N., R. 16 W. Cline and Greene (1950).

11. K. Dam (Kirksville Dam) S $\frac{1}{2}$ , Sec. 14, T. 62 N., R. 16 W. Bridges (1957).
12. CIV (Cline IV) SW $\frac{1}{4}$  SE $\frac{1}{4}$ , Sec. 30, T. 60 N., R. 22 W. Cline (1941).
13. C&G#13 (Cline and Greene #13) NW $\frac{1}{4}$  NW $\frac{1}{4}$ , Sec. 12, and SW $\frac{1}{4}$ , Sec. 8, T. 56 N., R. 23 W. Cline and Greene (1950).
14. \*Co. Mo. (Coloma, Missouri) NW $\frac{1}{4}$  NW $\frac{1}{4}$  SE $\frac{1}{4}$ , Sec. 8, T. 54 N., R. 23 W.
15. CIII (Cline III) SE $\frac{1}{4}$ , Sec. 13, and SW $\frac{1}{4}$ , Sec. 14, T. 52 N., R. 26 W. Cline (1941).
16. C&G#17 (Cline and Greene #17) SE $\frac{1}{4}$ , Sec. 32, T. 51 N., R. 27 W. Cline and Greene (1950).
17. Ath. (Atherton) NE $\frac{1}{4}$  NW $\frac{1}{4}$ , Sec. 11, T. 50 N., R. 31 W. Burnley (1938).
18. \*\*MLC (Missouri Lafayette Core) NE $\frac{1}{4}$ , Sec. 15, T. 48 N., R. 28 W. One-half of core stored at Central Missouri State University (Department of Geology) and one-fourth stored at University of Iowa (Department of Geology).
19. C-107 (Core 107) SE $\frac{1}{4}$  NE $\frac{1}{4}$  SW $\frac{1}{4}$ , Sec. 25, T. 47 N., R. 28 W. Missouri Geological Survey, Missile Site Core, open file report.
20. \*P. Mo. (Pittsville, Missouri) NE $\frac{1}{4}$  NE $\frac{1}{4}$ , Sec. 27, T. 46 N., R. 28 W.
21. C-102 (Core 102) SW $\frac{1}{4}$  SE $\frac{1}{4}$  SW $\frac{1}{4}$ , Sec. 12, T. 45 N., R. 27 W. Missouri Geological Survey, Missile Site Core, open file report.
22. C-104 (Core 104) NE $\frac{1}{4}$  SW $\frac{1}{4}$  NW $\frac{1}{4}$ , Sec. 5, T. 45 N., R. 28 W. Missouri Geological Survey, Missile Site Core, open file report.
23. C-206 (Core 206) SE $\frac{1}{4}$  SW $\frac{1}{4}$  SW $\frac{1}{4}$ , Sec. 13, T. 44 N., R. 25 W. Missouri Geological Survey, Missile Site Core, open file report.
24. C-96 (Core 96) NW $\frac{1}{4}$ , Sec. 27, T. 44 N., R. 30 W. Missouri Geological Survey, Missile Site Core, open file report.

25. G-31 (Gentile #31) SW $\frac{1}{4}$  SE $\frac{1}{4}$ , Sec. 1, T. 40 N., R. 32 W. Gentile (1976).
26. J-10 (Jewett #10) Center S. line, Sec. 26, T. 21 S., R. 25 E. Jewett (1945).
27. J-28 (Jewett #28) SW corner, Sec. 6, T. 23 S., R. 25 E. Jewett (1945).
28. \*Pres. (Prescott) SW $\frac{1}{4}$  NW $\frac{1}{4}$ , Sec. 18, T. 23 S., R. 25 E.
29. J-66 (Jewett #66) Center N. line, Sec. 1, T. 25 S., R. 24 E. Jewett (1945).
30. \*WPC (West Plains Cemetary) SW $\frac{1}{4}$  SW $\frac{1}{4}$ , Sec. 10, T. 25 S., R. 24 E.
31. J-69 (Jewett 69) SE $\frac{1}{4}$  SE $\frac{1}{4}$ , Sec. 15, T. 25 S., R. 24 E. Jewett (1945).
32. \*UBS (Union Bend School) NE $\frac{1}{4}$  NE $\frac{1}{4}$ , Sec. 33, T. 25 S., R. 24 E.
33. J-80 (Jewett 80) Center W. line, Sec. 1, T. 26 S., R. 23 E. Jewett (1945).
34. \*Jub (Jubilee Quarry) SE $\frac{1}{4}$  SW  $\frac{1}{4}$ , Sec. 16, T. 26 S., R. 24 E.
35. \*Cato, Center E line, Sec. 2, T. 27 S., R. 24 E.
36. \*P-Type (Pawnee Type) NE $\frac{1}{4}$  SW $\frac{1}{4}$ , Sec. 7, T. 27 S., R. 24 E.
37. \*FHLC (Fish Hatchery Lake Crawford) SW $\frac{1}{4}$  SW $\frac{1}{4}$ , Sec. 32, T. 27 S., R. 24 E.
38. \*MWMLC (Mid-West Minerals Lake Crawford) S $\frac{1}{2}$ , SW $\frac{1}{4}$ , Sec. 31, T. 27 S., R. 24 E.
39. \*LKC (Lake Crawford) NW $\frac{1}{4}$  NW $\frac{1}{4}$ , Sec. 8, T. 28 S., R. 24 E.
40. \*Braz (Brazilton) NE $\frac{1}{4}$  NE $\frac{1}{4}$ , Sec. 5, T. 29 S., R. 23 E.
41. \*Frog, SW corner, SE $\frac{1}{4}$ , Sec. 14, T. 30 S., R. 21 E.
42. \*Joe NE $\frac{1}{4}$  NW $\frac{1}{4}$ , Sec. 17, and SW $\frac{1}{4}$  SW $\frac{1}{4}$  SE $\frac{1}{4}$ , Sec. 8, and NW $\frac{1}{4}$  NE $\frac{1}{4}$ , Sec. 7, T. 31 S., R. 21 E. (composite section from these three localities).

