OUTCROP-BASED CYCLIC STRATIGRAPHY

OF THE CHEROKEE GROUP

(DESMOINESIAN,

PENNSYLVANIAN)

By

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF PHOTOGRAPHS

I.

INTRODUCTION

Statement of Problem and Purpose of Study

Moore (1936), Abernathy (1936), Searight and others (1953), Howe (1956), and Hemish (1986), among others, had noted the cyclical nature of deposition in the Cherokee Group. Despite the fact the Cherokee Group contains some of the most important hydrocarbon reservoirs in the Midcontinent, their position within cyclothemic sequence stratigraphic context is poorly understood. So, the question begs to be asked, "Are there any more cycles in the Cherokee Group to be accounted for?" since no major work has been recently attempted to determine the number of times and degree that the Midcontinent Sea transgressed and regressed over the land. These transgressions and regressions of the sea are known as transgressive-regressive units (T-R units or cycles) or cyclothems. Heckel (1986), Swade (1985), and others have completed some work in the upper part of the Senora Formation, but sea level curves do not extend below the Verdigris Limestone. This leaves the task of determining transgressive-regressive cycles and construction of a sea level curve for the entire Cherokee Group.

The main objective of this study is to establish the sea level curve and determine the number and nature of such cycles within the entire Cherokee Group (Desmoinesian Stage, Middle Pennsylvanian Series, Pennsylvanian Subsystem; Figure 1) based upon faunal assemblages and lithofacies. In order to ensure that the entire available Cherokee Group is included in the study, the transgressive-regressive cycles are studied from surface outcrops in eastern Oklahoma and southeastern Kansas, where the Cherokee

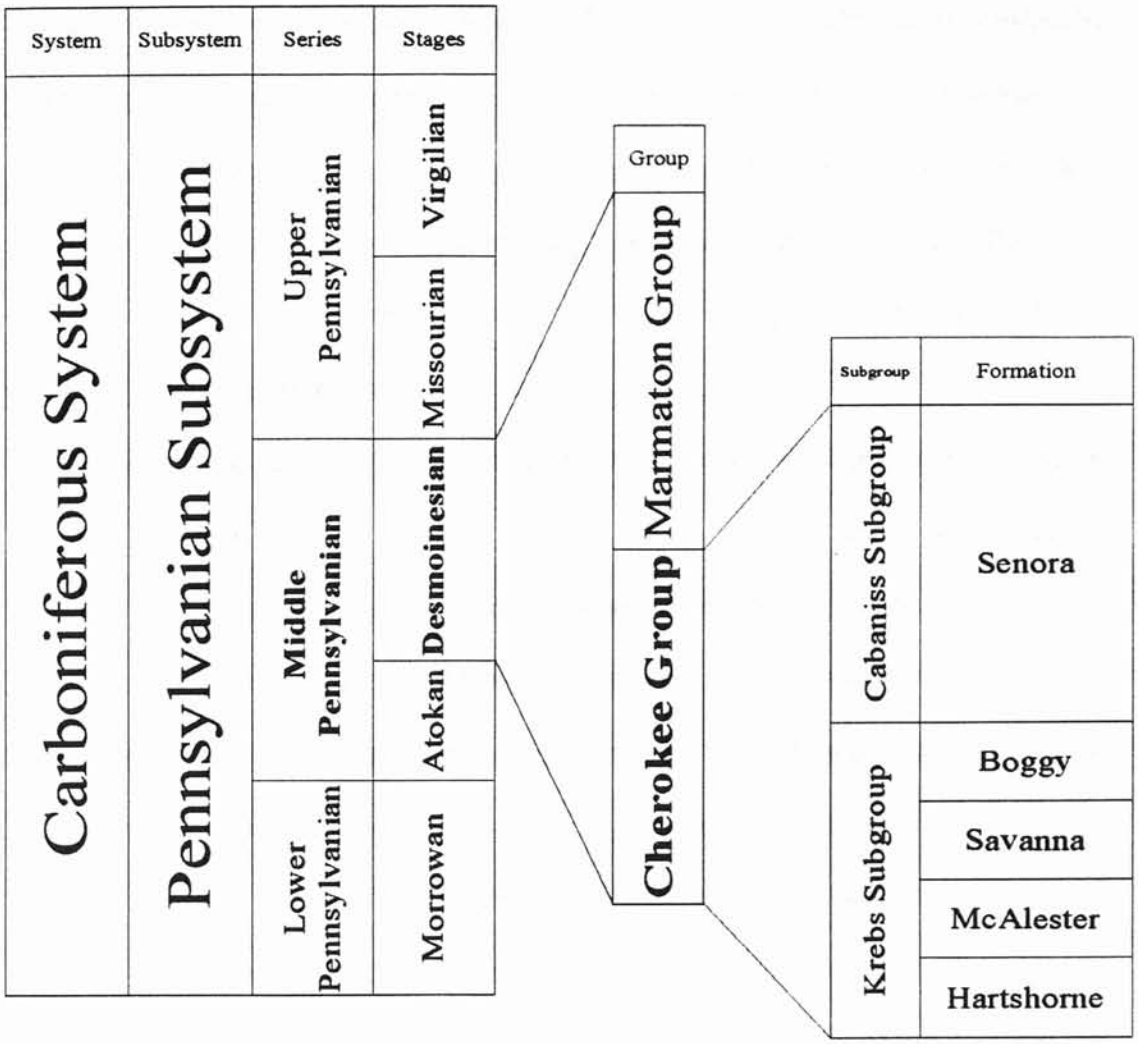

FIGURE 1. Relationship of the Cherokee Group within the Carboniferous System

Group is the most complete. Recognition of T-R cycles will be partly accomplished by identifying and describing the marine intervals found. In terms of marine intervals, limestones and black fissile shales are the focus of this study as they provide the best array of microfauna, and they will be the hinges for determining any cycles. The resulting cycles are divided into minor, intermediate, and major depending upon the degree of marine transgression.

The second objective is to systematically sample and establish a general database of identifiable fossils: conodonts, foraminifera, and ostracods. Conodonts will at least be identified down to genus, but since many of these conodonts have not been properly studied as of yet, morphotypes of the particular species of conodonts are not included. Due to the incredibly poor nature of their preservation, most foraminifera and ostracods cannot be fully identified, but when possible, at least the genus name will be provided for these microfossils. Lack of detailed identification of foraminifera and ostracods will not affect the study seriously since the presence of conodonts is the key factor for determining a marine interval. Once established, this database will be incorporated into the measured sections to provide a readily assessable guide in determining transgressive-regressive cycles.

Ultimately, once the stratigraphic interval of the Cherokee Group is analyzed, it is possible to establish 28 separate incidents of transgression and regression or transgressive-regressive cycles. From the incidence of transgression and regression, a sea level curve for the entire Cherokee Group was drawn to visually demonstrate the marine cycles.

It is necessary to at least assign tentative names to these 28 transgressive-regressive units or cyclothems in order to facilitate correlation of cyclothems in Oklahoma with cyclothems from other parts of the Midcontinent in later studies. These cyclothems are bounded from the top of a subaerial exposure (usually underclays, but not always) to the top of an overlying subaerial exposure. In the absence of a subaerial exposure, an equivalent unit must be used. Some cyclothems have special boundaries that will be discussed on a case by case basis.

A basic description of each of the 28 cyclothems should is provided. Descriptions are based upon one or two outcrops that best demonstrate that cyclicity. However, a small number of cyclothems are not present in outcrop. In these special cases, descriptions are based upon shallow subsurface cores, less than 300 feet (90 meters) deep, taken in the study area, and, in this way, every attempt has been made to fill in major gaps. The outcrop, if present, that best demonstrates a particular cyclothem will become the type locality for that cyclothem. Descriptions include the lithologic units present in each cycle, fossil contents, and if present, cyclothem boundaries. If possible, lateral extent and changes of facies over the shelf or basin are also provided. A brief synopsis of the thickness of each cyclothem in either its type locality or best exposure is included.

To facilitate cyclothem description and organization, each outcrop has become a locality and given a locality number (i.e. Locality #1). Since they cannot be considered localities, the core intervals are given measured section numbers (i.e. Measured Section #4). In Appendix B, a complete locality register with all of the studied localities or measured sections grouped into their respective cyclothems provides a quick guide to the organizational mechanics of this study.

Brief Description of the Cherokee Group

The Cherokee Group, as stated above, is notable for its numerous repetitions of underclay, coal, shale, limestone, and sandstone; most of these repeated lithologic packages can be classified into genetic coal cycles or cyclothems. The Cherokee Group overlies the Atoka Formation in the Arkoma Basin and the Mississippian in Kansas and northward; it is directly conformable to the overlying Marmaton Group. The Cherokee Group divides into 2 subgroups (the Krebs and the Cabaniss). The Krebs Subgroup contains 4 formations, and the Cabaniss contains one major formation, the Senora, along with two minor formations present only in the Arkoma Basin. Each formation has numerous smaller member units. Figure 2 provides a general overview of the stratigraphy of the Cherokee Group.

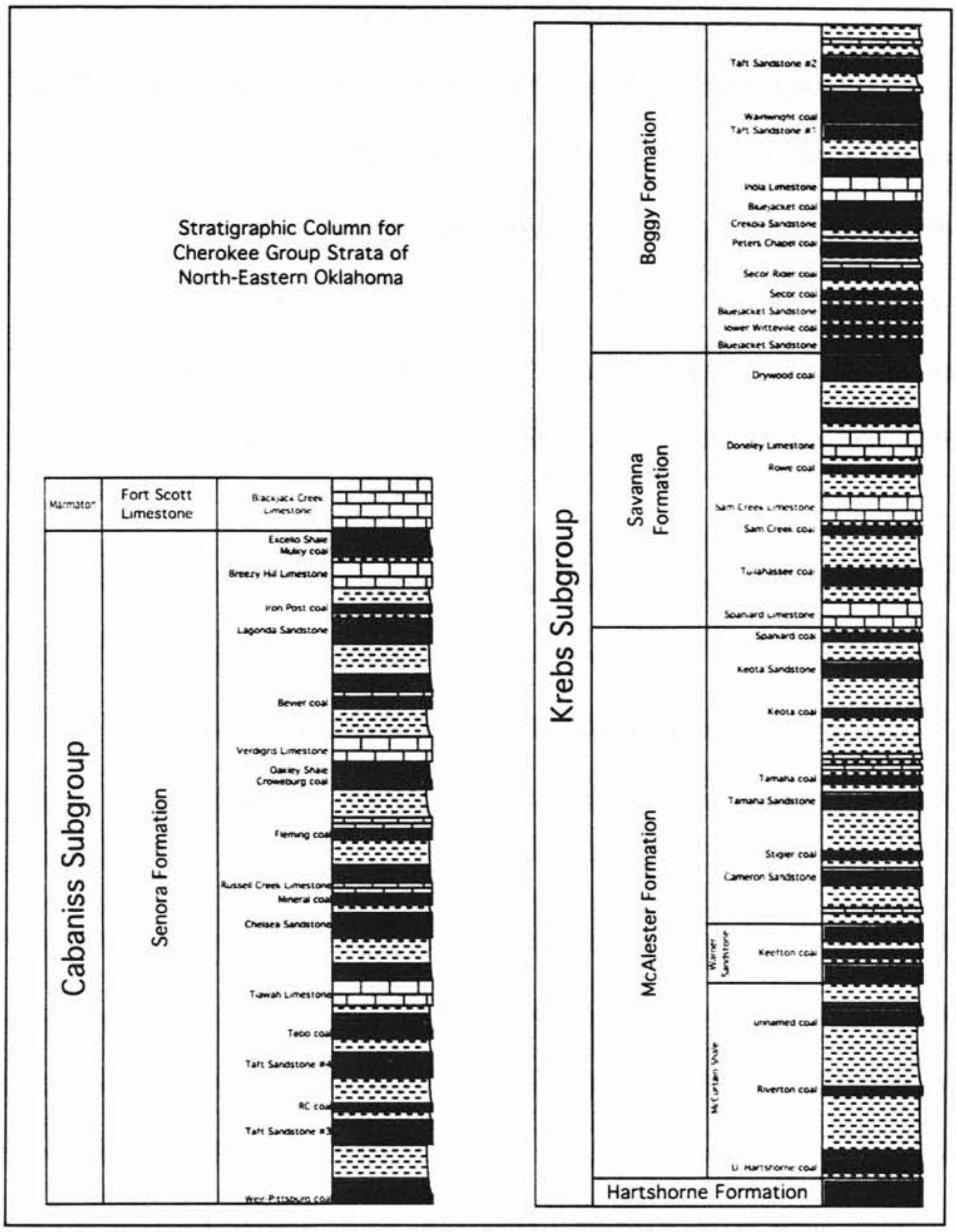

FIGURE 2. Generalized stratigraphic section of the Cherokee Group showing all of the subgroups, major formations, and member units, also shown are important unnamed bed

Location of Area of Study

The Cherokee Group described in this study is located within a north-northeasterly, south-southwesterly trending outcrop belt in eastern Oklahoma north to southeastern Kansas (Figure 3). The southernmost localities sampled were in Pittsburg, Latimer, and LeFlore counties (one locality each) of southeastern Oklahoma. One core of the Lower Witteville coal interval is located in McIntosh County. The bulk of the localities and cores are from Muskogee County, southeast of Tulsa, Oklahoma. Three localities are located in Wagoner County: one just north of Muskogee, Oklahoma, and two from Lake Bixhoma, southeast of Bixby, Oklahoma. Four of the localities and one core are from Rogers County. One core is from Mayes County. Two localities are from Craig County in northeastern Oklahoma: one near Pyramid Corners south of Welch, Oklahoma and four miles (6.4 km) west of Bluejacket, Oklahoma, and the other north and west of Welsh, Oklahoma.

Four localities are from southeastern Kansas. One is a highway cut on US 166 about 2.5 miles (4.0 km) west of Chetopa, Kansas in Labette County. The other three are from various locations around Oswego, Kansas in Labette and Cherokee Counties in extreme southeastern Kansas. Ultimately, ten core sections and twenty-six localities were measured, sampled, and described. Appendix A contains topographic maps showing the locations of the twenty-six localities and their relationships to various topographical features.

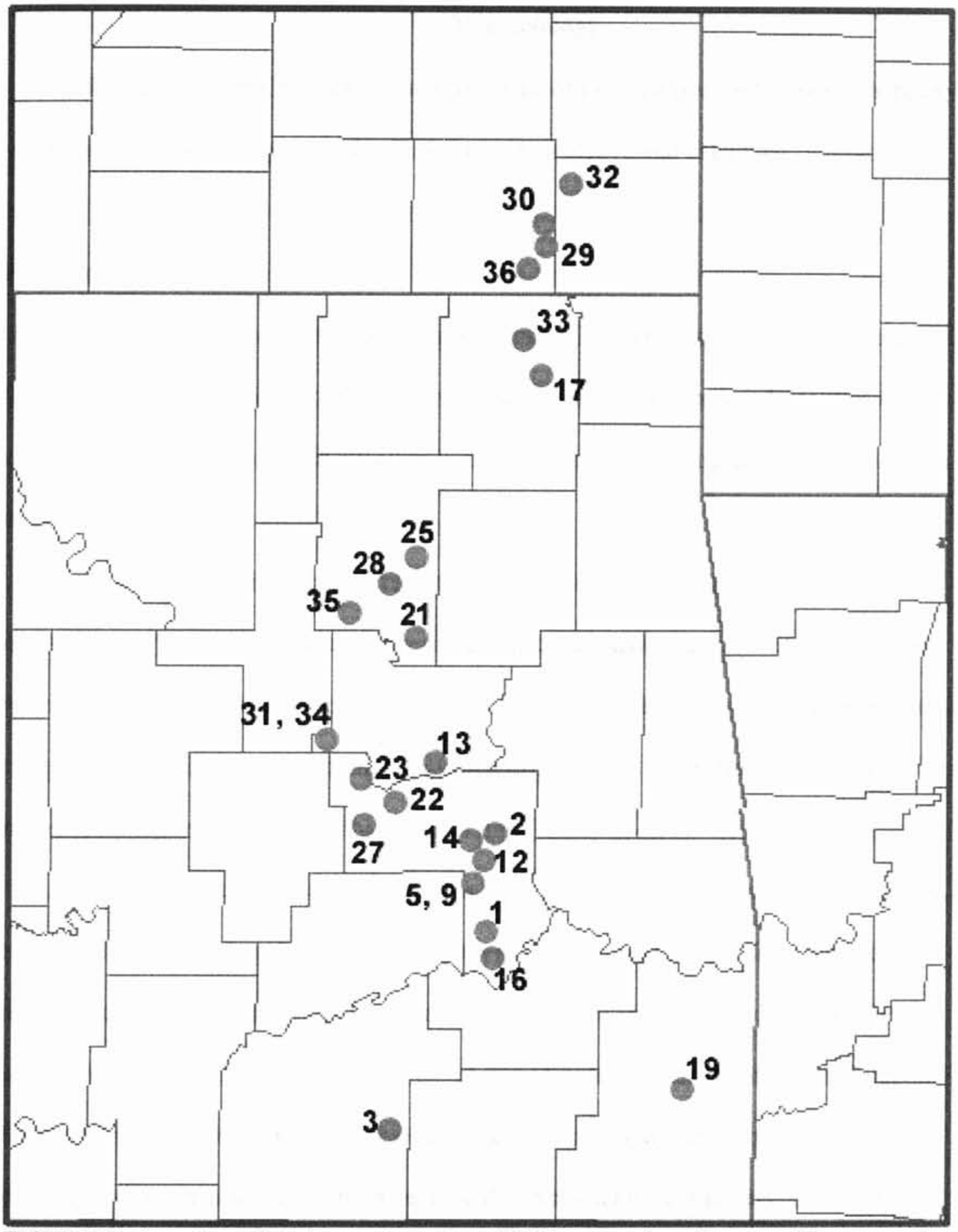

FIGURE 3. Location of study area in eastern Oklahoma and southeastern Kansas, each red dot represents a locality included in the study and the number associated with each dot corresponds to a locality number (based upon US Census Tiger Files)

Methodology

Research on the Cherokee Group consisted of three phases: field work, laboratory work, and post laboratory analysis. Fauna was then picked and cataloged.

Field work

Surface exposures and cores of the Cherokee Group include the Senora, Boggy, Savanna, McAlester, and Hartshorne Formations, in descending order. Localities and cores were also chosen in such a way as to provide extensive stratigraphic overlap within these five formations.

At a locality or in a core section, the primary focus was on the limestones and marine shales. Underclays, coals, silty or carbonaceous shale, siltstones, and sandstones were described but not sampled. Limestones and black fissile shales were described and sampled at regular intervals (six inches (15.2 (cm), one foot (0.3 meters), five feet (1.5 meters), etc...) depending upon thickness of unit.

Initially, 47 localities and eight cores were measured and/or described. However, each locality was analyzed and selected by their ability to best demonstrate the cyclic nature of deposition within the Cherokee Group. Some were eliminated due to either a poorly exposed or developed marine interval or a complete absence of a marine interval. Others were eliminated due to a lack of significant stratigraphic units to calibrate placement of the marine intervals and eventually cyclothems. Ultimately, 26 localities and measured sections from seven cores (producing ten core sections) remained for the study, producing 36 viable measured sections.

Laboratory work

Both the limestones and shales were processed to extract their microfossils. Some silty, carbonaceous, or marginal marine shales and underclays were not processed, but were described. Limestones were processed using formic acid. 500 ml of formic acid was added to approximately six liters of water to dissolve about 500 g of limestone. Limestone was mechanically crushed using a hammer to increase surface area for more efficient processing; the rock was only crushed to pebble sized fragments to prevent destruction of the microfossils. The resulting residue was sieved through 35 and 100 mesh screens to collect the microfossils.

Shale processing was somewhat more complicated. Very clayey or soft shales could be easily broken down just using kerosene. Black fissile shales had to be broken down using 30% solution hydrogen peroxide. 500 ml of hydrogen peroxide was added to approximately 500 g of shale sample. Depending upon how resistant the shale was, several applications of hydrogen peroxide were often necessary. Afterwards, the residue was given a final wash of kerosene to remove clay particles. All shale samples were baked to remove water particles that would hinder effective processing.
Shale residue was sieved through 35, 80, 100, and 220 mesh screens.

The 100 mesh residues of limestones and 80 and 100 mesh residues of shales were studied under a low powered microscope for microfossils. Any index microfossils (conodonts, foraminifera, ostracods, etc…) were collected for further analysis. Other types of microfossils (brachiopod shell fragments, crinoid stems, etc…) were merely described and noted. Conodonts and other index fossils were identified and photographed using a scanning electron microscope (S.E.M.).

Post Laboratory Analysis

All collected samples were given color descriptions based upon the Geological Society of America Rock Color Chart, 1984 reprint, utilizing Munsell's color chips. Both unweathered and weathered colors were noted. Other important features such as bedding planes, mineralogical content, oxidation state, limonite and iron nodules, and any other diagenetic, and deformation features were noted. Both megafossils and microfossils were incorporated into the overall description. Other important lithologic features such as phosphate nodules for black fissile shales were also noted. Limestones were classified according to Dunham's carbonate classification, and sandstones, where accessible for study, were classified as quartz arenite, arkose, etc....

Once all of the limestone and shale samples had been properly processed and described, detailed written measured sections were made of the 36 viable sections. Based upon the written descriptions, the sections were drafted using Canvas 7™. The purpose of the drafted sections is to show sampling intervals, thickness of units, stratigraphic relationships of marine bands and terrestrial units, and frequency of marine intervals.

Some sections had sequence boundaries. The sequence boundaries were often represented by unconformities or incised surfaces. One particularly intriguing sequence boundary lies between the Drywood coal and Bluejacket Sandstone. A conglomerate that contains numerous phosphate nodules and limestone and shale fragments represents the boundary at this locality, there is a strong possibility that a small cyclothem was removed by downcutting.

Photographs

Extensive photographs of the 47 localities were taken to provide a visual reference point for laboratory work. However, many of these photographs are too specific (such as a picture of a single limestone bed) to provide any good overview of Cherokee cyclicity. As the 47 localities were eliminated down to 26 localities, only the photographs of the 26 localities were kept to provide a photographic documentation of the fieldwork. Furthermore, photographs that only showed a specific bed were set aside to not be included in the final report. Eventually, eight photographs that best displayed the cyclothems identified within the Cherokee Group were chosen for inclusion within the final study. However, due to constraints of space, only photographs of selected cyclothems were included. Two photographs of the Sam Creek and Tiawah Limestones were included because they display unique characteristics of the limestones, as explained in Appendix B. Due to severe time constraints, photographs of the core sections were not made.

Geologic Setting

The Cherokee Group is a part of approximately 30,000 feet (9000 meters) of sediment that fill the Arkoma Basin (Branan, 1968, p. 1616), and of the 30,000 feet (9000 meters), approximately 20,000 feet (6000 meters) of this sediment is Atokan in age (Branan, 1968, p. 1619). The Arkoma Basin is one of seven foreland basins that line the northern edge of the Ouachita-Appalachian Mountain system (Branan, 1968, p. 1617). Figure 4 shows the location of the Arkoma Basin in relation to other tectonic features in Oklahoma.

The boundaries of the Arkoma Basin are as follows: the south, the Ouachita Mountains; the northeast, the Ozark uplift; the northwest, the shelf (also known as the Central Oklahoma Platform or Cherokee Platform), and the Nemaha Ridge; the southwest, the Arbuckle Mountains and Tishomingo anticline. Towards southeastern Kansas, the Arkoma Basin extends into the shelf or Cherokee Platform.

The strata that fill the Arkoma Basin range from approximately 3000 feet (900 meters) on the shelf margin to over 30,000 feet (9000 meters) along the forefront of the Ouachita Mountains (Branan, 1968, p. 1619). Some of the deltaic and fluvial sandstones derived their sediment load from the Ouachitas although some minor input must have come from the Ozark Mountains (Rascoe and Adler, 1983, p. 988). Closer to the Ouachitas, in southeastern Oklahoma, there are more silty and sandy shales, underclays, and coals. Larger sand bodies such as the Bluejacket or the Chelsea may have drained from a source to the northeast. In northern Oklahoma and southeastern Kansas, there are more marine shales and limestones, and sandstones, coals, and underclays are not as thick either. Again, this is indicative of being more offshore.

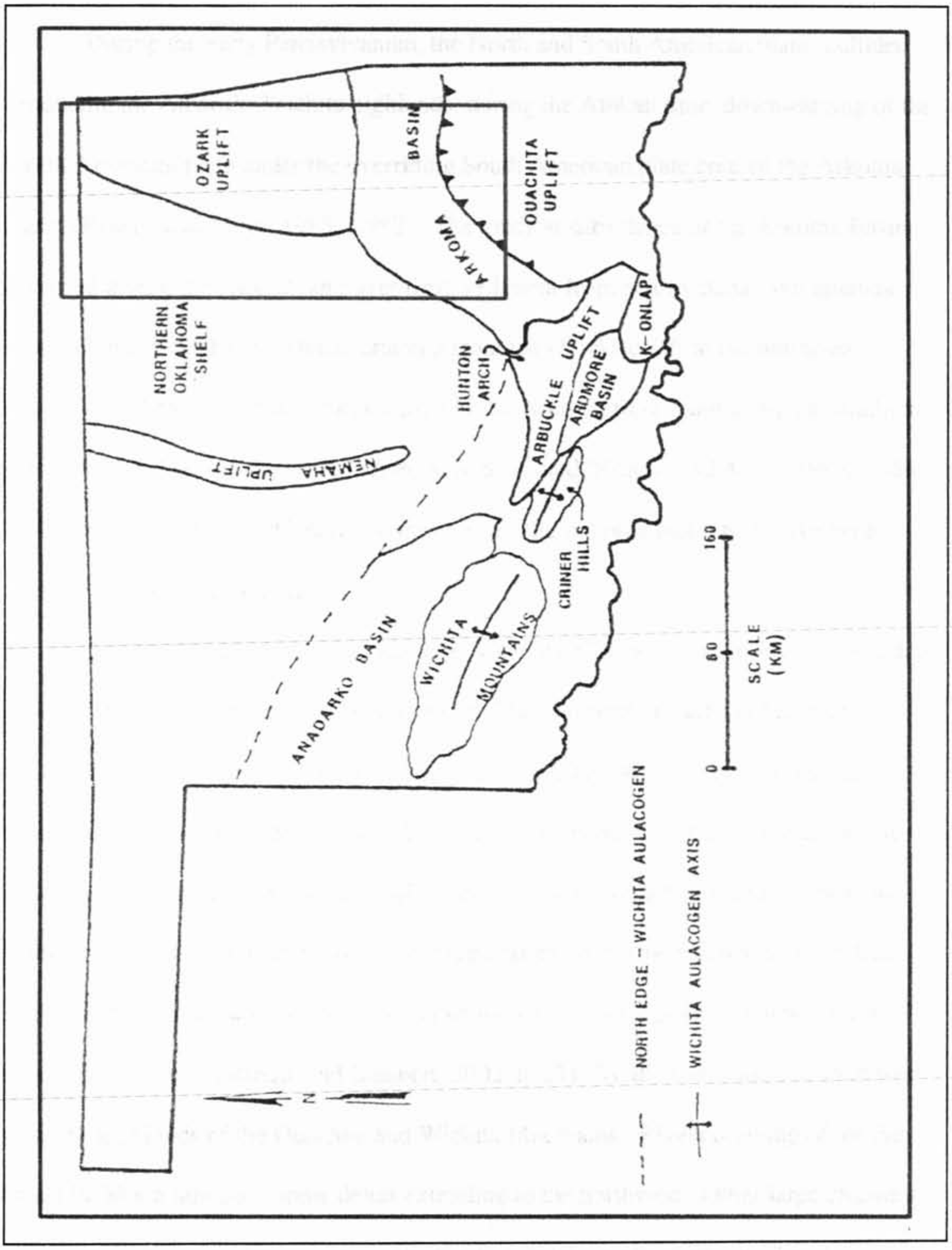

FIGURE 4. Tectonic features in Oklahoma, area of study within the green rectangle (Modified slightly from Henk 1981, p. 12)

Geologic History

During the early Pennsylvanian, the North and South American plates collided producing the Amarillo-Wichita highlands; during the Atokan time, downwarping of the North American plate under the overriding South American plate created the Arkoma Basin (Rascoe and Adler, 1983, p.982). The greatest subsidence of the Arkoma Basin occurred during the Atokan, and over time, sediment from nearby deltas and uplands accumulated in the basin. Deltas draining from the Ozarks uplift to the northeast deposited sediments on the northeast edge of the Arkoma Basin, and along the southern margin of the Arkoma Basin, turbidites were deposited (Rascoe and Adler, 1983, p.988). However, by the time of the early Desmoinesian, the Arkoma Basin may have been mostly filled with sediments.

During the early Desmoinesian time, when the Cherokee Group was deposited, a series of transgressions and regressions by the Midcontinent Sea affected eastern Oklahoma. During times of transgression, most of the area was covered by sea, and during regressions, the area may have been semi-continental to terrestrial (Rascoe and Adler, 1983) (Figure 5). Continued subsidence of the Arkoma Basin coupled with the glacial-eustatic marine transgressions and regressions over time and highstand deltaic sedimentation contributed to the great thickness of the Cherokee Group in the Arkoma Basin (Boardman, Marshall, and Lambert, 2002, p. 27). To the southeast and southwest were the highlands of the Ouachita and Wichita Mountains. Rivers draining off of the Ouachita Mountains built some deltas extending to the northwest. Other large channels depositing significant sand bodies on the Central Oklahoma Platform or Cherokee

Platform (such as the Chelsea Sandstone) drained from some source in Illinois to the northeast.

Rascoe and Adler (1983, p.992) noted that Weirich, in 1953, stated that the northern edge of the Arkoma Basin was along a hinge line that eventually migrated northward or shelfward. The margin between the shelf and basin may have been along what is now the Arkansas River. During the deposition of the Savanna Formation, shelf sediments were deposited as far south as southern Muskogee County, and during the deposition of the Boggy and Senora Formation, basinal sediments may have been deposited as north as Craig County (Branson, 1954, p. 1). Branson's (1954) observations of the deposition of the basinal and shelf sediments may add support to the northward migration of the margin between the Arkoma Basin and the shelf or Cherokee Platform.

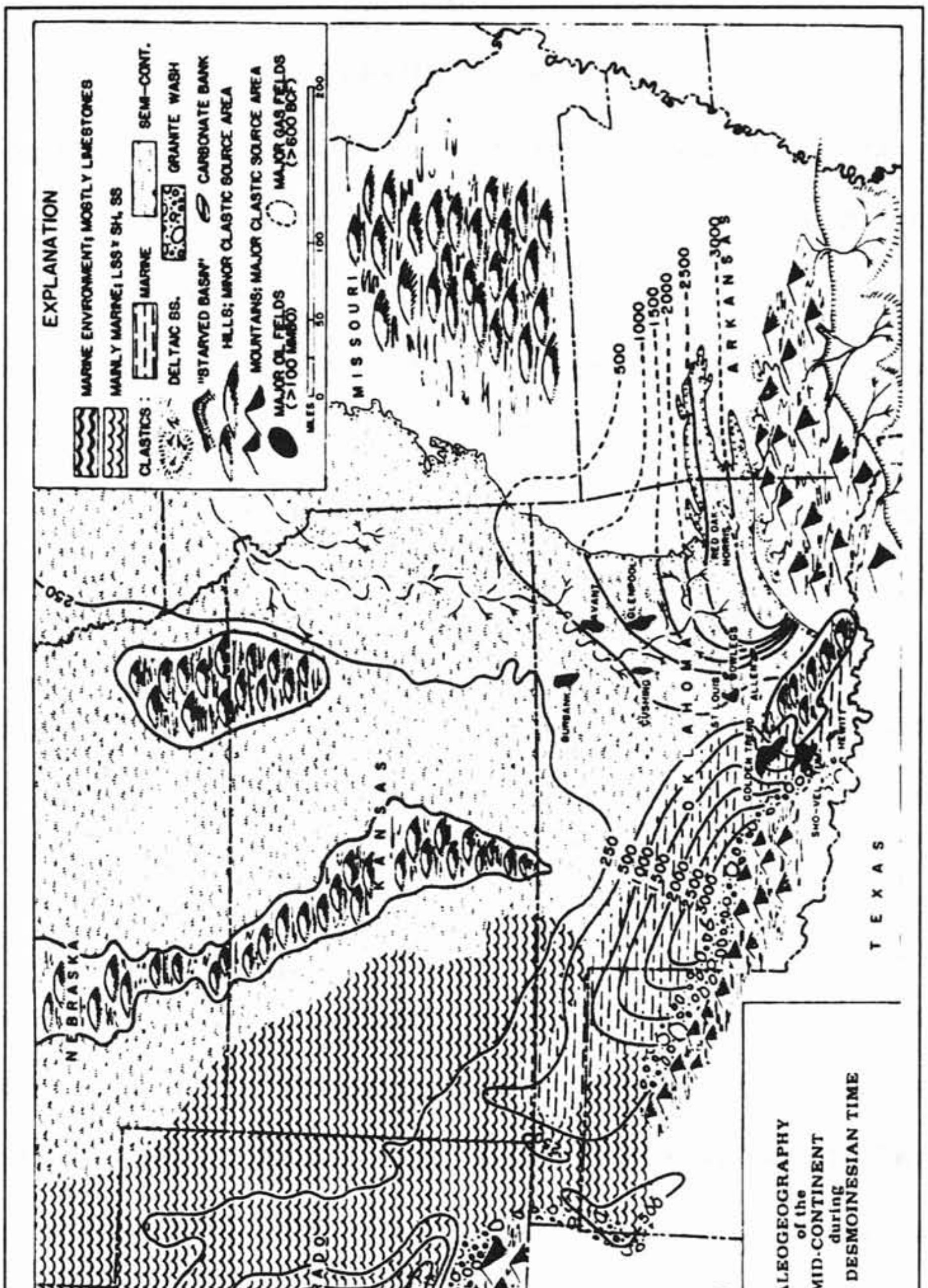

FIGURE 5. Paleogeographic map of the early Desmoinesian (From Rascoe and Adler, 1983, p.991)

II.

PREVIOUS WORKS

The first serious field research of the Cherokee Group was conducted in southeastern Oklahoma by Chance (1890). Haworth and Kirk (1894) termed the name "Cherokee Shale" in southeastern Kansas. Later, in the McAlester vicinity, Taff (1899 1901) and Taff and Adams (1900) measured and described several exposures within the Cherokee. Taff (1899, 1901) named the Hartshorne, McAlester, Savanna, Boggy, and Senora Formations. Early studies of the Cherokee Group centered on coal exploration and production. Wilson (1935), Dane and Hendricks (1936), Hendricks (1937, 1939), Knechtel (1937, 1949), Pierce and Courtier, in Kansas, (1937), Wilson and Newell (1937), Dane and others (1938), Oakes and Knechtel (1948), and Ries (1954), among others, all concentrated on the coals found in the Cherokee Group, but they did briefly describe some of the beds associated with these coals.

Moore (1936) discussed the cyclicity of the Pennsylvanian in Kansas and Nebraska, and from this study, he was able to establish an "ideal cyclothem" of the Midcontinent Pennsylvanian. Abernathy (1936), building upon Moore's work, divided the Cherokee Group into cyclothems. Later, Branson (1954) also divided the Cherokee Group into coal cycles or cyclothems, and, in addition, he provided a more realistic cyclothem likely to be found in the Cherokee of Oklahoma.

Moore (1949) proposed changing the name Cherokee Shale to Cherokee Group. Oakes (1953) divided the Cherokee Group into the Krebs and Cabaniss Group. Searight and others (1953), utilizing coal cycles, divided the Cherokee Group into 18 "formations". Searight and others (1953) also proposed dropping the term "Cherokee

Group" in favor of the Krebs and Cabaniss Groups. But, according to Howe (1956), the term Cherokee Group was reinstated at a meeting in Lawrence, Kansas in 1955. Howe (1956) produced a seminal work discussing many of the lithostratigraphic units of the Cherokee Group in Missouri, Kansas, and Oklahoma.

More recent studies of the Cherokee Group have been conducted by Oakes (1963, 1977), Branson and others (1965), Oakes and others (1967), Cassidy (1968), Knight (1983, 1985), and Ece (1987). Heckel and Baesemann (1975), Knight (1985), and Swade (1985) conducted important conodont biostratigraphic work involving the Cherokee Group.

The most recent critical contribution to the Cherokee Group has been by Hemish (1986b, 1988, 1997a,b) who provided numerous core descriptions, measured sections, localities, stratigraphic studies, and mapping through various publications. Many measured sections have been described and published by Hemish (1986a, 1989c, 1994a, 1998) in his descriptions of the coal geology of the various counties in eastern Oklahoma.

A more detailed discussion of the history of lithostratigraphic nomenclature in the Cherokee Group as well as previous work on the Cherokee by other authors can be found at the beginning of Appendix A. Appendix A also contains a detailed discussion of previous Cherokee cyclicity studies. Finally, a general listing of previously determined conodont bearing intervals is found at the end of Appendix A.

III.

CONCEPTS AND INTERPRETATIONS OF CYCLOTHEMS

Early Concepts of Cyclothems

Heckel (1984) wrote an excellent synopsis of the history of cyclothem concepts of the Midcontinent Pennsylvanian. Due to the completeness of Heckel's work and the fact that several authors previously have already covered this material in depth, this chapter will just be a summary of Heckel's (1984) report. Udden, (1912), was among one of the first to notice the cyclical nature of the Midcontinent Pennsylvanian (Heckel, 1984, p.535). In the vicinity of Peoria, Illinois, Udden observed four such cycles that he described as a succession of coal, shale, limestone, sandstone, and fire clay (Heckel, 1984, p.535). Each lithology was considered a separate stage in the cycle that Udden (1912, p.76) described as, "(1) accumulation of vegetation; (2) deposition of calcareous material; (3) sand importation; and (4) aggradation to sea-level and soil making". Udden felt it necessary to interpret the sequence of events that produced such a succession, and he believed that the sequence began with a coal swamp. Over time, a shallow sea, depositing the limestone, flooded this swamp. The sandstone was deposited when sand and other clastics filled up the sea, which eventually became subaerially exposed. Upon exposure, weathering of the sediments produced the fire clay. Eventually, another coal swamp developed, and the cycle began anew (Heckel, 1984, p.535). Heckel (1984, p.536) noted that Udden believed that the black shales above the coals were shallow water deposits. The black shales were deposited soon after the sea invaded the coal swamp but before the limestones were deposited.

Weller, (1930), agreed with most of Udden's interpretation for cycles save for sandstones (Heckel, 1984, p.536). Weller believed that fluvial channels deposited the sandstones, and therefore, the unconformity at the base of the sandstone would be the justifiable base of the cycle. Udden, however, placed the base of the cycle at the coal (Heckel, 1984, p.536). Weller (1930, p.127) also developed his own interpretations for the black fissile shales above the coals. While he agreed with Udden that the shale were at least initially deposited by shallow water, Weller (1930, p.127) did not believe that organic debris reworked from the peat bed (forming the coal) below was fully responsible for the shales' black color, "... as some of the black shales attain a considerable thickness without apparent decrease in carbon content above, and others are separated from the underlying coals by...50 feet of light gray...shales.". To better explain the black fissile shales, Weller (1930, p.127) introduced the concept of 'algal flotants', "lowly organized plants, such as marine algae, may have been present in sufficient abundance to prevent the development of waves, and when they died they left no other trace than the carbonaceous content of the shales."

A more controversial concept than 'algal flotants' proposed by Weller, (1930), was that of diastrophism (Heckel, 1984, p.536). Diastrophism is often referred to as "yo-yo" tectonics due to the constant uplift and subsidence that this model requires. According to Weller (1930), the diastrophic cycle begins with uplift. Eventually after uplift, clastics, possibly fluvial in origin, accumulated on the exposed surface. After a period of stability where non-deposition and erosion took place; subsidence occurred. As the land subsided, poor drainage allowed coal producing swamps to develop. Further subsidence allowed flooding by the seas, and the resulting shallow sea deposited the limestone. After even more time, uplift occurred again thus starting the cycle over again. Unfortunately, Weller (1930) failed to provide an adequate mechanism to explain the hundreds of uplifts and subsidence that must have taken place over the span of the Pennsylvanian.

Moore (1929, 1931) recognized cyclicity in Kansas and Nebraska (Heckel, 1984, p.538). Whereas Weller (1930) recognized two limestones (with only the upper containing marine fossils) in a typical Illinois cyclothem, Moore noted that cycles in Kansas and Nebraska contained three to four limestone with most of them containing marine fossils (Heckel, 1984, p.538). Moore also noted that some sandy shales above and below the limestones contained plant fossils and coals, but other contained marine fossils, and the only major explanation he provided for this difference in shales was deposition in turbid water or deposition in clear water (when interbedded with limestones) (Heckel, 1984, p.538). Moore, (1929), also attempted an explanation for black fissile shales. Unlike in Illinois, black shales in Kansas and Nebraska often lie between marine limestones or shales thus ruling out peat bogs as a possible origin for the organics in black shales. Moore believed in a marine origin for black fissile shales, but he stated that the organic matter and sulfides must have been deposited in a very shallow, stagnant, toxic sea. The shallowness of this sea prevented wave action, tidal agitation, and circulation so the sea may have also been anoxic. Moore also believed that there might have been abundant plant growth with this sea, a very similar concept to Weller's (1930) 'algal flotant' hypothesis.

Wanless and Weller (1932)

Wanless and Weller (1932, p.1003) first established the term cyclothem to define the numerous coal cycles found in Illinois and elsewhere. The word "cyclothem' is a combination of the Greek words: *cyclos* and *thema*. *Cyclos* means cycle, and *thema* means deposit, so cyclothem in effect literally means 'cyclic deposits' (Wanless and Weller, 1932, p.1003).

Wanless and Weller (1932) also attempted to mass correlate the cyclothems of Illinois, Iowa, western Missouri, eastern Kansas, and northeastern Oklahoma. They also included the uppermost member units of the Cherokee Group by assigning the Verdigris Limestone and Croweburg coal to the Liverpool cyclothem and the Chelsea Sandstone to the Greenbush or Liverpool cyclothems (Wanless and Weller, 1932, p.1015). Both the Liverpool and Greenbush are cyclothems identified in Illinois, and Wanless and Weller (1932) found that many of these cycles could be correlated over much of the Midcontinent.

Wanless and Shepard (1936)

One of the better known papers in the history of cyclothems, Wanless and Weller (1936) were among the first to provide a more realistic control method for the cyclothems of the Midcontinent and elsewhere. They proposed that the growth and shrinkage of glaciers in the Southern Hemisphere created worldwide (eustatic) sea level changes. These glacial-eustatic rise and falls of the sea level occurred repeatedly throughout the Pennsylvanian and Permian. When glaciers melted, a rise in sea level would cover large portions of the land resulting in widespread deposition of marine units such as limestones and shales, and buildup of glaciers would cause sea level to fall. Most of the land previously inundated would gradually dry out, and more terrestrial units such as paleosols and fluvial sandstones would be deposited.

Wanless and Shepard (1936) recognized three "facies" of cyclothems in North America: the 1. "piedmont facies", 2. "delta facies", and 3. "neritic facies". The piedmont facies were deposited near the source area in the Appalachians and southern Illinois; as to be expected, these cyclothems are predominantly terrestrial or marginal marine with a few poorly developed marine intervals. The delta facies was deposited farther from the source area, but clastic influx was still very significant so limestones are not well developed. However, marine deposits are present. The cyclothems of the delta facies are found mainly in Illinois and the eastern Midcontinent. The neritic facies is offshore so marine deposits are dominant. Limestones are thick and well developed while more onshore units such as coals and paleosols are not. Another feature of cyclothems of the neritic facies is the thickness and widespread lateral extent of the black fissile shale. The cyclothems of the western Midcontinent such as Kansas and Oklahoma fit into the neritic facies.

Megacyclothems

Moore (1936, pp.24-25) listed the components of an "ideal" cyclothem of the Pennsylvanian and Permian of the Midcontinent. Furthermore, he attached a Dewey decimal number to each distinctive unit within a cyclothem:

> ". 9. Shale (and coal).
> .8. Shale, typically with molluscan fauna.
> .7. Limestone, algal, molluscan, or with mixed molluscan and molluscoid fauna

.6. Shale, molluscoids dominant.
.5. Limestone, contains fusulinids, associated commonly with molluscoids.
.4. Shale, molluscoids dominant.
.3. Limestone, molluscan, or with mixed molluscan and molluscoid fauna.
.2. Shale, typically with molluscan fauna.
.1. *c*. Coal
.1. *b*. Underclay
.1. *a*. Shale, may contain land plant fossils.
.0. Sandstone." (Moore, 1936, pp.24-25)

The "ideal cyclothem" is based upon cycles within the upper Virgilian Wabaunsee Group in Kansas. From his studies of the lower Virgilian Shawnee Group in Kansas, Moore (1936, p.29) established the term "megacyclothem" by stating:

> "The repeated succession of cyclothems of differing character indicates a rhythm of larger order than that shown in the individual cycles and suggests the desirability of a term to designate a combination of related cyclothems. The word "megacyclothem" will be used in this sense to define a cycle of cyclothems."

Part of the purpose of the "Shawnee Megacyclothem" was to force the far more complex Shawnee cyclothems into the model for the simpler Wabaunsee Group cyclothems. This resulted in two drastic interpretations for the Shawnee megacyclothem. In the first alternative, Moore (1936) placed all four limestones with a single marine event. Without offering any explanations why, Moore (1936) believed that the fusulinid-bearing limestone was the most offshore of the four. However, it is possible that Elias (1937) who placed fusulinids as the deepest marine indicators in Permian cyclothems influenced Moore (1936). Above the four marine limestones, Moore (1936) noted a separate limestone in the upper part of the cycle, often referred to as the 'fifth' limestone.

The second interpretation gave rise to the concept of the megacyclothem. Each limestone is the marine culmination of a separate cycle. However, overall each of these cycles is genetically related in a much larger cycle or megacyclothem. Moore (1936) reinterpreted each shale-limestone package as Wabaunsee type cyclothems. Each Wabaunsee type cycle was in effect an "oscillation" in an overall cycle:

> "Careful analysis of this succession of units leads to the conclusion that we are dealing here not with a single unbroken rhythm in types of sedimentation, marked by the uniform direction of changes in what might be termed respectively transgressive and regressive hemicycles, but there is indication rather of oscillations that are superimposed on a large cyclic movement." (Moore, 1936, pp.31-32).

However, the one major flaw of the megacyclothem is that each individual cyclothem lacks many of the marine and terrestrial components of a cyclothem. Most of the limestone-shale packages contain only limestones and/or sandy or silty shales. Black fissile shales and coals only appear either one or twice in the entire megacyclothem.

Moore (1936), for his megacyclothems, also provided an interpretation of the black shales. Moore (1936, p.31) assigned the single black fissile shale within a typical Shawnee megacyclothem the Dewey number 0.1, described as "shale, may contain land plant fossils". This, however, reversed Moore's earlier interpretation of black shales as marine. Moore (1936, p.25) also stated, "The succeeding shale and coal (.1) are clearly continental in origin and indicate deposits made on an extremely low, flat coastal plain" and that the black shale contained "...brackish water molluscan fauna, locally insects, abundant macerated plant fragments." (Moore, 1936, p.31). Heckel (1984, p.540) concluded, "This essentially equated the black shale to the coal environment...". Furthermore, most of the shales listed as regressive were either sandy or silty. However, coals were identified, at most, only twice in the lower part of the megacyclothem, and only one black shale was present. Moore (1936) never provided an adequate explanation why nearshore conditions produced coals and black shales in some intervals but not in most of the others.

Later Concepts of Cyclothems

Most of the later theories about cyclothems centered on the issue of the black shale. For example, Moore, (1950), believed that the black shale was deposited in a marine swamp with a thick growth of seaweed (Heckel, 1984, p.545). However, Moore (1950) did note that the black shale was the only clastic member that did not thicken towards a source area (Heckel, 1984, p.551). Weller, (1956, 1957), tried to reinstate the diastrophic control model for cyclicity in the Cherokee Group, and believed that the black fissile shales were deposited in a very shallow sea choked by a thick growth of kelp-like algae. The algae prevented circulation of the water and oxygenation of the sea bottom thus producing anoxic conditions, and Weller, (1957), however did begin to mention anoxic conditions at the sea bottom to explain the nonbenthic fossils in the black shales (Heckel, 1984, p.546).

Attitudes towards the black fissile shales began to slowly change; Zangerl and Richardson (1963) recognized the black fissile shales as transgressive. But, they interpreted the black shale as being deposited by a rapid marine invasion of a shoreline bayou, and floating vegetation was once again invoked to explain the lack of circulation and aeration of the water (Heckel, 1984, p.547). In the early 1960s, J.K. Evans and P.E. Schenk independently concluded that the black shale was the most offshore facies in the cyclothem deposited during the maximum depth that the transgression sea achieved (Heckel, 1984, p.548). Payton (1966) argued the black shales in two Missourian cycles were offshore due to their positions between transgressive and regressive limestones (Heckel, 1984, p.548). James, (1970), believed that the Excello Shale in the uppermost Cherokee Group was offshore (Heckel, 1984, p.548).

Ferm, (1970), proposed the hypothesis of 'delta switching' to explain cyclothems. A delta lobe building out onto a shallow carbonate sea creates a coarsening-upward detrital sequence over the limestone. Eventual abandonment of the lobe would allow for the carbonate sea to redeposit limestone over the detrital clastics. Another lobe building out onto the sea repeats the cycle again. The range of environments possible in a delta can produce everything from coals to limestones without major sea level changes (Heckel, 1984, pp. 548-549). Merrill, (1975), used the delta-shifting model and Zangerl and Richardson's floating vegetation to establish the black fissile shales as deposited in shallow stagnant lagoons between the delta lobes and behind sedimentary barriers such as barrier islands (Heckel, 1975, p.549).

Seddon and Sweet (1971) believed that conodonts were pelagic and assigned to different depth zones within the water column of the sea. Heckel and Baesemann (1975) studied the conodont distribution of the cyclothems in the Missourian of eastern Kansas. They noted that both the limestone underlying and the limestone overlying the black fissile shale had similar conodont fauna that lived in relatively shallow zones. Furthermore, they also noted the black fissile shale contained two conodont genera that lived in the deepest depth zone (*Idioprioniodus* and *Gondolella*). From all of this information, Heckel and Baesemann (1975) were able to determine that perhaps the limestone below the black fissile shale is part of a transgression, the black fissile is the highstand, and the overlying limestone part of a regression.

Heckel

Heckel (1977) proposed a more integrated model for the cyclothems of the Midcontinent. His model included four components: the outside shale, middle (transgressive) limestone, core shale, and upper (regressive) limestone. The outside shale consists of sandy or silty shales, sandstones, paleosols, coals, and other nearshore deposits. The middle limestone is the limestone underlying the core shale. The core shale consists of two facies: the black fissile shale with phosphate nodules, and the gray shale with phosphate nodules. Finally, the upper limestone is the limestone that overlies the core shale. Based upon Heckel and Baesemann's (1975) conodont studies, Heckel (1977) determined that the core shale as the most offshore component of the cyclothem.

Heckel (1977) proposed that the black fissile shale was deposited in water depths up to 200 meters covering the Midcontinent. The depth of the water was great enough for a thermocline (or temperature differentiation between surface and bottom waters) to be established. Winds pushed the warmer waters out of the Midcontinent area, and cooler waters from below rose up to replace them. These cooler waters brought up with them phosphate, and with the increased phosphate in the surface waters, algae and other organisms exploded in population and depleted the available oxygen. The resulting mass death deposited huge amounts of organic debris in the now oxygen poor waters. The organic debris and the anoxic conditions allowed for the deposition of black fissile shales.

Heckel (1977) no longer defined the limestone-shale couplets as cyclothems, and this, in effect, dismantled Moore's (1936) definition of megacyclothems. Heckel (1977) applied the term megacyclothem for the more complex sequences of cycles in Kansas and Illinois. Heckel (1977) also recognized the existence of two types of black fissile shales:

the offshore black shales described above, and the more nearshore black shales possibly deposited in lagoons. However, Heckel (1977) extended his model of deep-water black fissile shales to Illinois where such shales often overlie coals.

IV.

CURRENT FIELD STUDIES

Introduction to Field Studies

A detailed study of 36 measured localities and core sections culminated in a more detailed division of the Cherokee Group into cycles. In order to sample as much of the Cherokee Group as available, all 36 localities or core sections are within either eastern Oklahoma or southeastern Kansas where the Cherokee Group is the thickest, and exposures in the rest of Kansas, Missouri, and Iowa were not taken into consideration in this study due to differences in stratigraphic nomenclature and relative thinness of the Cherokee Group. These 36 localities, in total, represent nearly the entire Cherokee Group, and localities that shared the member units of the five formations (Hartshorne, McAlester, Savanna, Boggy, and Senora) were selected for to create overlap and insure maximum stratigraphic coverage.

Cycles were established from a subaerial exposure surface (usually the top of an underclay below a coal) to the top of the next subaerial exposure surface. However, due to the inevitable gaps in the section, close approximations were determined for the boundaries of some of the sequences. Marine intervals normally included limestones, black fissile phosphatic shales, and other marine shales, and some of these intervals are conodont bearing.

Both micro- and macro- fossils from the Cherokee Group in the study area are poorly preserved. For most fossils, identification by genus or species was impossible; only a general designation, such as crinoids, brachiopods, or ostracods, was possible. For some foraminifera and most conodonts, identification down to genus was possible.

Special effort was made towards finding and identifying conodonts and deep-water foraminifera, as these were strong indicators of a marine pulse.

Previous cyclicity studies of the Cherokee Group utilized outcrops present in southeastern Kansas and northeastern Oklahoma (Cherokee Platform or shelf), and because outcrops of the Senora Formation are best developed on the shelf, most of the cycles identified previously are within the Senora Formation. Because fieldwork for this study is oriented more towards the Arkoma Basin (where outcrops in the McAlester and Savanna Formations are more common than on the shelf), it was possible to not only determine marine intervals that were already well established but to also identify previously unknown marine intervals. The addition of these new marine intervals into the Cherokee Group allowed for a division into more cycles than had been done by previous workers whose studies were based on the Cherokee Platform or shelf.

Comparison of Cycle Numbers

Abernathy (1936), Searight and others (1953), Howe (1956), and Branson (1954) completed the most significant previous divisions of the Cherokee Group into cycles. Abernathy's 1936 study was far more detailed than Branson's 1954 field guide was, which simply introduced the cycles. Basing his work on Moore's (1936) study on the cyclicity of Kansas and Nebraska, Abernathy (1936) (Figures 6 and 7) was able to divide the Cherokee Group into 25 cycles. However, many of Abernathy's divisions were based upon the stratigraphic nomenclature of Kansas and Missouri. As a result, many of Abernathy's cycles don't appear to extend southward into Oklahoma, but correlation of many of the coals and limestones from Kansas to Oklahoma makes it possible to fit

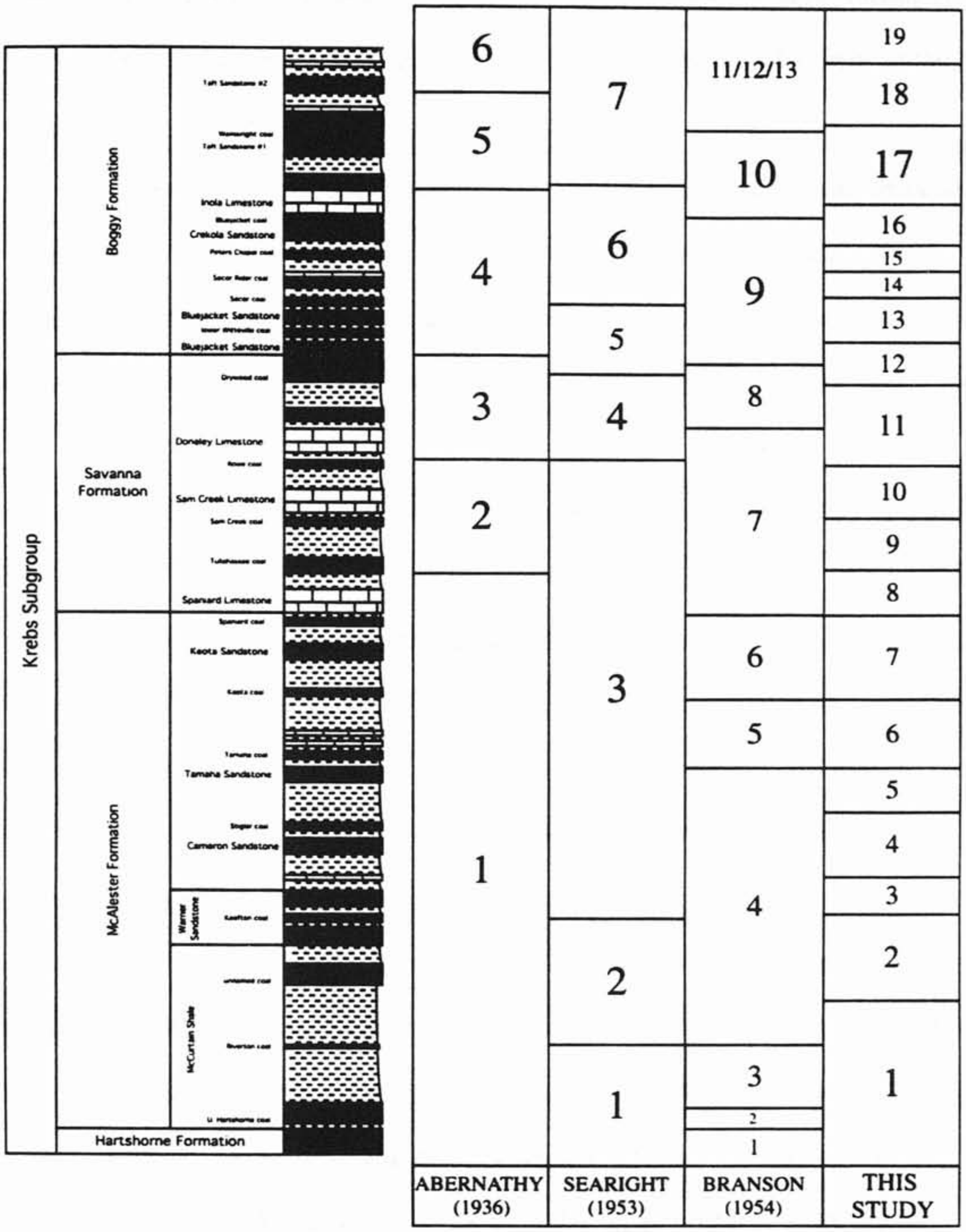

FIGURE 6. Comparison of Cherokee Cycles (Krebs Subgroup), each cycle assigned a number for direct numerical comparison. Two numbers within a box indicates that one of the cycles does not extend into and/or is equivalent to cycles in Oklahoma. (boundaries not exact but best possible fit)

Oklahoma stratigraphy to Abernathy (1936). A more detailed discussion of Abernathy (1936) can be found in Appendix A under the "Previous Studies in the Cyclicity of the Cherokee Group" section.

Searight and others (1953) (Figures 6 and 7) in a conference at Nevada, Missouri to resolve stratigraphic problems of the Cherokee Group recognized 18 cycles. They classified each of these cycles as a formation but did not provide any detailed description of them. Later, Howe (1956) expanded upon Searight and other's work provided lithostratigraphic and biostratigraphic descriptions of each cycle or formation. Appendix A contains a more detailed discussion on Searight and others (1953) and Howe (1956).

Branson (1954) (Figures 6 and 7) utilized Oklahoma stratigraphy in dividing the Cherokee Group into "cyclothems". He recognized 25 coal cycles or cyclothems within the Cherokee Group. However, unlike Abernathy (1936) or Howe (1956), Branson (1954) did not provide a detailed lithologic or biostratigraphic description of each cycle. He simply dedicated a few lines for each cyclothem to list the components. In terms of number and distribution of cycles, Branson (1954) most closely matches the cycles determined within this study. A more detailed discussion can be found in Appendix A.

The "Previous Studies in the Cyclicity of the Cherokee Group" section of Appendix A provides a detailed comparison between the cycles of Abernathy (1936), Searight and others (1953), and Branson (1954). Other analysis of their work can be found as well in this section. Finally, it should be noted that Abernathy's (1936), Searight and other's (1953), and Branson's (1954) cyclicity studies were all based upon outcrops found upon the Cherokee Platform of shelf.

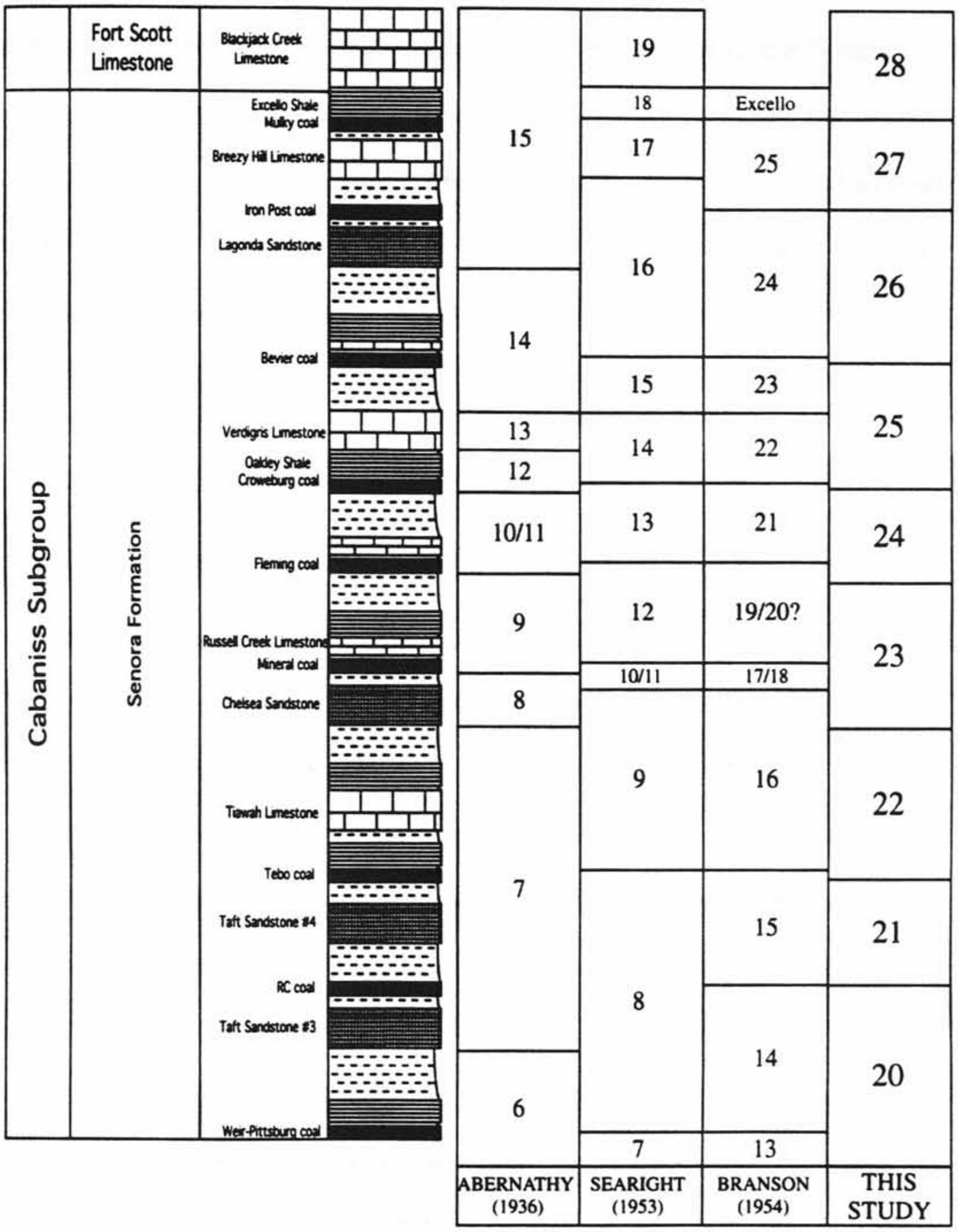

FIGURE 7. Comparison of Cherokee Cycles (Cabaniss Subgroup), each cycle assigned a number for direct numerical comparison. Two numbers within a box indicates that one of the cycles does not extend into and/or is equivalent to cycles in Oklahoma. (boundaries not exact but best fit possible)

From observing Cherokee outcrops closer to the Arkoma Basin, and due to the identification of new marine intervals within the McAlester, Savanna, and Boggy Formations, it is possible to divide the Cherokee Group into slightly more cycles than before (Figures 6, 7, 8, and 9). In this study, the Cherokee Group has been divided into 28 separate coal cycles or cyclothems. Most of the new cycles have been determined in the McAlester and Savanna Formations that had previously been incorporated into one or two very large cycles. In contrast, the Senora Formation has the least amount of new cycles compared to previous works.

The breakdown of new cycles is as follows...

HARTSHORNE FORMATION (Figures 6 and 8)

Branson (1954, p.6) is the only author to recognize any cycles within the Hartshorne Formation. He only recognized two cycles, but the upper coal cycle, the Riverton, would actually belong within the McAlester Formation. Because no marine units had been identified within the Hartshorne Formation, no new cycles have been determined in this study although the upper part of the Hartshorne Formation forms the lower part of the basal Cherokee cycle.

McALESTER FORMATION (Figures 6 and 8)

Abernathy (1936) only recognized one cycle within what is in Oklahoma the McAlester Formation. Another cyclothem involving the Neutral coal may also lie within the McAlester Formation. Searight and others (1953) recognized two cycles within the

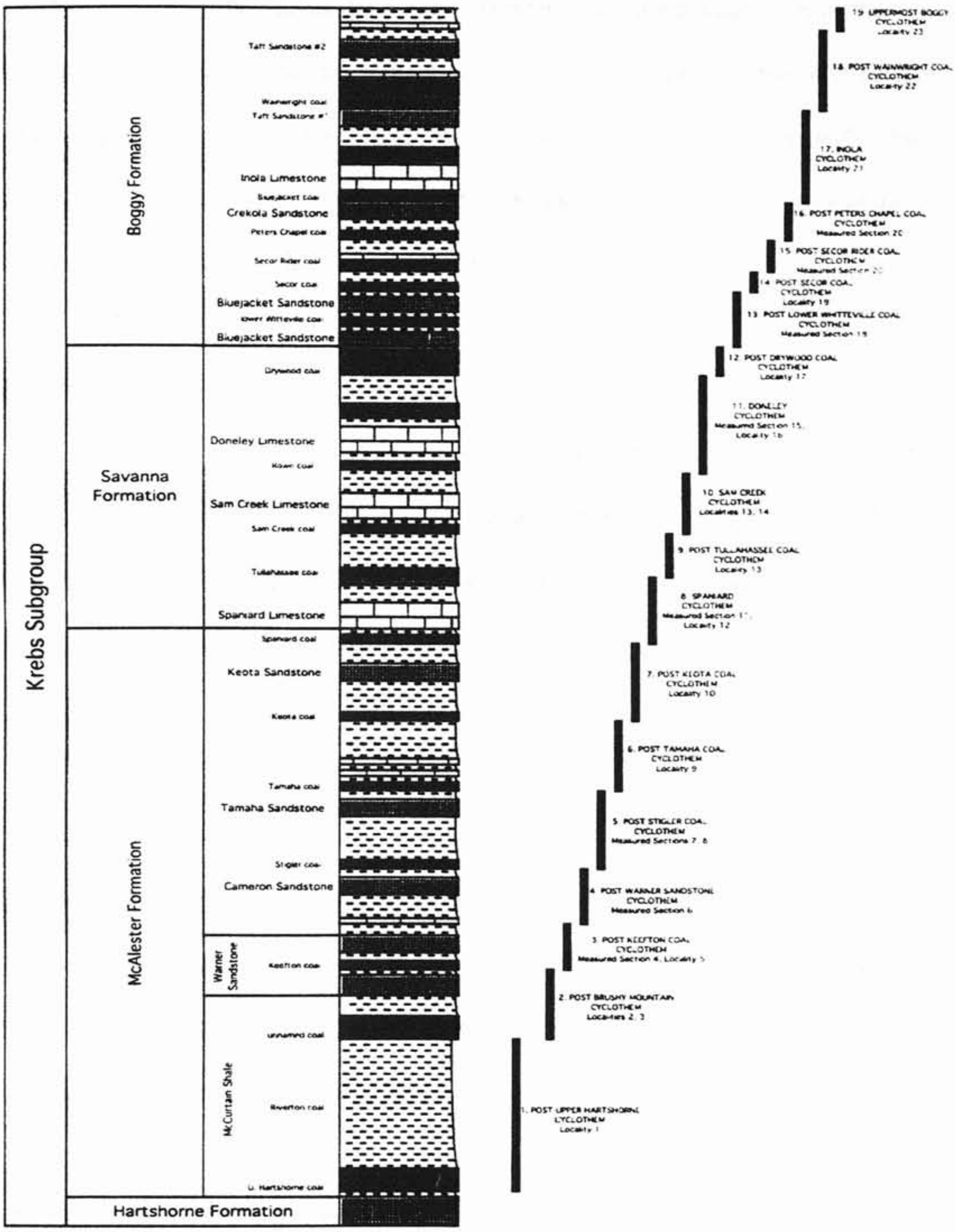

FIGURE 8. Newly Recognized T-R Cycles in the Krebs Subgroup (Cherokee Group)

interval occupied by the McAlester as well. However, the upper coal cycle of the McAlester Formation extends up to the lower part of the Savanna Formation (Searight and others, 1953, p. 2748). Branson (1954, p.6) identified four coal cycles within the McAlester Formation. For this study (2002), seven separate coal cycles or cyclothems have been identified in the McAlester Formation.

SAVANNA FORMATION (Figures 6 and 8)

Before this study, only two coal cycles or cyclothems had been identified within the Savanna Formation or its equivalent. Both of these cycles include either the Rowe and Drywood coals or their equivalents. In this study (2002), the number of coal cycles within the Savanna Formation is five.

BOGGY FORMATION (Figures 6 and 8)

Both Abernathy (1936) and Searight and others (1953) only recognized two coal cycles in the Boggy equivalent in Kansas and Missouri, the Bluejacket and an Inola equivalent. Branson (1954) more than doubled that number in dividing the Boggy Formation into five coal cycles or cyclothems. In this study (2002), the number of cyclothems within the Boggy Formation is seven.

SENORA FORMATION (Figures 7 and 9)

By far, the largest number of coal cycles or cyclothems lie within the Senora Formation or its equivalent elsewhere. Previously, ten to twelve coal cycles were

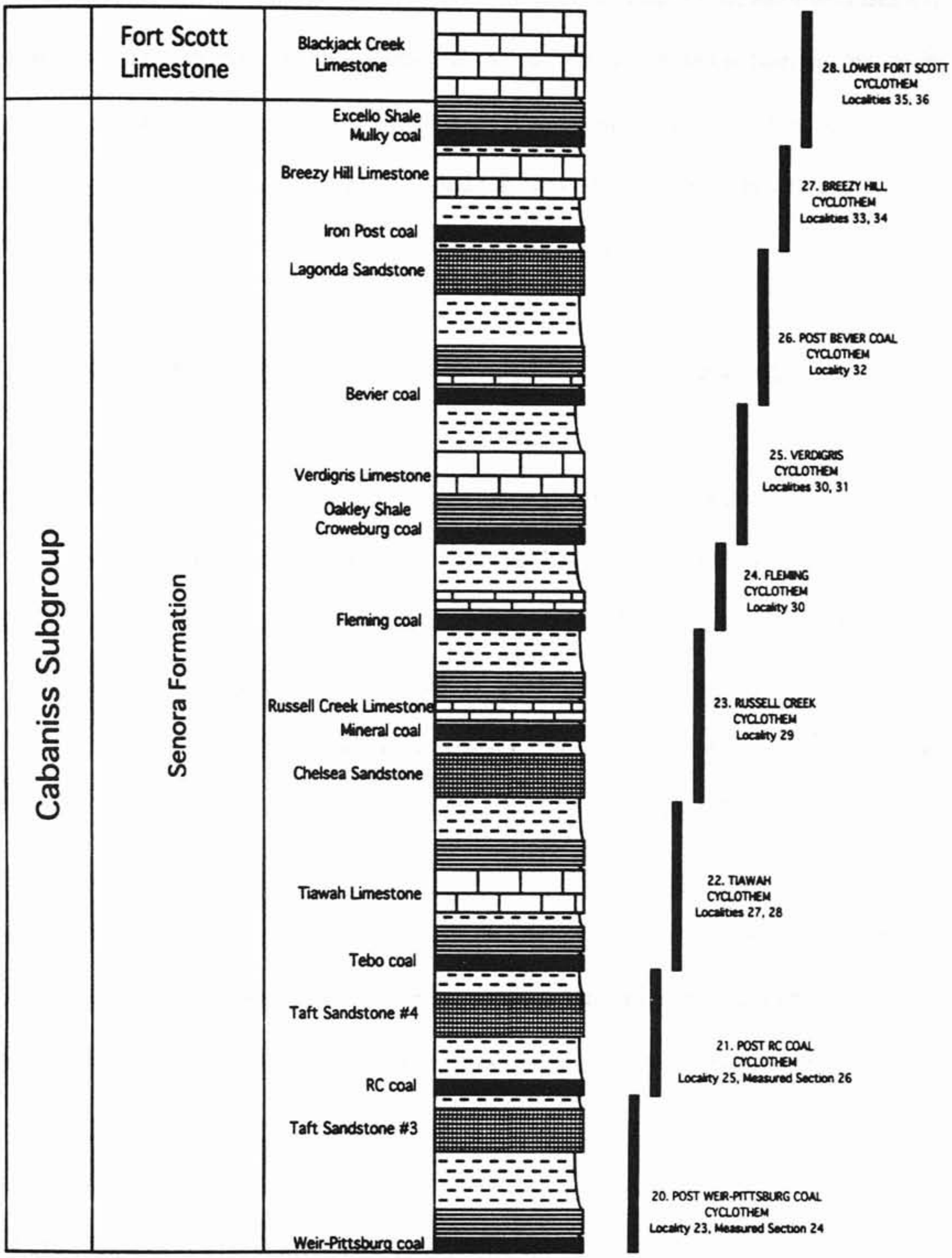

FIGURE 9. Newly Recognized T-R Cycles in the Cabaniss Subgroup (Cherokee Group)

recognized in the Senora Formation. However, three coals, Scammon, Robinson Branch, and Mulky, do not extend southward into Oklahoma. Therefore, ten to twelve coal cycles may exist in Kansas or Missouri, but in Oklahoma, only nine coal cycles can be identified. And, recent field studies and stratigraphic work reconfirm the presence of only nine coal cycles in the Senora Formation of Oklahoma.

Recognition of T-R units (Cyclothems) within the Cherokee Group

Over the following pages, a brief description of each of the 28 cyclothems identified by the author will be provided. A general description of the lithofacies and fauna found at each cyclothem in its type locality or best exposure will be discussed. If possible, a regional extent and lateral change in lithology will also be discussed per cyclothem. In addition, each cyclothem will be classified as to whether it represents a minor, intermediate, or major marine transgression. The localities and measured sections referred to in this section can be found in Appendix B. Furthermore, because each cyclothem will be described based upon the measured section of its type locality or best exposure, the unit numbers used in the measured section will be incorporated here to facilitate comparison between the descriptions here and the measured sections in Appendix B. As a further aid, the page numbers where the units of the cyclothem are described in the measured section are also provided.

1. POST-UPPER HARTSHORNE CYCLOTHEM (major)

The best exposure for this cyclothem is a road cut northwest of Hensley Mountain in Muskogee County, NW1/4NW1/4NW1/4NW1/4 Sec. 33, T11N, R19E, (Locality #1), and, therefore, Locality #1 would be designated as the type locality for the post upper Hartshorne cyclothem. As a result, descriptions of the post upper Hartshorne cyclothem are based upon the measured section of the exposure at Locality #1, p.291-92. The post upper Hartshorne cyclothem extends from the subaerial exposure at the top of the underclay below the upper Hartshorne coal to the subaerial exposure at the top of the underclay below the Brushy Mountain coal. In its type locality, the post upper Hartshorne cyclothem is 4.85 feet (1.45 meters) thick.

At its type locality, the base of the cyclothem is the upper Hartshorne coal (unit 3), which represents the beginning of transgression. Above the upper Hartshorne coal is a 0.5-foot (0.15-meter) dark yellowish brown grainstone (unit 4) and 3.0-foot (0.9 meters) medium dark gray phosphatic shale (unit 5). Overlying the gray phosphatic shale is a foot thick (0.3 meter) black fissile phosphatic shale (unit 6). Both the gray shale and black fissile shale may fit the gray shale facies and black fissile shale facies of the classical core shale as defined by Heckel (1977). A thin 0.2-foot (0.06-meter) ironstone (unit 7) overlies the black fissile phosphatic shale. Unfortunately, at this locality, no overlying coal or underclay could be found. Lateral extent of this cyclothem or its facies is largely unknown since this cycle is only fully developed at the type locality.

Faunal content within the post upper Hartshorne cyclothem includes ammonoid protoconchs, chonetid brachiopods, gastropods, ostracods, and foraminifera (mainly *Ammodiscus*). The lower gray phosphatic shale (unit 5) contains the conodonts *Idiognathodus* and *Idioprioniodus*. The upper black fissile phosphatic shale (unit 6) has the conodonts *Idiognathodus*, *Idioprioniodus*, and *Neognathodus*.

2. POST BRUSHY MOUNTAIN CYCLOTHEM (major)

The post Brushy cyclothem is known to extend from southeastern Muskogee County to at least northeastern Pittsburg County in Oklahoma. However, the extent of this cyclothem throughout the rest of the Arkoma Basin or onto the shelf is unknown. The post Brushy Mountain cyclothem extends from the subaerial exposure at the top of the underclay below the Brushy Mountain coal to the subaerial exposure at the top of the underclay below the Keefton coal. The cyclothem is the best developed on an exposure on the southeastern slope on Brushy Mountain in Muskogee County, (Locality #2, p.296-97, S1/2SE1/4SW1/4SE1/4 Sec. 28, T14N, R19E), and because of this, Locality #2 is designated here as the type locality for the post Brushy Mountain cyclothem. In this location, the post Brushy Mountain cyclothem is around 155 feet (47 meters) thick.

At the type locality, an unnamed coal (probably the Brushy Mountain coal) (unit 2) comprises the basal part of the cyclothem. However, immediately above the coal, a fifty five-foot (16.5-meter) ferruginous shale (unit 3), a clayey to silty ten foot (three foot) shale (unit 4), and a two foot (0.6-meter) underclay (unit 5) overlie the coal. A six foot (1.8 meter) black fissile phosphatic shale (unit 6) directly overlies the underclay. The black fissile phosphatic shale may represent the point of maximum water depth within the post Brushy Mountain cyclothem. The shale (unit 7) overlying the black fissile phosphatic shale is a forty two-foot (13-meter) clayey to silty gray shale below the Warner Sandstone.

Towards its southernmost exposure in Pittsburg County (Locality #3), the Post Brushy Mountain cyclothem begins to exhibit a stronger siliceous influence, probably due to the close proximity of the source area. Although not found by the author, other workers have described similar coals at both localities, and if they are equivalent, the coal does not change much from north to south. The massive ferruginous shale and the clayey to silty shale do not extend southward to Pittsburg County. A 1.5-foot (0.45-meter) medium dark gray, silty, clayey shale (unit 1) at Locality #3 may have replaced the underclay present at Locality #2.

One of the most important changes that occur within the post Brushy Mountain cyclothem southward from Muskogee to Pittsburg Counties is additional transgressive pulses that are picked up below the black fissile phosphatic shale. These transgressive pulses do not extend northward to Muskogee County, but since Locality #3 may be closer to the shoreline, they would be more readily picked here than out in the open marine environment represented by Locality #2.

At Locality #3 (p.300-01), overlying the silty clayey shale (unit 1) is a 0.75 to 1.3-foot (0.29 to 0.39-meter) dark gray shale containing marine fossils (unit 2). Above this, a thin ironstone (unit 3) overlain by another dark gray shale (unit 4), 0.58 feet (0.17 meters) thick, with ammonoids, were observed. A thin clay shale (unit 5) containing deep-water conodonts may be one of the lower transgressive pulses. A thin grayish black shale (unit 6) and ironstone stringer (unit 7) overlie the clay shale, and another conodont bearing clay shale (unit 8) may have resulted from another small transgressive spike. Another thin ironstone stringer (unit 9) overlies this shale.

At Locality #3 is a five foot (1.5-meter) black fissile shale (unit 10) similar to the black shale at Locality #2. However, this black shale lacks any phosphate nodules or conodonts, but this shale may still be a southern continuation of the black fissile phosphatic shale at Locality #2. There is a possibility that, due to diagenetic changes, conodont fossils may have either been leached out or destroyed (Boardman, personal communication, 2002). The overlying shale (unit 11) is similar to the one in Locality #2, but the shale thins dramatically from 42 feet to 3.5 feet. But, since the entire shale is not present at this locality, there is the possibility that more shale may be present but not exposed; the Warner Sandstone is not exposed at this locality but does cap the hills in the surrounding area.

Abundant fauna has been found in this cyclothem. At the northernmost exposure of the post Brushy Mountain Cyclothem, in Muskogee County, *Ammodiscus* is a primary microfauna. In Pittsburg County, the southernmost exposure of the cyclothem, there is a larger variety and number of microfauna. The transgressive pulses yielded *Ammodiscus*, gastropods, fish debris, pelecypods, brachiopods, and ammonoids. The 0.25-foot (0.075-meter) clay shale (unit 8) yielded *Ammodiscus* and *Endothyra* foraminifera, agglutinated foraminifera, *Glabrocingulum* and *Worthenia* gastropods, *Crurithyris* brachiopods, and *Nuculana* pelecypods. The black fissile phosphatic shale contains brachiopods, gastropods, pelecypods, and *Ammodiscus*. The conodonts *Idiognathodus*, *Neognathodus*, and *Idioprioniodus* are present in the black fissile phosphatic shale (unit 6) at Locality #2 and the two small clay shales (units 5 and 8) at Locality #3..

3. POST KEEFTON COAL CYCLOTHEM (minor)

The post Keefton coal Cyclothem is best developed at Locality #5, SE1/4SE1/4SW1/4SW1/4 Sec. 26, T13N, R18E and extends from the subaerial exposure at the top of the underclay below the Keefton coal to the top of the Warner Sandstone. The upper boundary is placed at the top of the Warner Sandstone because the Warner lies between two marine intervals. The Keefton coal is a poorly exposed coal, and the post Keefton coal cyclothem is poorly developed and sparsely exposed at best. The cyclothem was only found at one outcrop and two cores. At its best-developed surface exposure, Locality #5 (p.307), SE1/4SE1/4SW1/4SW1/4 Sec. 26, T13N, R18E, a 5.8-foot (1.74-meter) underclay-like shale lies between the Keefton coal and Warner Sandstone. In the core section described in Measured Section #6 (p.309-310), an 8-foot (2.4-meter) medium dark gray shale with siderite stringers (unit 2) and 4-foot (1.2-meter) silty shale (unit 3) occupies the interval between the Keefton coal and Warner Sandstone.

However, in the core described in Measured Section #4 (p.304), a significant marine interval was found above the Keefton coal. Since the post Keefton coal cyclothem is best developed in this core, the core section should serve as a basis for description. The Keefton coal (unit 2) marks the beginning of transgression. Above the coal are 0.2 feet (0.06 meters) of black carbonaceous shale (unit 3) and 19.2 feet (5.8 meters) of sandstone interbedded with silty shale (unit 4).

Three fossiliferous shales overlie the sandstone. The lowermost shale is 0.1 feet (0.03 meters) thick, massive, and micaceous with calcareous fossil hash (unit 5). The middle shale is 20.7 feet (6.21 meters) thick, medium dark gray, fissile with siderite concretions (unit 6). The uppermost fossiliferous shale is 9.7 feet (2.9 meters) thick, fissile with siderite concretions and numerous fossil debris (unit 7). The core, from which the interval described in Measured Section #4 was derived, came from the NE1/4NE1/4NW1/4NW1/4SW1/4 Sec. 7, T11N, R20E, Muskogee County.

The faunal content of the post Keefton coal cyclothem consists mainly of brachiopods and crinoids. All three fossiliferous shales described in Measure Section #4, to date, are barren of microfossils. Interestingly, a large 0.2-foot (0.06-meter) crinoid stem was observed on a shale face in the uppermost fossiliferous shale.

4. POST WARNER SANDSTONE CYCLOTHEM (intermediate)

The post Warner Sandstone cyclothem extends from the top of the Warner Sandstone to the top of the subaerial exposure at the top of the underclay below the Stigler coal. Outcrops of this cyclothem have not been found in the surface, and only one core section contains any kind of marine interval above the Warner Sandstone. Descriptions of this cyclothems and unit designations of member beds are based upon a measured section of this core interval, designated as Measured Section #6 (p.309). In the core, drilled in the SW1/4SE1/4SW1/4SW1/4 Sec. 16, T12N, R19E, a 0.9-foot (0.27-meter) fossiliferous limestone (unit 6) lie 0.5 feet (0.15 meters) above the top of the Warner Sandstone (unit 4). Overlying the Warner Sandstone but underlying the limestone is a 0.5-foot (0.15-meter) medium dark gray calcareous fissile shale (unit 5); the basal 0.05 feet (0.015 meters) of this shale is very silty. The limestone (unit 6) is 0.9-feet (0.27-meters), grading from packestone to mudstone, and fossiliferous. Overlying the limestone is a 0.5-foot (0.15-meter) dark gray to grayish black fissile shale (unit 7). Stratigraphically, the Cameron Sandstone and the underclay below the Stigler coal lie within the upper part of the post Warner Sandstone cyclothem. Fauna from the limestone includes brachiopod shells, and microfauna from the limestone include gastropod fragments and ostracods.

5. POST STIGLER COAL CYCLOTHEM (intermediate)

The post Stigler coal cyclothem is believed to be present only in cores as all surface exposures found during the field study have probably either been destroyed or very poorly developed. Although the post Stigler coal cyclothem is present at Locality #9, no marine intervals were found above the Stigler coal. Regionally, the post Stigler coal cyclothem extends from Muskogee County northward to Mayes County (the location of one core). The post Stigler coal cyclothem extends from the subaerial exposure at the top of the underclay below the Stigler coal to the subaerial exposure at the top of the underclay below the Tamaha coal.