43. \*Lab SW (Labette SW) Center W. line, NW $\frac{1}{4}$ , Sec. 3, T. 33 S., R. 20 E.
44. J164 (Jewett #164) NW $\frac{1}{4}$  NW $\frac{1}{4}$  NW $\frac{1}{4}$ , Sec. 22, T. 33 S., R. 20 E. Jewett (1945).
45. \*E.S. (Ellis School) SW $\frac{1}{4}$  SW $\frac{1}{4}$ , Sec. 12, T. 34 S., R. 19 E.
46. \*KA-OK (Kansas-Oklahoma) NW $\frac{1}{4}$  SW $\frac{1}{4}$ , Sec. 10, T. 35 S., R. 19 E.
47. \*BC (Big Creek) Center E Line, NE $\frac{1}{4}$  NE $\frac{1}{4}$ , Sec. 28, and SW $\frac{1}{4}$  NW $\frac{1}{4}$  NW $\frac{1}{4}$ , Sec. 27, T. 29 N., R. 19 E. (composite section from these two localities).
48. \*WS (Type Wimer School) SW $\frac{1}{4}$  SE $\frac{1}{4}$ , Sec. 19, T. 28 N., R. 18 E.
49. \*CS (Type Childers School) original location by Alcock (1942) was erroneously listed as SW $\frac{1}{4}$  SW $\frac{1}{4}$ , Sec. 6, T. 26 N., R. 17 E. Actual location is SE $\frac{1}{4}$  SE $\frac{1}{4}$ , Sec. 1, T. 26 N., R. 16 E.
50. \*NENB (NE Nowata Bridge) Center SE $\frac{1}{4}$ , Sec. 17, T. 26 N., R. 17 E.
51. \*No.Ok (Nowata Oklahoma) Center E. line, NE $\frac{1}{4}$ , Sec. 31, T. 26 N., R. 17 E.
52. \*AP (Allen Point) NE $\frac{1}{4}$ , Sec. 16, T. 24 N., R. 16 E.
53. T.Oo. (Type Oologah) SW $\frac{1}{4}$  SE $\frac{1}{4}$  SE $\frac{1}{4}$ , Sec. 16, T. 23 N., R. 15 E. Chenoweth (1966).
54. Spk #7 (Sparks #7) SW corner Sec. 3, T. 22 N., R. 15 E. Sparks (1955).
55. \*O.OK (Oologah Oklahoma) N $\frac{1}{2}$  SW $\frac{1}{4}$  NW $\frac{1}{4}$ , Sec. 11, T. 22 N., R. 15 E.
56. Spk #5 (Sparks #5) SE corner, NE $\frac{1}{4}$  NW $\frac{1}{4}$ , Sec. 24, T. 21 N., R. 14 E. Sparks (1955).
57. G-25 (Gentile #25) E $\frac{1}{2}$  SW $\frac{1}{4}$ , Sec. 8, T. 40 N., R. 30 W. Gentile (1976).
58. G-24 (Gentile #24) SE $\frac{1}{4}$  SE $\frac{1}{4}$ , Sec. 28, T. 40 N., R. 30 W. Gentile (1976).

59. G-20 (Gentile #20) SE $\frac{1}{4}$  SE $\frac{1}{4}$ , Sec. 11, T. 39 N., R. 30 W. Gentile (1976).
60. G-23 (Gentile #23) NW $\frac{1}{4}$  SW $\frac{1}{4}$ , Sec. 4, T. 37 N., R. 33 W. Gentile (1976).
61. ILC (Iowa Logan Core) NW $\frac{1}{4}$  SE $\frac{1}{4}$  NE $\frac{1}{4}$  NE $\frac{1}{4}$ , Sec. 19, T. 79 N., R. 42 W. Core stored at Iowa Geological Survey.

APPENDIX B

NEBRASKA OFFUTT CORE (NOC)

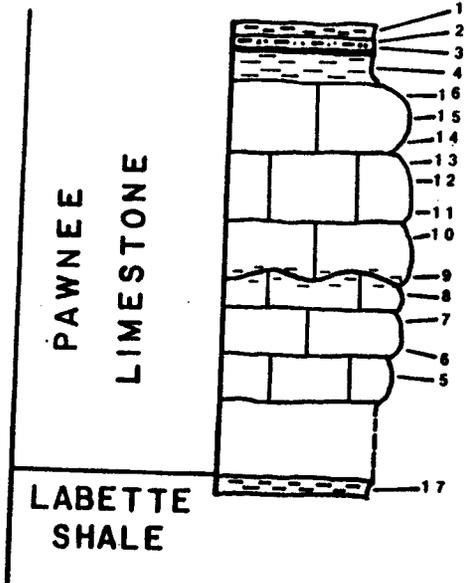
The Nebraska Offutt Core is discussed in this appendix because geopetal criteria indicate that the carbonate sequence from samples 5 through 16 (see measured section) has been overturned and therefore correlations would be uncertain.

The measured section shows the reoriented core and conodont data. Numbers correspond to location of sample from measured section. Symbols for conodonts are Ad = Adetognathus gigantus; An = Anchignathodus minutus; At = Aethotaxis sp.; Dp = Diplognathodus spp.; Ig = Idiognathodus delicatus; Ip = Idioproniodus conjunctus; Ng = Neognathodus spp.; and ram = undifferentiated ramiform elements of Ad, An, Dp, Ig, and Ng.

The following discussion is based upon reorientation of the Nebraska Offutt Core as is illustrated in the measured section of this Appendix. The missing interval at the base of the Limestone sequence apparently corresponds to the Anna Shale Member. The lower half of the overlying limestone (Samples 5-8) lacks preserved algal grains, osagia coatings, micrite envelopes, and well developed bladed rims lining interior voids. The upper half (9-16) has well developed osagia coatings, well developed interior bladed rims, and is extensively fractured. The lower half of the limestone is interpreted to have formed under deeper water,

and the upper half apparently formed in shallower water, with the fracturing possibly resulting from later subaerial exposure. Conodont data corroborate this shallowing upward sequence in that Adetognathus gigantus is restricted to the upper carbonate and to shale associated with the overlying coal. The Anna Shale, which would be in the missing interval at the base of the Offutt Core, is a fossiliferous gray marine shale in the Logan Core approximately 60 kilometers to the north. This suggests that water depths in western Iowa during maximum transgression were insufficient for anoxic conditions to develop.

Correlations from southwestern Iowa across the Forest City Basin to the Nebraska section are extremely tentative. The carbonate sequence (samples 5-16) of the Nebraska Offutt Core can represent 1) both the Myrick Station and Coal City limestone with the intervening Mine Creek Shale absent, or 2) only Myrick Station Limestone, with the Coal City corresponding to a calcareous shale horizon overlying the thin coal at the top. Additional cores across the Forest City Basin are required before definitive correlation can be determined.



Nebraska Offutt Core (NOC)

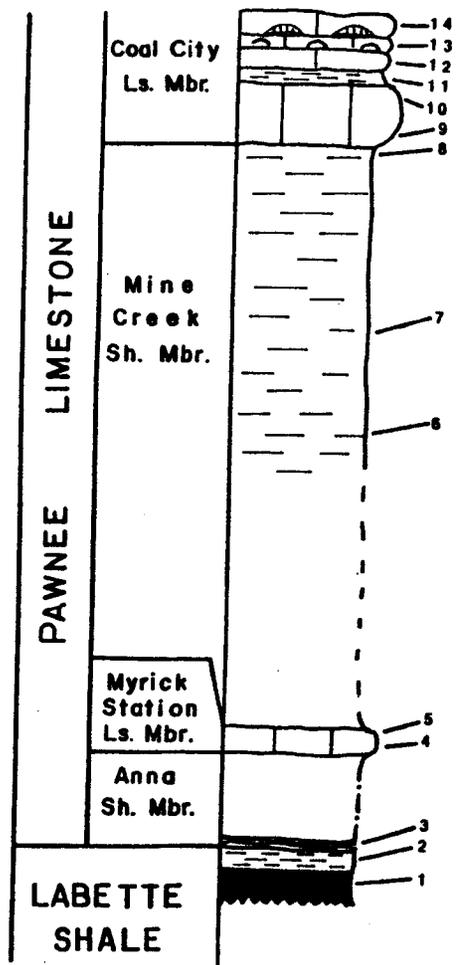
	Total Conodonts (Actual)	Total Conodonts (kg)	Ad		An		At		Dp		Ig		Ip		Ng		ram	
			1*	2 <sup>§</sup>	1*	2 <sup>§</sup>	1*	2 <sup>§</sup>	1*	2 <sup>§</sup>	1*	2 <sup>§</sup>						
1	1	3.5	1	3.5														
2																		
3																		
4																		
16	2	5	1	2.5							1	2.5						
15	7	27	6	24							1	3						
14	5	13.5	2	5.4														
13	7	18.7	1	2.8	1	2.8							1	2.7	1	2.7	1	2.7
12	28	42	5	7.5	1	1.5				3	7.5	1	2.8				1	2.8
11	1	2.5								14	21	2	3	3	4.5	3	4.5	
10	4	17.6	1	4.4											1	2.5		
9	18	43.2								3	13.2							
8	13	27.3			2	4.2				10	24	5	12	3	7.2			
7	4	10			1	2.5				6	12.6	3	6.3	1	2.1	1	2.1	
6										2	5				1	2.5		
5	7	19.6			1	2.8												
17										1	2.8				4	11.2	1	2.8

\* 1 = Actual number  
 § 2 = Cono./kg

APPENDIX C

CONODONT DATA

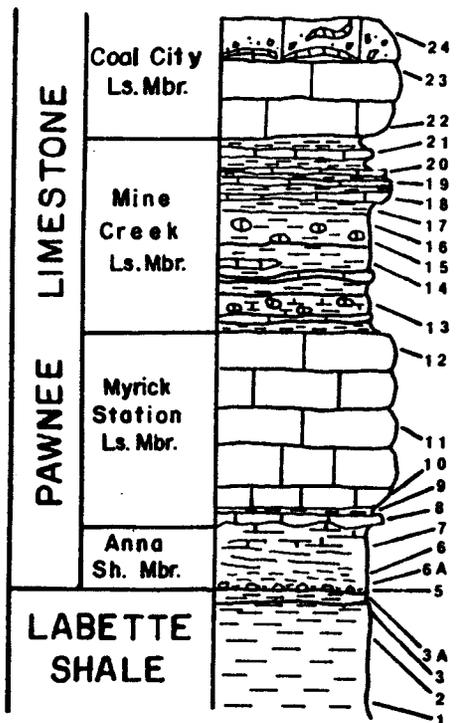
Numbers correspond to location of sample from adjacent measured section. Symbols for conodonts are Ad = Adetognathus gigantus; An = Anchignathodus minutus; At = Aethotaxis sp.; Dp = Diplognathodus spp.; Ig = Idiognathodus delicatus; Ip = Idioprioniodus conjunctus; Ng = Neognathodus spp.; and ram = undifferentiated ramiform elements of Ad, An, Dp, Ig, and Ng.