In the core taken from Muskogee County (NW1/4NE1/4SE1/4SW1/4NE1/4 Sec. 22, T10N, R19E), designated as Measured Section #7 (p.312), the Stigler coal (unit 1) marks the beginning of transgression, and an underclay (unit 2) and the Stigler Rider coal (unit 3) overlies the Stigler. Overlying the Stigler Rider coal is a thin 0.2-foot (0.06-meter) carbonaceous silty shale (unit 4) and a 0.5-foot (0.15-meter) dark gray, fissile, calcareous shale with intense fossil hash (unit 5). Overlying the calcareous shale is a 0.8-foot (0.24-meter) dark gray shale with siderite concretions (unit 6). Northward in Mayes County, Measured Section #8 (p.314), both the Stigler Rider coal and underclay disappear, and a fossiliferous limestone directly overlies the Stigler coal. Reports of other surface exposures of the Stigler coal throughout Muskogee County also suggest a marine limestone directly above the Stigler coal, but the author has been able to locate none of these. At Locality #9 (p.318), the post Stigler coal cyclothem includes the Tamaha Sandstone, one foot (0.3 meters) of silty, clayey shale, and the underclay below the Tamaha coal. Fauna includes ostracods, brachiopods, pelecypods, and bryozoans from the shales above the Stigler Rider coal, and brachiopods, bryozoans, crinoids, and ostracods from the limestone overlying the Stigler coal.

6. POST TAMAHA COAL CYCLOTHEM (intermediate)

Believed to be present at only one locality, Locality #9 (p.317-18), in the E1/2E1/2NE1/4SE1/4 Sec. 13, T13N, R18E, Muskogee County, the post Tamaha coal cyclothem extends from the subaerial exposure surface at the top of the underclay below the Tamaha coal to the subaerial exposure surface at the top of the underclay below the Keota coal. Since the post Tamaha coal cyclothem is found at only Locality # 9, that locality is designated as the type locality for the cyclothem. At the type locality, the post Tamaha coal cyclothem is 3.4 feet (1.1 meter) thick. Because it was found at only one locality, the lateral extent of this cyclothem is unknown.

At the type locality, the Tamaha coal (unit 4) is 0.1-feet (0.03-meters) thick and marks the beginning of transgression. Overlying the coal is a 0.6-foot (0.18-meter) calcareous shale (unit 5) and a 0.33-foot (0.1-meter) unnamed limestone (unit 6). Overlying the limestone designated as unit 6 is at a dark gray, fissile, silty, calcareous, conodont-bearing shale (unit 7); this shale is 0.7-feet (0.21-meters) thick. The uppermost beds of this cyclothem at the locality are an unnamed ferruginous limestone (unit 8) and a 1.5-foot (0.45-meter) silty, blocky shale (unit 9).

For such a small and siliceous influenced cyclothem, the post Tamaha coal cyclothem has an amazing abundance and variety of both macrofauna and microfauna. In the lower calcareous shale, productid brachiopods, fenestrate and ramose bryozoans, and echinoid spines comprise the majority of the macrofossils, and the ostracode *Bairdia* dominates the microfossils. The first unnamed limestone contains mainly productid brachiopods and crinoids. The dark gray, fissile, silty, calcareous shale yielded crinoid columnals, cups, and arm fragments, the brachiopod *Mesolobus*, echinoid spines, the foraminifera *Endothyra*, *Bairdia*, bryozoans, and *Idiognathodus*. The ferruginous unnamed limestone had poorly preserved brachiopods, gastropods, fenestrate bryozoans, and crinoids.

7. **POST KEOTA COAL CYCLOTHEM** (minor)

The post Keota coal cyclothem extends from the subaerial exposure at the top of the underclay below the Keota coal to the subaerial exposure at the top of the underclay below the Spaniard coal. This cyclothem is very poorly developed and probably exposed at only one locality, Locality #10 (p.321), in the NW1/4NW1/4NW1/4NW1/4 Sec. 16, T13N, R19E. Furthermore, the Keota coal was not found at this locality by the author, but Hemish (1998, p.53) did find the Keota coal here. Therefore, it is reasonably safe to assume that the Keota coal is present but just heavily covered. If so, then the entire post Keota coal cyclothem is present except for the underclay below the Spaniard coal. Therefore, this locality should be considered the type locality for the post Keota coal cyclothem.

The Keota coal marks the beginning of transgression, and overlying the coal is a light brownish gray blocky shale (unit 1), only 1.7 feet (0.51 meters) of which is exposed. The next overlying bed is either a fossiliferous ironstone or most likely a ferruginous limestone (unit 2), 0.3 feet (0.1 meters) thick. Overlying the ironstone or limestone is an alternating series of sandstones and silty shales (units 3-7). The Keota Sandstone (unit 8) is the highest sandstone exposed at Locality #10. In this location, the post Keota coal cyclothem is 16.1 feet (4.8 meters) thick. Since this cyclothem is exposed at only one location, the lateral extent of this sequence is unknown.

The faunal content of this cyclothem consists of macrofossils from the ironstone or ferruginous limestone. This bed produced the brachiopods *Spirifer*, *Neospirifer*, and *Composita*, chonetid, strophomenid, and orthid brachiopods, fenestrate bryozoans, and crinoid columnals. Most of the fossils found in this ironstone or limestone are very poorly preserved and mostly unidentifiable.

8. SPANIARD CYCLOTHEM (intermediate)

Although the Spaniard Limestone is widespread over Muskogee, Wagoner, and Rogers Counties and the cyclothem is likely to be as widespread as well, the Spaniard cyclothem is well developed at only one locality and one core section found to date. However, the locality (SE1/4SE1/4SW1/4SE1/4 Sec. 2, T13N, R18E, Locality #12) has since been destroyed in the widening of US 64 in central Muskogee County, but other Spaniard Limestone localities are sparse and do not seem to exhibit the cyclicity very well. Because the Spaniard cyclothem is so well developed at Locality #12, its description is based upon that locality, but since Locality #12 has been destroyed, it will not be a type locality. The Spaniard cyclothem extends from the subaerial exposure at the top of the underclay below the Spaniard coal to the subaerial exposure at the top of the underclay below the Tullahassee coal.

At Locality #12 (p.326-27), the Spaniard coal (unit 1) marks the beginning of transgression. Overlying the Spaniard coal is a 1.3-foot (0.39-meter) calcareous, silty, clay shale (unit 2). Overlying the clay shale is the Spaniard Limestone (units 3-5), but there are actually two beds of Spaniard Limestone separated by 0.17 feet (0.05 meters) of light bluish clay (unit 4). The lower Spaniard Limestone (unit 3) is 0.083 feet (0.02 meters) thick and conodont bearing. The upper Spaniard Limestone (unit 5) is 2 feet (0.6 meters) thick and conodont bearing. Overlying the Spaniard Limestone is 0.5 feet (0.6 meters) of siltstone (unit 6) overlain by 2.5 feet (0.75 meters) of a soil-like shale (unit 7). The underclay below the Tullahassee coal is not present at Locality #12, but at the type locality of the overlying post Tullahassee cyclothem, Hemish (1990) found the Spaniard Limestone in contact with the underclay.

In the core section (Measured Section #11, p.323) from the SE1/4SE1/4SW1/4NW1/4 Sec. 18, T21N, R18E, Rogers County, 24.1 feet (7.2 meters) of medium dark gray, silty, fissile shale (unit 2) overlies the Spaniard coal (unit 1), and this is overlain by 1.7 feet (0.51 meters) of underclay (unit 3). There is only one bed of Spaniard Limestone (unit 4) present in this interval, and the limestone thins down from over 2.5 feet to only 1 foot. Overlying the Spaniard Limestone is a 4.8-foot (1.4-meter) gray, fissile, silty shale (unit 5) with a 0.05-foot (0.0165-meter) band of marine fossils 0.3 feet (0.99 meters) above lower contact.

At Locality #12, the calcareous, silty, clay shale (unit 2) contains fauna typical of a shallow marine facies, echinoid spines, *Endothyra* and calcareous foraminifera, crinoids, and ramose bryozoans. The Spaniard Limestone yielded calcareous and encrusting foraminifera, crinoid columnals, and brachiopods. The light bluish gray clay between the two Spaniard Limestones produced ostracods, encrusting foraminifera, ramose bryozoans, spiriferid brachiopods, echinoid spines, and holothurian sclerites. The core section described in Measured Section #11 only produced significant fauna from the Spaniard Limestone. Brachiopod spines and ostracods were the only fossils found. However, the overlying shale had a band of whitish calcareous brachiopod shells 0.3 feet (0.09 meters) above lower contact. The conodont *Idiognathodus* is present in both the upper and lower Spaniard Limestones at Locality #12.

9. POST TULLAHASSEE COAL CYCLOTHEM (minor)

The post Tullahassee coal cyclothem extends from the subaerial exposure at the top of the underclay below the Tullahassee coal to the subaerial exposure at the top of the underclay below the Sam Creek coal or its equivalent units. At its type locality (Locality #13) in the NE1/4NE1/4NE1/4 Sec. 1, T15N, R17E and SW1/4SE1/4SE1/4SE1/4 Sec. 36, T16N, R17E, Wagoner County, Oklahoma, neither the Sam Creek coal nor its underclay is present. However, there is a distinct facies change from nonfossiliferous shales to fossiliferous shales that can serve as a sequence boundary.

At Locality #13 (p.332-33), the Tullahassee coal (unit 2) marks the beginning of transgression; overlying the Tullahassee coal is a dark gray, 6.9-foot (2.1-meter) silty, fissile shale (unit 3) with marine fossils. Overlying unit 3 is a foot thick (0.3-meter) dark gray and olive gray, fissile, soft, silty, degraded, fossiliferous shale (unit 4). The overlying clay shale (unit 5) yielded sparse marine fossils and carbonaceous plant debris. A series of ferruginous silty shales (units 6-10) compose the upper part of the cyclothem, and the uppermost 0.25 feet (0.075 meter) of shale (unit 10) is not as ferruginous as the shales below it. Overlying the ferruginous shale, a fossiliferous clay shale may mark the beginning of another transgression. The boundary between the slightly ferruginous shale (designated as unit 10 in the measured section of Locality #13) and the fossiliferous clay shale (unit 11) is the boundary between the post Tullahassee coal cyclothem and the overlying Sam Creek cyclothem. At this location, the post Tullahassee coal cyclothem is approximately 37 feet (12 meters) thick; lateral extent is unknown since this cyclothem is present at only one locality.

Fossils are very poorly preserved and sparse. Probably the most recognizable fossil is the brachiopod *Lingula* from a silty shale overlying the Tullahassee coal. Other fossils include unidentifiable gastropods and brachiopods.

10. SAM CREEK CYCLOTHEM (intermediate)

The Sam Creek cyclothem extends from the subaerial exposure at the top of the underclay below the Sam Creek coal to the subaerial exposure at the top of the underclay below the Rowe coal. Although outcrops of the Sam Creek Limestone are common, the Sam Creek cyclothem shares the same type locality (Locality #13, p.330-31) as the post Tullahassee coal cyclothem because the unique characteristics of this cycle are best demonstrated here. Descriptions of the Sam Creek cyclothem are based upon exposures at the type locality.

Where present, the Sam Creek coal marks transgression. At the type locality where the Sam Creek coal and its underclay are absent, the beginning of transgression lies at the lower contact of an 8.0-foot (2.4-meter) dark gray, blocky, fossiliferous clay shale (unit 11), and a 0.04-foot (0.012-meter) ferruginous limestone (unit 12) overlies it. The Sam Creek Limestone (units 13-15) may possibly be a transgressive limestone. There are actually two beds of the Sam Creek Limestone: a lower bed and an upper bed.

Both limestones contain conodonts, and the lower Sam Creek Limestone (unit 13) yielded several hundred elements of conodonts for every five hundred grams of sample. The lower Sam Creek Limestone is 0.7 feet (0.21 meters) thick, massive, silty, and ferruginous. A 0.5-foot (0.15-meter) clay shale (unit 14) above the lower Sam Creek Limestone may possibly indicate a minor regression between the two limestones. The upper Sam Creek limestone (unit 15) is 0.6 feet (0.18 meters) thick, silty, and impure. The next bed is a thin siltstone (unit 16) overlying the upper Sam Creek Limestone. A 7.0-foot (2.1-meter) black fissile carbonaceous shale (unit 17) overlies the siltstone; this may be a regressive shale due to the lack of phosphate nodules and conodonts or any other marine fossils and the presence of plant stem fragments at the upper contact.

At this locality, Hemish (1990a) had noted the presence of both the Rowe coal and Doneley Limestone above the Sam Creek Limestone; an intensive search over the hill slopes yielded no such beds. It is, however, reasonable to assume that both the Rowe and Doneley are present at this locality, and if so, this indicates the presence of the Doneley cyclothem at Locality #13. The hill is heavily forested and, not surprisingly, heavily covered with talus and soil. However, a massive 17.0-foot (5.1-meter) shale (unit 18) was observed directly above the black fissile shale. Talus and debris covers most of this shale, but the upper four feet (1.2 meters) is exposed. What is exposed of this shale is a silty, ferruginous, olive gray clay shale that could possibly be equivalent to an underclay. Tentatively, the boundary between the Sam Creek cyclothem and Doneley cyclothem at Locality #13 might be the top of this clay shale. At Locality #13, the Sam Creek cyclothem is approximately 34 feet (11 meters) thick.

Other outcrops of the Sam Creek Limestone lack the cyclicity present at the type locality of the Sam Creek cyclothem. In Muskogee County, in the NW1/4NW1/4SW1/4NW1/4 Sec. 26, T14N, R18E, Locality #14 (p.339), the Sam Creek Limestone (unit 1) also yields conodonts but underlies a 3.0-foot (0.9-meter) brown, silty, fissile shale (unit 2) and a 4.0-foot (1.2-meter) underclay (unit 3) below the Rowe coal. Other Sam Creek Limestones in Muskogee County also underlie silty shales of similar thickness. In consideration, the black fissile shale overlying the Sam Creek Limestone in Wagoner County may just be a localized facies that does not extend southward into Muskogee County.

At Locality #13, the basal clay shale (unit 11) only had a few sparse spiriferid brachiopods and poorly preserved ostracods. The 0.04-foot (0.012-meter) ferruginous limestone (unit 12) yielded very poorly preserved brachiopods, ostracods, pelecypods, gastropods, and crinoids. The lower Sam Creek Limestone had a larger faunal variety than the underlying beds. Fauna included brachiopods, gastropods, pelecypods, fish debris, ostracods, and the conodont *Idiognathodus*. The upper Sam Creek Limestone is somewhat more sparse in terms of faunal content. Only brachiopods and *Idiognathodus* were observed from the upper Sam Creek Limestone. The overlying siltstone contained reworked, degraded fish teeth. At Locality #14, in Muskogee County, faunal diversity in the Sam Creek Limestone is higher. Productid brachiopods, fish vertebrae and teeth, echinoid plates, calcareous (such as *Tetrataxis*) and encrusting foraminifera, and *Idiognathodus* are abundant in the limestone.

11. DONELEY CYCLOTHEM (major)

The Doneley cyclothem is best developed on the southeastern slope of Hensley Mountain, SW1/4SE1/4NE1/4 and NW1/4NE1/4SE1/4 Sec. 4, T10N, R19E, Muskogee County, and this locality carries the designation of Locality #16 and is the type locality for the Doneley cyclothem. The Doneley cyclothem extends from the subaerial exposure at the top of the underclay below the Rowe coal to the subaerial exposure at the top of the underclay below the Drywood coal. This particular cyclothem is widespread, at least, throughout Muskogee County and possibly southern Wagoner County to as far north as Mayes County in the subsurface. However, while the Rowe coal is continuous, the Doneley Limestone is sporadic and has few exposures, and even at the type locality of the Doneley cyclothem, the Doneley Limestone was not observed directly above the Rowe.

The Rowe coal marks the beginning of transgression. At the type locality (Locality #16, p.345-46), the Doneley Limestone (unit 6), a 0.7-foot (0.21-meter), ferruginous limestone, lies above the Rowe coal; although not found directly above the Rowe coal, the Doneley Limestone was found at a nearby slope exposure in the position above the Rowe coal. Overlying the Doneley Limestone is a 20.0-foot (6.0-meter) black fissile phosphatic shale (unit 7). However, phosphate nodules are only found within the lower ten feet (3 meters) of the shale and deep-water conodonts in the uppermost two feet (0.6 meters). A thin ironstone (unit 8) overlies the black fissile phosphatic shale. Overlying the ironstone, a 5.75-foot (1.7-meter) dark gray fissile shale (unit 9) contains a few marine foraminifera. Another thin ironstone (unit 10), a 6.2-foot (1.9-meter) dark gray fissile shale (unit 11), and a massive 165-foot (49.5-meter) silty brown shale (unit 12) comprise the upper part of the Doneley cyclothem at the type locality. The Drywood coal and its underclay are not present at the type locality so the upper boundary of the cyclothem cannot be determined; however, the Bluejacket Sandstone is present forming the bluffs at the top of Hensley Mountain. At the type locality, the Doneley cyclothem is over 36 feet (11 meters).

Northward to Locality #14 (p.338-39) in the NW1/4NW1/4SW1/4NW1/4 Sec. 26, T14N, R18E (Locality #14), Muskogee County, the Doneley Limestone is not present above the Rowe coal, but in its place is a 2.0-foot (0.6-meter) carbonaceous, plastic, reddish brown underclay-like shale (unit 5). A 3.0-foot (0.9-meter) black fissile phosphatic shale (unit 6) directly overlies the underclay-like shale. A thin ironstone (unit 7) and 0.25-foot (0.075-meter) black mudrock (unit 8) overlies the lowermost black fissile phosphatic shale. A 1.8-foot (0.54-meter) dark gray clay shale with marine fossils (unit 9) overlies the mudrock. A second black phosphatic shale with conodonts (unit 10) is found above the clay shale. Another thin ironstone (unit 11) overlies the second black fissile shale, and the uppermost shale exposed at Locality #14 is a dark gray to grayish black shale with conodonts (unit 12), 5.0 feet (1.5 meters) thick.

In comparing the two localities, both ironstones are persistent, but more importantly, two conodont bearing intervals are present in central Muskogee County (Locality #14) as opposed to one conodont bearing interval in southern Muskogee County (Locality #16). But, in comparison, the conodont bearing intervals in both localities are located near the upper ironstone stringer. In a core from SE1/4SE1/4SW1/4NW1/4 Sec. 18, T21N, R18E, Mayes County (Measured Section #15, p.341-42), the two ironstone beds may have been replaced with two calcareous stringers, but three shales are also present. Therefore, the two ironstone stringers may grade into calcareous stringers from south to north on the shelf, but quite possibly, the conodont bearing interval associated with the upper stringer may also be laterally persistent on the shelf.

At the type locality (Locality #16), the Doneley Limestone yielded productid brachiopods, calcareous foraminifera, crinoids, fenestrate bryozoans, and pelecypods. The overlying black fissile phosphatic shale has the deep-water foraminifera *Reophax*, and the upper two feet of shale produced a much larger faunal diversity with brachiopods, gastropods, ostracods, pelecypods, nautiloids, the foraminifera *Endothyra* and *Reophax*, and *Idiognathodus*. Both ironstones had impressions of brachiopods and pelecypods on the surface. The highest fossiliferous interval at the type locality is the 5.75-foot (1.7-meter) dark gray fissile shale (unit 9) with the foraminifera *Ammodiscus*. At Locality #14, the second black fissile phosphatic shale (unit 10) produced ostracods, pelecypods, gastropods, *Ammodiscus*, *Reophax*, crinoid stems, *Lingula* brachiopods, and *Idiognathodus* and *Idioprioniodus* conodonts. The uppermost fossiliferous shale (unit 12) had ostracods, foraminifera, gastropods, orthid brachiopods, and *Idiognathodus* and *Idioprioniodus* conodonts.

In the core section from Mayes County, (Measured Section #15), the Doneley Limestone contained brachiopods, bryozoans, crinoid columnals, foraminifera, *Ammodiscus*, and pyritized ostracods. The shale overlying the Doneley Limestone yielded brachiopods, pelecypods, crinoids, ostracods, and fenestrate bryozoans. The lower unnamed limestone stringer had large brachiopods on the surface, and ostracods (*Bairdia*). The upper two shales only produced brachiopods, pelecypods, and crinoids. The upper unnamed limestone stringer has brachiopods, pelecypods, crinoid ossicles, and nautiloids.

12. POST DRYWOOD COAL CYCLOTHEM (major)

The post Drywood cyclothem has been identified at one locality, in the SE1/4SE1/4NE1/4 Sec. 27, T27N, R20E, Craig County, designated as Locality #17, and therefore, that should be the type locality for the cyclothem. The post Drywood coal cyclothem extends from the subaerial exposure at the top of the underclay below the Drywood coal to the lower contact of the lowermost Bluejacket Sandstone. At its type locality, the post Drywood coal cyclothem is 17.4 feet (5.2 meters) thick. Lateral extent of this cyclothem is unknown. Descriptions of the cyclothem are based upon exposures at the type locality (p.349-50).

The Drywood coal (unit 2) marks the start of transgression. Overlying the Drywood is a 0.5-foot (0.15-meter) grayish black to medium dark gray, blocky, silty shale (unit 3). The maximum point of transgression for this cyclothem may be at a 5.5-foot (1.65-meter) black fissile phosphatic shale (unit 4), containing deep-water conodonts. Overlying the black fissile phosphatic shale is a 1.5-foot (0.45-meter) grayish black, blocky, clay shale (unit 5) that contains marine foraminifera. The upper part of the cyclothem consists of two ferruginous clay shales (units 6 and 7) and an overlying 7.5-foot (2.2-meter) soil-like shale (unit 8). The upper contact of the post Drywood coal cyclothem is the unconformity at the base of the lower bed of the Bluejacket Sandstone. At the type locality of the post Drywood coal cyclothem, the Bluejacket Sandstone is probably a channel sandstone that downcut into underlying beds. The basal part of the Bluejacket Sandstone consists of a foot (0.3-meter) thick conglomerate as evidence of this downcutting. Clasts of this conglomerate are pebbles of phosphate nodules, ironstones, shale, shell fragments, and quartz grains; quite possibly, another sequence overlain the post Drywood coal cyclothem at this locality but was eradicated by the incisement of the Bluejacket Sandstone.

The black fissile phosphatic shale yields *Ammodiscus*, ostracods, and the conodonts *Idiognathodus* and *Idioprioniodus*. The only other fossiliferous interval is the overlying clay shale that contains the foraminifera *Ammodiscus*.

13. POST LOWER WITTEVILLE COAL CYCLOTHEM (minor)

The post lower Witteville coal cyclothem extends from the incisement surface at the basal Bluejacket Sandstone to the subaerial exposure at the top of the underclay below the Secor coal. The post lower Witteville coal cyclothem is a poorly developed cyclothem present only in one core section, designated as Measured Section #18, from the SW1/4SE1/4SE1/4NE1/4SE1/4 Sec. 3, T11N, R17E, McIntosh County. The lower Witteville coal lies between the lower and upper beds of the Bluejacket Sandstone, both of which are within the cyclothem. The post lower Witteville cyclothem is approximately 60 feet (20 meters) thick in this core.

In the core section described by Measured Section #18 (p.352-53), the basal unit consists of 10 feet (3.0 meters) of the lower Bluejacket Sandstone (unit 1). Overlying the lower Bluejacket Sandstone, a carbonaceous, silty shale (unit 3) may be equivalent to the underclay below the lower Witteville coal; the lower Witteville coal (unit 4) is 0.6 feet (0.18 meters) thick. Overlying the lower Witteville coal is 45.8 feet (13.7 meters) of sandstone (possibly the upper Bluejacket) interbedded with shale containing carbonaceous plant debris (unit 5). Overlying this sandstone is 0.8 feet (0.24 meters) of soft black shale (unit 6) and 0.67 feet (0.20 meters) of brownish black, silty, hard shale (unit 7). The one probable marine unit is a 0.06 feet (0.018 meters) fossiliferous limestone (unit 8). Overlying the limestone is a thin, silty, brownish black, fossiliferous shale (unit 9).

14. POST SECOR COAL CYCLOTHEM (minor)

The post Secor coal cyclothem extends from the subaerial exposure at the top of the underclay below the Secor coal to the subaerial exposure at the top of the underclay below the Secor Rider coal. The Secor coal is poorly exposed, and the cyclothem is fully developed at one known locality, SE1/4NW1/4NE1/4 Sec. 13, T6N, R23E and SW1/4SW1/4NW1/4 Sec. 18, T6N, R24E, LeFlore County, designated as Locality #19. However, this locality is a highwall in a strip pit that was in the process of being reclaimed, and the locality was measured and described four years ago so has probably been reclaimed by now. Despite this, the descriptions of this cyclothem will still be based upon exposures at Locality #19 (p.356-57).

The Secor coal (unit 1) marks the beginning of transgression. Overlying the Secor coal is 32.0 feet (9.6 meters) of a silty blocky shale with numerous siderite stringers (unit 2), and ten feet above the Secor coal, a thin zone of this shale yields conodonts. The remaining 22 feet (6.6 meters) of this shale is primarily barren of fossils, and overlying the shale is 6.0 feet (1.8 meters) of siltstone (unit 3), and 5.5 feet (1.7 meters) of sandstone (unit 4). Overlying the sandstone, a dark gray, carbonaceous, fissile shale (unit 5) may be equivalent to the underclay below the Secor Rider coal. Therefore, the contact between this shale and the Secor Rider coal is the upper boundary of the post Secor coal cyclothem.

Fossils in the cyclothem are found only in the lower ten feet (3 meters) of the shale overlying the Secor coal. At lower contact with the Secor coal, the shale yields pyritized orthid and strophomenid brachiopods, and ten feet (3 meters) above the Secor coal, the shale has pyritized *Lingula* brachiopods, and sparse, fragmentary *Idiognathodus* conodonts.

15. POST SECOR RIDER CYCLOTHEM (intermediate)

The post Secor Rider cyclothem extends from the subaerial exposure at the top of the underclay below the Secor Rider coal to the subaerial exposure top of the underclay below the Peters Chapel coal. Like the Secor coal, the Secor Rider coal is discontinuous and poorly exposed, and even though the Secor Rider coal is present at Locality #19, silty, carbonaceous, ferruginous shales overlie it. The cyclothem is best developed in a core described in Measured Section #20 (p.361), SE1/4NW1/4SE1/4NE1/4NW1/4 Sec. 7, T13N, R18E, Muskogee County. In this core, the post Secor Rider coal cyclothem is 49 feet (16 meters) thick.

The Secor Rider coal (unit 10) marks the beginning of transgression; water level may have increased to deposit a 0.1-foot (0.03-meter) thick limestone (unit 11). A grayish black, carbonaceous shale (unit 12) overlies the limestone. Overlying the grayish black shale is another thin fossiliferous limestone (unit 13). Overlying the limestone is a 4.3-foot (1.3-meter) black fissile phosphatic shale (unit 14) with deep-water conodonts. Overlying the black fissile phosphatic shale is a 41.5-foot (12.5-meter) silty, grayish-black shale (unit 15) and a 2.1-foot (0.63-meter) grayish black to dark gray, carbonaceous shale (unit 16). Possibly, a rare 0.3-foot (0.10-meter) silty, carbonaceous underlime (unit

17) overlies the carbonaceous shale. The upper contact between the underlime and the Peters Chapel coal is probably the upper boundary of the post Secor Rider cyclothem.

The shale (unit 12) between the two limestones yielded the brachiopod *Lingula*. The upper unnamed limestone had only brachiopod debris. The black fissile phosphatic shale yielded brachiopods, pelecypods, mesogastropods, the archaeogastropod *Platyceras*, the ostracode *Bairdia*, and the conodonts *Idiognathodus* and *Idioprioniodus*.

16. POST PETERS CHAPEL CYCLOTHEM (intermediate)

The post Peters Chapel cyclothem extends from the subaerial exposure at the top of the underclay below the Peters Chapel coal to the subaerial exposure at the top of the underclay below the Bluejacket coal. This cyclothem was only identified in the same core (Measured Section #20, p.360-61) as the post Secor Rider coal cyclothem. The Peters Chapel coal (unit 18) marks the beginning of transgression. A carbonaceous, shaly limestone (unit 19) with pelecypods probably represents a slight deepening of sea level. Overlying the carbonaceous limestone is at a 3.7-foot (1.1-meter) black fissile shale with conodonts (unit 20). The overlying units of the post Peters Chapel cyclothem include the Crekola Sandstone (unit 21), a 7.5-foot (2.3-meter) siltstone (unit 22), and a 11.5-foot (3.4-meter) unnamed sandstone (unit 23). The upper contact of the post Peters Chapel cyclothem is at the top of a 2.5-foot (0.75-meter) medium light gray, silty, sandy underclay (unit 24); although the Bluejacket coal is not present, this is probably the underclay beneath the Bluejacket coal. The post Peters Chapel cyclothem is approximately 29 feet (9 meters) thick.

Save for carbonaceous plant fragments in the Peters Chapel coal, the black fissile phosphatic shale is the only fossiliferous interval in the core exposure of the cyclothem. Pelecypods, ostracods, and *Idiognathodus* dominate the fauna of the shale.

17. INOLA CYCLOTHEM (major)

Previously, Branson (1954, p. 6) recognized the Inola coal cycle from the Inola Limestone to the top of an unidentified underclay, but the Inola cyclothem extends the genetic unit down to the Bluejacket coal and up to the underclay below the Wainwright coal (which may be equivalent to Branson's upper boundary). Therefore, the Inola cyclothem extends from the subaerial exposure at the top of the underclay below the Bluejacket coal to the subaerial exposure at the top of the underclay below the Wainwright coal. The Inola Limestone and its cyclothem are widespread over the northeastern shelf area in Oklahoma, but extensive field searches revealed only one locality where this cyclothem is fully developed. Another potential locality along State Highway 20 near Pryor, Oklahoma had become grassed over. This locality, NE1/4SW1/4NW1/4 Sec. 10, T19N, R17E, Rogers County, on the southwestern slope of Inola Hill, is designated as Locality #21 and is also the type locality for the Inola Limestone Member of the Boggy Formation. Because of the completeness of the cycle present in outcrop, this locality should serve as the type locality for the Inola cyclothem as well. At its type locality, the Inola cyclothem is approximately 66 feet (20 meters) thick.

At the type locality (Locality #21, p.365-66), the Bluejacket coal (unit 1) marks the beginning of transgression. However, several heavily covered silty or carbonaceous shales (units 2-4) overlie the Bluejacket coal. The Inola Limestone (unit 5) overlies a carbonaceous shale; at the type locality, it is 0.3 feet (0.09 meters) thick, medium dark gray, and massive. There are actually two beds of the Inola Limestone present in outcrop; this particular bed is the upper Inola Limestone. The lower Inola Limestone lies below the Bluejacket coal and is inconsequential to the cyclothem. Overlying the Inola Limestone is at a 4.0-foot (1.2-meter) black phosphatic fissile shale with deep-water conodonts (unit 6). Another black fissile shale (unit 7), 17.0 feet (5.1 meters) thick and lacking phosphate nodules or conodonts, overlies the black phosphatic fissile shale. Overlying the upper black fissile shale is an 18.0-foot (5.4-meter) covered interval (unit 8) and a 0.3-foot (0.09-meter) ferruginous, silty, clay shale (unit 9). Overlying the clay shale, the lower Taft Sandstone (unit 10), 6.0 feet (1.8 meters) of interbedded sandstones and siltstones (unit 11) and a very thin ferruginous zone (unit 12) comprise the rest of the cyclothem. A 3.0-foot (0.9-meter) clay shale (unit 13) may be the underclay underlying the Wainwright coal, and, if so, the top of this shale is the upper boundary of the Inola cyclothem. The rest of the exposure overlying this shale possibly belongs in the post Wainwright coal cyclothem, but, unfortunately, most of this interval is heavily covered, with facies difficult to determine.

At the type locality of the Inola cyclothem, only the upper Inola Limestone and the overlying black phosphatic fissile shale are fossiliferous. The upper Inola Limestone yielded brachiopod shells, gastropods, rugose corals, fusulinids, fish teeth, the foraminifera *Ammodiscus*, and the conodonts *Idiognathodus* and *Idioprioniodus*. The black phosphatic fissile shale is primarily barren of fossils except for *Idiognathodus* and the deep-water conodont *Gondolella*, present one foot (0.30 meters) above lower contact.

18. POST WAINWRIGHT COAL CYCLOTHEM (intermediate)

The post Wainwright coal cyclothem extends from the subaerial exposure at the top of the underclay below the Wainwright coal to the top of Taft Sandstone #2; the reason for placement of the upper boundary of the cyclothem at the top of Taft Sandstone #2 will be given later. The best exposure of the post Wainwright coal cyclothem is at a stream cut in the W1/2NW1/4NE1/4NW1/4 Sec. 26, T15N, R16E, Muskogee County, and this locality, designated as Locality #22, is the type locality of the post Wainwright coal cyclothem. Several black phosphatic shales and conodont intervals occur above the Wainwright coal; these create a quite complex cyclothem involving the Wainwright coal. It is also possible that the numerous packages of black fissile shales and black fissile phosphatic shales are parasequences. The post Wainwright coal cyclothem, including an upper minor cyclothem, is 39 feet (13 meters) thick at its type locality in Muskogee County; in Rogers County, the covered interval representing the Post Wainwright coal cyclothem on Inola Hill is only over 22 feet (7.3 meters) thick. Therefore, going southward from Rogers County into Muskogee County, the cyclothem nearly doubles in thickness.

At the type locality (Locality #22, p.369-72), the Wainwright coal (unit 3) marks the beginning of transgression. Overlying the Wainwright coal is 0.25 feet (0.08 meters) of dark gray, carbonaceous, silty, fissile shale (unit 4), 0.30 feet (0.09 meters) of grayish black, fissile shale (unit 5), and 0.54 feet (0.16 meters) of black fissile phosphatic shale (unit 6). 1.9 feet (0.57 meters) of grayish black nonphosphatic fissile shale (unit 7) overlies the black fissile phosphatic shale.

Another 3.0 feet (0.9 meters) of black phosphatic shales (units 8-10), the upper part of which is conodont bearing, overlie the shale designated as unit 6. A 0.33-feet (0.1-meter) unnamed limestone (unit 11) overlies the black fissile phosphatic shales. A 3.0-foot (0.9-meter) black fissile shale bearing conodonts (unit 12) overlies the limestone. A thicker unnamed limestone (unit 13) overlies the shale; at 3.5 feet (1.1 meters) thick, this limestone is the major carbonate unit above the Wainwright coal. The uppermost conodont-bearing black fissile shale (unit 14) about 3.2 feet (0.96 meters) thick overlies the limestone.

Overlying the uppermost black fissile shale is a thin ironstone (unit 15), 12.0 feet (3.6 meters) of silty, ferruginous, grayish black to dark gray fissile shale (unit 16), 5.3 feet (1.6 meters) of olive gray, silty, blocky, clay shale (unit 17), and 0.58 feet (0.2 meters) of dark gray, silty, fissile shale (unit 18). A 3.0-foot (0.9-meter) carbonaceous clay shale (unit 19) overlain by a thin ironstone bed (unit 20) and black phosphatic shale (unit 21) probably represents a minor secondary cyclothem in the upper part of the Post Wainwright coal cyclothem; more research would be necessary to determine the extent and importance of this cycle. Stratigraphically, the Taft Sandstone #2 occupies the upper part of the post Wainwright coal cyclothem. Even though the second Taft Sandstone is not present at this locality; 0.5 miles (0.81 km) to the west, a small outcrop of siltstones, silty shales, and sandstones may represent the second Taft Sandstone.

The lower shales (units 4-7) above the Wainwright coal yield only inarticulate brachiopods and brachiopod shell impressions. The overlying 3.0-foot (0.9-meters) of black fissile phosphatic shales (units 8-10) has a somewhat larger diversity of fauna. Orthid brachiopods and the brachiopods *Linoproductis* and *Crurithyris*, crinoid columnals, and pelecypods are sparsely scattered throughout the shales; the upper half foot (0.15 meters) of this interval yielded the conodont *Idiognathodus*. The lower unnamed limestone produced brachiopod shells, crinoid columnals, and *Idiognathodus*. The overlying black fissile shale (unit 12) produced *Idiognathodus* and the deeper-water *Idioprioniodus*, ostracods, and brachiopods. The upper unnamed limestone only contained *Idiognathodus*. The uppermost black fissile shale (unit 14) yielded *Crurithyris*, the ostracode *Healdia*, and *Idiognathodus*.

19. UPPERMOST BOGGY CYCLOTHEM (minor)

The uppermost Boggy cyclothem extends from the top of Taft Sandstone #2 to the subaerial exposure at the top of the underclay beneath the Weir-Pittsburg coal. The reason for establishment of this cyclothem is the presence of a rare fusulinid bearing limestone above Taft Sandstone #2 and between two nearshore units. The limestone was found at only one locality so this cyclothem may be very localized. The type locality is in the NE1/4NW1/4NW1/4NE1/4 Sec. 6, T15N, R16E, Muskogee County, Locality #23 (p.376-77), the only location where this limestone was found. At the type locality, a thin 1.8-foot (0.54-meter) silty, carbonaceous shale (unit 2) overlies the Taft Sandstone #2 (unit 1). The carbonaceous shale may be a coal equivalent and the beginning of a minor transgression. The presence of a possible transgression above the Taft Sandstone warranted placement of the sequence at the top of the sandstone. The most probable marine unit of this cyclothem is the fusulinid-bearing limestone (unit 3). The fusulinids are highly degraded and therefore unidentifiable, but they definitely indicate that the limestone is a marine limestone and not an underlime. Other fossils from the limestone include productid brachiopods and other shell fragments. However, the silty, impure, ferruginous nature of the limestone may indicate that the water level probably was shallow. The upper boundary of this cyclothem is at the top of the underclay (unit 4) beneath the Weir-Pittsburg coal. At the type locality, the thickness of the Uppermost Boggy cyclothem is 5.4 feet (1.8 meters) thick.

20. POST WEIR-PITTSBURG COAL CYCLOTHEM (intermediate)

The post Weir-Pittsburg coal cyclothem extends from the subaerial exposure at the top of the underclay below the Weir-Pittsburg coal to the subaerial exposure at the top of the underclay below the RC coal. The Weir-Pittsburg coal has a large regional extent over Kansas and Oklahoma, and the Weir-Pittsburg coal cycle has been recognized by Abernathy (1936), Searight and others (1953), and Branson (1954). However, all other coal cycles either extends from the Seville Limestone (possibly the Inola Limestone equivalent) to the Weir-Pittsburg coal or from the Taft Sandstone to the black shale above the Weir-Pittsburg coal. In comparison, the post Weir-Pittsburg coal cyclothem only includes the transgressive and regressive units overlying the Weir-Pittsburg coal. In Oklahoma, only one locality, Locality #23 in the NE1/4NW1/4NW1/4NE1/4 Sec. 6, T15N, R16E, Muskogee County, had any appreciable exposures of this cyclothem.

At Locality #23, p.376, the Weir-Pittsburg coal (unit 5) marks the beginning of transgression. A lower 0.5-foot (0.15-meter) carbonaceous, blocky clay shale (unit 6) overlies the Weir-Pittsburg coal. A lower 2.0-foot (0.6-meter) strongly bedded black shale with phosphate nodules (unit 7) overlies the lower carbonaceous clay shale, and a middle carbonaceous clay shale (unit 8) overlies the lower black fissile phosphatic shale. An upper 0.5-foot (0.15-meter) black fissile phosphatic shale (unit 9) overlies the middle carbonaceous clay shale, and a third carbonaceous clay shale (unit 10) is the uppermost shale bed exposed at Locality # 23.

In the core section described by Measured Section #24 (p.379), SE1/4SW1/4NW1/4SE1/4 Sec. 12, T21N, R16E, Rogers County, the cyclothem contains the Weir-Pittsburg coal, a black fissile phosphatic shale, and an overlying silty, fissile shale. Northward into Rogers County, the two black fissile phosphatic shales above the Weir-Pittsburg coal merge into a 2.1-foot (0.63-meters) single black fissile phosphatic shale. The overlying regressive silty shale is also the only fossiliferous interval found in the cyclothem so far. Brachiopods, pelecypods, and fern impressions have all been found in this shale. In Muskogee County, the post Weir-Pittsburg coal cyclothem is 5 feet (1.7 meters) thick and thins down to 3 feet (0.9 meters) in Rogers County.

21. POST RC COAL CYCLOTHEM (minor)

The post RC coal cyclothem extends from the subaerial exposure at the top of the underclay below the RC coal to the subaerial exposure at the top of the underclay below the Tebo coal. The best exposure of this cyclothem is in Rogers County at Locality #25 (p.382), Center East Line SE1/4SE1/4 Sec. 27, T22N, R17E, but the RC coal is not properly exposed at this locality. In its place, an equivalent of the RC coal is present. A zone of smutty, thin, discontinuous carbonaceous stringers (unit 3) represents the RC coal equivalent and perhaps the beginning of transgression. Overlying this zone is a series of beds that includes a thin poorly exposed clay fissile shale (unit 4), and a 5.0-foot (1.5-meter) black fissile phosphatic shale (unit 5). In a core section, described in Measured Section #26 (p.384-85), from SE1/4SW1/4NW1/4SE1/4 Sec. 12, T21N, R16E, the Post RC coal cyclothem the facies are similar to the ones exposed in outcrop except for an uppermost 6.2-foot (1.9-meter) silty shale (unit 7) with carbonized plant fragments. Fossils in this cyclothem are poorly preserved and unidentifiable. An upper black blocky shale (unit 6) in the core section did yield the conodont *Idiognathodus*.

22. TIAWAH CYCLOTHEM (major)

The Tiawah cyclothem extends from the subaerial exposure at the top of the underclay below the Tebo coal to the unconformity at the base of the Chelsea Sandstone. However, there are actually two cycles present in this cyclothem. The lower cycle extends from the subaerial exposure at the top of the underclay below the Tebo coal to an intraformational conglomerate (possible subaerial exposure) in the Tiawah Limestone, and the upper cycle extends from the intraformational conglomerate to the unconformity at the base of the Chelsea Sandstone. However, since the boundary between these two cycles lie in the Tiawah Limestone, for the time being, this interval will be considered one cyclothem. The Tiawah cyclothem is widespread over most of the shelf area in Oklahoma. Abernathy (1936) and Searight and others (1953) also recognized a similar interval in Kansas and Missouri. Branson (1954), in northeastern Oklahoma, placed the lower part of the Tiawah cyclothem within the Tebo coal cycle and the upper part within the Scammon coal cycle. Since the Scammon coal is absent in Oklahoma, such a division is not possible.

The Tiawah cyclothem is best exposed at Locality #28, SE1/4SW1/4 Sec. 12, T21N, R16E, Rogers County, and at Locality #28 (p.394-96), most of the cyclothem is present except for the Tebo coal and the underclay below the Mineral coal. However, the interval between the Taft Sandstone and the Tiawah Limestone is heavily covered so the Tebo coal may be present but just covered. Therefore, the Tiawah cyclothem is almost entirely exposed along the outcrop. So, the type locality of the Tiawah cyclothem should be in the SE1/4SW1/4 Sec. 12, T21N, R16E, Rogers County, and the description of the Tiawah cyclothem will be based upon the type locality.

A 3.4-foot (1.02-meter) sandstone (unit 1) is the lowest exposed bed at Locality #28. This sandstone, known as the "White Sand" in the subsurface, is probably Taft Sandstone #4, but marine fossils are present within the sandstone. Most likely, this is a marine sandstone. Above the sandstone, the beds are heavily covered, but some poorly exposed silty shales and ironstone stringers were observed. There may be a possibility that the Tebo coal and its underclay is present above the Taft Sandstone, but further trenching of the outcrop would be required to positively determine the presence of the Tebo coal. Digging a foot deep vertical trench from the base of the Tiawah Limestone downward to about two feet below the Tiawah exposed the upper foot of a thick black fissile phosphatic shale with conodonts (unit 7). A 0.83-foot (0.25-meter) dark gray, silty clay shale (unit 8) and 0.75-foot (0.23-meter) blocky, silty shale (unit 9) overlie the black fissile phosphatic shale. The lower 1.75 feet (0.52 meters) of the Tiawah Limestone (unit 10) may be regressive, and a possible subaerial exposure surface is at a 1.7-foot (0.50-meter) thick intraformational conglomerate of the Tiawah Limestone (unit 11). The intraformational conglomerate contains clasts of limestones and reworked brachiopod shells and conodonts; the upper boundary of the lower cycle of the Tiawah cyclothem is at the top of the intraformational conglomerate.

A light brownish gray wackestone of the Tiawah Limestone (unit 12) overlies the intraformational conglomerate and may be considered a flooding surface. This also marks the beginning of the upper cycle within the Tiawah cyclothem. Transgression may continue through a upper 0.92-foot (0.27-meter) bed (unit 13) of the Tiawah Limestone, and overlying the Tiawah Limestone is at a 2.0-foot (0.6-meter) black phosphatic clay shale (unit 14). This shale has deeper water conodonts than the lower black fissile phosphatic shale, and the upper part of this shale lacks phosphate nodules. The interval above this shale is covered but would most likely be shale as well. The uppermost unit exposed at Locality #28 is the Chelsea Sandstone (unit 16), and the base of the Chelsea Sandstone is an unconformity due to the regional incisement of lower beds by the Chelsea. This unconformity can serve as the upper boundary of the Tiawah cyclothem. At the its type locality, the Tiawah cyclothem is over 32 feet (11 meters) thick.

At least the lower cycle and the lower part of the upper cycle of the Tiawah cyclothem is present at Locality #27 (p.388-90), in the SE1/4NE1/4NE1/4SE1/4 Sec. 14, T14N, R15E, Muskogee County. The lower shale interval thickens from 8.0 feet (2.6 meters) in Rogers County to over 13.0 feet (4.3 meters) in Muskogee County. The Taft #4 Sandstone is not found in the Muskogee outcrop, but the black phosphatic shale below the Tiawah Limestone thickens southward from one foot (0.30 meters) to three feet (0.90 meters). In Muskogee County, the black phosphatic shale of the lower cycle has a high abundance of the deep-water conodont *Gondolella*. Although *Gondolella* wasn't observed in Rogers County, this shale may persist northward to Iowa, as a similar shale is present there (Heckel, personal communication, 2002). The Tiawah Limestone thins from over six feet (1.28 meters) in Rogers County to just a foot (0.30 meters) in Muskogee County. Furthermore, only the lower regressive limestone is present. The shale overlying the Tiawah Limestone thickens from two feet (0.6 meters) to over 17 feet (5.1 meters) southward from Rogers to Muskogee Counties. For this shale, downcutting of the Chelsea Sandstone can attribute to the thinness in Rogers County.

At the type locality, the marine sandstone yielded brachiopods and crinoid columnals. The next higher important fossiliferous interval is the black phosphatic shale below the Tiawah Limestone that has *Lingula* brachiopods, gastropods, and *Idiognathodus* conodonts. The basal Tiawah Limestone yielded mainly spiriferid and strophomenid brachiopods, and the intraformational conglomerate contained reworked brachiopods and conodonts. The flooding surface of the Tiawah Limestone yielded productid brachiopods, fish teeth, and calcareous foraminifera, and the uppermost Tiawah Limestone produced large pelecypods, productid brachiopods, fenestrate bryozoans, rugose corals, crinoid columnals, and calcareous shell hash. The black phosphatic shale overlying the Tiawah Limestone yielded the ostracods *Bairdia* and *Sansabella*, *Ammodiscus* and *Bigeneria* foraminifera, orthid brachiopods, gastropods, and the conodonts *Idiognathodus* and *Idioprioniodus*.

In Muskogee County, the black fissile phosphatic shale below the Tiawah Limestone yielded the conodonts *Idiognathodus* and *Gondolella* along with gastropods and pelecypods. The ammonoid *Glaphyrites* is present in many of the limestone concretions below the Tiawah Limestone; these limestone concretions may be a southern continuation of the ironstone stringers found in the type locality. *Idiognathodus* and the deep-water foraminifera *Reophax* are the only significant fossils found in the black shales between the black phosphatic shale and the Tiawah Limestone. At its southern exposure, the Tiawah Limestone yielded brachiopods, gastropods, the archaeogastropod *Platyceras*, pyritized ostracods, fish teeth, and *Idiognathodus*. In Muskogee County, the shale above the Tiawah Limestone seems largely barren of any significant fauna.

23. RUSSELL CREEK CYCLOTHEM (intermediate)

To date, the Russell Creek cyclothem was only found at one ditch cut in the Middle North Line Sec. 14, T34S, R21E, Labette County, Kansas, designated as Locality #29. However, the cyclothem is well developed here, and the locality is established as the type locality for the Russell Creek cyclothem. Descriptions of the cyclothem are based upon exposures at the type locality. The Russell Creek cyclothem extends from the unconformity at the base of the Chelsea Sandstone to the subaerial exposure at the top of the underclay below the Fleming coal.

At the type locality, p.400-01, the Mineral coal (unit 3) marks the beginning of transgression. Overlying the Mineral coal are a 0.21-foot (0.06-meter) carbonaceous shale (unit 4) and the Russell Creek Limestone (units 5 and 6). Overlying the Russell Creek Limestone is a 0.5-foot (0.15-meter) medium to dark gray, blocky phosphatic shale with conodonts (unit 7). The uppermost exposures of the cyclothem at Locality #29 include a foot of fossiliferous, blocky, silty clay shales with carbonaceous streaks (units 8 and 9) and an overlying thin ironstone stringer (unit 10). At its type locality, the Russell Creek cyclothem is approximately 3.0 feet (0.9 meters) thick.

The Russell Creek cyclothem is very fossiliferous. The Russell Creek Limestone yielded brachiopods, crinoids, fusulinids, and the conodont *Idiognathodus*. The overlying phosphatic shale produced the conodonts *Idiognathodus* and *Idioprioniodus*. The two carbonaceous clay shales are also very fossiliferous. The lower shale yielded rugose corals, holothurian sclerites, echinoid spines, crinoids, *Worthenia* and *Bellerophon* gastropods, ostracods, and *Idiognathodus*. The upper shale yielded pelecypods, the brachiopod *Chonetes*, *Trepospira* gastropods, ostracods, holothurian sclerites, and echinoid plates. The abundance and type of fauna in addition to the calcareous nature of the shales may indicate a shallow marine environment.

24. FLEMING CYCLOTHEM (minor)

The Fleming cyclothem extends from the subaerial exposure at the top of the underclay below the Fleming coal to the subaerial exposure at the top of the underclay below the Croweburg coal. The entire cyclothem is present at Locality #30 on the Center South Line SW1/4SW1/4 Sec. 35, T33S, R21E, Labette County, Kansas, on the banks of the Neosho River near the Overman Bridge spanning the Neosho River. The Fleming cyclothem has a widespread lateral extent on the shelf in Kansas and Oklahoma, and many authors have recognized this cycle over the years. Descriptions of the Fleming cyclothem are based upon exposures at the locality described above, p.404. At Locality #30, the Fleming cyclothem is nearly 10.0 feet (3.3 meters) thick.

The Fleming coal (unit 3) marks the beginning of transgression. Overlying the Fleming coal is a 0.08-foot (0.02-meter) thick carbonaceous clay shale (unit 4). An unnamed grainstone (unit 5), 1.25 feet (0.38 meters) thick, fossiliferous, and containing conodonts, overlies the carbonaceous shale. A thin ferruginous unnamed limestone (unit 6) overlies the grainstone. A six-foot (1.98-meter) covered interval overlies the ferruginous limestone. The upper boundary of the Fleming cyclothem is the subaerial surface at the top of the underclay below the Croweburg coal, and it should be noted that the Fleming cyclothem is one of the few cyclothems found complete with the overlying underclay.

The lower unnamed grainstone yielded brachiopods, crinoids, fish debris, and the conodont *Idiognathodus*. The overlying ferruginous limestone yielded large spiriferid brachiopods, gastropods, crinoid stems, and unidentifiable foraminifera.

25. VERDIGRIS CYCLOTHEM (major)

The Verdigris Limestone is laterally persistent throughout the shelf, Oklahoma, Kansas, and Missouri; furthermore, the Verdigris cyclothem is just as persistent. A coal cycle involving the Verdigris Limestone has been recognized since Abernathy (1936), but most cycles extend from a shale or sandstone below the Verdigris Limestone to the top of the underclay below the Wheeler coal. However, since the Wheeler coal does not outcrop in Oklahoma, the top of the Verdigris cyclothem has been extended to the top of the underclay below the Bevier coal. Therefore, the Verdigris cyclothem extends from the subaerial exposure at the top of the underclay below the Croweburg coal to the subaerial exposure at the top of the underclay below the Bevier coal.

In Oklahoma, the best-exposed and largest outcrop of the Verdigris cyclothem is at the spillway of Lake Bixhoma south of Bixby, Oklahoma in Wagoner County. The locality has been designated as Locality #31 and is in the N1/2SE1/4NW1/4 Sec. 2, T16N, R14E. Descriptions of this cyclothem will be taken from the measured section of the spillway, p.408-411.

The Croweburg coal marks the beginning of transgression, but the coal is not present at the Lake Bixhoma spillway. Fortunately, the underclay beneath the Croweburg is present (unit 6), and the lower boundary of the cyclothem can be established. A 0.25-foot (0.08-meter) impure limestone (unit 7) overlies the underclay. The Oakley Shale (unit 8) overlies this limestone, and is a black phosphatic shale. An overlying 0.6-foot (0.18-meter) calcareous brown shale with deep-water conodonts (unit 9) may be analogous to the gray shale facies of a core shale (Heckel, 1977). The overlying Verdigris Limestone may be a regressive limestone; there are actually three beds of the Verdigris (units 10, 12, 14) separated by two clay shales (units 11, 13). A 0.2-foot (0.06-meter) silty, conodont-bearing limestone (unit 15) overlies the upper Verdigris Limestone. A massive 21.0-foot (6.3-meter) silty, gray calcareous shale (unit 16) and ferruginous sandstone (unit 17) overlie the limestone. Even though neither the Bevier coal nor its underclay is present at this locality, the argument can be made for the placing the upper boundary at the top of the sandstone. The shale (unit 16) below the sandstone is not fossiliferous, but the shales overlying the sandstone (units 18-19) are fossiliferous. And, the shales overlying those shales (units 20-23) have even deeper-water fossils. Therefore, it is possible that this may be a sequence boundary. If so, all beds overlying the sandstone (units 18-26 on the measured section of Locality #31) then belong in the overlying post Bevier coal cyclothem. At the Lake Bixhoma spillway locality, the Verdigris cyclothem is approximately 28 feet (9.0 meters) thick.

The Croweburg coal, Oakely Shale, and Verdigris Limestone of the Verdigris cyclothem overlie the Fleming cyclothem at the Overman Bridge Locality (Locality #30, p.403-04) in southern Kansas. From Wagoner County north to southern Kansas, the Oakley Shale does not change in terms of thickness or lithofacies, but the thin limestone underlying the Oakley Shale does not persist northward leaving the Oakley Shale directly overlying the Croweburg coal. The thin calcareous brown shale above the Oakely is missing as well. The Verdigris Limestone and its clay shales thicken from around 2.5 feet (0.82 meters) at Lake Bixhoma to over 6.0 feet (2.0 meters) in southern Kansas. It should be noted that in southern Kansas only the lower two Verdigris beds were found in outcrop.

The Oakley Shale in both localities yielded the conodonts *Idiognathodus* and *Idioprioniodus*. At Lake Bixhoma, the Oakley Shale also yielded the conodonts *Neognathodus* and *Gondolella*, crinoid columnals, brachiopods, deep-water foraminifera *Reophax*, and ostracods. The brown calcareous shale above the Oakley yielded crinoids, echinoid spines, gastropods, pelecypods, and *Idiognathodus*, *Idioprioniodus*, and *Neognathodus*. The Verdigris Limestone, at Lake Bixhoma, contained *Idiognathodus*, the foraminifera *Orthovertella*, nautiloids, crinoids, fish debris, ostracods, and gastropods. The middle bed of the Verdigris Limestone yielded *Idioprioniodus*, *Neognathodus*, and *Idiognathodus*. At the Overman Bridge Locality in Kansas, The Verdigris Limestone yielded *Idiognathodus*, holothurian sclerites, encrusting and calcareous foraminifera, and the foraminifera *Cornuspira* and *Tetrataxis*.

26. POST BEVIER COAL CYCLOTHEM (intermediate)

The post Bevier coal cyclothem extends from the subaerial exposure at the top of the underclay below the Bevier coal to the subaerial exposure at the top of the underclay below the Iron Post coal. The Bevier cyclothem is widespread over the shelf area in Kansas and Missouri. The Bevier coal itself is sparse in Oklahoma, but the post Bevier coal cyclothem may extend as far south as Wagoner County, Oklahoma. Like most of the other upper Senora cyclothems, a coal cycle involving the Bevier coal has been widely recognized since Abernathy (1936). Descriptions of the cyclothem in this report will be based upon a stream cut in the W1/2NE1/4NW1/4 Sec. 30, T32S, R22E, Cherokee County, Kansas (Locality #32, p.415-16).

The Bevier coal (unit 2) marks the beginning of transgression. Overlying the Bevier coal is a very thin cobbly limestone (unit 3), and a thin carbonaceous, fissile, black shale (unit 4). An unnamed thicker limestone (unit 5) overlies the carbonaceous black shale. This limestone has an extremely high abundance of conodonts (several thousand conodont elements in a 3 kg sample), particularly in the upper portion of the bed. A thin conodont-bearing carbonaceous clay shale (unit 6) overlies the limestone. However, a 0.33-foot (0.10-meter) black phosphatic shale (unit 8) overlies the clay shale. The uppermost beds exposed at Locality #32 include a 1.58-foot (0.47-meter) silty gray shale (unit 9) and a 0.5-foot (0.15-meter) olive brown, earthy shale (unit 10). The thickness of the post Bevier coal cyclothem at this locality is 5.3 feet (1.7 meters) thick.

While the Bevier coal does not extend very far south into Oklahoma, the black fissile shales above the Bevier coal have been identified well above the Verdigris Limestone at the Lake Bixhoma spillway (Locality #31, p.408-09). Therefore, it is reasonable to assume that the post Bevier coal cyclothem extends south to at least Wagoner County. The black fissile shale above the Bevier coal thickens from 0.33 feet (0.10 meters) in Kansas to 2.0 feet (0.6 meters) in Wagoner County. The nearly foot (0.30 meter) thick shale interval between the black shale and the Bevier coal thickens to around 6.5 feet (1.95 meters) in Wagoner County. Below this shale, 18.0 feet (6 meters) of gray, silty, calcareous shales may represent a transgressive pulse above the Bevier coal that does not persist northward to Kansas.

In Kansas, the cobbly limestone overlying the Bevier coal yielded crinoids, corals, brachiopods, pyritized gastropods and ostracods, and the conodonts *Idiognathodus* and *Idioprioniodus*. The overlying carbonaceous clay shale yielded *Idiognathodus*. The unnamed limestone yielded a high abundance of *Idiognathodus* with a few sparse *Idioprioniodus*, and other fossils from the unnamed limestone include bryozoan fragments, gastropods, ostracods, and fish teeth. The foot (0.3 meter) thick shale interval above the unnamed limestone yielded poorly preserved foraminifera, and *Idiognathodus*. The black phosphatic fissile shale yielded *Idiognathodus*. The overlying silty shale contains strophomenid brachiopods, crinoid stems, and sparse *Idiognathodus*, and the upper earthy shale has a dominant brachiopod fauna.

At the Bixhoma spillway, the lower shale interval is not only thicker but has a larger abundance of fauna. Included in the shale are brachiopods, gastropods, crinoids, ostracods, pelecypods, the foraminifera *Endothyra*, and the conodonts *Idiognathodus* and *Idioprioniodus*. The overlying black fissile shale yielded ammonoids, brachiopods, and *Idiognathodus* and *Idioprioniodus*.

27. BREEZY HILL CYCLOTHEM (intermediate)

The Breezy Hill cyclothem extends from the subaerial exposure at the top of the underclay below the Iron Post coal to the subaerial exposure at the top of the underclay below the Mulky coal. But, the Mulky coal does not extend as far south as Oklahoma, and where the Mulky coal and its underclay are absent, the upper boundary of the Breezy Hill cyclothem lies at the top of the Breezy Hill Limestone, where solution vugs at an outcrop in Kansas indicate subaerial exposure. The Breezy Hill cyclothem consists of the Iron Post coal, Kinnison Shale, Breezy Hill Limestone, and underclay below the Mulky coal or equivalent units. All of the facies of the Breezy Hill cyclothem have a widespread lateral extent over the shelf area in Oklahoma, Kansas, and Missouri. The Breezy Hill cyclothem or at least parts of it have been found at four localities: on the south shore of Lake Bixhoma in Wagoner County (Locality #34, Center N1/2N1/2SW1/4 Sec. 2, T16N, R14E, p.423-24); near Catoosa, Oklahoma in Rogers County (Locality #35, N1/2N1/2 Sec. 32, T20N, R15E, p.428); 5 miles north of Welsh, Oklahoma in Craig County (Locality #33, W1/2SW1/4 Sec. 35, T29N, R19E, p.419); and in Labette County in southern Kansas (Locality #36, SE1/4SE1/4SE1/4 Sec. 30 and S1/2S1/2SW1/4 Sec. 29, T34S, R21E, p.433-34).

The basal component of the Breezy Hill cyclothem, the Iron Post coal, was found only in the locality 5 miles (8 km) north of Welsh, Oklahoma (Locality #33) where it was a foot (0.3 meters) thick. The overlying Kinnison Shale was found from the south shore of Lake Bixhoma (Locality #34), the Catoosa locality in Rogers County (Locality #35), and the Welsh locality in Craig County, Oklahoma (Locality #33). On the south shore of Lake Bixhoma, the Kinnison Shale is a 6.3-foot (1.9-meter) thin-bedded, silty clay shale with brachiopods. In Rogers County, the Kinnison Shale is 0.33 feet (0.10 meters) thick, fissile, thick, soft, and carbonaceous, and in Craig County, the Kinnison Shale thickens back to 6.5 feet (2.1 meters). At this locality (Locality #33), the Kinnison has a basal transgressive limestone, lower black fissile shale, silty clay shale, regressive limestone, and an upper calcareous clay shale. The basal transgressive shale yielded crinoid fragments, pyritized brachiopods, the foraminifera *Ammodiscus*, fish teeth, carbonized ostracods, and the conodonts *Idiognathodus* and *Idioprioniodus*. The lower black fissile shale yielded the deep-water foraminifera *Reophax*. The silty clay shale yielded unidentifiable foraminifera and fusulinids. The regressive limestone contained brachiopods, crinoids, fish teeth, and conodonts. The uppermost calcareous clay shale has a typical open marine fauna: crinoids, brachiopods, holothurian sclerites, fish teeth, ostracods, calcareous foraminifera, and *Idiognathodus*.

The Breezy Hill Limestone is possibly the point of maximum transgression in the Breezy Hill cyclothem. The Breezy Hill is found at all four localities. On the south shore of Lake Bixhoma, the Breezy Hill Limestone is over 20 feet (6.7 meters) thick, and fossils found in the Breezy Hill Limestone at this locality includes *Platyceras* archaeogastropods, mesogastropods, brachiopods, *Cornuspira* calcareous foraminifera, crinoid columnals, and *Idiognathodus*. Near Catoosa, Oklahoma, Rogers County, the Breezy Hill Limestone is 6.8 feet (2.0 meters) thick and contains fish teeth, *Idiognathodus*, encrusting and calcareous foraminifera, and sparse algae. Farther north into Craig County, the Breezy Hill Limestone is only 5.0 feet (1.5 meter) thick, but it is possible that only the basal part of the unit is exposed. Even further north into Labette County in southern Kansas, the Breezy Hill Limestone thickens back to over 20 feet (6.7

meters) thick. Dominant fauna of the Breezy Hill Limestone in Labette County includes the calcareous foraminifera *Cornuspira*, the foraminifera *Ammodiscus*, encrusting foraminifera, phylloid algae, sponge spicules, holothurian sclerites, brachiopods, fusulinids, and the conodont *Idiognathodus*.

The thickness of both the Breezy Hill Limestone and Kinnison Shale seem similar in both their northern and southern exposures, but both the Breezy Hill and Kinnison inexplicably thins near Catoosa, Oklahoma in Rogers County. One explanation for this thinning at one locality may be a topographic or structural high in the area that prevented significant accumulations of sediment.

28. LOWER FORT SCOTT CYCLOTHEM (major)

The Lower Fort Scott cyclothem extends from the subaerial exposure at the top of the underclay below the Mulky coal to the subaerial exposure at the top of the underclay below the Summit coal in the Marmaton Group. The only Cherokee components of this cyclothem are the Mulky coal (not present in Oklahoma) and the Excello Shale; the rest of the cyclothem, the Blackjack Creek Limestone and the underclay below the Summit coal, is in the Marmaton Group. The Excello Shale is a significant black fissile phosphatic shale that represents a major transgression over the Midcontinent, and the Excello is continuous from Oklahoma to Illinois. The Lower Fort Scott cyclothem was studied in two localities: Locality #35 (N1/2N1/2 Sec. 32, T20N, R15E, p.427) near Catoosa, Oklahoma, and Locality #36 (SE1/4SE1/4SE1/4 Sec. 30 and S1/2S1/2SW1/4 Sec. 29, T34S, R21E, p.432-33) in Labette County in southern Kansas.

Near Catoosa, Oklahoma, the Excello Shale and the Blackjack Creek Limestone are the only components of the Lower Fort Scott cyclothem. The Excello Shale is a little over 3.0 feet (0.9 meters) thick and contains two facies: a 0.1-foot (0.03-meter) basal medium dark gray calcareous shale, and a 3.0-foot (0.9-meters) black fissile phosphatic shale. Lacking the Mulky coal and its underclay, at Locality #35, the contact between the Breezy Hill cyclothem and the Lower Fort Scott cyclothem may be at a corresponding subaerial exposure at the top of the Breezy Hill Limestones. Strangely, the Excello Shale is devoid of conodonts or any other microfauna at the Catoosa locality.

In Labette County, the Excello Shale overlies the Breezy Hill Limestone, and most of the Lower Fort Scott cyclothem is present either at Locality #36 or at a roadcut just to the west. The Excello Shale at Locality #36 is around 4.5 feet (1.5 meters) thick. The basal shale is present at this locality in addition to a black fissile phosphatic shale facies and an overlying clay shale facies of the Excello Shale. The black fissile phosphatic shale facies may represent the maximum transgression within the Lower Fort Scott cyclothem. This facies is also fossiliferous with the deep-water conodonts *Idiognathodus* and *Idioprioniodus*. The presence of phosphate nodules and lack of other fauna indicates the Excello Shale may have been deposited in the anoxic conditions described by Heckel (1977).

Newly Determined Conodont-bearing Intervals

KREBS SUBGROUP

McALESTER FORMATION

Black and gray shale above the upper Hartshorne coal

This seems to be the lowest conodont-bearing interval ever found in the Cherokee Group. At a locality in the NW1/4NW1/4NW1/4NW1/4 Sec.33, T11N, R19E (Locality #1) in Muskogee County, Oklahoma, broken fragments of *Idiognathodus* and *Idioprioniodus* were found in a medium dark gray shale above the upper Hartshorne coal. In an overlying black shale, broken fragments of *Idiognathodus*, *Neognathodus*, and *Idioprioniodus* were identified. Both shales also had phosphate nodules.

Black fissile shale below the Warner Sandstone

A poorly exposed black shale exposed on the upper slopes of Brushy Mountain, S1/2SE1/4SW1/4SE1/4 Sec 28, T14N, R19E (Locality #2), in southeastern Muskogee County has produced poorly preserved elements of *Idiognathodus*, *Idioprioniodus*, and *Neognathodus*. Near the base of Brushy Mountain is a thin, smutty, poorly exposed coal, but it is unclear whether this is the Brushy Mountain coal or an unnamed coal. Bluffs of Warner Sandstone cap the top of Brushy Mountain.

Another unnamed shale, probably in the same stratigraphic position, near Adamson, Pittsburg County, Oklahoma also has poorly preserved elements of conodonts, *Neognathodus*, *Idiognathodus*, and *Idioprioniodus*. About half a foot (0.15 meters) below this shale, an inch thick dark yellowish orange clay produced elements of

Idiognathodus and *Idioprioniodus*. The legal description of this locality is SW1/4SW1/4SE1/4SW1/4 Sec 19, T5N, R17E and NW1/4NW1/4NE1/4NW1/4 Sec 30, T5N, R17E (Locality #3).

Gray shale above the Tamaha coal

At a stream cut in E1/2E1/2NE1/4SE1/4 Sec 13, T13N, R18E (Locality #9), a gray calcareous, micaceous above an unnamed limestone bed was found to have elements of *Idiognathodus*. The conodont-bearing shale was about a foot (0.30 meters) above the Tamaha coal.

SAVANNA FORMATION

Sam Creek Limestone

Several exposures of the Sam Creek Limestone contained elements of *Idiognathodus*. At one locality, NE1/4NE1/4NE1/4 Sec. 1, T15N, R17E and SW1/4SE1/4SE1/4SE1/4 Sec. 36, T16N, R17E (Locality #13), in Wagoner County, Oklahoma, the Sam Creek Limestone contained several hundred elements of *Idiognathodus* in a three kilogram processed sample. However, the black shales above and below the Sam Creek have so far been barren of conodonts or any other fossils.

Black fissile shale above the Rowe coal

At an exposure in NW1/4NW1/4SW1/4NW1/4 Sec 26, T14N, R18E (Locality #14), Muskogee County, Oklahoma, a black fissile shale approximately 7 feet (2.1 meters) above the Rowe coal yielded conodonts. The two genera found were

Idiognathodus and *Idioprioniodus*. An overlying gray silty shale also produced *Idiognathodus* and *Idioprioniodus* at the base. The black fissile shale also contained phosphatic nodules.

Black fissile shale above the Doneley Limestone

The previously mentioned black shale above the Rowe coal also overlies the Doneley Limestone, but the Doneley was not present at that locality. This exposure is on Hensley Mountain in southwestern Muskogee County, SW1/4SE1/4NE1/4 and NW1/4NE1/4SE1/4 Sec. 4, T10N, R19E (Locality #16). The shale is a 20-foot (6.0 meters) black fissile shale directly above the Doneley Limestone, and at several intervals within this shale, several half inch to inch (1.3 to 2.5 cm) wide oval to suboval phosphate nodules could be found. In the upper part of this shale, sparse broken fragments of *Idiognathodus* were identified. Further study is necessary to determine if this shale is equivalent to the black fissile above the Rowe coal mentioned above.

Black shales above the Drywood coal

At a roadcut along State Highway 2 in the Timbered Hills in SE1/4SE1/4NE1/4 Sec 27, T27N, R20E (Locality #17), several heavily weathered and poorly exposed shales overlie the Drywood coal. About 0.5 feet (0.15 meters) above the Drywood coal, a 5.5-foot (1.65-meter) black fissile shale contains *Idioprioniodus*, *Idiognathodus*, and whitish impressions of *Idiognathodus*. The lower part of this shale also has half-inch (1.3 cm) elongate to suboval phosphatic nodules. The Bluejacket Sandstone caps this roadcut; at the base of the Bluejacket, the characteristic conglomerate was found. Pebbles of shale and phosphate nodules constitute several of the fragments within this conglomerate. Therefore, it is possible that another conodont-bearing shale above the Drywood coal was removed by downcutting of the Bluejacket Sandstone.

BOGGY FORMATION

Gray blocky shale above the Secor coal

In SE1/4NW1/4NE1/4 Sec 13, T6N, R23E and SW1/4SW1/4NW1/4 Sec 18, T6N, R24E (Locality #19) at an open strip mine near Wister Oklahoma, a 32-foot (9.6-meter) gray blocky shale was observed above the Secor coal. At about 10 feet (3.0 meters) above lower contact, sparse fragmentary element of *Idiognathodus* were found.

Black shale above the Secor Rider coal

In a core drilled by the Oklahoma Geological Survey (designation C-MM-51) in Muskogee County, Oklahoma, a black fissile shale about 0.5 feet (0.15 meters) above the Secor Rider coal was found to have both *Idiognathodus* and *Idioprioniodus*.

Black shale above the Peters Chapel coal

In the same core previously mentioned, approximately 0.2 feet (0.06 meters) above the Peters Chapel coal, a black fissile shale was identified. This shale contained elements of *Idiognathodus*.

Inola Limestone and black fissile shale overlying the Inola

On the southwestern slope of Inola Hill in Rogers County, Oklahoma (Locality #21), an exposure from the Bluejacket Sandstone to the Middle Taft Sandstone was measured and described. An upper bed of the Inola Limestone was found to contain *Idiognathodus* and *Idioprioniodus*.

Overlying the Inola Limestone, a four-foot (1.2-meter) fissile black shale was also conodont bearing. The ubiquitous conodont *Idiognathodus* was identified. In addition, the deeper water conodont *Gondolella* was identified as well. This shale also has quarter inch (0.64 cm) to walnut sized elongate to oval phosphate nodules. The combination of *Gondolella* and phosphate nodules indicates that a core shale overlies the Inola Limestone.

Black fissile shales and limestones above the Wainwright coal

At a stream cut in W1/2NW1/4NE1/4NW1/4 Sec 26, T15N, R16E (Locality #22) in northern Muskogee County, Oklahoma, several black fissile phosphatic shale and two limestones above the Wainwright coal were determined to be conodont-bearing. The two limestones produced *Idiognathodus*. There were several shale intervals that contained *Idiognathodus*, and one black shale had both *Idiognathodus* and *Idioprioniodus*. Boardman (personal communication, 2002) determined that the species of *Idiognathodus* from above the Wainwright coal are more closely related to species found in the Cabaniss Subgroup.

CABANISS SUBGROUP

SENORA FORMATION

Black shale above the RC coal

A core was taken from SE1/4SW1/4NW1/4SE1/4 Sec. 12, T21N, R16E in Rogers County, Oklahoma by the Oklahoma Geological Survey (core designation C-RM-2). In this core, approximately 1.8 feet (0.54 meters) above the RC coal a conodont-bearing black shale was identified. However, only sparse fragments of *Idiognathodus* were found. In the field, a thin black fissile phosphatic shale was identified above the RC coal, but to date, the shale is devoid of conodonts.

Russell Creek Limestone

A small road ditch exposure in the Middle North Line Sec 14, T34S, R21E in Cherokee County, Kansas (Locality #29) had two beds of the Russell Creek Limestone, a half-foot (0.15-meter) dark gray phosphatic shale, and a half-foot (0.15-meter) clay calcareous shale. Both beds of the Russell Creek Limestone contained elements of *Idiognathodus*. The overlying gray shale had a deeper water assemblage of conodonts with both *Idiognathodus* and *Idioprioniodus*. The uppermost calcareous clay shale only contained *Idiognathodus*.

Fleming limestone

At the Overman Bridge Locality in Cherokee County, Kansas, Center South Line SW1/4SW1/4 Sec 35, T33S, R21E (Locality #30), two beds of the Fleming Limestone were measured and described. The lower Fleming Limestone is a medium gray grainstone, and sparse elements of the conodont *Idiognathodus* were found in this limestone. The upper Fleming Limestone is a ferruginous packestone. Although the upper Fleming Limestone is fossiliferous with brachiopods, crinoid stems, and gastropods, no conodonts have been found to date.

Limestone above the Bevier coal

Along Lightning Creek, in W1/2NE1/4NW1/4 Sec 30, T32S, R22E (Locality #32), Cherokee County, Kansas, a limestone overlying the Bevier coal had an abundant assemblage of conodont elements. In the upper part of this limestone, a 3-kilogram sample contained thousands of elements of *Idiognathodus*. A few *Idioprioniodus* were found as well.

Below the limestone, a thin, soft, fissile carbonaceous shale contains elements of *Idiognathodus*. Below the shale and above the Bevier coal, a thin, cobbly, carbonaceous limestone produced fragments of *Idiognathodus* and *Idioprioniodus*.

Kinnison Shale

At the type Kinnison locality, W1/2SW1/4 Sec 35, T29N, R19E (Locality #35), in Craig County, Oklahoma, several conodont intervals were identified. A basal limestone within the Kinnison produced *Idiognathodus* and *Idioprioniodus*. A second upper limestone bed yielded conodonts as well. A clay shale in the uppermost part of the Kinnison Shale produced sparse fragments of *Idiognathodus*.

Breezy Hill Limestone

On the south shore of Lake Bixhoma, Center N1/2N1/2SW1/4 Sec 2, T16N, R14E (Locality #34), in extreme northwestern Wagoner County, a massive exposure of the Breezy Hill Limestone was described and measured. Within the Breezy Hill, conodonts were found at several limestone beds. Except for one limestone bed, most of the limestone beds produced elements of *Idiognathodus*. The calcareous shales between the limestone beds have been found to be devoid of conodonts. At another locality, in N1/2N1/2 Sec32, T20N, R15E (Locality #35), Rogers County, Oklahoma, the Breezy Hill Limestone produced sparse elements of *Idiognathodus*.

Sea Level Curve for the Cherokee Group

Once all of the T-R cycles were identified and characterized, it was possible to draw a crude sea level curve for the Cherokee Group (Figure 10). Points where the sea may have reached maximum regression (MR) were anchored at the subaerial exposures, and points where the sea may have reached maximum transgression (MT) were anchored at the deepest marine interval within the cyclothems. The size of the transgressive spikes and how close they were to maximum transgression was determined by the lithofacies and microfossil extensively discussed before. For example, a black fissile phosphatic shale with deep-water conodonts represented a major transgression, and the transgressive spike was drawn all the way to maximum transgression. A shale or limestone with marine fossils or relatively shallow-water conodonts represented an intermediate transgression; the transgressive spike was drawn approximately halfway between maximum transgression and maximum regression. Poorly developed marine intervals were probably deposited during times of minor regressions, and the transgressive spike was drawn closer to maximum regression. A very good example of a poorly developed marine interval is the thin ironstone or ferruginous limestone with marine fossils above the Keota coal in the McAlester Formation. In addition, all known conodont intervals and black fissile phosphatic shales have been identified on this curve. For reference, the sea level curve extends through the overlying Marmaton Group.

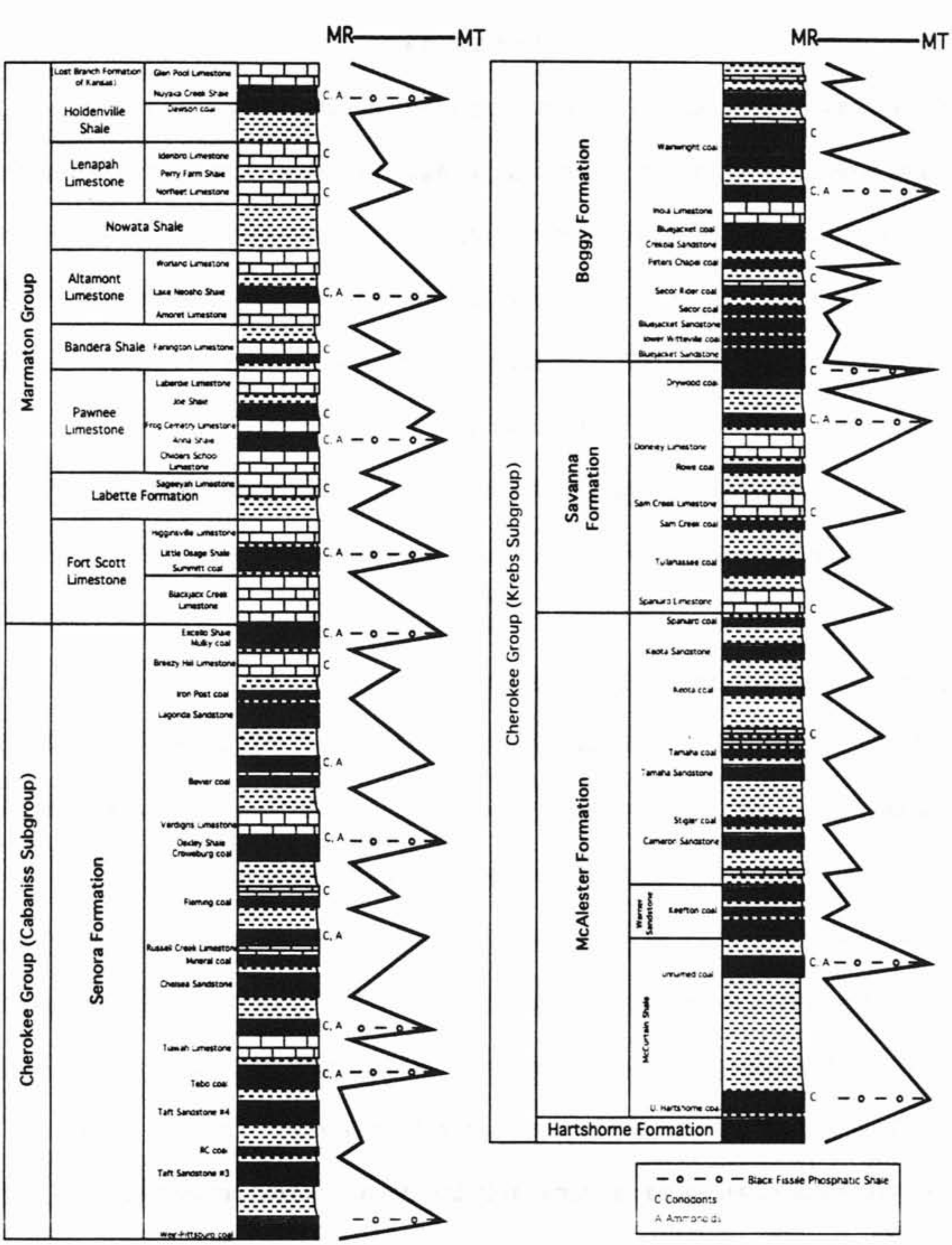

FIGURE 10. Sea level curve for the Cherokee Group, curve for the overlying Marmaton Group included for reference (Boardman, Marshall, and Lambert, 2002, p.28)

V.

Future Work

As stated in the introduction, the purpose of this study was solely to determine the number of marine transgressions and regressions in the Cherokee Group in Oklahoma and to draw up a sea level curve for the entire Cherokee Group. However, a great amount of work is still needed to fully realize the sequence stratigraphy of the Cherokee Group. There are three main tasks needed to accomplishing this: 1. correlation of T-R cycles throughout the Midcontinent, 2. subsurface correlation of T-R cycles, and 3. providing proper stratigraphic names to many of the unnamed shales and limestones of the Cherokee Group. Once all of these goals are accomplished, construction of a sequence stratigraphic framework can begin.

The first goal can be accomplished immediately. Since the stratigraphy of the northern Midcontinent differs dramatically, lithostratigraphic analysis would fail, but these transgressive-regressive cycles are continuous as far north as Iowa. As an example, the Tiawah Limestone is not recognized in Iowa, but both the Tiawah and its equivalent in Iowa have shales beneath them with a high abundance of the deep-water conodont *Gondolella*. A high abundance of *Gondolella* is extremely rare having only been observed once in the entire Cherokee interval. Since two separate shales with a high *Gondolella* abundance is unlikely, these two shales might be equivalent. If so, with the direct correlation of the *Gondolella* interval, that particular transgressive-regressive cycle is present in both Oklahoma and Iowa and can be considered to be persistent throughout much of the Midcontinent, and there are many more such cycles that are just as persistent. Since the Cherokee Group is the most complete in Oklahoma, the best way to correlate these cycles throughout the Midcontinent is to establish them in Oklahoma and see how many are traceable to the north. With the establishment of 28 cyclothems in Oklahoma, the question can now involve identifying these 28 cycles, if possible, in Iowa, Kansas, and Missouri. Ultimately, the cycles of the Midcontinent could be correlated with cycles in Illinois, Kentucky, and the Appalachian Mountains.

Once surface correlations of T-R cycles are completed, it is important to determine what happens to these cycles in the subsurface. Deep core studies (over 500 feet (150 meters) deep) are necessary to trace out the cyclothems over larger areas within the basin and shelf. By doing so, a three-dimensional mapping of the cyclicity of the Cherokee Group is possible. Such a map can provide a very good model for the subtle facies change that occurs within each cyclothem throughout the Midcontinent, and this would make future recognition of these cycles in more diverse areas possible.

Several shales and limestones need to be given proper stratigraphic nomenclature. Cyclothems with all major components properly named would make future recognition and characterization of cyclothems far away from their type area easier. As an another example, the *Gondolella* abundant shale along with the Tiawah Limestone is part of the Tiawah cyclothem in Oklahoma. If the shale was given a proper stratigraphic name in Oklahoma and was equivalent to the shale in Iowa, it is possible to directly correlate the cyclothem to Iowa. Therefore, even if the Tiawah Limestone were not recognized in Iowa, the shale could be acknowledged making recognition of the Tiawah cyclothem in Iowa easier.

To establish stratigraphic names for these unnamed beds, the following recommendations are made…

1. Determine the location of exposures of the unnamed shale or limestone with the best conodont fauna and/or developed lithofacies. Best-developed lithofacies implies the presence of things such as phosphate nodules or some other distinct feature yet to be determined.
2. Provide a detailed measured section of the outcrop where this bed is best exposed.
3. Formally establish the type locality.
4. Name the unit according to proper stratigraphic procedure.

Once this is accomplished, it will be possible to utilize the name of the unit to correlate T-R cycles. For example, the post Bevier coal cyclothem might extend from Kansas to Oklahoma because the black shale above the Bevier coal is found in both Kansas and Wagoner County, Oklahoma. So, if the black shale above the Bevier coal is assigned a proper name, then it may be easier to recognize the extent of the post Bevier coal cyclothem.

Combined with the extensive previous studies of the sandstones, both surface and subsurface, of the Cherokee Group, a three-dimensional model of Cherokee cyclicity could be established for the transition from the basin to the shelf. From this, proper sequence stratigraphic work, such as establishing transgressive systems tract, highstand, regressive systems tract, etc…, could begin within the Cherokee Group.

VI.

Conclusions

28 tentative cyclothems have been identified within the Cherokee Group. No cyclothems have been identified within the Hartshorne Sandstone, which may be deltaic. Seven cyclothems have been identified in the McAlester Formation, and the Savanna Formation has five cyclothems. The Boggy Formation also has seven cyclothems. The Senora Formation contains the most number of cyclothems, nine. Because the outcrops in this study are oriented towards the basin, both the McAlester, Savanna, and Boggy Formations have the biggest increase in cycle numbers; marine intervals of these three formations are more apparent in outcrops in the basin than on the shelf. The number of coal cycles of the Senora Formation agrees with the amount of coal cycles in the Senora Formation from previous cyclicity studies of the Cherokee Group.

Of these 28 cyclothems, 17 contain black phosphatic shales. Most of the phosphatic bearing black shales are concentrated within the Senora Formation. However, within the lower McAlester Formation, black phosphatic shales have been identified above the upper Hartshorne coal and above an unnamed coal that may be the Brushy Mountain coal. Major black phosphatic shale intervals are found above the Rowe coal and Doneley Limestone, and the Drywood coal within the Savanna Formation. Approximately four black phosphatic shales are in the Boggy Formation. In near surface core, black phosphatic shales are above the Secor Rider and Peters Chapel coals. A major black phosphatic shale interval is above the Inola Limestone. Black phosphatic shales were also described above the Wainwright coal.

Major marine transgressions, as illustrated on the sea level curve (p. 95), may have taken place at several points in the Cherokee Group. The earliest major transgressions may have occurred above the upper Hartshorne coal and Brushy Mountain coal. In the upper part of the Savanna Formation, major transgressions may have occurred above the Doneley Limestone and Drywood coal. In the Boggy Formation, a major transgression may have taken place above the Inola Limestone, and a significant transgression may have occurred above the Wainwright coal. Several major marine transgressions have been identified within the Senora Formation. The earliest major transgression in the Senora Formation occurred above the Weir-Pittsburg coal. Other major transgressions may have taken place between the Tebo coal and Tiawah Limestone, above the Tiawah Limestone, above the Bevier coal, and at the Oakely Shale. The Excello Shale, the uppermost member unit of the Senora Formation and the Cherokee Group, is a major transgressive shale recognized from Oklahoma to Illinois.

Four main conodont genera were identified during this study: *Idiognathodus*, *Idioprioniodus*, *Neognathodus*, and *Gondolella*. *Idiognathodus* is found in limestones, black phosphatic shales, grey shales, clay shales, and even some silty shales. *Neognathodus* is normally associated with *Idiognathodus*. *Idioprioniodus* is found in black shales and black phosphatic shales; however, some limestones also contain *Idioprioniodus*. *Gondolella* is a deep water conodont found in black phosphatic shales. *Gondolella* was identified in black shales above the Inola Limestone, below the Tiawah Limestone, and within the Oakely Shale.

New conodont bearing intervals were identified for the first time within this study. Previously, conodonts have been identified from the Spaniard Limestone, Sam

Creek Limestone, Tiawah Limestone, Oakely Shale, Verdigris Limestone, shales above the Bevier coal, and the Excello Shale. In the McAlester Formation, new conodont intervals were identified in the shales above the upper Hartshorne coal and possibly the Brushy Mountain coal. In the Savanna Formation, conodont fragments were identified in the black shales above the Rowe coal and Doneley Limestone, and the Drywood coal. Within the Boggy Formation, conodonts were identified in shales above the Secor Rider and Peters Chapel coals. Black shales above the Inola contain conodonts as well, and conodonts are also found in the shales above the Wainwright coal. Some new conodont intervals in the Senora include possibly the shales above the RC coal, shales above the Russell Creek Limestone, the Fleming Limestone, and possibly the Kinnison Shale.

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APPENDIX A- DETAILED DISCUSSION OF PREVIOUS STUDIES
A.

Stratigraphy

The Cherokee Group, the lowermost of the Desmoinesian Stage, consists of siliciclastics and carbonates. The siliciclastics and carbonates of the Cherokee are repeated throughout the section in a series of cycles or cyclothems. A typical sequence within the Cherokee Group may consist of a coal, gray shale, black phosphatic shales, limestone, another gray and/or black phosphatic shale, a fluvial or deltaic sandstone, and an underclay or paleosol. The fluvial sandstone and underclay may represent the point of maximum regression of the sequence. Coals, being mostly coastal deposits within the Cherokee, mark the beginning of transgression. The black phosphatic shale, when present, usually represents the point of maximum depth. Heckel (1977) has termed these particular shales core shales. A gray or silty shale above the black phosphatic shale is the regressive phase of the sequence while the upper fluvial sandstone marks another point of maximum regression. Sequence boundaries may be incisement surfaces of fluvial sandstones or disconformities between shales and/or limestones.

Lithostratigraphic Description

Haworth and Kirk (1894), in southeastern Kansas, termed the interval between the Mississippian System and the Fort Scott Formation of the Marmaton Group the "Cherokee shales". Abernathy (1936) believed that the Cherokee shales could be considered a group since it was possible to subdivide the interval into formations. Moore (1949, p.17, figure 2) officially recognized the Cherokee Shales as the Cherokee Group.

North of Oklahoma, Moore (1949, p.39) stated that the Cherokee Group was thickest in the Forest City basin in northeastern Kansas and northwestern Missouri. There, the Cherokee Group is over 700 feet (210 meters) thick. In southeastern Kansas, Moore (1949, p.39) stated that the average thickness of the Cherokee Group was around 400 feet (120 meters); in Labette County, Kansas, the Cherokee Group was the thickest at 500 feet (150 meters). Southward into Oklahoma, the Cherokee Group thickens considerably. Oakes (1953) divided this same interval into the Krebs and Cabaniss Group. Searight and others (1953) recognized the Krebs and Cabaniss Groups as the official division of the Cherokee interval, and therefore, the Cherokee Group became an unofficial name. Branson (1954, p.1) also noted that the term "Cherokee" was dropped from formal nomenclature in Oklahoma. However, Howe (1956, p.21) reported that, during a meeting in Lawrence, Kansas on October 17, 1955, the term "Cherokee" was re-instated to group status relegating the Krebs and Cabaniss as subgroups. In this report, the Cherokee will be recognized as a group while the Krebs and Cabaniss will be recognized as subgroups.

In Kansas, the Cherokee Group includes everything from the top of the Mississippian System to the base of the Marmaton Group. In Oklahoma, the Cherokee Group includes everything from the top of the Atoka Formation to the base of the Fort Scott Formation of the Marmaton Group.

KREBS GROUP (SUBGROUP)

Oakes (1953) further divided the Cherokee Group into two smaller groups: the Krebs and the Cabaniss (which will both be treated as subgroups within this study). The lowermost group or subgroup is the Krebs. The Krebs is also the lowermost unit of the

Desmoinesian Stage. Oakes (1953) named the Krebs from the town of Krebs in Pittsburg County, Oklahoma, approximately one mile (1.6 km) east of McAlester, Oklahoma. The top of the Krebs Subgroup is the top of the Boggy Formation, and the Krebs conformably overlies the Atoka. However, the contact between the Krebs and the Cabaniss is probably unconformable (Oakes, 1953). In the Arkoma basin, the Krebs is overlain by two minor formations of the Cabaniss: the Thurman Sandstone and the Stuart Shale, but once on the shelf, both formations abruptly disappear leaving an unconformity between the Krebs and Cabaniss (Oakes, 1953).

Along the axis of the Arkoma Basin, the Krebs is significantly thicker than the Cabaniss. West of McAlester, not far from its type locality, the Krebs is approximately 6,000 feet (1800 meters) thick, and eastward to around Poteau, Oklahoma in Le Flore County, it is over 8,000 feet (2400 meters) thick (Oakes 1953). However, northward onto the Northeast Oklahoma Shelf, the Krebs thins considerably: around 540 feet (162 meters) thick at the Arkansas River, and 340 feet (102 meters) thick along the Kansas-Oklahoma border (Oakes, 1953).

Both the Krebs and Cabaniss Subgroups are further divided into formations. Oakes (1953) listed the four formations of the Krebs in ascending order as the Hartshorne, McAlester, Savanna, and Boggy. Each formation is further divided into member units, which will be discussed on the following pages.

Hartshorne Formation or Sandstone

H.M. Chance (1890) first named the sandstones of the Hartshorne Formation as the "Tobucksy" which he termed as a 200-foot (60-meter) basal sandstone. Taff (1899, p.436) gave the sandstone the name "Hartshorne" after the type locality near Hartshorne, Oklahoma in Pittsburg County. Taff described the Hartshorne Sandstone as a brown to light gray sandstone with a thickness of up to 200 feet (60 meters) (1899,p. 436). Oakes and Knechtel (1948, p.25) raised the contact between the Hartshorne and McAlester to the top of the upper Hartshorne coal. The Hartshorne Formation overlies the Atoka Formation and underlies the McAlester Formation. Oakes (1953) placed the Hartshorne Formation within the Krebs Subgroup.

Hartshorne coal

Taff (1899) also named the Hartshorne coal, and Taff and Adams (1900) divided the unit into the lower and upper Hartshorne coals. Wilson (1935, p.507) placed the upper Hartshorne coal as the base of the McAlester Formation. However, in 1948, Knechtel observed that both the lower and upper Hartshorne coals underwent a northward and westward convergence within Le Flore County in southeastern Oklahoma. He further stated that in northern Le Flore County and Haskell County both coals had to be mapped as one unit (Oakes and Knechtel, 1948, p.24). Oakes and Knechtel (1948, p.24) proposed two solutions to deal with the problem of convergence and determining the upper boundary of the Hartshorne Formation:

> "1. Revert to Taff's original usage and that followed by Arkansas geologists, by lowering the top of the Hartshorne sandstone to the top of the first sandstone below the Lower Hartshorne coal, thus placing both coals in the McAlester formation.
>
> 2. Raise the top of the Hartshorne sandstone to the top of the Upper Hartshorne coal, thus including both coals in the Hartshorne."

They chose the second solution establishing the contact between the Hartshorne and McAlester Formations at the top of the upper Hartshorne coal; Oakes and Knechtel (1948, p.25) gave two reasons for this decision:

> "The first (solution) appears more logical, both on the grounds of stratigraphic history and precedent of usage; but the latter (solution) is considered more desirable from a utilitarian standpoint, because of the association of the name Hartshorne, and because it probably will cause least confusion among Oklahoma geologists."

The thickness of the two Hartshorne coals has been reported at around 0.8 feet (0.24 meters) (Wilson, 1935, p.508). Hemish (1987, p.99) listed the thickness of an undifferentiated Hartshorne coal from 0.1 (0.3 meters) to 0.4 feet (0.12 meters).

<u>McAlester Formation</u>

Taff (1899, p.437) named 2,000 feet (600 meters) of shale, sandstones and coals the McAlester Shale from exposures around McAlester, Pittsburg County, Oklahoma. He established three units for the formation as well. The lower unit consists of 800 feet (240 meters) of shale with thin sandstones and coals; the middle unit consists of three or four sandstones separated by shales from 100 to 200 feet (30 to 60 meters) thick, 500 feet (150 meters) total thickness. The uppermost unit is 700 feet (210 meters) of shale. Furthermore, Taff (1899, p.437) recognized two coal beds within the McAlester Formation: the Hartshorne coal at the base, and the McAlester coal approximately 50 feet (15 meters) above the base. He also described a fossiliferous iron ore associated with 50-foot (15-meter) thick-bedded sandstone near and below the McAlester coal (Taff, 1899, p.451). He believed that the sandstone and possibly the ore were laterally continuous throughout the area surrounding McAlester, Oklahoma.

Wilson (1935, p.507) placed the upper Hartshorne coal and the McAlester or Stigler coal within the McAlester Formation. He further stated the upper Hartshorne coal occurred near the base anywhere from a few inches to four feet above the Hartshorne Formation. In addition, Wilson recognized four new members to the McAlester Formation, in ascending order: the McCurtain Shale, Warner Sandstone, Lequire Sandstone, and Cameron Sandstone. Wilson placed the base of the McAlester Formation with the top of the Hartshorne Formation. The Savanna Formation overlies the McAlester Formation, but Wilson placed the McAlester and Savanna contact at the base of the Tamaha Sandstone (1935, p.508).

Hendricks (1937, pp.13-15), like Taff (1899), divided the McAlester Formation into three units. The lowermost unit consisted of 500 to 640 feet (150 to 192 meters) of shale; the upper Hartshorne coal was located approximately 1 to 50 feet (0.3 to 15 meters) above the base of the McAlester Formation. The lower 350 feet (105 meters) consisted mostly of interbedded thin sandstones, shales, and coal. The middle unit is 595 to 1,030 feet (179 to 309 meters) of shale with as many as five sandstone members present, but, however, three sandstone units are common in most places. The thickness of the sandstones range from a few feet to 140 feet (42 meters). Hendricks (1937, p.14) noted a significant coal unit just above the second sandstone. The uppermost unit is 300 to 925 feet (90 to 278 meters) of shale. The base of this unit has been placed at the top of the first sandstone below the McAlester (Stigler) coal, which is only a few feet above. Also, Hendricks (1937, p.15) identified several types of marine and marginal marine invertebrate fossils from two primary intervals: just above the McAlester (Stigler) coal, and an interval near the top of the McAlester Formation. Hendricks's (1937) breakdown of the McAlester Formation coincided well with Taff's (1899).

Hendricks (1937) and Dane and others (1938) believed that the contact between the McAlester and overlying Savanna Formations was probably unconformable. Knechtel (1937, p.106), however, did not find any other evidence of an unconformable McAlester-Savanna contact. And, Hemish (1997a, p.202-203) stated that the McAlester-Savanna contact was generally conformable. However, Hemish and Suneson (1997) did elaborate by stating that the McAlester-Savanna contact was paraconformable locally.

Knechtel (1937, p.105) identified plant, invertebrate, and vertebrate fossils from the McAlester Formation. The vertebrate fossils found were mainly fish teeth and debris. This led Knechtel (1937, p.105) to conclude that the McAlester Formation had both marine and terrestrial deposits.

Hendricks (1939, p. 268-269) stated that McAlester Formation in the eastern part of the basin (Le Flore and Latimer Counties) has at least two continuous sandstone units although there may be up to seven sandstone units locally. He also identified lenticular units of fossiliferous limestones locally within the McAlester Formation. Hendricks (1939, p.269) placed the upper Hartshorne coal 2 to 30 feet (0.6 to 9 meters) above the base of the McAlester Formation; the McAlester coal was placed 20 to 100 feet (6 to 30 meters) above the second persistent sandstone in the formation. Interestingly, he correlated the Stigler coal with a continuous coal bed 58 feet (17 meters) above the McAlester coal. Later workers believe that the McAlester coal itself is equivalent to the Stigler coal. Above the Stigler coal, Hendricks (1939, p.269) stated that there were four more coals present locally between it and the top of the McAlester Formation.

Oakes and Knechtel (1948, p.27) included the Tamaha and Keota Sandstones in the McAlester. The base of the McAlester Formation was readjusted to exclude the upper Hartshorne coal. Therefore, after the readjustments, the member units of the McAlester Formation were, in ascending order: the McCurtain Shale, Warner Sandstone, unnamed shale, Lequire Sandstone, unnamed shale, Cameron Sandstone, unnamed shale, Tamaha Sandstone, unnamed shale, Keota Sandstone, and unnamed shale. Oakes (1953) placed the McAlester Formation within the Krebs Subgroup. Hemish (1997a, p.207) established a composite-stratotype for the McAlester Formation utilizing five measured sections from the Blanco-Ti Creek-Gardner Creek area southwest of Hartshorne in eastern Pittsburg County, Oklahoma. Hemish (1997a, p.218) further stated that the three units of the McAlester Formation as described by Taff (1899) and Hendricks (1937) are readily apparent within the composite-stratotype.

The McAlester Formation is thickest within the Arkoma Basin. This is where the coals of the McAlester Formation are also best developed. Because of the thickness and favorable economic potential of the coals within the McAlester Formation, most of the studies about the McAlester Formation have taken place in the Arkoma Basin. Some studies of the McAlester Formation on the Northeast Oklahoma Shelf or Platform have been made. However, most of these studies were conducted in the northern part of the Midcontinent in Kansas or Missouri. Not only are these areas beyond the scope of this study, but most of the stratigraphic nomenclature of Kansas and Missouri are not recognized in Oklahoma.

Taff (1899) stated that the McAlester Formation was around 2,000 feet (600 meters) thick in its type locality near McAlester, Pittsburg County, Oklahoma. Morgan

(1924) listed the thickness of the McAlester Formation at the west line of the Coalgate quadrangle in southeastern Coal County, Oklahoma as more than 1,000 feet (300 meters). Hendricks (1937, p.15), within the McAlester district of Pittsburg, Atoka, and Latimer Counties, Oklahoma, gave a range of 1,904 to 2,420 feet (571 to 726 meters). However, southeast of Savanna, Oklahoma in central Pittsburg County, the McAlester Formation, at two localities only a mile (1.6 km) apart, is 1,500 and 2,800 feet (450 to 840 meters) thick, respectively. Hendricks (1937, p.15) explains the extreme range in thickness at such a short distance due to horizontal compression of the soft shales.

Knechtel (1937, p.104) examined the thickness of the McAlester Formation at several locations. In the central part of T1S, R10E, near Lehigh in the southern part of Coal County, about 1,650 feet (495 meters) of McAlester Formation was observed and measured. Over six or seven miles (10 to 11 km) to the northeast but still in Coal County, on the south limb of the Coalgate anticline, Secs. 10 and 15, T1N, R11E, over 1,000 feet (300 meters) of McAlester Formation was measured. From a well drilled in the NE1/4 Sec. 19, T3N, R12E in extreme southwestern Pittsburg County, around 1,150 feet (345 meters) of McAlester Formation was obtained. Knechtel (1937, p.104) further reported that in a well drilled by the Carter Oil Company in Centrahoma, central Coal County, 930 feet (279 meters) of rocks between the Atoka and Savanna Formations were encountered. The company geologists determined that the rocks were probably part of the McAlester Formation since the Hartshorne Sandstone was either unrecognizable or absent.

Hendricks (1939) studied the McAlester Formation in northern Latimer and north central Le Flore Counties. He reported the thickness of the McAlester Formation from several localities in that area. Southeast of Red Oak, Oklahoma, in northeastern Latimer County, he reported a thickness of 2,830 feet (849 meters) for the McAlester Formation. On the south side of Poteau Mountain, in Le Flore County, Hendricks calculated a thickness of 1,240 feet (372 meters) for the McAlester Formation. He further added that this thickness was identical to that reported in a gas well drilled in Sec. 11, T5N, R26E. Overall, throughout the northern Latimer-north central Le Flore area, Hendricks (1937, p.269) provided a range of 2,000 to 2,400 feet (600 to 720 meters) for the McAlester Formation. However, Hendricks (1939, p.271) placed the greatest thickness of the McAlester Formation at over 2,250 feet (675 meters) just southeast of McAlester, Oklahoma.

Oakes and Knechtel (1948) described the thickness of the McAlester Formation in Haskell County from 700 to 2,000 feet (210 to 600 meters). Suneson and Hemish (1996) found 1,600 to 2,000 feet (480 to 600 meters) of McAlester Formation in the Hartshorne SW quadrangle in eastern Pittsburg County. Nearby, Hemish (1997a, p.219) stated that thickness of the McAlester Formation in the composite-stratotype is 1,816 feet (545 meters).

Two main reports, Wilson (1935) and Wilson and Newell (1937), dealt with the McAlester Formation in the basin to shelf transition zone within Muskogee County. Wilson (1935, p.507) described surface thickness of the McAlester Formation in Muskogee County between 125 and 150 feet (38 to 45 meters) and well log thickness between 150 to 500 feet (45 to 150 meters). Wilson and Newell (1937, p.36) stated that the McAlester Formation is 220 feet (66 meters) thick in northern Muskogee County and 380 feet (114 meters) in northeastern McIntosh County. On the shelf, Hemish (1987, p.99) listed a thickness of 100 to 400 feet (30 to 120 meters) for the McAlester Formation in northeastern Oklahoma.

McCurtain Shale Member

Wilson (1935, p.508) named the McCurtain Shale Member of the McAlester Formation after the fact that McCurtain, Haskell County, Oklahoma was built upon the shale. He placed the McCurtain Shale as the lowest member unit of the McAlester Formation containing the upper Hartshorne coal and overlying the Hartshorne Formation. The McCurtain Shale was described as a series of sandy, calcareous, and dark blue fissile shales with the upper Hartshorne coal above the sandy shale and below the calcareous shale. Thickness of the unit is about 171 feet (51 meters).

Wilson and Newell (1937, p.37) provided a detailed description of the McCurtain Shale when they wrote:

> "This unit consists almost entirely of shale, unbroken by resistent beds. The lower half is commonly dark gray to black, slabby, and silty, and contains abundant unfossiliferous clay-ironstone concretions. The upper half is argillaceous, and buff to greenish, and concretions are not generally abundant. A thin coal bed ranging from an inch [2.54 cm] or so to more than one foot [0.3 meters] occurs at the base of the McCurtain division in Tps. 12 and 13 N."

Oakes and Knechtel (1948, p.31) adjusted the base of the McCurtain Shale to the top of the upper Hartshorne coal and stated the McCurtain Shale includes strata above the top of the upper Hartshorne coal and below the base of the Warner Sandstone. They also identified a calcareous fossiliferous zone at a road cut at the center of Sec. 15, T8N, R 22E about a mile and a half (2.4 km) north of McCurtain, Oklahoma. Oakes and

Knechtel (1948, p.32) described a thickness of the McCurtain Shale from 200 to 500 feet (60 to 150 meters) thick in Haskell County.

Riverton coal

Originally termed the "Little Cabin coal" in 1935 by Pierce, et. al., Pierce and Courtier (1937, p.62) renamed it the Riverton coal after Riverton, Kansas in Cherokee County in order to conform to usage adopted by the Kansas Geological Survey. They placed the Riverton coal approximately 15 to 20 feet (4.5 to 6 meters) above the base of the Cherokee Group and described its thickness from 3 to 14 inches (7.6 to 36 cm). Searight and others (1953, p. 2748) placed the Riverton coal as the uppermost member of the Riverton Formation of the northern Midcontinent. Howe (1956, p.29-31) described the Riverton Formation as the lowermost Desmoinesian unit including everything up to the top of the Riverton coal. He also believed that the Riverton Formation may be equivalent to the McCurtain Shale Member in Oklahoma, and that the coals of the Riverton Formation may correlate to the upper Hartshorne coal. Howe (1956, p.31) also broke the Riverton Formation up into three primary units: a 4- to 13-foot (1.2- to 3.9-meter) basal dark gray to black fissile shale; 2- to 4-foot (0.6- to 1.2-meter) underclay; and the Riverton coal, the uppermost unit of the Riverton Formation. He also described the Riverton coal as being about one to two feet (0.3 to 0.6 meters) in thickness; the total thickness of the Riverton Formation (as described by Howe) is about 10 to 20 feet (3 to 6 meters) with an average thickness of 15 feet (4.5 meters) (1956, p.31).

Reed and others (1955) proposed the equivalency of the Riverton coal of the Northeast Shelf area with the upper Hartshorne coal of the Arkoma Basin. However during personal communication between Robert O. Fay and Leroy A. Hemish in 1979, Fay established that the McCurtain Shale Member was present in the Northeast Shelf area; this meant that the Riverton coal is probably stratigraphically higher than the upper Hartshorne coal (Hemish, 1987). Hemish (1987, p.99) described the thickness of the Riverton coal from 0.1 to 0.3 feet (0.03 to 0.09 meters) in northeastern Oklahoma.

Brushy Mountain coal

Hemish (1998, p.9) proposed this name from an exposure of coal on Brushy Mountain in southeastern Muskogee County. The location of the type locality is NE1/4SW1/4SW1/4SW1/4 Sec. 27, T14N, R19E, and two other occurrences of the Brushy Mountain coal were given by Hemish as Sec. 7, T15N, R19E and Sec. 11, T15N, R18E (1987, p.9). In the type locality of the coal, Hemish (1998, p. 9) listed a thickness of 0.2 feet (0.06 meters) for the Brushy Mountain coal, and, according to Hemish, the Brushy Mountain coal lies somewhere near the middle of the McCurtain Shale. Thickness for the coal in the other two locations range from 0.1 to 0.4 feet thick (0.03 to 0.12 meters).

Warner Sandstone Member

In 1914, Ohern termed this sandstone member unit the Little Cabin (Howe, 1956, p.33). Wilson (1935, p. 508) named the unit the Warner Sandstone from an exposure 1 mile (1.6 km) north of Warner, Muskogee County, Oklahoma; the thickness of the Warner Sandstone in its type area is approximately 40 feet (12 meters). Wilson and Newell (1937, p.37-39) stated that the Warner Sandstone is one of the most prominent escarpments in the Muskogee area and described it as, "massive, bluff, calcareous, and hard sandstone," and they also stated that the Warner Sandstone is equivalent with the Little Cabin Sandstone of northeastern Oklahoma and Kansas. Wilson (1935, p. 508) stated that the thickness of the Warner Sandstone was around 40 feet (12 meters), and Wilson and Newell (1937, p. 37) gave a thickness of 5 to 30 feet (1.5 to 9 meters). Oakes and Knechtel (1948, p.33) stated that the location of the type locality of the Warner Sandstone is, "about one-fourth of a mile east of the northwest corner of sec. 21, T. 21 N., R. 19 E., 1 mile [1.6 km] north of Warner." Oakes and Knetchel also stated that the Warner Sandstone was the most prominent sandstone above the base of the McAlester Formation with an exception of a sandstone in the McCurtain shale (1948, p.34).

At a conference on classification and nomenclature of rocks in the Cherokee Group in Nevada, Missouri in 1953, Searight and others chose "Warner" over "Little Cabin" as the official name of the sandstone due to widespread usage (Howe, 1956, p.33). Howe (1956, p.33) described the Warner Sandstone as fine to medium-grained quartz arenite with abundant mica. He divided the sandstone into two units: a lower, massively cross-bedded interval, 10 to 15 feet (3 to 4.5 meters) thick; and 5 to 10 feet (1.5 to 3 meters) of siltstone and sandy shale overlain by 5 feet (1.5 meters) of massive sandstone. According to Howe, the Warner Sandstone is continuous from its type locality near Warner, Oklahoma to the Oklahoma-Kansas state line and from there up to western Missouri (1956, p.33). Howe described the thickness of the Warner Sandstone from 10 to about 25 feet (3 to 7.5 meters). The Warner Sandstone is underlain by the McCurtain Shale and overlain by an unnamed shale member.

Keefton coal

Hemish (1998, p. 9) named the Keefton coal from outcrops 1 to 2 miles (1.6 to 3.2 km) southwest of Keefton, Oklahoma and established the type locality in the NE1/4NE1/4SE1/4SE1/4 Sec. 28, T13N, R18E. At the type locality, the Keefton coal is 0.7 feet (0.21 meters) thick, and the maximum thickness of the Keefton coal is around 1.0 feet (0.3 meters) (Hemish, 1998). Hemish stated that the Keefton coal is equivalent to the Warner coal named by Bennison and others (1979), but Keefton was chosen to conform to usage standards set by the Oklahoma Geological Survey (1987, pp. 108-109). The Keefton coal may the coal bed in the upper part of the Warner Sandstone described by Oakes and Knechtel (1948, p. 34). Hemish (1987, p.99) described the thickness of the Keefton coal on the shelf from 0.1 to 1.0 feet (0.03 to 0.3 meters) thick.

Lequire Sandstone Member

Wilson (1935, p.508) named a 25-foot (7.5-meter) bed of sandstone above the Warner Sandstone the Lequire Sandstone. It was named after exposures north of Lequire, Haskell County, Oklahoma. He provided type localities at Secs. 4 and 5, T7N, R21E, and Secs. 32, 33, and 34, T8N, R21E and described it as, "Massive sandstone; medium texture; friable; brown-to-gray; contains plant remains." Wilson and Newell (1937, p.41) provided a thickness ranging from 8 to 10 feet (2.4 to 3 meters) at T10N to three feet (0.9 meters) at T13N; they further stated that the Lequire is replaced by shale northward. Oakes and Knechtel (1948, p.37) corrected Wilson's type localities stating that those outcrops are actually of the Warner Sandstone. They provided a corrected locality at Sec. 31, T8N, R21E about 1.5 miles (2.4 km) north of Lequire. The Lequire

Sandstone overlies an unnamed shale above the Warner Sandstone and underlies an unnamed shale and sandstone (Oakes and Knechtel, 1948, pp.38-39).

Cameron Sandstone Member

Named by Wilson (1935, p.507), he described the sandstone as, "Commonly thin and regularly bedded, but locally massive and irregularly bedded; fine-to-medium texture; usually light gray, but in places brown; ...ripple marks common; fossiliferous." Wilson also described a thickness of 20 feet (6 meters) for the member unit. The Cameron Sandstone was named after exposures northwest and west of Cameron, Le Flore County, Oklahoma, T8N, R26E (Wilson, 1935, p.507). The Cameron Sandstone overlies unnamed shales and sandstones above the Lequire Sandstone and underlies an unnamed shale; the Stigler coal is only a few feet above the Cameron Sandstone (Oakes and Knechtel, 1948, pp. 39-40).

Stigler coal

Chance (1890) first named this coal as the McAlester coal after McAlester, Oklahoma in Pittsburg County, and, in a generalized columnar section of the area, he listed a thickness of 4 feet (1.2 meters) for the coal. Taff (1904) applied the name "Stigler" to coal beds around Stigler, Oklahoma in Haskell County. The name "Stigler" appeared on a map identifying these coal beds. Taff (1899, p.437) placed the McAlester (Stigler) coal approximately 50 feet (15 meters) above the base of the McAlester Formation. Wilson and Newell (1937, p.42) placed the Stigler coal from a few inches to about five feet (1.5 meters) above the Cameron Sandstone; they also listed a thickness from a thin streak to about 2 feet (0.6 meters). A half-foot (0.15-meter) thick limestone or calcareous shale overlies or is just above the Stigler coal (Wilson and Newell, 1937, p.42). Friedman (1974, p.28) believed that the McAlester coal correlated with the Stigler coal. However, Hemish (1987, p.108) stated that widespread usage of the name "Stigler" should prevent it from being abandoned in favor of the older name, "McAlester coal".

Tamaha Sandstone Member

In 1935, Thom named the Tamaha Sandstone from exposures around Tamaha, Haskell County, Oklahoma (Wilson, 1935, p.509). Wilson (1935, p.509) placed the Tamaha Sandstone as the lowest member of the Savanna Formation and described it as:

> "Thin-bedded, slabby sandstone, rarely massive; bedding regular; fine-to-medium texture; color brown; in places greenish brown and gray, weathering to dark brown; contains much mica and many dark, argillaceous streaks; ripple marks abundant."

He also stated that the Tamaha Sandstone was around twenty feet (6 meters) thick. Wilson and Newell (1937, p.43) described the Tamaha Sandstone as shaly or thin-bedded and unfossiliferous. Oakes and Knechtel (1948, pp.40-42) corrected several aspects of the Tamaha Sandstone. First, they placed it within the McAlester Formation instead of the basal Savanna Formation. Second, Oakes and Knechtel stated that the type locality established for the Tamaha Sandstone is actually an exposure of a combined Warner-Lequire Sandstone, and they (1948, p.40) provided a corrected type locality at Sec. 30, T11N, R22E, 2 miles (3.2 km) west of Tamaha, Oklahoma. The Tamaha Sandstone is underlain by an unnamed shale and overlain by an unnamed shale (Oakes and Knechtel, 1948. P.39). A few feet above the Tamaha Sandstone, the Tamaha coal is found (Wilson and Newell, 1937).

Tamaha coal

Wilson and Newell (1937, p.44) first made mention of the Tamaha coal when they wrote, "A thin coal bed, from 5 to 15 feet [1.5 to 4.5 meters] 13N., and probably is also present in T. 12N." Bennison and others first published the name "Tamaha coal" in 1979 (Hemish, 1987, p.108).

Keota coal

Wilson and Newell (1937, p.44) first mentioned this coal:

> "A persistent coal and overlying limestone occur in the midst of the Keota division, as mapped by Wilson in the southern part of the area. Traced northward the lower sandstone of the section becomes sporadic, and at many localities is absent. Where this lower sandstone of the Keota is absent the unnamed coal has been arbitrarily selected as the basal unit."

They further stated that, "The lower sandstone is generally absent in Tps. 13 and 14 N., but the coal, limestone, and upper Keota beds are quite persistent and uniform." (Wilson and Newell, 1937, p.45). At a locality in Sec. 10, T12N, R18E, Wilson and Newell (1937, p. 45) listed a coal (possibly the Keota) as 0.2 feet (0.06 meters) thick. Hemish, in the preparation of the Coal Geology of McIntosh and Muskogee Counties, Oklahoma, named the coal the "Keota coal bed" because of its association with the Keota Sandstone (Hemish, 1987, p.107).

Keota Sandstone Member

Thom, in 1935, named the Keota Sandstone after exposures near Keota, Haskell County, Oklahoma (Wilson, 1935, p.509). Initially, the Keota Sandstone was a member unit of the Savanna Formation (Wilson, 1935, p.509 and 510); later, the Keota Sandstone was included as a member of the McAlester Formation by Oakes and Knechtel (1948, p.27). Wilson and Newell (1937, p.44-45) established six separate lithologic units as belonging to the Keota Sandstone, including two sandstones: 1. lower shaly sandstone, 2. gray shale with an upper underclay, 3. coal, 4. ferruginous limestone, 5. gray silty shale, and 6. an upper calcareous sandstone. According to Wilson and Newell, the lower sandstone is not laterally continuous, but the upper sandstone is quite "persistent and uniform" (1937, p.45). On a generalized section of the Keota Sandstone, Sec. 10, T12N, R18E, Wilson and Newell (1937, p.45) listed a thickness of 28.4 feet (8.5 meters) for all six units of the Keota Sandstone. Oakes and Knechtel (1948, p.43) described the Keota Sandstone as having a variable thickness and called it, "a sequence of lenticular sandstones and arenaceous shale beds, locally including one or more coal seams of no economic value."

An unnamed shale overlies the Keota Sandstone, and it has widely varying descriptions of thickness and lithology. In southern Muskogee County, Wilson (1935, p.509) called it a brown, sandy shale, fifty feet (15 meters) thick. In the northern part of Muskogee County, the shale has a different character; Wilson (1935, p.510) lists two shales and a limestone, at a maximum thickness of 3 feet 2 inches (0.95 meters), above the Keota Sandstone. The first shale is a blue-gray fossiliferous, calcareous shale. The middle shale is dark gray to black and fossiliferous. The upper limestone is dark gray and fine grained and lies just below the Spaniard Limestone Member of the Savanna Formation. Wilson and Newell (1937, p.45-46) only have 2 to 5 feet (0.6 to 1.5 meters) of shale separating the Keota Sandstone and Spaniard Limestone; they also observe a thin coal and underclay above this shale as well. In Haskell County, Oakes and Knechtel

(1948, p.44) observe 75 to 500 feet (22.5 to 150 meters) of shale above the Keota Sandstone. The shale is 500 feet (150 meters) in the southern part of the county and 75 to 200 feet (22.5 to 60 meters) in the northern part. A one-inch (2.54 cm) coal seam was identified about 205 feet (61.5 meters) above the base of this shale (Oakes and Knechtel, 1948, p.44). This shale exhibits a rapid thinning northward as it leaves the Arkoma Basin and moves onto the shelf.

The Keota Sandstone is underlain by an unnamed shale that is above the Tamaha Sandstone or coal and overlain by the aforementioned unnamed shale (Oakes and Knechtel, 1948, p.44). The Spaniard coal is only a few feet above the Keota Sandstone (Wilson and Newell, 1937, p.45).

Spaniard coal

The Spaniard coal was mentioned by Wilson and Newell (1937, p. 45) as, "A thin coal and underclay were observed at the top of the shale in Tps. 10, 13, and 15 N." In a measured section from the South Line Sec. 14 and 15, T10N, R19E, Wilson and Newell (1937, p.158) listed a 0.1-foot (0.03-meter) coal between the Keota Sandstone and Spaniard Limestone. Oakes and Knechtel (1948, p.44) mentioned a coal 205 feet (61.5 meters) above the base of an unnamed shale above the Keota Sandstone. Bennison and others first published the name "Spaniard coal" in 1979 (Hemish, 1987, p.107). The Spaniard coal is the uppermost named member unit of the McAlester Formation. Hemish (1987, p.99) provided a thickness of 0.1 to 1.1 feet (0.03 to 0.33 meters) for the Spaniard coal.

Savanna Formation

Taff (1899) named 1,150 feet (345 meters) of sandstones and shales as the Savanna Sandstone from the town of Savanna, Pittsburg County, Oklahoma. He gave his justifications for terming the unit the "Savanna Sandstone" when shales dominated by stating:

> "The shaly beds combined are probably thicker than the sandstones, but since the sandstones are better exposed and their presence is so strongly impressed upon the observer in the prominent ridges which they make, sandstone seems the more appropriate term."

Taff and Adams (1900) described the Savanna Formation in the eastern part of Oklahoma near Arkansas once again emphasizing the conspicuous nature of the sandstones:

> "The Savanna Formation contains three prominent divisions or collections of sandstone beds, having thicknesses of from 100 to 200 feet [30 to 60 meters] each and separated by masses of shale and thin sandstone, with two known workable coal beds. The upper division of this series of sandstones is the thickest, being nearly 200 feet [60 meters] thick; its upper strata are locally massive..."

Initially, Taff and Adams (1900) had placed the top of the Savanna Formation with the top of the Witteville coal and the base with the base of an unnamed sandstone.

Wilson (1935, pp.509-510) added the following member units to the Savanna Formation: Tamaha Sandstone, Keota Sandstone, Spaniard Limestone, Sam Creek Limestone, "Spiro" Sandstone (now obsolete), and Bluejacket Sandstone. The Tamaha, Keota, and "Spiro" were named by Thom in 1935 (Wilson, 1935). The Spaniard and Sam Creek were named by Lowman in 1932 (Wilson, 1935).

Afterwards, several adjustments were made to the stratigraphy of the Savanna Formation. Dane and Hendricks (1936) excluded the Bluejacket from the Savanna Formation, instead placing it within the overlying Boggy Formation. Hendricks (1937, p.16) believed that the Savanna rested unconformably upon the McAlester; one reason he gave for this was a 20- foot (6-meter) downcutting of the McAlester Formation by the Savanna Formation at the center of Sec. 6, T1N, R12E. Two other reasons he gave to support his argument were the variable thickness of the McAlester Formation in the McAlester district and the fact that the Savanna Formation increased its thickness to the southwest of the district while the upper part of the McAlester Formation remained thin. However, Hemish (1995, p.209) believed that Hendricks only observed minor erosional contacts. Hendricks (1937, p.17) also observed "5 to 13 distinguishable sandstone beds separated by shale," and due to the difficulty of mapping out each sandstone bed, he proposed "for convenience in mapping several sandstones separated by thin shale beds were mapped together as sandstone groups." Hendricks (1937, p.18) also noted marine invertebrates and plant fossils at various intervals within the Savanna Formation; he further stated, "...as nearly as could be determined, marine invertebrates and continental plant fossils are present at the same horizon in different parts of the district." Knechtel (1937, p.106) stated that except for the unconformity observed by Hendricks (1937, p.16) there was no other evidence of an unconformable contact between the McAlester and Savanna Formations.

Wilson and Newell (1937, p. 50-51) placed the top of the Savanna Formation at the "Spiro" Sandstone (term now obsolete) stating that it was the first heavy sandstone below the Bluejacket Sandstone. However, throughout most of Muskogee County and shelf area, the "Spiro" is thin and rests directly above the Sam Creek Limestone (Wilson and Newell, 1937, p.50).

Like Hendricks, Dane and others (1938, p.158) also believed that the McAlester-Savanna contact was an unconformity. They described the Savanna Formation as variable due to the lenticular nature of the sandstone bodies and also noted that sandstones probably constituted less than half of the total formation. Dane and others (1938, p.159) observed thin fossiliferous limestones from about 150 to 180 feet (45 to 54 meters) below the top of the Savanna Formation in the eastern parts of T7N, R17E, northern parts of T7N, R18E, and southeast corner of T8N, R18E. Of these limestones, Dane and others (1938, p.160) stated:

> "Although tracing of these beds was not accomplished, there is a strong suggestion that the outcrops represent a definite zone of marine limestone beds, although individual beds may not be continuous."

Oakes and Knechtel (1948, p.47 and 48) placed both the Tamaha and Keota Sandstones within the McAlester Formation, and established the McAlester-Savanna contact at the, "top of the first shale unit above the Keota Sandstone Member of the McAlester formation." But, because of the absence of the lowermost Savanna sandstone northward from Sec. 18, T9N, R19E in northwestern Haskell County, Oakes and Knechtel (1948, p.49) could not determine the actual McAlester-Savanna contact. Therefore, they also stated that the actual McAlester-Savanna contact may be at the base of a fossiliferous calcareous zone found at a roadcut 1/4 mile (0.40 km) north of SW corner Sec. 18, T10N, R21E, 1 1/4 mile (2 km) north of Perry (possibly the name of older town no longer in existence). Oakes and Knechtel (1948, p.48) further indicated that the actual McAlester-Savanna contact may lie at the stratigraphic position of the base of the Spaniard Limestone. Oakes and Knechtel (1948, p.51, figure 7) correlated the Spaniard Limestone as being in the same stratigraphic position as the lowermost Savanna sandstone. According to them, the Spaniard Limestone does not continue south from Muskogee County into Haskell County, and the lowermost Savanna Sandstone does not continue any further north than northern Haskell County. Like Taff, Oakes and Knechtel (1948, p.44) also described the relationship between the sandstones and shales of the Savanna Formation:

> "The Savanna formation, or Savanna sandstone as originally called, is a succession of sandstone and shale beds in which shale predominates but sandstone is most conspicuous in outcrops. It contains a minor amount of limestone in thin lenses and beds, and fossils of both marine animals and land plants are present locally."

Knechtel (1949, p.27) noted:

> "The lower sandstone unit of the Savanna formation cannot be traced farther north than sec. 18, T. 9 N., R. 19E., northwestern Haskell County, but seems to occupy about the same stratigraphic position as the Spaniard limestone."

Knechtel further stated that he believed that the shales beneath the Spaniard Limestone are part of the McAlester Formation. Knechtel (1949, p.28) observed several coal beds at the base of fossiliferous zones which he believed were of "marine or brackish water origin."

Branson (1952) added a new member unit to the Savanna Formation when he named the Doneley Limestone. Oakes (1953) placed the Savanna Formation within the Krebs Subgroup. Searight and others (1953) named a coal within the Savanna Formation, the Drywood. In preparing the *Geologic Map of Oklahoma* in 1954, Misner redefined the Savanna-Boggy contact as the base of the Bluejacket Sandstone due to the extensive nature of the horizon (Hemish, 1994b, p.12). However, he maintained the McAlester-Savanna contact defined by Oakes and Knechtel (1948).

Hemish (1993) extended the basal limestone members of the Savanna Formation to the Summerfield and Wister 7.5' Quadrangles in Le Flore County, Oklahoma. This was accomplished by a tentative correlation of unnamed limestones in the area with the Spaniard and Sam Creek Limestones Hemish (1993, p.98) placed the McAlester-Savanna contact at a small but sharp leftward deflection on the gamma ray curve which approximately marks the stratigraphic position of the Spaniard Limestone. Furthermore, Hemish (1993, p.99) believed that the fossiliferous calcareous zone identified by Oakes and Knechtel (1948, p.49) signifying the McAlester-Savanna contact is equivalent to the Spaniard (?) Limestone found in the Summerfield and Wister 7.5' Quadrangles. Utilizing the works of Oakes and Knechtel (1948, p.49 and 51, figure 7) and Knechtel (1949, p.27), Hemish (1994b, p.13) redefined the McAlester-Savanna contact as the base of the Spaniard Limestone or first mappable sandstone body above the Keota Sandstone if the Spaniard Limestone is not present. However, he maintained the Savanna-Boggy contact at the base of the Bluejacket Sandstone.

Since neither a type section or type locality were ever established, Hemish (1995) established a principal reference section (neostratotype) for the Savanna Formation between Sec. 1, T5N, R16E, and Sec. 6, T5N, R17E, and between Sec. 36, T6N, R16E, and Sec. 31, T6N, R17E, approximately 0.5 miles (0.15 km) north of Adamson, Pittsburg County, Oklahoma. Hemish (1995, p.210) also described the seven sandstone "groups" that were established while mapping the Wilburton 7.5' Quadrangle in 1990. He then extended the seven sandstone units westward across the Gowen 7.5' Quadrangle to the Adamson 7.5' Quadrangle. Hemish (1996, p.195) designated the Lodi Section, La-1-94-H, Secs. 1 and 2, T6N, R21E, and Sec.35, T7N, R21E, Latimer County, Oklahoma, as a supplementary reference section of the Savanna Formation. Furthermore, Hemish (1996, p.197) established a reference well for the Savanna Formation from a core, designated C-RM-1 by the Oklahoma Geological Survey, taken from SE1/4SE1/4SW1/4NW1/4 Sec. 18, T21N, R18E in Mayes County, Oklahoma. Hemish (1996, p.190) stated that the Spaniard, Sam Creek, and Doneley Limestones formed three persistent key beds within the Savanna Formation.

Various workers have reported a wide range in the thickness of the Savanna Formation . The primary cause of this variety in range is the fact that the Savanna Formation, like the rest of the Cherokee Group, thins out dramatically from the Arkoma Basin to the shelf. Those who worked in the basin have reported a thickness of the Savanna Formation in thousands of feet while thickness on the shelf may be anywhere from hundreds to tens of feet.

Most of the early work was done within the Arkoma Basin. Taff (1899) reported a thickness of 1,150 feet (345 meters) for the Savanna Formation in the McAlester area. Wilson (1935, pp.509) reported 205 feet (61.5 meters) in southern Muskogee County. Hendricks (1937, p.19) reported 1,120 to 1,325 feet (336 to 398 meters) of Savanna Formation from measured sections and 500 feet (150 meters), 3 1/2 miles (5.6 km) northwest of McAlester, Oklahoma. He attributes this sudden reduction of thickness due to tectonic squeezing. However, in other parts of Pittsburg County, Hendricks (1937, p.19) reported a more normal thickness: 2,500 feet (750 meters) 4 miles (6.4 km) southwest of Pittsburg, Oklahoma, and immediately to the west, 1,700 feet (510 meters). However, he also stated that is was difficult to determine which thickness was due to tectonic squeezing of shales or to depositional thickening of the formation. Knechtel

(1937, p.106) reported 1,400 to 1,600 feet (420 to 480 meters) of Savanna Formation in Coal, Atoka, and western Pittsburg Counties, Oklahoma. Hendricks (1939, p.272) listed a thickness of 1,750 feet (525 meters) for the Savanna Formation in Latimer and Le Flore Counties. Oakes and Knechtel (1948, p.45) included the thickness of the Savanna Formation from several locations across the Arkoma Basin: McAlester vicinity, 1,000 to 1,300 feet (300 to 390 meters); Poteau vicinity, 1,700 feet (510 meters); Haskell County, 500 to 1,150 feet (150 to 345 meters); and southern Muskogee County, 80 feet (24 meters). Knechtel (1949, p.28) reported 140 to 960 feet (42 to 288 meters) of Savanna Formation in northern Le Flore County and further added that the formation grew thicker in a general southeasterly direction. Hemish (1995, p.211) reported that within the principal (Adamson) reference section (neostratotype) of the Savanna Formation, the formation is around 1,450 feet (435 meters) thick. In Latimer County, within the supplementary (Lodi) reference section of the Savanna Formation, Hemish (1996, p.198) noted around 1276 feet (383 meters) of the Savanna Formation.

In the transition between the basin and shelf, the Savanna Formation thins to several hundred and, in some cases, tens of feet thick. Wilson (1935, p.510) reported a thickness of 205 feet (61.5 meters) in northern Muskogee County. Wilson and Newell (1937, p.43) stated that the Savanna Formation is 166 to 260 feet (50 to 78 meters) thick in Muskogee County. Oakes and Knechtel (1948, p.45) reported only a thickness of 25 feet (7.5 meters) for the Savanna Formation around the city of Muskogee, Oklahoma. However, Hemish (1995, p.209) has held this number suspect.

Out onto the shelf, the Savanna Formation thins dramatically. Hemish (1990b, p.37-39, 50-51) had measured 82.9 feet (25 meters) of Savanna Formation from cores in

Mayes County and 70.0 feet (210 meters) from cores in Craig County (15 miles (24 km) south of the Oklahoma/Kansas border). Hemish (1996, p.180) stated that the Savanna Formation thins from 1,450 feet (435 meters) in the Arkoma Basin to around 70 feet (21 meters) at the Oklahoma/Kansas border.

Previously, several workers had commented on how prominent the sandstone units of the Savanna Formation were; however, Hemish (1995, p.222, and 1996, p.198) through simple calculations had demonstrated that within both the principal (Adamson) reference section and supplementary (Lodi) reference section only around 16% of the formation is actually sandstone. The percent amount of sandstone drops to only 2.4 % in cores from Mayes County, well upon the shelf.

The Savanna Formation is underlain by the McAlester Formation and overlain by the Boggy Formation. Incisement at the base of the Bluejacket Sandstone indicates that the contact between the Savanna and Boggy Formations may be an unconformity.

Spaniard Limestone Member

The Spaniard is the lowest named member unit of the Savanna Formation, and Hemish placed the base of the Savanna at the base of the Spaniard (1994, p.13). Lowman, in 1932, named the Spaniard Limestone from exposures along Spaniard Creek in Muskogee County, and the type locality was established at SW1/4NE1/4 Sec. 11, T13N, R18E approximately 7 miles (11 km) due south of Muskogee, Oklahoma and a few yards west of what is now US 64 (Wilson, 1935, p. 504 and 510). Wilson (1935) relegated the Spaniard as a member unit of the Savanna Formation. In the northern part of Muskogee County, Wilson (1935, p.510) included Lowman's description of the

Spaniard as three feet (0.9 meters) of calcareous, fossiliferous shale capped by a limestone, but he did not extend the Spaniard into southern Muskogee County.

Wilson and Newell (1937, pp. 46-47) stated that the Spaniard Limestone was one of the most, "uniform and persistent limestones in the local geologic column." They also noted that the Spaniard Limestone thickened northward from about 9 inches (23 cm) at T10N in the extreme southern part of Muskogee County to about 2 feet (0.6 meters) in T15N in the northern part along the Arkansas River (Wilson and Newell, 1937, pp.46-47). A short list of fauna from the Spaniard Limestone was described by Wilson and Newell (1935, pp.46-47) including fusulinids, crinoid stems, and the horn coral *Campophyllum*. *Heliospongia*, a cylindrical sponge, was listed as being present at some localities.

Oakes and Knechtel (1948, p.54, figure 7) did not find the Spaniard Limestone within Haskell County but did correlate the Spaniard Limestone with the lowermost Savanna sandstone in Haskell County. However, they stated that the Spaniard and Sam Creek Limestones have been traced as far north as Mayes County and are reported from even farther north. Oakes and Knechtel (1948, p.49) did find a fossiliferous calcareous zone which they believed might be the McAlester-Savanna contact; they also stated that the base of this zone might be in the same stratigraphic position of the Spaniard Limestone. Hemish (1993, p.99) believed that this fossiliferous calcareous zone is equivalent to a potential Spaniard Limestone found in the Summerfield and Wister 7.5' Quadrangle.

Alexander (1954, pp.38-39, 49) identified the fusulinid *Fusulina novamexicana* from the Spaniard Limestone in the SW1/4 of Sec. 2, T14N, R18E, Muskogee County, Oklahoma. He also states that this fusulinid is closely related to a species from the Pumpkin Creek Limestone in the Ardmore Basin.

Branson and others (1965, pl.1) determined the northern most exposure of the Spaniard Limestone was in the SW1/4 Sec. 21, T27N, R21E, south of the town of Bluejacket, Craig County, Oklahoma. The southernmost exposure of the Spaniard Limestone was found by Oakes (1977, pl.1) in the NW1/4 Sec. 34, T10N, R19E, just north of the Canadian River in Muskogee County. Hemish (1990b, p.51) found the northernmost documented occurrence of the Spaniard Limestone in NW1/4NE1/4NE1/4NE1/4 Sec. 24, T27N in a core from Mayes County.

Most of the occurrences of the Spaniard Limestone seem to be restricted to the Northeastern Oklahoma Shelf, the Spaniard Limestone itself seems to be absent from the Arkoma Basin. Workers in the Arkoma Basin, Morgan (1924), Hendricks (1937, 1939), Knechtel (1937, 1949), Dane and others (1938), Russell (1960), or Webb (1960), have not found either the Spaniard Limestone or any of its equivalents within the Arkoma Basin. Only Oakes and Knechtel (1948, p. 54, figure 7) found a sandstone equivalent of the Spaniard Limestone in Haskell County. However, Hemish (1993) believed that limestones found in the Wister and Summerfield 7.5' Quadrangles in Le Flore County, Oklahoma may be equivalents to the Spaniard and Sam Creek Limestones.

The Spaniard Limestone overlies the McAlester Formation and underlies an unnamed shale. Above the Spaniard Limestone and below the Sam Creek Limestone are the Tullahassee and Sam Creek coals.

Tullahassee coal

Hemish (1990a), in preparing for the Coal geology of Creek, Tulsa, Wagoner, and Washington Counties, Oklahoma, named the Tullahassee coal and established a type locality at NE1/4NE1/4NE1/4 Sec. 1, T15N, R17E, approximately 1.5 miles (2.4 km) south of Tullahassee, Wagoner County, Oklahoma (Hemish, 1987). Hemish (1990a) listed a thickness for the coal in a measured section of the type locality, around 0.5 feet (0.15 meters) thick, and at the type locality is a massive shale pit above the Tullahassee coal where over fifty feet (15 meters) of gray shale, and the Sam Creek Limestone are well exposed. Strata above the Sam Creek are also present but poorly exposed.

Sam Creek coal

Wilson and Newell (1937, pp.48-49) first mentioned the Sam Creek coal when they stated:

> "At the top there occurs locally a thin coal and underclay, or simply the underclay. This coal and underclay horizon, indicating emergence, logically separates the variable fossiliferous limestones and shales below from the single persistent fossiliferous limestone, the Sam Creek, above....T. 13 N., and to the southward, coal and underclay occur sporadically beneath the upper limestone of the original definition."

Bennison and others, in 1979, first published the name "Sam Creek coal" (Hemish, 1987, p.107).

Sam Creek Limestone Member

In 1932, Lowman also named the Sam Creek Limestone from its exposure at Sam Creek in Muskogee County (Wilson, 1935, pp. 504 and 510). The type locality of the Sam Creek Limestone is only about four or five miles (6.4 to 7 km) north of the type locality of the Spaniard; Lowman placed it at Center West Half, East Half Sec. 15, T14N, R18E, approximately 2.5 miles (0.75 km) south of Muskogee, Oklahoma and half a mile (0.81 km) west of present day US 64 (Wilson, 1935, 504). Wilson (1935, p.510) also presented the description of the Sam Creek Limestone by Lowman, approximately 9 feet (2.7 meters) of alternating gray shale and limestone. The uppermost limestone of the Sam Creek was described by Lowman as very fossiliferous, almost a coquina. Wilson (1935, p.504) placed the Sam Creek Limestone within the Savanna Formation.

Of the 8 feet 7 inches (2.5 meters) of limestone originally defined as the Sam Creek Limestone, Wilson and Newell (1937, p. 49) stated that only the uppermost six inches (15.2 cm) were continuous. Because of the inconsistent nature of the lower beds, Wilson and Newell (1937, p. 49) proposed to restrict the term Sam Creek to only the continuous upper six inches (15.2 cm).

Like the Spaniard Limestone, the Sam Creek Limestone is a very fossiliferous unit; Lowman, Wilson and Newell all identified abundant assemblages of fauna from the limestones they studied. Lowman identified the horn coral *Campophyllum* in one bed; in fact, *Campophyllum* was so numerous, that Lowman termed that particular unit a reef (Wilson, 1935, p. 510). The brachiopods *Mesolobus* and *Spirifer* were also very abundant.

Alexander (1954,p.18, 49) identified a new species of the fusulinid *Fusulinella* from the Sam Creek Limestone in SW 1/4 of Sec. 4, T21N, R18E, Mayes County, Oklahoma. He further added that the fusulinids are more abundant in the overlying shale, up to four feet (1.2 meters) above the Sam Creek Limestone.

Branson and others (1965, pl.1) determined the northernmost exposure of the Sam Creek Limestone northwest of the town of Big Cabin, Craig County, Oklahoma, SW1/4 Sec. 15, T24N, R19E, and Hemish (1990b, p.51) found the northernmost documented exposure of the Sam Creek Limestone in a core in the NW1/4NE1/4NE1/4NE1/4 Sec. 24, T27N. Stine (1958, p.42) mapped the southernmost known exposure of the Sam Creek Limestone in Secs. 33 and 34, T10N, R19E, just north of the Canadian River in Muskogee County. Furthermore, Hemish (1998. p.27, 36) found exposures of the Sam Creek Limestone in two shale pits in SW1/4SW1/4NW1/4NE1/4 Sec.11, T10N, R18E (pit#1), and N1/2SW1/4NW1/4 Sec.25 and E1/2NE1/4NE1/4 Sec.26, T11N, R17E (pit #2) in eastern McIntosh County, Oklahoma. The Sam Creek Limestone in McIntosh County is at roughly the same latitude as the southernmost exposure of Sam Creek Limestone in Muskogee County. Oakes and Knechtel (1948, p.51) observed limestone float 20 feet (6 meters) below the "Spiro" Sandstone northwest of Hoyt in Haskell County. The unnamed limestone occupied the same stratigraphic position as the Sam Creek Limestone in Muskogee County. If so, this would extend the southernmost exposure of the Sam Creek Limestone into Haskell County. Other workers in the Arkoma Basin, Morgan (1924), Hendricks (1937, 1939), Knechtel (1949), Russell (1960), and Webb (1960), did not find either the Sam Creek Limestone or any of its equivalents. Hemish (1993) believes that limestones found in the Summerfield and Wister 7.5' Quadrangles in Le Flore County, Oklahoma may be equivalents of the Spaniard and Sam Creek Limestones.

The Sam Creek Limestone overlies and underlies unnamed shales. At one locality, NE1/4NE1/4NE1/4 Sec. 1, T15N, R17E and SW1/4SE1/4SE1/4SE1/4 Sec. 36, T16N, R17E, the Sam Creek Limestone underlies a very thin siltstone (personal field observations).

Rowe coal

Pierce and Courtier (1937, p.65) named the Rowe coal for the Rowe School at the northeast corner of Sec. 34, T30S, R25E in Cherokee County, Kansas. They also identified a persistent shale parting associated with the Rowe coal that was uniquely characteristic. Pierce and Courtier (1937, p.65) measured 3.5 to 4 inches (8.9 to 10 cm) of coal, 2 inches (5.1 cm) of gray shale, and 14 to 16 inches (35 to 41 cm) of upper coal within the Rowe Bed. Searight and others (1953) placed the Rowe coal as the upper unit in the Rowe Formation of the northern Midcontinent.

Doneley Limestone Member

Wilson and Newell (1937, p.53) first mentioned the Doneley Limestone when they described a six inch (15.2 cm) fossiliferous limestone within the lower Boggy shale; this limestone was above a coal that they termed the "lower Boggy" coal. Branson (1952, p.192) named the Doneley Limestone after the Doneley School about 4 miles (6.4 km) north of Vinita, Craig County, Oklahoma. He established a type locality at NW1/4 Sec. 16, T26N, R20E, about a mile (1.6 km) north of the school in a south creek bank 100 feet (30 meters) east of a section road. At its type locality, Branson (1952, p.192) described the Doneley Limestone as a three inch (7.6 cm) thick calcareous clay ironstone about eight inches (20.3 cm) above a thin coal and underclay. He also stated that the Doneley Limestone was traceable over a wide area from the Kansas border to just south of Warner, Muskogee County, Oklahoma. The Doneley Limestone overlies the Rowe coal in some places and underlies an unnamed shale. The Spaniard, Sam Creek, and Doneley Limestones together are referred to as the "Brown Limes" of the subsurface.

Drywood coal

During a conference on classification and nomenclature of rocks of the Cherokee Group at Nevada, Missouri, Searight and others (1953) named the Dry Wood coal from Dry Wood Creek in Vernon County, Missouri. The type locality was established at Sec. 4, T32N, R33W , but no thickness of the coal at the type locality was listed. In the northern part of the Mid-Continent, the name is spelled "Dry Wood," two words. However, in Oklahoma, only one word, "Drywood," is used (Oklahoma Geological Survey, 1954, p.124). In northeastern Oklahoma, the thickness of the coal is 0.1 to 3.0 feet (0.03 to 0.9 meters) (Hemish, 1987, p.99).

Boggy Formation

3,000 feet (900 meters) of shales and sandstones above the Savanna Sandstone were given the named Boggy Shale by Taff (1899, p.438). He also identified 16 beds of sandstone, 100 to 600 feet (30 to 180 meters) thick, separated by shales, 100 to 600 feet (30 to 180 meters) thick. Taff also identified one coal bed approximately 400 feet (120 meters) above the base of the Boggy Shale. However, neither Taff (1899) nor Taff and Adams (1900) made any attempt to subdivide the Boggy Formation into member units; although, Taff and Adams (1900, p. 294) did name the Lower Witteville coal.

Over time, the Boggy Formation was divided up into member units by other authors. Chance (1890) established the Secor coal. Ohern (1914) described and named the Bluejacket Sandstone. Lowman named an outlier of limestone on a hill near Inola, Oklahoma, the Inola Limestone (Wilson, 1935, p.504). Wilson (1935, p.405) established the Crekola and Taft Sandstones and listed the member units of the Boggy Formation as shale, Crekola Sandstone, shale, Inola Limestone, shale, and Taft Sandstone.

Dane and Hendricks (1936) stated that the Bluejacket Sandstone was a member unit of the Boggy Formation, and Wilson and Newell (1937, p.54) placed the Bluejacket Sandstone well above the base of the Boggy Formation. Hendricks (1937, p.23) identified up to 18 sandstone units alternating with shales within the Boggy Formation although the total amount of sandstones was less than 7.5 %. Oakes and Knechtel (1948) placed the base of the Boggy Formation at the base of an unnamed shale below the Bluejacket Sandstone. They also stated that the Boggy Formation was probably named by Taff (1899) for exposures along Clear and Muddy Boggy Creeks in Pontotoc, Coal, and Pittsburg Counties.

Several fossiliferous zones were identified in the Boggy Formation as well; both plants and marine invertebrates observed by Knechtel (1937, p.107) are good indicators of depositional environment, "The Boggy shale, as indicated by plant and invertebrate fossils, includes both marine and continental deposits." Hendricks (1937, p.23) identified various dark fossiliferous shales within the Boggy Formation as well as plant remains at the base and top of the formation. He further observed that in some of the sandstones "Worm trails, fucoid markings, and fragments of *Sigillaria*, *Lepidodendron*, and *Calamites*" were common. Marine invertebrate fossils were also identified at 500, 700, and 1,000 feet (150, 210, and 300 meters) above the base of the unit (Hendricks, 1937, p.23). Knechtel (1937, p.107) observed sparse thin lenses of very fossiliferous marine limestones within the Boggy Formation. Dane and others (1938, p.162) noted that the Secor coal overlies a gray clay and underlies a fossiliferous calcareous black shale. They also identified a massive gray fossiliferous limestone approximately 170 feet (51 meters) above the Secor coal.

Oakes (1953) placed the Boggy Formation as the uppermost formation of the Krebs Subgroup. Searight and others (1953) added a coal unit, the Bluejacket coal, to the Boggy Formation. In 1954, Misner placed the Savanna-Boggy contact at the base of the Bluejacket Sandstone (Hemish, 1994, p.13). Reed and Schoff (1955) established the Boggy Formation from the base of the Bluejacket Sandstone to an unconformity at the base of the Cabaniss Group.

Hemish (1986b, 1990e) identified four coal beds between the base of the Bluejacket Sandstone and the shale unit above the Inola Limestone in northwestern Muskogee and southwestern Wagoner Counties and the Beland-Crekola area, Muskogee County. In the northwestern Muskogee-southwestern Wagoner study, Hemish (1986b, p.177) named the Peters Chapel coal. In order to clarify terminology and reduce confusion within the study areas, Hemish (1986b, 1990e) determined that the lowermost coal above the Bluejacket Sandstone was the Secor coal, and then, in ascending order, he listed the other three coals as the Secor Rider, Peters Chapel, and Bluejacket. The Bluejacket coal, the uppermost of the four, was just below the Inola Limestone.

Hemish (1986b, p.180) also noted that the four coals were deposited in four separate cycles of sedimentation. Furthermore, Hemish believed that the lower Boggy

Formation was deposited in a graben in northwestern Muskogee County along with contemporaneous faulting and subsidence; this resulted in a relatively thicker section of lower Boggy in northwestern Muskogee County. In comparison, Hemish (1986b, p.181) noted that this same interval is thinner in the central part of Muskogee County where the Secor and Secor Rider coals may be absent locally. However, all four coals may be present further south in McIntosh County. Hemish (1986b, p.181) believed that this indicates at least two marine transgressions into the graben while the central part of Muskogee County was above sea level.

In preparing the Coal Geology of McIntosh and Muskogee Counties, Hemish proposed to apply the name "Wainwright" to the uppermost coal bed of the Boggy Formation which was adopted by the Oklahoma Geological Survey (Hemish, 1987, p.104).

The various authors had reported various thicknesses for the Boggy Formation as well; this variation in thickness depended upon where in the basin or shelf the study was. Taff (1899), Morgan, Hendricks, Dane, and Knechtel, and Oakes and Knechtel (1948) worked in the McAlester area, Haskell and Le Flore Counties, or in other areas of southeastern Oklahoma. These are all areas within the Arkoma Basin where the Boggy Formation is very thick, up to several thousand feet thick. Whereas, Wilson (1935) and Wilson and Newell (1937) worked in areas on or near the shelf where the Boggy Formation becomes significantly thinner, only a few hundred feet thick. Taff (1899) reported around 3,000 feet (900 meters) of the Boggy Formation in the McAlester area. Morgan (1924) reported 1,500 feet (450 meters) of Boggy Formation on the east side of the Stonewall Quadrangle in Coal County, Oklahoma. Wilson (1935, p.511) measured

172 to 242 feet (52 to 73 meters) of Boggy Formation in Muskogee County; Hendricks, Dane, and Knechtel (1936, p.1352) stated that the maximum thickness of the Boggy Formation in their study area was 2,850 feet (855 meters), 12 miles (19.2 km) southwest of McAlester, OK. Hendricks (1937, p.24) gave the thickness of the Boggy Formation as 2,850 feet (855 meters) in the southeast quarter of T4N, R13E in Pittsburg County. Dane and others (1938, p.160) listed an aggregate thickness of 1,700 to 1,900 feet (510 to 570 meters) for the Boggy Formation in the Quinton-Scipio district. Hendricks (1939, p.272) stated that around 4,000 feet (1200 meters) of Boggy Formation was present on Cavanal Mountain in Le Flore County. Oakes and Knechtel (1948, p.55) reported the thickness of the Boggy Formation to be anywhere from a "thin edge" in the Arbuckles to at least 4,000 feet (1200 meters) thick in Le Flore County (however top of the formation had eroded away), and 1,100 to 2,000 feet (330 to 600 meters) within Haskell County. Hemish (1994b, pp. 8-9) noted a generalized thickness of 2900 feet (870 meters) for the Boggy Formation on Cavanal Mountain in Le Flore County and 530-2900 feet (159 to 870 meters) for McIntosh and northern Pittsburg County. On the shelf, Hemish (1987, p.99) listed a thickness of 35-700 feet (10.5 to 210 meters) for the Boggy Formation in northeastern Oklahoma.

The Boggy Formation is the uppermost formation of the Krebs Subgroup. It is underlain by the Savanna Formation and overlain by the Thurman Sandstone of the Cabaniss Subgroup in the Arkoma Basin. Upon the shelf, an erosional surface allows the Boggy Formation to be directly overlain by the Senora Formation of the Cabaniss Subgroup (Oakes, 1953, p.1524).

Bluejacket Sandstone Member

Taff (1906) first described but did not name the Bluejacket Sandstone when he stated:

> "The overlying sandstone is a gray to yellowish-brown rock, and occurs for the most part in thick or massive and moderately hard beds. The lower sandstone beds are usually exposed in cliffs and bluffs at the crests of escarpments which they produce. The upper layers make flat and gently rolling tracts of sandy loam which slope westward from the escarpment of the Rattlesnake Mountains. Toward the northwest this sandstone gradually grows thinner, more shaly, and softer, the decrease in thickness and the change in character being emphasized by the topographic expression of the rock. Near the southern boundary of the quadrangle the sandstone is marked by the strong escarpment and timbered table-land of the Rattlesnake Mountains."

Ohern (1914) also described the Bluejacket Sandstone and named it from the town of Bluejacket, Craig County, Oklahoma:

> "...a second sandstone, whose base lies about 130 feet above the top of the Little Cabin sandstone, being the most salient feature of the stratigraphy from the Kansas line southward to the limits of the Vinita-Nowata area....In many places its total thickness of 50 to 60 feet [15 to 18 meters] is a solid mass of sandstone, but usually it is broken up into several beds by intervening shales. This sandstone is well exposed on the west bank of Neosho River a mile south of the Kansas line, where more than 30 feet [9 meters] is seen above the river surface. It forms an escarpment in the eastern part of T. 28 N., R. 21 E., and is widespread east of Welch. It extends southward past Bluejacket and its typical development is found in the hills west of the town from which it is proposed to name it the Bluejacket sandstone member."

Wilson (1935, pp. 504 & 509) placed the Bluejacket Sandstone as the uppermost member unit of the Savanna Formation. Pierce and Courtier (1937, p.27) stated that the Bluejacket Sandstone is between 20 and 50 feet (6 and 15 meters) thick, and its base is about 50 to 100 feet (15 to 30 meters) below the Weir-Pittsburg coal. Interestingly, at

800 feet (240 meters) east of the center of Sec. 20, T33N, R24E, in a small strip pit, a basal conglomerate to the Bluejacket Sandstone was discovered. The conglomerate had six-inch (15.2 cm) pebbles that seem to have derived from underlying shales. Pierce and Courtier (1937, pp.27-28) stated, "All of the material composing the conglomerate was apparently derived from the Cherokee shale. There were no pieces of chert or limestone from the underlying Mississippian rocks." Dane and Hendricks (1936) removed the Bluejacket Sandstone from the Savanna Formation and made it a member unit of the Boggy Formation, and they described it with a thickness of 100 to 500 feet (30 to 150 meters). The base of the Bluejacket Sandstone, according to Dane and Hendricks (1936 p.313), is 200-250 feet (60 to 75 meters) above the top of the Savanna Formation in Ts. 7 and 8N, R18E, and the top of the Bluejacket is 100 to 200 feet (30 to 60 meters) below the Secor coal. Wilson and Newell (1937, p.54), based on Dane and Hendricks (1936), placed the Bluejacket Sandstone well above the base of the Boggy Formation. In Muskogee County, Wilson and Newell, described the Bluejacket Sandstone as 20-60 feet (6 to 18 meters) thick, thin-bedded, shaly, and somewhat lenticular although they didn't believe that the Bluejacket Sandstone at this point was a channel sand. Oakes and Knechtel (1948, p.61) found that in Haskell County, up to T8N, the Bluejacket Sandstone was 100 to 150 feet (30 to 45 meters) thick. North of T8N, the Bluejacket Sandstone thins down to 50 to 75 feet (15 to 22.5 meters) thick.

At the type locality of the Bluejacket Sandstone, according to Howe (1951, pp. 2088 & 2090), there are at least three sandstone beds; furthermore, shales, coals, and sandy shales separate the sandstones. Because of the difficulty in determining which sandstone is the type Bluejacket, Howe (1951, p.2090) measured most of the section exposed in the hills and drafted a generalized measured section of the area. On that section, he marked which of the sandstone beds should be the type Bluejacket which was described as coarse, coarsely cross-bedded, ripple-marked, and about 25 feet (7.5 meters) thick. Howe then designated the type locality of the revised Bluejacket Sandstone in the NE1/4NE1/4 Sec. 25, T27N, R20E, approximately two miles (3.2 km) west of Bluejacket, Oklahoma on State Highway 25 along the eastern slopes of Timbered Hill.

Misner redefined the base of the Boggy Formation in 1954 as the base of the Bluejacket Sandstone making the Bluejacket Sandstone the lowest member unit of the Boggy Formation (Hemish, 1994, p.13). Hemish (1989a, p.74) stated that the type locality of the Bluejacket Sandstone established by Howe (1951, p.2090) is in reality an exposure of the Dickson Sandstone (Branson and others, 1965, p.27, pl.1). He provided a correct type locality in the NW1/4NE1/4 Sec. 25, T27N, R20E. Hemish (1989a, p.77) also provided two reference wells for the Bluejacket Sandstone. The first well is located in the SE1/4NE1/4NW1/4SW1/4 Sec. 25, T27N, R20E, and the second well is located in the NW1/4NE1/4NE1/4NE1/4 Sec. 24, T27N, R20E. Both cores were taken from the type area of the Bluejacket Sandstone in Craig County, Oklahoma. In determining depositional environment, Hemish believed that the Bluejacket Sandstone from the first well represented fine-grained deposits deposited by a crevasse-splay and overbank deposits on an interchannel deltaic plain (1989a, p.80). A distributary channel in a delta deposited the coarser grained Bluejacket Sandstone from the second well (Hemish, 1989a, p.80).

The Bluejacket Sandstone underlies the Savanna Formation and overlies an unnamed shale. The contact of the Bluejacket and Savanna Formations is probably an erosional one as evidenced by a conglomerate with reworked shale fragments. The Lower Witteville coal is present above the Bluejacket Sandstone primarily in McIntosh County and Cavanal Mountain in Le Flore County. The Secor coal lies above the Bluejacket from only a few feet to over 200 feet (60 meters). In the subsurface, the Bluejacket Sandstone is referred to as the Bartlesville sand.

Lower Witteville coal

Taff and Adams (1900, p.294) named the lower and upper Witteville coals when they stated:

> "There are two beds of coal separated by about 250 feet [75 meters] of shale and sandstone, which will be known as the Witteville coal beds, from the mines upon them at Witteville, in the east end of Cavanal Mountain.
>
> The upper Witteville coal is 3 feet 10 inches [1.2 meters] thick, separated into two nearly equal benches by a thin parting of shale...
>
> The lower Witteville coal is 4 feet 8 inches [1.4 meters] thick, and is separated into three benches by two variable bands of bone and carbonaceous shale."

Taff and Adams (1900) also placed the Lower Witteville coal as the uppermost bed of the Savanna Formation. Dane and Hendricks (1936, p.313) believed that the Upper Witteville and Blocker coals were equivalent to the Secor coal (Chance, 1890). Knechtel (1949, p.51) favored "Secor" instead of "upper Witteville" (which was dropped) for the coal name. Branson (Oklahoma Geological Survey, 1954, p.131) stated the upper Witteville and Secor coals occupied the same stratigraphic position. After the upper Witteville became an obsolete term, the lower coal still continued to be referred to as the lower Witteville coal out of convention (Hemish, 1994b, p.7).

Several attempts had been made previously to extend the Witteville or lower Witteville coal beyond its exposure on Cavanal Mountain. Hendricks (1937, p.23) believed that a coal mined in the NW1/4 Sec. 3, T4N, R14E south of McAlester, Pittsburg County, Oklahoma was equivalent to the lower Witteville near Poteau, Oklahoma, 70 miles (112 km) to the east. Dane and others (1938, p.200) mentioned a coal about 50 to 75 feet (15 to 22.5 meters) below the Secor coal in NW1/4 Sec. 2, T6N, R16E in Pittsburg County that possibly might be the lower Witteville coal. Trumbull (1957, p.350) stated that in Pittsburg County, "a coal bed of unknown thickness which may correlate with the Lower Witteville bed occurs near the base of the Boggy Formation." Hemish (1994, p.15) also believed that the lower Witteville coal was not just limited to Cavanal Mountain in Le Flore County; he correlated the lower Witteville coal with similar coal beds in McIntosh and northern Pittsburg Counties.

Friedman (in a personal communication with Hemish, 1988) made a very strange correlation with lower Witteville coal. He believed that the lower Witteville coal occurred at the top of the Savanna Formation and was possibly equivalent with the Drywood coal. If this correlation was true, then the sandstone below the lower Witteville coal would be an upper Savanna sandstone and not part of the Bluejacket Sandstone. However, Hemish (1994b, p.20) stated that mapping had proven that the sandstone below the lower Witteville coal was a lower unit of the Bluejacket Sandstone which would make correlations with the Drywood coal difficult. Friedman (1974, 1978) also believed that the lower Witteville coal was equivalent to the Rowe coal.

Knechtel (1949, p.51, 65) reported 4.8 feet (1.44 meters) of lower Witteville coal with shale partings in the E1/2 Sec. 15, T7N, R25E on the east side of Cavanal Mountain.

Hemish (1994b, p.6) stated that within his study area the thickness of the lower Witteville coal ranged from 0.5 to 4.5 feet (0.15 to 1.4 meters) on the slopes of Cavanal Mountain in Le Flore County to 0.1 to 2.2 feet (0.03 to 0.66 meters) in northeastern McIntosh County.

Secor coal

Chance (1890) named the Secor coal, and, in a generalized stratigraphic column of the area, he listed a thickness of 2.5 feet (0.75 meters) for the coal. It was believed that the name was derived from the Secor Family which lived in that area (Oklahoma Geological Survey, 1954, p.129). Dane and Hendricks (1936), Knechtel (1949), and Branson (1954) correlated the upper Witteville coal (Taff and Adams, 1900) with the Secor coal, and the name "upper Witteville" was abandoned in favor of "Secor". Dane and Hendricks (1936, p.313) stated that the Secor coal is about 100 –200 feet (30 to 60 meters) above the top of the Bluejacket Sandstone in the Quinton-Scipio District in Pittsburg and Haskell Counties. Wilson and Newell (1937, p.55) placed the Secor coal about 20 or more feet (6 or more meters) above the top of the Bluejacket Sandstone in the vicinity of Summit and Crekola in northern Muskogee County, and farther north near the town of Taft, the Secor coal is almost directly above the Bluejacket Sandstone. Oakes and Knechtel (1948, p.61) stated that the Secor coal is approximately 100 feet (30 meters) above the Boggy in western Haskell County. Bennison and others (1979) proposed the names "lower Secor coal," "middle Secor coal," and "upper Secor coal" for the coals between the Bluejacket and Crekola Sandstones. Hemish (1986b, p.177) proposed that the terms "lower Secor," "middle Secor," and "upper Secor" are too confusing and should be abandoned, and Hemish (1987, p.105) stated that the lower Secor coal was also equivalent to the Secor coal.

Wilson (1935, p.511) had measured 1.1 feet (0.33 meters) of Secor coal with a "thin dirt band near middle" in Muskogee County. Hemish (1987, p.99) listed the thickness of the Secor in northeastern Oklahoma as 0.1-1.8 feet (0.3-0.54 meters).

Secor Rider coal

Dane and others (1938) first recognized the Secor Rider coal when they described it as a thin coal just above the Secor in several localities, but they did not name it. The term "Secor Rider" had been used informally for several years by miners and geologists (Hemish, 1987, p.105), but Friedman (1974) was the first to mention a "rider" of the Secor coal in a publication. The term "Secor Rider" was first published by Friedman (1978, p.28). Hemish (1987, p.105) stated that the Secor Rider coal was equivalent to the middle Secor coal. Above, Hemish (1990e, p.214) noted that a "thin, fossiliferous, impure limestone" overlies the Secor Rider coal; he further mentioned that the limestone was a useful marker bed for the Secor Rider coal.

Peters Chapel coal

Hemish (1986b, p.177) named the Peters Chapel coal from an exposure about a quarter mile south of Peters Chapel, Muskogee County, Oklahoma. He established a type locality in the NW1/4SE1/4NW1/4NE1/4 Sec. 14, T15N, R17E, and the Peters Chapel coal is 0.9 feet (0.27 meters) thick at that locality. Hemish (1987, p.105) stated that the Peters Chapel coal is equivalent to the upper Secor coal.

There is, however, some confusion between the Secor and Peters Chapel coals. Hemish (1990e, p.201) mentioned that an unnamed sandstone lies between the Bluejacket and Crekola Sandstones. The Peters Chapel coal occurred above the unnamed sandstone and below the Crekola Sandstone whereas the Secor coal is between the Bluejacket Sandstone and the unnamed sandstone. Furthermore, Oakes (1977) misidentified this unnamed sandstone as the Crekola Sandstone. Believing that only one coal, the Secor, existed between the Bluejacket and the Crekola Sandstones, several workers called any coal between the Bluejacket and Crekola Sandstones the Secor coal; therefore, the Peters Chapel coal was misidentified as the Secor coal several times. Hemish (1990e, p.201) further added that several early workers, Wilson (1935), Wilson and Newell (1937), Stewart (1949), Bell (1959), and Oakes (1977), had also confused the Peters Chapel coal for the Secor coal.

Crekola Sandstone Member

Named by Wilson (1935, p.511) for the fact that Crekola (east 1/2 Sec. 10, T14N, R17E) in Muskogee County, Oklahoma is built upon this sandstone. He described the Crekola Sandstone as a brown, regularly bedded, blocky, medium textured sandstone about 10 feet (3 meters) thick. Wilson and Newell (1937, p.55) describe the Crekola Sandstone as thin-bedded, soft, buff, and unfossiliferous and list the thickness from 4 to 10 feet (1.2 to 3 meters) in Muskogee County. Oakes (1977) misidentified an unnamed sandstone above the Bluejacket Sandstone for the Crekola Sandstone. Hemish (1990e, p.201) established a reference well, OGS designation C-MM-54, for the Crekola Sandstone. The well is located in the NE1/4NW1/4SW1/4NE1/4NE1/4 Sec. 15, T14N, R17E, approximately 0.6 miles (0.96 km) south of Crekola, Muskogee County, Oklahoma. Hemish (1990e, pp. 216-17) measured 8.5 feet (2.6 meters) of Crekola Sandstone within the reference well.

Bluejacket coal

Wilson and Newell (1937, p.56) first mentioned this coal but didn't name it:

> "Between the Crekola sandstone and the Inola limestone above occurs 5 to 10 feet [1.5 to 3 meters] of sandy buff shale, at the top of which, occurs a thin coal and underclay (B_{10})."

Searight and others (1953) name the coal the Bluejacket coal probably from its association with the Bluejacket Sandstone. Branson and others (1965) stated that in Mayes County and southward the Bluejacket coal is between the Bluejacket Sandstone and Inola Limestone. In the southern part of the shelf, this association with the Inola Limestone is a characteristic of the Bluejacket coal. Hemish (1990c, p.11) reported a thickness of 0.2 to 0.6 feet (0.06 to 0.18 meters) for the Bluejacket coal on Inola Hill and 0.04 to 1.8 feet (0.012 to 0.54 meters) thick in the Osage Hills (location of the type section of the Inola Limestone). In northeastern Oklahoma, Hemish (1987, p.99) listed a thickness of 0.1 to 1.5 feet (0.03 to 0.45 meters). The Bluejacket Sandstone closely underlies the Bluejacket coal (Hemish, 1990c, p.11).

Inola Limestone Member

Lowman (1932) named the Inola Limestone from an outlier of limestone on a hill (probably Inola Hill) in Sec. 10, T19N, R17E, about half a mile (0.8 km) east of Inola, Rogers County, Oklahoma. Wilson (1935, p.511) described the Inola Limestone as a dark blue limestone and fossiliferous, with large sponges, and listed a thickness of 10 inches (25.4 cm) for the Inola Limestone in Muskogee County. Branson (1954, p.192) designated a measured section by Tillman (1952, p.32) as type section of the Inola Limestone, near the type locality established by Lowman (1932). Tillman (1952, p.32) measured four separate limestone exposures within his type section and named them "upper Inola," "second Inola," "third Inola," and "lower Inola". Branson (1954, p.192) stated that each limestone was "lying in a separate cyclothem and with coal seams under the first, third, and fourth." Therefore, he restricted the term Inola Limestone to Tillman's "lower Inola". The type section is located in the NE1/4NW1/4NW1/4 Sec. 18, T21N, R18E, approximately 12 miles (19.2 km) northeast of Inola Hill at a south roadcut on Oklahoma Highway 20 within the Osage Hills. The type section is just east of the border between Rogers and Mayes Counties and a few yards east of the northwest corner of the section. Branson (1954, p.192) further stated that the Inola Limestone was a good marker bed to differentiate between the Bluejacket and Taft Sandstones, but in many places, the Inola Limestone is heavily weathered and difficult to identify.

Hemish (1990c) established a principal reference section in the NE1/4NW1/4 Sec. 10, T19N, R17E on Inola Hill. He also established a reference well from a core taken from SE1/4SE1/4SW1/4NW1/4 Sec. 18, T21N, R18E, Mayes County, Oklahoma, designated by the Oklahoma Geological Survey as C-RM-1 (Hemish, 1990c, p.17). Within several of the measured sections and in the principal reference section, Hemish (1990c) identified both an upper and lower bed of the Inola Limestone.

In addition to the large sponges identified by Wilson (1935, p.511), Wilson and Newell (1937, p.56) reported the sponge, *Heliospongia*. Branson (1952, p.192) identified several species of fusilinids from the Inola Limestone, *Wedekindellina henbesti* (Skinner, 1931), *Fusulina leei* (Skinner, 1931), and *Eoschubertella gallowayi* (Skinner, 1931). Alexander (1954, p.33-34, 49) identified five fusulinid species from the Inola Limestone. The first, *Fusulina leei* (Skinner, 1931), was identified in the lower Inola Limestone in the SE1/4 of Sec. 7, T21N, R18E at a roadcut on Highway 20 in Mayes County, Oklahoma. The other four species, *Pseudostaffella hollingsworthi* (Thompson, 1935), *Eoschubertella gallowayi* (Skinner, 1931), *Fusulinella trisulcata* (Thompson, 1935), and *Wedekindellina henbesti* (Skinner, 1931), were all identified in the same locality as *Fusulina leei* (Skinner, 1931) (Alexander, 1954, pp.17-18, 20-23). Hemish (1990c) also describes the Inola Limestone as fossiliferous although he did not identify any specific fossils.

The thickness of the Inola Limestone has remained fairly consistent with the various authors. Wilson (1935, p.511) had the thickness of the Inola Limestone at ten inches (25 cm). Wilson and Newell (1937) reported a thickness of about a foot (0.3 meters). Tillman (1952, p.32) measured the "upper Inola" at 3.5 feet (1.05 meters), "second Inola" at 0.5 feet (0.15 meters), "third Inola" at 2.1 feet (0.63 meters), and "lower Inola" at 1.9 feet (0.57 meters). Branson (1954, p.191) reported the Inola Limestone at 1.9 feet (0.57 meters) thick. Hemish (1990c, pp.9-12) reported a thickness from 0.2 to 0.8 feet (0.06 to 0.24 meters) of Inola Limestone for the measured sections and 3.7 and 5.4 feet (1.1 to 1.6 meters) for the principal reference well for the Inola Limestone. At it southernmost extension, in McIntosh County, the Inola Limestone condenses down to a single bed about 0.5 to 1.0 feet (0.15 to 0.3 meters) thick (Hemish, 1988, core-hole logs 17, 20, 23).

The northernmost known exposure of the Inola Limestone was reported by Hemish (1989b, p.79, 82) from a core in Sec. 25, T27N, R20E in northern Craig County, Oklahoma. Hemish (1990c, p.12) stated that the Inola Limestone does not occur northward beyond Oklahoma.

The Inola Limestone is underlain by an unnamed shale and overlain by an unnamed black phosphatic shale. Branson (1952, p.192) placed the Inola Limestone only a few feet above the Bluejacket Sandstone. Hemish (1990c, p.12) noted that a 0.1-foot (0.03- meter) coal bed (possibly the Bluejacket) closely underlies the Inola Limestone.