Coal City (CC)

Total Conodonts (Actual)	Total Conodonts (kg)	Ad		An		At		Dp		Ig		Ip		Ng		ram	
		1*	2 <sup>§</sup>	1*	2 <sup>§</sup>												
14	6			1	2.1					5	10.5						
13	5			1	2												
12	18			1	3.3					7	23.1	3	9.9	2	4	1	2
11	121	5	12.5	18	45	1	2.5			36	90	34	85	3	7.5	24	60
10	4			1	2.3					3	6.9						
9	14			2	4.2					7	14.7	2	4.2			3	6.3
8																	
7																	
6																	
5	3			1	2.3					1	2.3	1	2.3				
4																	
3																	
2																	
1																	

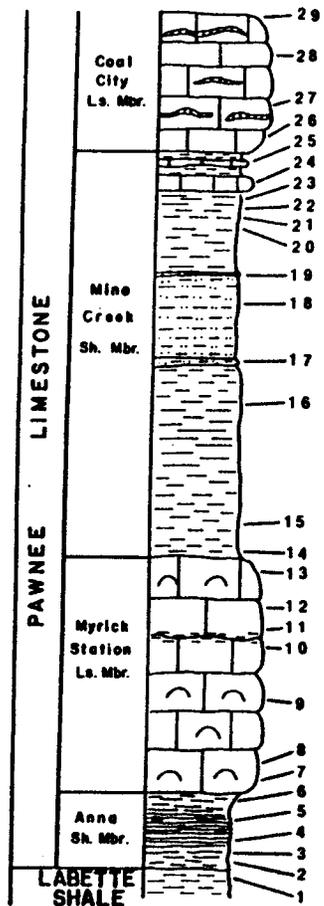
\* 1 = Actual number  
 § 2 = Cono./kg



Coloma, Missouri (Co. Mo.)

Ft	M	Total Conodonts (Actual)	Total Conodonts (kg)	Ad		An		At		Dp		Ig		Ip		Ng		ram		
				1*	2§	1*	2§	1*	2§	1*	2§	1*	2§	1*	2§	1*	2§	1*	2§	
24																				
23	22	44																		
22	30	75				2	5					13	26	2	4	3	6	4	8	
21	3	6				2	4			1	2.5	8	20	9	22.5	4	10	6	15	
20	5	25	1	5		1	5					1	2							
19	9	18	3	6								2	10						1	5
18	10	20	1	2		1	2					6	12							
17	50	220	19	83.6		5	22					5	10	1	2				2	4
16	5	10	1	2								20	88	4	17.6				2	8.8
15	6	24.6	1	4.1		1	4.1					3	6	1	2					
14												3	12.3	1	4.1					
13	1	4.4				1	4.4													
12	4	8.4																		
11	3	6										3	6.3			1	2.1			
10	9	18				1	2	1	2			1	2					1	2	
9	12	78				1	6.5					4	8	4	8					
8	7	14.7										3	19.5	5	32.5	2	13	1	6.5	
7	53	233.2				3	13.2					1	2.1	6	12.6					
6	86	283.8						1	3.3			12	52.8	30	132	5	22	3	13.2	
6-A	487	4236.9										30	99	37	122.1	14	46.2	4	13.2	
5	88	1464.6										231	2009.7	116	1009.2	129	1122.3	11	95.7	
3-A	17	56.1										42	701.4	39	631.3	5	85.5	2	33.4	
2												6	19.8	10	33	1	3.3			
1																				

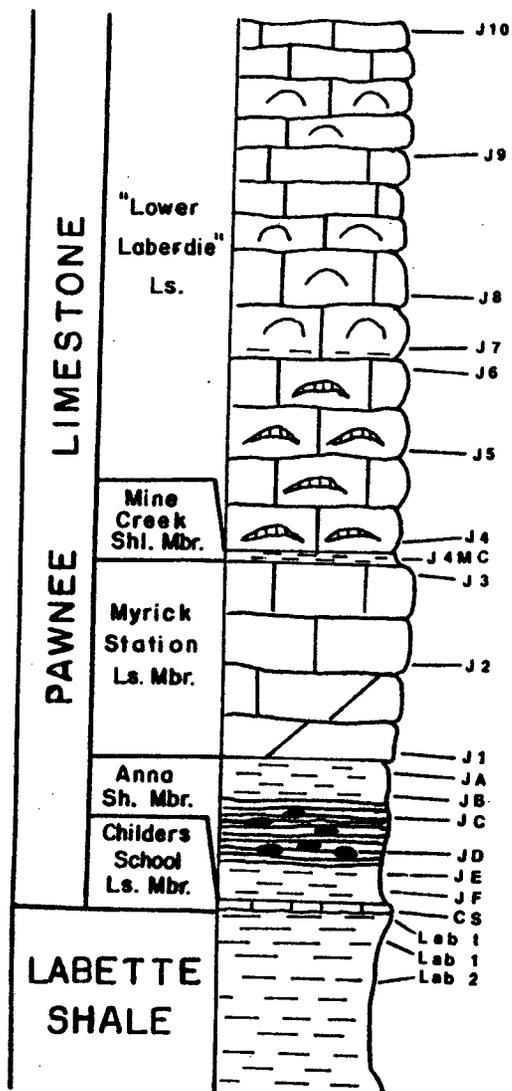
\* 1 = Actual number  
 § 2 = Cono./kg



Pittsville, Missouri (P. No.)