Taft Sandstone Member

Wilson (1935, p.510) named the Taft Sandstone from exposures south of Taft, Muskogee County, Oklahoma, Sec. 19, T15N, R17E. He described the Taft Sandstone as a "Massive gray-to-light brown sandstone; contains small pebbles of quartz T. 14 N, and large pebbles of sandstone, shale, and quartz in southwest corner of T. 15 N." Because he did trace the conglomerate within the Taft Sandstone farther north than the Arkansas River, Wilson (1935, p.510) believes that the type sandstone might have been deposited in a coastal swash zone; he also included a thickness of 30 feet (9 meters) in the description of the type Taft Sandstone.

Wilson and Newell (1937, pp.56-57) described a series of massive sandstones and interbedded shales in T14N that comprise an 80-foot (24-meter) Taft interval. They believed that the Taft Sandstone at the type locality may just be the lower part of the unit at T14N. Wilson and Newell (1937, p.56) also state that the Taft Sandstone forms a prominent 200-foot (60-meter) escarpment over the Crekola-Inola plain.

In the subsurface, the collection of sandstones that comprise the Taft Sandstone are called the Redfork. On the surface however, a confusing terminology of referring to four different sandstones as the Taft #1, Taft #2, Taft #3, and Taft #4 is in place. Since the Redfork of the subsurface is regarded as one sequence, it is possible that the four sandstones were named in this way to fit the model of a single sequence.

The first two Taft Sandstones lie within the Boggy Formation. Taft Sandstone #1 lies between the Inola Limestone and Wainwright coal, and Taft Sandstone #2 lies between the Wainwright coal and the Weir-Pittsburg coal. The upper two Taft Sandstones lie within the Senora Formation. Taft Sandstone #3 lies between the Weir-Pittsburg and RC coals, and Taft Sandstone # 4 lies between the RC and Tebo coals. Between each of these Taft Sandstones is at least one marine interval with a black or gray phosphatic shale. If the Taft Sandstones were considered the regressive part of a sequence and the black or gray phosphatic shale the transgressive, each of the four sandstones considered to be part of the Taft occupies an entirely different T-R unit.

According to the North American Commission on Stratigraphic Nomenclature (1983, Article 22d), "Inferred geologic history, depositional environment, and biological sequence have no place in the definition of a lithostratigraphic unit, which must be based on composition and other lithic characteristics.". Therefore, each Taft Sandstone cannot be classified as separate sandstones if they just occupy different sequences. However, because a significant marine transgression separates each sandstone, it is doubtful that the sandstones are genetically related so each may exhibit distinct lithologic differences.

Wainwright coal

The name "Wainwright" had been used informally for over six decades by residents and local miners for a coal mined around Wainwright, Muskogee County, Oklahoma. Hemish proposed the use of the name officially in the preparations for Coal Geology of McIntosh and Muskogee Counties, Oklahoma, and it was adopted by the Oklahoma Geological Survey (Hemish, 1987, p.104). Hemish believes that the Wainwright coal is equivalent to the "Taft" coal (Bennison and others, 1979) of northwestern Muskogee County.

CABANISS GROUP (SUBGROUP)

The uppermost group or subgroup of the Cherokee is the Cabaniss. Oakes named the Cabaniss from the village of Cabaniss in Pittsburg County, Oklahoma. The top of the Cabaniss was established at the base of the Fort Scott Limestone, which is also the base of the Marmaton Group in the upper Desmoinesian Stage (Oakes, 1953). The contact between the Marmaton and the Cabaniss is conformable (Oakes, 1953).

Around its type locality, the Cabaniss is approximately 1,000 feet (300 meters) thick but thins northward to approximately 160 feet (48 meters) at the Kansas-Oklahoma border (Oakes, 1953). This thinning occurs as the Cabaniss leaves the Arkoma Basin near McAlester and southeastern Oklahoma and enters the northeastern shelf (Oakes, 1953).

Oakes (1953) listed the three formations for the Cabaniss as the Thurman Sandstone, Stuart Shale, and the Senora Formation. However, the Thurman Sandstone and Stuart Shale are formations that are only present in the Arkoma Basin. Once on the shelf, they either pinch out or were removed by erosion leaving an unconformity between the Krebs and Cabaniss Subgroups, the Boggy and Senora Formations. Because of this, both the Thurman Sandstone and Stuart Shale are minor formations that will not be dealt with in this study. Only the Senora Formation of the Cabaniss Subgroup will be included. The Senora Formation itself is further subdivided into numerous member units that will be discussed in the following pages.

Senora Formation

Not as much has been published on the Senora Formation as had been for the lower formations of the Krebs Subgroup. There are two primary reasons for this. The first reason is that the Senora Formation is much thinner than most of the other formations. Taff (1901) reported a thickness of 500 to 150 feet (150 to 45 meters) in Okmulgee County. Oakes (1953) listed a thickness of 160 feet (48 meters) for the Senora Formation at the Oklahoma-Kansas border. Ries (1954) stated that only 190 feet (57 meters) of the Senora Formation was exposed in Okfuskee County. In comparison, the McAlester, Savanna, and Boggy Formations are 1,000 to 2,000 feet (300 to 600 meters) or more in thickness in the Arkoma Basin. The second reason is that the Senora Formation is not as well exposed in the Arkoma Basin as it is on the shelf, but most of the early studies are coal studies of the Cherokee Group, focused on the Arkoma Basin. However, many cyclicity studies of the Cherokee Group are focused on the shelf and not the basin so cyclothems in the Senora Formation are bettered developed than cyclothems in the lower formations.

Taff (1901) named the Senora Formation from the village of Senora, Okmulgee County, Oklahoma. He provided a description of the Senora Formation as it appeared in the Coalgate Quadrangle in southern Okmulgee County:

> "This formation is composed of interstratified sandstones and shaly beds having a thickness of nearly 500 feet [150 meters] in the northeastern corner of the quadrangle. The thickness of the formation decreases toward the southwest chiefly by the thinning of the sandstone beds, until at the western border of the quadrangle, it does not exceed 150 feet [50 meters]. The outcrop of the formation in the northern part of the quadrangle averages about 10 miles [16 km] in width. The lower 320 feet [96 meters] of the formation there is composed almost entirely of sandstone which forms a very rugged and stony highland with sandstone bluffs, in places nearly 100 feet [30 meters] high, along the eastern side. This sandstone grades upward through thin sandy beds into shale strata which are approximately 160 feet [48 meters] in thickness.
>
> Near the middle of the quadrangle, the lower massive sandstone becomes divided and shale beds 20 to 75 feet [6 to 22.5 meters] in thickness appear. With this change in character, the surface becomes less rugged and stony. In the western part of the quadrangle, the sandstone beds become quite variable in thickness and their position in the formation. The outcrop of the formation here varies in width from 1 to 4 miles [1.6 to 6.4 km] depending chiefly upon the erosion of the streams which cross it. The upper and more shaly members have a variable thickness from 100 to 120 feet [30 to 40 meters] in the western part.
>
> In texture, the sandstones are generally fine-grained and are gray or reddish brown in color. The shales, which occupy the more level land in the western and northern parts of the outcrop, are rarely well exposed and their original physical characteristics were not satisfactorily determined. Bluish clay shales and brownish sandy shales belonging in the upper part of the series, however, are exposed in the deeper cuttings of the streams which flow from the higher land of the succeeding Calvin sandstone." (Taff, 1901).

Very little has been written about the Senora Formation in Oklahoma. In Kansas and Missouri, the Senora Formation is not recognized as a stratigraphic unit, and, furthermore, in Kansas and Missouri, the interval covering the Senora Formation is subdivided based upon other criteria, which will be discussed in succeeding chapters.

Dane and others (1938) did describe an outcrop of the Senora Formation in the Quinton-Scipio coal district in Pittsburg, Latimer, and Haskell Counties, Oklahoma. They identified the lower contact of the Senora Formation from the northeastern part of T6N, R12E and traced it northward to the northwestern part of T7N, R13E and southwestern part of T8N, R13E. Within this area, Dane and others (1938, p.168) noted that only 70 feet (21 meters) of the Senora Formation was exposed; the exposed part of the Senora Formation consisted mainly of sandstones with interbedded shales. They also noted a 10-foot (3-meter) sandstone unit at the base of the Senora Formation. Dane and others (1938, p.168) believed that elsewhere the Senora Formation was as thick as 500 feet (150 meters).

Oakes (1953) included the Senora Formation as the uppermost formation within the Cabaniss Subgroup. The Senora Formation is either conformably underlain by the Stuart Shale in the Arkoma Basin or unconformably underlain by the Boggy Formation on the shelf.

Ries (1954, p.25) noted several fossiliferous intervals within the Senora Formation in Okfuskee County, Oklahoma. 83 feet (25 meters) below the base of the Calvin Sandstone, in Sec. 11, T10N, R12E, Ries (1954, p.25) noted a 1 to 2 foot (0.3 to 0.6 meter) thick sandy fossiliferous limestone and collected and cataloged the fossils found in this limestone. From this, Ries (1954, pp.25-26) listed 19 genera of fossils that included the crinoids *Aatocrinus*, *Delocrinus*, and *Ethelocrinus*; bryozoan *Rhombopora*; brachiopods *Chonetes*, *Composita*, *Derbyia*, *Dictyoclostus*, *Hustedia*, *Juresania*, *Linoproductus*, *Marginifera*, *Neospirifer*, and *Punctospirifer*; gastropods *Bucanopsis*, *Euphemites*, and *Worthenia*, and nautiloids *Liroceras* and *Metacoceras*.

Below the limestone, Ries (1954, p.25) described a 4-foot (1.2-meter) sandstone 82 feet (25 meters) below the limestone, and 24 feet (7.2 meters) below the upper sandstone, the basal part of the Senora Formation exposed in Okfuskee County was occupied by a massive sandstone. Overall, Ries (1954) observed nearly 190 feet (57 meters) of Senora Formation in Okfuskee County. Above the limestone, shales dominate the upper part of the Senora Formation (Ries, 1954, p.25).

In northeastern Oklahoma, Ries (1954, p.26) only included four member units within the Senora Formation: the Tiawah Limestone, Chelsea Sandstone, Verdigris Limestone, and Breezy Hill Limestone. In Okfuskee County, the sandy limestone described by Ries (1954) may very well be equivalent to the Tiawah Limestone.

Howe (1956) did not discuss the Senora Formation directly but did discuss many of the member units of the formation. His discussion of each member unit will be dealt with in the member units of the Senora Formation section.

Oakes (1963) studied the Senora Formation in Okmulgee County. He provided a general description of the Senora Formation within that county:

> "The Senora Formation is divided naturally into two intergrading parts. The lower part, approximately that part older than the Croweburg (Henryetta) coal, consists of sandy to silty shale, fine-grained to silty sandstone, and a few limestone beds. The upper part consists of less silty shale, a minor amount of silty sandstone, and still less limestone." (Oakes, 1953, p.26)

Oakes (1963, p.27) also noted the interfingering of the Calvin Sandstone with the shales in the upper part of the Senora Formation. Oakes (1963, p.28) believes that these tongues of sandstones were deposited by mud deltas which were later abandoned. Sand was later deposited upon these deltas some of which may have spilled down the sides. More mud was deposited covering the sand on top and down the sides of the delta. More sand was probably deposited on top of the mud. This sequence of events could, according to Oakes (1963), created the tongues of Calvin Sandstone in the upper shales of the Senora Formation; however, the presence of black phosphatic shales (particularly the Excello) in the upper part of the Senora Formation may indicate deeper water shales than just a mud delta. Oakes (1963, p.26) reported about 800 feet (240 meters) of Senora Formation in Okmulgee County.

Branson and others (1965, p.34) placed the lower boundary of the Senora Formation at the base of the Weir-Pittsburg coal and the upper boundary at the base of the Blackjack Creek Limestone member of the Fort Scott Formation. Branson and others (1965, p.34) also noted additional member units of the Senora Formation including the Weir-Pittsburg coal, Tebo coal, Tiawah Limestone, Chelsea Sandstone, Mineral coal, Russell Creek Limestone, Fleming Limestone, Croweburg coal, Verdigris Limestone, Bevier coal, Lagonda Sandstone, Iron Post coal, Kinnison Shale, Breezy Hill Limestone, and Excello Shale. They also noted the cyclic nature of the beds within the Senora Formation and described a typical cycle as sandstone, shale, underclay, coal, and limestone.

Oakes and others (1967, pp.33-34) also noted that the Senora Formation in McIntosh County consisted of two basic units: the lower part dominated by sandstones and the upper part dominated by shales. In McIntosh County, there are about 9 mappable sandstone units within the lower Senora Formation. Oakes and others (1967, p.34) described these sandstones as thus:

> "The Senora sandstones of McIntosh County are light gray to tan, where freshly exposed, and weather to various shades of reddish brown. Most are fine grained, micaceous, lenticular, and contain plant fossils.

> Ripple marks, cross-bedding, and penecontemporaneous folding are common."

The lower Senora Formation ranges from 600 feet to about 700 feet (180 to 210 meters) thick in the extreme southwestern corner of McIntosh County. Oakes and others (1967, p.34) stated that the upper part of the Senora Formation is dominated by silty shales. Since McIntosh County is in the Arkoma Basin, the source area is nearby explaining the increased siliceous influx of the shales in this area. The thickness of the upper Senora Formation in McIntosh County is around 350 feet (105 meters). Oakes and others (1967, p.34) reported approximately 950 feet (285 meters) of the Senora Formation in McIntosh County.

Oakes (1977, pp.36-37) listed the thickness of the Senora Formation from several localities. In Muskogee County, southern half of T16N, Oakes (1977, p.37) noted that the Senora Formation was about 480 feet (144 meters) thick. In T12N, Okmulgee and McIntosh Counties, the Senora Formation was as great as 910 feet (273 meters) thick. In northern Okmulgee County, Oakes (1977, p.37) reported the Senora Formation from 700 to 820 feet (210 to 246 meters) thick. Hemish (1987, p.99) listed the Senora Formation as 160-500 feet (48 to 150 meters) thick in the Northeastern Oklahoma Shelf area.

In the Arkoma Basin, the Senora Formation conformably overlies the Stuart Shale, but once out of the basin and onto the shelf, the Stuart Shale and underlying Thurman Sandstone pinch out. Therefore, the Senora Formation unconformably overlies the Boggy Formation. In the basin, the Calvin Sandstone overlies the Senora Formation. On the shelf, the Fort Scott Limestone conformably overlies the Senora Formation. Both the Calvin Sandstone and Fort Scott Limestone are part of the Marmaton Group.

Weir-Pittsburg coal

Haworth and Crane (1898, pp.25-26) named this coal after that fact that it was mined around Weir City and Pittsburg, Cherokee and Crawford Counties, Kansas, and the average thickness of the coal in its type area is around 40 inches (102 cm). Howe (1956, p.47) stated that the Weir-Pittsburg coal, at an average thickness of 38 inches (97 cm), is the thickest and most economically important coal in southeastern Kansas.

A characteristic of the Weir-Pittsburg coal is the presence of a "blackjack" clay beneath it; Crane (in Haworth and Crane, 1898), Abernathy (1936), Moore (1949), and Howe (1956) have all mentioned the "blackjack" clay. The "blackjack" clay has been described as a "uneven, plastic, dark-gray clay containing abundant fossil plant impressions and coaly material, and showing profuse slickensides." (Howe, 1956, p.47) The "blackjack" clay is present mainly in southeastern Kansas, notably northern Cherokee County and southern Crawford County, but doesn't seem to be present near the Kansas-Missouri border or in Oklahoma.

Howe (1956, p.48) reported the informal mining terms for the Weir-Pittsburg as the "Weir-Pittsburg lower," "Cherokee," "4-foot," and "Big Lower". Hemish (1987, p.104) mentioned that in Rogers and Mayes Counties the Weir-Pittsburg has been referred to as the "Pawpaw" coal.

RC coal

Hemish named the RC coal while preparing the *Coal Geology of Rogers and western Mayes Counties, Oklahoma* (Hemish, 1987, p.103). The RC coal may also be equivalent to a coal in western Mayes County referred to as the "Lower Tebo" coal by

Bennison and others in 1979 (Hemish, 1987, p.103). The term "RC" refers to Rogers County (Bennison, personal communications, 1998).

Tebo coal

Marbut (1898) named the Tebo coal for exposures of the coal along Tebo Creek in Henry County, Missouri. In the type area, along the banks of Tebo Creek, Marbut (1898, p.126) noted approximately 3 feet (0.9 meters) of Tebo coal in outcrop. Pierce and Courtier (1937, pp.68-69) named a coal above the Weir-Pittsburg coal and below the Mineral coal the "Pilot" coal. Howe (1956, p.51) stated the "Pilot" and Tebo coals were equivalent. Searight and others (1953) and Howe (1956) elected to use the name Tebo since it was older. Howe (1956, p.52) listed the average thickness of the Tebo coal at around half a foot (0.15 meters).

In northwestern Cherokee County, Kansas, NW1/4 Sec. 25, T32S, R22E, and NE1/4 Sec. 30, T32S, R23E, Howe (1956, p.49) stated that the Tebo and Weir-Pittsburg coals are in contact with one another. Apparently, the interval between the two coals pinches out leaving both coals in contact with only a thin clay parting separating the two; the thickness of the combined Weir-Pittsburg-Tebo coal bed is 30 to 40 inches (76 to 102 cm).

Tiawah Limestone Member

Lowman, in 1932, named the Tiawah Limestone from exposures around the town of Tiawah in the Tiawah Hills, Rogers County, Oklahoma (Branson and others, 1965, pp.34-35). Tillman (1952, p.23) proposed the type section of the Tiawah Limestone that

Branson (1952, p.192) formally established at the south road cut on State Highway 20 in the SW1/4 Sec. 12, T21N, R16E, and in a measured section of the type section, Tillman (1952) reported 6.3 feet (1.9 meters) of Tiawah Limestone. Branson (1952, p.191) described the Tiawah Limestone as "two thin clay ironstone beds"; he also stated that the Tiawah Limestone was a caprock of the Tebo coal at the Kansas-Oklahoma border. However, Branson (1952, p.191) did note a black phosphatic shale below the Tiawah Limestone. And, while the Tiawah Limestone and the Tebo coal seem to be in contact near the Kansas border, southward towards the Arkansas River, Branson (1952) stated that this shale becomes increasingly thicker. In the area of southwestern Wagoner County, Branson (1952, p.191) further noted that the Tiawah Limestone is a coquina composed mostly of *Myalina* shells.

In the SE1/4 Sec. 26, T19N, R15E, Wagoner County, Oklahoma, Alexander (1954, pp. 24, 49) reported abundant *Fusulina attenuata* from the Tiawah Limestone. He also reported that this species of *Fusulina* was a new one. Furthermore, Alexander (1954, p.49) states that this is the lowest reported occurrence of fusulinids within the Cabaniss Subgroup.

Searight and others (1953), at a conference in Nevada, Missouri, officially adopted the name Tiawah Limestone. Howe (1956, pp.54-55) described the Tiawah Limestone in Crawford County, Kansas as "extremely dense, tough, and pyritic", but in nearby Cherokee County, Kansas, the Tiawah Limestone is shaly and carbonaceous. Howe (1956, p.54) also stated that the Tiawah weathers to "a soft hematitic and limonitic mass." , and in Rogers County, Oklahoma, the Tiawah Limestone closely resembles the Verdigris Limestone (Howe, 1956, p.54).

Below the Tiawah Limestone, Howe (1956, p.54) noted two black fissile shales. The lower black fissile shale directly overlies the Tebo coal and is 1 to 2 feet (0.3 to 0.6 meters) thick. Above the lower black fissile shale, Howe (1956, p.54) observed a 4-inch (10.2 cm) impure pyritic limestone. Another black fissile shale overlies the limestone; this shale is approximately 5 to 7 feet (1.5 to 2.1 meters) thick. In some places, Howe (1956, p.54) stated that the black fissile shale above the Tebo coal contains small phosphate nodules, and the upper black fissile shale contains several clay ironstone stringers. In addition, Howe (1956, p.55) noted the presence of conodonts in the black shales above and below the Tiawah Limestone.

Howe (1956, pp.54-55) elaborated upon the very fossiliferous nature of the Tiawah Limestone by listing several different types of fossils from the Tiawah. Among gastropods, *Nacticopsis* and *Trachydomia* are abundant. There are several brachiopods within the Tiawah as well, *Mesolobus*, *Chonetina*, and *Dictyoclostus*. Howe (1956, p.55) also reported that Johnson in 1956 had identified the algae *Archaeolithophyllum* within the Tiawah Limestone, and, in many areas in southeastern Kansas and southwestern Missouri, the limestone is heavily laminated with *Archaeolithophyllum*.

Parker (1958), studying the Tiawah Limestone in Wagoner, Roger, and Craig Counties, Oklahoma, Crawford County, Kansas, and Vernon County, Missouri, compiled a more detailed list of the fauna of the Tiawah than Howe (1956) did. By observing the Tiawah Limestone in 18 separate localities, Parker (1958) was able to determine some of the most common fauna within the Tiawah Limestone. Of the brachiopods, Parker (1958) noted *Dictyoclostus*, *Crurithyris*, *Echinoconchus*, *Composita*, *Cleiothyridina*, *Spirifer*, *Leiorhynchus*, *Marginifera*, *Phricodothyris*, and *Mesolobus*. Brachiopods are abundant in the Tiawah Limestone, and *Dictyoclostus*, *Crurithyris*, *Marginifera*, and *Spirifer* are the common brachiopod genera. Among gastropods, Parker (1958) listed *Bellerophon*, *Straparrolus*, *Trepospira*, *Worthenia*, *Glabrocingulum*, and small high-spired archaeogastropods. *Bellerophon* seems to be the most abundant gastropod within the Tiawah Limestone. Parker (1958) listed four foraminifera from the Tiawah Limestone, Fusulinidae, Paleotextularidae, *Tetrataxis*, and *Nubecularia*. The families Fusulinidae and Paleotextularidae and the genus *Tetrataxis* seem to be the most abundant foraminifera in the Tiawah Limestone. Minor faunal assemblages of the Tiawah Limestone include pelecypods *Myalina* and *Aviculopecten*, and bryozoans *Rhobopora* and fenestrate fragments. Parker (1958) also found echinoderm debris within the Tiawah Limestone, mainly crinoid stem ossicles, plates, and spines; some of the crinoid ossicles achieved diameters of 29 to 31 mm. Along the North Line Sec. 12, T18N, R15E, in northwestern Wagoner County, Oklahoma, Parker (1958, p.27) reported the blue-green algae, *Epimastopora*, from the upper beds of the Tiawah Limestone. In reference to Johnson's 1956 findings, Parker (1958, pp.61-62) confirmed the presence of *Archaeolithophyllum* in two localities in Barton and Henry Counties, Missouri. Parker (1958, p.61) also noted that *Archaeolithophyllum* is probably a red algae.

Parker (1958, p.8) described the Tiawah Limestone as fine-grained, dense, fossiliferous, and either massive or thin-bedded. He stated that the color ranges from black to dark blue-gray to gray. In the Northeast Oklahoma Shelf, Parker (1958, p.122) noted that the depositional environment of the Tiawah Limestone was probably shallow marine, "Northward to northern Craig County, Oklahoma a shallow water marine community of brachiopods, bryozoans, echinoderms, and calcareous foraminifera, furnished most of the fossil calcite and calcium carbonate…". The shallow sea that possibly deposited the Tiawah Limestone probably only extended as far south as Wagoner County, "Central Wagoner County, Oklahoma represents the southern marine depositional edge of the Tiawah Limestone." (Parker, 1958, p.122). However, outcrops of the Tiawah Limestone in nearby western Muskogee County are present. Parker (1958, p.122) also added that *Myalina*, *Bellerophon*, and *Tetrataxis* were common fossils in this area and were the best adapted to the brackish water of the marginal marine environment.

Like Branson (1952) and Howe (1956), Branson and others (1965, p.34) noted a black fissile phosphatic shale below the Tiawah Limestone. They listed the thickness of this shale from 1.5 to 5 feet (0.45 to 1.5 meters). In addition, Branson and others (1965, p.35) recognized a black phosphatic shale above the Tiawah Limestone. In describing the regional distribution of the limestone, Branson and others (1965, p.35) stated that the Tiawah Limestone is present in numerous exposures from southern Wagoner County, Oklahoma to Missouri.

In southern part of the exposure area, Wagoner County, Branson and others (1965, p.35) described the Tiawah Limestone as grading, "southward from a myalinid coquinite into a dense crystalline limestone with abundant fusulinids." In Craig County, Branson and others (1965, p.35) described the Tiawah Limestone from several localities. In the NE1/4 Sec. 26, T27N, R19E, east bank of the Middle Fork of Big Cabin Creek, Branson and others observed (1965, p.35), "…the Tiawah is a double bed, 0.3 foot [0.09 meters] of clay-ironstone, over 0.1 foot [0.03 meters] of black fissile shale, over 0.3 foot [0.09 meters] of dark clay-ironstone." In NE1/4NW1/4NW1/4 Sec. 15, T28N, R20E, in Wolfe Creek, the Tiawah Limestone was described as a 0.2-foot (0.06-meter) clay-ironstone stringer. In Secs. 20, 21, T26N, R19E, along PawPaw Creek, Branson and others (1965, p.35) described the Tiawah Limestone as a clay-ironstone ledge; southwestward, the Tiawah Limestone becomes numerous clay ironstone concretions. Also in this area, both the Tiawah Limestone and Tebo coal are cut off by the downcutting of the Chelsea Sandstone (Branson and others, 1965, p.35).

Branson and others (1965, p.35) listed a limited number of fauna from the Tiawah Limestone, mostly gastropods and the brachiopod *Desmoinesia*, from the Wolfe Creek locality. But, Branson and others (1965, p.35) did report that Chrisman in 1951 provided a more complete listing of the fauna of the Tiawah Limestone; the list of fauna provided by Chrisman is similar to that provided by Parker (1958). Among the fauna identified by Chrisman are brachiopods *Cleiothyridina*, *Desmoinesia*, *Mesolobus*, and *Crurithyris*; pelecypods *Aviculopecten* and *Nuculopsis*; and the coral *Lophophyllidium*. Chrisman collected from two localities, NE1/4 Sec. 20, T26N, R19E, and NW1/4 Sec. 32, T26N, R19E.

Oakes (1977, p.38) noted a black fissile shale below the Tiawah Limestone that may also extend above the Tiawah. He described the shale as a sixteen-foot (4.8-meter) black fissile shale with iron carbonate concretions. Oakes (1977, p.38) described the Tiawah Limestone as dark gray, dense, fossiliferous limestone that weathers to reddish brown.

Hemish (1990d, p.42) observed two beds of the Tiawah Limestone; he also stated that Jordan (1957) observed "two beds at places" of the Tiawah Limestone as well. Hemish (1990d, p.43) described the lower bed as "~0.6 ft [0.18 meters] thick, dark-gray with reddish-brown staining, very ferruginous and silty in the upper part, abundantly fossiliferous, and has a hackly appearance on weathered surfaces owing to the abundance of broken fossils." The upper bed of the Tiawah Limestone is "~0.4 ft [0.12 meters] thick, dark-gray with reddish-brown iron oxide staining, fossiliferous, and very hard, forming a ledge in the creek bed." (Hemish, 1990d, p.43). In the SE1/4NW1/4 Sec. 1, T16N, R15E, in Wagoner County, Hemish (1990d, p.43) described the lower bed of the Tiawah Limestone as a wavy-bedded coquinoidal limestone, and the upper bed was described as shaly and carbonaceous.

Hemish (1990d) also noted a black phosphatic shale below the Tiawah Limestone. He stated that the shale was 6.8 feet (2.04 meters) thick and possibly extended above the Tiawah Limestone as well. If so, this indicates that black fissile phosphatic shales both overlie and underlie the Tiawah Limestone.

Because Branson's (1952) type section is outside the type locality of the Tiawah Limestone, Hemish (1990d, p.42) established a principal reference section in the SE1/4SW1/4SW1/4SW1/4 Sec. 26, T21N, R16E in the Tiawah Hills in Rogers County, Oklahoma. The principal reference section is well within the type locality of the Tiawah Limestone. Hemish (1990b, p.46) also established a reference well for the Tiawah Limestone in the SE1/4SW1/4NW1/4SE1/4 Sec. 12, T21N, R16E, Rogers County. The reference well is approximately a half-mile (0.81 km) northeast of the type section established by Branson (1952).

Various authors have reported the thickness of the Tiawah Limestone. Tillman (1952), in a measured section of the type section, reported 6.3 feet (1.9 meters) of Tiawah Limestone. In Cherokee County, Kansas, Howe (1956) observed 0.33 feet (0.01 meters) of Tiawah; Howe also mentioned that the Tiawah is around 4 feet (1.2 meters) in Rogers

County. Branson and others (1965) noted 0.4 to 0.6 feet (0.12 to 0.18 meters) of Tiawah Limestone in Craig County. Oakes (1977) noted approximately a half-foot (0.15 meters) of Tiawah Limestone in Muskogee County. Hemish (1990d) included 5.6 feet (1.7 meters) of Tiawah Limestone in the reference well for the Tiawah and 2.9 feet (0.87 meters) of Tiawah Limestone in the principal reference section. The Tiawah Limestone seems thickest in its type area (Tiawah Hills) and thins dramatically to the north and south.

The Tiawah Limestone lies between the Tebo coal and the Chelsea Sandstone. The Tiawah overlies and underlies unnamed shales, and in many locations, either one or both shales are black fissile phosphatic shales. In some places, the Tiawah Limestone is absent due to downcutting by the Chelsea Sandstone. In the subsurface, the Tiawah Limestone is known as the "Pink" Lime.

Chelsea Sandstone Member

Ohern (1914) named the Chelsea Sandstone from exposures around the town of Chelsea in Rogers County, Oklahoma. Branson (1952, p.191) stated that the Chelsea Sandstone has a discontinuous distribution. In northern Craig County, Oklahoma, the Chelsea Sandstone seems to be absent, and instead, both the Mineral coal and Russell Creek Limestone occupy the stratigraphic position of the Chelsea Sandstone (Branson, 1952, p.191).

Oakes (1944, p.5) noted two distinct phases within the upper Chelsea Sandstone. The lower phase was described as coarse-grained, cross-bedded, and tree bearing. Oakes (1944, p.5) described the upper phase of the Chelsea Sandstone as a zone of silty shales overlain by thin-bedded silty to shaly sandstones. Oakes (1944, p.10) further noted that both lateral and vertical gradation occurred within the Chelsea Sandstone.

Howe (1956, pp.57-58) discussed the Chelsea Sandstone and stated that the Chelsea Sandstone is "locally conglomeratic, particularly in the lower part. Conglomeratic material in the Chelsea in northern Oklahoma consists entirely of fragments of clay-ironstone, concretions, phosphatic nodules, and detrital wood and coal, seemingly all of local origin." Howe (1956, p.58) also described the Chelsea Sandstone as a gray to brown, friable, very fine-grained, micaceous sandstone. Furthermore, Howe (1956, p.58) also observed fine to coarse cross-bedding within the Chelsea Sandstone. The maximum thickness of the Chelsea Sandstone that Howe (1956, p.58) observed is around 30 feet (9 meters).

The conglomerate in the lower part indicates that the Chelsea Sandstone is probably a channel sandstone. Most channel sandstones, especially with conglomerates, usually have downcutting associated with them, and the Chelsea Sandstone has a significant amount of downcutting associated with it. Howe (1956, pp.45, 57) noted that locally the Chelsea downcuts through the Tiawah Limestone and Tebo coal. And, in some cases, the magnitude of downcutting is significant with the Chelsea Sandstone incising down to the Weir-Pittsburg coal. In personal field observations, in west-central Muskogee County, the shale between the Tiawah Limestone and Chelsea Sandstone is approximately 20 feet (6 meters), but in Rogers County, the same interval is only around 6 feet (1.8 meters) thick. In Craig County, Branson and others (1965, p.36) reported that the Chelsea Sandstone is only 5 feet (1.5 meters) above the Bluejacket Sandstone. In southeastern Labette County, Kansas, Howe (1956, p.45) stated the possibility that the Bluejacket and Chelsea Sandstones have merged to form one large sandstone bed.

In southwestern Craig, northern Mayes, and Rogers County, Branson and others (1965, p.36) placed the Chelsea Sandstone approximately 200 feet (60 meters) above the Bluejacket Sandstone. They described the Chelsea Sandstone as "reddish-brown to yellow, medium-grained, well-sorted, ferruginous, micaceous, massive, cross-laminated sandstone." (Branson and others, 1965, p.36). Branson and others (1965, p.36) stated that the Chelsea Sandstone grades upwards into a silty shale; they also noted a conglomerate in the basal Chelsea. The thickness of the Chelsea Sandstone in northeastern Oklahoma ranges from 0 to 70 feet (21 meters) with the average thickness being 50 feet (15 meters); however, near the Oklahoma-Kansas border, Branson and others (1965, p.36) observed that the Chelsea Sandstone seems to grade laterally into a thick shale.

In confirming Branson's (1952) earlier findings, Branson and others (1965, p.36) stated that the Chelsea Sandstone is absent in north-central Craig County. It is possible that at this point the Chelsea Sandstone has already graded into shale. Branson and others (1965, pp.36-37) did confirm the presence of the overlying Mineral coal and Russell Creek Limestone in northern Craig County.

Scammon coal

Abernathy (1936, pp.83-84) named this coal from town of Scammon, Cherokee County, Kansas. The type locality (Sec. 26, T31S, R24E) of the Scammon coal is exposed along Cherry Creek northwest of Scammon, Kansas; at the type locality, 3 feet (0.9 meters) of black fissile shale and thin limestones overlie the 0.3 feet (0.09 meters) of

Scammon coal. Howe (1956, p.58) listed the coal from 4 to 9 inches (10.2 to 23 cm) in thickness where it was exposed in Cherokee and Crawford Counties, Kansas. However, Howe (1956) mentioned that the coal is absent in Labette County, Kansas, and the coal is entirely absent in Oklahoma. But, it is mentioned in this report because it is an important stratigraphic marker in the Cherokee Group.

There is some difficulty in determining just what position the Scammon coal occupies. Howe (1956, p.52), noting the similarities of the overlying beds of the Tebo and Scammon coals, believed that the Scammon and Tebo coals may be equivalent. The Scammon coal's position is above both the Tiawah Limestone and the Chelsea Sandstone, but the Tebo coal lies below the Tiawah Limestone making any correlation with the Tebo impossible. A more detailed analysis of the Scammon problem can be read in the Previous Cyclicity Studies in Appendix A, pp. 227, 245-46

Mineral coal

Pierce and Courtier (1937, p.70) named the Mineral coal from the town of Mineral, Cherokee County, Kansas where it is extensively mined. Pierce and Courtier (1937, p.70) also stated that popular names for the Mineral coal include "Weir-Pittsburg Upper," "Lightning Creek," "Baxter," "22-inch vein," "top vein," and "upper seam" coals. They stated that Haworth and Crane called the Mineral coal the Weir-Pittsburg upper coal. Pierce and Courtier (1937, p.71) provided a thickness of 17 to 24 inches (43 to 61 cm) for the Mineral coal.

Howe (1951, p.2091) stated that the Mineral coal was present in northeastern Oklahoma in T28N, R20E and T29N, R20E. He also stated that that the characteristic of the Mineral coal was a limestone caprock (Russell Creek Limestone). Howe (1956) also discussed the Mineral coal. He stated that the Mineral coal is anywhere from 60 to 80 feet (18 to 24 meters) above the Weir-Pittsburg coal in Cherokee and Crawford Counties, Kansas (Howe, 1956, p.62). In the eastern part of southeastern Kansas, Howe (1956, p.62) provided a range of 18 to 32 inches (46 to 81 cm) for the Mineral coal. In the western part of southeastern Kansas (mainly Labette County), Howe (1956, p.62) noted a thickness of around 12 inches (30 cm).

In northern Craig County, Oklahoma, Branson and others (1965, p.36) noted the Mineral coal 54 feet (16 meters) above the Weir-Pittsburg coal and 28 feet (8.4 meters) above the Tebo coal. They listed the thickness of the Mineral coal as 14 to 22 inches (36 to 56 cm) thick (Branson and others, 1965, p.36). Hemish (1987, p.103) stated that the Mineral coal is known in Okmulgee County as the "Eram" or "Morris" coal. In northeastern Oklahoma, Hemish (1987, p.99) listed a thickness of 0.1 to 2.7 feet (0.03 to 0.81 meters) for the Mineral coal.

Russell Creek Limestone Member

Branson (1952, p.191) named the Russell Creek Limestone from exposures along Russell Creek in the NE1/4SW1/4 Sec. 15, T29N, R20E, northernmost Craig County, Oklahoma, calling the Russell Creek Limestone a caprock of the Mineral coal. But, he did not provide any thickness of the limestone at the type locality. Alexander (1954, p.25), studying the Russell Creek Limestone in the SW1/4 Sec. 11, T28N, R20E in Craig County, identified the fusulinid *Fusulina equabilis*. Alexander (1954, p.26) also stated that *Fusulina equabilis* was associated with molluscan fauna (mostly gastropods) in exposures of the limestone.

Howe (1956, p.65) noted within the Russell Creek Limestone and overlying calcareous shale the brachiopods *Dictyoclostus*, *Neospirifer*, *Composita*, *Mesolobus*, and *Marginifera*, crinoid debris, and the fusulinids *Fusulina*, *Wedekindellina*, and *Fusulinella*.

Branson and others (1965, p.38) described the Russell Creek Limestone as, "...a dense, black, finely crystalline, impure limestone 2 to 3 feet [0.6 to 0.9 meters] thick.", and they also stated that the Russell Creek Limestone was a caprock of the Mineral coal. Branson and others (1965, p.38) reported that Claxton in 1952 identified several fossils from North Center Sec. 23, T29N, R20E in Craig County. Claxton found the coral *Lophophyllidium*, brachiopods *Neospirifer*, *Composita*, and *Desmoinesia*, and the gastropod *Naticopsis*. Furthermore, Claxton also identified the fusulinid *Fusulina equabilis* (Alexander, 1954).

The Russell Creek Limestone lies between the Mineral coal and the Fleming coal. The Russell Creek overlies the Mineral coal and in some places an unnamed clay shale. An unnamed shale, which in some places is a black phosphatic fissile shale, overlies the Russell Creek Limestone.

Fleming coal

Pierce and Courtier (1937, p.73) named the Fleming coal from exposures north of the village of Fleming, Crawford County, Kansas. Pierce and Courtier (1937, p.73) stated that they previously referred to this coal as the "Mineral Rider," and "Bastard bed" was a common name for this coal. They described the thickness of the Fleming coal as variable ranging from trace to 18 inches (46 cm). In Crawford County, the Fleming coal ranges from trace to 10 inches (25 cm), and in Cherokee County, Kansas, the Fleming ranges from 12 to 18 inches (30 to 46 cm) in thickness (Pierce and Courtier, 1937, p.73).

Howe (1956, p.67) also mentioned the variability of the thickness of the Fleming coal in southeastern Kansas. Howe (1956, p.68) stated that the Fleming coal ranged from a trace to a foot in thickness, with the maximum thickness in southeastern Kansas being 26 inches (66 cm).

<u>Fleming limestone</u>

Pierce and Courtier (1937), Alexander (1954), Howe (1956), and Branson and others (1965) have all mentioned a limestone caprock above the Fleming coal. The caprock of the Fleming coal was referred to as the Fleming limestone by Bennison (personal communications, 1998) after the Fleming coal.

Alexander (1954, p.50) identified two fusulinid species from the limestone caprock above the Fleming coal, *Fusulina kayi* (Thompson, 1934) and *Wendekindellina euthusepta* (Henbest, 1928). Alexander (1954, p.33) collected both species of fusulinids from a strip pit 2.5 miles north of Fleming, Kansas, probably near the type area of the Fleming coal. Alexander (1954, p.13) stated that the Fleming caprock in Kansas was a dirty fusulinid-bearing limestone.

Howe (1956, p.68) described this limestone as lenticular, dark-gray, and coquinoidal. He stated that the thickness of the limestone ranged from trace to about 3 feet (0.9 meters). There are fossils present in this limestone, but brachiopods (*Crurithyris*, *Marginifera*, and *Neospirifer*) dominate (Howe, 1956, p.68).

Branson and others (1965, p.38) only identified this limestone at one locality in Craig County, Oklahoma. There, they described the limestone as, "...6 inches [15 cm] of dense, yellowish, finely crystalline limestone." (Branson and others, 1965, p.38). They did not report any fossils from this locality. The Fleming limestone should be considered an informal name as opposed to a proper lithostratigraphic unit.

McNabb limestone

Branson (1954, pp. 3 and 5) made the earliest and one of the few known published references to the McNabb limestone by including the limestone in the Croweburg coal cycle. However, the only description he made of the McNabb limestone was to describe it as an underlime. The term "McNabb" has not been recognized since. However, Howe (1956, p.71) believed that an underlime below the Croweburg coal might be called the McNabb limestone in Oklahoma, and Hemish (1994a) did utilized the term in a measured section of an outcrop in the NE1/4SE1/4SE1/4NE1/4 Sec. 21, T12N, R13E, Okmulgee County. Since no type localities were established or descriptions made of the limestone, the McNabb limestone is not considered a proper lithostratigraphic term.

Croweburg coal

Pierce and Courtier (1937, p.74) stated that the Croweburg coal was named by the Kansas Geological Survey from strip pits a mile east of Croweburg, Crawford County, Kansas in the SE1/4 Sec. 34, T28S, R25E and NE1/4 Sec. 3, T29S, R25E. Pierce and Courtier (1937, p.75) provided a thickness of 10 to 18 inches (25 to 46 cm) for the Croweburg coal and that a succession of coal, gray shale, and black phosphatic shale was a unique characteristic of the Croweburg coal.

Oakes (1944, p.12) and Branson (1954, p.2) correlated the Croweburg coal of Kansas with the Broken Arrow coal of Oklahoma. Howe (1956, p.71) confirmed this correlation and noted that popular miners' terms for this coal included "Fireclay," "One-Foot," and "Soapstone". Howe (1956, p.71) described this coal as thin and irregular in Crawford County (near the location of the type locality) and listed the thickness from 9 to 15 inches (23 to 38 cm) in the rest of southeastern Kansas.

Branson and others (1965, p.36) described the Croweburg coal from 6 to 19 inches (15 to 48 cm) in thickness and 40 to 50 feet (12 to 15 meters) above the Chelsea Sandstone. In two localities in Craig County, Branson and others (1965, p.36) mentioned that the Croweburg coal contained plant microfossils. Hemish and Chaplin (1999, p.133) placed the Croweburg coal approximately 47 feet (14.1 meters) below a black fissile phosphatic shale underlying the Verdigris Limestone. Hemish (1987, p.102) stated that the Croweburg coal is also called the "Henryetta coal" in Oklahoma. Hemish (1987, p.99) listed the Croweburg coal as 0.2 to 3.4 feet (0.06 to 1.02 meters) thick in the northeastern Oklahoma shelf area.

Oakley Shale Member

Pierce and Courtier (1937, pp.31, 75) were among the first to mention a black fissile phosphatic shale between the Croweburg coal and Verdigris Limestone. They also stated that this shale averaged about three feet (0.9 meters) in thickness and contained black siliceous limestone concretions (Pierce and Courtier, 1937, p.75). In addition, Abernathy (1936), Moore (1949), Searight and others (1953), Howe (1956), and Branson and others (1965) have observed a black fissile phosphatic shale between the Croweburg coal and Verdigris Limestone. Branson (1954, p.5) called this shale the Verdigris black shale.

In Iowa, Ravn and others (1984, p.35) termed the shale between the Whitebreast coal (equivalent to the Croweburg coal) and Ardmore Limestone (equivalent to the Verdigris Limestone) the Oakley Shale. Ravn and others (1984, pp.35-37) described a lower black fissile phosphatic shale facies and an overlying gray shale facies within the Oakley Shale. The black fissile shale was described as one-foot (0.3 meters) thick and containing non-skeletal phosphate at its base. In other parts of Iowa, there are additional shale beds below and above the black fissile shale, but these will not be discussed within this author's report. Ravn and others (1984, p.37) believed that the black fissile phosphatic shale bed was equivalent to the Mecca Quarry Shale (Hopkins and Simon, 1975) in Illinois. However, Ravn and others (1984, p.37) did not extend that name to the black shale in the Midcontinent.

Hemish and Chaplin (1999, p.133) believed that the Oakley Shale in Iowa correlated with the Verdigris black shale described by Branson (1954). This would extend the Oakley Shale southward to the black shale in Kansas and Oklahoma.

Some fossils had been identified from the Oakley Shale. Pierce and Courtier (1937, p.75) stated that several phosphate nodules within the black shale contained small fossils in their nuclei. Abernathy (1936, p.90) identified the bryozoans *Prismopora* and

Rhombopora, fusulinid *Fusulina*, crinoid stems, and brachiopods *Orbiculoidea*, *Derbya*, *Chonetes*, *Mesolobus*, *Marginifera*, *Squamularia*, *Neospirifer*, and *Dictyoclostus* in a black shale that would correlate with the Oakley Shale. Howe (1956, p.73) identified brachiopod *Mesolobus* and the pelecypod *Dunbarella* in what would be the gray shale facies of the Oakley Shale. In the black fissile shale facies, Howe (1956, p.74) observed orbiculoid brachiopods and the brachiopods *Marginifera* and *Composita*, small ammonoids, simple corals, fish scales (within the phosphate nodules), and conodonts. Several genera of conodonts have been found in the Oakley Shale in Iowa; Swade (1985) had identified *Gondolella*, *Idiognathodus*, *Neognathodus*, *Idioprioniodus*, and *Diplognathodus*.

The Oakley Shale is the major black fissile shale within the upper part of the Senora. Using Heckel's (1977) terminology, it is considered a core shale. The Oakley Shale overlies the Croweburg coal and underlies the lower limestone of the Verdigris Limestone Member of the Senora Formation.

Verdigris Limestone Member

Quite possibly one of the most important limestone beds in the Senora Formation, the Verdigris Limestone is certainly one of the most traceable and distinct limestones in the Senora Formation. Furthermore, the Verdigris Limestone is an important marine interval with an abundant assemblage of fossils.

In a Missouri Geological Survey report, Gordon (1893) first called the limestone the Ardmore Limestone on the Bevier topographic map, and in a locality 0.5 miles (0.8 km) northeast of Ardmore, Missouri, he listed a thickness of 2.5 feet (0.75 meters) for a limestone believed to be the Ardmore Limestone. Pierce and Courtier (1937, p.31) stated that, in 1926, Greene and Pond also proposed a name for this limestone. In Vernon County Missouri, Greene and Pond called the limestone the "Rich Hill" and believed that the "Rich Hill" correlated with the Ardmore. On a geologic map accompanying Woodruff and Cooper (1928), Smith called the limestone the Verdigris Limestone from exposures along the Verdigris River in Rogers County, Oklahoma. Many older workers continued to use the name Ardmore Limestone. But, Searight and others (1953) resolved the issue of the name for the limestone; despite the fact that the Ardmore Limestone was older usage, they choose the name Verdigris Limestone because of wider usage.

Pierce and Courtier (1937, p.32) divided the Verdigris Limestone into a lower and upper part. They described the lower part as a single limestone bed, 1 to 2 feet (0.3 to 0.6 meters), jointed, compact, very hard, fine-grained, and fossiliferous. The limestone is a dark bluish gray to buff and weathers to a mottled yellow-buff color. Pierce and Courtier (1937, p.32) described the upper part as "...much softer than the lower part, is nodular and concretionary, and contains thin beds of shale or clay. It is from an inch or less to 3 feet [0.9 meters] thick."

Oakes (1944, p.13) noted that, "The Verdigris limestone is remarkably uniform in thickness and character across the area.". He further described the Verdigris Limestone as massive, dark, fossiliferous and 2 to 2.5 feet (0.6 to 0.75 meters) in thickness. Oakes (1944, p.13) also noted that in fresh exposures in strip pits the Verdigris Limestone had a more shaly appearance.

In the SE1/4 Sec. 3, T23N, R17E, Rogers County, Oklahoma, Alexander (1954, pp.27, 50) identified a new species of *Fusulina*, *Fusulina equilaqueata*. Alexander

(1954, p.27, 13) also noted that the Verdigris Limestone had an abundance of fusulinids in northeastern Oklahoma, "…and at nearly every crop it contains fusulinids." Alexander (1954, p.13) also described the Verdigris Limestone, "It is a gray, siliceous and ferruginous, crystalline limestone which characteristically is brown on weathered surfaces.". The thickness of the Verdigris Limestone in Rogers County ranged from 5 to 11 feet (1.5 to 3.3 meters) (Alexander, 1954, p.13).

Howe (1956, pp.74-77) stated that the Verdigris Limestone was one of the thickest and most persistent and prominent limestones in the Senora Formation. In Cherokee and Crawford Counties, Kansas, there is a succession of three limestones and two shales within the Verdigris Limestone (Howe, 1956, p.74), but westward in Labette County, there is only one thin massive, brittle, dark-gray to black bed of limestone with an intervening calcareous shale (Howe, 1956, p.77). Howe (1956, p.77) believed that the limestone present in Labette County correlated to one of the lower two limestones present in Cherokee and Crawford Counties, Kansas. Howe (1956, p.77) had been able to trace out or correlate the Verdigris Limestone from Oklahoma and Kansas northward to Iowa and eastward to as far as Ohio (where it is known as the Hamden Limestone).

Branson and others (1965, p.38) described the Verdigris Limestone as "gray to dark-gray, finely crystalline, compact fossiliferous limestone that weathers yellow brown." Some of the fossils in the Verdigris Limestone identified by Branson and others (1965, p.38) are brachiopods *Condrathyris* and *Desmoinesia*, and fusulinids *Fusulina equilaqueata* (Alexander, 1954). Branson and others (1965, p.38) also reported the thickness of the Verdigris Limestone from 2 to 7 feet (0.6 to 2.1 meters).

Three distinct beds of limestones are recognized within the Verdigris Limestone. Furthermore, these beds seem continuous over a widespread area. Most beds have either a thin-bedded or flaggy appearance or are lenticular, and most of the limestones of the Verdigris seem to have a ferruginous rind. Each of these beds will be discussed separately in this report.

lower limestone bed

Howe (1956, p.77) described the lower bed as a zone of "dark-gray to black limestone concretions." The thickness of the lower bed is around three feet. Howe (1956, p.77) stated that a 10 to 15 inch (25 to 38 cm) dark-gray to black fissile shale separated the lower limestone bed from the middle limestone bed.

At a locality near Lake Bixhoma in Wagoner County, Oklahoma, N1/2SE1/4NW1/4 Sec. 2, T16N, R14E, the lower Verdigris limestone bed is dark gray to medium dark gray weathering to grayish orange, nodular, and jointed. This bed is also very fossiliferous with brachiopods, crinoid stems, foraminifera (including *Orthovertella*), nautiloids, and conodonts *Idiognathodus*. Approximately 0.3 feet (0.09 meters) of clay shale separate the lower limestone from the middle limestone.

middle limestone bed

Howe (1956, pp.75-77) observed 8 inches (20 cm) of dense dark-gray to black limestone for the middle limestone bed in the Verdigris Limestone. Above this limestone, there are two shale facies underlying the upper limestone bed. The lower shale facies is 1.5 to 5 feet (0.45 to 1.5 meters) of black fissile shale, and the upper shale is a light-gray fossiliferous shale. A 0.9-foot (0.27-meter) clay separates the middle limestone bed from the upper one.

At the Lake Bixhoma locality, the middle bed of the Verdigris is brownish gray weathering to medium light gray, shaly, and jointed. This bed is also fossiliferous with brachiopods, crinoids, encrusting foraminifera, and conodonts *Idiognathodus*, *Neognathodus*, and *Idioprioniodus*.

upper limestone bed

The upper limestone bed is the thickest and most prominent of the three limestone beds within the Verdigris Limestone. Howe (1956, p.75) described the bed as massive, mottled light and dark gray weathering to light gray to buff, and jointed. The dark gray portions of this limestone are angular to rounded. Because the dark gray clasts are harder and more resistant to weathering, the surface of this limestone often has a nodular, broken appearance (Howe, 1956, p.75).

Howe (1956, pp.75, 77) noted several different types of fossils within the upper limestone bed. Algal debris, foraminifera *Ptychocladia*, crinoid debris, fusulinids *Fusulina*, and brachiopods *Mesolobus* and *Chaetetes* were all identified by Howe (1956). Howe (1956, p.77) also identified other brachiopods, *Composita*, *Crurithyris*, *Dictyoclostus*, and *Neospirifer*, from all three beds of the Verdigris Limestone.

At the Lake Bixhoma locality, the upper bed ranges from a packestone to a grainstone and is medium light gray weathering to grayish orange, massively bedded, ferruginous, and jointed. Fossils include corals, scattered crinoid fragments, ostracods, gastropods, fish debris, and conodonts *Idiognathodus*.

Swade (1985), in his study, referred to the Verdigris Limestone as the Ardmore Limestone Member of the Verdigris Formation. He provided conodont data for limestones and shales of the Verdigris Limestone. According to Swade (1985), the limestones contained mostly *Idiognathodus* and *Neognathodus*. *Idioprioniodus* was also common, but *Anchignathodus*, and *Aethotaxis* were rarer. Near the upper contact of the Verdigris Limestone, *Adetognathus*, *Diplognathodus*, and *Aethotaxis* were common indicating nearshore conditions (Swade,1985). The shales within the Verdigris yielded a few elements of Idiognathodus and Neognathodus. Deep-water conodonts *Gondolella* and *Idioprioniodus* were even rarer (Swade, 1985).

The presence of the Verdigris Limestone over a deep-water shale (Oakley Shale) and nearshore conditions near the upper contact indicate that the Verdigris Limestone was probably a regressive limestone, uncommon in the Cherokee Group. The Verdigris Limestone directly overlies the Oakley Shale and underlies an unnamed shale.

Bevier coal

McGee (1888) named the Bevier coal from the town of Bevier, Macon County, Missouri where it was mined. In its type area, the Bevier coal ranges from 4.5 to 5 feet (1.3 to 1.5 meters), and the maximum thickness noted by McGee (1888, p.335) near the type area is 5.5 feet (1.7 meters) to the southeast, 3 miles (4.8 km) west of Excello, Missouri. Searight and others (1953) restricted the term Bevier to the upper coal while the lower coal was termed the Wheeler (Weller and others, 1942). The Wheeler coal is an Iowa term, and it does not outcrop in southeastern Kansas or Oklahoma (Howe, 1956, p.78).

Pierce and Courtier (1937, p.77) noted a thickness of 18 inches (46 cm) for the Bevier coal. In Cherokee County, Kansas, only 6 to 12 inches (15.2 to 30 cm) of clay shale separate the Bevier coal from the Verdigris Limestone. Southward, in Wagoner County, Oklahoma, the interval between the Verdigris Limestone and equivalent Bevier interval is considerably thicker, 47 feet (14 meters). Unnamed shales and limestones overlie the Bevier coal, and in some parts of southeastern Kansas, a black fissile phosphatic shale overlies the Bevier coal. Pierce and Courtier (1937, p.77) stated that the positioning between the Verdigris Limestone and unnamed limestone beds is a characteristic of the Bevier coal.

In the NE1/4 Sec. 33, T33S, R21E, Pierce and Courtier (1937, pp.77-78) identified a coal bed 15 to 25 feet (4.5 to 7.5 meters) above the Verdigris Limestone. They named the coal the Stice coal after a school in that area. Pierce and Courtier (1937, p.78) listed the thickness of the Stice coal from 13 to 15 inches (33 to 38 cm).

Howe (1956, pp.79-80) noted that the Bevier thins southward to just a thin smut in Craig County, Oklahoma. However, in some parts of southern Craig County, the Bevier coals is nearly a foot (0.3 meters) thick. South of Craig County, the Bevier coal disappears, but the black fissile shale above it seems to persist at least as far south as Wagoner County. In Cherokee, Crawford, and Bourbon Counties, Kansas, Howe (1956 p.80) stated that the Bevier coal was 15 to 24 inches (38 to 61 cm) thick. The Bevier coal was described as "characteristically bright, hard, and blocky" with deposits of pyrite and calcite common (Howe, 1956, p.80). Howe (1956, p.60) also believed that the Stice coal identified by Pierce and Courtier (1937) is the same coal as the Bevier; therefore, the Stice coal and Bevier coal are equivalent. If so, this would place the Bevier coal 15 to 25 feet (4.5 to 7.5 meters) above the Verdigris Limestone, closer to the distance the Bevier interval lies above the Verdigris Limestone in Wagoner County.

Branson and others (1965, p.40) also described the Bevier coal in Craig County. They described the Bevier as a 4 to 15 inch (10 to 38 cm) discontinuous bed of coal. Branson and others (1965, p.40) placed the Bevier coal one foot (0.3 meters) below the base of the Lagonda Sandstone.

Lagonda Sandstone Member

Gordon (1893, p.19) designated 18 to 50 feet (5.4 to 15 meters) of arenaceous deposits overlying the Bevier coal as the Lagonda sandstones and shales, after the Lagonda post office in Missouri. Pierce and Courtier (1937, p.33) noted that this sandstone is "fine-grained and grades laterally into sandy shale", and in many locations, there may be no sandstone present at all. Pierce and Courtier (1937, p.33) also observed an interesting weathering phenomena of this sandstone. Apparently, the sandstone weathers out "dike-like" structures of sandstone or shale that lie at a different angle than the rest of the sandstone. This anomaly was observed along the West Line of NW1/4 Sec. 5, T28S, R25E, Crawford County, Kansas.

Howe (1956) was the next to discuss the Lagonda Sandstone in any significant detail. In describing the Lagonda Sandstone of southeastern Kansas, he stated that it was characteristically thin, and finely cross-bedded. Howe (1956, p.82) also observed limestone concretions in a few outcrops of the Lagonda Sandstone, and some of the limestone concretions contained sparse marine fossils. The average thickness of the Lagonda Sandstone in southeastern Kansas was around 8 feet (2.4 meters) (Howe, 1956, p.82).

Branson and others (1965) also discussed the Lagonda Sandstone in Craig County, Oklahoma. The Lagonda Sandstone differs from the south to the north of the county. In southern Craig County, Branson and others (1965, p.40) described the Lagonda Sandstone as a fine-grained, cross-bedded, brown sandstone. In northern Craig County, the Lagonda Sandstone splits into two sandstone beds separated by 6 to 12 feet (1.8 to 3.6 meters) of silty, micaceous shale that graded laterally into sandstone. The upper sandstone bed was 4 to 10 feet (1.2 to 3 meters) thick, and the lower sandstone bed ranged from 3 to 8 feet (0.9 to 2.4 meters) thick (Branson and others, 1965, p.40).

Aden (1982) believed that the Lagonda Sandstone and the coals and shales above it were deposited by a prograding delta lobe following the southwestward retreat of the shallow sea that deposited the Verdigris Limestone. He divided the interval between the Lagonda and the Breezy Hill into three distinct facies: 1. prodeltaic mud, 2. shoreline coastal, and 3. prograding delta front and applied these depositional models to the Lagonda sequences in Kansas and Missouri.

According to Aden (1982), the prodeltaic mud facies consist primarily of mudstones with very little siltstones or shales. The mudstone is primarily clayey with little silt. There is little silt because a terrestrial sediment is fairly far away at this point yielding only mud sized clastic material (Aden, 1982).

The shoreline coastal facies consists of coals, fluvial sandstones, underclays, and siltstones. These lithologies were deposited in mainly coastal swamps and estuaries (Aden, 1982).

The prograding delta front facies would consist of channel sandstone bodies and shale. Because of increasing clastic influx, the shales would be siltier than the prodelta mudstones. Progradation of delta lobes would begin as sediment build up would occur during either stillstand or regression of marine water (Aden, 1982, pp.91-92). The build up of terrestrial sediments would ultimately force their way into basins if rising sea levels did not keep them in check.

Nelson (1985, p.42) applied the Heckel terminology "outside shale" to the Lagonda interval. Nelson (1985, p.79) justified classifying the Lagonda interval as an outside shale by providing his interpretation of the sequence of events between the Oakley Shale and Breezy Hill Limestone. Nelson (1985) believed that the interval between the Oakley shale and the Excello shale was one large cycle riddled by numerous minor transgressions and regressions. The Oakley Shale, obviously, represented the maximum trangression of this sequence. Above, the sea level dropped enough to deposit the Verdigris Limestone. Finally, above the Verdigris Limestone, sea level dropped enough that clastic influx began to outstrip accommodation allowing the deposition of prodelta muds and sheet sands (Nelson, 1985, p.80). Maximum regression was achieved when the delta plain was subaerially exposed creating marshes. Probably the alternating sandstones and shales noted within the Lagonda Sandstone resulted from minor transgressions depositing prodelta muds and regressions where distributary channels took over and deposited channel sands. Further regression may have resulting in downcutting of the channels (Nelson, 1985, p.80). The sea once again transgressed depositing the Breezy Hill Limestone and Excello Shale (Nelson, 1985, p.85).

Hemish and Chaplin (1999, p.133) stated that the Verdigris Limestone directly underlies the Lagonda Sandstone. Branson and others (1965, p.40) stated that in Craig County the Lagonda Sandstone directly overlies the Bevier coal. In southeastern Kansas, Howe (1956, pp.81-82) observed that the Lagonda Sandstone overlies an unnamed gray silty clay shale.

In Kansas, Howe (1956, p.82) reported that the Lagonda Sandstone was in direct contact with the overlying Breezy Hill Limestone. In Oklahoma, the Iron Post coal and an underclay appears between the Lagonda Sandstone and Breezy Hill Limestone. Where the Iron Post coal is present, the Lagonda Sandstone underlies the underclay of the Iron Post. In southern Craig County, Branson and others (1965, p.40) observed that the Lagonda Sandstone was overlain by an unnamed silty shale. Hemish and Chaplin (1999, p.133) stated that the Iron Post coal was stratigraphically the top bed of the Lagonda Sandstone.

Pierce and Courtier (1937, p.32) mentioned that the Lagonda Sandstone often varied the distance between it and the Breezy Hill Limestone. Because of its propensity to "jump around", drillers gave the subsurface name "Squirrel sand" to the Lagonda Sandstone.

<u>Iron Post coal</u>

Howe (1951, p.2092), upon the suggestion of Carl C. Branson, named the Iron Post coal for a rural school located in the SW1/4 Sec. 31, T29N, R20E, extreme northern

Craig County, Oklahoma. At a nearby locality in the W1/2SW1/4 Sec. 36, T29N, R19E, Howe (1951, p.2092) measured 0.8 feet (0.24 meters) of Iron Post coal and described it as "hard and bright, dull red along joints.".

Howe (1956, p.84) noted that the Iron Post coal did not extend north of the Kansas-Oklahoma border. Howe also reported that Oakes (1944, p.16) mistakenly correlated the Iron Post coal in Oklahoma with the Mulky coal in Kansas even though the "Mulky" in Oklahoma was below the Kinnison Shale. Common mining names for the Iron Post coal provided by Howe (1956, p.84) include the "Fort Scott" and "red" coals.

Branson and others (1965, p.40) noted 10 to 18 inches (25 to 45 cm) of Iron Post coal in Craig County. Furthermore, they observed 5 to 10 feet (1.5 to 3 meters) of shale and underclay between the Lagonda Sandstone and the Iron Post coal (Branson and others, 1965, p.40). Hemish (1987, p.99) listed 0.3 to 1.6 feet (0.9 to 0.48 meters) of Iron Post coal in the northeast Oklahoma shelf area. Hemish and Chaplin (1999, p.133) observed 1.2 feet (0.36 meters) of Iron Post coal along a PSO railroad spur in central Rogers County, Oklahoma. They also noted that the Iron Post coal was the top bed of the Lagonda Sandstone.

Kinnison Shale Member

Howe (1951, p.2093) named the Kinnison Shale from the old settlement of Kinnison in Craig County, Oklahoma. The type section of the Kinnison, W1/2SW1/4 Sec. 35, T29N, R19E, is approximately 2.5 miles (4 km) north of the settlement of Kinnison. In the locality in the W1/2SW1/4 Sec. 36, T29N, R19E, Howe (1951, p.2092) measured over 6 feet (1.8 meters) of Kinnison Shale. He described the Kinnison Shale as dark gray with the upper 2 feet (0.6 meters) being calcareous and fossiliferous. Howe (1951) noted several limestone beds within the Kinnison Shale. The lowest limestone bed is a basal limestone that is carbonaceous and conglomeratic with fragments of wood; Howe (1951, p.2093) called it a caprock to the Iron Post coal. Howe (1951, p.2092) described the upper limestone beds as rough and non-persistent. All of the limestones in the Kinnison Shale were fossiliferous. The basal limestone contained the brachiopods *Marginifera* and *Derbyia*, and the upper limestones contained crinoid fragments and the brachiopod *Chonetes*.

Howe (1956, p.84) noted that, like the Iron Post coal, the Kinnison Shale pinches out before reaching the Kansas-Oklahoma border. He also noted that the basal limestone was not very widespread. Howe (1956, p.84) stated that the Kinnison Shale ranged from 2 to 6 feet (0.6 to 1.8 meters) in Craig County.

Branson and others (1965, p.40) also called the basal limestone of the Kinnison Shale a caprock of the Iron Post coal. And, they believed that the basal limestone was best developed in Craig County. Branson and others (1965, p.40) observed 2 to 3 feet (0.6 to 0.9 meters) of clay shale within the Kinnison in Craig County. In addition to thinning dramatically northward, Branson and others (1965, p.40) also noted that the Kinnison Shale thinned down southward to just ten inches in Rogers County.

While Branson and others (1965) observed only ten inches (25 cm) of Kinnison Shale in Rogers County, Hemish and Chaplin (1999, p.134) measured 1.3 to 3.5 feet (0.39 to 1.1 meters) of Kinnison Shale along a PSO railroad spur in central Rogers County. They noted that the Kinnison Shale ranged from grayish black to dark gray and from calcareous to noncalcareous. Hemish and Chaplin (1999, p.134) observed that the

Kinnison Shale was fossiliferous within their study area. They also noted pyritized brachiopods in the Kinnison.

The Kinnison Shale is within the upper part of the Senora Formation. It overlies the Iron Post coal and underlies the Breezy Hill Limestone. Where present, the boundaries of the Kinnison Shale seem pretty consistent from Rogers to Craig counties.

Breezy Hill Limestone Member

Pierce and Courtier (1937, p.33) named the Breezy Hill Limestone from exposures around Breezy Hill in Crawford County, Kansas. Breezy Hill is southwest of Mulberry, Kansas, which on the Kansas-Missouri border. In the type area, on the west side of Breezy Hill, Pierce and Courtier (1937, p.33) described the Breezy Hill Limestone as "a foot or two [0.3 to 1.8 meters] of impure limestone", but the Breezy Hill Limestone thickens considerably to 8 feet (2.4 meters) on the east side of the hill. For the rest of southeastern Kansas, Pierce and Courtier (1937, p.33) provided a general description of the Breezy Hill Limestone, "...it is a gray, impure, concretionary to nodular limestone...". They also placed the Breezy Hill anywhere from 4 to 8 feet (1.2 to 2.4 meters) below the top of the Cherokee Group. In Crawford and Cherokee Counties, Pierce and Courtier (1937, p.33) noted only 6 inches (15 cm) to 2 feet (0.6 meters) of Breezy Hill Limestone, but westward in Labette County, the Breezy Hill Limestone thickens to 20 feet (6 meters) (Pierce and Courtier, 1937, p.35).

Howe (1951, p.1091) described the Breezy Hill in Crawford County, Kansas as "an impure, nodular limestone, varying in thickness from a few inches to a foot [0.3 meters] or more." And stated that the Breezy Hill grades southward in Crawford County into a typical marine limestone. At a locality in Craig County, W1/2SW1/4 Sec. 36, T29N, R19E, Howe (1951, p.2092) measured 3 feet (0.9 meters) of Breezy Hill Limestone. He noted that the limestone was very massive, fractured vertically, and medium gray weathering to buff. Some of the fossils from the Breezy Hill Limestone identified by Howe (1951, p.2092) include productid brachiopods *Echinoconchus* and *Dictyoclostus*, spiriferid brachiopods *Composita*, and fusulinids *Fusulina*.

Branson (1952, p.191) traced the Breezy Hill Limestone from around Fort Scott, Bourbon County, Kansas to western Wagoner County, Oklahoma near the Arkansas River. Branson (1952, p.191) also observed a few feet of black fissile phosphatic shale separating the Breezy Hill Limestone and the Blackjack Creek Member of the Fort Scott Formation.

In the SW1/4 Sec. 24, T28N, R19E, Craig County, Alexander (1954, p.28) identified a new species of fusulinid, *Fusulina expedita*, from the Breezy Hill Limestone. In the SE1/4 Sec. 3, T23N, R17E, Rogers County, Alexander (1954, p.43) identified another new species of fusulinid from the Breezy Hill Limestone, *Fusulina plena*. Alexander (1954, p.50) stated that the Breezy Hill Limestone is the highest (youngest) fusulinid bearing interval within the Cherokee Group.

Howe (1956, p.85) noted that two types of limestone constitute the Breezy Hill Limestone. The first type of limestone is an irregularly bedded, nodular, sandy to conglomeratic limestone. The second type of limestone is a thin-bedded to massive marine limestone. Both types of limestones outcrop in different geographical areas. Howe (1956, p.85) observed that the nodular, conglomeratic limestone outcrops in southeastern Kansas and northern Missouri. In Cherokee and Labette Counties, Howe

(1956, p.85) noted that beds of the Breezy Hill Limestone are composed almost entirely of tests of *Fusulina*.

The massive limestone is found primarily in northern Oklahoma but is found in southeastern Kansas as well. This limestone, however, is not found at all in Missouri (Howe, 1956, p.85). At the type locality, Howe (1956, p.85) reported that the massive limestone is what is exposed. Howe (1956, p.86) listed the thickness of the Breezy Hill Limestone from around 2 feet (0.6 meters) at the type locality to over 16 feet (4.8 meters) west of Chetopa, Labette County, Kansas.

Howe (1956, p.87), like Howe (1951) and Alexander (1954), noted fossils in the Breezy Hill Limestone. From the nodular limestone, Howe (1956, p.87) identified the foraminifera, *Ptychocladia* in an outcrop in Crawford County, and the fusulinid *Fusulina* in Cherokee and Labette Counties. From the massive marine limestone, Howe (1956, p.87) observed fusulinids and the brachiopod *Dictyoclostus*.

Oakes (1963, pp.31-32), in Okmulgee County, identified a succession of limestone, gray calcareous shale, and black fissile phosphatic shale that he believed represented the "Fort Scott Limestone, and, possibly, the Breezy Hill Limestone", and in all likelihood, the black fissile phosphatic shale is the Excello Shale. However, Oakes (1963, p.32) noted that there is both an upper and lower bed of the Fort Scott Limestone separated by a black fissile phosphatic shale (possibly the Little Osage Shale). In Tulsa County, the lower Fort Scott limestone and the overlying black shale are present, and a few feet below the lower Fort Scott is the Breezy Hill Limestone (Oakes, 1963, p.32). Separating the Breezy Hill Limestone from the Fort Scott Limestone, the black phosphatic Excello Shale was also found in Tulsa County (Oakes, 1963, p.32).

Oakes (1963, p.32) reported that Misner, in 1954, correlated both the Breezy Hill Limestone and the Fort Scott Limestone southward into Okmulgee County. However, both limestones seem to merge and become a calcareous shale with limestone stringers upon entering Okmulgee County. But, even the limestone stringers in the calcareous shale did not extend south of SE1/4 Sec. 17, T15N, R14E in northeastern Okmulgee County. The black phosphatic shales extend even farther south to Sec. 1, T14N, R13E (Oakes, 1963, p.32). Oakes (1977, p.41) believed that a limestone and overlying gray calcareous shale and black fissile phosphatic shale in Muskogee County may be correlated to the Fort Scott and Breezy Hill Limestones identified by Oakes (1963).

Branson and others (1965, pp.40-42) described the Breezy Hill Limestone as "gray to light-brown, dense, fine- to medium-crystalline, silty, fossiliferous" and noted a thin algal limestone and a fusulinid limestone near the base of some exposures of the Breezy Hill Limestone. The thickness for the Breezy Hill Limestone in Craig County reported by Branson and others (1965, p.42) is similar to that reported by previous authors, 2 to 10 feet (0.6 to 3 meters).

According to Branson and others (1965, p.42), Chrisman in 1951 identified the corals *Lophophyllidium* and *Caninia torquia*, and brachiopods *Desmoinesia*, *Cleiothyridina*, *Antiquatonia*, *Condrathyris*, and *Mesolobus* in the Breezy Hill Limestone at a locality in the NW1/4 Sec. 36, T26N, R18E, Craig County. In exposures of the Breezy Hill around Welsh, Oklahoma, Claxton, in 1952, identified a more diverse fauna than Chrisman. The brachiopods *Desmoinesia*, *Neospirifer*, *Spirifer*, *Cleiothyridina*, *Composita*, *Antiquatonia*, *Echinaria*, *Chonetinella*, and *Linoproductus* dominate the

Breezy Hill fauna found by Claxton, but pelecypods *Wilkingia* and *Astartella*, and gastropods *Meekospira* are found as well (Branson and others, 1965, p.42).

According to Cassidy (1968), the Breezy Hill Limestone had an eight-foot (2.4-meter) high reef complex approximately at the Oklahoma-Kansas border. This topographic high was a major dividing point between the facies of the Excello Shale in Kansas and Oklahoma (Cassidy, 1968). However, Ece (1987) disputed the interpretation of reef complexes, but the Breezy Hill does have algal mounds at the Oklahoma-Kansas border. Furthermore, Cassidy probably interpreted these algal mounds as the eight-foot (2.4-meter) reef complex (Ece, 1987).

Knight (1983, 1985) noted that the Breezy Hill Limestone was part of a minor transgressive-regressive cycle separate from the major Excello Shale-Blackjack Creek cycle. Knight (1985, p.73) divided the Breezy Hill Limestone into five lithologic facies: 1. Barren silty calcilutite, 2. Sandy skeletal calcarenite, 3. Silty skeletal calcilutite, 4. Skeletal calcilutite, and 5. Oolitic calcarenite. Although Knight (1985) discussed each of these facies in detail, they will not be discussed here. However, in the skeletal calcilutite facies, Knight (1985, p.103) did identify the algae *Archaeolithophyllum* and *Anchicodium*. Knight (1985, pp.234, 242) also observed the conodonts *Anchignathodus*, *Idiognathodus*, and *Neognathodus* within the Breezy Hill Limestone.

According to Ece (1987, p.244), the maximum thickness achieved by the Breezy Hill is approximately 12 feet (3.6 meters) in southern Tulsa county and maintains an average thickness between 6 to 11 feet (1.8 to 3.3 meters). The thinnest Breezy Hill is in northern Missouri at about 1 to 2 feet (0.3 to 0.6 meters) and in Okmulgee County at 2 inches (5.1 cm). Ece (1987, p.245) listed diagnostic features of the Breezy Hill

Limestone as being well-bedded, hard, and resistant. Ece (1987, p.145) also noted that the Breezy Hill Limestone had sparse fauna even though other authors noted an abundance of fossils from the limestone. Within Kansas, Ece (1987, p.145) stated that the Breezy Hill Limestone is siltier than in Oklahoma.

Hemish and Chaplin (1999, p.134) described the Breezy Hill Limestone as light brownish gray weathering to orange, 7.5 to 8.7 feet (2.25 to 2.6 meters) thick, and with sharp upper and lower contacts. They classified the limestone as a mudstone but noted that it grades into a skeletal wackestone. Hemish and Chaplin (1999, p.134) also noted fossils within the Breezy Hill Limestone but only brachiopods and crinoids were identified.

The Breezy Hill Limestone is the uppermost important limestone bed in the Cherokee Group. Since the Iron Post coal and Kinnison Shale are only present in Oklahoma and the Mulky coal and its underclay present in Kansas and Missouri, the lower and upper contacts of the Breezy Hill Limestone differ from Oklahoma and Kansas.

In Kansas, Howe (1956, pp.84-85) states that the Breezy Hill Limestone overlies the Lagonda Sandstone, and the Breezy Hill Limestone underlies the underclay of the Mulky coal. In Oklahoma, Howe (1956, p.85) noted that the Breezy Hill Limestone overlies the Kinnison Shale. Throughout most of Oklahoma, the Breezy Hill Limestone underlies the Excello Shale.

Mulky coal

Although not present in Oklahoma, the Mulky coal is an important enough stratigraphic marker to warrant a brief discussion. The Mulky coal, named by Broadhead (1873), is the highest coal bed within the Cherokee Group. Howe (1956, p.87) noted the Mulky coal primarily in the northeastern part of Crawford County and eastern part of Bourbon County. The Mulky coal is also present in western Missouri. The maximum thickness of the Mulky coal as noted by Howe (1956) is around 18 inches (45 cm). Even though the Mulky coal does not extend southward into Oklahoma, Howe (1944, p.84) reported that Oakes (1944) listed the Mulky coal in Oklahoma because he had erroneously correlated the Iron Post coal with the Mulky coal. Common mining terms for the Mulky coal include "Red" coal, "Fort Scott" coal, and "Bunker Hill" coal (Howe, 1956, p.88).

Ece (1987), in his study of the overlying Excello Shale, attempted some environmental interpretations of the Mulky coal. Ece (1987) reported that sulfur contents of the Mulky coal range from 3.8 to 6.8 wt % indicating a saltwater dominated coal swamp. Most likely, the Mulky swamp was a coastal swamp that developed after the Breezy Hill Limestone.

Excello Shale Member

The Excello Shale is the highest member unit in the Cherokee Group; it is also the highest black fissile shale in the Cherokee Group as well. The top of the Excello Shale marks the contact between the Cherokee and Marmaton Groups. The Blackjack Creek Limestone Member of the Fort Scott Formation conformably overlies the Excello Shale.

The Excello Shale has been widely noted as the uppermost black shale in the Cherokee Group by several authors. Abernathy (1936), Pierce and Courtier (1937), Oakes (1944, 1963), Moore (1935, 1949), Howe (1951, 1956), Branson (1952, 1954), and Branson and others (1965) have either described or noted a black fissile phosphatic shale several feet thick at the top of the Cherokee interval. Searight and others (1953) named this black fissile phosphatic shale the Excello Shale after the town of Excello, Macon County, Missouri. The Excello Shale is also a widespread black shale noted from Oklahoma to Kansas, Missouri, Iowa, and as far east as Illinois.

However, despite its distinct and widespread nature, the Excello Shale was not named until the early 1950's, and there were no serious discussions on it until around that time either. Howe (1956, pp.88-89) noted that "The shale is almost universally characterized by abundant round phosphate concretions or nodules, which have coprolitic nuclei.", and he also described the brachiopod *Orbiculoidea* and conodonts from the Excello Shale. In southeastern Kansas, Howe (1956, p.89) noted a range of 2 to 5 feet (0.6 to 1.5 meters) for the thickness of the Excello Shale.

There are actually two shale facies within the Excello Shale. According to Cassidy (1968), the Breezy Hill "reef" complex at the Oklahoma-Kansas border divided the surrounding shelf into two basins: a forereef basin in Oklahoma and a brackish lagoon in Kansas. Furthermore, Cassidy (1968) stated that the reef complex divided the Excello shale into two distinct lithofacies. North of the Kansas-Oklahoma border, Cassidy (1968, p.297) described a carbonaceous facies in the Excello Shale, possibly lagoonal deposits. South of the Kansas-Oklahoma border, the Excello Shale is dominated by a "bituminous" facies. At a locality in Sec. 20, T29N, R20E, Craig County, Cassidy (1968, p.297) noted the presence of both facies. The carbonaceous facies was the lower one, and Cassidy (1968, p.297) described it as 5.5 feet thick (1.7 meters), black, "sooty", and micaceous. Furthermore, Cassidy (1968, p.297) stated that the carbonaceous facies also contains phosphate nodules and conodonts. Overlying the carbonaceous facies, Cassidy (1968, p.297) described the bituminous facies as 6 ft (1.8 meters) thick, resinous, black, and phosphatic. The base of the bituminous facies is a pyritized zone containing pyritized chonetid brachiopods (Cassidy, 1968, p.297).

In outcrop, Cassidy (1968) noted numerous other features of the Excello Shale. It is unclear exactly how these features relate to the two facies of the Excello Shale. At the upper contact with the Blackjack Creek Limestone, Cassidy (1968, p.297) found a brown, carbonaceous, friable clay. Below the clay seems to be in what Cassidy refers to as a "transition zone"; however, Cassidy does not fully describe what constitutes this zone except that the shale is brown to chocolate-brown near fracture zones and bedding planes. Below the transition zone, the black, fissile, phosphatic zone is present.

In the lower part of the Excello Shale, Cassidy (1968, p.297) described only two zones. The previously mentioned pyritized zone lies near the lower contact of the Excello Shale; this zone is also one of the few fossiliferous intervals within the Excello Shale. At the base of the Excello Shale, a calcareous zone directly overlies the Breezy Hill Limestone. Cassidy (1968, p.297) noted the presence of large pyritized reticulate productid brachiopods. Cassidy (1968, p.297) also mentions that the Excello Shale seems to grade into the Breezy Hill Limestone below. From personal field observations at a locality in the N1/2N1/2 Sec32, T20N, R15E, a thin 0.1 foot (0.03 meter) calcareous shale with brachiopods may constitute the base of the Excello Shale, and if true, this calcareous shale may possibly be related to the calcareous zone noted by Cassidy (1968). Unfortunately, Cassidy does not provide many details about the regional or stratigraphic extent of these Excello zones in the outcrop area of the Excello Shale. It should also be noted that the presence of deep-water conodonts from the Excello Shale in Kansas makes Cassidy's (1968) interpretation of lagoonal deposits unlikely.

During the Pennsylvanian, sea levels at maximum highstand deposited offshore black shales. Most of these shales were probably deposited in stagnant silled basins such as the Black Sea or Baltic Sea, and, within the basins, temperature differences between the colder bottom waters and the warmer surface waters probably created a thermocline (Heckel, 1977, pp.1053-1054). In effect, the thermocline prevented the proper circulation of oxygen rich surface water downward towards the bottom, and the bottom waters soon became oxygen poor or anoxic (Heckel, 1977, pp.1053-1054). At these great depths and conditions hostile to carbonate deposition and life, fine organic matter rich in phosphate (PO_4) was slowly deposited resulting in black organic muds. Heckel (1977, p.1048) noted that the anoxic conditions were represented by the deep-water black fissile phosphatic shales of the Mid-Continent, therefore he indirectly referred to the black fissile phosphatic shale of the Excello as an anoxic facies. Overlying the black fissile phosphatic shale facies, Heckel (1977, p.1062) also noted a greenish-gray shale facies of the Excello Shale.

Heckel (1977) believed that black fissile phosphatic shales, like those of the Excello Shale, represent maximum transgression within a sequence. In contrast, some workers, like Merrill (1975) and Merrill and Martin (1976), believed that black fissile phosphatic shales that overlie coals (the Excello Shale overlies the Mulky coal in Kansas) are in effect shallow water shales. This interpretation is similar to Cassidy's (1968) interpretation of a brackish lagoon for the Excello Shale in Kansas.

However, deep-water conodonts have been identified from the Excello Shale in both Oklahoma and Kansas. Furthermore, even though the Excello Shale overlies the Mulky coal in some parts of Kansas and in Missouri, in Labette and Cherokee Counties, Kansas and Oklahoma, the Excello Shale both overlies and underlies marine limestones. Since phosphate nodules form at depths below 80 meters where phytoplankton is not present to use up phosphorous (Ece, 1987, p.245), the presence of phosphate nodules within the Excello Shale is a strong indicator of a deep-water shale.

One difficulty in interpreting black shales above coals as deep-water is having sea levels rise dramatically from coastal marsh or coastline to several hundred meters in depth. As difficult as that scenario may be, Heckel (1977, p.1059) did propose a mechanism where such a rise in sea level would be possible:

> "Although the coals are non-marine to shoreline deposits, the overlying beds do not necessarily have to be very shallow-water deposits. If terrigenous detrital influx were cut off by delta abandonment as Merrill (1975, p.17) implied, and if transgression were rapid enough over an environment unfavorable to carbonate production (low pH or low oxygen conditions over a broad area of decaying vegetation), the coal swamp could have foundered with no significant deposition. Ultimately, water could become deep enough for establishment of offshore anoxic environment, where only the finest detritus from distant deltas settled out together with organic matter and phosphate, as James (1970) proposed for the Middle Pennsylvanian Excello black shale, which overlies coals in Illinois and Missouri."

Heckel (1977, p.1059) believed that depth of the transgressing sea over the landscape could have been around 100 meters. Ece (1987, p.250) interpreted this as indicating that sea level rose from around 1 meter deep to over 100 meters deep from the Mulky coal to the Excello Shale.

Knight (1985, p.120) believed that there were three facies present within the Excello Shale. The first is the pyritized zone mentioned by Cassidy (1968). The second is the universal fissile phosphatic black shale. The uppermost of the three facies is a dark to light gray, bioturbated, fossiliferous clay that grades into a pliable gray-blue to green to yellow claystone (Knight, 1985, p.121). This may be similar to the greenish-gray shale facies mentioned by Heckel (1977).

In Rogers County, Knight (1985, p.121) stated that the Excello Shale achieves its greatest thickness at 1.6 meters; in this area, the black phosphatic shale facies is predominant. Southward to Tulsa County, the Excello Shale thins to 0.3 meters (approximately 1 foot). Northward to south central Labette County, the Excello Shale thins to 0.6 meters. However, throughout the rest of southeastern Kansas, the Excello Shale maintains a thickness of 0.9 meters and is dominated by the black shale facies (Knight, 1985, pp.121-122).

Both Heckel (1977) and Knight (1985) believed that the overlying gray shale in the Excello marks a return of more oxygenated water. It is possible that at this point sea levels have dropped somewhat. The decrease in depth allows the bottom waters to be warmed thus destabilizing the thermocline. Without the thermocline in place, the more oxygenated surface waters can circulate more successfully with the oxygen poor bottom waters. The bottom waters become more replenished in oxygen and are no longer anoxic, resulting in lighter colored detritus and carbonates (Heckel, 1977, p.1054, fig. 5).

Ece (1987, p.253) believed that a pycnocline better explained the formation of anoxic conditions than a thermocline. Water stratification of water salinity, as in the Black Sea or Baltic Sea, would create highly saline bottom waters and fresher surface waters; the difference in the salinity from bottom to top would create a pycnocline. Ece (1987, p.250) noted that a cap of fresher water over the marine water may have been the agent that prevented circulation of oxygen to bottom waters. This pycnocline would have eventually created an anoxic bottom in the basin.