	Total Conodonts (Actual)	Total Conodonts (kg)	Ad		An		At		Dp		Ip		Ng		ram	
			1*	2§	1*	2§	1*	2§	1*	2§	1*	2§	1*	2§	1*	2§
29	3	6.6								2	4.4				1	2.2
28																
27	1	2.6													1	2.6
26																
25	13	59.8	1	4.6						11	50.6			1	4.6	
24	3	9								3	9					
23	6	22.2			1	3.7				5	18.5					
22	5	17.5	1	3.5						3	10.5					
21	3	10.5	3	10.5											1	3.5
20																
19																
18																
17																
16	1	3.4										1	3.4			
15																
14																
13																
12																
11																
10	1	4								1	4					
9	6	12.5			1	2.1				1	2.1			1	2.1	3 6.3
8	2	4												1	2	1 ?
7	6	36.6														
6	30	99								6	36.6					
5	38	152								20	66	5	16.5	2	6.6	3 9.9
4	81	255.6								15	60	15	60	4	16	4 16
3	4	13.6	1	3.4						23	73.6	46	147.2	8	25.6	4 12.8
2	19	77.9			2	8.2				3	10.2					
1	1	3.3								15	61.5	1	4.1		1	4.1
												1	3.3			

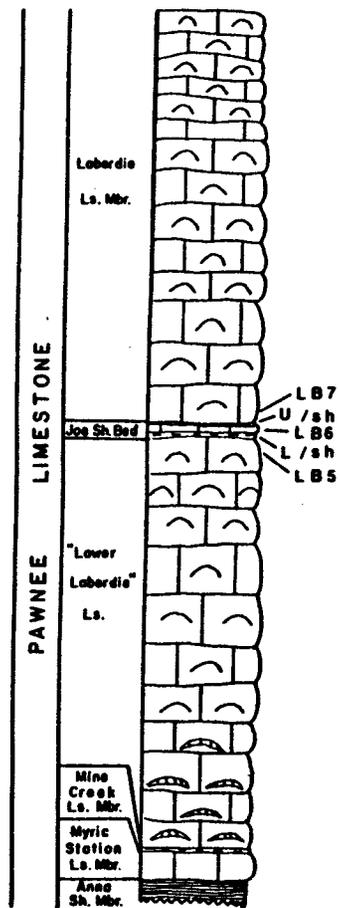
\* 1 = Actual number  
 § 2 = Cono./kg



Jubilee Quarry (JUB)

Total Conodonts (Actual)	Total Conodonts (kg)	Ad		An		At		Dp		Ig		Ip		Ng		ram	
		1*	2 <sup>§</sup>	1*	2 <sup>§</sup>	1*	2 <sup>§</sup>	1*	2 <sup>§</sup>	1*	2 <sup>§</sup>	1*	2 <sup>§</sup>	1*	2 <sup>§</sup>	1*	2 <sup>§</sup>
J10																	
J9																	
J8	4	7.6		2	3.8												
J7	19	19		3	3									1	1.9	1	1.9
J6	1	4.1		1	4.1					2	2	1	1	6	6	7	7
J5	1	3															
J4	1	3								1	3						
J4MC	9	7.2								6	4.8						
J3	28	28								28	28					3	2.4
J2	1	3.5		1	3.5												
J1	23	11.5		4	2					8	4	1	0.5	4	2	6	3
JA	9	17.1								7	13.3	1	1.9	1	1.9		
JB	19	47.5								14	35	4	10	1	2.5		
JC	14	35								7	17.5	7	17.5				
JD	38	95								22	55	14	35	2	5		
JE	42	105								9	22.5	31	77.5			2	5
JF	7	14.7								4	8.4	2	4.2			1	2.1
CS	1	2.1								1	2.1						
CS	154	77	26	13						1	2.1						
Lab-t	1	2.1								113	56.5	14	7				
Lab-1'																1	2.1
Lab-2'																	

\* 1 = Actual number  
 § 2 = Cono./kg

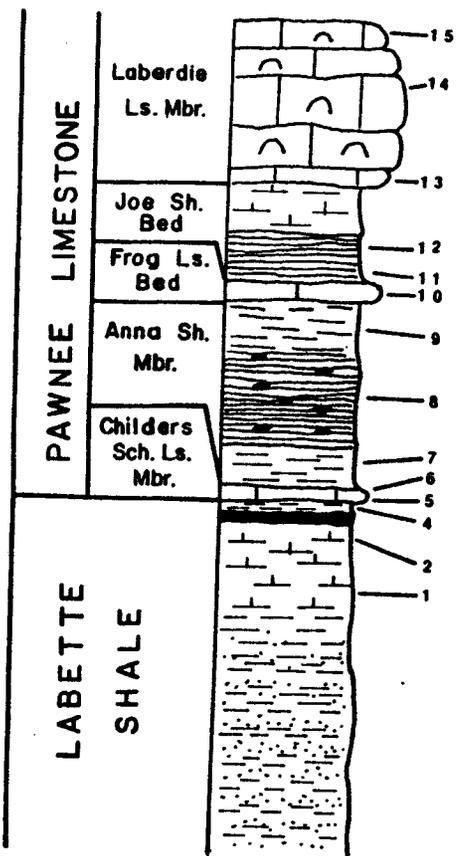


Ft 10  
M 3  
0-0

Midwest Mineral Lake Crawford (MMMLC)

Total Conodonts (Actual)	Total Conodonts (kg)	Ad		An		At		Dp		Ig		Ip		Ng		ram	
		1*	2 <sup>§</sup>	1*	2 <sup>§</sup>												
LB7	5									1	2						
W/sh	1									1	2	1	2				
LB6	50			1	2	1	2			1	6.5			2	4		1 2
L/sh										22	44	8	16	11	22		7 14
LB5																	

\* 1 = Actual number  
§ 2 = Cono./kg



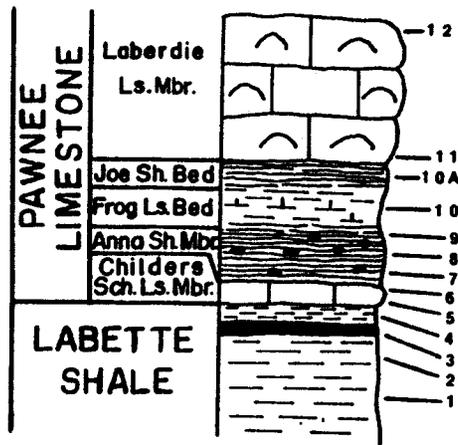
Ft M  
10 3

0-0

Labette SW (IAB SW)

Total Conodonts (Actual)	Total Conodonts (kg)	Ad		An		At		Dp		Ig		Ip		Ng		ram	
		1*	2§	1*	2§	1*	2§	1*	2§	1*	2§	1*	2§	1*	2§	1*	2§
15	5	10								1	2	1	2				
14	15	30		1	2	3	6	3	6							3	6
13																8	16
12	107	214								54	108	30	60	18	36	5	10
11																	
10	40	80		1	2					16	32	5	10	5	10	13	26
9	91	345.8								48	182.4	25	95	6	22.8	12	45.6
8	26	91								4	14	20	70	1	3.5	1	3.5
7																	
6	15	31.5	6	12.5	2	4.2				6	12.6	1	2.1				
5	2	4.8	1	2.4						1	2.4						
4																	
2																	
1																	

\* 1 = Actual number  
 § 2 = Cono./kg



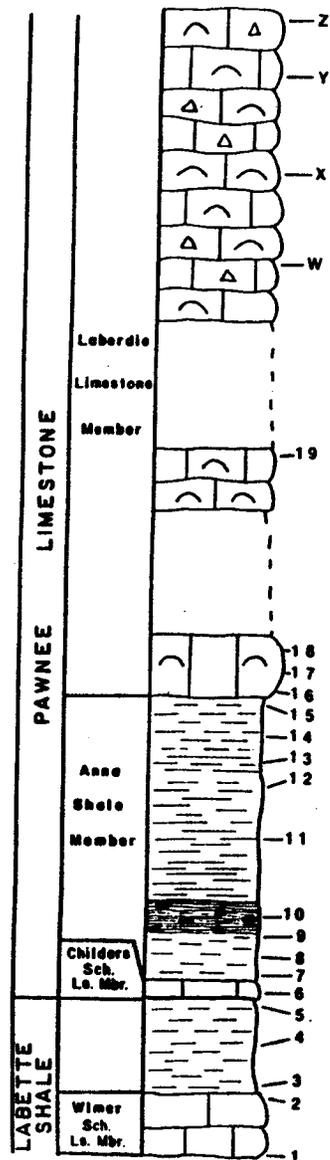
Ft M  
10 3

0-0

Ellis School (E.S.)

	Total Cono- dents (Actual)	Total Cono- dents <sup>§</sup> (kg)	Ad		An		At		Dp		Ig		Ip		Ng		ram	
			1*	2 <sup>§</sup>	1*	2 <sup>§</sup>												
12	1	2	1	2														
11	1	2																
10-A	19	47.5							4	10	12	30			3	7.5	1	2
10	9	29.7							4	13.2	2	6.6					3	9.9
9	38	125.4							21	69.3	7	23.1			4	13.2	6	19.8
8	31	102.3							18	59.4	13	42.9						
7	15	79.2							10	44	6	26.4					2	8.8
6	32	64							21	42	7	14			2	4	2	4
5																		
4																		
3																		
2																		
1																		

\* 1 = Actual number  
§ 2 = Cono./kg

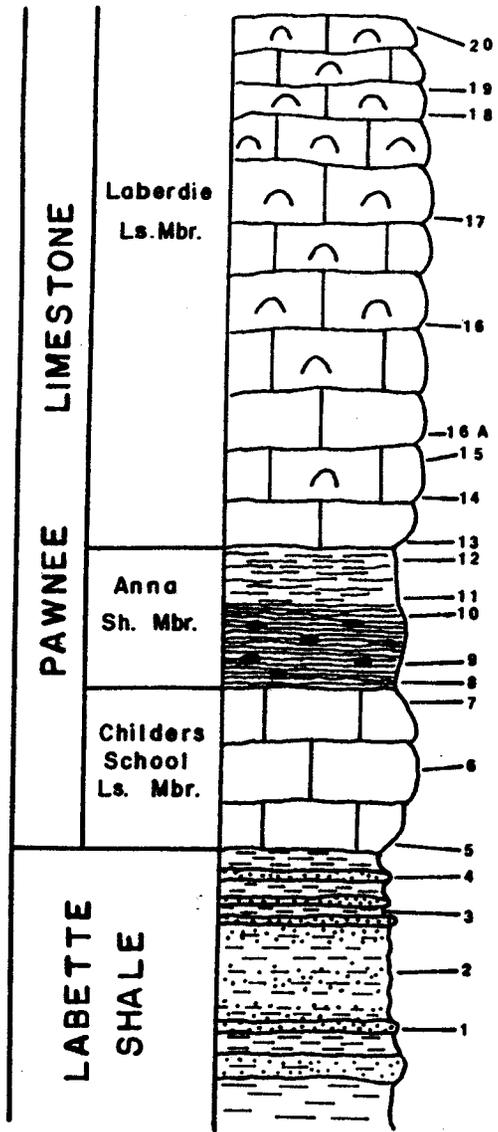


10  
0

Wimer School (W.S.)