Ece (1987, p.245) noted two facies for the Excello Shale: the black fissile phosphatic shale and a yellowish-brown shale. He also stated that the calcareous zone recognized by Cassidy (1968) at the base of the Excello Shale may possibly be misinterpreted limestone concretions within the shale (Ece, 1987, p.244). The yellowish-brown shale both underlies and overlies the black fissile phosphatic shale; both facies share a gradational contact. The lower yellowish-brown shale may be similar to the pyritized zone identified by Cassidy (1968) due to the presence of pyrite and brachiopod fragments. Thicknesses of the black shale listed by Ece (1987) seem to correspond well with Cassidy (1968). The black shale facies ranged from 3.7 to 0.8 feet (1.1 to 0.19 meters) at its southern exposure in southern Tulsa County to around 3 ft (0.9 meters) in southeastern Kansas (Ece, 1987, p.245). Ece (1987, p.245) noted the black fissile phosphatic shale was at its thickest in Rogers and Craig Counties at 6.7 feet (2.0 meters).

Ece (1987, p.253) believed that the Excello Shale may have been deposited in a stagnant epeiric sea, possibly even a restricted or silled basin such as the Black Sea or Baltic Sea. The Excello sea had a great deal of dissolved organic carbon; the lack of oxygen prevented the organic carbon from being converted to calcium carbonate which Ece (1987) explains as a reason for a lack of carbonate material in the Excello Shale. Shoreline of the Excello sea ran along the Arkoma Basin in Oklahoma and in Iowa in the north; thinning of the Excello towards Iowa and a reduction of organic carbon in that direction as well indicate possible shoreline. The shoreline in the Arkoma Basin would have been determined by the presence of the Ouachitas. The average surface temperature of the Excello Sea would have been around 82° F (28°C) with high rainfall (Ece, 1987, p.251, fig. 7).

Hemish and Chaplin (1999, p.134) briefly described the Excello Shale exposed at a railroad spur in Rogers County. They noted that the Excello Shale was around 5 to 6 feet thick (1.5 to 1.8 meters) and contained numerous ovoid to spherical phosphate nodules 0.5 to 2.0 inches (1.2 to 5.1 cm) in diameter. It should be noted that at a locality in the SE1/4SE1/4SE1/4 Sec 30 and S1/2S1/2SW1/4 Sec 29, T34S, R21E, Labette County, Kansas, an oxidized clay shale was observed at the base of the Excello Shale, and several varieties of clay shales were observed above the black fissile phosphatic shale (personal field observations, 2002).

Given the anoxic conditions that the Excello Shale was deposited in and the hostile environmental conditions that a silled or restricted stagnant basin offered, it should be no surprise that the Excello Shale, in general, often contains sparse fauna. Moreover, most fossils are found in the various lighter shales below and above the black fissile phosphatic shales. Again, since such shales represented slightly more oxygenated environments than black shales, a higher fauna content would be expected. Howe (1956, p.88) found conodonts and the brachiopod *Orbiculoidea*, possibly from the black fissile shale facies. Cassidy (1968, p.307) found a sparse array of fauna in the Excello Shale. In addition to the pyritized chonetid at the base of the Excello Shale, he also found brachiopods *Lingula*, *Orbiculoidea*, reticulate productids, and chonetids, spores, and wood fragments. Approximately 10 inches (25 cm) above the base of the Excello Shale, Cassidy (1968, p.308) observed a zone of the cephalopod *Eoasianites*; he believed that the concentration of *Eoasianites* in one layer suggests a mass death. Knight (1985, p.121) found unidentified cephalopods, fish spines and scales, and inarticulate brachiopods in the black fissile shale facies of the Excello. Ece (1987, p.245) noted that the yellowish-brown shale facies of the Excello Shale produced fragments of molluscan shells, brachiopods, crinoid pieces, and conodonts.

Cassidy (1968, p.308) also stated that the carbonaceous facies in Kansas had a variety of conodonts, but the bituminous facies in Oklahoma was mostly barren of conodonts. Swade (1985) has found a significant abundance of conodonts within the Excello; amounts greater than 1000 elements per kilogram were common. The two most common genera were *Idiognathodus* and *Neognathodus*. *Idioprioniodus* and *Gondolella* were also present within the Excello Shale. *Idioprioniodus* is common throughout the Excello, but *Gondolella* is restricted to the black fissile phosphatic shale facies (Swade, 1985). Knight (1985, p.121) observed a high abundance of conodonts (mostly *Gondolella*) within the black fissile shale of the Excello Shale.

In Kansas, the Excello Shale overlies the Mulky coal, and in Oklahoma, the Excello Shale overlies, for the most part, the Breezy Hill Limestone. The Excello Shale conformably underlies the Blackjack Creek Limestone Member of the Fort Scott Formation. It is possible that the Excello Shale is the core shale of a cycle that includes the Fort Scott Limestone. The contact between the Excello Shale and Blackjack Creek Limestone is also the contact between the Cherokee and Marmaton Groups.

the two unnamed coal cycles, and the Weir coal cycle are all coal cycles of the old Inola Limestone designation. Either one of the two unnamed coals between the Inola and Weir coal cycles may be the Wainwright coal. Branson (1954, p.6) included the Weir-Pittsburg coal as the uppermost coal within the Boggy Formation.

Bluejacket coal cycle

The Bluejacket coal cycle contains a lowermost limestone cap rock, the Bluejacket Sandstone, unnamed underclay, coal, sandstone, and the Bluejacket coal. Branson (1954, p.6) noted only one occurrence of the limestone cap rock but did not mention the locality where it was identified. The Bluejacket coal cycle (Branson, 1954) is similar to the Bluejacket Formation (Searight and others, 1953). However, the Bluejacket coal cycle, except for the limestone caprock, would only correspond to the terrestrial units within the Bluejacket cyclothem (Abernathy, 1936).

Inola coal cycle

Branson (1954, p.6) included the Inola Limestone, unnamed underclay, and shale within the Inola coal cycle, but did not find any coal within this cycle. The Inola Limestone is probably equivalent to the fossiliferous marine limestone in the upper part of the Bluejacket cyclothem (Abernathy, 1936). Furthermore, the Inola Limestone within the Inola coal cycle (Branson, 1954) is probably equivalent to the Seville Limestone (Howe, 1956) of the Seville Formation (Searight and others, 1953). Branson (1954, p.6) also identified fusulinids from the Inola Limestone which were identified as

Abernathy (1936) recognized fifteen cyclic sequences within the Cherokee Group in southeastern Kansas based upon the definition of cyclothem by Weller (1930). He also believed that the faunal succession of each sequence is different enough to consider them as formations, and furthermore, to make correlations possible, each formation was called a cyclothem.

Building upon Moore (1936), within southeastern Kansas, Abernathy (1936, p.60) redefined and elaborated upon the lithologic succession of a typical Cherokee cyclothem as:

Shale
Limestone
Gray shale
Black shale
Coal
Underclay
Sandy and micaceous shale
Sandstone
Unconformity

The terrestrial or continental deposits consist of sandstone, sandy and micaceous shale, underclay, and coal. The marine interval consists of black shale, gray shale, limestone, and shale. Like Moore (1936), Abernathy (1936, p.59), to better demonstrate the genetic relationships among the cyclothems, gave each cyclothem a whole number designation (1...15) and each component a decimal designation (0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8). The primary usefulness of this numbering system is to determine how many components each cyclothem has and which components are missing.

Abernathy (1936, pp.60-61) described the transgressive and regressive phases of each cyclothem. The point of regression is at the sandstone, sandy and micaceous shale, underclay, and coal interval, and the coal was noted as the beginning of transgression.

Abernathy (1936, p.60) didn't believe that contact between the coal and the overlying black shale was gradual; he described the contact as sharp. Above the coal, the transgressive phase was represented by the black and grey shale. Abernathy (1936, p.61) placed the period of maximum transgression, at the limestone. Therefore, the uppermost shale represented the regressive phase of the cyclothem. Separating one cyclothem from another is an unconformity. In establishing a cause for the cyclic nature of the Cherokee Group, Abernathy (1936, p.58) believed that it was tectonic.

CYCLOTHEM 1 (RIVERTON CYCLOTHEM)

Abernathy (1936, p.73) assigned the name Riverton Cyclothem to this cyclothem from Riverton, Cherokee County, Kansas and described it from exposures in Sec. 24, T34S, R24E. This cyclothem is not complete, however; it is missing the sandy and micaceous shale as well the upper limestone and shale (Figure 12). Although Abernathy stated that the coal within this interval was unnamed, Pierce and Courtier (1937, p.62) named the coal the Riverton coal. Abernathy (1936, p.74) stated that this cyclothem was unfossiliferous. The average thickness of this cyclothem is about 38 feet (11 meters).

CYCLOTHEM 2 (NEUTRAL CYLOTHEM)

Named from the town of Neutral, Cherokee County, Kansas, this cyclothem is also incomplete missing the lowermost sandstone and uppermost limestone and shale (Figure 12). Within this cyclothem, Abernathy (1936, p.74) identified two coal beds with a three foot (0.9 meter) shale parting; the coal beds are known as the Neutral coal. Howe (1956, p.34) recognized three coal beds of the Neutral. However, the Neutral coal is not recognized in Oklahoma where the middle coal is possibly equivalent to the Rowe coal and the upper coal is possibly equivalent to the Drywood coal (Howe, 1956, p.34). Howe (1956, p.34) called the lowermost coal the Neutral coal. Abernathy (1936, p.74) stated that the Neutral cyclothem was unfossiliferous as well. The Neutral cyclothem is bounded at the base and the top by unconformities. The average thickness of the cyclothem is 26 feet (7.8 meters).

CYCLOTHEM 3 (COLUMBUS CYCLOTHEM)

Named after the Columbus coal that occupies the upper part, this cyclothem has several distinguishing characteristics as listed by Abernathy (1936, pp.75-76) (Figure 12). One characteristic is a very thick basal sandstone (around 28 feet [8.4 meters] thick); another characteristic is the absence of an underclay. The final characteristic recognized by Abernathy is an unfossiliferous black shale above the Columbus coal. Besides the underclay, this cyclothem is also missing the sandy and micaceous shale; the only marine component present within this cyclothem is the black shale above the Columbus coal. Pierce and Courtier (1937, p.65) stated that the Columbus and Rowe coals might occupy the same stratigraphic horizon. But, Howe (1956, p.37) stated explicitly that the Columbus and Rowe coals were the same bed. This indicates that the Columbus cyclothem covers the stratigraphic interval of the Rowe to the Drywood coal in Oklahoma; it also means that the Columbus cyclothem occupies part of the underlying Neutral cyclothem. This cyclothem is bounded at the base and top by unconformities. The average thickness of the Columbus cyclothem is 30 feet (9 meters).

CYCLOTHEM 4 (BLUEJACKET CYCLOTHEM)

Named by Abernathy (1936, p.76) after the basal Bluejacket Sandstone, this cyclothem is complete with all 8 components represented to some degree (Figure 12). A measured section of this cyclothem was made in Sec. 28, T30S, R25E. Unlike the lower cyclothems, this interval does contain marine fossils. Abernathy (1936, p.76) stated that this was the oldest fossiliferous cyclothem within the Cherokee Group of southeastern Kansas. The fossils were all found with the limestone. Among the fossils identified by Abernathy (1936, p.78) were crinoid fragments and the brachiopods *Marginifera muricatina* (Dunbar and Condra, 1932), *Linoproductus pratteniaus* (Norwood and Pratten), *Squamularia perplexa* (McChesney), and *Cleiothyridina orbicularis* (McChesney). In addition to marine fossils, an ironstone, which Abernathy (1936, p.76) called an "iron ore," was found below the limestone. It may be possible that this limestone is equivalent to the Inola Limestone in Oklahoma. Abernathy (1936, p.76) stated that a "non-evident unconformity" separated Cyclothem 3 and 4, and an erosional unconformity separated Cyclothem 3 from the basal conglomerate of the overlying cyclothem. The average thickness of the Bluejacket cyclothem is 68 feet (20.4 meters).

Formation or Cyclothem		Member or Phase		
No.	Nomenclature	No.	Lithologic Nature	Thickness in Feet
4	Bluejacket	4.7	Limestone	3.0
		4.6	Gray shale	21.0
		4.5	Black shale	4.0
		4.3	Underclay	8.0
		4.2	Sandy shale	12.0
		4.1	Sandstone	20.0
3	Columbus	3.5	Black shale	1.0
		3.4	Coal	1.3
		3.1	Sandstone	28.0
2	Neutral	2.6	Gray shale	5.0
		2.5	Black shale	3.0
		2.4	Coal	1.0
		2.3	Underclay	3.0
		2.4	Coal	1.0
		2.3	Underclay	10.0
1	Riverton	1.6	Gray shale	24.0
		1.5	Black shale	4.0
		1.4	Coal	2.0
		1.3	Underclay	3.0
		1.1	Sandstone	5.0

FIGURE 11. Division of the lower Cherokee Group into cycles by Abernathy (1936). In Oklahoma, these cycles would extend from the lower part of the McAlester Formation to the lower part of the Boggy Formation (Taken from Abernathy, 1936).

CYCLOTHEM 5 (KNIVETON OR KNIFETON CYCLOTHEM)

Abernathy (1936, p.78) named the Kniveton cyclothem from Kniveton, Crawford County, Kansas. The distinguishing characteristic of this cyclothem is a basal conglomerate indicating downcutting into underlying units. This cyclothem is nearly complete with the conglomerate replacing the basal sandstone (Figure 13). Missing units include the sandy and micaceous shale and upper limestone and shale. The Kniveton or Knifeton cyclothem may occupy the same stratigraphic position as the post Wainwright coal cyclothem. The average thickness of the Kniveton is about 24 feet (7.2 meters).

CYCLOTHEM 6 (WEIR CYCLOTHEM)

Abernathy (1936, p.79) named this cyclothem from the village of Weir, Cherokee County, Kansas. This cyclothem is also fairly complete except for the sandy and micaceous shale and the upper limestone and shale (Figure 13). The coal of this cyclothem is the Weir-Pittsburg coal (Haworth and Crane, 1898). Abernathy (1936, p.81) described a feature within this cyclothem unique to the Weir-Pittsburg coal, namely the "blackjack" shale. The "blackjack" shale or clay, according to Howe (1956, p.47) underlies the Weir-Pittsburg and is a plastic, dark-gray, carbonaceous clay with numerous fossil plant impressions. Howe (1956, p.47) further stated that this clay outcrops primarily in southern Crawford County and northern Cherokee County. Abernathy (1936, p.79) also noted the presence of numerous channel sandstones within the marine shales as well as the unfossiliferous nature of these shales. This cyclothem is bounded at the base and top by unconformities. The average thickness of the Weir cyclothem is 36 feet (11 meters).

CYCLOTHEM 7 (PILOT CYCLOTHEM)

The Pilot cyclothem is fairly complete with just the absence of the limestone and upper shale (Figure 13). Within this cyclothem, the black shale overlying the coal is very fossiliferous. Abernathy (1936, p.83) identified the bryozoan *Rhombopora*, brachiopods *Orbiculoidea*, *Conetes*, *Mesolobus*, *Wellerella*, and *Punctospirifer*, and the pelecypod *Nuculana* from the black shale. Howe (1956, p.51) correlated the "Pilot" coal with the Tebo coal. Therefore, this cyclothem consists of the sandstone and underclay below the Tebo coal to the black shale above it but not the Tiawah Limestone. The average thickness of the Pilot cyclothem is 35 feet (11 meters).

CYCLOTHEM 8 (SCAMMON CYCLOTHEM)

Named from the town of Scammon, Cherokee County, Kansas, this is a complete cyclothem with a very fossiliferous lowermost black shale and the limestone (Figure 14). Descriptions of this cyclothem were based upon a locality measured in Sec. 26, T31N, R24E. The coal of this cyclothem would be the Scammon coal. Within the black shale, Abernathy (1936, p.84) identified the following: brachiopods *Orbiculoidea*, *Chonetes*, *Marginifera*, and *Wellerella*; pelecypods *Nuculopsis*, *Nuculana*, and *Yoldia*; and the gastropods *Trepospira*, *Naticopsis*, *Euphemites*, and *Pleurotomaria*. Abernathy (1936, p.84) also identified the ammonoid *Domatoceras williamsi* (Miller and Owen) from the black shale interval.

The limestone of this cyclothem is a gray, dense six-inch (15-cm) limestone that is unnamed (Abernathy, 1936, p.84). It could possibly be the Tiawah Limestone, but this correlation is unclear since Searight and others (1953) and Howe (1956) placed the

Formation or Cyclothem		Member or Phase		
No.	Nomenclature	No.	Lithologic Nature	Thickness in Feet
		8.3	Underclay	1.5
		8.2	Sandy shale	4.0
		8.1	Sandstone	4.0
7	Pilot	7.6	Gray shale	2.0
		7.5	Black shale	8.0
		7.4	Coal	0.5
		7.3	Underclay	1.0
		7.2	Sandy shale	16.0
		7.1	Sandstone	8.0
6	Weir	6.5	Black shale	1.0
		6.4	Coal "Weir-Pittsburg"	2.5
		6.4	Blackjack	2.0
		6.4	Coal	0.5
		6.3	Underclay	0.5
		6.1	Sandstone	30.0
5	Kniveton	5.6	Gray shale	16.0
		5.5	Black shale	7.0
		5.4	Coal	0.7
		5.3	Underclay	1.0
		5.1	Conglomerate	1.0

FIGURE 12. Division of the lower middle part of the Cherokee Group into cycles by Abernathy (1936). In Oklahoma, these cycles would extend from the Boggy Formation to the lower part of the Senora Formation (Taken from Abernathy, 1936).

Tiawah Limestone well below the Scammon coal. But, this correlation has the Tiawah placed above the Scammon coal. Most likely, the limestone is actually an unnamed limestone that Searight and others (1953) placed above the Scammon coal at the base of the Mineral Formation.

According to Abernathy (1936, p.84), this limestone is not as fossiliferous as the lower black shale, however it does have a good assemblage of cephalopods. Among the fauna identified from the limestone by Abernathy (1936, p.84) are crinoid stems; brachiopods *Marginifera*, *Squamularia*, *Chonetes*; gastropod *Bellerophon*; nautiloid *Orthoceras*; bactritoid *Bactrites*; ammonoids *Metacoceras*, *Domatoceras*, and *Temnocheilus*.

Howe (1956, p.52) stated the possibility that the Scammon and Tebo coal may be equivalent; however, he also demonstrated that the Tebo coal is equivalent to the "Pilot" coal, which would make the Scammon a separate coal bed between the Tebo and Mineral coals. At any rate, Howe (1956, p.54) placed the Tiawah Limestone below the Scammon coal; therefore, it is likely that the Scammon and Tebo coals are separate beds. This cyclothem is bound at the base and top by unconformities. The average thickness for the Scammon cyclothem is 33 feet (9.9 meters).

CYCLOTHEM 9 (MINERAL CYCLOTHEM)

This cyclothem contains only the underclay, coal, and the black and grey shales above the coal (Figure 14). Named from the Mineral coal, Abernathy (1936, p.85) described two distinguishing characteristics of this cyclothem. The first characteristic is the thickness and consistency of the Mineral coal. The second is the diverse faunal assemblage in the black shale above the Mineral coal. Moore (1949, p.45) noted that this black shale is very fossiliferous when thin limestone stringers are present. Abernathy (1936, p.86) reported that most of the fossils from the black shale are in the lower part of the unit along bedding planes. Furthermore, fossils within this interval are mostly composed of white calcite whereas other fossils identified by Abernathy (1936, p.86) have just been casts and molds. Brachiopods, most of which are well preserved, are the most common type fossils; brachiopod genera found by Abernathy (1936) above the Mineral include *Orbiculoidea*, *Derby*, *Chonetes*, *Mesolobus*, *Linoproductus*, *Marginifera*, *Squamularia*, and *Neospirifer*. Also in the black shale above the Mineral coal, Abernathy (1936) found crinoid stems, the bryozoan *Rhombopora*, and the bactritoid *Bactrites*. Concerning *Marginifera*, Abernathy (1936, p.86) stated that it is a rare fossil in the black shale above the Mineral coal although it is a very common fossil elsewhere in the Cherokee Group. The average thickness of the Mineral cyclothem is 12 feet (3.6 meters).

CYCLOTHEM 10 (FLEMING CYCLOTHEM)

This is a fairly complete cyclothem missing only the upper grey shale and limestone (Figure 14). Abernathy (1936, p.87) named this cyclothem from the town of Fleming, Crawford County, Kansas. He also stated that the coal was unnamed, but Pierce and Courtier (1937, p.73) named the coal the Fleming coal. Abernathy (1936) also believed that this cyclothem is barren of fossils; however, recent field studies have revealed several fossils from a limestone above the Fleming coal, which will is discussed elsewhere in this report.

Formation or Cyclothem		Member or Phase		
No.	Nomenclature	No.	Lithologic Nature	Thickness in Feet
11	Coalvale	11.6	Gray shale	1.0
		11.5	Black shale	1.0
		11.4	Coal	1.0
		11.3	Underclay	2.2
		11.2	Sandy shale	3.0
		11.1	Sandstone	1.0
10	Fleming	10.8	Shale	2.0
		10.5	Black shale	6.0
		10.4	Coal	1.0
		10.3	Underclay	1.6
		10.2	Sandy shale	12.0
		10.1	Sandstone	1.0
9	Mineral	9.6	Gray shale	1.0
		9.5	Black shale	7.0
		9.4	Coal	1.8
		9.3	Underclay	2.0
8	Scammon	8.8	Shale	2.0
		8.7	Limestone	0.5
		8.6	Gray shale	2.0
		8.5	Black shale	7.0
		8.4	Coal	0.8

FIGURE 13. Division of the upper middle part of the Cherokee Group by Abernathy (1936). In Oklahoma, these cycles would extend from above the Chelsea Sandstone Member to below the Croweburg coal within the Senora Formation (Taken from Abernathy, 1936).

CYCLOTHEM 11 (COALVALE CYCLOTHEM)

Possibly one of the thinnest cyclothems at only nine feet (2.7 meters), the Coalvale cyclothem lacks the upper limestone and shale above it (Abernathy, 1936, pp.87-88) (Figure 14). The cyclothem was named after Coalvale, Crawford County, Kansas.

CYCLOTHEM 12 (CATO CYCLOTHEM)

This cyclothem is fairly incomplete containing only the underclay, coal, and overlying black shale (Figure 15). Abernathy (1936, p.89) stated that the black shale above the Cato coal is very fossiliferous with a diverse fauna. Bryozoans *Prismopora* and *Rhombopora*, fusulinid *Fusulina*, crinoid stems, and brachiopods *Orbiculoidea*, *Derbya*, *Chonetes*, *Mesolobus*, *Marginifera*, *Squamularia*, *Neospirifer*, and *Dictyoclostus* have all been identified from the black shale of the Cato Cyclothem by Abernathy (1936, p.90). Abernathy (1936, p.89) stated that local names for the Cato coal were the "Fireclay," "Pioneer," and "One-Foot" (in Missouri) coals. Moore (1949, pp.43 and 45) referred to this particular interval as the Croweburg cyclothem. Howe (1956, p.71) stated that popular names for the Croweburg were "Fireclay" and "One-Foot" coals, among others. Considering its stratigraphic position between the Fleming and Verdigris cyclothems and the previous correlations with the Croweburg coal, it is likely that the Cato coal is equivalent to the Croweburg coal, and therefore the Cato cyclothem is the same, at least in part, as the Croweburg cyclothem. The average thickness of the Cato cyclothem is 18 feet (5.4 meters).

CYCLOTHEM 13 (ARDMORE OR VERDIGRIS CYCLOTHEM)

At only five feet (1.5 meters) thick, only the underclay and limestone are a part of this cyclothem (Abernathy, 1936, p.90) (Figure 15). Abernathy (1936, pp.90-91) described this limestone as a fine-grained, dark gray, fossiliferous limestone. Gordon (1893) first called the limestone the Ardmore Limestone. Smith (in Woodruff and Cooper, 1928) named the limestone the Verdigris from exposures along the Verdigris River in Rogers County, Oklahoma. Due to wider usage, Searight and others (1953) officially adopted the name Verdigris Limestone at the Nevada, Missouri Conference. Abernathy (1936, p.91) identified several fossils from the Verdigris Limestone such as crinoid stems, brachiopods *Marginifera*, *Squamularia*, and *Composita*, and the gastropod *Pleurotomaria*.

CYCLOTHEM 14 (BEVIER CYCLOTHEM)

Although containing only the underclay, coal, and black shale of a typical Cherokee cyclothem, Abernathy (1936, p.92) stated that, in many places, above the black shale, in addition to a caprock, there are three limestone beds separated by shale partings (Figure 15). The black shale above the Bevier coal is very fossiliferous containing pyritized *Marginifera*. The limestone above the black shale is fossiliferous, as well, containing the brachiopods *Squamularia* and *Composita* (Abernathy, 1936, p.93). The average thickness of the Bevier cyclothem is nine feet (2.7 meters).

Formation or Cyclothem		Member or Phase		
No.	Nomenclature	No.	Lithologic Nature	Thickness in Feet
15	Mulky	15.7	Limestone	6.0
		15.5	Black shale	8.0
		15.4	Coal "Ft. Scott"	2.0
		15.3	Underclay	2.0
		15.2	Sandy shale	40.0
		15.1	Sandstone	11.0
14	Bevier	14.5	Black shale	6.0
		14.4	Coal	2.0
		14.3	Underclay	1.5
13	Ardmore	13.7	Limestone	4.0
		13.3	Underclay	1.0
12	Cato	12.5	Black shale	7.5
		12.4	Coal	1.5
		12.3	Underclay	9.0

FIGURE 14. Division of the uppermost Cherokee Group into cycles by Abernathy (1936). In Oklahoma, these cycles would extend from the underclay below the Croweburg coal in the Senora Formation to the top of the Blackjack Creek Limestone Member of the Fort Scott Formation in the Marmaton Group. The uppermost black shale (15.5) could possibly be the Excello Shale.

CYCLOTHEM 15 (MULKY CYCLOTHEM)

With an average thickness of 65 feet (19.5 meters), the very complex Mulky cyclothem is nearly complete lacking only the grey shale and uppermost shale (Figure 15). In a section measured in Sec. 31, T28S, R25E, Abernathy (1936, p.94) determined that the black shale (designation 0.5) was present again above the upper limestone (designation 0.7). Abernathy (1936, p.95) described the interval around the upper limestone: "The limestone member (Phase 15.7) is underlain by eight feet (2.4 meters) of non-fossiliferous black shale and overlain by four feet (1.2 meters) of fossiliferous black shale." The limestone itself was described as "fine-grained, compact, light gray, impure, and fossiliferous; it averages about six feet [1.8 meters] thick." Abernathy (1936, p.95) stated that, in addition to the limestone, the shale above it was fossiliferous although faunal diversity was low. Within the lower limestone, Abernathy (1936) found crinoid stems, the fusulinid *Fusulina*, the brachiopod *Squamularia*, the sponge *Chaetetes*, and the pelecypod *Myalina*. The uppermost black shale was found to contain only the brachiopod *Orbiculoidea* (Abernathy, 1936, p.95). In addition to fossils, Abernathy (1936, p.95) identified quarter to three-quarter inch (1.9 cm) spherical concretions (probably phosphate nodules); he further stated these concretions were abundant and a characteristic of the upper black shale. Abernathy (1936, p.94) stated that the coal is the "Mulky" coal, and the uppermost black shale is probably the Excello Shale. But, the Mulky coal is not present in Oklahoma.

Moore (1949, p.43) believed that the Cato (Croweburg) and the Ardmore (Verdigris) cyclothems (Abernathy, 1936) actually were part of the same cycle. He also broke up the Mulky cyclothem (Abernathy, 1936) into three cyclothems: Stice, Breezy Hill, and Blackjack Creek. Moore (1949, p.43) split the Breezy Hill cyclothem from the Mulky cyclothem on the basis of arenaceous beds between the Breezy Hill Limestone and the Mulky coal. The presence of these arenaceous beds indicates a regression between the Breezy Hill Limestone and the Mulky coal, meaning that both units occupy separate cycles. The cycle containing the Mulky coal was renamed by Moore (1949, p.47) the Blackjack Creek cyclothem.

Moore (1949, p.43) found, "a definite cyclic succession which includes (in upward order) sandstone, light-colored clayey to sandy shale, coal (Stice), black platy shale, limestone, and relatively thick light-colored shale,[which] occurs between the Bevier and Breezy Hill cyclothems…". He termed this cyclothem the Stice.

STICE CYCLOTHEM

Moore (1949, p.45) measured 45 feet (13.5 meters) of this cyclothem in southeastern Kansas. The strata of this interval underlie the "Squirrel" sand of the subsurface.

BREEZY HILL CYCLOTHEM

The next cyclothem above the Stice, an unnamed sandstone is the regressive phase of the Breezy Hill cyclothem. Moore (1949, p.45) stated that the Breezy Hill Limestone itself was the "calcareous phase" of the cycle. Moore (1949, p.47) observed no coal or underclay between the sandstone and the Breezy Hill Limestone. Moore (1949, p.47) stated that the Breezy Hill cyclothem was 50 to 70 feet (15 to 21 meters) thick.

BLACKJACK CREEK CYCLOTHEM

Moore (1949, p.47) grouped sandy shale, underclay, Mulky coal, black shale (probably Excello), and Blackjack Creek Limestone of the post-Cherokee Fort Scott Formation into the Fort Scott cyclothem. Abernathy (1936) had previously termed this interval the Mulky cyclothem. Moore (1949, p.47) stated that the average thickness of the cyclothem is 15 feet (4.5 meters).

Moore (1949, pp.43-44) further stated that the basis for formational subdivision should be lithological, and that the cyclothems should not be classified as formations.

Nevada, Missouri Conference

From March 31 to April 1, 1953, representatives of the five states that compose the northern Midcontinent met in Nevada, Missouri to resolve several stratigraphic problems involving the Cherokee Group. The representatives included from Iowa, Richard Northup; Kansas, state geologist R. C. Moore, A. L. Hornbaker, and J. M. Jewett; Nebraska, state geologist G. E. Condra, and Gerald Svoboda; Missouri, state geologist Edward L. Clark, F. C. Greene, W. B. Howe, and Walter V. Searight; Oklahoma, state geologist William E. Ham, C. C. Branson, and Malcolm C. Oakes. Although the primary purpose of the conference was not to determine the cyclic intervals of the Cherokee Group, the representatives did utilize the repetition of cyclicity of the Cherokee Group:

> "Cyclic or repetitive sedimentation in Cherokee rocks was recognized by the conference participants and made the basis of

> formational division. Coal beds are regarded as the most persistent units in the succession. Divisions of formational rank as adopted include beds from the top of a coal bed, to the top of the next higher coal bed.... Participants agreed to restrict usage of such formational units to those areas where shelf conditions prevail. Most of the Oklahoma outcrop area is of basin facies or facies intermediate between basin and platform. In view of these conditions basin facies classification for that state seems advisable but platform classification is recognized and correlation made with it" (Searight and others, 1953, 2747).

Unlike Moore (1949, pp.43-44), Searight and others (1953) did hinge formational subdivisions upon cyclothems. And, unlike Moore (1935, 1949) and Abernathy (1936) who bounded cycles from one unconformity at the base of a sandstone to the next, Searight and others (1953) determined cycles from the top of one coal to the next. This is an unrealistic division however, since each sequence boundary actually separates the regressive phase of a cycle from its transgressive phase.

The cyclothem based formations of Searight and others (1953) are similar to the cyclothems recognized by Abernathy (1936). However, Searight and others (1953) did not recognize as formations some of the minor cyclothems of Abernathy (1936) such as the Kniveton and Coalvale. Furthermore, Searight and others (1953) listed the Rowe and Dry Wood Formations within the stratigraphic position of the Columbus cyclothem (Abernathy (1936). Searight and others (1953) named the intervals occupied by the Pilot and Cato cyclothems (Abernathy 1936) the Tebo and Croweburg Formations, respectively. In the lower Cherokee, Searight and others (1953) recognized a cycle in the stratigraphic position of the Neutral cyclothem (Abernathy 1936); they called it the Warner Formation. Within the uppermost Cherokee, whereas Abernathy (1936) recognized one cyclothem, the Mulky, like Moore (1949), Searight and others recognized three cycles in the uppermost Cherokee: the Lagonda, Mulky, and the newly named Excello Formations.

In total, Searight and others (1953) divided the Cherokee into 18 formations (Figure 16):

Excello Formation
Mulky Formation
Lagonda Formation
Bevier Formation
Verdigris Formation
Croweburg Formation
Fleming Formation
Robinson Branch Formation
Mineral Formation
Scammon Formation
Tebo Formation
Weir Formation
Seville Formation
Bluejacket Formation
Dry Wood Formation
Rowe Formation
Warner Formation
Riverton Formation

Therefore, Searight and others (1953) by using cyclicity to determine formational divisions also recognized 18 cycles within the Cherokee Group. But, Searight and others (1953) listed only the names of the various formations without describing or defining them. However, Howe (1956) described and elaborated upon the work of Searight and others (1953).

RIVERTON FORMATION

The Riverton is the lowest formation in the Desmoinesian identified by Searight and others (1953). Searight and others (1953, p.2748) established the Riverton from the

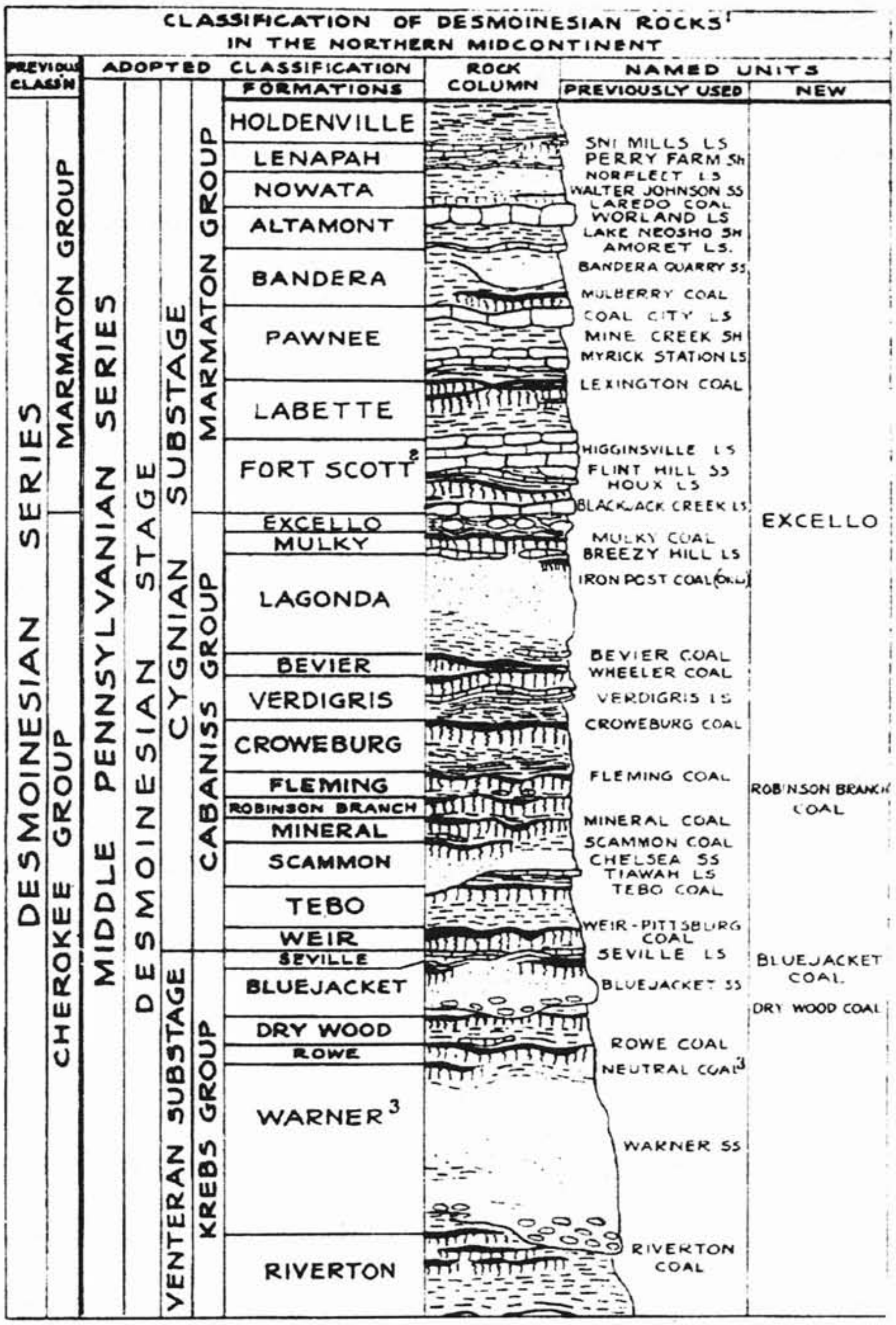


FIGURE 15. Division of the Cherokee Group into "formations" based upon cyclicity by Searight and others (1953). (Taken from Searight and others, 1953, p.2748)

base of the Desmoinesian to the top of the uppermost Riverton coal. Because of the multiple coal beds within the Riverton and in order to simply division into a formation, Howe (1956, p.29) termed the Riverton as a composite of several coal beds. The lowermost "unit" of the Riverton Formation is a black to grey unfossiliferous fissile shale. At the base, the shale is in contact with Mississippian chert. The thickness of this shale ranges from 4 to 13 feet (1.2 to 3.9 meters) thick. Above the coal, a 2 to 4-foot (0.6 to 1.2-meter) underclay, and the uppermost "unit" of the Riverton Formation comprise the Riverton coal beds. Howe (1956, p.31) attempted to correlate the Riverton Formation with the stratigraphy within Oklahoma. He believes that the Riverton Formation may be equivalent to the McCurtain Shale (Wilson 1935) with the coals in the upper part tentatively correlated with the upper Hartshorne coal (Howe, 1956, p.31).

WARNER FORMATION

The second lowest formation assigned by Searight and others (1953), the base of the Warner Formation, was defined from the top of the uppermost Riverton coal to the top of the Neutral coal (as defined by Howe, 1956). The formation is named from the Warner Sandstone, a prominent sandstone within the formation. Wilson and Newell (1937) note that an unnamed coal lies directly above the Warner Sandstone (possibly the Keefton coal), and Howe (1956) believed that this coal may be possibly traced into Kansas. If this coal were continuous, that would indicate another cycle between the Warner Sandstone and the Neutral coal; Howe (1956, p.32) believed that this additional cycle should be split off as a separate formation, the Neutral Formation. This would redefine the Warner Formation from the top of the Riverton coals to the top of the unnamed coal above the Warner Sandstone. But until further study, Howe (1956) continued to include the Neutral coal in the Warner Formation.

The lowermost unit in the Warner Formation is a dark gray unfossiliferous shale. The Warner Sandstone is above the shale. Above the Warner Sandstone, an unnamed sandstone was found. A dark gray fissile shale overlies the Warner Sandstone and coal. Howe (1956, p.34) noted the presence of numerous clay ironstone nodules and stringers within this shale; at a locality in NE1/4SW1/4 Sec. 10, T34S, R24E in Cherokee County, Kansas, Howe (1956, p.34) noted poorly exposed underclays and clay ironstone stringers that may represent either the Spaniard or Sam Creek zones. If so, then the Warner Formation spans the McAlester and Savanna Formations of Oklahoma. The uppermost units of the Warner Formation are the Neutral coal and its underclay.

As previously mentioned, Howe (1956, p.34) identified three coal beds of the Neutral coal. The lower coal he called the Neutral coal. Howe (1956, p.34) correlated the middle coal with the Rowe coal and the upper coal with the Dry Wood. Howe (1956, p.35) believed that the Neutral coal of Kansas was equivalent with the "Lower Boggy" coal (Wilson and Newell, 1937) of Oklahoma. Wilson and Newell (1937, p.53) place the "Lower Boggy" coal below a limestone that Branson (1952, p.192) called the Doneley Limestone. In Oklahoma, the Warner Formation may cover the stratigraphic interval from the Riverton coal to the base of the Rowe coal.

ROWE FORMATION

Searight and others (1953) established the base of the Rowe Formation at the top of the Neutral coal. The top of the Rowe Formation is at the top of the Rowe (Pierce and

Courtier, 1937) coal. Howe (1956, p.35) described the lowermost unit of the Rowe Formation as a six-inch impure, ferruginous limestone. In places, this limestone is very fossiliferous containing the brachiopods *Derbyia*, *Marginifera*, *Neospirifer*, *Spirifer*, and *Composita*, pelecypods *Aviculopecten* and *Astartella*, and crinoid fragments (Howe, 1956, p.36). Howe (1956) called this limestone a caprock of the Neutral coal and believed it corresponded to a six-inch (15.2 cm) limestone above the "Lower Boggy" coal (Wilson and Newell, 1937). Howe (1956, p.36) further stated that this limestone might be equivalent to the Doneley Limestone (Branson, 1952) of Oklahoma. However, in the Rowe Formation, the Doneley Limestone is below the Rowe coal, but in Oklahoma, the Doneley is above the Rowe. If the Neutral coal were equivalent to the Rowe coal, the Doneley Limestone in the Rowe Formation (Searight and others, 1953) would be in the proper stratigraphic position. Between the limestone and the Rowe coal, Howe (1956, p.37) identified a 5 to 10-foot (1.5 to 3-meter) black fissile shale and a 2 to 3-foot (0.6 to 0.9-foot) underclay. Howe (1956) believed that this shale is unfossiliferous and poorly exposed. The uppermost unit in the Rowe Formation is the Rowe coal from which the formation derived its name. Howe (1956, p.37) correlated the Rowe with several other coal beds such as the Columbus coal and the middle Neutral coal. Therefore, the Rowe Formation (Searight and others, 1953) is equivalent to the Columbus cyclothem (Abernathy, 1936). The Rowe coal is also the second coal bed recognized in the Neutral cyclothem (Abernathy, 1936).

DRY WOOD FORMATION

Established by Searight and others (1953), they defined the Dry Wood Formation as being from the top of the Rowe coal to the top of the Dry Wood coal. According to Howe (1956, p.38), the lowermost unit of the Dry Wood Formation is a dark gray to black fissile shale, and in northeastern Cherokee County, Kansas, a lenticular limestone is at the base of this shale. The limestone being the fossiliferous interval of this shale, Howe (1956, p.38) listed several types of fossils, brachiopods, *Spirifer*, *Composita*, *Derbyia*, *Linoproductis*, *Punctospirifer*, and *Orbiculoidea*; bryozoans *Rhombopora* and *Fenestrellina*; and the shark *Petalodus*. Branson (1954, p.192) believed that this limestone could be correlated with the Doneley in Oklahoma, but Howe (1956, p.38) believed that the Doneley was equivalent to a limestone lower down in the section above the Neutral coal. Above the shale is a silty limestone, which Howe (1956, p.39) stated resembles a clay ironstone stringer. Howe (1956, p.39) also believes that this limestone may be an underlimestone associated with the underclay above it. The only fossils reported from this limestone were worm trails (Howe, 1956, p.39). Above the limestone, the Dry Wood coal and its underclay are the uppermost units of the Dry Wood Formation. The Dry Wood Formation could be equivalent to the upper part of the Neutral cyclothem (Abernathy, 1936).

BLUEJACKET FORMATION

Searight and others (1953, p.2748) placed the lower boundary of the formation at the top of the Dry Wood coal and the upper boundary at the top of the Bluejacket coal. The formation is named from the Bluejacket Sandstone (Searight and others 1953, Howe, 1956). Howe (1956) did not report any fossils from any of the other units within the formation. The lowermost units are a shale and sandy shale between the top of the Dry Wood coal and the base of the Bluejacket Sandstone. Howe (1956, p.40) reported a small discontinuous coal within the lower shale. However, this coal is not significant enough to warrant establishment of a new cycle. This unit is often not present due to the erosional nature of the base of the Bluejacket Sandstone (Howe, 1956, p.40). The Bluejacket Sandstone is above this shale. Howe (1956, pp.42-43) reported a conglomerate at the base of the Bluejacket Sandstone, containing fragments of shale and clay ironstone (p.42). The uppermost unit of the Bluejacket Sandstone is the Bluejacket coal.

SEVILLE FORMATION

Searight and others (1953) established the Seville Formation as the uppermost formation of the Krebs Subgroup. The formation represents a relatively minor cycle with only one member unit, the Seville Limestone (Howe, 1956, p.44). Searight and others (1953, p.2748) placed the base of the formation at the top of the Bluejacket coal. The upper boundary of the formation is at the base of the underclay below the Weir-Pittsburg coal. The Seville Limestone is fossiliferous; Howe (1956) reported the foraminifera *Tetrataxis*, fusulinid *Fusulinella*, and bryozoan *Prismopora* from the Seville Limestone in southeastern Kansas. Farther east, in northwestern Barton County and southwestern Vernon County, Missouri, the Seville Limestone contains mostly brachiopods such as *Marginifera*, *Mesolobus*, and *Derbyia* (Howe, 1956, p.44). In Oklahoma, the Inola Limestone may be equivalent to the Seville Limestone of Kansas, Missouri, and Iowa (Howe, 1956, p.44).

WEIR FORMATION

The lowest formation of the Cabaniss Subgroup, the Weir Formation (Searight and others, 1953), is equivalent to the Weir cyclothem (Abernathy, 1936). However, the boundaries differ since Searight and others (1953) bounded cycles from coal to coal and Abernathy (1936) did not. Searight and others (1953, p.2748) defined the lower boundary of the Weir Formation at the top of the Seville Limestone and the upper boundary at the top of the Weir-Pittsburg coal. Another difference between the Weir Formation (Searight and others, 1953) and the Weir cyclothem (Abernathy, 1936) is that Abernathy (1936) reported a black and a grey shale above the Weir-Pittsburg, whereas Howe (1956, p.46) stated that the Weir Formation contains only the Weir-Pittsburg and its underclay. However, since the cycles were measured from coal to coal, it is likely that the dark shale above the Weir-Pittsburg was included in the overlying Tebo Formation. A feature common to both the Weir cyclothem and the Weir Formation is the presence of a "blackjack" clay below the Weir-Pittsburg coal (Abernathy, 1936, Howe, 1956).

TEBO FORMATION

Searight and others (1953) defined the base of the Tebo Formation from the top of the Weir-Pittsburg coal to the top of the Tebo (Marbut, 1898, p.123) coal. Howe (1956, p.49) stated that in northwestern Cherokee County, Kansas, in NW1/4 Sec. 25, T32S, R22E and NE1/4 Sec. 30, T32S, R23E, the Weir-Pittsburg and Tebo coals are in contact. Where present, Howe (1956, p.49) listed the lowest unit of the Tebo Formation as a gray silty shale. In some areas of southern Crawford and northern Cherokee County, Howe (1956, p.49) reported that this shale was interbedded with sandstones; he further believed that the depositional environment for this shale and underlying Weir-Pittsburg coal was deltaic. Above this shale, Howe (1956, p.51) reported what he termed as an underlimestone to the underclay below the Tebo coal; the underlimestone was found only in Crawford County, Kansas and Barton County, Missouri and no where else. Howe (1956, p.51) described this limestone as nodular to massive, silty, and impure. The uppermost units of the Tebo Formation are the Tebo coal and its underclay. Howe (1956, p.51) correlated the "Pilot" coal with the Tebo coal, therefore making the Tebo Formation a correlative of the Pilot cyclothem (Abernathy, 1936).

SCAMMON FORMATION

The Scammon Formation represents a very complex cycle that includes a marine limestone, two dark shales, a channel sandstone (the Chelsea Sandstone), underclay, and a coal (the Scammon coal). Searight and others (1953, p.2748) placed the lower boundary of the Scammon Formation at the top of the Tebo coal and the upper boundary at the top of the Scammon coal. While he believed that the "Pilot" and Tebo coals were equivalent, Howe (1956, p.52) also believed that the Scammon and Tebo coals might be equivalent as well. However, Howe (1956, p.52) reported that the Scammon was defined as being between the Tebo and Mineral coals. Furthermore, the Scammon is placed above the Chelsea Sandstone while the Tebo coal is below the Chelsea. Because of this, Howe (1956, p.52) believed that it was justifiable to include the Scammon as a separate cycle between the Tebo and Mineral coals. The Scammon does not extend southward into Oklahoma and is not recognized there. The lowermost unit of the Scammon

Formation is a black fissile shale above the Tebo coal. Howe (1956, p.54) reported phosphate nodules within this shale but no fossils.

Above this shale, the Tiawah Limestone (Lowman, 1932) is found. Howe (1956, p.54) reported abundant brachiopod and gastropod fossils from the Tiawah Limestone. Brachiopod fossils from the Tiawah include *Mesolobus*, *Chonetina*, and *Dictyoclostus*, and gastropods from the Tiawah Limestone are *Naticopsis* and *Trachydomia* (Howe, 1956, p.54). In many places, especially in Kansas and Missouri, the Tiawah is laminated with an algae to which Johnson, in 1956, assigned the name *Archaeolithophyllum* (Howe, 1956, p.55). Below and above the Tiawah Limestone, Howe (1956, p.55) made mention of black shales which contain, among other fossils, conodonts.

Above the Tiawah Limestone, Howe (1956, p.55) listed an unnamed shaly sandstone and siltstone. Mostly near shore and terrestrial fossils such as worm trails and plant impressions are present within this sandstone and siltstone (Howe, 1956, p.57). Howe (1956, p.57) reported an unnamed coal above this sandstone and below the Chelsea Sandstone. Howe (1956) believes that this coal may mark the beginning of another cycle separate from that of the underlying Tiawah Limestone that would justify breaking the Scammon Formation up into two smaller formations. The lower formation would extend from the top of the Tebo coal to the top of the unnamed coal, and the upper formation would extend from the top of the unnamed coal to the top of the Scammon coal.

There are not any significant fossiliferous intervals above the Tiawah Limestone within the Scammon Formation. Between the unnamed coal and the Chelsea, Howe (1956, p.57) did report a dark to light gray clay shale, but he did not find any marine fossils within it. The Chelsea Sandstone lies above this shale. Howe (1956, pp.57-58) reported that in northern Oklahoma, a conglomerate at the base of the Chelsea contained fragments of phosphate nodules, wood, and coal. In some places, the Chelsea Sandstone has significantly downcut through lower units. Howe (1956, p.53) notes that the erosional surface of the Chelsea Sandstone extends through the Tiawah Limestone and Tebo coal. In northern Oklahoma, near Timbered Hill east of Bluejacket, Oklahoma in Craig County, the Chelsea Sandstone sits upon an unconformity with the Weir-Pittsburg coal (Howe, 1956, p.53). The extent of incisement caused by the Chelsea Sandstone has caused Howe (1956, p.45) to note:

> "A single prominent unconformity has been observed within the Cabaniss subgroup, at the base of the Chelsea sandstone; its local relief is about 30 feet [9 meters] in Cherokee and Crawford Counties, but is much greater in northern Oklahoma, where the unconformity seems to be associated with faulting. In southeastern Labette County no beds between the Bluejacket sandstone and the Mineral coal (about 70 feet [21 meters] above the base of the Cabaniss) have been identified positively, and it is possible that the Chelsea and the Bluejacket together form the unusually thick sandstone previously regarded...as Bluejacket."

The uppermost units of the Scammon Formation are the Scammon coal and its underclay.

The primary difference between the Scammon cyclothem (Abernathy, 1936) and the Scammon Formation (Searight and others, 1953) is that Abernathy places a limestone above the Scammon coal and Searight and others place the limestone below the Scammon coal.

MINERAL FORMATION

Searight and others (1953) defined the Mineral Formation from the top of the Scammon coal to the top of the Mineral (Pierce and Courtier, 1937) coal. Howe (1956, p.60) stated that the lowest member of the formation is a limestone caprock above the Scammon coal. This limestone may be equivalent to the unnamed limestone that Abernathy (1936) identified above the Scammon coal in the Scammon cyclothem. But Howe (1956, p.61) stated: "The limestone identified by Abernathy in the vicinity of the type section of the Scammon coal as the cap-rock of that coal is not regarded as part of the Mineral formation...." Since Howe (1956, p.60) reported the limestone from only one exposure in SE1/4NW1/4 Sec. 24, T28S, R25E, Crawford County, Kansas, it would seem difficult to determine the proper stratigraphic relationship of this limestone without further field study. Howe (1956, p.61) listed only the brachiopods, *Dictyoclostus*, *Neospirifer*, *Mesolobus*, and *Chonetina*, and fusulinids from this limestone, and, in terms of faunal content, Abernathy (1936) reported a different fossil assemblage from the unnamed limestone above the Scammon coal. Howe's (1956, p.61) description of the Scammon limestone caprock, because of different faunal contents, may indicate that the two limestone beds are not related at all. Above the limestone, Howe (1956, p.61) noted about ten feet (0.3 meters) of a dark fissile shale, but the shale was not described as fossiliferous. Above the shale, there is an underlimestone to the underclay of the Mineral coal. Howe (1956, p.61) described this underlimestone as argillaceous, ferruginous, heavily weathered, and unfossiliferous. Although (Howe, 1956, pp.61-62) noted only one occurrence of this underlimestone, he believed it to be widespread. The uppermost units of the Mineral Formation are the Mineral coal and its underclay. Popular mining terms for the Mineral coal are "Weir-Pittsburg upper," "Lightning Creek," "Baxter," "22-inch," and "Top vein" (Howe, 1956, p.62).

ROBINSON BRANCH FORMATION

Searight and others (1953) defined the Robinson Branch Formation from the top of the Mineral coal to the top of the Robinson Branch coal. Howe (1956, p.63) stated that the Robinson Branch coal was named from a stream called the Robinson Branch in Vernon County, Missouri. Howe (1956, p.64) stated that the lowermost unit of the Robinson Branch Formation was a limestone and calcareous shale. The limestone is described as lenticular, massive, and coquinoidal. Although absent in some areas, Howe (1956, p.64) believed the limestone to be continuous in eastern Labette County, Kansas and Craig County, Oklahoma. Howe (1956, p.64) also called this limestone a caprock of the Mineral coal and believed that the limestone may be the Russell Creek Limestone (Branson, 1952) present in Craig County, Oklahoma. Above the limestone, Howe (1956, p.64) reported a calcareous shale, and where the limestone is absent, the shale rests directly upon the Mineral coal. Within both the limestone and shale, Howe (1956, p.64) noted the presence of small phosphate nodules. Some of the nodules contain the shells of the brachiopod *Orbiculoidea*. Howe (1956, p.65) listed the fossils as existing in both the limestone and calcareous shale but did not distinguish which fossils came from where. Fossils included the brachiopods *Dictyoclostus*, *Neospirifer*, *Composita*, *Mesolobus*, and *Marginifera*, fusulinids *Fusulina*, *Wedekindellina*, and possibly *Fusulinella*, and crinoid stems (Howe, 1956, p.65). Howe (1956, p.65) reported that some of the crinoid stems were larger than average for the Cherokee Group (1/2 to 2 inches [1.3 to 5.1 cm] in diameter).

Above the limestone and calcareous shale, Howe (1956, p.65) described a black to dark gray fissile shale. Where the Robinson coal was absent, the shale was overlain by the underclay of the Fleming coal (Howe, 1956, p.65). The fossils identified by Howe (1956) within this unit were the brachiopods *Mesolobus*. At one locality in SE1/4 Sec. 24, T31S, R24E in southeastern Kansas, Howe (1956, p.65) observed a sandstone above the black shale. The uppermost units of the Robinson Branch Formation are the Robinson Branch coal and its underclay.

Howe (1956, p.66) only positively identified the Robinson Branch coal from one locality in NE1/4 Sec. 34, T32S, R22E in Cherokee County, Kansas, but the Robinson Branch coal is present in various areas in Kansas and Missouri. However, the Robinson Branch coal does not extend southward into Oklahoma even though the other components of the cyclothem, such as the Russell Creek Limestone and the black shale above the Russell Creek, may extend into at least Craig County in northern Oklahoma.

FLEMING FORMATION

Searight and others (1953) defined the Fleming Formation from the top of the Robinson Branch coal to the top of the Fleming coal. Where the Robinson Branch coal is absent, the base of the Fleming Formation may rest at the top of the black shale above the Russell Creek Limestone. Howe (1956, p.66) reported that where the Robinson Branch coal is absent the underclay beneath the Fleming coal may be unusually thick. Howe (1956, p.66) concluded that the very thick underclay may be the combination of underclays of both the Fleming and Robinson Branch coals. The lowermost units of the Fleming Formation are a impure shaly limestone, calcareous shale, and a massive ferruginous limestone that Howe (1956, p.66) reported from a locality in NE1/4 Sec. 34, T32S, R22E, Cherokee County, Kansas. The shaly limestone and calcareous shale are very fossiliferous with brachiopods predominant, *Mesolobus*, *Marginifera*, *Dictyoclostus*, and *Neospirifer*. The upper ferruginous limestone contains mostly the brachiopod *Crurithyris*. Howe (1956, p.67) reported a dark gray to black shale above the ferruginous limestone, and that four feet (1.2 meters) above lower contact, there are thin limestone stringers that have abundant amounts of the brachiopod *Marginifera*. Above the black shale, a possible channel sandstone is present. Howe (1956, p.67) notes potential incisement through the Robinson Branch Formation and possibly the Mineral coal by this sandstone, and there is also a conglomerate at the base of this sandstone with pebbles of shale and limestone at the locality mentioned above (Howe, 1956, p.67). The uppermost units of the Fleming Formation are the Fleming coal and its underclay.

The sandstone, underclay, and Fleming coal are equivalent to the Fleming cyclothem (Abernathy, 1936). The upper black shale within the Fleming cyclothem would likely be a black shale from the Croweburg Formation (Searight and others, 1953). The lower calcareous shale and limestone and overlying black shale of the lower part of the Fleming Formation (Searight and others, 1953) could possibly constitute the upper marine units of the underlying Mineral cyclothem (Abernathy, 1936).

CROWEBURG FORMATION

The next higher formation established by Searight and others is the Croweburg Formation, and it is more or less equivalent to the upper part of the Fleming cyclothem (Abernathy, 1936) and the regressive interval of the Cato (Croweburg) cyclothem (Abernathy, 1936). Searight and others (1953) defined the boundaries of the Croweburg Formation from the top of the Fleming coal to the top of the Croweburg coal. Howe (1956, pp.68-71) noted several fossiliferous marine intervals within the Croweburg Formation including a sandstone. The lowermost units of the formation are a lenticular, dark gray coquinoidal limestone and an overlying calcareous shale (Howe, 1956, p.68). Howe (1956, p.68) lists mostly brachiopods, *Marginifera*, *Crurithyris*, and *Neospirifer*, and fusulinids from the lower limestone. Like the limestone, the calcareous shale contains mainly brachiopods as well, mostly *Crurithyris* and *Marginifera* (Howe, 1956, p.69). Where the limestone is absent, the calcareous shale sits directly upon the Fleming coal. Another shale is present above the calcareous shale, but this shale is a dark gray or black shale. Howe (1956, p.69) noted the thin-bedded nature of this shale but added that is not fissile. Howe (1956, p.69) did not mention that this shale is fossiliferous.

Above the shales is either an underlimestone or a sandstone. The limestone grades laterally into a massive fine grained sandstone (Howe, 1956, p.69). Howe (1956, p.70) stated that the limestone has been observed north and east of Pittsburg, Crawford County, Kansas and southwest of Mineral, Cherokee County, Kansas. The sandstone is present in south central T30S, R24E in south central Crawford County, northern and western T31S, R24E on the boundary between Crawford and Cherokee Counties, and southeastern T31N, R23E, in northern Cherokee County. In addition, the sandstone has been found north of Hallowell, Cherokee County, Kansas and north of Chetopa, Labette County, Kansas. The sandstone also extends southward into northern Oklahoma (Howe, 1956, p.70-71). Roughly speaking, the limestone seems to be present in the eastern part of the outcrop area and grades westward into a conglomerate and then a sandstone.

The sandstone is unique within the Cherokee Group in that it is a fossiliferous marine sandstone. Howe (1956, p.70) reported the molds of gastropods, pectinoid clams, and brachiopods *Marginifera*, *Juresania*, *Composita*, and *Linoproductus* within the sandstone from localities in NW1/4NW1/4 Sec. 32, T31S. R24E and SE1/4NE1/4 Sec. 36, T31S, R23E, in Cherokee County, Kansas. The limestone, where present, ranges from silty, nodular, unfossiliferous limestone to an impure, shaly limestone with marine fossils (Howe, 1956, p.71). Howe (1956, p.71) reported the presence of the brachiopods, *Composita*, *Marginifera*, *Derbyia*, *Juresania*, *Mesolobus*, *Orbiculoidea*, and *Crurithyris*, clams, and crinoid stems from this limestone. Howe (1956, p.71) also stated that this limestone was an underlimestone of the underclay below the Croweburg coal; and that this limestone may be equivalent to the McNabb limestone (informal) of Oklahoma. The uppermost units of the Croweburg Formation are the Croweburg coal and its underclay. Popular mining terms for the Croweburg coal include "Fireclay," "One-foot," "Ten-inch," and "Soapstone" coals (Howe, 1956, pp.71-72). It was already demonstrated earlier within this chapter that the Croweburg coal was equivalent to the coal Abernathy (1936) identified as the Cato coal.

VERDIGRIS FORMATION

Searight and others (1953) named the Verdigris Formation from the widespread and easily recognizable Verdigris Limestone. The formation was established from the top of the Croweburg coal to the top of the Wheeler coal (not found in Oklahoma) (Searight and others, 1953). Where the Wheeler coal is absent, the top of the formation is at the base of the underclay beneath the Bevier coal (Howe, 1956, p.72). The Verdigris Formation is equivalent to the transgressive (black shale) part of the Cato cyclothem in addition to the Ardmore or Verdigris cyclothem (Abernathy, 1936) itself.

Howe (1956, pp.72-74) identified two shales at the base of the Verdigris Formation, a lower gray shale and an upper black fissile shale. Furthermore, Howe (1956, p.73) identified a periodic black fissile shale at the base of the gray shale. The basal black fissile shale was observed at two localities, SE1/4NW1/4 Sec. 24, T29S, R25E and NW1/4SW1/4 Sec.27, T30S, R24E, in Crawford County, Kansas (Howe, 1956, p.73). When present, the basal black fissile shale directly overlies the Croweburg coal. Howe (1956, pp.72-73) described the gray shale itself as thin-bedded, clayey, and containing small clay ironstone nodules. Howe (1956, p.73) stated that the basal black shale was unfossiliferous, but the gray shale itself was fossiliferous. Fossils from the gray shale included the brachiopod *Mesolobus*, and the pelecypod *Dunbarella*.

The upper black fissile shale is very phosphatic with Howe (1956, p.74) observing numerous small phosphate nodules within this shale. In addition, the shale is prominent and widespread in its exposure area in Oklahoma, Kansas, Missouri, and Iowa; Howe (1956, p.74) gave a thickness range for this shale of 2 to 5 feet (0.6 to 1.5 meters) with the average thickness being 3 feet (0.9 meters). Unlike the lower gray shale, the upper black fissile shale had a larger diversity in fossils. Howe (1956, p.74) listed the brachiopods, *Marginifera*, *Composita*, and orbiculoid brachiopods, ammonoids, ahermatypic corals, and conodonts from this black shale. Howe (1956, p.74) especially commented upon the abundance of orbiculoid brachiopods and conodonts in this shale, and he also noted that several of the phosphate nodules contained fish scales within their nuclei. The grey shale and black fissile shales of the Verdigris Formation described by Howe (1956) were most likely the gray shale facies and black shale facies of the Oakely Shale, which in Oklahoma directly underlies the Verdigris Limestone.

Above the upper black fissile shale, the Verdigris Limestone is present. Howe (1956, p.74) stated that the Verdigris Limestone was the thickest and most persistent limestone of the Cabaniss Subgroup. The Verdigris Limestone normally consists of three beds interbedded with calcareous shales, the upper, middle, and lower limestones. In Cherokee and Crawford Counties, Kansas, Howe (1956, p.75) described the upper limestone as massive and regular. There are actually two types of limestones present within this bed. The first type is a dark gray nodular limestone present in a lighter gray matrix that may be fragments of reworked limestone. The second type of limestone is the light gray matrix. This limestone contains abundant encrusting foraminifera, *Ptychocladia*. Other fossils present in the upper bed of the Verdigris include crinoid ossicles and fragments, the brachiopod *Mesolobus*, the sponge *Chaetetes*, and the fusulinid *Fusulina* (Howe, 1956, p.77). The upper bed of the Verdigris Limestone probably grades westward to just a calcareous shale with irregular discontinuous limestone in eastern Labette County, Kansas (Howe, 1956, p.75). The uppermost interval of the Verdigris Limestone in this area is probably the middle bed. In Labette County, Kansas, the middle bed of the Verdigris Limestone consists of flaggy limestones and calcareous shales; elsewhere, the middle bed is dense and ranges anywhere from a single continuous bed to a string of closely linked calcareous nodules (Howe, 1956, p.75). A light gray fossiliferous shale and a 1.5 to 5-foot (0.45 to 1.5-meter) black fissile shale separates the middle bed from the lower bed (Howe, 1956, pp.75 and 77). The lower bed of the Verdigris, like the middle bed, is nodular. According to Howe (1956, p.77), the nodules are either flattened, spherical, or dumbbell shaped and have a pyritic rind. Southward into Oklahoma, the three beds of the Verdigris become less flaggier and nodular and more massive and prominent.

Howe (1956, p.77) identified several different types of fossils from the shales and limestones of the Verdigris Limestone. From the lower, middle, and upper limestone beds, Howe (1956, p.77) listed the brachiopods *Neospirifer*, *Composita*, *Phricodothyris*, *Crurithyris*, and *Dictyoclostus*, and crinoid debris. The brachiopod *Marginifera* is common in several of the shales within the Verdigris Limestone (Howe, 1956, p.77).

In the western part of the outcrop area, eastern Labette County and northern Oklahoma, a gray shale and fine-grained sandstones are the upper units of the Verdigris Formation (Howe, 1956, p.78). In the eastern part of the outcrop area, Cherokee and Crawford Counties, Kansas and in southwestern Missouri, the upper gray shale and sandstone are not present. In this case, the Verdigris Limestone is in direct contact with the underclay below the Bevier coal (Howe, 1956, p.78).

BEVIER FORMATION

Searight and others (1953) included the Bevier coal and underclay as member units of the Bevier Formation. Most of the Bevier Formation is equivalent to the Bevier cyclothem (Abernathy, 1936) except for the upper black shale within the cyclothem. This black shale would likely correlate to the lower black shale within the Lagonda Formation (Searight and others, 1953). There are no marine units with the Bevier Formation as defined by Searight and others (1953). However, Pierce and Courtier (1937, pp.77-78) named the Stice coal and placed the coal above the Bevier coal and about 15 to 25 feet (4.5 to 7.5 meters) above the Verdigris Limestone. Between the Verdigris and Stice, they identified thin beds of sandstone, shale, and black shale. Moore (1949, p.43) identified a similar succession between the Bevier coal and Breezy Hill Limestone which he called the Stice cyclothem. Howe (1956, p.80) stated that the Stice and Bevier coals are equivalent which places the Stice cyclothem (Moore, 1949) within the Bevier Formation and lower Lagonda Formation (Searight and others, 1953).

LAGONDA FORMATION

Searight and others (1953) defined the Lagonda Formation from the top of the Bevier coal to the top of the Iron Post coal. Gordon (1893) first termed the interval between the Bevier coal and the underclay of the Mulky coal "the Lagonda." Like the formations above it, many of the units within the Lagonda Formation have received proper stratigraphic nomenclatures. Howe (1956, p.81) stated that the lowest units of the Lagonda Formation are interbedded limestones and shales. The basal part of these units is a fossiliferous shale that grades laterally into a shaly coquinoidal limestone (Howe, 1956, p.81). The lower gray shales between the limestone beds are very fossiliferous, and in the upper part, an unfossiliferous dark shale (Howe, 1956, p.81) separates the limestones. Furthermore, the upper limestone beds are silty and impure and grade into clay ironstone stringers (Howe, 1956, p.81). Howe (1956, p.81) reported the brachiopod *Marginifera*, and mollusks as being very abundant in these lower units. The lower shales and limestones of the Lagonda Formation are present only in southeastern Kansas and parts of western Missouri and do not extend down into Oklahoma (Howe, 1956, p.81).

Above the lowermost limestones and shales, Howe (1956, p.81) reported a light- to medium- gray, micaceous, silty clay shale. This shale has a somewhat gradational contact on both its upper and lower contact. Locally, this shale is also ferruginous and contains calcareous shale nodules (Howe, 1956, p.82). Above this shale, a sandstone, called in the subsurface the "Squirrel" sand, is found. In southeastern Kansas, the Breezy Hill Limestone overlies this sandstone, but in Oklahoma, the underclay of the Iron Post coal overlies this sandstone. This sandstone is sparsely fossiliferous with marine fossils contained in calcareous nodules (Howe, 1956, p.82). In Oklahoma, the sandstone is known as the Lagonda Sandstone.

The uppermost units of the Lagonda Formation are the Iron Post coal and its underclay. But, the Iron Post coal and underclay are present only within Oklahoma and do not extend northward into southeastern Kansas. Oakes (1944) attempted to correlate the Iron Post coal with the Mulky coal of the northern Mid-Continent, but Howe (1956, p.84) stated that this correlation was errant. Popular mining terms for the Iron Post include the "Fort Scott coal" or "red coal" (Howe, 1956, p.84).

The Lagonda Formation (Searight and others, 1953) would correspond to the lower part of the Mulky cyclothem (Abernathy, 1936). Furthermore, the Lagonda Formation (Searight and others, 1953) would correspond to the lower part of the Breezy Hill cyclothem (Moore, 1949).

MULKY FORMATION

Searight and others (1953) defined the Mulky Formation from the top of the Iron Post coal to the top of the Mulky coal. This formation contains the Kinnison Shale, Breezy Hill Limestone, and Mulky coal (providing the formation with its name).

The Kinnison Shale is the lowest member of the Mulky Formation. Howe (1951, p.2092) defined the Kinnison from above the upper contact of the Iron Post coal to the lower contact of the Breezy Hill Limestone in northern Craig County, Oklahoma. Howe (1956, p.84) noted two limestones within the Kinnison Shale, a basal limestone and a limestone near the top. These two limestones are consistent with this author's personal field observations of the Kinnison Shale in northern Craig County. Howe (1956, p.84) described the basal limestone as conglomeratic with carbonaceous and wood fragments. This limestone is fossiliferous as well with abundant brachiopods, *Marginifera* and *Derbyia*. The overlying shale is dark gray and calcareous. Howe (1956, p.84) also identified fossils in the shale, mostly the brachiopod *Chonetes* and crinoid columnals. Howe (1956, p.84) described the upper limestone as thin and rough. Like the Iron Post coal below it, the Kinnison Shale is known only in Oklahoma and does not extend northward into Kansas or Missouri (Howe, 1956, p.84).

The Breezy Hill Limestone is above the Kinnison Shale. Howe (1956, p.85) notes two distinct variations of the Breezy Hill in Kansas and Oklahoma:

> "The lithology of the Breezy Hill is extremely variable along the outcrop in southeastern Kansas. Two distinct types of limestone constitute the member, of which the more widespread is irregularly bedded and sandy to conglomeratic. It is common in southeastern Kansas and is recognized also in western and northern Missouri, but not in northern Oklahoma. Less common in Kansas and unknown in Missouri, but representing the Breezy Hill in its entirety in northern Oklahoma is thin-bedded to massive limestone, which is characteristically dense to medium grained, brown to gray, and weathers buff to brown."

Furthermore, Howe (1956, p.85) notes a third variation of the Breezy Hill Limestone in southern Kansas which seems to occupy the position of an underlimestone. He describes it as: "...made up of angular to rounded fragments of dense dark-gray limestone in a matrix of light-gray, friable, sandy, impure limestone, and weathers to a coarse rubble on the outcrop" (Howe, 1956, p.85). In some localities in southern Kansas, the thin-bedded to massive limestone is found below the nodular limestone. Howe (1956, p.85) believed that the thin-bedded to massive limestone in southern Kansas was deposited in shallow, isolated basins.

At least two of the three variations are fossiliferous, and the faunal assemblages change depending upon the variation. Howe (1956, pp. 85 and 87) noted that the nodular limestone contained the encrusting foraminifera *Ptychocladia*, and the fusulinid *Fusulina*. In some places in Cherokee and Labette Counties, the nodular limestone is composed of nothing but *Fusulina* tests (Howe, 1956, p.85). The thin-bedded to massive limestone is dominated by the brachiopod *Dictyoclostus* although fusulinids are present to a lesser degree (Howe, 1956, p.87).

The uppermost units of the Mulky Formation are the Mulky coal and its underclay. Howe (1956, p.87) noted that the Mulky is the highest coal bed within the Cabaniss Subgroup and Cherokee Group. However, the Mulky does not extend southward into Oklahoma, and what Oakes (1944) called the "Mulky" in Oklahoma was in actuality the Iron Post coal (Howe, 1956, p.88). Therefore, in Oklahoma, the Iron Post coal is the highest coal bed within the Cherokee Group.

The Mulky Formation (Searight and others, 1953) is equivalent to the middle and upper parts of the Mulky cyclothem (Abernathy, 1936). In addition, the Mulky Formation corresponds to the upper part of the Breezy Hill cyclothem (Moore, 1949) and all but the uppermost black shale in the Blackjack Creek cyclothem (Moore, 1949).

EXCELLO FORMATION

The Excello Formation is the highest formation established by Searight and others (1953) within the Cabaniss Subgroup and Cherokee Group. Searight and others (1953) designated only one member unit within this formation, the Excello Shale. The Excello Shale overlies the Mulky coal (in Kansas and Missouri) or the Breezy Hill Limestone (in Oklahoma) and underlies the Blackjack Creek Limestone of the Marmaton Group. Howe (1956, pp.88-89) notes that a characteristic of the Excello Shale are numerous phosphate nodules, and in eastern Bourbon County, Kansas, the Excello may have large limestone concretions as well. Howe (1956, p.88) noted that the Excello Shale has the brachiopod *Orbiculoidea* and conodonts. With an average thickness of five feet (1.5 meters), the Excello Shale is a very widespread black phosphatic shale ranging from Oklahoma to Kansas, Missouri, and Iowa and can be found as far east as Illinois and Indiana. The

Excello Formation is the uppermost black fissile shale in both the Mulky cyclothem (Abernathy, 1936) and Blackjack Creek cyclothem (Moore, 1949).

Cherokee Cyclicity in Oklahoma

Previous Cherokee cyclicity studies by Moore (1935, 1949), Abernathy (1936), Searight and others (1953), and Howe (1956) concentrated primarily on southeastern Kansas and some of western Missouri. Nobody had really attempted to establish cyclothems within the Cherokee Group utilizing stratigraphy recognized by Oklahoma until Branson (1954).

Studying the stratigraphy on the northern shelf area in western Ottawa, Craig, Nowata, Rogers, Western Mayes, and Wagoner counties, Oklahoma, Branson (1954, pp.5-6) identified several coal cycles within the Cherokee. Like Moore (1935) and Abernathy (1936), Branson (1954, p.1) also described an ideal cyclothem:

> dark shale, thin limestone beds
> limestone
> limestone
> calcareous shale
> cap rock, limestone, clay-ironstone, or black fissile shale
> coal
> underclay
> underlime, nodular, pisolitic
> silty shale, micaceous sandstone, shale
> sandstone, conglomerate
> disconformity

However, Branson (1954, p.1) further noted that such an ideal cyclothem is not seen within the Cherokee Group of northeastern Oklahoma. Therefore, Branson (1954) presented a more realistic cyclothem model that is found in northeastern Oklahoma:

"shale, clay-ironstone concretions
limestone, or clay-ironstone, the limestone fusulinid-bearing
coal
underclay
micaceous silty shale
sandstone"

Minus the black and gray shales directly above the coal, this model closely resembles the one established by Abernathy (1936).

Like Moore (1949), the Oklahoma Geological Survey did not base formational divisions upon cyclothems. When Searight and others (1953) created the formations of the Cherokee Group, the Oklahoma Geological Survey recognized these divisions as coal cycles (Branson, 1954, p.2). Other proposals made by Searight and others (1953) directly affected Oklahoma Cherokee stratigraphy as well. They adopted the name Croweburg which Howe (1956, p.71) applied to the coal known in Oklahoma as the Broken Arrow coal. Searight and others (1953) chose the name Verdigris Limestone over the older name Ardmore Limestone. The Oklahoma Geological Survey made some of their own changes to the stratigraphy of the Cherokee Group in Oklahoma. First, they no longer recognized the term "Cherokee Group" as formal stratigraphic nomenclature, and in place of the Cherokee Group, the Oklahoma Geological Survey divided the Desmoinesian Series into three groups: the Krebs, Cabaniss, and Marmaton (Branson, 1954, p.1). However, Howe (1956) had noted that in 1955 the Cherokee Group has been reinstated as a formal name while the Krebs and Cabaniss have been reduced to subgroups.

The formation names recognized by Taff (1899, 1901) within the Arkoma Basin were applied by the Survey to the units present on the shelf (Branson, 1954, p.2). This created a unified stratigraphy for both the basin and shelf facilitating the recognition and division of the Cherokee Group into coal cycles in Oklahoma. Branson (1954, pp.3-4) used the stratigraphic column in northeastern Oklahoma modified by the changes proposed by both Searight and others (1953) and the Oklahoma Geological Survey to create 25 coal cycles.

HARTSHORNE FORMATION

Branson (1954, p.6) recognized two coal cycles within the Hartshorne Formation. The upper coal cycle was the Riverton coal cycle correlated with the Riverton cyclothem (Abernathy, 1936) and Riverton Formation (Searight and others, 1953). But, in addition, Branson (1954, p.6) recognized an unnamed lower coal cycle that had not been identified before. In ascending order the two cycles are:

Unnamed coal cycle

Branson (1954, p.6) grouped an unnamed sandstone, conglomerate, underclay, shale, and coal into an unnamed coal cycle. This is the lowest cyclothem recognized within the Cherokee Group whereas previous workers had the Riverton coal as part of the basal sequence.

Riverton coal cycle

Branson (1954, p.6) grouped an unnamed siltstone, shale, a limestone which he termed the "Elm Creek," underclay, shale, and the Riverton coal into the Riverton coal cycle.

McALESTER FORMATION

Branson (1954, p.6) divided the McAlester Formation into 4 coal cycles. The lower coal cycle is the Warner coal cycle, and the upper three are all minor unnamed coal cycles. These three unnamed coal cycles have previously been unidentified since earlier workers usually grouped the upper McAlester and lower Savanna Formations into one cycle.

Warner coal cycle

Branson (1954, p.6) listed the members of the Warner coal cycle as an unnamed black shale, Warner Sandstone, unnamed underclay, siltstone, shale, and the Neutral coal. Branson's division of the Warner Sandstone plus the inclusion of the Neutral coal closely fits with the Warner Formation (Searight and others, 1953) save for the possible inclusion of the Spaniard or Sam Creek Limestones. However, Branson's (1954, p.6) inclusion of the Neutral coal is problematic since he lists the Rowe coal much farther up. Howe (1956, p.34) noted that there were the three coal beds within the Neutral coal, the upper two beds correlated with the Rowe and Drywood coals respectively. Howe (1956, p.34) correlated the lowermost bed of the Neutral coal with the "Lower Boggy" coal (Wilson and Newell, 1937), which was placed beneath the Doneley Limestone (Wilson and Newell, 1937, Branson, 1952). Therefore, the Neutral coal should belong somewhere within the lower Savanna Formation, but Branson (1954, p.6) has placed the Neutral within the lower McAlester Formation. It may be possible that what Branson believes to be the Neutral coal is actually the Keefton coal.

Unnamed coal cycle

An unnamed coal, underclay, and shale are part of a small coal cycle that had previously been unidentified (Branson, 1954, p.6). It is possible that the coal may be the Stigler coal.

Unnamed coal cycle

A middle coal cycle between the Warner and Rowe cycles, similar to the one below it, was listed by Branson (1954, p.6). The coal may possibly be the Tamaha coal.

Unnamed coal cycle

The uppermost coal cycle between the Warner and Rowe cycles, this cycle contains an unnamed coal, underclay, shale, sandstone, and shale (Branson, 1954, p.6). This coal may either be the Keota coal, placing it beneath the Keota Sandstone, or the Spaniard coal.

SAVANNA FORMATION

Branson (1954, p.6) neatly divided the Savanna Formation into two major coal cycles. The lower coal cycle encompassed all of the beds from the Spaniard Limestone to the top of the Rowe coal. The upper coal cycle ranged from the top of the Rowe coal to the top of the Drywood coal.

Rowe coal cycle

The Rowe coal cycle consists (in ascending order) of: the Spaniard Limestone, unnamed shale, Sam Creek Limestone, underclay, shale, and the Rowe coal (Branson, 1954, p.6). The Rowe coal cycle corresponds to the middle part of the Neutral cyclothem (Abernathy, 1936) and the Rowe Formation (Searight and others, 1953). Since the relationship between the Rowe and the Neutral is unclear, it would be difficult to correlate the Neutral coal at the top of the Warner Formation (Searight and others, 1953) with the Rowe coal within this cycle.

Drywood coal cycle

The Drywood coal cycle (in ascending order) consists of: the Doneley Limestone, unnamed shale, underclay, coal, sandstone, and the Drywood coal (Branson, 1954, p.6). The Drywood coal cycle corresponds to the upper part of the Neutral cyclothem and the Columbus cyclothem (Abernathy, 1936). The Drywood Formation (Searight and others, 1953) is more or less equivalent to the Drywood coal cycle.

BOGGY FORMATION

Branson (1954, p.6) divided the Boggy Formation into five coal cycles: the Bluejacket coal cycle, Inola coal cycle, two unnamed coal cycles, and the Weir coal cycle. There were originally four Inola Limestone beds, and for each bed, Branson (1954, p.31) stated that there was a coal cycle with each of these beds within the Inola Limestone. Later, Branson (1952) restricted the term "Inola Limestone" to the bed originally called "Inola No. 4" limestone. Therefore, it seems that the Inola coal cycle, the two unnamed coal cycles, and the Weir coal cycle are all coal cycles of the old Inola Limestone designation. Either one of the two unnamed coals between the Inola and Weir coal cycles may be the Wainwright coal. Branson (1954, p.6) included the Weir-Pittsburg coal as the uppermost coal within the Boggy Formation.

Bluejacket coal cycle

The Bluejacket coal cycle contains a lowermost limestone cap rock, the Bluejacket Sandstone, unnamed underclay, coal, sandstone, and the Bluejacket coal. Branson (1954, p.6) noted only one occurrence of the limestone cap rock but did not mention the locality where it was identified. The Bluejacket coal cycle (Branson, 1954) is similar to the Bluejacket Formation (Searight and others, 1953). However, the Bluejacket coal cycle, except for the limestone caprock, would only correspond to the terrestrial units within the Bluejacket cyclothem (Abernathy, 1936).

Inola coal cycle

Branson (1954, p.6) included the Inola Limestone, unnamed underclay, and shale within the Inola coal cycle, but did not find any coal within this cycle. The Inola Limestone is probably equivalent to the fossiliferous marine limestone in the upper part of the Bluejacket cyclothem (Abernathy, 1936). Furthermore, the Inola Limestone within the Inola coal cycle (Branson, 1954) is probably equivalent to the Seville Limestone (Howe, 1956) of the Seville Formation (Searight and others, 1953). Branson (1954, p.6) also identified fusulinids from the Inola Limestone which were identified as

Eoschubertella, *Pseudostaffella*, *Fusulinella*, *Wedekindellina*, and *Fusulina* (1954, p.31). This is the limestone that Branson (1952) officially termed the Inola Limestone.

Unnamed coal cycle

An unnamed clay-ironstone, coal, underclay, and shale was identified as a minor coal cycle by Branson (1954, p.6). Branson (1954, p.31) stated that this coal cycle was fossiliferous with the clay-ironstone containing the brachiopod *Dictyoclostus*. The clay-ironstone bed was originally called the "Inola No.3" limestone, and therefore, this may the second cyclical unit within the Inola Limestone mentioned by Branson (1954, p.31).

Unnamed coal cycle

The second unnamed coal cycle of the Boggy Formation is identical with the coal cycle below it. Branson (1954, pp. 6) stated that this coal cycle was fossiliferous as well. The clay ironstone was originally called the "Inola No.2" limestone and contained chonetid brachiopods (Branson, 1954, p.31). This is the third cyclical unit within the old Inola Limestone designation.

Either one of the coals within these unnamed coal cycles could be in the stratigraphic position of the Wainwright coal. It seems difficult to correlate the four cyclic units of the Inola Limestone with the cycles identified by Abernathy (1936) and Searight and others (1953). However, Abernathy (1936) did recognize a separate cycle between the Bluejacket cyclothem and the Weir cyclothem, the Knifeton cyclothem. So, it is possible that one or both of the unnamed coal cycles could be equivalent to the

Knifeton cyclothem. Searight and others (1953) only recognized one cycle between the Bluejacket and Weir Formations, the Seville Formation, and the Seville Formation has only one member unit, the Seville Limestone. This means that there does not seem to be four cycles at the stratigraphic position of the Inola Limestone in southeastern Kansas. However, Howe (1956, p.44) after a personal communication with Branson (1953), noted that, "This limestone, (the Seville) which here forms the uppermost unit of the Krebs Subgroup, also crops out in Iowa and at various places in Missouri. Probably it is represented in Oklahoma by one of the several limestones called Inola, which are known only south of the latitude of Chelsea." It is also possible that the lower coal cycles with the Inola Limestone are those of the Secor, Secor Rider, and Peters Chapel coals which merge and thin out northwards to Kansas (Darwin R. Boardman, personal communication, 2002).

Weir coal cycle

The uppermost coal cycle within the Boggy Formation, the Weir coal cycle, contains the lowermost "Seville" Limestone (which Branson also referred to as the "Inola No.1" limestone), unnamed shale, Lower Taft Sandstone, unnamed shale, Middle Taft Sandstone, unnamed shale, underclay, and the Weir-Pittsburg coal (Branson, 1954, p.6). The Weir coal cycle may the uppermost cyclic unit within the old Inola Limestone designation. Weir coal cycle corresponds closely to the Weir Formation (Searight and others, 1953) except that the base of the Weir Formation was placed at the top of the Seville Limestone while the Weir coal cycle includes a limestone referred to as the

Seville. Furthermore, the Weir coal cycle is equivalent to the terrestrial units within the Weir cyclothem (Abernathy, 1936).

SENORA FORMATION

Because of better-developed marine intervals and more units with proper stratigraphic names, it is easier to divide the Senora into more coal cycles than the Boggy, Savanna, McAlester, or Hartshorne Formations. Branson (1954, p.5) divided the Senora Formation into 12 coal cycles. These coal cycles correspond closely to those created by Abernathy (1936), Searight and others (1953), and Howe (1956). At least three of the coals with these cycles are noted by Branson (1954, p.5) as not being present in Oklahoma. It seems that he still continued using these cycles because many of the member units are present in Oklahoma.

Unnamed coal cycle

The basal coal cycle within the Senora Formation contains an unnamed shale, sandstone, shale, and coal (Branson, 1954, p.5). Branson (1954, p.6) notes that the basal unnamed shale has a thin black shale at its base. This coal cycle may represent a cycle previously not noted by Abernathy (1936) or Searight and others (1953). It is possible that the coal may be the RC coal. It should also be noted that in personal field observations a thin black fissile shale was found just above the RC coal.