	Total Conodonts (Actual)	Total Conodonts (kg)	Ad		An		At		Dp		Ig		Ip		Ng		ram	
			1*	2 <sup>§</sup>	1*	2 <sup>§</sup>	1*	2 <sup>§</sup>	1*	2 <sup>§</sup>	1*	2 <sup>§</sup>						
2																		
Y																		
X																		
W																		
19																		
18																		
17																		
16	1	3			1	3												
15	6	20.4			1	3.4												
14	1	3.3								3	10.2				2	6.8		
13	29	104.4								1	3.3							
12	1	3.3								23	82.8	2	7.2	1	3.6	3	10.8	
11	111	366.3										1	3.3					
10	38	140.6								4.7	155.1	50	165	1	3.6	6	19.8	
9	44	154	1	3.5						9	33.3	28	103.6			1	3.7	
8										39	136.5	3	10.5			1	3.5	
7																		
6																		
5	2	17.4	2	17.4														
4																		
3																		
2																		
1																		

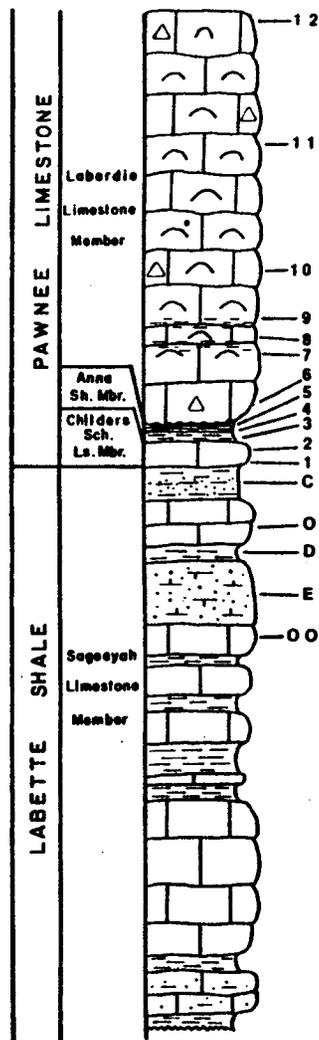
\* 1 = Actual number  
 § 2 = Cono./kg



Nowata Bridge, Oklahoma (No. OK.)

	Total Cono- dents (Actual)	Total Cono- dents (kg)	Ad		An		At		Dp		Ig		Ip		Ng		ram	
			1*	2 <sup>§</sup>	1*	2 <sup>§</sup>												
20																		
19	2	5.2									1	2.6					1	2.6
18	1	2															1	2
17																		
16	1	2.7															1	2.7
16-A	2	5.8															1	2.9
15																		
14																		
13																		
12	80	240									14	42	60	180	2	6	4	12
11	1	2.9									1	2.9						
10	5	14.5									4	11.6	1	2.9				
9	1	3.3											1	3.3				
8	41	159.9	2	7.8							24	93.6	12	46.8	2	7.8	1	3.9
7	5	5	5	5														
6	12	13.2	8	8.8	1	1.1											3	3.3
5																		
4																		
3																		
2																		
1																		

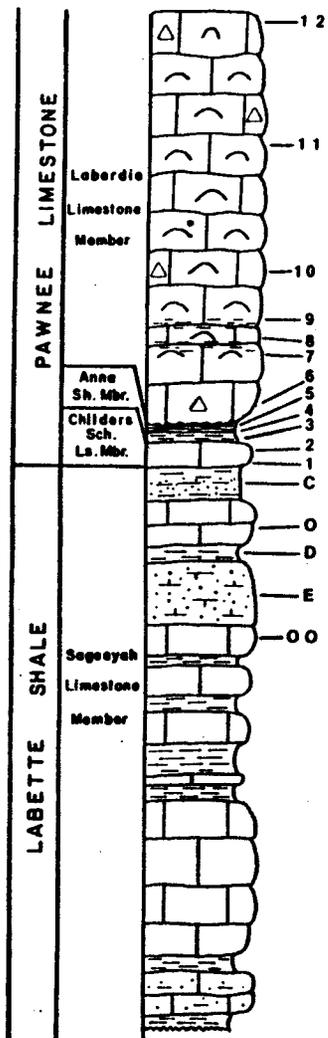
\* 1 = Actual number  
 § 2 = Cono./kg



Oologah, Oklahoma (O.OK.)