Tebo coal cycle

Branson (1954, p.6) placed an unnamed black shale, Upper Taft Sandstone, unnamed shale, and Tebo coal within the Tebo coal cycle. The Tebo coal cycle seems to correspond closely with the Pilot cyclothem (Abernathy, 1936) and the Tebo Formation (Searight and others, 1953).

Scammon coal cycle

A black fissile shale, the Tiawah Limestone, unnamed shale, Chelsea Sandstone, and Scammon coal comprise the Scammon coal cycle (Branson, 1954, p.5). Branson (1954, p.5) referred to the black fissile shale below the Tiawah Limestone as the "Tiawah black shale." Even though Branson noted that the Scammon coal wasn't present in Oklahoma, this cycle was included here because the Tiawah Limestone and the black shale below it are present in Oklahoma. Branson (1954, p.30) noted fusulinids and mytiloids within the Tiawah Limestone. The Scammon coal cycle corresponds closely with the Scammon Formation (Searight and others, 1953) and the lower part of the Scammon cyclothem (Abernathy, 1936).

Mineral coal cycle

Branson (1954, p.5) included three units, an unnamed underclay, shale, and the Mineral coal, within the Mineral coal cycle. Most likely, this cycle is present only in the northernmost part of northeastern Oklahoma. The Mineral coal cycle corresponds with the Mineral Formation (Searight and others, 1953). Save for the black shale above the

Mineral coal, the Mineral coal cycle is also closely equivalent to the Mineral cyclothem (Abernathy, 1936).

Robinson Branch coal cycle

The Russell Creek Limestone, shale, sandstone, and the Robinson Branch coal are all part of the Robinson Branch coal cycle (Branson, 1954, p.5). Branson (1954) stated that the Robinson Branch coal was not present in Oklahoma, and it is unclear if the other member units of this coal cycle extend southward into Oklahoma as well. Branson (1954 p.15) did note the presence of the Russell Creek Limestone in Oklahoma in the SE1/4 Sec. 30, T28N, R20E. Branson (1954, p.5) noted the presence of fusulinids within the Russell Creek Limestone. The Robinson Branch coal cycle seems to be equivalent the Robinson Branch Formation (Searight and others, 1953).

Fleming coal cycle

The Fleming coal cycle consists of limestone or clay-ironstone, unnamed shale and underclay, and the Fleming coal (Branson, 1954, p.5). The Fleming coal cycle more or less corresponds to the Fleming Formation (Searight and others, 1953) and the Fleming cyclothem (Abernathy, 1936).

Unnamed coal cycle

Branson (1954, p.5) grouped an unnamed limestone or clay-ironstone, shale, sandstone, and coal into an unnamed coal cycle between the Fleming and Croweburg coal cycles. Even though he did not name the coal cycle, Branson (1954, p.5) referred to the coal as the Sequoyah coal. He also identified fusulinids from the lowermost limestone or clay-ironstone.

Croweburg coal cycle

Branson (1954, p.5) grouped an unnamed shale, the McKnabb Limestone, underclay, and the Croweburg coal into the Croweburg coal cycle. Branson (1954, pp. 1 and 5) stated that the McKnabb was the only underlimestone present within the Cherokee Group. The Croweburg coal cycle more or less corresponds to the Croweburg Formation (Searight and others, 1953). It also corresponds to the Cato cyclothem (Abernathy, 1936) although the upper black shale is probably part of the overlying Verdigris coal cycle (Branson, 1954).

Verdigris coal cycle

The Verdigris coal cycle contains an unnamed shale, sandstone, black fissile shale, the Verdigris Limestone, and the Wheeler coal (Branson, 1954, p.5). Branson (1954) referred the black fissile shale below the Verdigris Limestone to as the Verdigris black shale. Today, this shale is known as the Oakley Shale. Branson (1954, p.5) also noted the presence of the Wheeler coal in Oklahoma, but it is not well exposed. Branson (1954, p.5) noted that there were fusulinids present with the Verdigris Limestone. The Verdigris coal cycle corresponds closely to the Verdigris Formation (Searight and others, 1953), but Abernathy (1936) only included the Verdigris Limestone and underlying underclay within the Verdigris cyclothem.

Bevier coal cycle

Branson (1954, p.5) acknowledged the presence of the Bevier coal and its associated cycle in Oklahoma. Unfortunately, the coal cycle is too thin and not exposed or developed enough to properly describe or assign member units to it.

Lagonda coal cycle

The Lagonda Sandstone, shale, upper Lagonda Sandstone, and Iron Post coal are part of the Lagonda coal cycle. Branson (1954, p.5) referred to the shale above the Lagonda Sandstone as the Lagonda shale. Searight and other (1953) noted that the basal units of the Lagonda Formation included interbedded limestones and shales. Branson (1954) placed the base of the Lagonda coal cycle at the sandstone in the middle of the Lagonda Formation. The Lagonda coal cycle would also be equivalent to the lower part of the Mulky cyclothem (Abernathy, 1936).

Mulky coal cycle

The uppermost full coal cycle within the Cherokee Group, the Mulky coal cycle, contains the Kinnison shale, Breezy Hill Limestone, underclay, and the Mulky coal (Branson, 1954, p.5). Branson (1954, p.5) notes a limestone caprock of the Iron Post coal at the base of the Kinnison Shale. The uppermost member of this coal cycle, the Mulky coal, is not present in Oklahoma (Branson, 1954, p.5). Fusulinids were identified from the Breezy Hill Limestone by Branson (1954, p.5). The member units of the Mulky coal cycle are the same as that of the Mulky Formation (Searight and other, 1953). The Mulky coal cycle corresponds to the upper part of the Mulky cyclothem (Abernathy, 1936). It is also equivalent to the Breezy Hill cyclothem except for the presence of the Mulky coal (Moore, 1949).

Excello Shale Member

Because the Excello Shale is not associated with a coal, Branson (1954, p.5) felt that the Excello should not be included within a coal cycle. Therefore, it was listed separately. The Excello Formation (Searight and others, 1953) also includes only the Excello Shale. The Excello Shale is probably the uppermost black shale of the Mulky cyclothem (Abernathy, 1936). Moore (1949) included the Excello Shale in a cycle spanning from the uppermost Cherokee to the lowermost Marmaton Groups.

C.

CONODONT DISTRIBUTION

Conodont Distribution within a Sequence

Only four genera of conodonts have been found to be common within marine units of the Cherokee Group within eastern Oklahoma and extreme southeastern Kansas. Of the four, *Idiognathodus* is the most common, and *Neognathodus* is the second most common. The other two genera are somewhat rarer, *Idioprioniodus* and *Gondolella.* Conodonts are restricted to marine units, and to date, conodonts have not been found in terrestrial units (fluvial sandstones and underclays) or units that are formed on the boundary between terrestrial and marine (coals and silty and micaceous shales). Within this study, conodonts have been found in black shales, gray shales, calcareous shales, and limestones.

Heckel and Baesemann (1975) conducted a study of conodont distributions in Missourian megacyclothems in eastern Kansas. Swade (1985) observed conodont distributions and interpreted the paleoecology of the upper Cherokee and Marmaton Groups in Iowa. Although both of their studies are geographically and stratigraphically beyond the scope of this study, the findings of Heckel, Baesemann, and Swade can be extrapolated to the Cherokee Group. The cyclothems of the Cherokee Group are very similar to those of the Marmaton Group, and both groups are close to one another in age thus sharing similar genera of conodonts.

To better understand what particular suite of conodonts would be found at a particular point in a sequence, it would be ideal to describe the life habits and environments of the four conodont genera common to the Cherokee Group of Oklahoma:

Idiognathodus, Neognathodus, Idioprioniodus, and *Gondolella* (Figure 13). All four of these genera were thought to be pelagic (Swade, 1985). Most of the above conodonts were found in black fissile shales that were believed to have been deposited in anoxic seas. If the conodonts were benthic, they would not have survived in the oxygen poor water so they were most likely pelagic (Swade, 1985).

Idiognathodus and *Neognathodus* preferred warm surface offshore waters; these waters would have also been oxygen rich (Swade, 1985). *Idiognathodus* and to a lesser degree *Neognathodus* are very wide spread found in almost every marine phase of a sequence. This may due to a pelagic lifestyle or post-mortem transport. Between the two genera, *Idiognathodus* was believed to have been more onshore while *Neognathodu*s was believed to have been more offshore (Swade, 1985). It is possible that *Idiognathodus* may have ranged as far deep as nearly the anoxic zone in deep seas (Heckel and Baesemann, 1975).

Idioprioniodus and *Gondolella* lived in offshore deep waters. They probably preferred the cold, low oxygen conditions found in this zone. Both genera are almost exclusively associated with black shale. *Gondolella* lived in deeper water than *Idioprioniodus* and may have lived as deep as the upper limits of the anoxic zone (Swade, 1985, Heckel and Baesemann, 1975).

Knowledge of conodont environments can shed light on how conodont assemblages change within a sequence as transgression or regression takes place (Figure 11). As water levels increase or decrease, the abundance of conodonts in shallower or deeper zones will change. It is this shift in conodont abundance that creates unique assemblages within each depositional member of a sequence.

Black shales or black fissile shales

The highest diversity and abundance of conodonts are usually found within black shales or black fissile shales. It is possible for these shales to produce over 4 genera and 100 specimens per kilogram; some very prolific black shales in the upper Cherokee, such as the Oakely and Excello, have produced anywhere from 1000 to 3000 specimens per kilogram (Heckel and Baesemann, 1975, and Swade, 1985).

Four genera are common in core shales: *Idiognathodus*, *Idioprioniodus*, *Neognathodus*, and *Gondolella*, but *Idiognathodus* is the dominant genus (Swade, 1985, and Heckel and Baesemann, 1975). *Idiognathodus* ratios over *Neognathodus* range from 2:1 to 5:1; within the Oakely shale, the *Idiognathodus-Neognathodus* ratio is equal at 1:1 (Swade, 1985). The third most common genus is *Idioprioniodus*, and ratios with *Idiognathodus* may be similar to those with *Neognathodus* (Heckel and Baesemann, 1975).

Gondolella is common to the black fissile shales and has been identified in upper Cherokee shales such as the Oakely and Excello (Swade 1985). One black fissile shale below the Tiawah Limestone is unusual due to a super abundance of *Gondolella*, and between the two genera present within the shale, *Idiognathodus* and *Gondolella*, over half of the conodonts were *Gondolella*. *Gondolella*, of all the conodonts, would have been most suited to living in conditions just above the anoxic zone and has been found in shales lacking any benthic fauna (Heckel and Baesemann, 1975). Because of this, *Gondolella* is a good index fossil for core shales.

Gray shales

Gray shales may either be separate or part of the gray shale facies of what Heckel (1975) termed the core shale. If present as the gray shale facies of a core shale, the grey shale is usually clayey and may contain more conodonts than the black fissile shale facies of a core shale. As part of a core shale, the gray shale may contain deep-water genera such as *Idioprioniodus* and *Gondolella*. *Idiognathodus* and sometimes *Neognathodus* are also found within these shales. Outside the core shale, the gray shale usually contains *Idiognathodus* and *Neognathodus*. Some silty gray shales, particularly above the Verdigris Limestone, have also yielded conodonts, primarily *Idiognathodus*.

Calcareous shales

For the most part, the conodont assemblages of calcareous shales are similar to those of limestones. Two genera dominate these assemblages, *Idiognathodus* and *Neognathodus*. At a locality at Lake Bixhoma, south of Tulsa, Oklahoma, one brown calcareous shale just below the Verdigris Limestone contained *Idiognathodus*, *Idioprioniodus*, and *Neognathodus*. This particular shale was associated with the core shale of the Oakely Shale and may have occupied the place of the gray shale facies. Most other calcareous shales are found between or just below or above limestone beds.

Limestones

Most of the limestones of the Cherokee Group contain primarily *Idiognathodus*. Some limestone beds, such as the Sam Creek, Inola, and a limestone above the Bevier coal, contain hundreds or even thousands of elements of *Idiognathodus*. *Neognathodus* is also present in some limestone beds. At the locality mentioned above, several beds of the Verdigris Limestone have also yielded *Idioprioniodus*.

Heckel and Baesemann (1975) noted that the abundance of *Idiognathodus* changes within a limestone. Towards a black shale or other marine units, *Idiognathodus* becomes more frequent. Towards a more terrestrial unit, *Idiognathodus* becomes rarer.

Although Heckel (1975) distinguished between a middle and an upper limestone, it would be difficult to make such distinction within the Cherokee Group as many sequences only have one limestone bed. Some limestones, such as the Verdigris and the lower part of the Tiawah, are regressive; these regressive limestones produce abundant amounts of *Idiognathodus*.

Conodont Distribution within the Cherokee Group

Previous studies of the Cherokee Group identified few conodont-bearing intervals. Some workers did note conodonts within a few major marine units. The lowermost unit identified as bearing conodonts was the Spaniard Limestone at the base of the Savanna Formation. Recent field studies conducted by Marshall and Boardman (2002) placed the lowermost conodont-bearing interval of the Cherokee Group at the base of the McAlester Formation. Furthermore, Marshall and Boardman (2002) have only recently identified many of the conodont bearing units within the McAlester, Savanna, and Boggy Formations.

Previously identified conodont-bearing intervals

KREBS SUBGROUP

Spaniard Limestone

Wright (1949) identified the conodont genera *Pinacognathodus*, *Polygnathodella*, *Spathognathodus*, and *Prioniodinidae* from an exposure of the Spaniard Limestone at Sec. 4, T21N, R18E in Rogers County, Oklahoma. Wright (1949) also identified *Prioniodidae*, *Spathognathodus*, and *Polygnathodella* from a second locality in Sec. 27, T19N, R17E. Most of the conodonts were found in a brown calcareous marl facies immediately above the Spaniard Limestone (Wright, 1949, p.11).

CABANISS SUBGROUP

Tiawah Limestone

Howe (1956, p.22) stated that conodonts were found in black shales above and below the Tiawah Limestone, but he failed to provide any further identification of the conodonts. In addition, Howe (1956, p.22) did not provide any localities where the conodont-bearing shales were found.

Swade (1985) identified various genera of conodonts within member units of the upper Cherokee in south central Iowa. His findings are included here as a guide to conodont diversities found in the upper Cherokee.

Oakley Shale

Swade (1985) has found *Gondolella*, *Idiognathodus*, *Neognathodu*s, and *Idioprioniodus* in the Oakley Shale. By far, the most abundant conodont genus was *Idiognathodus*, and *Neognathodus* was the second most abundant genus. *Gondolella* and *Idioprioniodus* were also common. A few rare elements were identified as *Diplognathodus* (Swade, 1985).

Verdigris Limestone

Swade (1985) termed the Verdigris the Ardmore Limestone Member of the Verdigris Formation in his study. He also provided conodont data for limestones and shales of the formation. According to Swade (1985), the limestones contained mostly *Idiognathodus* and *Neognathodus*. *Idioprioniodu*s was rarer (Swade, 1985).
Near the upper contact of the Verdigris Limestone, the shallower water conodont genera *Adetognathus*, *Diplognathodus*, and *Aethotaxis* were common indicating nearshore conditions (1985).

The shales within the Verdigris yielded a few elements of *Idiognathodus* and *Neognathodus*. Deep-water conodonts *Gondolella* and *Idioprioniodu*s were even rarer (Swade, 1985).

Black shale above the Bevier coal

Swade (1985) sampled shale above the Bevier coal and identified three genera of conodonts. The shale was sparsely fossiliferous only containing a few elements.

Idiognathodus was the most common conodont genus. Elements of *Adetognathus* and *Neognathodus* were sparse (Swade, 1985).

Excello Shale

The Excello is a major transgressive black shale. Swade (1985) has found a significant abundance of conodonts within the Excello; amounts greater than 1000 elements per kilogram were common. The two most common genera were *Idiognathodus* and *Neognathodus*. Ratios of *Idiognathodus* to *Neognathodus* ranged from 2:1 in the middle of the shale to 5:1 near the lower and upper contacts (Swade, 1985). *Idioprioniodus* was another conodont genus common throughout the Excello. In contrast, *Gondolella* was present only in the black fissile phosphatic shale facies of the Excello (Swade, 1985). The conodont assemblage and extreme abundance strongly indicate that the Excello is a core shale.

APPENDIX B- PRESENTATION OF FIELD DATA

A. LOCALITY REGISTER FOR THE CHEROKEE GROUP

Krebs Subgroup

19. Uppermost Boggy cyclothem
23. Abandoned shale pit- NE1/4NW1/4NW1/4NE1/4 Sec 6, T15N, R16E

18. Post Wainwright coal cyclothem
22. Stream cut- W1/2NW1/4NE1/4NW1/4 Sec 26, T15N, R16E

17. Inola cyclothem
21. Hill slope exposure- NE1/4NW1/4 Sec 10, T19N, R17E

16. Post Peters Chapel cyclothem and **15. Post Secor Rider cyclothem**
20. Core- SE1/4NW1/4SE1/4NE1/4NW1/4 Sec 7, T13N, R18E

14. Post Secor coal cyclothem
19. Surface coal mine exposure- SE1/4NW1/4NE1/4 Sec 13, T6N, R23E and SW1/4SW1/4NW1/4 Sec 18, T6N, R24E

13. Post Lower Witteville coal cyclothem
18. Core- SW1/4SE1/4SE1/4NE1/4SE1/4 Sec. 3, T6N, R23E

12. Post Drywood coal cyclothem
17. Roadcut- SE1/4SE1/4NE1/4 Sec27, T27N, R20E

11. Doneley cyclothem
16. Hill slope exposure- SW1/4SE1/4NE1/4 and NW1/4NE1/4SE1/4 Sec 4, T10N, R19E
15. Core- SE1/4SE1/4SW1/4NW1/4 Sec 18, T21N, R18E

10. Sam Creek cyclothem
14. Stream bed exposure and cut- NW1/4NW1/4SW1/4NW1/4 Sec 26, T14N, R18E
13. Shale pit and hill slope exposure- NE1/4NE1/4NE1/4 Sec 1, T15N, R17E and SW1/4SE1/4SE1/4SE1/4 Sec 36, T16N, R17E

9. Post Tullahassee coal cyclothem
13. Shale pit and hill slope exposure- NE1/4NE1/4NE1/4 Sec 1, T15N, R17E and SW1/4SE1/4SE1/4SE1/4 Sec 36, T16N, R17E

8. Spaniard cyclothem

12. Stream bed exposure- SE1/4SE1/4SW1/4SE1/4 Sec 2, T13N, R18E
11. Core- SE1/4SE1/4SW1/4NW1/4 Sec 18, T21N, R18E

7. Post Keota coal cyclothem

10. Roadcut- NW1/4NW1/4NW1/4NW1/4 sec 16, T13N, R19E

6. Post Tamaha coal cyclothem

9. Stream bed exposure and cut E1/2E1/2NE1/4SE1/4 Sec 13, T13N, R18E

5. Post Stigler coal cyclothem

8. Core- SE1/4SE1/4SW1/4NW1/4 Sec 18, T21N, R18E
7. Core- NW1/4NE1/4SE1/4SW1/4NE1/4 Sec 22, T10N, R19E

4. Post Warner Sandstone cyclothem

6. Core- SW1/4SE1/4SW1/4SW1/4 Sec 16, T12N, R19E

3. Post Keefton coal cyclothem

5. Road ditch exposure- SE1/4SE1/4SW1/4SW1/4 Sec26, T13N, R18E
4. Core NE1/4NE1/4NW1/4NW1/4SW1/4 Sec7, T11N, R20E

2. Post Brushy Mountain cyclothem

3. Roadcut- SW1/4SW1/4SE1/4SW1/4 and NW1/4NW1/4NE1/4NW1/4 Sec 30, T5N, R17E
2. Hill slope exposure- S1/2SE1/4SW1/4SE1/4 Sec 28, T14N, R19E

1. Post Upper Hartshorne cyclothem

1. Roadcut and hill slope exposure- NW1/4NW1/4NW1/4NW1/4 Sec 33, T11N, R19E

28. Lower Fort Scott cyclothem
36. Roadcut- SE1/4SE1/4SE1/4 Sec 30 and S1/2S1/2SW1/4 Sec 29, T34S, R21E
35. Stream cut- N1/2NW1/4NW1/4 Sec 32, T20N, R15E

27. Breezy Hill cyclothem
34. Roadcut- Center N1/2N1/2SW1/4 Sec 2, T16N, R14E
33. Abandoned coal pit- W1/2SW1/4 Sec 35, T29N, R19E

26. Post Bevier coal cyclothem
32. Stream cut- W1/2NE1/4NW1/4 Sec 30, T32S, R22E

25. Verdigris cyclothem
30. Driveway exposure- SW1/4SW1/4 Sec 35, T33S, R21E
31. Spillway exposure- N1/2SE1/4NW1/4 Sec 2, T16N, R14E

24. Fleming cyclothem
30. Driveway exposure- SW1/4SW1/4 Sec 35, T33S, R21E

23. Russell Creek cyclothem
29. Road ditch exposure- Middle North Line Sec 14, T34S, R21E

22. Tiawah cyclothem
28. Roadcut- SE1/4SW1/4 Sec 12, T21N, R16E
27. Roadcut- SE1/4NE1/4NE1/4SE1/4 Sec 14, T14N, R15E

21. Post RC coal cyclothem
26. Core- SE1/4SW1/4NW1/4SE1/4 Sec 12, T21N, R16E
25. Roadcut- Center West Line SE1/4SE1/4 Sec 27, T22N, R17E

20. Post Weir-Pittsburg coal cyclothem
24. Core- SE1/4SW1/4NW1/4SE1/4 Sec 12, T21N, R16E
23. Abandoned coal pit- NE1/4NW1/4NW1/4NE1/4 Sec 6, T15N, R16E

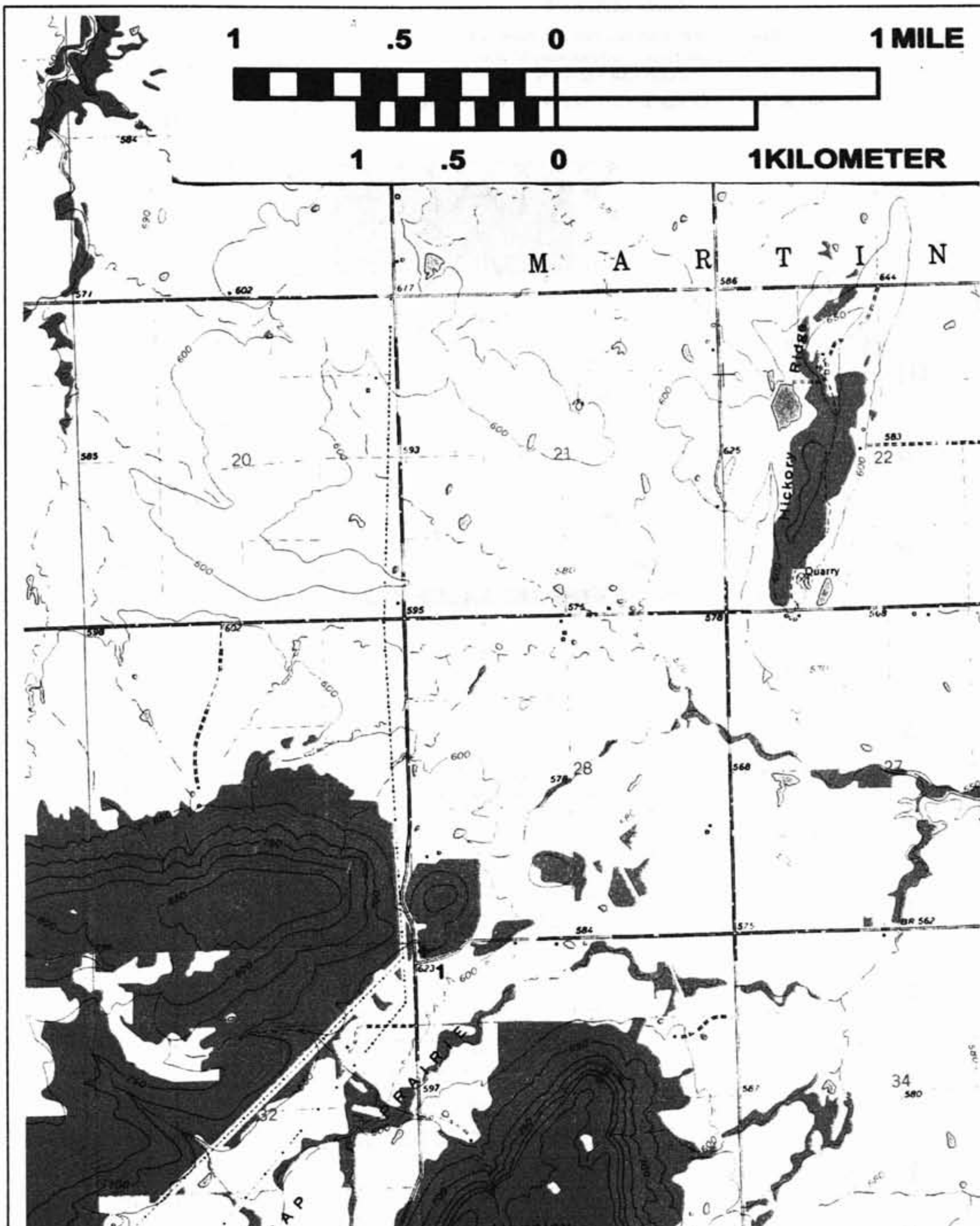


FIGURE 16. Topographic map of Locality #1, Muskogee County, Oklahoma

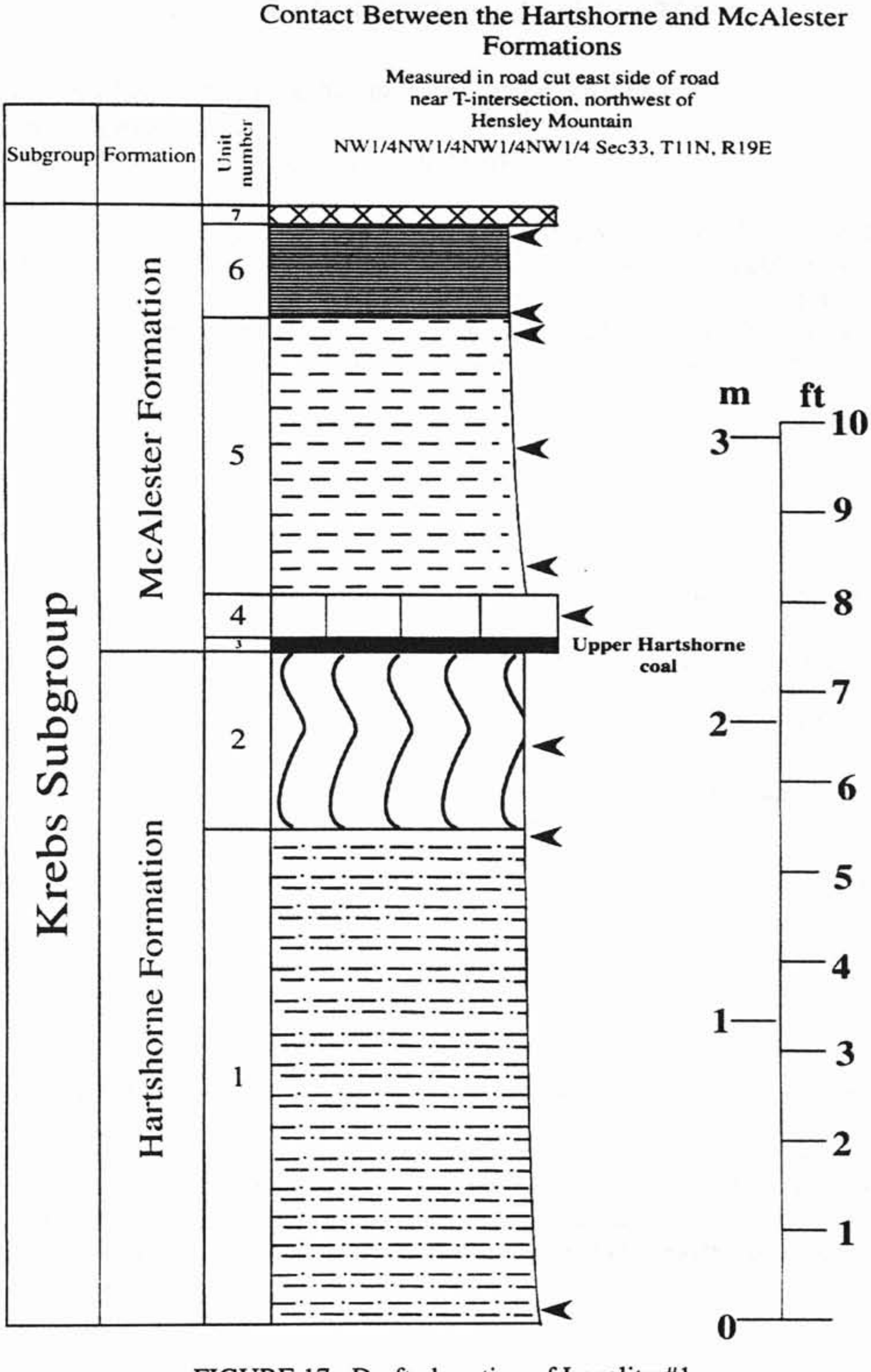


FIGURE 17. Drafted section of Locality #1

MEASURED SECTION of LOCALITY #1

Contact between the Hartshorne Formation and the McAlester Formation

NW1/4NW1/4NW1/4NW1/4 Sec 33, T11N, R19E

Measured in road cut east side of road near T-intersection northwest of Hensley Mountain. Measured from ditch up hill slope. Fresher exposure of outcrop is found on newly excavated hill slope on the northern side of the hill in a shale pit. The two exposures may be separated by a fault. Based on Hemish, L.A., 1998, *Coal geology of Muskogee County, Oklahoma*: Oklahoma Geological Survey Special Publication 98-2, pp. 41, Measured Section 9.

CHEROKEE GROUP
KREBS SUBGROUP

McALESTER FORMATION: Thickness in feet (meters)

7. Ironstone; dark gray weathers to purplish red and dark yellowish orange; pucky; weathers to sharp angular flakes; exposed surface in ditch exhibits cubic or septarian surface 0.2 (0.06)

6. Black shale; grayish black (N2) weathers to medium dark gray (N4); upper contact has a half-inch rust streak; shale below rust streak is blackish red (5R 2/2) weathering to brownish gray (5YR 4/1) with a moderate yellowish brown (10YR 5/4) crust of iron; dime to quarter sized spherical and irregular shaped phosphate nodules (N3); fissile becoming very hard and platy at upper contact; breaks off into flakes with sharp edges; poorly exposed; fauna includes broken fragments of *Idiognathodus*, *Neognathodus*, and *Idioprioniodus* conodonts, gastropods, and *Ammodiscus* foraminifera 1.0 (0.3)

5. Shale; medium dark gray (N4) weathers to medium gray (N5) and pale yellowish brown (10YR 6/2) mottled with yellowish gray (5Y 8/1) and grayish orange (10YR 7/4); fissile; breaks off into blocky fragments; numerous orangish brown clay ironstone stringers' some stringers have a cubic or septarian appearance; phosphate nodules; upper portion of shale becomes very plastic; fauna comprise primarily of broken fragments of *Idiognathodus* and *Idioprioniodus* conodonts, ostracods, gastropods, *Ammodiscus* foraminifera, and ammonoid protoconchs 3.0 (0.9)

4. Limestone; grainstone; dark yellowish brown (10YR 4/2) with a grayish orange (10YR 7/4) rind weathers to dark yellowish orange (10YR 6/6) and pale yellowish brown (10YR 6/2); numerous dark gray calcareous streaks; very fossiliferous; impure; somewhat sandy; very shaly; on northern exposure, limestone is fresh; on eastern exposure, limestone is very weathered and heavily degraded, somewhat resembles a silty shale; weathered rock has ovoid ironstone nodules as part of a one inch stringer in middle of unit; ironstone is dark yellowish orange (10YR 6/6) with a dark reddish brown (10R 3/4) rind; creamy yellow at lower contact; chonetid brachiopods and pelecypods common 0.5 (0.15)

3. Upper Hartshorne coal; black (N1) to brownish black (5YR 2/1); fine cleated; crumbly; weathered 0.1 (0.03)

HARTSHORNE FORMATION:

2. Underclay; medium gray (N5) weathers to pale yellowish brown (10YR 6/2), mottled with dark yellowish orange (10YR 6/6); heavily fractured; fractures filled with dry orange clay; crumbly; blocky; massive; undulating lower contact 2.0 (0.60)

1. Silty shale; moderate yellowish brown (10YR 5/4) weathers to grayish orange (10YR 7/4) becomes light olive gray near upper contact; shale surface exhibits dark yellowish orange (10YR 6/6) splotches; hard; blocky; coal streaks; filled cubic fractures; numerous reddish brown clay ironstone stringers; shale could possibly be siltstone; base covered 5.5 (1.65)

TOTAL: 12.35 (3.7)

PHOTOGRAPH 1

Photograph of Locality #1

Visible in the extreme lower right hand corner is the upper Hartshorne coal, and above the upper Hartshorne coal, the gray and black fissile shales can be seen. The head of the rock hammer used for scale points to the lower part of the black fissile phosphatic shale.

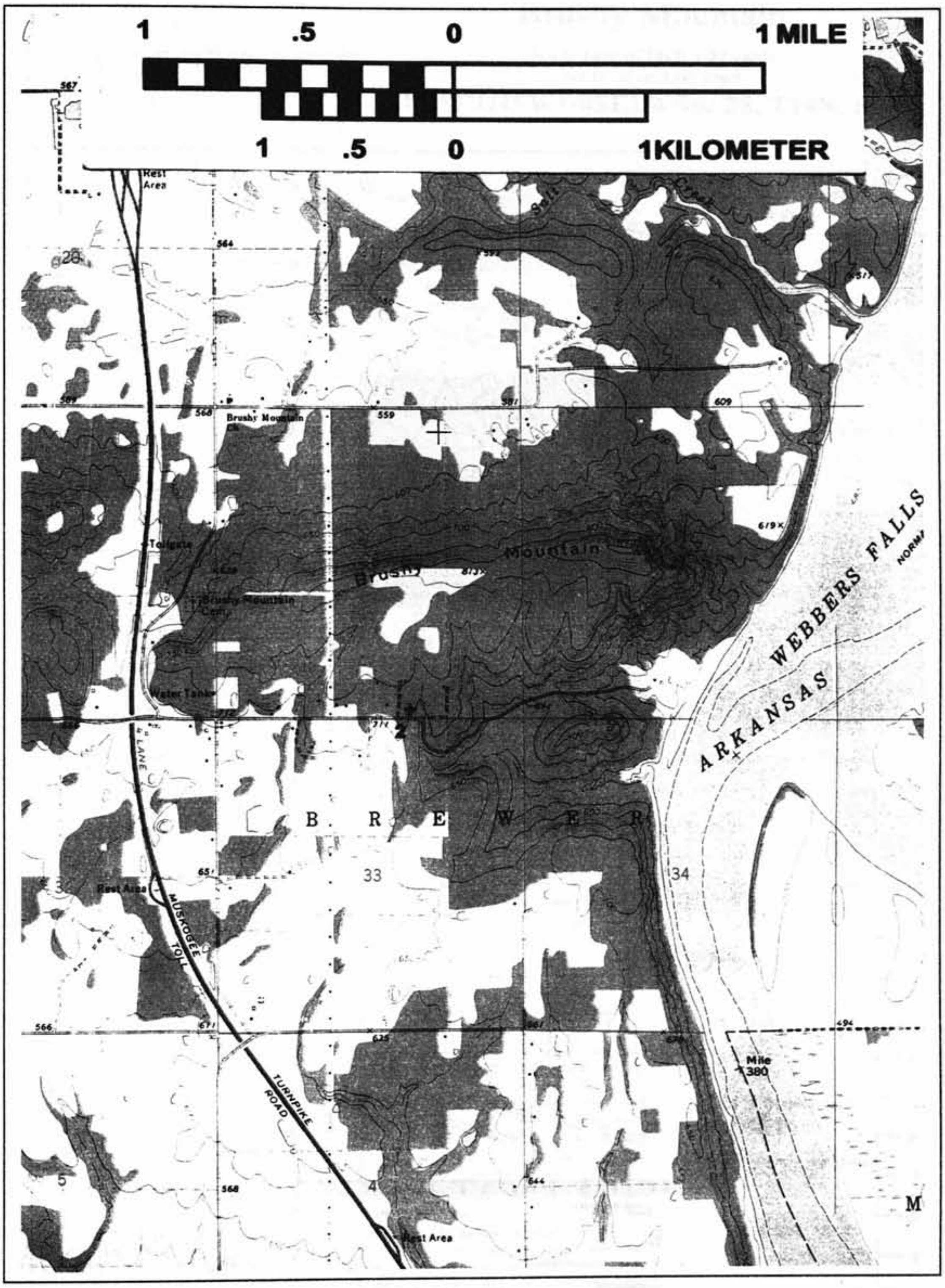


FIGURE 18. Topographic map of Locality #2, Muskogee County

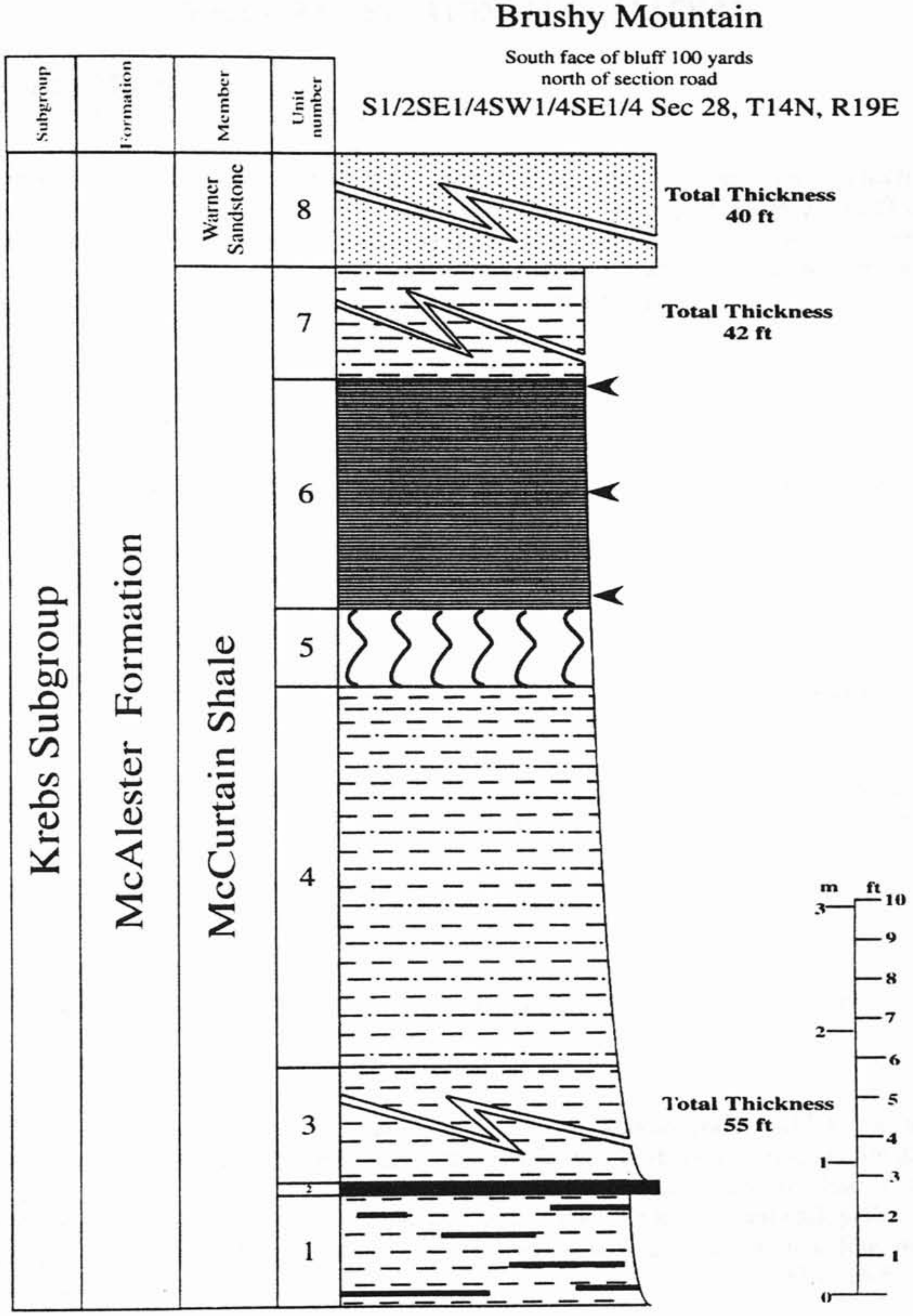


FIGURE 19. Drafted section of Locality #2, coal unit 2 is probably the Brushy Mountain coal.

MEASURED SECTION of LOCALITY #2

Brushy Mountain

S1/2SE1/4SW1/4SE1/4 Sec 28, T14N, R19E

Exposed along south face of bluff approximately 100 yards (90 meters) north of section road in the southeast part of Brushy Mountain. Most of the exposures on this bluff are very poor and mainly covered with vegetation, soil, and talus. Only two units were exposed well enough to be sampled and described: a black shale below the Warner and a ferruginous shale above what may be the Brushy Mountain coal.

CHEROKEE GROUP
KREBS SUBGROUP

McALESTER FORMATION: Thickness in feet (meters)

8. Warner Sandstone; buff; fine grained to medium grained; hematitic; obscured by trees and other vegetation; forms bluff on top of mountain 40.0 (12)

McCurtain Shale Member:

7. Shale; dark gray (N3) to medium gray (N5); clayey to silty; too poorly exposed to properly describe or sample 42.0 (13)

6. Black shale; grayish black (N2) weathers to medium dark gray (N4) and dark gray (N3); blocky; some shale surfaces exhibit moderate brown (5YR 4/4) iron crusting; phosphate nodules; fractured conodonts have been found in this unit, mostly *Idiognathodus*, *Idioprioniodus*, and *Neognathodus*, some complete *Idiognathodus* platforms have been identified however, also foraminifera, mainly *Ammodiscus* 6.0 (1.8)

5. Underclay; medium gray (N5); silty; fossil log present 2.0 (0.6)

4. Shale; gray; clayey to silty; mostly covered 10.0 (3.0)

3. Clay shale; ferruginous; dark gray (N3) weathers to grayish orange (10YR 7/4) and dark yellowish orange (10YR 6/6); large iron nodules within shale; iron nodules are dark gray (N3) with flecks of grayish black (N2) and dark yellowish orange mottling (10YR 6/6) weathers to grayish orange (10YR 7/4), pale brown (5YR 5/2), and dark yellowish orange (10YR 6/6); blocky; heavily weathered; mostly covered with a few poor exposures 55.0 (16.5)

2. Unnamed coal 0.25 (0.08)

1. Shale; mottled yellow and light gray; carbonaceous		3.0 (0.90)
	TOTAL:	158.2 (47.5)

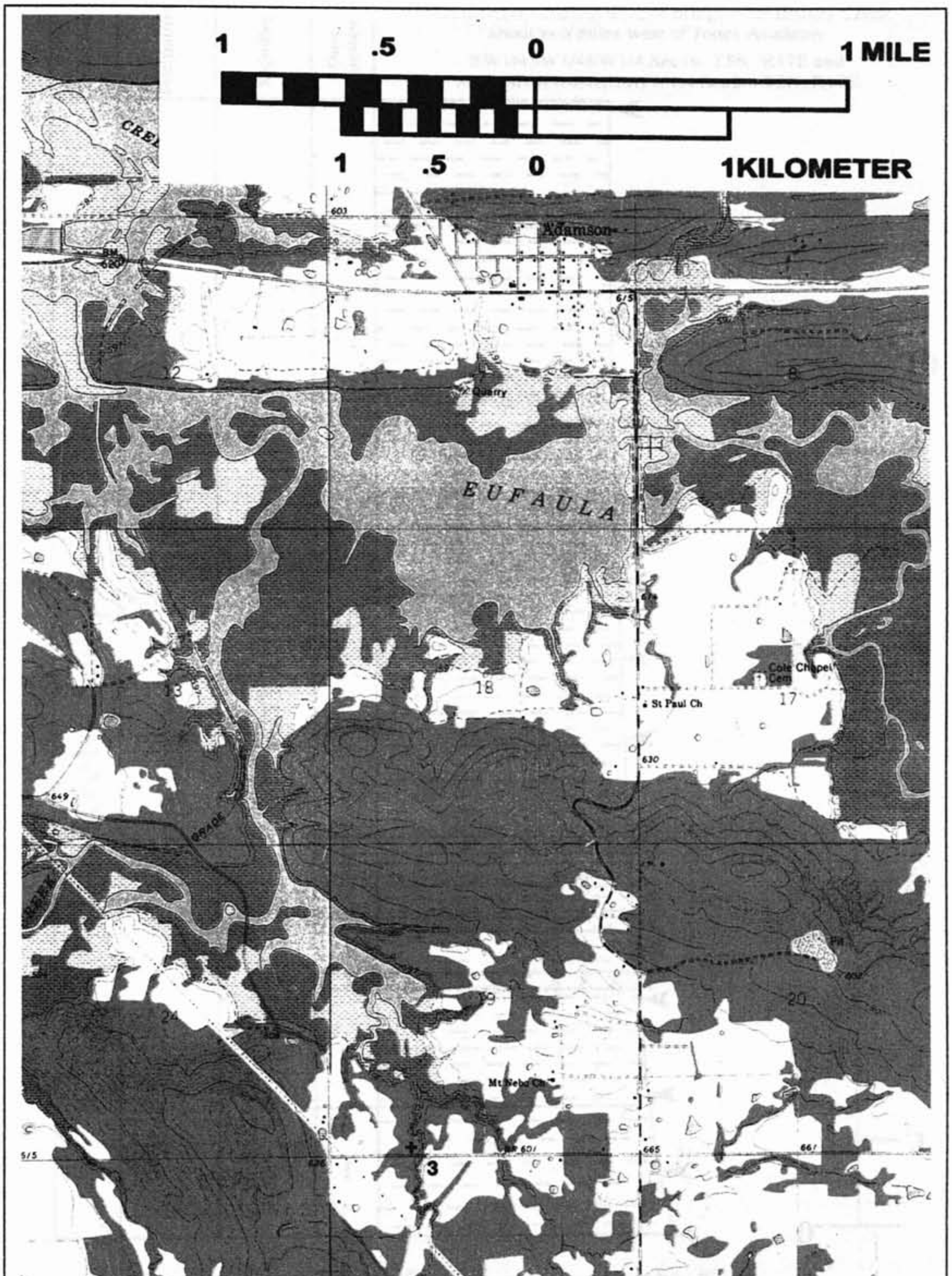


FIGURE 20. Topographic map of Locality #3, Pittsburg County, Oklahoma

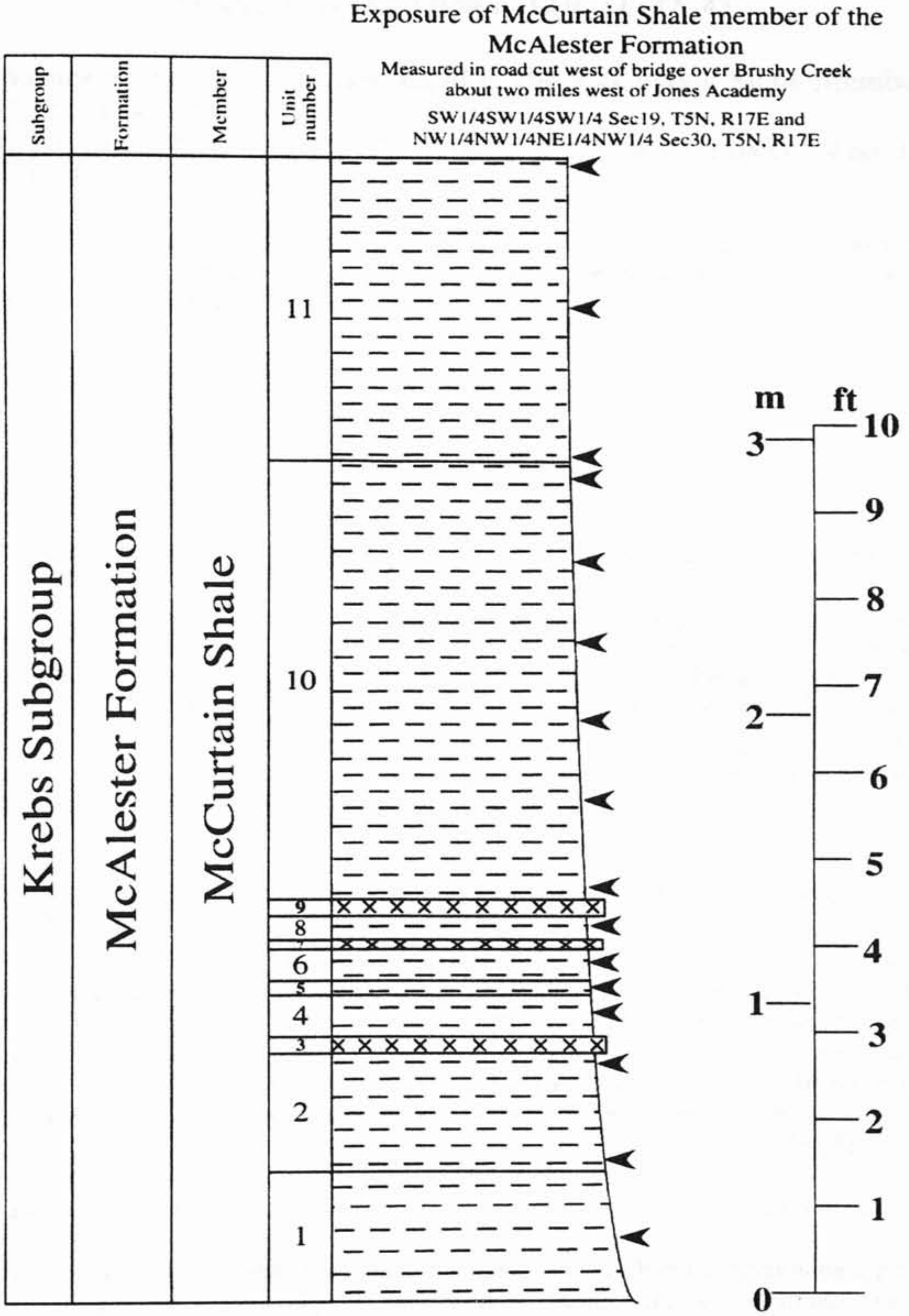


FIGURE 21. Drafted section of Locality #3

MEASURED SECTION of LOCALITY #3

Exposure of the Upper Marine Band of the McCurtain Shale Member of the McAlester Formation

SW1/4SW1/4SE1/4SW1/4 Sec 19, T5N, R17E and NW1/4NW1/4NE1/4NW1/4 Sec 30, T5N, R17E

Measured in roadcut west of bridge over Brushy Creek about two miles (3.2 km) west of Jones Academy in Pittsburg County, OK. Locality is approximately two miles (3.2 km) north of Haileyville, OK.

CHEROKEE GROUP
KREBS SUBGROUP

McALESTER FORMATION:

McCurtain Shale Member: Thickness in feet (meters)

11. Clay shale; grayish black (N2) to dark gray (N3) mottled with light brownish gray (5YR 6/1) weathers to pale yellowish brown (5YR 6/12), light brown (5YR 6/4), yellowish gray (5Y 7/2), and light brownish gray; moderate reddish brown (10R 4/6) and moderate brown (5YR 5/6) oxidation; blocky, becomes more fissile towards upper contact; silty; ferruginous; intermixed with light gray (N7) clay; pale yellowish orange (10YR 8/6) elongate inch wide clay iron nodules; limonite stringers; heavily weathered; gradational contact with underlying unit; probably weathered lower unit 3.5 (1.1)

10. Shale; grayish black (N2) mottled with grayish orange pink (5YR 7/2) weathers medium dark gray (N4), grayish orange (5Y 8/4), light brownish gray (5YR 6/1), and dark yellowish orange (10YR 6/6); moderate brown (5YR 4/4) and light brown (5YR 5/6) oxidation; yellowish gray (5Y 8/4) streaking; highly fissile, becomes blockier and clayier toward lower contact; inch thick silty ironstone stringers, dark gray (N3) with light brown (5YR 5/6) rind; ironstone nodules with redeposited calcite crystals; diagonal limonite filled joints across outcrop surface; very fossiliferous at lower contact, dark yellowish orange (10YR 6/6) gastropods, brachiopods, and pelecypods, *Ammodiscus* foraminifera in upper foot; gypsum crystals on bedding planes at lower contact
5.0 (1.5)

9. Ironstone; reddish brown; nodular 0.08 (0.02)

8. Shale; dark gray (N3) weathers to light brownish gray (5YR 6/1), medium dark gray (N4), and grayish orange (10YR 7/4); blocky; hard; slightly calcareous; very fossiliferous, *Wiedeyoceras* ammonoids, *Crurithyris* brachiopods, *Glabrocingulum* and other unidentifiable gastropods, *Nuculana* pelecypods, calcareous foraminifera, ammonoid protoconchs, and *Neognathodus*, *Idiognathodus*, and *Idioprioniodus* conodonts 0.25 (0.08)

7. Ironstone; dark gray (N3); nodular 0.08 (0.02)

6. Shale; grayish black (N2) to dark gray (N3) weathers to light brownish gray (5YR 6/1), light olive gray (5Y 6/1), and medium gray (N5); blocky; tabular gypsum crystals on bedding planes; fossiliferous, numerous dark yellowish orange (10YR 6/6) fossils, *Worthenia* and other gastropods, brachiopods, pelecypods, and *Endothyra* foraminifera 0.33 (0.10)

5. Clay; dark yellowish orange (10YR 6/6); calcareous; fossiliferous, *Idiognathodus* and *Idioprioniodus* conodont fragments, *Ammodiscus* and agglutinated foraminifera, and poorly preserved ostracods 0.08 (0.02)

4. Shale; dark gray (N3) weathers to pale yellowish brown (10YR 6/2); yellowish gray (5Y 8/4) streaks and spots; blocky; crumbly; dark yellowish orange (10YR 6/6) fossil fragments, gastropods, planoconvex spiriferid brachiopods, ostracods, *Ammodiscus* foraminifera, pelecypods, and ammonoids, possibly goniatites 0.58 (0.17)

3. Ironstone; multicolored; light olive gray (5Y 6/1) and olive gray (5Y 4/1) cores, succession of dark yellowish orange (10YR 6/6), moderate reddish brown (10R 4/2), grayish red (10R 4/2), and moderate yellowish brown (10YR 5/4) outer rind, weathers to pale yellowish brown (10YR 6/2); blocky; dense; very hard; calcareous; very micaceous; large three to five inch diameter dusky yellow (5Y 6/4) silty nodules embedded in ironstone; nodules are very well rounded; fractures filled with bluish white (5B 9/1) recrystallized calcite 0.16 (0.05)

2. Shale; dark gray (N3) weathers to medium light gray (N6) and pale yellowish brown (10YR 6/2); some grayish red purple (5RP 4/2) oxidation; blocky; silty; hard; large two inch diameter oval to suboval clay nodules (N4); numerous scattered shells, possibly pelecypod; other fossils include *Ammodiscus* and calcareous foraminifera, gastropod fragments, brachiopods, and fish debris; gradational contact with lower unit; thickness of unit varies 0.75 to 1.3 (0.23 to 0.39)

1. Shale; medium dark gray (N4) mottled with dark yellowish orange (10YR 6/6) weathers to light brownish gray (5YR 6/1); moderate reddish brown (10R 4/6) oxidation; yellowish gray (5Y 8/4) streaks; numerous very thin (0.1 inch) limonite stringers (10YR 6/6); clayey; crumbly; lower contact covered 1.5 (0.45) +

TOTAL: 12.9 (3.9)

PHOTOGRAPH 2

Photograph of Locality #3, southernmost known exposure of the post Brushy Mountain cyclothem

Maximum transgression of this cyclothem may be at the five-foot (1.5-meter) black fissile shale, a southward continuation of the black fissile phosphatic shale at Locality #2. However, this particular shale is barren of any conodonts. Below the shale, two small clay beds serve as smaller transgressive pulses not present in the northern locality.

Keefton Sequence taken from core. Taken from core designation C-MM-31, cored by Oklahoma Geological Survey and described by Leroy A. Hemish

NE1/4NE1/4NW1/4NW1/4SW1/4 Sec. 7, T11N, R20E

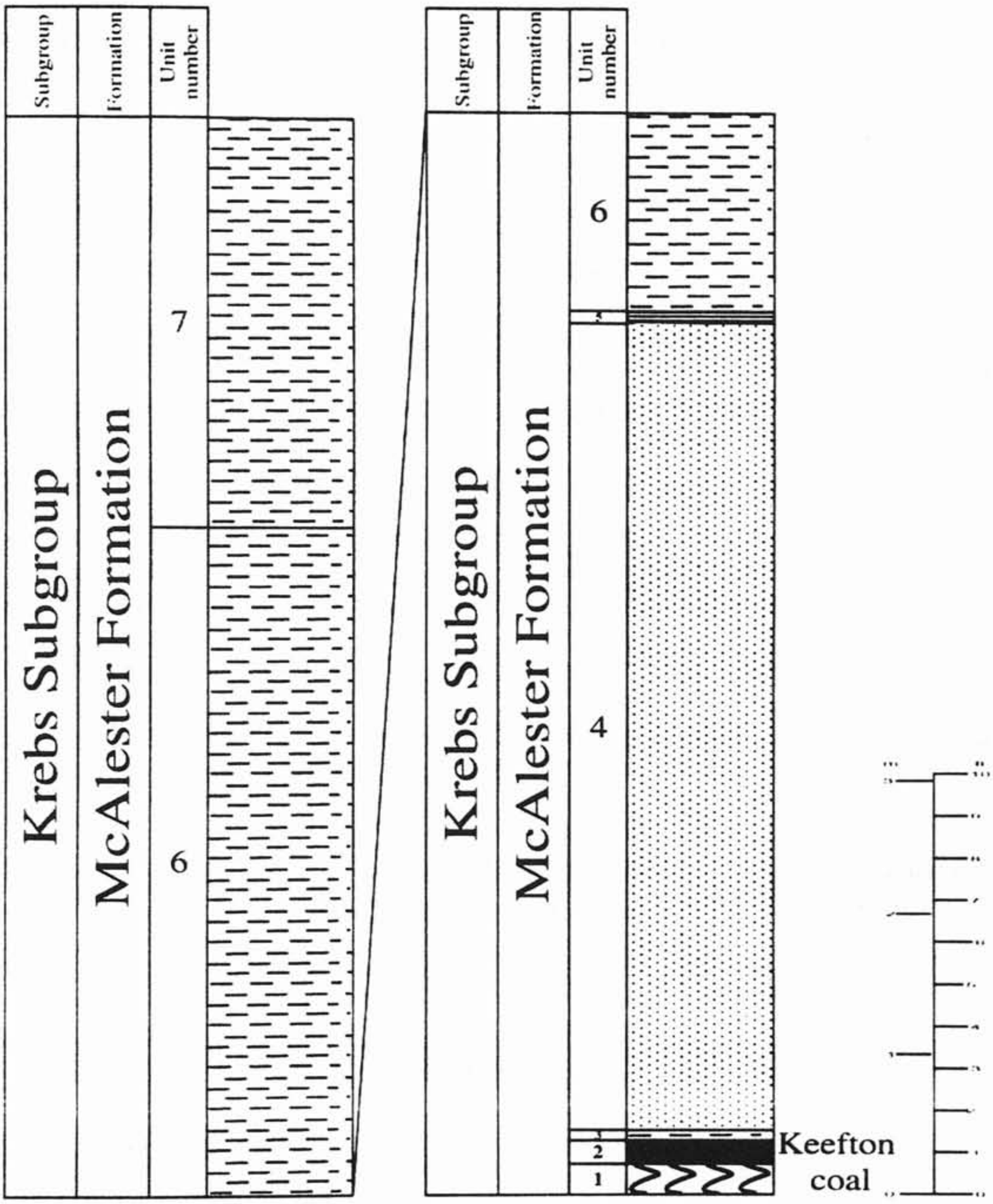


FIGURE 22. Drafted interval of a core section described by Measured Section #4

MEASURED SECTION #4

Keefton Sequence taken from Core C-MM-31.

NE1/4NE1/4NW1/4NW1/4SW1/4 Sec. 7, T11N, R20E

Based upon core description by Leroy Hemish, Hemish, L.A., 1998, *Coal geology of Muskogee County, Oklahoma*: Oklahoma Geological Survey Special Publication 98-2, pp. 79, Core-Hole Log 4.

CHEROKEE GROUP
KREBS SUBGROUP

McALESTER FORMATION:	Depth: feet (meters)	Thickness: feet (meters)
7. Shale; medium dark gray (N4) to dark gray (N3), fissile; noncalcareous; 0.1 foot thick dark reddish brown (10R 3/9) siderite concretions; calcareous fossil shell fragments; 0.25 foot calcareous shell band from 14 to 14.25 feet; numerous other 0.05 foot shell bands throughout unit; fossiliferous, spiriferid brachiopods and crinoid stems; one 0.2 foot long crinoid stem observed on a shale face	10.3 (3.1)	9.7 (2.9)
6. Shale; medium dark gray (N4); grayish orange pink (5YR 7/2) discoloration; fissile; noncalcareous; siderite concretions; olive gray (5Y 4/1) pyrite lenses; scattered brachiopod shell fragments	20.0 (6.0)	20.7 (6.21)
5. Shale; grayish black (N2) to dark gray (N3); massive; micaceous; hard; contains sparse calcareous fossil shell fragments, mostly crinoid	40.7 (12.2)	0.1 (0.03)
4. Sandstone; very light gray (N8); up to 0.1 foot thick lenses of sandstone interbedded with medium dark gray (N4) silty, micaceous shale; fine grained; 0.1 foot thick moderate brown (5YR 3/4) siderite stringers	40.8 (12.2)	19.2 (5.8)
3. Shale; black (N1); carbonaceous	60.0 (18)	0.2 (0.06)
2. Keefton coal; black (N1)	60.2 (18.1)	0.5 (0.15)
1. Underclay; dark gray (N3); plant debris	60.7 (18.2)	0.7 (0.21)
	TOTAL:	51.1 (15.3)

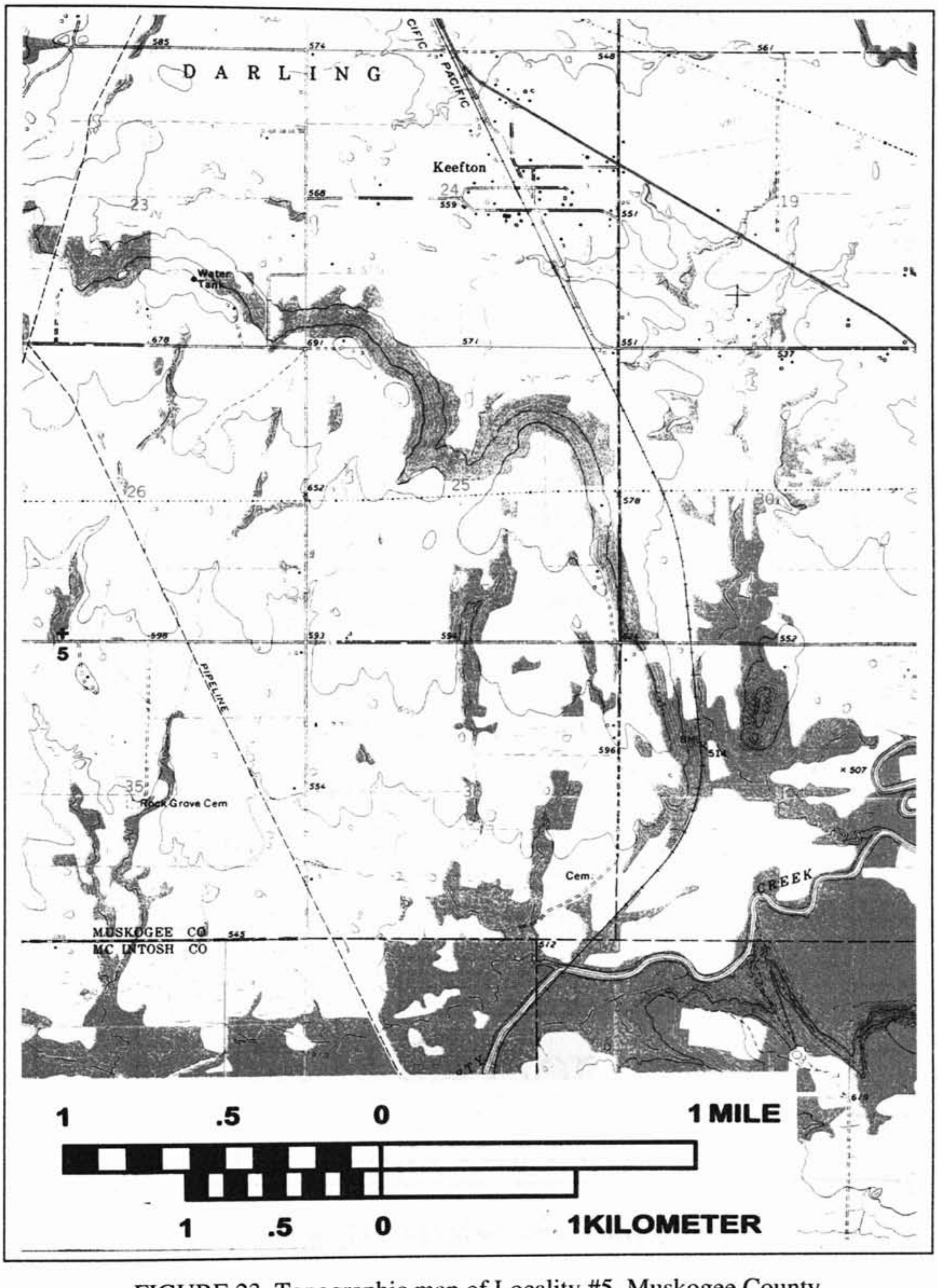


FIGURE 23. Topographic map of Locality #5, Muskogee County

Keefton Coal Locality

SE1/4SE1/4SW1/4SW1/4 Sec. 26, T13N, R18E

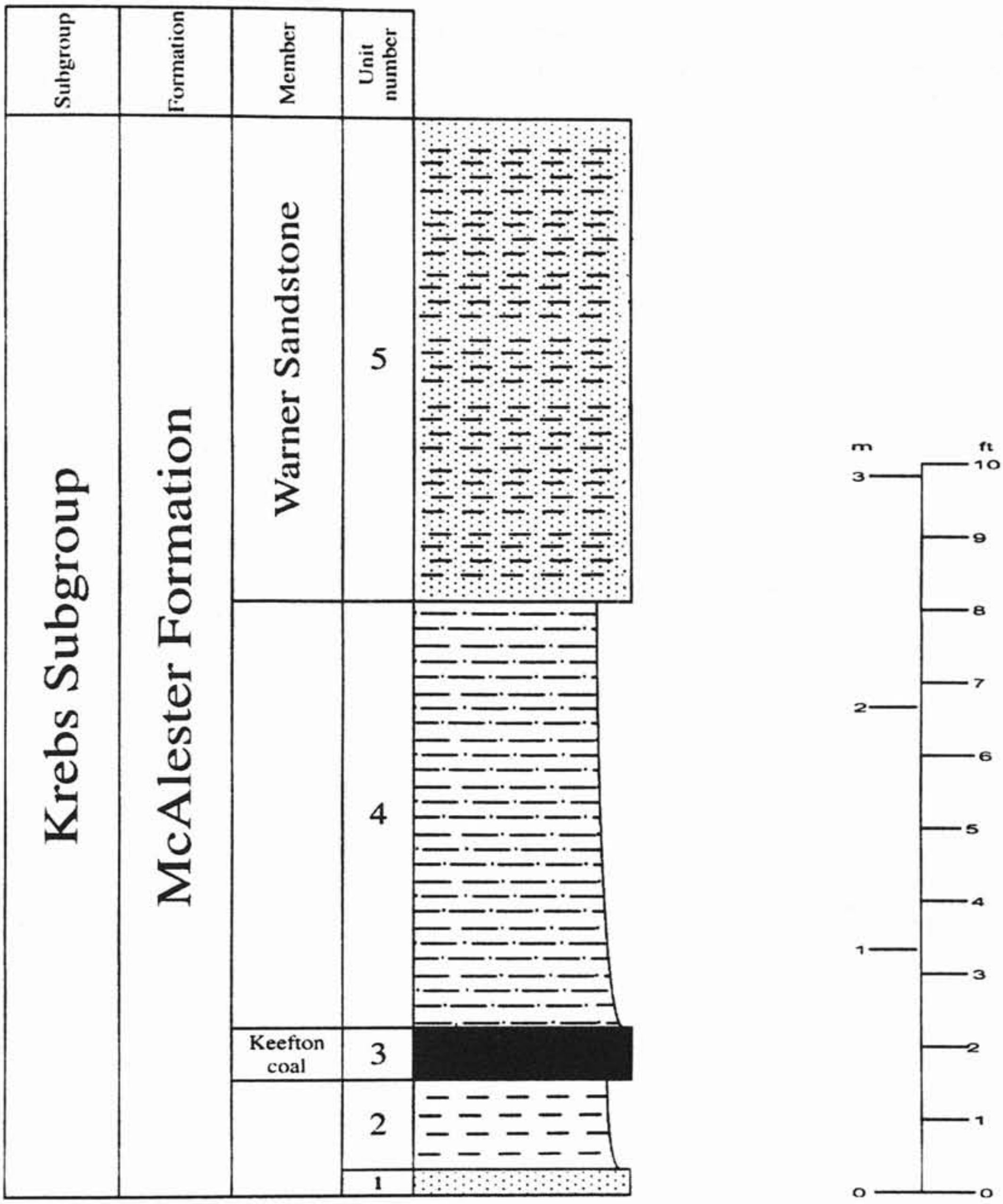


FIGURE 24. Drafted section of Locality #5

MEASURED SECTION of LOCALITY #5

Keefton coal Locality

SE1/4SE1/4SW1/4SW1/4 Sec 26, T13N, R18E

Measured along north and south road ditches along section road. Measured from bridge to top of hill. Based on Hemish, L.A., 1998, *Coal geology of Muskogee County, Oklahoma*: Oklahoma Geological Survey Special Publication 98-2, pp. 50, Measured Section 37.

CHEROKEE GROUP
KREBS SUBGROUP

McALESTER FORMATION: Thickness in feet (meters)

5. Warner Sandstone; quartz arenite; buff to tan; medium bedded; interbedded with sandy shale; medium grained; hematitic/limonitic cement; exhibits flow structures and diagonal fractures; forms kink in road 6.5 (1.95)

4. Clay shale; dark gray (N3) to brown weathers to light tan/pink; resembles underclay or soil; silty; blocky; somewhat fissile; numerous black (N1) carbonaceous spots and streaks near upper contact; soft, very carbonaceous at lower contact 5.8 (1.74)

3. Keefton coal; black (N1); cubic cleats; some oxidized streaks on cleats 0.7 (0.21)

2. Shale; purplish-red black; soft; rust streaks; becomes clayier near upper contact 1.2 (0.36)

1. Sandstone; quartz arenite; grayish-red brown; medium grained; hematite and silica cement; micaceous; hard 0.25 (0.08)

TOTAL: 14.45 (4.3)

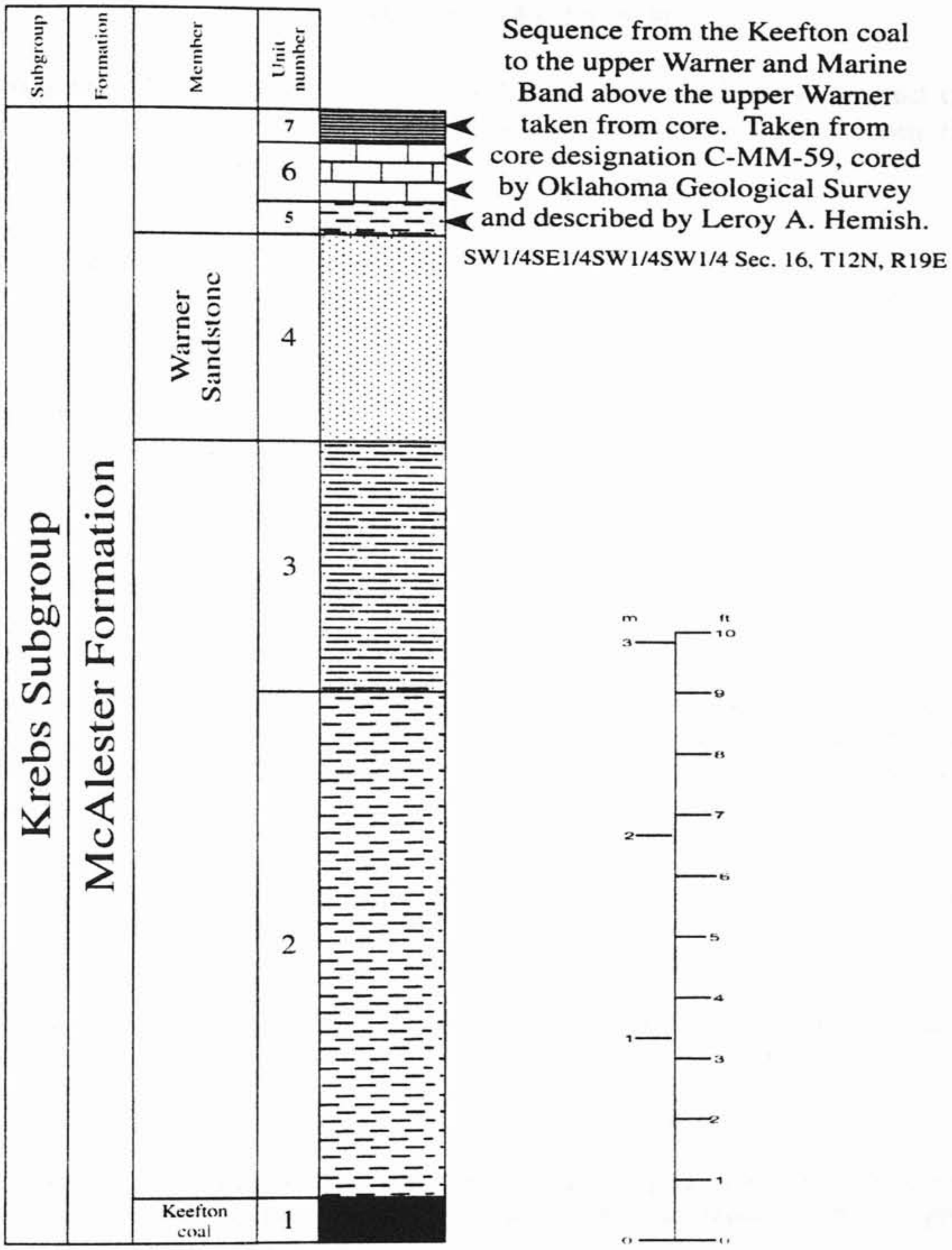


FIGURE 25. Drafted interval of a core section described in Measured Section #6, two cyclothems are present within this interval

MEASURED SECTION #6

Sequence from the Keefton to the Upper Warner Sandstone and the Marine Band above the Upper Warner Sandstone Taken from the Crawley Core (C-MM-59).
SW1/4SE1/4SW1/4SW1/4 Sec. 16, T12N, R19E

Based upon core descriptions by Leroy Hemish, Hemish, L.A., 1998, *Coal geology of Muskogee County, Oklahoma*: Oklahoma Geological Survey Special Publication 98-2, pp. 80, Core-Hole Log 5.

CHEROKEE GROUP
KREBS SUBGROUP

McALESTER FORMATION: Depth: feet (meters) Thickness: feet (meters)

7. Black shale; grayish black (N1) to dark gray (N3); contains shell hash
30.9 (9.3) 0.5 (0.15)

6. Limestone; mudstone, lower third of limestone packestone; medium dark gray (N4); micaceous; broken surface of limestone has pebbly/ sucrosic texture; calcareous concretions middle 0.3 feet of unit; shaly; fossil hash and scattered brachiopod shells; fossil hash becomes more abundant in upper 0.25 feet of limestone; microfauna includes gastropod fragments and poorly preserved ostracods; irregular shaped pyrite crystals also
31.4 (9.42) 0.9 (0.27)

5. Shale; medium dark gray (N5) to medium gray (N5); slightly micaceous; calcareous; fissile; lower 0.05 feet of unit very silty
32.3 (9.7) 0.5 (0.15)

4. Warner Sandstone (upper unit); very light gray (N8); lenses of sandstone interbedded with medium dark gray (N4) silty shale; fine grained; very slightly micaceous; slightly calcareous
32.8 (9.8) 3.2 (0.96)

3. Shale; medium dark gray (N4); silty; large mica flakes; grayish red (10R 4/2) 0.05 to 0.1 foot siderite stringers/concretions; numerous bands of interbedded very light gray (N8) sandstone and pale brown (5YR 5/2) shale
36.0 (10.8) 3.9 (1.2)

2. Shale; medium dark gray (N4); grayish red (10R 4/2) 0.2 foot siderite concretions
39.9 (12) 7.9 (2.4)

1. Keefton coal; black (N1)		
	47.8 (14.3)	0.7 (0.21)
	TOTAL:	17.6 (5.3)

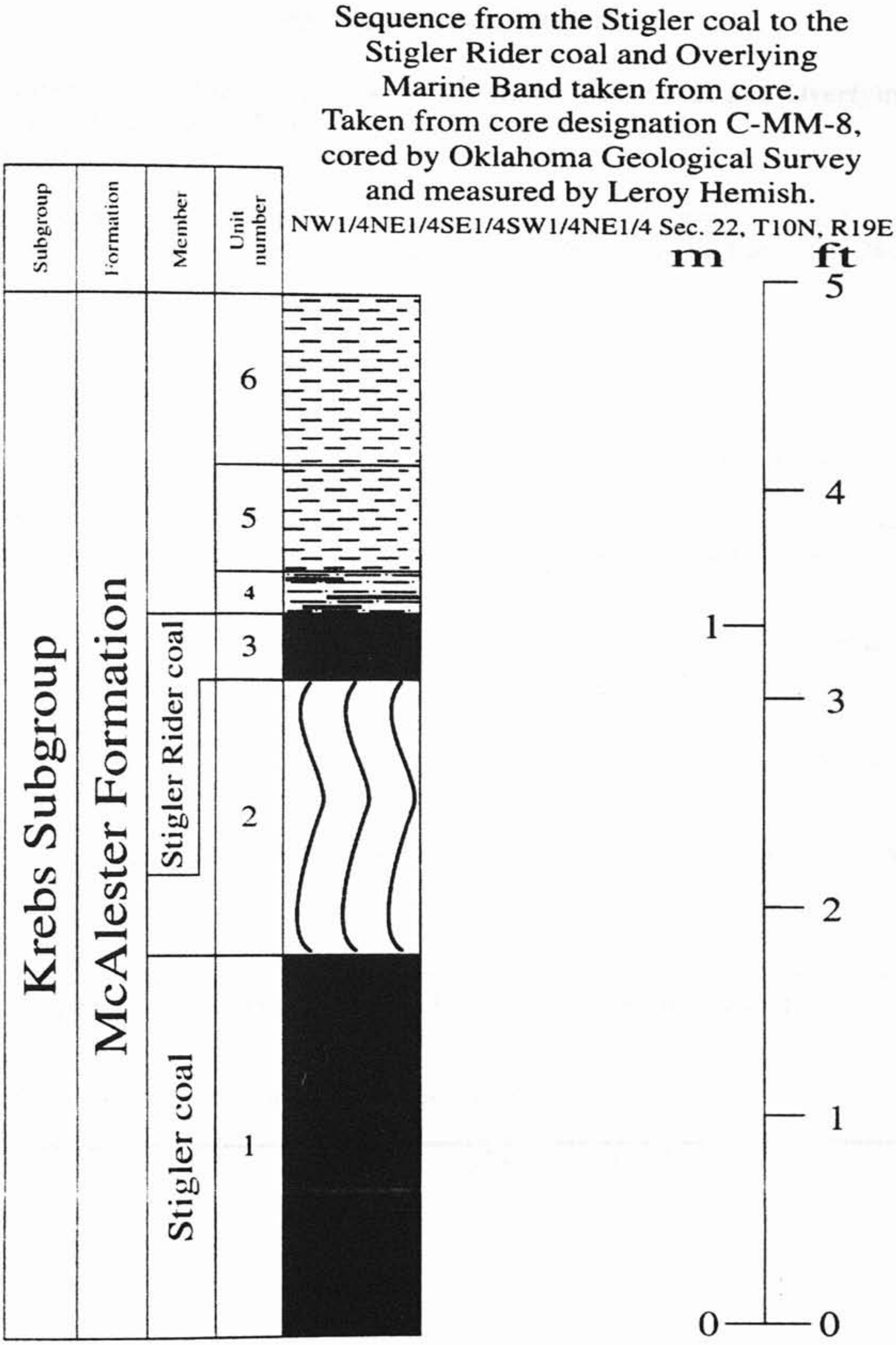


FIGURE 26. Drafted interval of a core section described by Measured Section #7

MEASURED SECTION #7

Sequence from the Stigler coal to the Stigler Rider coal and Overlying Marine Band Taken from the Brinkley Core (C-MM-8).
NW1/4NE1/4SE1/4SW1/4NE1/4 Sec. 22, T10N, R19E

Based upon core descriptions by Leroy Hemish, Hemish, L.A., 1998, *Coal geology of Muskogee County, Oklahoma*: Oklahoma Geological Survey Special Publication 98-2, pp. 79, Core-Hole Log 3.

CHEROKEE GROUP
KREBS SUBGROUP

McALESTER FORMATION:	Depth: feet (meters)	Thickness: feet (meters)
6. Shale; dark gray (N3); possibly fissile; siderite concretions; sparse brachiopods, pelecypods, bryozoan fragments, and poorly preserved ostracods (probably *Bairdia*)	270.0 (81.0)	0.8 (0.24)
5. Shale; dark gray (N3); fissile; calcareous; intense fossil hash; microfauna dominated by poorly preserved ostracods	270.8 (81.2)	0.5 (0.15)
4. Shale; dark gray (N3); grayish yellow (5Y 8/4) streaking; fissile; silty; carbonaceous	271.3 (81.4)	0.2 (0.06)
3. Stigler Rider coal; black (N1); finely cleated; friable; soft, degraded; yellowish gray (5Y 8/1) spots	271.5 (81.5)	0.3 (0.09)
2. Underclay; dark gray (N3) to medium dark gray (N4); shaly; silty; hard; plastic; glossy surface; thin coal streaks in lower 0.3 feet of unit; scattered bark-like plant impressions	271.8 (81.54)	1.3 (0.4)
1. Stigler coal; black (N1); finely cleated; glassy surface	273.1 (81.9)	1.8 (0.5)
	TOTAL:	16.6 (5.0)

Marine Band above the Stigler taken from core.
Taken from core designation C-RM-1, cored by
Oklahoma Geological Survey and described
by Leroy A. Hemish.

SE1/4SE1/4SW1/4NW1/4 Sec. 18, T21N, R18E

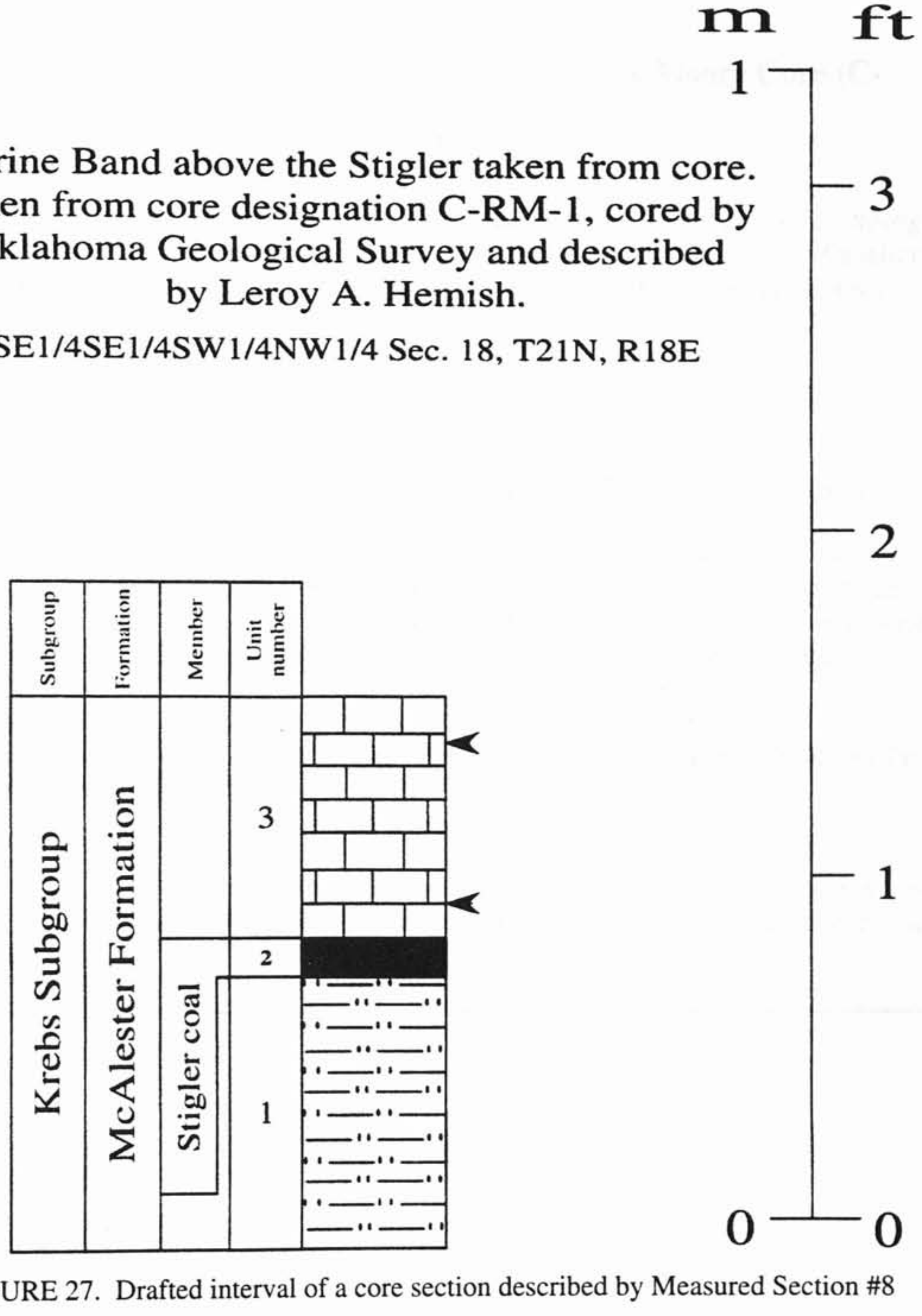


FIGURE 27. Drafted interval of a core section described by Measured Section #8

MEASURED SECTION #8

Marine Band above the Stigler coal Taken from the Moore Core (C-RM-1).

SE1/4SE1/4SW1/4NW1/4 Sec. 18, T21N, R18E

Based upon core descriptions by Leroy Hemish, Hemish, L.A., 1997b, *Lithologic descriptions of Pennsylvanian strata north and east of Tulsa, Oklahoma*: Oklahoma Geological Survey Special Publication 97-2, pp 42, Core-Hole Log 7, Mayes County.

CHEROKEE GROUP
KREBS SUBGROUP

McALESTER FORMATION:	Depth: feet (meters)	Thickness: feet (meters)
3. Limestone; mudstone to wackestone, at some intervals, limestone almost becomes a grainstone; grayish black (N2) to dark gray (N3); somewhat shaly; numerous moderate brown (5YR 4/4) ironstone stringers from 316.8-317.3; extensive fossil hash; fossiliferous, brachiopods, bryozoans, crinoids, and ostracods (probably *Bairdia*)	316.8 (95)	0.7 (0.21)
2. Stigler coal; black (N1); soft, degraded; glassy surface; wood impressions on surface; calcite filled fractures	317.5 (95.2)	0.1 (0.03)
1. Siltstone; medium dark gray (N4) to medium gray (N5); thick-bedded to massive; micaceous; hard; noncalcareous; possible leaf impressions on surface; gradational contact with underlying unit	317.6 (95.3)	0.8 (0.24)
	TOTAL:	1.6 (0.48)

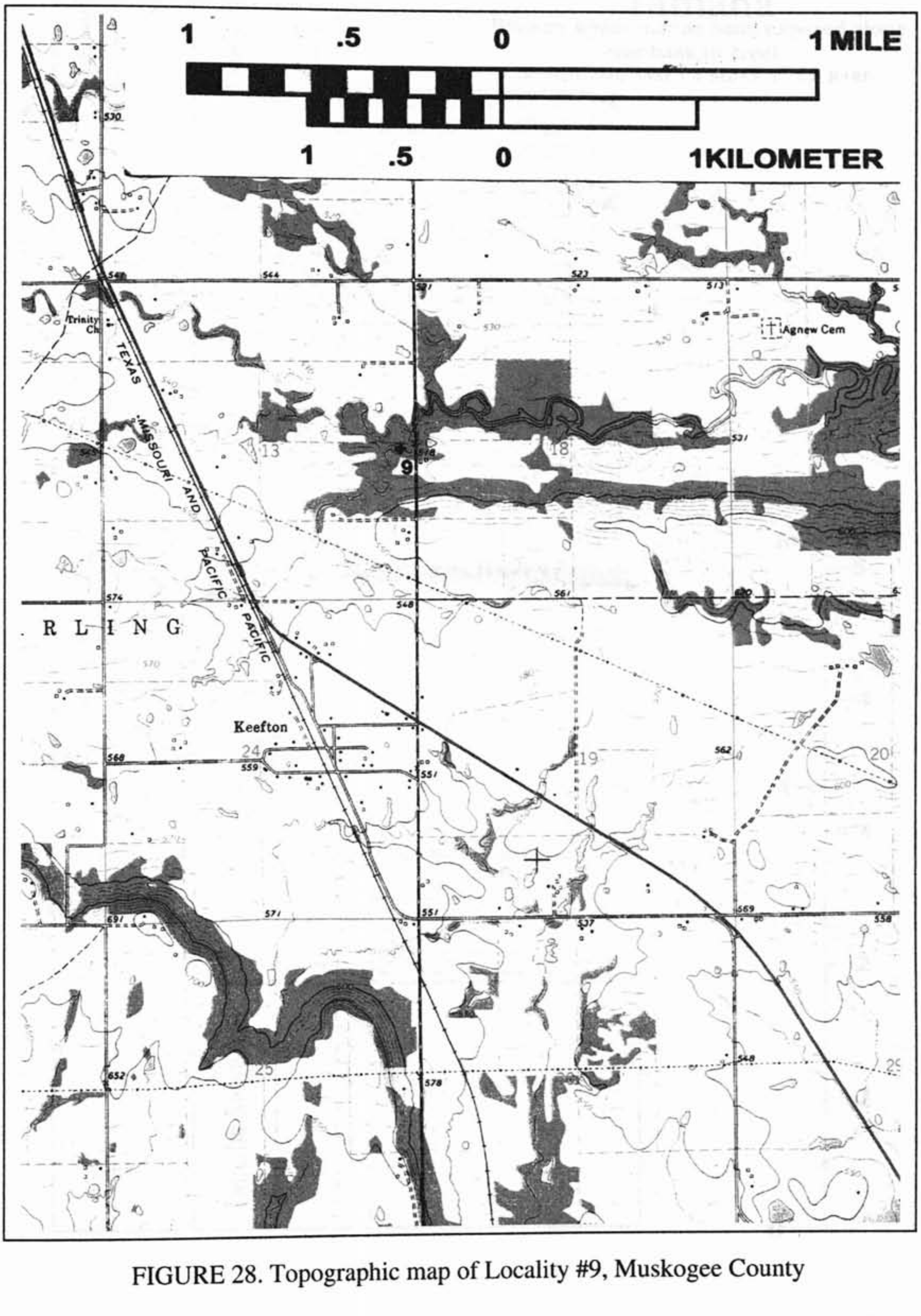


FIGURE 28. Topographic map of Locality #9, Muskogee County

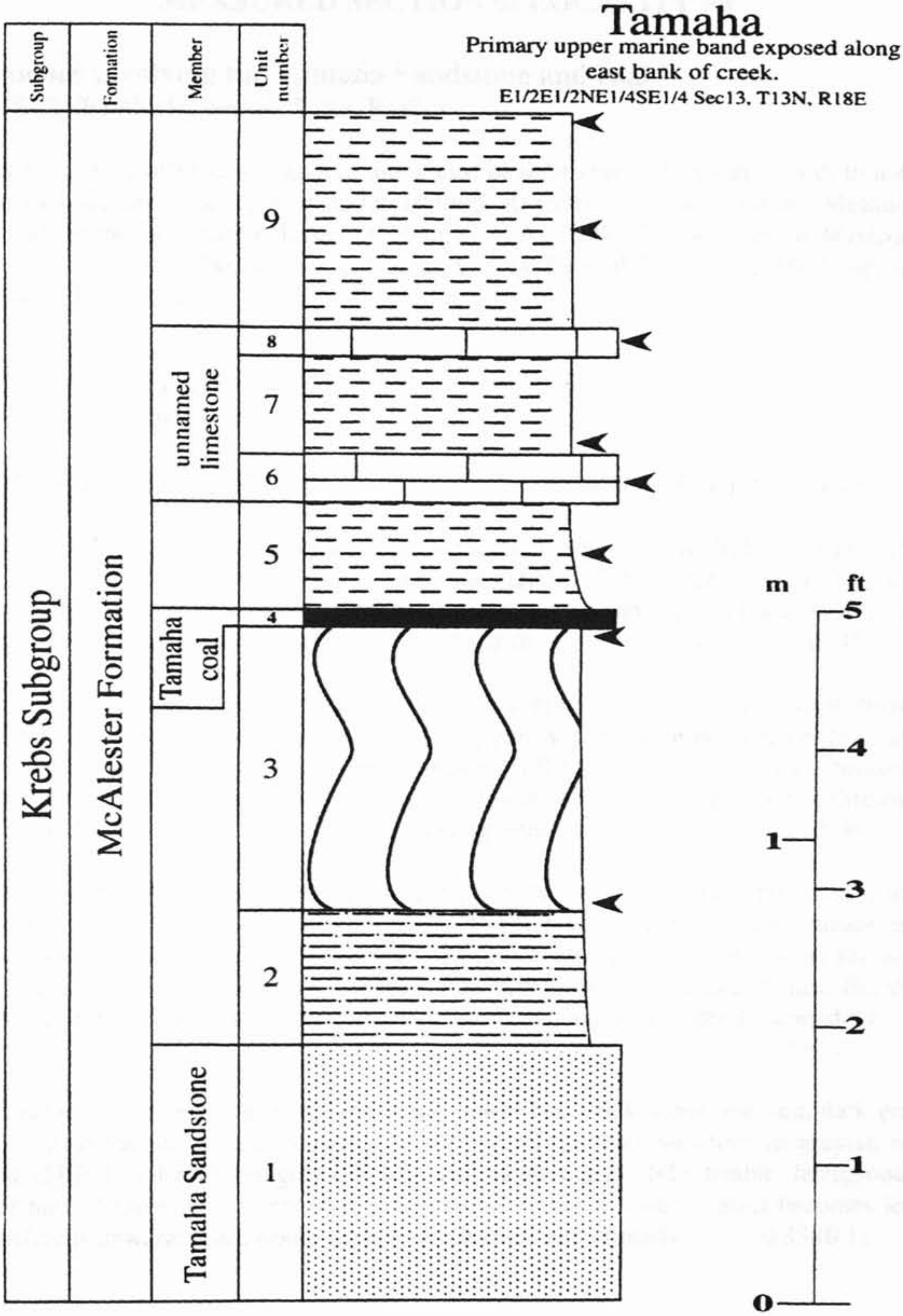


FIGURE 29. Drafted section of Locality #9

MEASURED SECTION of LOCALITY #9

Sequence involving the Tamaha Sandstone and coal

E1/2E1/2NE1/4SE1/4 Sec 13, T13N, R18E

Primary upper marine band exposed along east bank of creek. Measured south to north from siltstone above water level to top of bluff 30 yards (27 meters) north. Measured along streambed and banks. Based on Hemish, L.A., 1998, *Coal geology of Muskogee County, Oklahoma*: Oklahoma Geological Survey Special Publication 98-2, pp. 48, Measured Section 32

CHEROKEE GROUP
KREBS SUBGROUP

McALESTER FORMATION: Thickness in feet (meters)

9. Shale; medium dark gray (N4) weathers to medium gray (N5) and light olive gray (5Y 6/1); very dusky red purple (5RP 2/2) oxidation staining; 2 to 3 inch diameter clay iron nodules with light olive gray cores and medium dark gray rind; silty; micaceous; blocky; some beds swaly; breaks up into sharp angular shards 1.5 (0.45)

8. Unnamed limestone; wackestone; medium dark gray (N4) with dark reddish brown (10R 3/4) rind weathers to medium gray (N5), pale yellowish brown (10YR 6/2), and dusky yellow (5Y 6/4); dark yellowish orange (10YR 6/6) oxidation surfaces; massive; hard; dense; nodular exposure; extremely ferruginous; noncalcareous; very fossiliferous, brachiopods, gastropods, fenestrate bryozoan fragments, and crinoids 0.2 (0.06)

7. Shale; dark gray (N3) weathers to light gray (N7), medium light gray (N6), and medium gray (N5); dark yellowish orange (10YR 6/6) mottling; fissile; micaceous; calcareous; very fossiliferous, wide variety of fauna, crinoid columnals, cups, and arm fragments, *Mesolobus* and other strophomenid brachiopods, echinoid spines, *Bairdia* ostracods, *Endothyra* foraminifera, bryozoan fragments, and *Idiognathodus* conodonts 0.7 (0.21)

6. Unnamed limestone; upper part mudstone; lower part wackestone; medium dark gray (N4) with moderate reddish brown (10R 4/6) filled fractures weathers to grayish red purple (5RP 4/2), light olive gray (5Y 6/1), and medium gray (N5); friable; ferruginous; lower half of limestone is very shaly; very fossiliferous at lower contact becomes less fossiliferous upward; brachiopods (mostly productids) and crinoids 0.33 (0.1)

5. Calcareous shale; medium light gray (N6) with pinkish gray (5YR 8/1) and dark gray (N3) flecks weathers to light olive gray (5Y 6/1) and yellowish gray (5Y 7/2); mixed in with a pale yellowish brown (10YR 6/2) and dark yellowish brown orange (10YR 6/6) soil-like clay; blocky; micaceous; very fossiliferous, productid brachiopods, fenestrate bryozoan fragments, ramose bryozoans, echinoid spines, and *Bairdia* ostracods; gradational contact with overlying Tamaha; possibly weathered limestone 0.6 (0.18)

4. Tamaha coal; black (N1); thin-bedded; cubic cleats; weathered 0.1 (0.03)

3. Underclay; medium light gray (N5) mottled with dark yellowish orange (10YR 6/6) weathers to light gray (N6); plastic; slightly carbonaceous; gradational contact with underlying shale 1.0 (0.3)

2. Shale; dusky yellow (5Y 6/4) with dark yellowish orange (10YR 6/6) mottling weathers to yellowish gray (5Y 7/2); moderate brown (5YR 4/4) oxidation surfaces; blocky; silty; gradational contact with overlying underclay 1.0 (0.3)

1. Tamaha Sandstone; medium light gray (N6) to light greenish gray (5GY 8/1); thin-bedded to shaly; well exposed along stream bank 3.7 (1.1)

TOTAL: 9.13 (2.7)

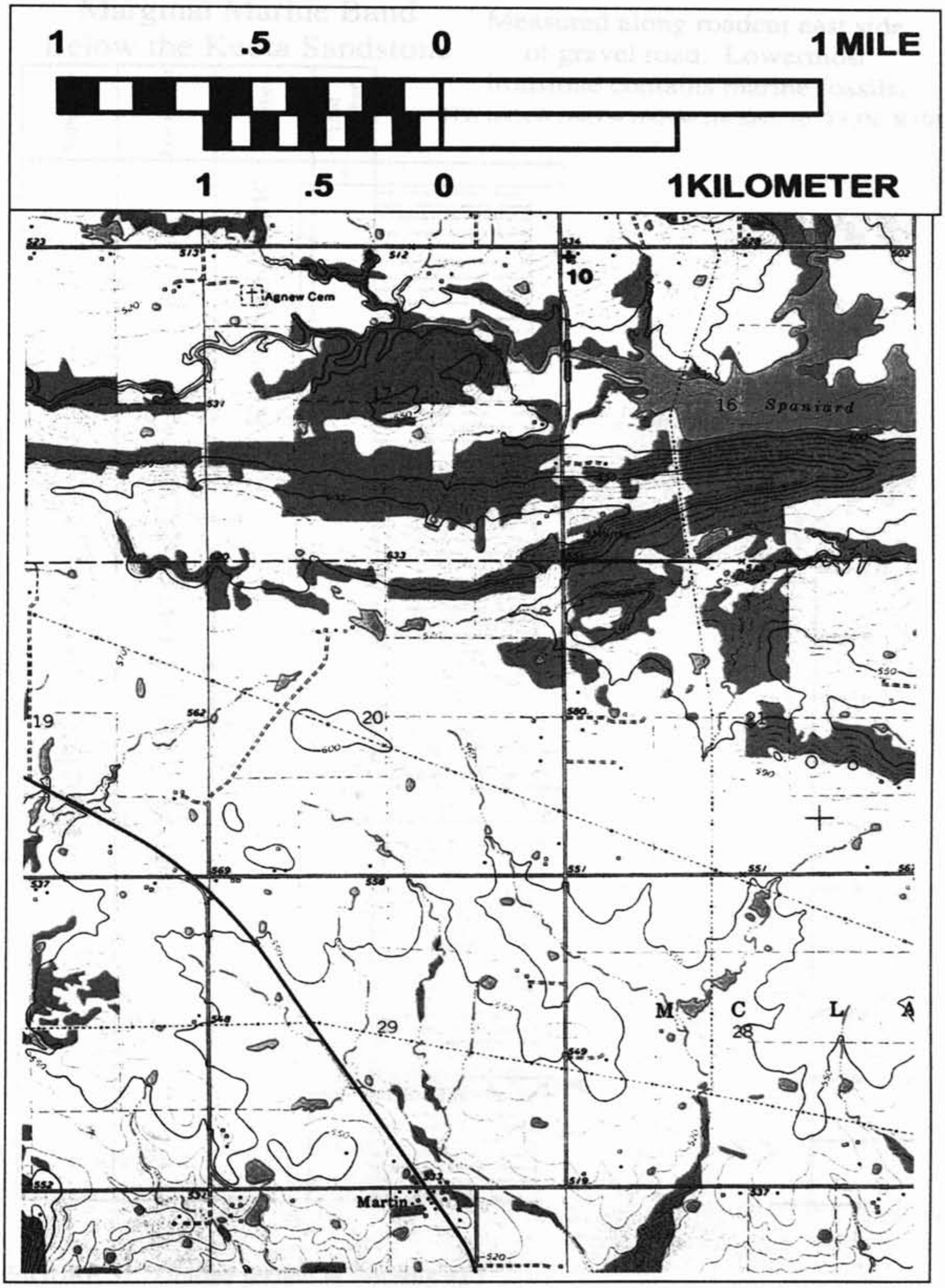


FIGURE 30. Topographic map of Locality #10, Muskogee County

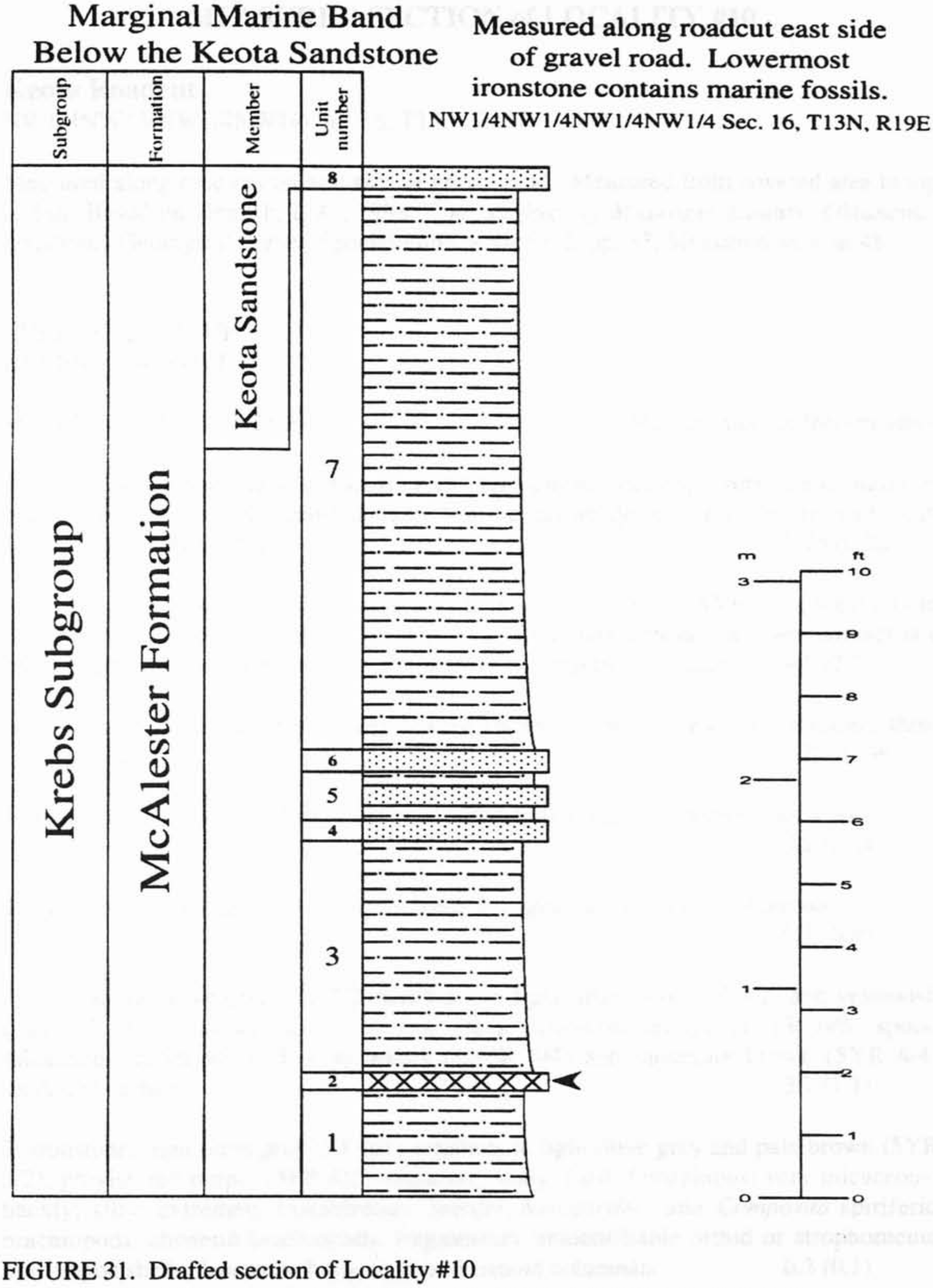


FIGURE 31. Drafted section of Locality #10
The lowest fossiliferous unit may either be ironstone or ferruginous limestone.

MEASURED SECTION of LOCALITY #10

Keota Roadcut

NW1/4NW1/4NW1/4NW1/4 Sec 16, T13N, R19E

Measured along road cut on east side of gravel road. Measured from covered area to top of hill. Based on Hemish, L.A., 1998, *Coal geology of Muskogee County, Oklahoma*: Oklahoma Geological Survey Special Publication 98-2, pp. 53, Measured Section 48

CHEROKEE GROUP
KREBS SUBGROUP

McALESTER FORMATION: Measurement in feet (meters)

8. Keota Sandstone; dark brownish gray; ferruginous staining; very hard; massive; micaceous; fine grained; ripple marks; trough cross-bedding; forms kink in road; only lowermost unit measured 0.25 (0.08)

7. Shale; olive gray (5Y 4/1) weathers to grayish orange pink (5YR 7/2); weathers to flakes; some ironstone stringers; blocky; silty; about five feet above lower contact is a rubbly purplish black ferruginous zone; heavily covered by vegetation 9.0 (2.7)

6. Sandstone; dark gray brown with orange staining; fine grained; wavy-bedded; thin-bedded to shaly 0.25 (0.08)

5. Shale; grayish brown; silty; very fissile; interbedded with thin-bedded sandstones 0.8 (0.24)

4. Sandstone; chocolate brown; thin-bedded; ferruginous; fine grained; burrows 0.1 (0.03)

3. Clay shale; olive gray (5Y 3/2) weathers to light olive gray (5Y 5/2) and yellowish gray (5Y 7/2); blocky; silty; massive; dark yellowish orange (10YR 6/6) spots; micaceous; moderate yellowish brown (10YR 5/4) and moderate brown (5YR 4/4) oxidation surfaces 3.7 (1.1)

2. Ironstone; light olive gray (5Y 6/1) weathers to light olive gray and pale brown (5YR 5/2); grayish red purple (5RP 4/2) oxidation; shaly; hard; ferruginous; very micaceous; hackly; silty; extremely fossiliferous, *Spirifer*, *Neospirifer*, and *Composita* spiriferid brachiopods, chonetid brachiopods, fragmentary unidentifiable orthid or strophomenid brachiopod shells, fenestrate bryozoans, and crinoid columnals 0.3 (0.1)

1. Shale; light brownish gray (5YR 6/1); blocky; very silty; oxidized surfaces; lower contact of unit not present 1.7 (0.51)

TOTAL: 16.1 (4.8)

Sequence with the Spaniard Limestone taken from core. Taken from core designation C-RM-1, cored by Oklahoma Geological Survey, described by Leroy Hemish.

SE1/4SE1/4SW1/4NW1/4 Sec. 18, T21N, R18E

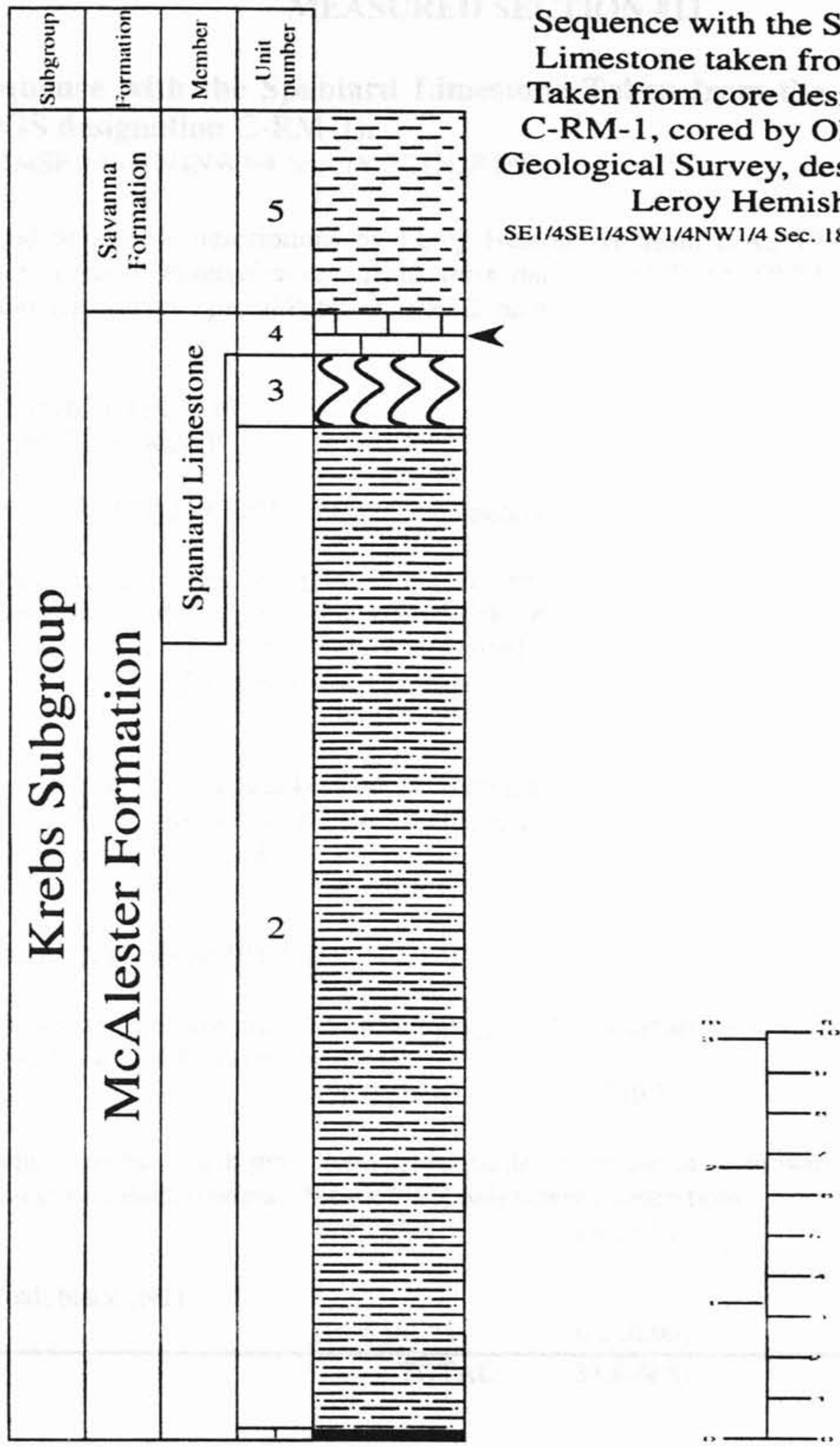


FIGURE 32. Drafted interval of core section described by Measured Section #11, Measured Section #11 describes the lowest cyclothem within the Savanna Formation.

MEASURED SECTION #11

Sequence with the Spaniard Limestone Taken from the Moore Core (OGS designation C-RM-1).

SE1/4SE1/4SW1/4NW1/4 Sec. 18, T21N, R18E

Based upon core descriptions by Leroy Hemish, Hemish, L.A., 1997b, *Lithologic descriptions of Pennsylvanian strata north and east of Tulsa, Oklahoma*: Oklahoma Geological Survey Special Publication 97-2, pp 40, Core-Hole Log 7, Mayes County.

CHEROKEE GROUP
KREBS SUBGROUP

SAVANNA FORMATION: Depth: feet (meters) Thickness: feet (meters)

5. Shale; medium dark gray (N4) to medium gray (N5); fissile; micaceous; inch diameter iron nodules; nodules have light brown (5YR 5/6) cores and moderate brown (5YR 4/4) rinds; 0.05 foot band of heavily degraded whitish calcareous brachiopod shells approximately 0.3 feet above lower contact

172.2 (51.7) 4.8 (1.4)

4. Spaniard Limestone; wackestone; medium gray (N5); shaly; siderite concretions; silty; fossiliferous, numerous brachiopod shells; microfauna includes brachiopod spines and poorly preserved ostracods

177.0 (53.1) 1.0 (0.3)

McALESTER FORMATION:

3. Underclay; medium gray (N5) with light gray (N7) weathering; shaly; silty; hard; dark reddish brown (10R 3/4) rust staining

178.0 (53.4) 1.7 (0.51)

2. Shale; medium dark gray (N4); silty; fissile; moderate olive brown (5Y 4/4) pyrite staining; foot thick moderate brown (5YR 3/4) siderite concretions

179.7 (54) 24.1 (7.2)

1. Coal; black (N1)

203.8 (61.1) 0.2 (0.06)

TOTAL: 31.8 (9.5)

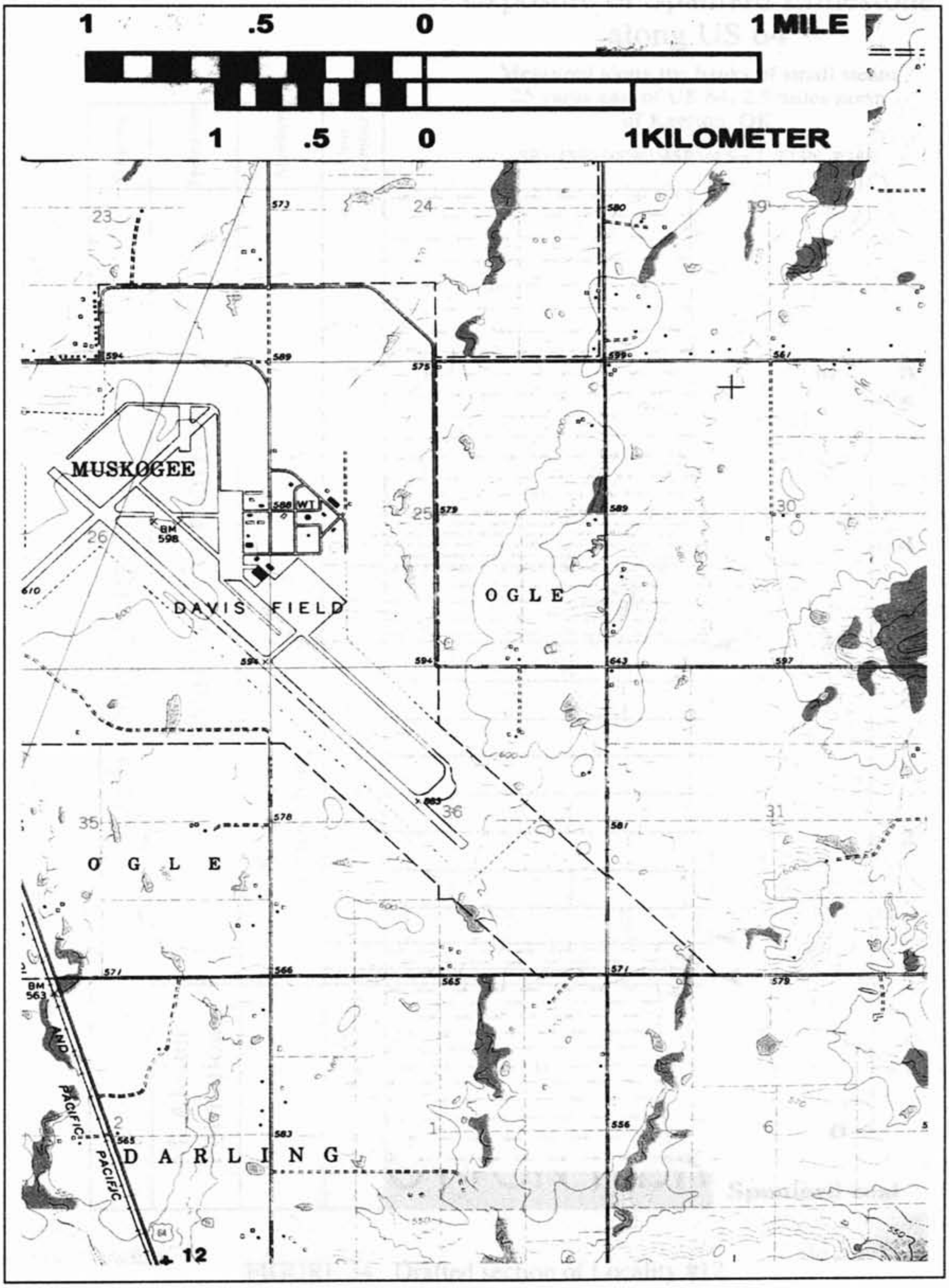


FIGURE 33. Topographic map of Locality #12, Muskogee County, this is the same cycle described in Measured Section #11.

Exposure of Spaniard Limestone along US 64

Measured along the banks of small steam 25 yards east of US 64, 2.5 miles north of Keefton, OK

SE1/4SE1/4SW1/4SE1/4 Sec2, T13N, R18E

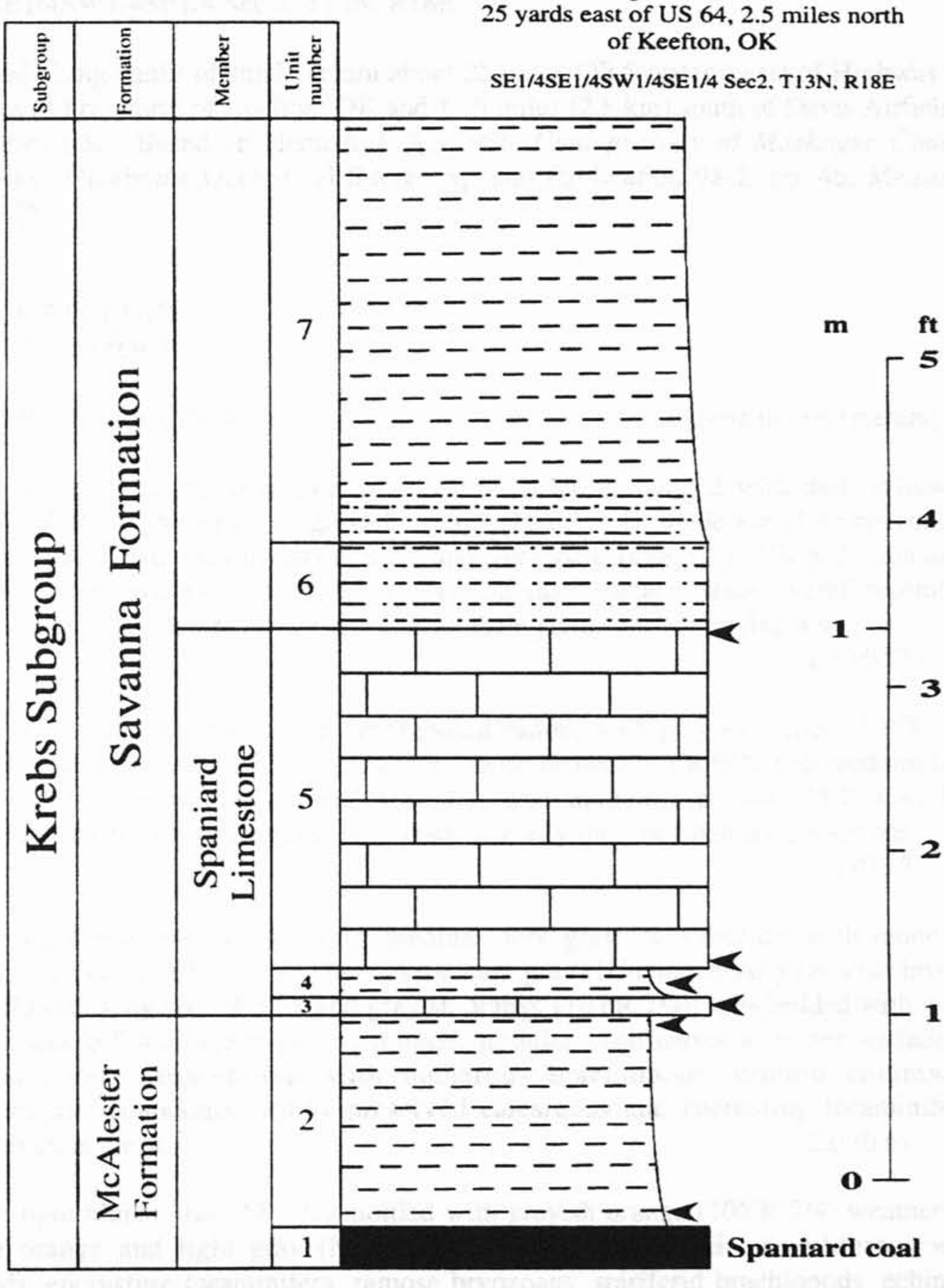


FIGURE 34. Drafted section of Locality #12

MEASURED SECTION of LOCALITY #12

Contact between the McAlester and Savanna Formations

SE1/4SE1/4SW1/4SE1/4 Sec 2, T13N, R18E

Measured along banks of small stream about 25 yards (22.5 meters) east of Highway 64, 2.5 miles (4 km) north of Keefton, OK and 1.75 miles (2.8 km) south of Davis Airfield in Muskogee, OK. Based on Hemish, L.A., 1998, *Coal geology of Muskogee County, Oklahoma*: Oklahoma Geological Survey Special Publication 98-2, pp. 46, Measured Section 26.

CHEROKEE GROUP
KREBS SUBGROUP

SAVANNA FORMATION: Thickness in feet (meters)

7. Clay shale; light greenish gray (5GY 8/1) mottled or banded with dark yellowish orange (10YR 6/6) weathers to grayish orange (10YR 7/4), moderate olive brown (5Y 4/4), pale yellowish brown (10YR 6/2), and very pale orange (10YR 8/2); massive; crumbly; micaceous; gypsum crystals present on shale surface; shale overall resembles underclay; becomes darker brown upwards as shale grades into overlying soil 2.5 (0.75)

6. Siltstone; light olive brown (5Y 5/6) mottled/banded with grayish orange (10YR 7/4) weathers to yellowish gray (5Y 7/2), pale yellowish brown (10YR 6/2), and medium light gray (N6); numerous grayish red (10R 4/2) and moderate brown (5YR 4/4) leaf impressions; extremely micaceous; may grade laterally into the Spaniard Limestone 0.5 (0.15)

5. Spaniard Limestone; wackestone; medium dark gray (N4) mottled with moderate yellowish brown (10YR 5/4) weathers to medium gray (N5), moderate yellowish brown, dark yellowish gray (10YR 6/6), and grayish orange (10YR 7/4); thin-bedded with wavy beds; breaks off into sharp flakes; jointed; nodular protrusions at upper surface of limestone; very fossiliferous with numerous brachiopods, crinoid columnals, *Idiognathodus* conodonts, poorly preserved calcareous and encrusting foraminifera; forms bench in creek 2.0 (0.6)

4. Clay; light bluish gray (5B 7/1) mottled with grayish orange (10YR 7/4) weathers to grayish orange and light gray (N7); calcareous; slightly fissile; fossiliferous with ostracods, encrusting foraminifera, ramose bryozoans, spiriferid brachiopods, echinoid spines, and holothurian sclerites 0.17 (0.05)

3. Spaniard Limestone; mudstone; medium dark gray (N4) with a dark yellowish orange rind (10YR 6/6) weathers to dark yellowish orange; thin; shaly; *Idiognathodus*

conodonts, poorly preserved calcareous and encrusting foraminifera, and crinoid columnals 0.083 (0.02)

McALESTER FORMATION:

2. Clay shale; dusky yellow (5Y 6/4) weathers to very pale orange (10YR 8/2); massive; blocky; slightly micaceous; silty; calcareous; soft; becomes rustier near upper contact; fossiliferous, ramose bryozoans, echinoid spines, *Endothyra* and calcareous foraminifera (possibly *Cornuspira*), and crinoid columnals; mostly covered by stream water and alluvium 1.3 (0.39)

1. Spaniard coal; black (N1); soft; weathered 0.3 (0.09)

TOTAL: 6.9 (2.1)

FIGURE 35. Topographic map of Locality #13, Wagoner County, Oklahoma

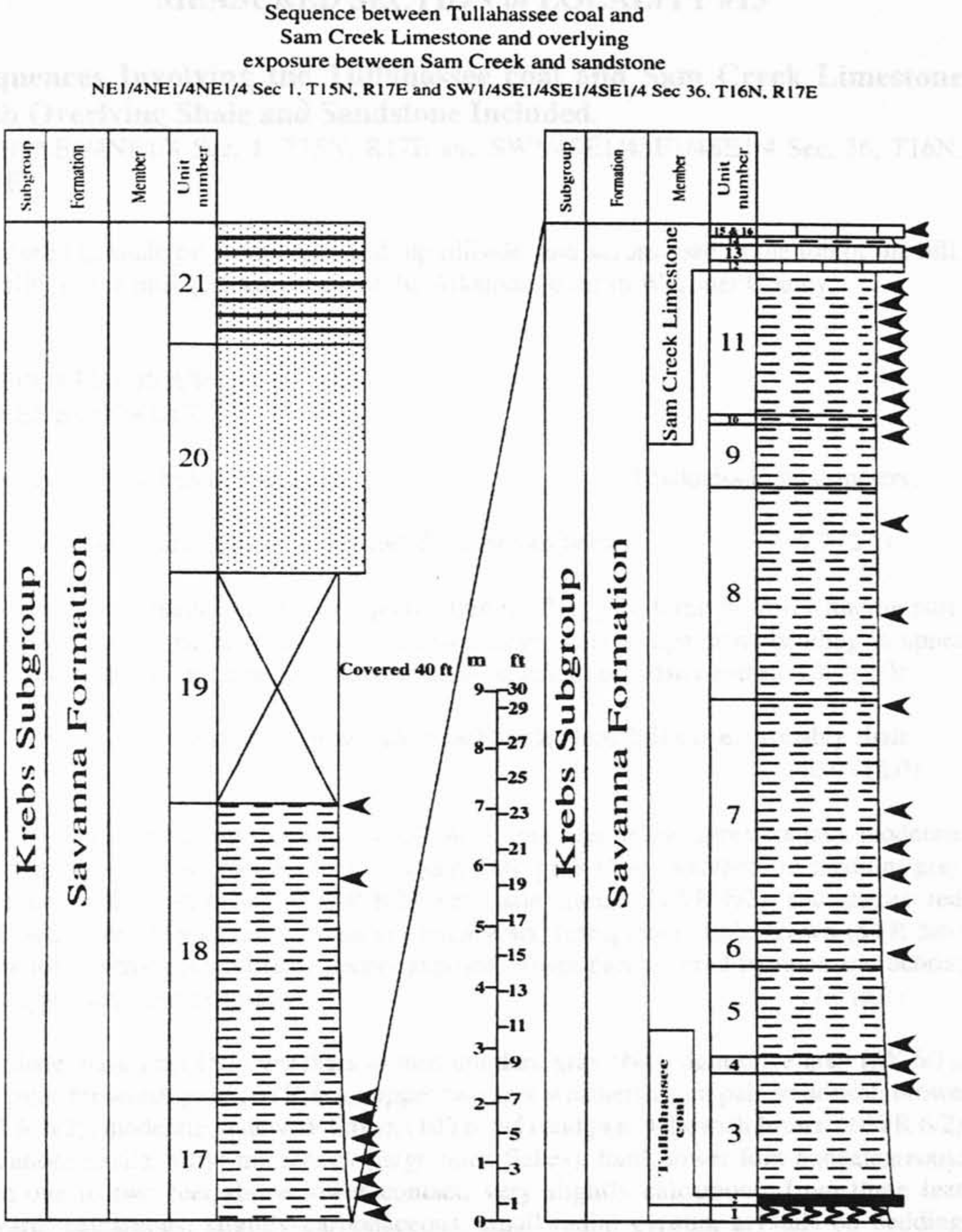


FIGURE 36. Drafted section of Locality #13, two cyclothems (post Tullahassee and Sam Creek) are present at this locality; a possible third (Doneley cyclothem) may be present from the top of unit 18 to the top of unit 21.

MEASURED SECTION of LOCALITY #13

Sequences Involving the Tullahassee coal and Sam Creek Limestone with Overlying Shale and Sandstone Included.
NE1/4NE1/4NE1/4 Sec. 1, T15N, R17E and SW1/4SE1/4SE1/4SE1/4 Sec. 36, T16N, R17E

Measured in shale pit from creek bed, up hillside, and across road to the top of the hill. Locality is one mile (1.6 km) north of the Arkansas River in Wagoner County.

CHEROKEE GROUP
KREBS SUBGROUP

SAVANNA FORMATION: Thickness in feet (meters)

21. Sandstone; quartz arenite; thin-bedded; numerous beds 6.9 (2.1)

20. Sandstone; channel sandstone; quartz arenite; flaggy bedding in lower middle part; massive bedding rest of sandstone; numerous large scale trough cross-bedding in upper part; heavily fractured; large blocks form talus on hill slope; base covered 13.4 (4.0)

19. Covered; exposed spots of brown and black shale along hill slope; probably shale 40.0 (12.0)

18. Clay shale; upper part, olive gray (5Y 4/1), four feet below upper contact, moderate olive brown (5Y 4/4) banded with medium dark gray (N4); weathers to medium gray (N5), pale yellowish brown (10YR 6/2), very pale orange (10YR 6/2), and grayish red (10R 4/2); very blocky; silty; massive; micaceous; ferruginous; light brown (5YR 5/6) oxidation; forms steep hillside; poorly exposed; lower part covered by talus and debris; only upper four feet exposed 17.0 (5.1)

17. Shale; dark gray (N3) weathers to medium dark gray (N4), light olive gray (5Y 6/1), and light brownish gray (5YR 6/1); upper two feet weathers more pale yellowish brown (10YR 6/2); moderate yellowish brown (10YR 5/4) and pale yellowish brown (10YR 6/2) oxidation; fissile; silty; micaceous (large mica flakes); hard; lower foot noncalcareous; from one to two feet above lower contact, very slightly calcareous; from three feet upward, calcareous; slightly carbonaceous; small radial gypsum crystals on bedding planes in upper three feet of unit; upper contact thicker bedded; sparse light brownish gray (5YR 6/1) plant stem fragments at upper contact 7.0 (2.1)

16. Siltstone; moderate yellowish brown (10YR 5/4) with dark gray (N3) banding, banding is sometimes cross-bedded forming lenses of moderate yellowish brown; weathers to pale yellowish brown (10YR 6/2) and grayish orange (10YR 7/4); thin-bedded; micaceous; ferruginous; hard; fine grains of angular quartz; lenses of medium gray (N5) calcareous siltstone; rest of siltstone noncalcareous; calcareous lenses found at top of unit; fossiliferous, degraded fish teeth 0.08 (0.02)

15. Sam Creek Limestone (upper bed); wackestone; medium dark gray (N4) with a very silty dark yellowish orange (10YR 6/6) rind weathers to pale yellowish brown (10YR 6/2); grayish red purple oxidation; hard; massive; dense; micaceous; silty; impure; fine angular quartz grains; siliciclastic stratification within limestone; very calcareous; fossiliferous, scattered brachiopod shells and *Idiognathodus* conodonts; lenticular appearance in outcrop; thickness varies 0.6 (0.18)

14. Clay shale; medium dark gray (N4) weathers to light olive gray (5Y 6/1) and light brownish gray (5YR 6/1); blocky; somewhat fissile; silty; dark yellowish orange (10YR 6/6) and grayish red (10R 4/2) oxidation; noncalcareous; fossiliferous with calcareous brachiopods (probably suborder Atrypidina) and pelecypods 0.5 (0.15)

13. Sam Creek Limestone (lower bed); packestone; dark gray (N3) with a ferruginous, silty moderate yellowish brown (10YR 5/4) rind; rind weathers to moderate red (5R 5/4); limestone weathers to pale yellowish orange (10YR 8/6) and brownish gray (5YR 4/1); grayish red (10R 4/2) oxidation; massive; hard; dense; very micaceous; silty; impure; fine angular quartz grains; very calcareous; lower part of limestone has numerous medium dark gray (N4) round intraclasts; intraclasts are up to half inch in diameter; very fossiliferous, brachiopods, numerous, mainly *Idiognathodus* conodonts, gastropod fragments, pelecypod fragments, fish teeth and debris, and ostracods 0.7 (0.21)

12. Limestone; packestone; dark gray (N3) and brownish gray (5YR 4/1) weathers to pale yellowish brown (10YR 6/2) and olive gray (5Y 3/2); thin; hard; micaceous; silty; ferruginous; noncalcareous; dark reddish brown (10R 3/4) oxidation; fossiliferous, numerous poorly preserved dark yellowish orange (10YR 6/6) brachiopods, ostracods, pelecypods, gastropods, and crinoids 0.04 (0.012)

11. Clay shale; dark gray (N3) weathers to medium gray (N5), light olive gray (5Y 6/1), medium dark gray (N4), and pale yellowish brown (10YR 6/2); moderate yellowish brown (10YR 5/4) oxidation; silty; blocky; breaks up into shards; up to two inch diameter flattened oval clay nodules (N5); lower three feet of unit, thin to medium bedded; upper five feet of unit, medium to thick bedded; micaceous with large mica flakes; lower two feet, noncalcareous; from two feet upward becomes increasingly calcareous; middle part of shale not as oxidized as upper and lower parts; sparingly fossiliferous, a possible crushed spiriferid brachiopod three feet above lower contact; microfauna consists mainly of poorly preserved ostracods 8.0 (2.4)

10. Shale; dark gray (N3) weathers to medium dark gray (N4) and light olive gray (5Y 6/1); grayish red (10R 4/2) oxidation; medium bedded; soft; calcareous; silty; micaceous; very slightly ferruginous; breaks up into large blocks 0.25 (0.075)

9. Shale; dark gray (N3) interbedded with moderate yellowish brown (10YR 5/4) weathers to medium dark gray (N4), pale yellowish brown (10YR 6/2), and brownish gray (5YR 4/1); numerous half-inch oval to circular moderate yellowish brown iron nodules in bedding planes; light brown (5Y 5/6) and grayish red (10R 4/2) oxidation; thick-bedded; blocky; hard; hackly surface; micaceous with large mica flakes; iridescent blue play of colors on some shale surface; very ferruginous; iron crusts; large three inch diameter flattened clay nodules; breaks off into thin shards 1.7 (0.51)

8. Shale; dark gray (N3) weathers to medium dark gray (N4) and pale yellowish brown (10YR 6/2); moderate yellowish brown (10YR 5/4) and light brown (5YR 5/6) oxidation; thick-bedded; very blocky; hard; micaceous; silty; iron concretions; unit becomes increasingly more nodular with moderate brown (5YR 4/4) iron cores and more oxidized with pale red (10R 6/2) oxidation towards upper contact 10.0 (3.0)

7. Calcareous shale; dark gray (N3) weathers to dark gray and pale yellowish brown (10YR 6/2); fissile to thin-bedded; silty; micaceous; hard; dark yellowish orange (10YR 6/6) and light brown (5YR 5/6) oxidation; at upper contact, 0.75 foot dark yellowish brown (10YR 4/2) subcircular iron concretions; quarter inch thick dark gray silty clay iron stringers 10.0 (3.0)

6. Clay shale; medium dark gray (N4) weathers to medium dark gray, pale yellowish brown (10YR 6/2), grayish orange (10YR 7/4), and brownish gray (5YR 4/1); dark reddish brown (10R 3/4) oxidation; medium-bedded; very blocky; hard; ferruginous; breaks up into large cubic blocks; silty; micaceous 2.0 (0.6)

5. Clay shale; dark gray (N3) and olive black (5Y 2/1) weathers to medium gray (N5) mottled with moderate yellowish brown (10YR 5/4); dark yellowish orange (10YR 6/6) and light brown (5YR 5/6) oxidation; blocky; thick-bedded; silty; micaceous; soft; slightly ferruginous; upper part of unit more heavily oxidized; quarter inch thick silty, shaly, clay cubic iron stringers; sparsely fossiliferous, small unidentifiable fossil shell fragments, gastropods, and carbonaceous plant fragments 5.0 (1.5)

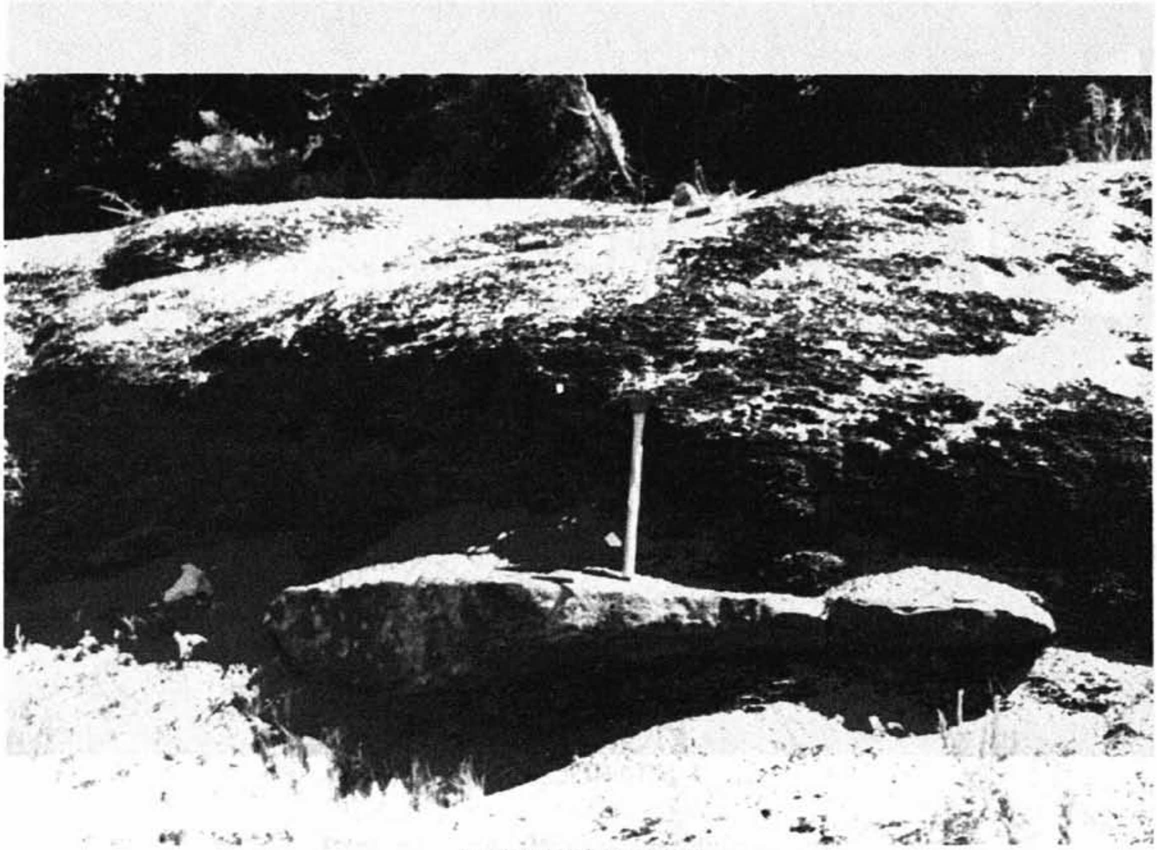
4. Shale; dark gray (N3) and olive gray (5Y 2/4) weathers to brownish gray (5YR 4/1), dark gray, and olive gray; very soft, degraded; moist; fissile; silty; slightly micaceous; quarter inch thick moderate yellowish brown (10YR 5/4) irregular shaped iron stringers; dark yellowish orange (10YR 6/6) heavily weathered, poorly preserved, and broken shell fragments, primarily gastropod and brachiopod 1.0 (0.3)

3. Shale; dark gray (N3) weathers to dark gray, olive gray (5Y 4/1), and pale yellowish brown (10YR 6/2); very fissile; silty; heavily micaceous; dark yellowish orange (10YR 6/6) oxidized flakes on bedding planes; soft; noncalcareous; inch thick thick-bedded olive gray clay stringers; heavily weathered and broken up inarticulate brachiopod shells (possibly *Lingula*); lower contact covered by soil and shale pit debris 6.9 (2.1)

2. Tullahassee coal; black (N1); light brown (5YR 5/6) and dark yellowish orange (10YR 6/6) oxidation weathers to dark yellowish brown (10YR 4/2) and grayish black (N2); heavily weathered; cubic cleats; dull to greasy surface 0.5 (0.15)

1. Underclay; medium gray (N5) mottled with moderate reddish brown (10R 4/6), pale yellowish orange (10YR 8/6), and light brown (5YR 5/6) weathers to dark gray (N3), medium dark gray (N4), moderate reddish orange (10R 6/6), and dark yellowish orange (10YR 6/6); very plastic; carbonaceous; grayish black (N2) coal chunks and streaks; lower contact covered by soil and debris 1.0 (0.3)

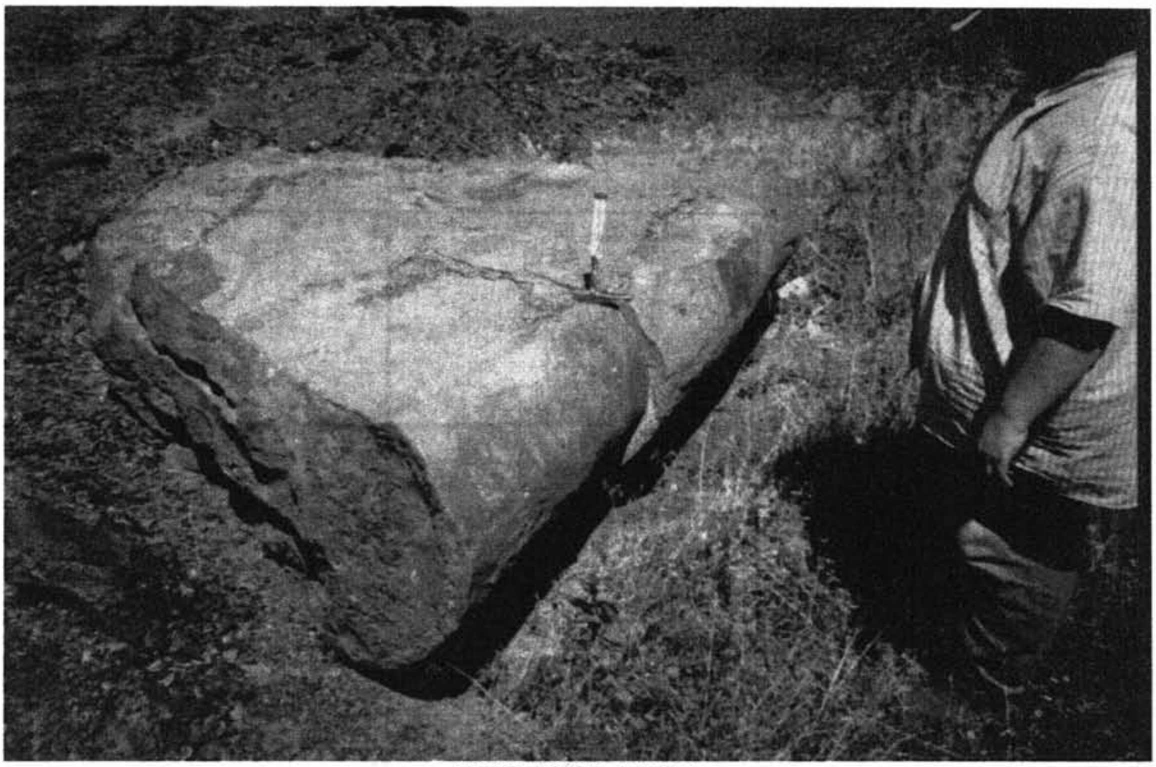
TOTAL: 132.57 (39.8)



PHOTOGRAPH 3

Photograph of lenticular Sam Creek Limestone exposed at Locality #13.

Within this cyclothem, the Sam Creek Limestone and no the overlying black fissile shale contains abundant offshore conodonts. The overlying black shale may only be marginal marine. Geological pick for scale.



PHOTOGRAPH 4

Photograph of soft sediment deformation

Unusual soft sediment deformation of what may be a bed of Sam Creek Limestone at Locality #13. The limestone bed has apparently folded back unto itself and has been transported from an unknown location to present location.

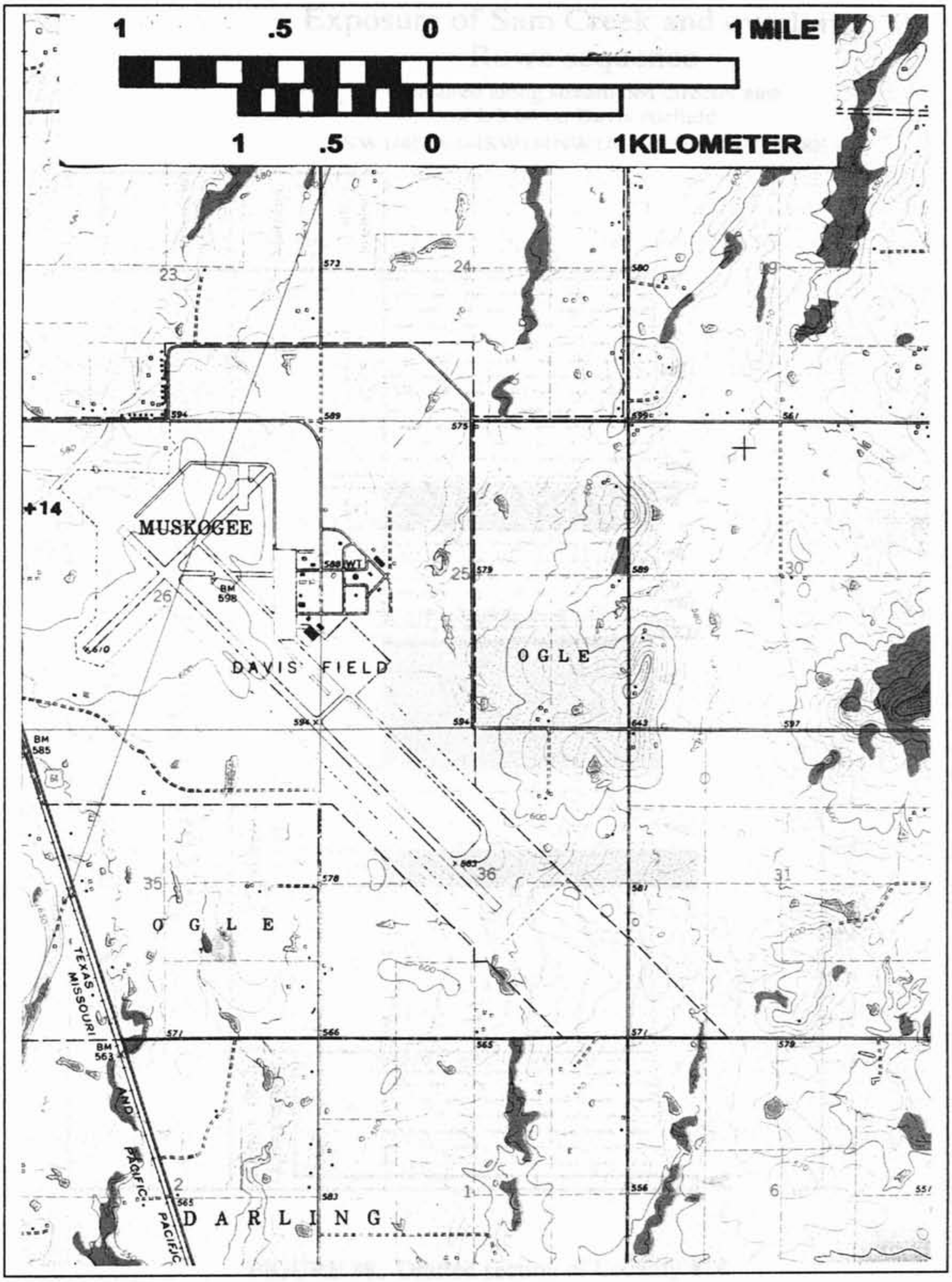


FIGURE 37. Topographic map of Locality #14, Muskogee County

Exposure of Sam Creek and overlying Rowe sequence

Measured along stream bed directly east of US 64 on Davis Airfield
NW1/4NW1/4SW1/4NW1/4 Sec26, T14N, R18E

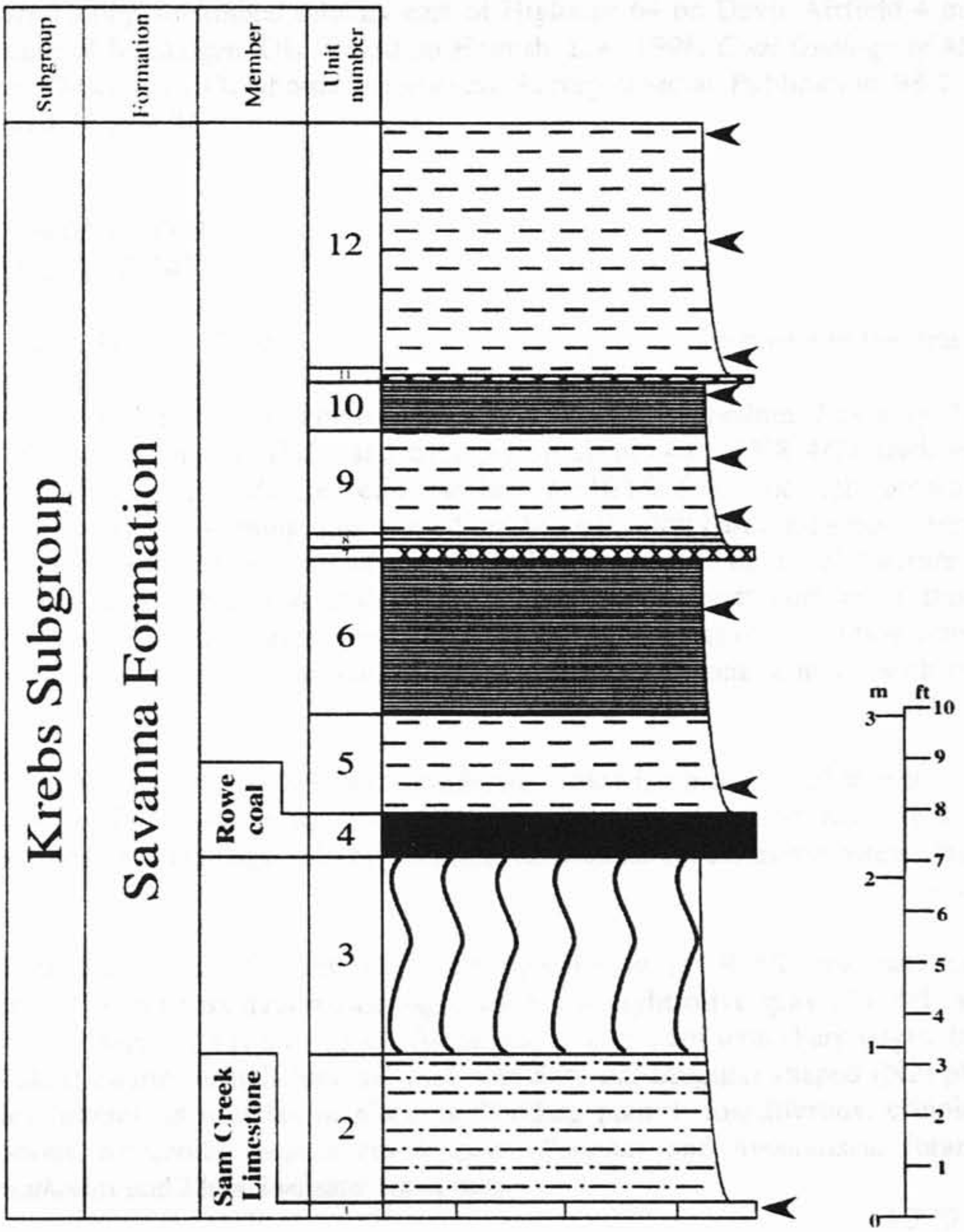


FIGURE 38. Drafted section of Locality #14

MEASURED SECTION of LOCALITY #14

Exposure of Sam Creek Limestone and Overlying Rowe Sequence
NW1/4NW1/4SW1/4NW1/4 Sec 26, T14N, R18E

Measured along streambed directly east of Highway 64 on Davis Airfield 4 miles (6.4 km) south of Muskogee, OK. Based on Hemish, L.A.,1998, *Coal Geology of Muskogee County, Oklahoma*: Oklahoma Geological Survey Special Publication 98-2, pp. 61, Measured Section 74

CHEROKEE GROUP
KREBS SUBGROUP

SAVANNA FORMATION: Thickness in feet (meters)

12. Shale; dark gray (N3) to grayish black (N2) weathers to medium dark gray (N4), dark gray (N3), medium gray (N5), and dark yellowish brown (10YR 4/2); dark yellowish orange (10YR 6/6), moderate yellowish brown (10YR 5/4), and light brownish gray (5YR 6/1) oxidation staining; thin to medium bedded; silty; hard; micaceous; weathers to flakes on the surface; middle of unit slightly calcareous; diagonal fracture pattern; exposed in stream bed and along stream banks; lowermost portion of this unit is fossiliferous, ostracods, foraminifera, gastropods, impressions of orthid brachiopods, and *Idiognathodus* and *Idioprioniodus* conodonts; semigradational contact with overlying alluvium and soil 5.0 (1.5)

11. Ironstone; dark gray (N3) with moderate yellowish brown (10YR 6/6) outer rind weathers to pale yellowish brown (10YR 6/2) and dusky yellow (5Y 6/4); massive; hard; nodular with rounded edges; slightly calcareous; nodular appearance in stream bed 0.13 (0.04)

10. Black shale; grayish black (N2) with light brown (5YR 5/6) and dark yellowish orange (10YR 6/6) oxidation staining weathers to light olive gray (5Y 6/1) and dark yellowish orange (10YR 6/6); platy; fissile; paper-like; hard with sharp edges; breaks up into flakes; quarter to half inch suboval, circular, and irregular shaped (N2) phosphate nodules; numerous nodules in place on bedding planes; fossiliferous, crinoid stems, gastropods, ostracods, *Lingula* brachiopods, *Reophax* and *Ammodiscus* foraminifera, *Idiognathodus* and *Idioprioniodus* conodonts 1.2 (0.36)

9. Clay shale; dark gray (N3) with moderate reddish brown (10R 4/6), moderate brown (5YR 4/4), and grayish orange (10YR 7/4) oxidation staining; weathers to pale yellowish brown (10YR 6/2), light olive gray (5Y 6/1); medium gray (N5), and grayish yellow (5Y 8/4); upper portion of unit is blocky; lower portion fissile; becomes increasingly more ferruginous towards upper contact; soft; moderate reddish brown (10R 4/6) iron stringers; lower contact exhibits numerous streaks of grayish yellow; fossiliferous, ostracods, pelecypods, gastropods, and possibly *Ammodiscus* foraminifera 1.8 (0.54)

8. Mudrock; dark gray (N3) weathers to medium dark gray (N4), moderate yellowish brown (10YR 5/4), and dark yellowish orange (10YR 6/4); fissile to medium bedded; breaks up into large chunks; micaceous; hard; very slightly calcareous 0.25 (0.08)

7. Ironstone; grayish black (N2) with grayish red (5R 4/2) outer rind weathers to moderate yellowish brown (10YR 5/4), light olive gray (5Y 5/2), and very pale orange (10YR 8/2); silty; micaceous; granular appearance; core of ironstone massive and hard; forms bench in stream bed 0.25 (0.08)

6. Black shale; dark gray (N3) to grayish black (N2) mottled with grayish brown (5YR 3/2) weathers to medium dark gray (N4), grayish red purple (5RP 4/2), and moderate yellowish brown (10YR 5/4); very fissile; paper-like; hard; micaceous; numerous quarter inch oval (N3) phosphate nodules; poorly exposed; base covered 3.0 (0.9)

5. Shale; moderate reddish brown (10R 4/6) mottled with pinkish brownish gray (5YR 6/1); plastic; highly weathered; carbonaceous; coal streaks and chunks (N1); poorly exposed 2.0 (0.6)

4. Rowe coal; black (N1); heavily weathered; crumbly 0.83 (0.25)

3. Underclay; orange-yellow mottling; numerous rust streaks; red stains; clayey 4.0 (1.2)

2. Shale; brown with yellow and orange mottling; silty; fissile; some rust staining; poorly exposed 3.0 (0.9)

1. Sam Creek Limestone; packestone; medium dark gray (N4) interior; light brown (5YR 5/6) rind; interior weathers to medium light gray (N6); rind weathers to grayish orange (10YR 7/4) and light olive brown (5Y 5/6); hard; massive; nodular with rounded edges; some parts very shaly; ferruginous; dense; fossiliferous, productid brachiopods, fish vertebrae and teeth, echinoid plates, poorly preserved calcareous, possibly *Tetrataxis*, and encrusting foraminifera, and *Idiognathodus* conodonts; forms bench in stream bed 0.3 (0.09)

TOTAL: 21.8 (6.52)

Sequence from the Rowe coal to the Doneley Limestone
and upper Marine Bands taken from core. Taken from core
designation C-RM-1, cored by Oklahoma Geological Survey
and described by Leroy Hemish.

SE1/4SE1/4SW1/4NW1/4 Sec. 18, T21N, R18E

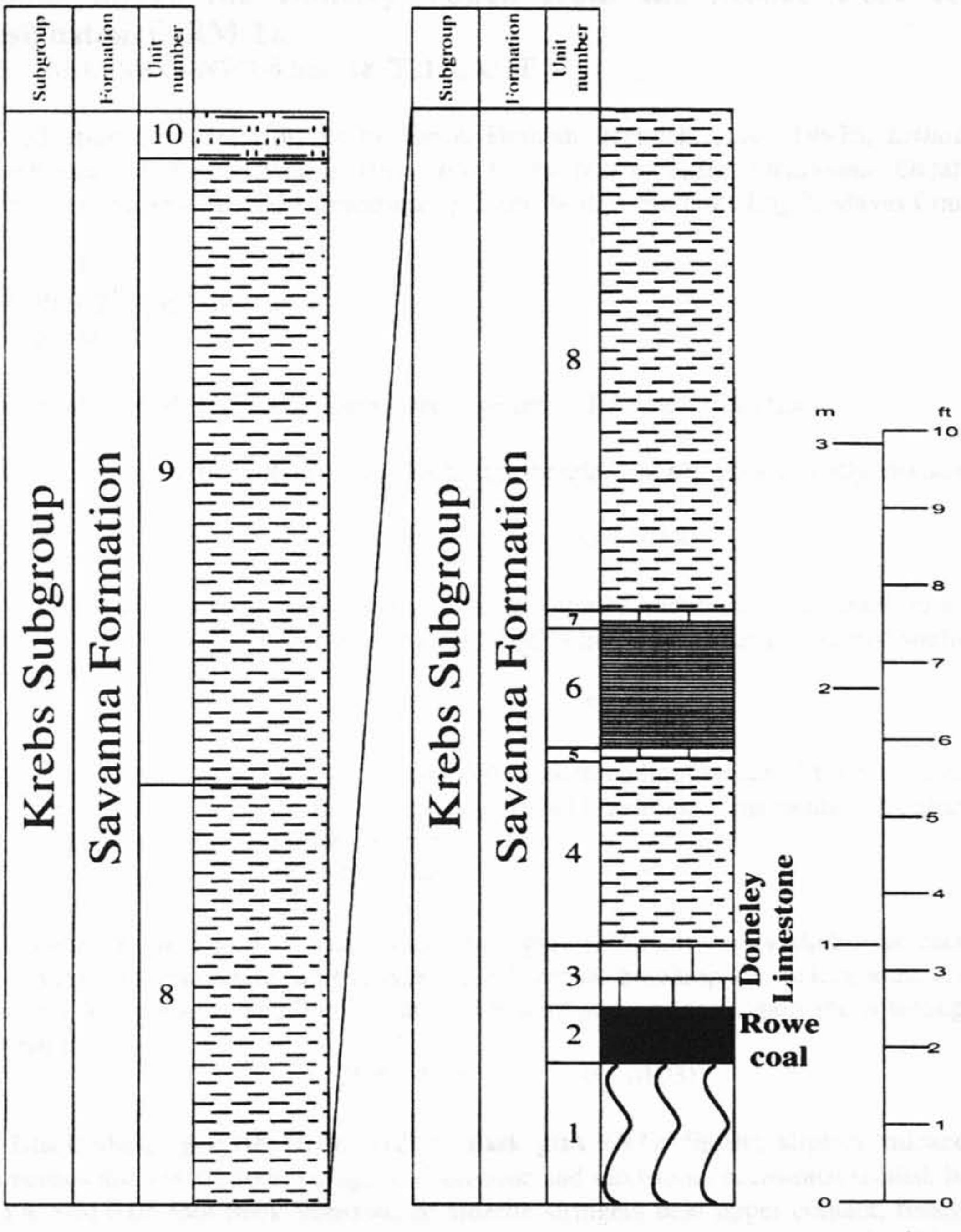


FIGURE 39. Drafted interval of the core section described by Measured Section #15

MEASURED SECTION #15

Sequence from the Rowe coal to the Doneley Limestone and Marine Bands above the Doneley Taken from the Moore Core (OGS designation C-RM-1).

SE1/4SE1/4SW1/4NW1/4 Sec. 18, T21N, R18E

Based upon core descriptions by Leroy Hemish, Hemish, L.A., 1997b, *Lithologic descriptions of Pennsylvanian strata north and east of Tulsa, Oklahoma*: Oklahoma Geological Survey Special Publication 97-2, pp 39-40, Core-Hole Log 7, Mayes County.

CHEROKEE GROUP
KREBS SUBGROUP

SAVANNA FORMATION: Depth: feet (meters) Thickness: feet (meters)

10. Siltstone; medium dark gray (N4); thin-bedded; hard; very slightly micaceous; carbonized leaf fragments

106.3 (31.9) 0.6 (0.18)

9. Clay shale; dark gray (N3); massive; hard; slightly micaceous; foot thick moderate brown (5YR 4/4) siderite stringers; calcite filled veins and fractures; scattered shells and fragments

106.9 (32.1) 8.1 (2.4)

8. Shale; medium dark gray (N4); fissile; 0.05 foot thick light brown (5YR 5/6) ironstone stringer at around 26.5 feet; fossiliferous, pyritized brachiopod fragments and pelecypod (clam) shells on surface at lower contact

115.0 (34.5) 11.8 (3.5)

7. Limestone; mudstone to wackestone; dark gray (N3); silty; very slightly micaceous; silty vein cuts diagonally across; very fossiliferous, brachiopods, pelecypods, crinoid ossicles, and possibly nautiloids; scattered brachiopod and pelecypod shells throughout limestone

126.8 (38.0) 0.1 (0.03)

6. Black shale; grayish black (N2) to dark gray (N3); fissile; slightly micaceous; numerous thin (>0.01 foot) stringers of siltstone and sandstone; occasional reddish brown (5YR 5/6) 0.05 foot thick ironstone or siderite stringers near upper contact; fossils not common but becomes more abundant near upper contact with limestone, brachiopods, crinoids, and pelecypods; brachiopods and clams on shale surface

126.9 (38.1) 1.6 (0.48)

5. Limestone; wackestone to packestone; dark gray (N3); silty; impure; pyrite flakes; much fossil hash, large brachiopods on surface; microfauna includes ostracods, possibly *Bairdia*; gradational contact with underlying shale

128.5 (38.6) 0.1 (0.03)

4. Shale; dark gray (N3) to medium dark gray (N4); fissile; slightly micaceous; calcareous; numerous white calcareous shell fragments, brachiopods, pelecypod, and crinoids; some productid brachiopods and pelecypods on surface; microfauna include poorly preserved ostracods, and fenestrate bryozoan fragments; grades into the Doneley Limestone

128.6 (38.6) 2.4 (0.72)

3. Doneley Limestone; dark gray (N3); shaly; pyrite flakes; fossiliferous, brachiopods, bryozoans, and crinoid columnals; microfauna consists of poorly preserved foraminifera, possibly *Ammodiscus*, pyritized crinoid columnals, and pyritized ostracods

131.0 (39.3) 0.8 (0.24)

2. Rowe coal; black (N1)

131.8 (39.5) 0.7 (0.21)

1. Underclay; medium gray (N5) to brownish gray (5YR 4/1); top of unit, grayish black (N2); silty; shaly; hard; degraded; grayish yellow (5Y 8/4) streaking; macerated carbonized plant fragments

132.5 (39.8) 1.8 (0.54)

TOTAL: 28.0 (8.4)

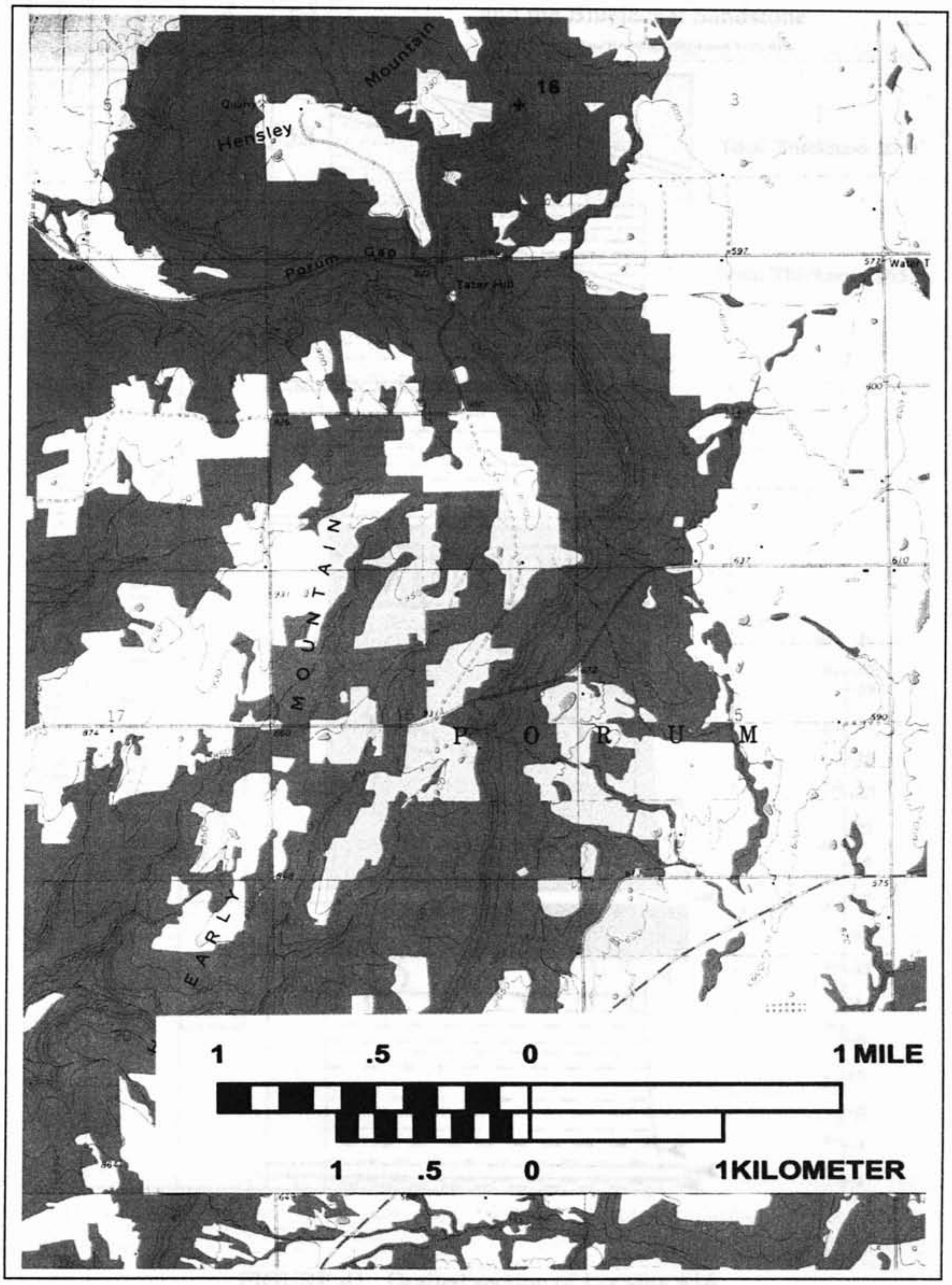


FIGURE 40. Topographic map of Locality #16, Muskogee County

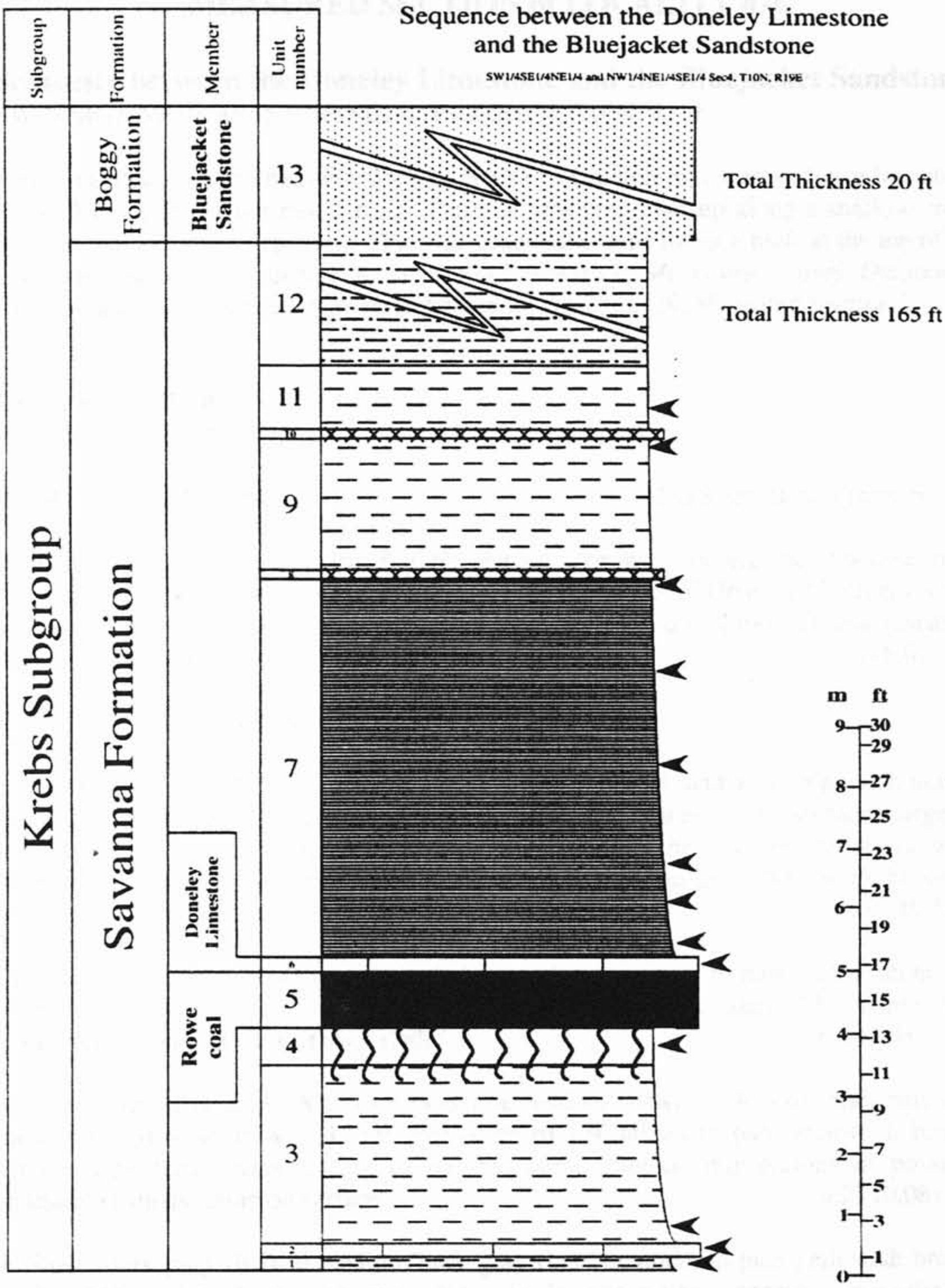


FIGURE 41. Drafted section of Locality #16

MEASURED SECTION of LOCALITY #16

Sequence between the Doneley Limestone and the Bluejacket Sandstone

SW1/4SE1/4NE1/4 and NW1/4NE1/4SE1/4 Sec. 4, T10N, R19E

Measured along the southeastern slope of Hensley Mountain just west of fence line about 3/4 miles (1.2 km) from paved road. Outcrop was measured up along a shallow creek bed and massive shale exposure. The Bluejacket Sandstone forms a bluff at the top of the mountain. Based on Hemish, L.A.,1998, *Coal geology of Muskogee County, Oklahoma*: Oklahoma Geological Survey Special Publication 98-2, pp. 39, Measured Section 2.