	Total Conodonts (Actual)		Total Conodonts (kg)		Ad		An		At		Dp		Ig		Ip		Ng		ram		
	1*	2 <sup>§</sup>	1*	2 <sup>§</sup>	1*	2 <sup>§</sup>	1*	2 <sup>§</sup>	1*	2 <sup>§</sup>	1*	2 <sup>§</sup>	1*	2 <sup>§</sup>	1*	2 <sup>§</sup>	1*	2 <sup>§</sup>	1*	2 <sup>§</sup>	
12	1	2			1	2															
11																					
10																					
9																					
8	2	4.4											1	2.2						1	2.2
7	8	26.4	1	3.3	1	3.3							1	3.3						5	16.5
6	33	273.9											8	66.4	21	174.3	3	24.9		1	8.3
5	105	1239											35	413	61	719.8	8	94.4		1	11.8
4	3	8.7													3	8.7					
3	94	357.2	2	7.6											77	292.6	9	34.2	5	19	1 3.8
2																					
1																					
C																					
O																					
D																					
E																					
00																					

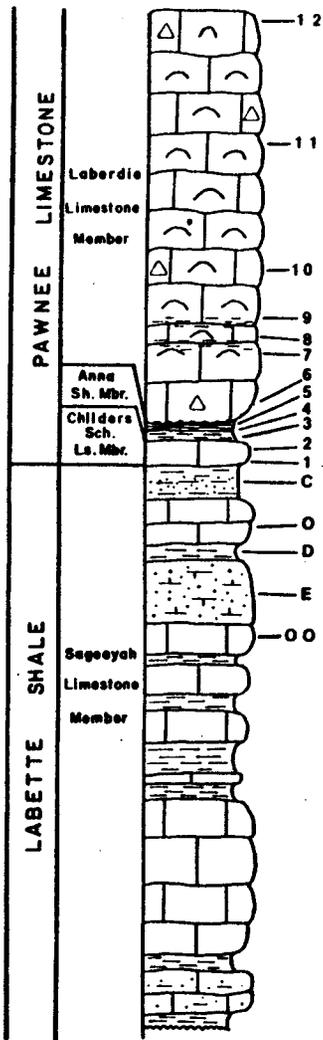
\* 1 = Actual number  
 § 2 = Cono./kg



Oologah, Oklahoma (O.OK.)

	Total Conodonts (Actual)	Total Conodonts (kg)	Ad		An		Ac		Dp		Ig		Ip		Ng		ram	
			1*	2 <sup>§</sup>	1*	2 <sup>§</sup>	1*	2 <sup>§</sup>	1*	2 <sup>§</sup>								
12	1	2	1	2														
11																		
10																		
9																		
8	2	4.4									1	2.2					1	2.2
7	8	26.4	1	3.3	1	3.3					1	3.3					5	16.5
6	33	273.9									8	66.4	21	174.3	3	24.9	1	8.3
5	105	1239									35	413	61	719.8	8	94.4	1	11.8
4	3	8.7										3	8.7					
3	94	357.2	2	7.6							77	292.6	9	34.2	5	19	1	3.8
2																		
1																		
C																		
O																		
D																		
E																		
OO																		

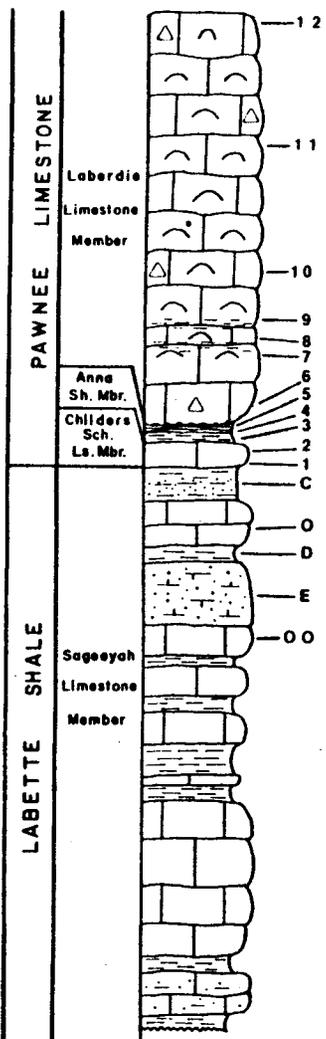
\* 1 = Actual number  
 § 2 = Cono./kg



Oologah, Oklahoma (O.OK.)

	Total Conodonts (Actual)	Total Conodonts (kg)	Ad		An		Ac		Dp		Ig		Ip		Ng		ram	
			1*	2 <sup>§</sup>	1*	2 <sup>§</sup>	1*	2 <sup>§</sup>	1*	2 <sup>§</sup>	1*	2 <sup>§</sup>						
12	1	2	1	2														
11																		
10																		
9																		
8	2	4.4								1	2.2						1	2.2
7	8	26.4	1	3.3	1	3.3			1	3.3							5	16.5
6	33	273.9							8	66.4	21	174.3	3	24.9	1	8.3		
5	105	1239							35	413	61	719.8	8	94.4	1	11.8		
4	3	8.7									3	8.7						
3	94	357.2	2	7.6							9	34.2	5	19	1	3.8		
2																		
1																		
C																		
O																		
D																		
E																		
OO																		

\* 1 = Actual number  
 § 2 = Cono./kg



Oologah, Oklahoma (O.OK.)

	Total Conodonts (Actual)	Total Conodonts (kg)	Ad		An		At		Dp		Ig		Ip		Ng		ram	
			1*	2 <sup>§</sup>	1*	2 <sup>§</sup>	1*	2 <sup>§</sup>	1*	2 <sup>§</sup>	1*	2 <sup>§</sup>						
12	1	2	1	2														
11																		
10																		
9																		
8	2	4.4								1	2.2						1	2.2
7	8	26.4	1	3.3	1	3.3				1	3.3						5	16.5
6	33	273.9								8	66.4	21	174.3	3	24.9		1	8.3
5	105	1239								35	413	61	719.8	8	94.4		1	11.8
4	3	8.7										3	8.7					
3	94	357.2	2	7.6						77	292.6	9	34.2	5	19		1	3.8
2																		
1																		
C																		
O																		
D																		
E																		
OO																		

\* 1 = Actual number  
 § 2 = Cono./kg