CHEROKEE GROUP
KREBS SUBGROUP

BOGGY FORMATION: Thickness in feet (meters)

13. Bluejacket Sandstone; quartz arenite; yellowish brown; fine-grained; massive; non-calcareous; blocks, some as big as small cars, litter the slopes of Hensley Mountain; some blocks display large vugs; these vugs may have been the dissolution of less resistant, possibly calcareous, material in the rock 20.0 (6.0)

SAVANNA FORMATION:

12. Shale; dark gray (N3) weathers to medium dark gray (N4) and grayish pinkish orange (5YR 7/2); micaceous; thin-bedded; silty; weathers to flakes at the surface; large (3 inches thick) clay cubic ironstone stringers and nodules near lower contact of unit; stringers and nodules are light brown (5YR 6/4) and medium gray (N5); shale becomes increasingly sandier closer to contact with the Bluejacket 165.0 (49.5)

11. Shale; dark gray (N3) to medium dark gray (N4) weathers to pale yellowish brown (10YR 6/2) and medium dark gray (N4); rust staining; fissile; shard-like; paper thin; gradational contact with overlying shale 6.2 (1.9)

10. Ironstone; dark gray (N3) with moderate reddish brown (10R 4/6) inner rind and moderate yellowish brown (10YR 5/4) outer rind weathers to pale yellowish brown (10YR 6/2); hard; massive; breaks up into cubic chunks; impressions of possible brachiopod shells found on surface 0.25 (0.08)

9. Shale; dark gray (N3) to medium dark gray (N4) weathers to pale yellowish brown (10YR 6/2) and medium dark gray (N4); fissile; paper-like; contains *Ammodiscus* foraminifera 5.75 (1.7)

8. Ironstone; dark gray (N3) with moderate reddish brown (10R 4/6) inner rind and moderate yellowish brown (10YR 5/4) outer rind weathers to pale yellowish brown (10YR 6/2); hard; massive; breaks up into cubic chunks; impressions of both brachiopods and pelecypods found on surface 0.25 (0.08)

7. Black shale; medium dark gray (N4) to grayish black (N2) weathers to pale yellowish brown (10YR 6/2); lower two feet weathers to medium dark gray mottled with brownish gray (5YR 4/1); fissile; thin paper-like; breaks up into flakes; very thin moderate reddish orange (10R 6/6) iron stringers; at ten feet, numerous half-inch oval dark gray (N3) phosphate nodules; at lower contact, inch wide oval to suboval dark gray (N3) phosphate nodules; fossiliferous interval, brachiopods, gastropods, ostracods, pelecypods, nautiloids; *Reophax*, *Endothyra*, and other unidentifiable foraminifera; sparse broken elements of *Idiognathodus* conodonts have been found in upper part of shale; blockier and clayier at lower contact 20.0 (6.0)

6. Doneley Limestone; packestone almost a grainstone; dark gray (N3) weathers to light brownish gray (5YR 6/1); shaly; very fossiliferous, numerous productids, poorly preserved calcareous foraminifera, crinoids, fenestrate bryozoans, and pelecypods; some brachiopods have grayish red purple (5RP 4/2) shells; the Doneley is not exposed directly above the Rowe but is found nearby on the bank of the ravine 0.7 (0.21)

5. Rowe coal; black (N1); prominently exposed; cleats columnar in appearance; many cleats near perfect cubes 3.0 (0.9)

4. Underclay; moderate reddish brown (10R 6/6) mottled with light gray (N7) and medium dark gray (N4) weathers to light brownish gray (5YR 6/1), medium gray (N5), and moderate reddish orange; plastic; slightly micaceous; black (N1) coal fragments; gypsum crystals; lower contact heavily covered 2.0 (0.6)

3. Clay shale; moderate olive brown (5Y 4/4) mottled with dark yellowish orange (10YR 6/6) weathers to pale yellowish brown (10YR 6/2) mottled with dark yellowish orange and medium gray (N5); blocky; silty; slightly micaceous; plastic when weathered; dark gray (N3) carbonaceous fragments; breaks off into thick slabs; heavily covered; possibly weathering into soil; ironstone stringer observed at lower contact; due to cover, difficult to distinguish from overlying underclay 10.0 (3.0)

2. Limestone; packestone; dark gray (N3) weathers to medium dark gray (N4) and light olive gray (5Y 6/1); shaly; weathers to a craggy appearance; very hard and resistant; micaceous; coal fragments; fossiliferous, mostly indeterminate, possibly fusulinids, algae, and/or brachiopods; some shell fragments have a rust color 0.6 (0.18)

1. Coaly black shale; probably a mixture of weathered coal and clayey black shale; very carbonaceous near upper contact; very clayey near lower portion; when rubbed in hand, shale left a black carbon residue; lower contact not present 0.7 (0.21)

TOTAL: 234.0 (70.3)

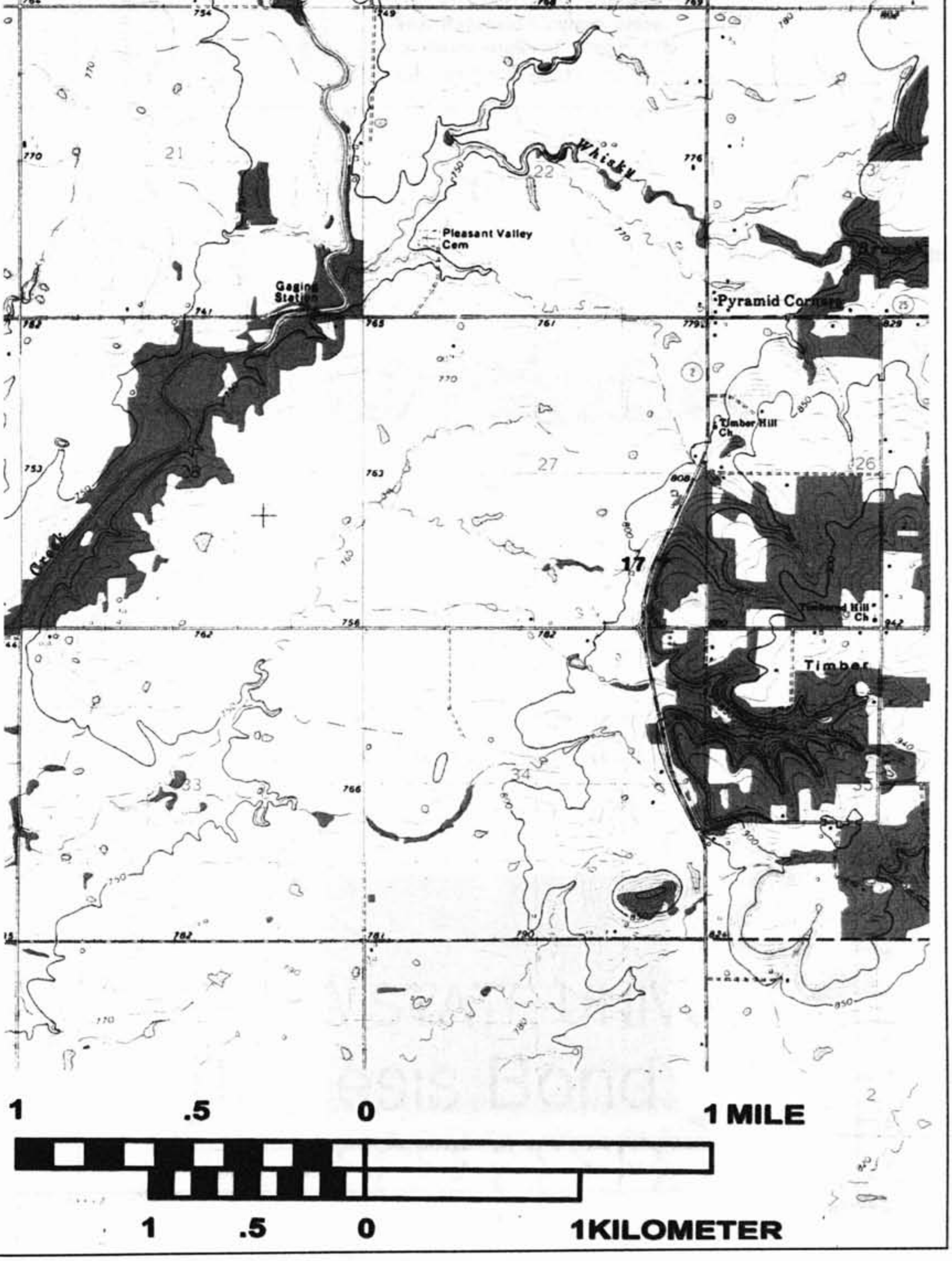


FIGURE 42. Topographic map of Locality #17, Craig County, Oklahoma

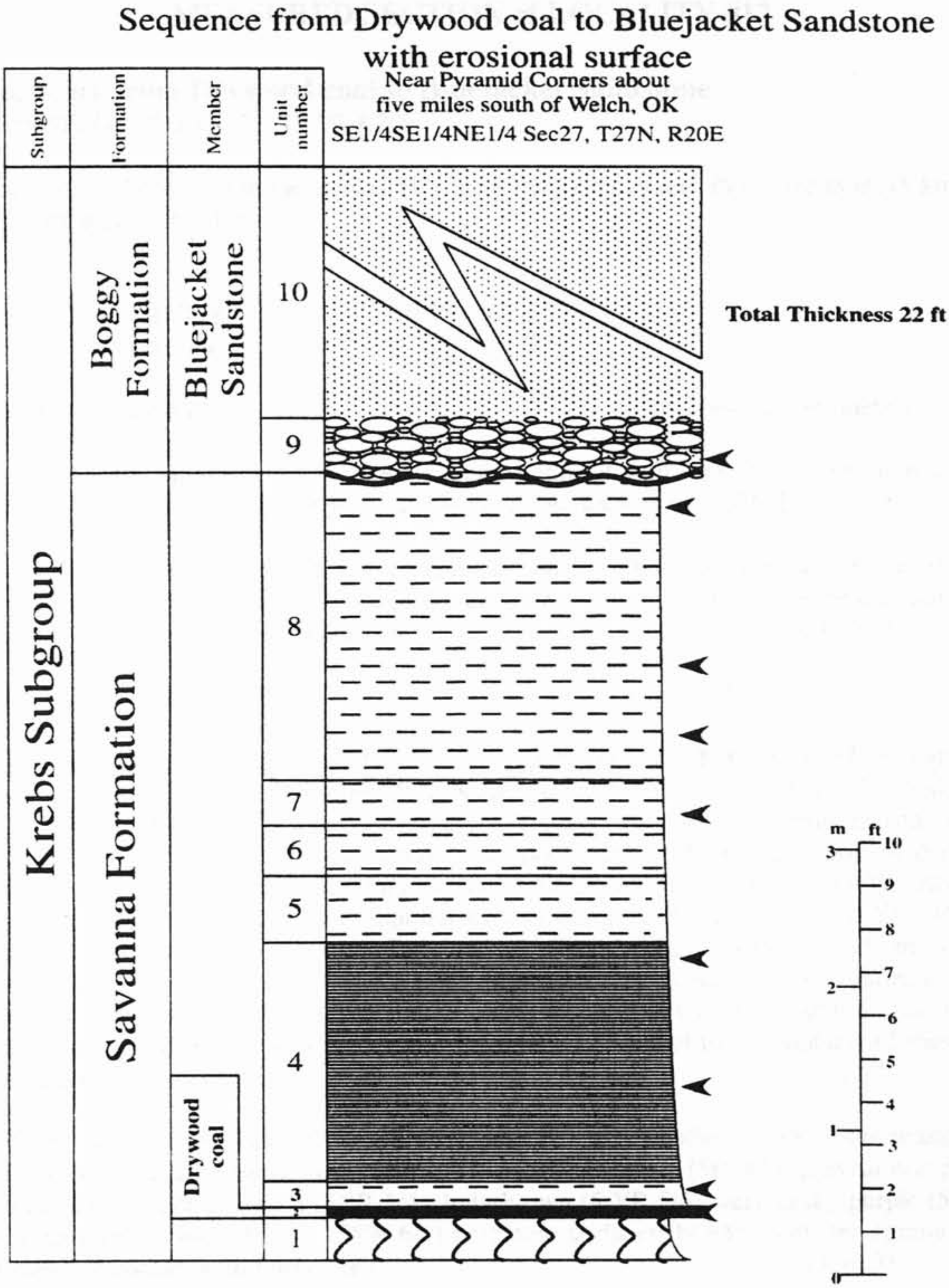


FIGURE 43. Drafted section of Locality #17,
This is the highest cyclothem within the Savanna Formation.

MEASURED SECTION of LOCALITY #17

Sequence from Drywood coal to Bluejacket Sandstone

SE1/4SE1/4NE1/4 Sec 27, T27N, R20E

Roadcut on Highway 2 in the Timber Hills near Pyramid Corners about five miles (8 km) south of Welch, Oklahoma.

CHEROKEE GROUP
KREBS SUBGROUP

BOGGY FORMATION: Thickness in feet (meters)

10. Bluejacket Sandstone; quartz arenite; coarse grained; hematite cement; ferruginous; slightly friable; medium to thin beds; unit is poorly exposed in side of hill 22.0 (6.6)

9. Conglomerate; basal Bluejacket; contains pebbles of phosphate nodules, ironstones, shell fragments, shale, and quartz granules; calcareous; very poorly exposed; quite possibly an incisement into a highstand 1.0 (0.3)

SAVANNA FORMATION:

8. Shale; soil-like; unit has three distinct zones; upper zone is light brown (5YR 5/6) and brownish black (5YR 2/1) weathers to moderate brown (5YR 4/4) mottled with dusky yellow brown (10YR 2/2); sandy near upper contact; very soil-like; middle zone is grayish orange (10YR 7/4) mottled with very pale orange (10YR 8/2); spots of dark yellowish orange(10YR 6/6) and large spots of bluish white (5B 9/1); crumbly; silty; lower zone is grayish black (N2) mottled with moderate yellowish brown (10YR 5/4) weathers to bluish white, grayish orange, and grayish red purple (5RP 6/2); light brown and moderate brown oxidation; fissile to blocky; silty; clay shale; resembles underclay; chunks of lower shale included within shale giving it a slightly fissile appearance. Due to poor exposure of unit, it was difficult to determine upper and lower contacts of these three zones so it was necessary to place them within one unit 7.5 (2.2)

7. Clay shale; grayish black (N2) and olive gray (5Y 4/1) weathers to very pale orange (10YR 8/2), grayish orange pink (5YR 7/2), and bluish white (5B 9/1); grayish orange (10YR 7/4), moderate brown (5YR 3/4), light brown (5 YR 5/6), very dusky purple (5P 2/2), and light brownish gray (5YR 6/1) oxidation surfaces; blocky; soft; ferruginous; gradational contact with lower shale 1.0 (0.3)

6. Clay shale; dark gray (N3), medium dark gray (N4), brownish gray (5YR 4/2), and grayish red purple (5RP 4/2) weathers to grayish orange (10YR 7/4), dark yellowish orange (10YR 6/6), and dark yellowish brown (10 YR 4/2); soft; grayish orange pink (10R 8/2) mottling and streaks; blocky; breaks off into shards; numerous inch thick limonite stringers, hackly, pale yellowish brown (10YR 6/2), light brown (5YR 5/6), dark yellowish orange, and a brownish gray (5 YR 4/1) rind; cubic, honeycomb appearance; gradational contact with upper shale 1.2 (0.36)

5. Clay shale; grayish black (N2) weathers to medium dark gray (N4), grayish orange pink (5YR 7/2), and dark yellowish orange (10YR 6/6); slightly blockier than lower shale; numerous thin grayish orange pink streaks with rounded edges (possibly plant material); soft; gradational contact with overlying unit; *Ammodiscus* foraminifera 1.5 (0.45)

4. Black shale; grayish black (N2) weathers to grayish orange (10YR 7/4), dark yellowish orange (10YR 6/6), pale yellowish brown (10YR 6/2), and grayish orange pink (5YR 7/2); moderate brown (5YR 4/4) to light brown (5YR 5/6) and dark yellowish orange oxidation staining; very fissile; paper-like; hard; pea sized phosphate nodules (N2) around three to four feet above lower contact; numerous 0.1-0.5 inch elongate to suboval (N2) phosphate nodules from lower contact to about one foot above lower contact; conodont bearing, *Idiognathodus* and *Idioprioniodus* conodonts, mostly fragmentary; also has *Ammodiscus* and other foraminifera, and ostracods; from lower contact to about one foot above lower contact, numerous whitish impressions of primarily *Idiognathodus* on bedding planes 5.5 (1.65)

3. Shale; grayish black (N2), medium dark gray (N4) weathers to medium gray (N5), olive gray (5Y 4/1), moderate reddish brown (10R 4/6), and dark yellowish orange (10YR 6/6); light brown (5YR 5/6), pale yellowish orange (10YR 8/6), and dark yellowish orange oxidation staining; blocky; silty; slightly micaceous; very small gypsum crystals on bedding planes 0.5 (0.15)

2. Drywood coal; black (N1); cubic cleats; oxidized surfaces (10YR 6/6); hard 0.21 (0.06)

1. Underclay; medium light gray (N6) with flecks of medium dark gray (N4) mottled with yellowish gray (5Y 8/1) and dark yellowish orange (10YR 6/6); plastic; carbonaceous with black (N1) coal fragments with dark yellowish orange oxidized surfaces 1.0 (0.3) +

TOTAL: 41.4 (12.4)

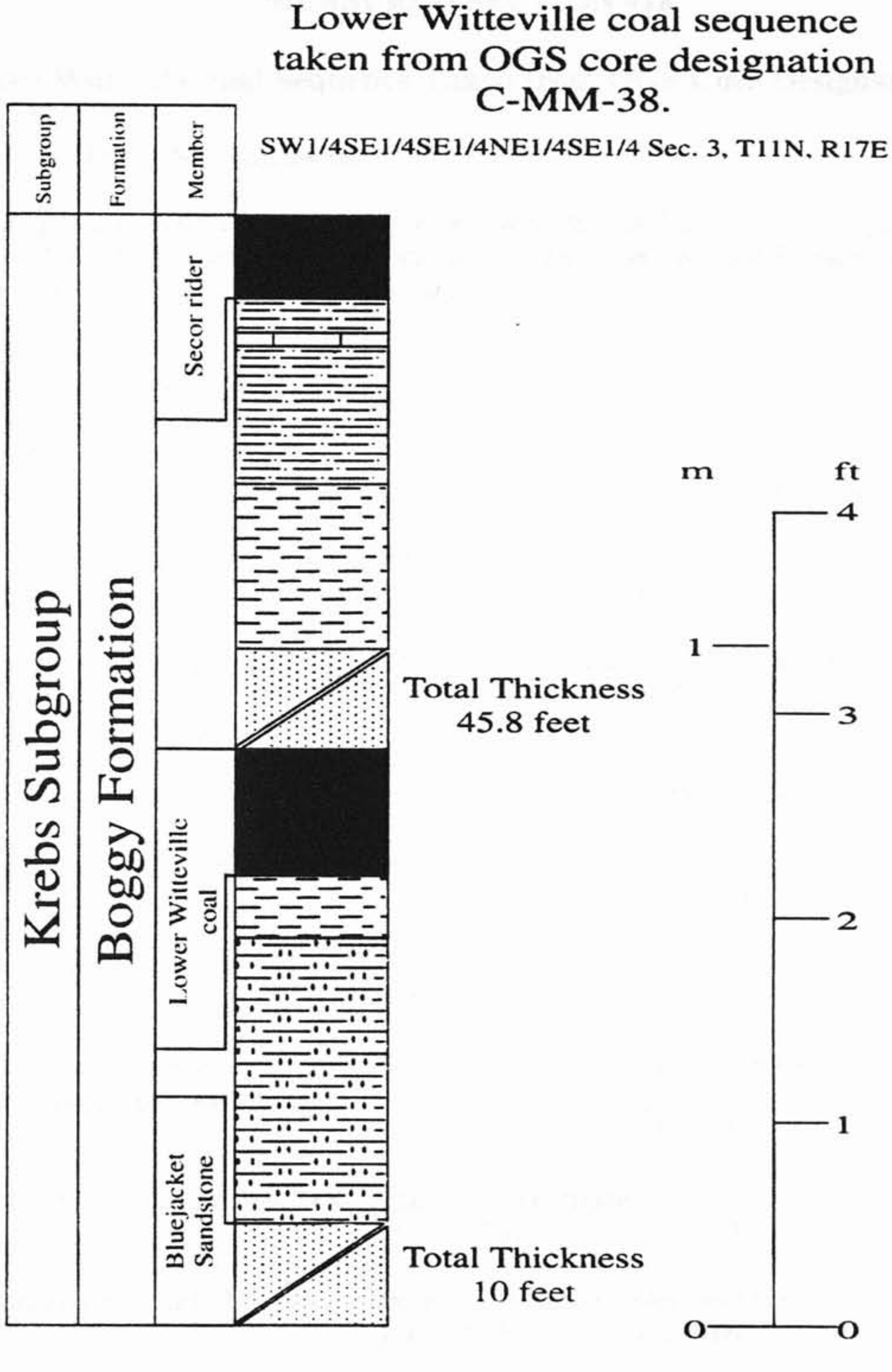


FIGURE 44. Drafted interval of the core section described by Measured Section #18, This is the lowest cyclothem within the Boggy Formation.

MEASURED SECTION #18

Lower Witteville coal Sequence Taken from OGS Core Designation C-MM-38.
SW1/4SE1/4SE1/4NE1/4SE1/4 Sec. 3, T11N, R17E

Based upon core descriptions by Leroy A. Hemish, Hemish, L.A., 1998, *Coal geology of McIntosh County, Oklahoma*: Oklahoma Geological Survey Special Publications 98-6, pp.53, Core-Hole Log 13, McIntosh County.

CHEROKEE GROUP
KREBS SUBGROUP

BOGGY FORMATION:	Depth: feet (meters)	Thickness: feet (meters)
10. Secor coal; black (N1); friable; pyritic	109.8 (32.9)	0.4 (0.12)
9. Shale; brownish black (5YR 2/1); silty; hard; fossiliferous, pyritized shells	110.2 (33.1)	0.17 (0.051)
8. Limestone; black (N1); shaly; fossiliferous	110.37 (33.1)	0.06 (0.018)
7. Shale; brownish black (5YR 2/1); silty; hard	110.43 (33.1)	0.67 (0.20)
6. Shale; black (N1); soft	111.1 (33.3)	0.8 (0.24)
5. Sandstone; medium light gray (N6); fine grained; cross-bedded; interbedded with shale; carbonaceous plant debris	111.9 (33.6)	45.8 (13.7)
4. Lower Witteville coal; black (N1); glassy surface; friable	157.7 (47.3)	0.6 (0.18)
3. Shale; grayish black (N2); silty; carbonaceous; carbonaceous plant debris	158.3 (47.5)	0.3 (0.09)
2. Siltstone; medium dark gray (N4); shaly; carbonaceous plant fossils	158.6 (47.6)	1.4 (0.42)

1. Bluejacket Sandstone; medium gray (N5); shaly; plant fossils (ferns)		
	160.0 (48.0)	10.0 (3.0)
	TOTAL:	60.2 (18.1)

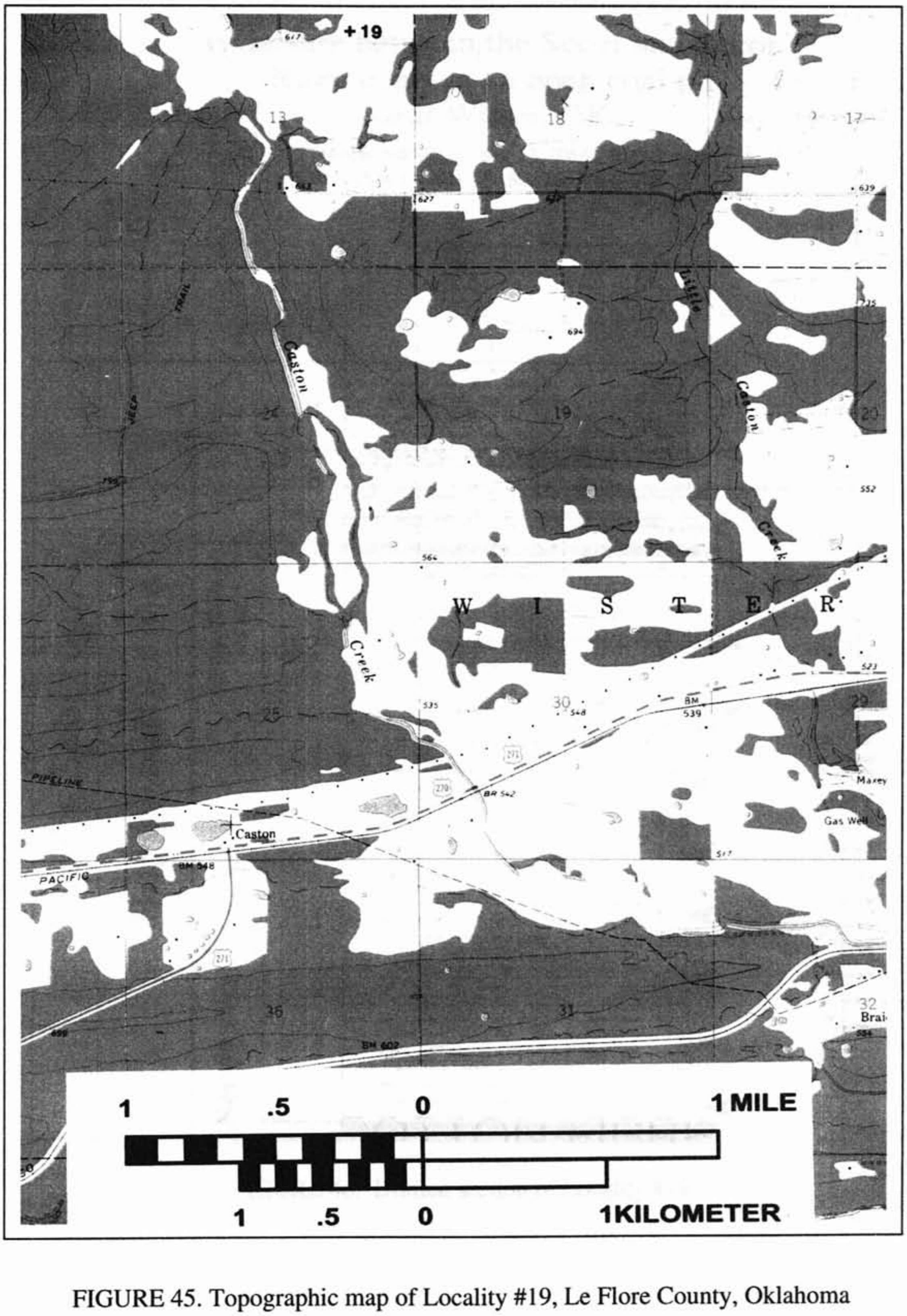


FIGURE 45. Topographic map of Locality #19, Le Flore County, Oklahoma

Exposure between the Secor and Secor Rider coals in an open coal pit near Wister, OK

SE1/4NW1/4NE1/4 Sec13, T6N, R23E and SW1/4SW1/4NW1/4 Sec18, T6N, R24E

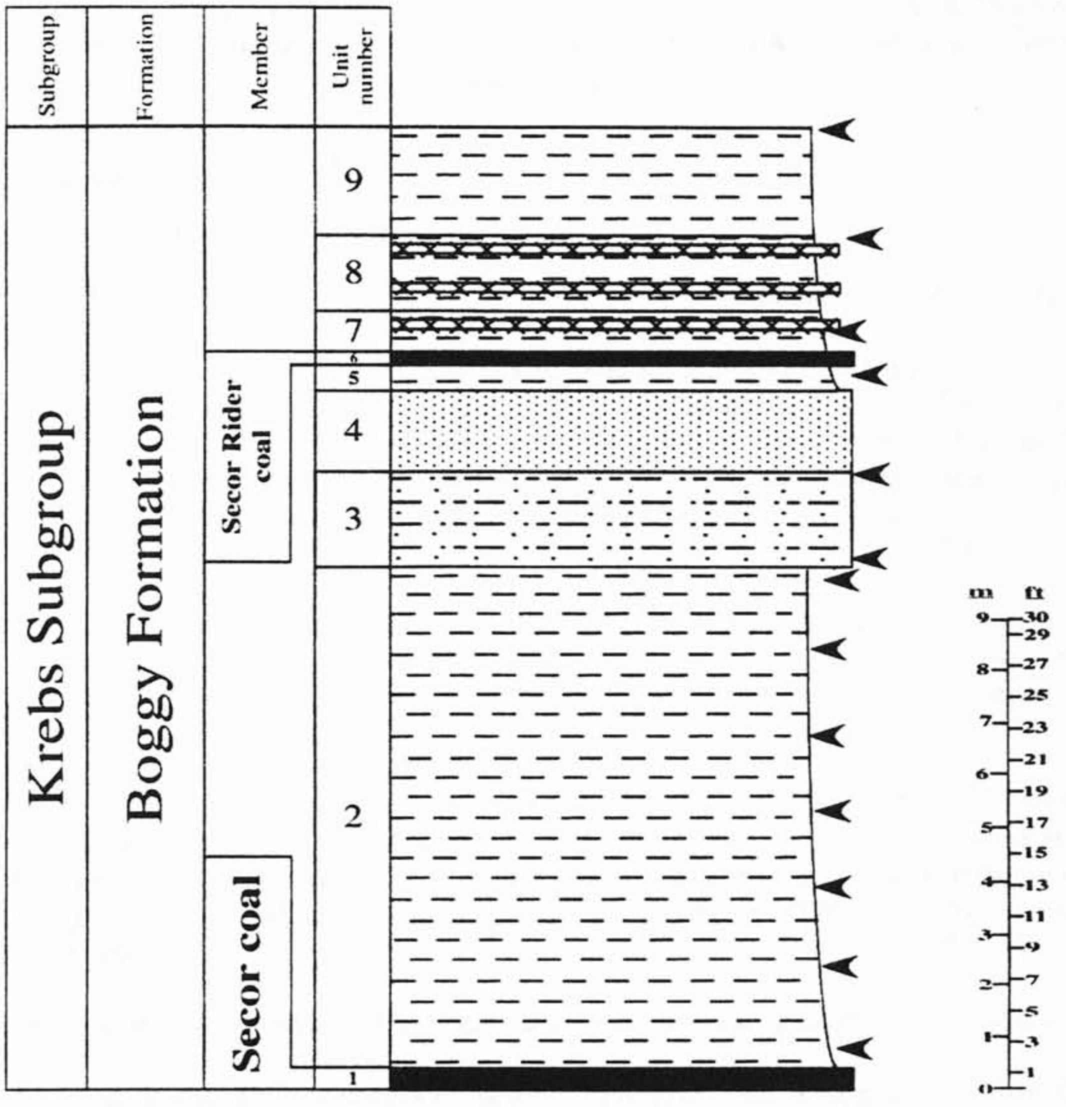


FIGURE 46. Drafted section of Locality #19

MEASURED SECTION of LOCALITY #19

Exposure between the Secor and Secor Rider coals in an open coal pit near Wister, OK

SE1/4NW1/4NE1/4 Sec 13, T6N, R23E and SW1/4SW1/4NW1/4 Sec 18, T6N, R24E

Measured in high wall in an exposed pit that had not been reclaimed yet. Measured four years ago, pit has probably been reclaimed by now. Based on Suneson, N.H., and Hemish, L.A. (eds.),1994, *Geology and resources of the eastern Ouachita Mountains frontal belt and southeastern Arkoma Basin, Oklahoma*: Oklahoma Geological Survey Guidebook 29, pp. 44, Composite Measured Section, Stop 5.

CHEROKEE GROUP
KREBS SUBGROUP

BOGGY FORMATION: Thickness in feet (meters)

9. Shale; medium dark gray (N4) weathers to medium gray (N5), dark yellowish orange (10YR 6/6), and pale yellowish brown (10YR 6/2); moderate brown (5YR 4/4) rust staining; pale yellowish brown (10YR 8/6) soil-like clay on some surfaces; thin-bedded; hard; silty; very micaceous; interbedded with light brownish gray (5YR 6/1) sandy layers; carbonized plant fragments on surface; capped by alluvium and mining debris 6.5 (2.0)

8. Shale; dark gray (N3) weathers to medium gray (N5) and light brownish gray (5YR 6/1); pale yellowish orange (10YR 8/6) oxidation; thin-bedded but not fissile; individual shale beds form rectangular blocks; hard; resistant; indeterminate carbonized fragments; numerous ironstone stringers and nodules 5.0 (1.5)

7. Shale; dark gray (N3) mottled with brownish gray (5YR 4/1) weathers to pale brown (5YR 5/2), light brown (5YR 5/6), and dark yellowish brown (10YR 6/6); pale yellowish orange (10YR 8/6) spots on bedding planes; thin-bedded; micaceous; soft; ferruginous; silty; carbonaceous; half inch to inch dark yellowish orange (10YR 6/6) iron nodules; poorly exposed 2.5 (0.75)

6. Secor Rider coal; jet black (N1); small cubic cleats; somewhat hard 0.83 (0.25)

5. Shale; dark gray (N3) weathers to medium light gray (N6) with grayish yellow (5Y 8/4) and pale yellowish orange (10YR 8/6) mottling; fissile; very soft; flaky; carbonaceous; near lower contact shale becomes more resistant, clayier, and carbonaceous 1.5 (0.45)

4. Sandstone; dark gray (N3) weathers to pale yellowish brown (10YR 6/2); upper foot of unit interbedded with silty shale; middle part of unit is massive bedded; lower part of unit is thin-bedded; fine grained; silica cement; hematite staining; blocky; very hard; flaser bedding 5.5 (1.7)

3. Siltstone; medium dark gray (N4) to dark gray (N3) weathers to light brownish gray (5YR 6/1) with medium gray (N5) banding and grayish orange (10YR 7/4); very blocky; massive bedded; interbedded with sandy shale or fine grained sandstone; wavy bedding; jointed appearance in outcrop; very micaceous; resembles slate in appearance; flaser bedding; very fissile at certain intervals 6.0 (1.8)

2. Shale; dark gray (N3) with medium light gray (N6) flecks weathers to medium dark gray (N4) sometimes with a pale yellowish brown (10YR 6/2) or dark yellowish orange (10YR 6/6) coating; very blocky; hard; massive; numerous 0.25 to 1.5 inch thick brownish gray (5YR 4/1) siderite stringers; stringers are placed apart at regular intervals (approximately 0.33 to 0.5 feet); stringers are continuous throughout shale; between siderite stringers, numerous ironstone nodules; fossiliferous, pyritized orthid and strophomenid brachiopods and possibly pelecypods at lower contact; numerous pyritized *Lingula* brachiopods at around ten feet; very sparse fragmentary *Idiognathodus* conodonts also found at around ten feet; lower five feet heavily covered by talus from mining operation; forms most of high wall in pit 32.0 (9.6)

1. Secor coal; black (N1); weathered with whitish staining at top of coal; blocky; very hard; lower contact covered 1.3 (0.39)

TOTAL: 61.1 (18.3)

PHOTOGRAPH 5

Photograph of Wister Mine, Locality #19

The Secor coal is visible just above the water line at the bottom of the quarry in Wister Mine. The massive unit 2 shale and overlying unit 3 siltstone overlie the Secor coal. Approximately ten feet above the Secor coal, the shale (unit 2) produced the conodont *Idiognathodus*. The brachiopod *Lingula* is also found ten feet above the Secor coal.

Sequences above the Secor Rider and Peters Chapel coals taken from core. Both coals have an overlying core shale that produce conodonts. Taken from core designation C-MM-51, cored by Oklahoma Geological Survey and described by Leroy A. Hemish.
SE1/4NW1/4SE1/4NE1/4NW1/4 Sec 7, T13N, R18E

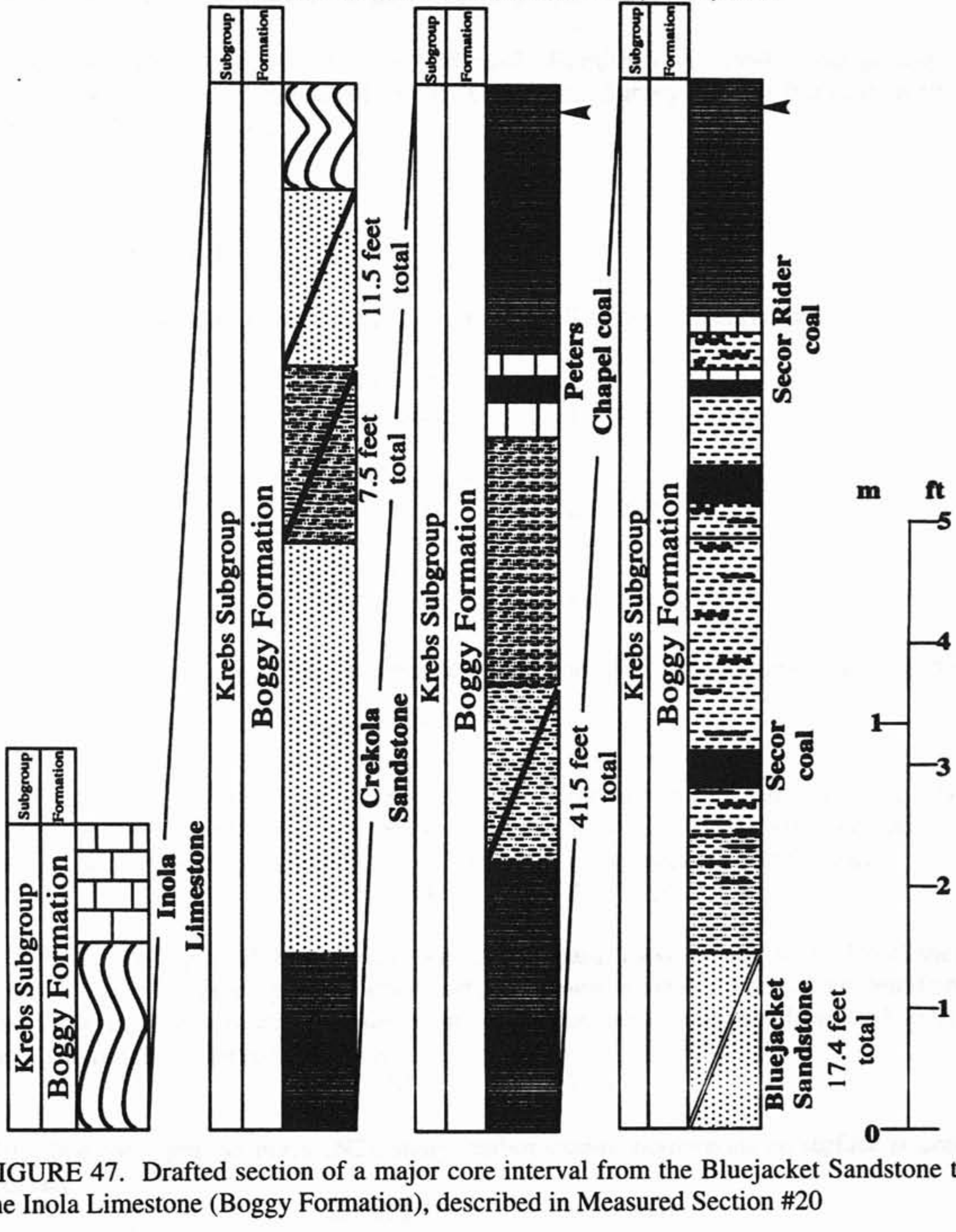


FIGURE 47. Drafted section of a major core interval from the Bluejacket Sandstone to the Inola Limestone (Boggy Formation), described in Measured Section #20

MEASURED SECTION #20

Sequences above the Secor Rider and Peters Chapel coals taken from the Eller Core (OGS designation C-MM-51).
SE1/4NW1/4SE1/4NE1/4NW1/4 Sec 7, T13N, R18E

Based upon core description by Leroy Hemish, Hemish, L.A., 1998, *Coal geology of Muskogee County, Oklahoma*: Oklahoma Geological Survey Special Publication 98-2, pp. 86-87, Core-Hole Log 13.

CHEROKEE GROUP
KREBS SUBGROUP

BOGGY FORMATION: Depth: feet (meters) Thickness: feet (meters)

25. Inola Limestone; dark gray (N3); silty
34.0 (10.2) 1.0 (0.3)

24. Underclay; medium light gray (N6); sandy; silty
35.0 (10.5) 2.5 (0.75)

23. Sandstone; medium gray (N5); very fine grained
37.5 (11.2) 11.5 (3.4)

22. Siltstone; dark gray (N3); interbedded with fine grained sandstone; wavy bedded; large mica flakes; hard; shaly
49.0 (14.7) 7.5 (2.3)

21. Crekola Sandstone; medium light gray (N6) interbedded with very light gray (N8) sandstone; cross-bedded; fine grained; dark reddish brown (10R 3/4) 0.05 foot thick iron nodules and stringers; grayish red (5R 4/2) staining; carbonaceous plant fragments
56.5 (17.0) 3.5 (1.05)

20. Black shale; grayish black (N2); very fissile; hard; fossiliferous, white fossil shells from 60.8 to 61.2, pelecypods on shale surface at lower contact; numerous unidentifiable shell fragments; microfauna includes mainly *Idiognathodus* conodonts, from 61.5 to 61.8 feet, and poorly preserved ostracods
60.0 (18.0) 3.7 (1.1)

19. Limestone; grayish black (N2); shaly; carbonaceous; pelecypods on surface at upper contact
63.7 (19.1) 0.2 (0.06)

MEASURED SECTION of LOCALITY #27

Sequence between the Tebo coal and Tiawah Limestone

SE1/4NE1/4NE1/4SE1/4 Sec 14, T14N, R15E

Measured on hill slope adjacent to bridge over Cane Creek. Measured from water level to field next to bend in road above bridge. Based on Hemish, L.A.,1998, *Coal geology of Muskogee County, Oklahoma*: Oklahoma Geological Survey Special Publication 98-2, pp. 55, Measured Section 55.

CHEROKEE GROUP
CABANISS SUBGROUP

SENORA FORMATION: Thickness in feet (meters)

15. Black shale; grayish black (N2); fissile; hackly; phosphate nodules; very poorly exposed 1.0 (0.3)

14. Tiawah Limestone; wackestone; brownish gray (5YR 4/1) and medium dark gray (N4) weathers to brownish gray (5YR 4/1), moderate yellowish brown (10YR 5/4), and pale yellowish brown (10YR 6/2); shaly; hard; fossiliferous, brachiopods, gastropods (including *Platyceras*), pyritized ostracods, fish teeth, and *Idiognathodus* conodonts; forms prominent bench at top of outcrop 1.0 (0.3)

13. Shale; dark gray (N3) weathers to medium dark gray (N4), light olive brown (5Y 5/6), dark reddish brown (10R 3/4), and pale brown (5YR 5/2); dark yellowish orange (10YR 6/6) oxidation; fissile; hard; platy; ferruginous; grayish yellow (5Y 8/4) spots and streaks; numerous inch thick cubic light olive brown ironstone stringers at around two feet above lower contact; inch thick black (N1) and dark yellowish orange (10YR 6/6) hackly, nodular ironstone stringers at upper contact; tabular gypsum crystals on bedding planes; fossiliferous, *Reophax* and other foraminifera, and broken, heavily degraded gastropods 4.25 (1.3)

12. Limestone; mudstone; dark gray (N3) weathers to light olive gray (5Y 5/2) and medium dark gray (N4); dark yellowish orange (10YR 6/6) oxidized rind; hard; massive; nodular; discontinuous stringer in outcrop; *Glaphyrites* ammonoids, and sparse conodont fragments 0.10 (0.03)

11. Shale; grayish black (N2) to dark gray (N3) weathers to grayish blue (5PB 5/2), brownish gray (5YR 4/1), and dark gray (N3); dark yellowish orange (10YR 6/6) and pale yellowish brown (10YR 6/2) oxidation; fissile; soft; crumbly; weathered; tabular gypsum crystals on bedding planes; broken iron crusts in upper part of unit 1.0 (0.3)

9. Shale; medium dark gray (N4); silty; micaceous; massive; hard

112.9 (33.9)	0.6 (0.18)

8. Coal; black (N1); very friable; glassy surface; grayish yellow (5Y 8/4) staining; degraded, soft

113.5 (34.1)	0.3 (0.09)

7. Shale; grayish black (N2); carbonaceous; numerous thin stringers of glassy black (N1) coal; fissile; soft; friable

113.8 (34.14)	0.1 (0.03)

6. Coal; black (N1); friable; soft, degraded; consists primarily of large broken fragments in core

113.9 (34.17)	0.2 (0.06)

5. Shale; dark gray (N3); fissile; numerous thin glassy, black (N1) coal stringers; one 0.1 foot degraded broken up whitish stringer at 115 feet; sparse plant and bark impressions on shale surface

114.1 (34.2)	1.8 (0.54)

4. Secor coal; black (N1); hard; glassy; thin-bedded

115.9 (34.8)	0.3 (0.09)

3. Shale; dark gray (N3); carbonaceous

116.2 (34.9)	0.4 (0.12)

2. Siltstone; medium dark gray (N4); carbonized plant fragments

116.6 (35)	1.0 (0.3)

1. Bluejacket Sandstone; medium gray (N5)

117.6 (35.2)	17.4 (5.2)
TOTAL:	101.0 (30.3)

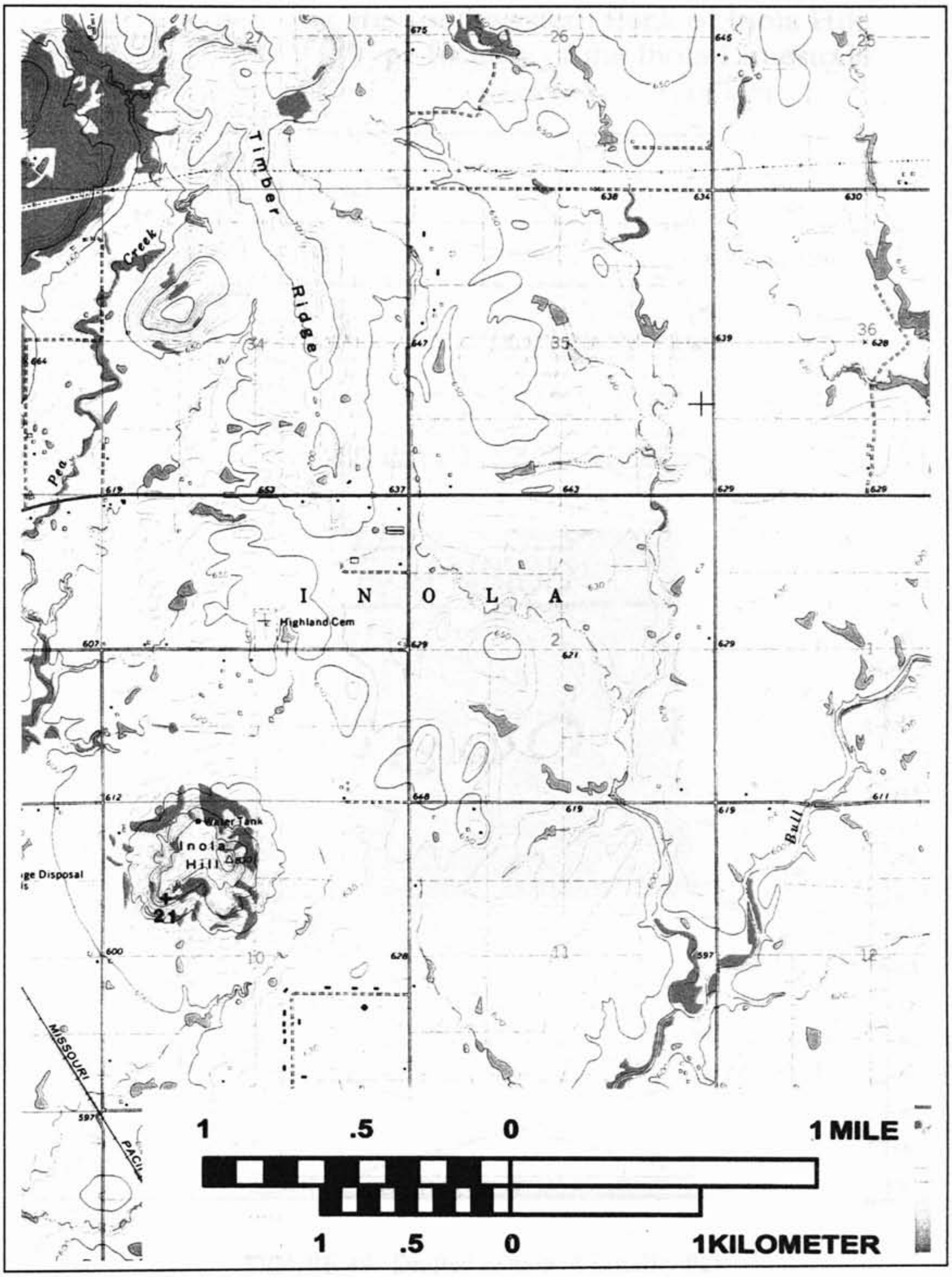


FIGURE 48. Topographic map of Locality #21, Rogers County, Oklahoma

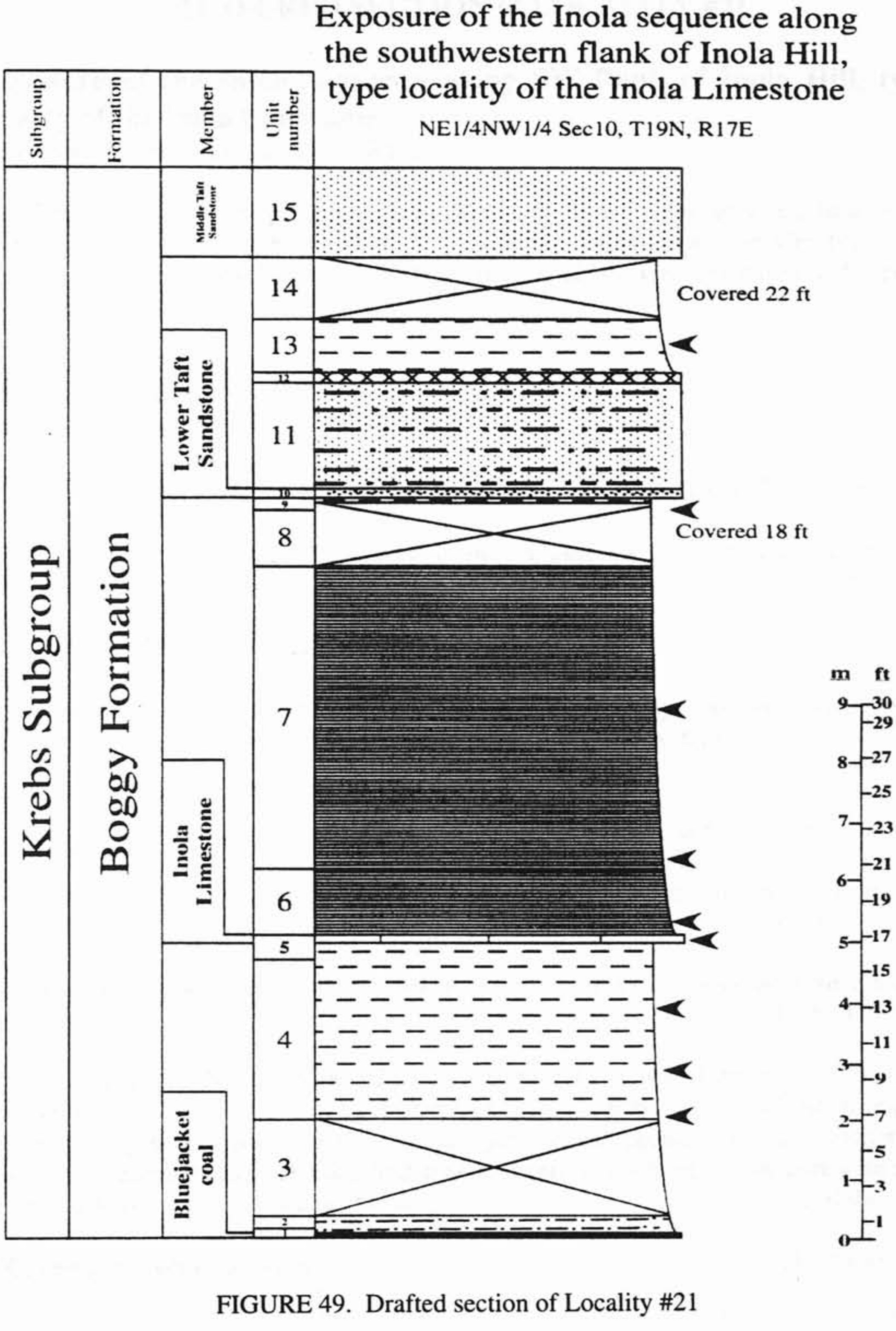


FIGURE 49. Drafted section of Locality #21

MEASURED SECTION of LOCALITY #21

Exposure of the Inola Sequence along SW flank of Inola Hill, type locality of the Inola Limestone

NE1/4SW1/4NW1/4 Sec 10, T19N, R17E

Measured on southwest slope of Inola Hill. Measured from covered area near base of hill to bluff at top of hill. Based on Hemish, L.A.,1990c, Inola Limestone Member of the Boggy Formation (Pennsylvanian) in its type area: Oklahoma Geology Notes, v. 50, pp.4-23.

CHEROKEE GROUP
KREBS SUBGROUP

BOGGY FORMATION: Thickness in feet (meters)

15. Middle Taft Sandstone; dark reddish brown; micaceous; fine grained; thin bedded; float of sandstone covers slope of hill 5.0 (1.5)

14. Covered; probably clay shale grading into siltstone 22.0 (6.6)

13. Clay shale; medium gray (N5) weathers to medium gray, pale yellowish brown (10YR 6/2), and grayish orange (10YR 7/4); blocky; very poorly exposed 3.0 (0.9)

12. Ferruginous zone; purplish red with black surfaces; nodular; rubbly 0.5 (0.15)

11. Interbedded sandstone and siltstone; light brown gray; thin-bedded; micaceous; poorly exposed 6.0 (1.8)

10. Lower Taft Sandstone; brown to greenish gray; thin-bedded; fine grained; very poorly exposed 0.25 (0.08)

9. Clay shale; pale brown (5YR 5/2) weathers to pale yellowish brown (10YR 6/2), grayish orange (10YR 7/4), and light brownish gray (5YR 6/1); dark yellowish orange (10YR 6/6), greenish black (5GY 2/1), and grayish red purple (5RP 4/2) oxidation; fissile; silty; ferruginous; inch thick ironstone stringers, grayish red purple core with pale yellowish brown rind; hard; cubic; blocky 0.3 (0.09)

8. Covered; probably clay shale 18.0 (5.4)

7. Black shale; grayish black (N2) to dark gray (N3) weathers to medium dark gray (N4) and pale yellowish brown (10YR 6/2); fissile; clayey; soft; dark yellowish orange (10YR 6/6) ironstone stringers; some ironstone stringers have a septarian appearance; weathers to flakes on surface; gradational contact with lower unit 17.0 (5.1)

6. Black shale; grayish black (N2) to dark gray (N3) weathers to pale yellowish brown (10YR 6/2) and medium dark gray (N4); dark yellowish orange (10YR 6/6) oxidized streaks; very fissile; breaks off into flakes with sharp edges; grayish black flattened iron nodules; quarter inch to walnut sized spherical, oval, irregular-shaped, and elongated phosphate nodules; fossiliferous with *Idiognathodus* and *Gondolella* conodonts 4.0 (1.2)

5. Inola Limestone (upper unit); mudstone; medium dark gray (N4) weathers to medium gray (N5) and pale yellowish brown (10YR 6/2); dark reddish brown (10R 3/4) oxidation; hard; massive; discontinuous crystalline horizontal bands scattered throughout limestone; fossiliferous, brachiopod shells, gastropods, rugose corals, fusulinids, *Ammodiscus* foraminifera, fish teeth, and *Idiognathodus* and *Idioprioniodus* conodonts 0.3 (0.09)

4. Shale; medium dark gray (N4) weathers to pale yellowish orange (10YR 6/2); moderate brown (5YR 4/4) oxidation; fissile; silty; micaceous; breaks off into blocks; coal fragments; base covered 10.0 (3.0)

3. Covered; streaks of gray shale and thin limestones 5.5 (1.65)

2. Clay shale; dark gray (N3); flaky; fissile; weathers to flakes 1.0 (0.3)

1. Bluejacket coal; black (N1); heavily weathered; poorly exposed 0.25 (0.08)

TOTAL: 93.2 (27.94)

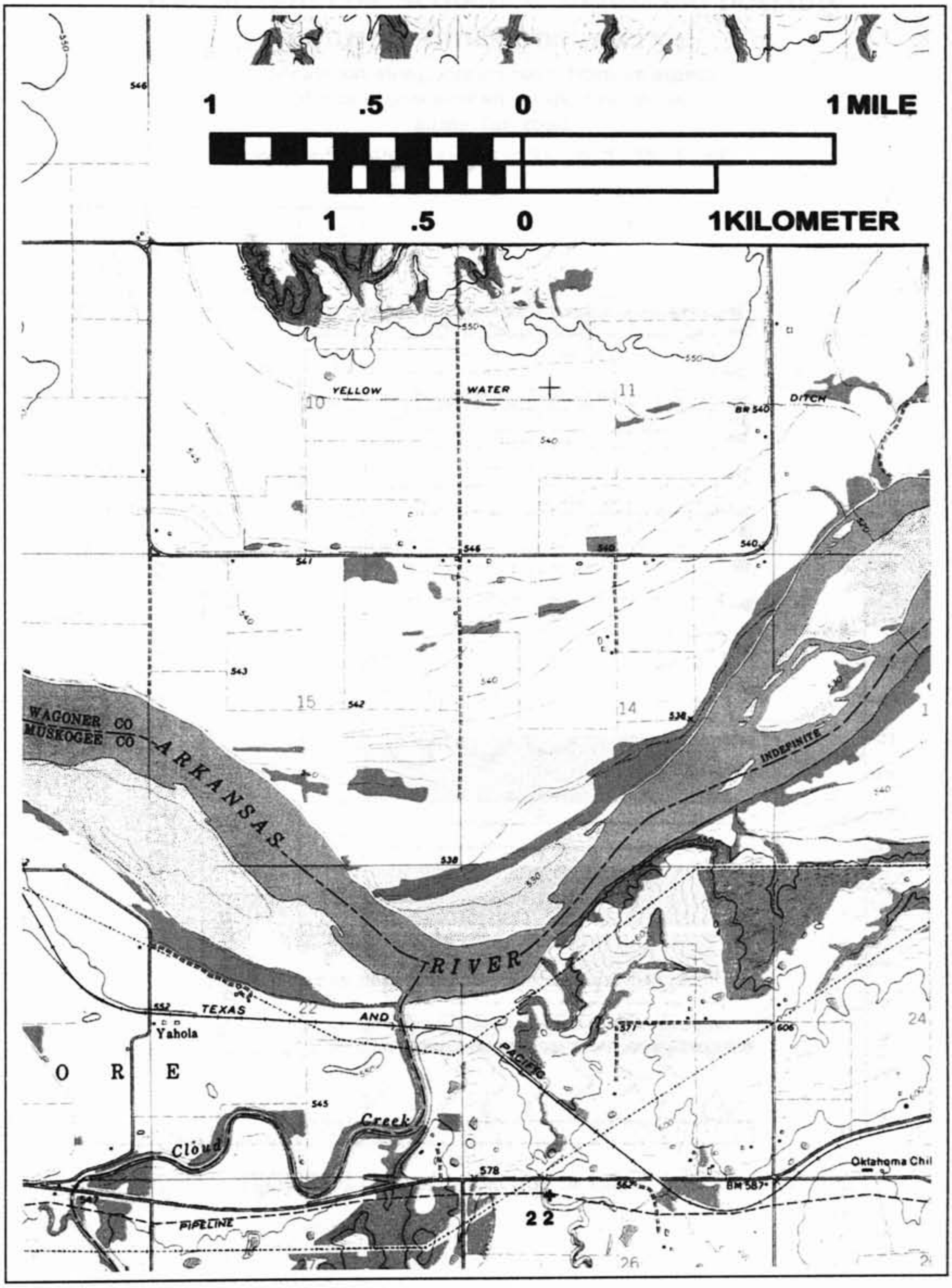


FIGURE 50. Topographic map of Locality #22, Muskogee County

Wainwright coal sequence, highstand possibly at upper limestone interval

Measured along stream bank from an eighth of a mile downstream to shallow ravine along Taft road

W1/2NW1/4NE1/4NW1/4 Sec26, T15N, R16E

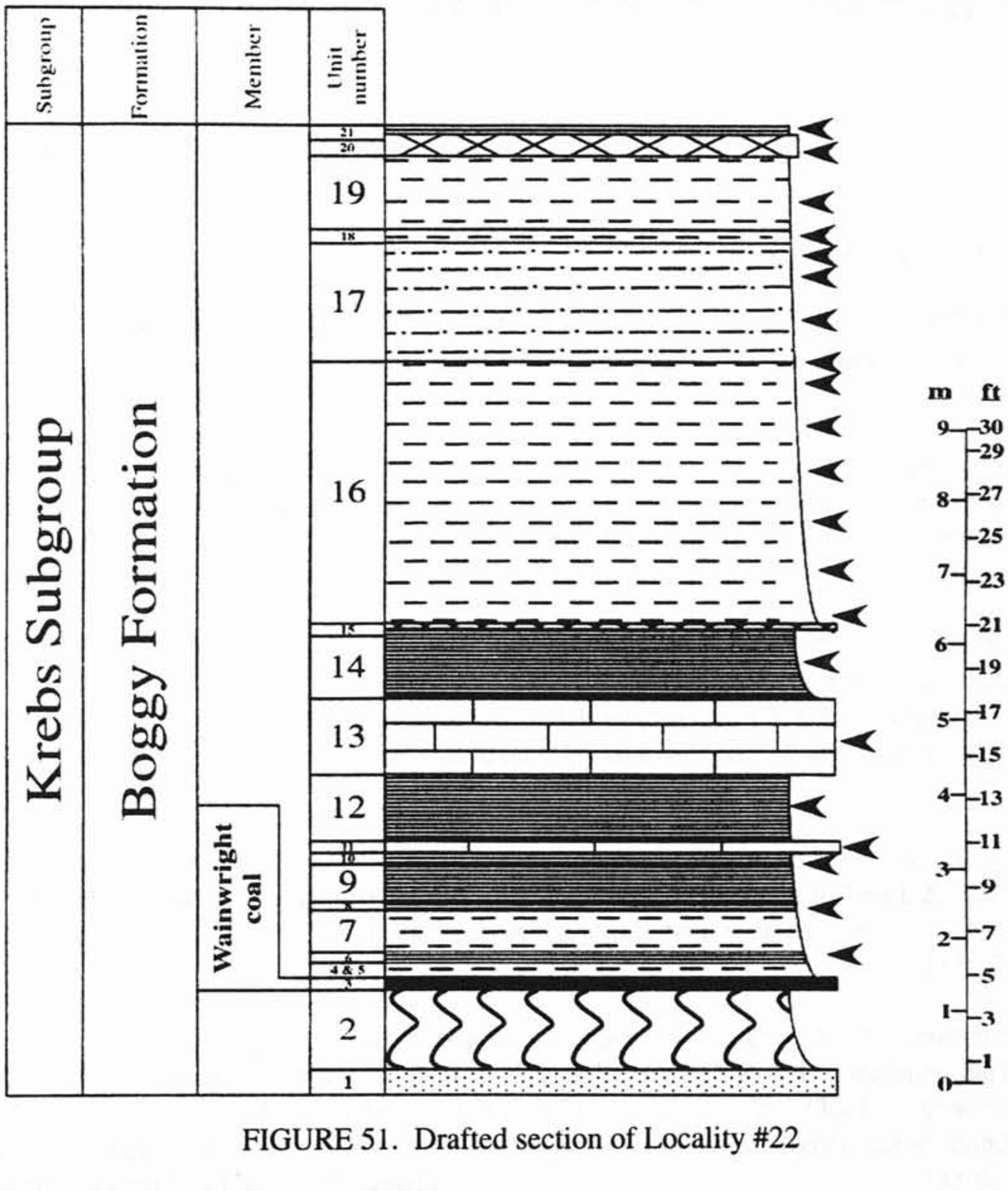


FIGURE 51. Drafted section of Locality #22

MEASURED SECTION of LOCALITY #22

Wainwright coal Sequence

W1/2NW1/4NE1/4NW1/4 Sec 26, T15N, R16E

Measured along stream bank from an eighth of a mile (0.20 km) downstream to shallow ravine along Taft Road. Based on Hemish, L.A., 1998, *Coal geology of Muskogee County, Oklahoma*: Oklahoma Geological Survey Special Publication 98-2, pp. 65-66, Measured Section 88.

CHEROKEE GROUP
KREBS SUBGROUP

BOGGY FORMATION: Thickness in feet (meters)

21. Black shale; grayish black (N2) weathers to pale yellowish brown (10YR 6/2) and medium bluish gray (5B 5/1); very hard; slate-like; breaks off into massive thin sheets; sparse inch long elongate phosphate nodules 0.25 (0.08)

20. Ironstone; grayish black (N2) mottled with grayish red (5R 4/2), dark yellowish orange (10YR 6/6) outer rind weathers to moderate yellowish brown (10YR 5/4) with grayish red (5R 4/2); pale reddish brown (10R 5/4) staining; hard; silty; cubic; dense; strongly bedded 1.1 (0.33)

19. Clay shale; dark gray (N3) mottled with pale brown (5YR 5/2) weathers to light brownish gray (5YR 6/1); grayish yellow (5Y 8/4) mottling/streaking; moderate yellowish brown (10YR 5/4) and pale yellowish orange (10YR 8/6) oxidation; fissile; soft; carbonaceous; silty; yellowish gray underclay in lower part of unit; unit is poorly exposed 3.0 (0.9)

18. Shale; dark gray (N3) weathers to pale yellowish brown (10YR 6/2) and dark gray (N4); dark yellowish orange (10YR 6/6) oxidation; fissile to medium-bedded; hard; very micaceous; breaks off into hard thin sheets when struck by a rock hammer 0.58 (0.2)

17. Clay shale; olive gray (5Y 4/1) weathers to light olive gray (5Y 6/1), medium gray (N5), grayish orange (10YR 7/4), and moderate brown (5YR 4/4); becomes dark gray (N3) near upper contact; light brown (5YR 5/6) oxidation; silty; blocky; thick-bedded; inch thick dark yellowish orange (10YR 6/6) clay ironstone stringers, cubic, concentric layering; forms bluff at top of cutbank 5.3 (1.6)

16. Shale; grayish black (N2) to dark gray (N3) weathers to medium dark gray (N4) and pale yellowish brown (10YR 6/2); dark yellowish orange (10YR 6/6), dark yellowish brown (10YR 4/2), and very dusky red (10R 2/2) oxidation; fissile; platy; slightly micaceous; broken fragments of dark yellowish orange ferruginous crust; slightly silty; numerous clay iron stringers, quarter-inch thick, silty, calcareous, medium dark gray (N4) and olive gray (5Y 4/1) weathering to light medium gray (N5); upper contact heavily oxidized; bark impressions near lower contact 12.0 (3.6)

15. Ironstone; dark gray (N3) weathers to pale brown (5YR 5/2), medium dark gray (N4), and brownish gray (5YR 4/1); grayish red (10R 4/2) and dark yellowish orange (10YR 6/6) oxidation; dense; hard; cubic; silty; massive; numerous calcareous fractures 0.17 (0.05)

14. Black shale; grayish black (N2) to dark gray (N3) weathers to medium dark gray (N4) and brownish gray (5YR 4/1); dark yellowish brown (10YR 4/2), dark reddish brown (10R 3/4), and dark yellowish orange (10YR 6/6) oxidation/crusting; hard; fissile; platy; about a foot above lower contact is a white and yellow clay which contains numerous pectin-like shells and *Crurithyris* brachiopods; fossiliferous, *Idiognathodus* conodonts, and *Healdia* ostracods 3.2 (0.96)

13. Limestone; mudstone; dark gray (N3) weathers to pale yellowish brown (10YR 6/2) and dark yellowish orange (10YR 6/6); very hard; massive; chips of dark reddish brown (10R 3/4) on surface; scattered brachiopods and *Idiognathodus* conodonts 3.5 (1.1)

12. Black shale; grayish black (N2) weathers to brownish gray (5YR 4/1), bluish white (5B 9/1), and medium gray (N5); dark yellowish orange (10YR 6/6), grayish red purple (5RP 4/2), and moderate reddish brown (10R 4/6) oxidation; fissile; hard; ferruginous; waxy, greasy surface; half inch thick grayish black weathering to brownish gray ironstone stringer; middle of unit heavily oxidized; fossiliferous, *Idiognathodus* and *Idioprioniodus* conodonts, ostracods, and brachiopods 3.0 (0.9)

11. Limestone; wackestone; grayish black (N2) weathers to pale brown (5YR 5/2) and grayish red (10R 4/2); hard; massive; scattered whitish brachiopod shells, crinoid columnals, and *Idiognathodus* conodonts 0.33 (0.1)

10. Black shale; grayish black (N2) weathers to brownish gray (5YR 4/1) and pale yellowish brown (10YR 6/2); moderate brown (5YR 3/4), grayish red purple (5RP 4/2), and moderate reddish brown (10R 4/6) oxidation; extremely fissile; paper-like; hard with sharp edges; dull waxy surface; circular 0.12 inch grayish black phosphate nodules in bedding planes in lower part of shale; *Idiognathodus* conodonts 0.58 (0.17)

9. Black shale; black (N1) to grayish black (N2) weathers to dark gray (N3); fissile to medium bedded; weathered; hard; dark yellowish orange (10YR 6/6) and very pale orange (10YR 8/2) oxidation; very slightly micaceous; at upper contact, sparse 0.05 inch spherical phosphate nodules; fossiliferous, *Linoproductis*, *Crurithyris*, and scattered orthid brachiopods, crinoid columnals, and other scattered calcareous shell fragments 2.0 (0.6)

8. Black shale; grayish black (N2) weathers to dark gray (N3) and grayish orange (10YR 7/4); dusky yellowish brown (10YR 2/2) and grayish red purple (5RP 4/2) oxidation; moderate reddish brown (10R 4/6) spots; very fissile; paper-like; sharp edges; slightly micaceous; numerous 0.10 inch spherical phosphate nodules on bedding planes; fossiliferous, scattered fragmentary brachiopod, ostracode, and pelecypod shells; forms bench in outcrop 0.33 (0.1)

7. Shale; grayish black (N2) weathers to brownish gray (5YR 4/1), dark gray (N3), and grayish red purple (5RP 4/2); very dusky purple (5RP 2/2), dark yellowish orange (10YR 6/6), and dark yellowish brown (10YR 4/2) oxidation; fissile; hard; platy; waxy surface; ferruginous; grayish yellow (5Y 8/4) sulfur banding among some bedding planes; breaks up into flakes with thin sharp edges; sparse brachiopod shell impressions 1.9 (0.57)

6. Black shale; black (N1) to grayish black (N2) weathers to brownish gray (5YR 4/1) and grayish orange pink (5YR 7/2); moderate brown (5YR 4/4), light brown (5YR 5/6), and grayish red (5R 4/2); very fissile; paper-like with sharp edges; hard; waxy-greasy surface; quarter inch suboval to circular phosphate nodules in bedding planes; bench former in outcrop 0.54 (0.16)

5. Shale; grayish black (N2) weathers to light gray (N7), grayish orange pink (5YR 7/2), and dark yellowish orange (10YR 6/6); fissile; paper-like with sharp edges; slightly micaceous; breaks off into large sheets; inarticulate brachiopods 0.30 (0.09)

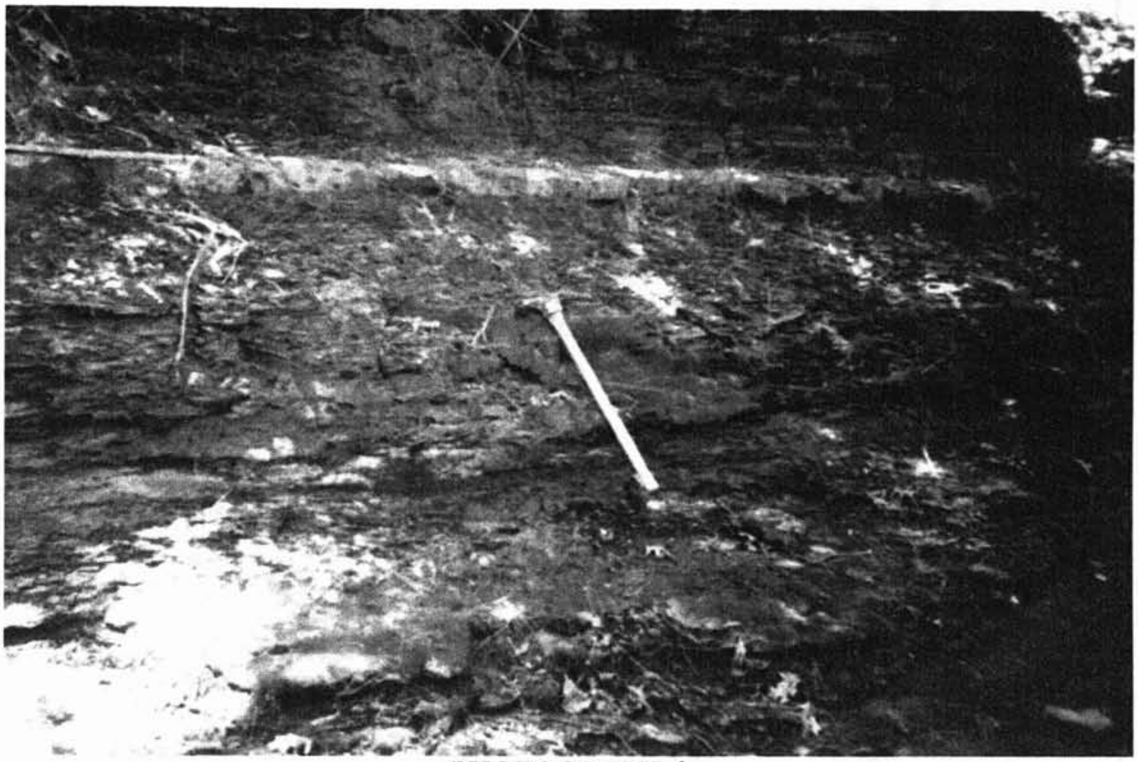
4. Shale; dark gray (N3) heavily streaked with grayish yellow (5Y 8/4) weathers to light brownish gray (5YR 6/1) and grayish yellow; soft; fissile; silty; carbonaceous; fibrous gypsum crystals on shale surface; dark yellowish orange (10YR 6/6) oxidation surface 0.25 (0.08)

3. Wainwright coal; jet black (N1) with grayish yellow (5Y 8/4) streaks weathers to medium gray (N5); glassy surface; cubic; light brown (5YR 5/6) oxidation surfaces; vivid bluish play of colors on some surfaces 0.5 (0.15)

2. Underclay; pinkish gray (5YR 8/1) mottled with light brownish gray (5YR 6/1) plant fragments weathers to pinkish gray mottled with pale yellowish orange (10YR 8/6), and grayish yellow (5Y 8/4); dark yellowish orange (10YR 6/6) and very dusky red (10R 2/2) oxidation; dark gray (N3) carbonaceous streaks; hard; breaks up into blocky chunks; some underclay is cemented to form resistant beds especially near upper contact; becomes clayey and sandier towards lower contact 3.6 (1.1)

1. Taft Sandstone; quartz arenite; thin-bedded; shaly; very fine grained; poorly cemented; ripple marks present on some surfaces; faint log impression on upper surface; lower contact covered 1.2 (0.36)

TOTAL: 43.6 (13.1)



PHOTOGRAPH 6

Photograph of Locality #22

Massive exposure of black fissile shale and black fissile phosphatic shale above the Wainwright coal at Locality #22. The large tan bed visible in the upper third of the picture is the 0.33-foot (0.1-meter) limestone (unit 11). Trenching tool in photograph is approximately two feet (0.6 meters) long.

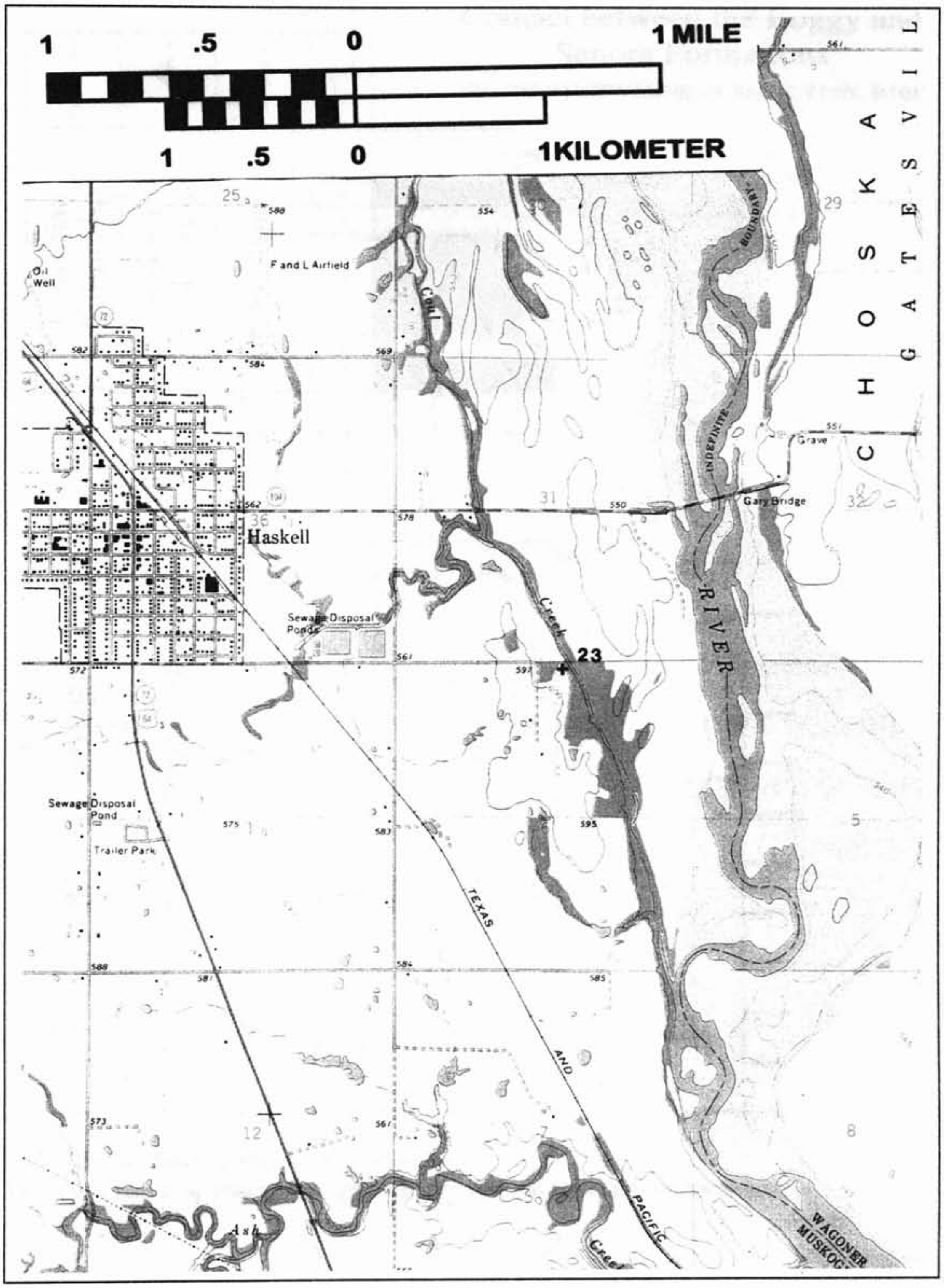


FIGURE 52. Topographic map of Locality #23

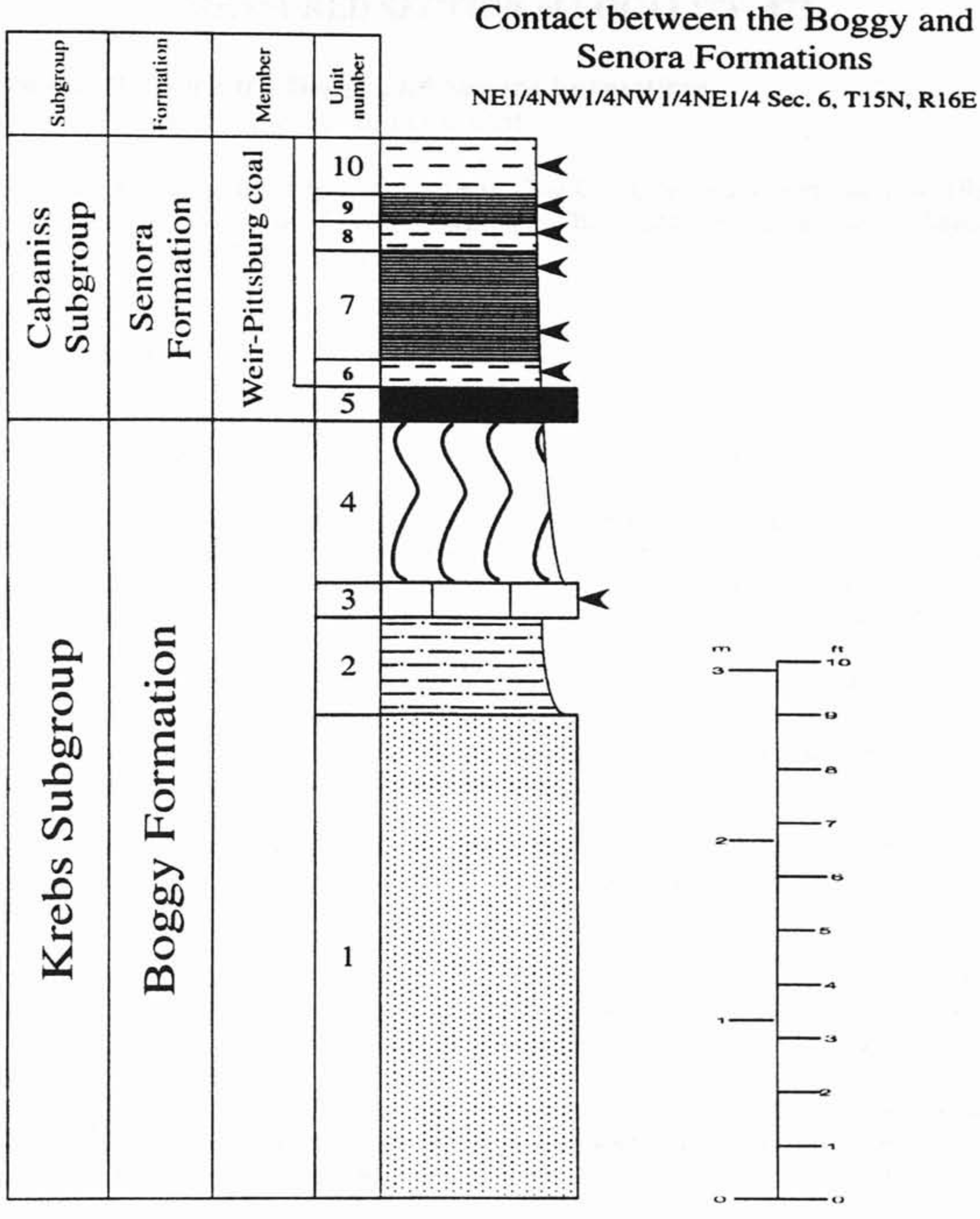


FIGURE 53. Drafted section of Locality #23,
Two cyclothems spanning the upper Boggy and basal Senora Formations.

MEASURED SECTION of LOCALITY #23

Contact Between the Boggy and Senora Formations

NE1/4NW1/4NW1/4NE1/4 Sec 6, T15N, R16E

Measured in small gully in bluff west side of Coal Creek. Based on Hemish, L.A.,1998, *Coal geology of Muskogee County, Oklahoma*: Oklahoma Geological Survey Special Publication 98-2, pp. 64, Measured Section 85

CHEROKEE GROUP
CABANISS SUBGROUP

SENORA FORMATION: Thickness in feet (meters)

10. Clay shale; black (N1) to grayish black (N2) weathers to brownish gray (5YR 4/1) and dark gray (N3); soft; blocky; carbonaceous; massive; numerous circular to suboval phosphate nodules (around an inch diameter) possibly reworked from below; weathered; poorly exposed 1.0 (0.3)

9. Black shale; grayish black (N2) weathers to grayish red (5R 4/2), brownish black (5YR 2/1), and very pale orange (10YR 8/2); pale yellowish orange (10YR 8/2) and moderate reddish brown (10R 4/6) oxidation; fissile; hard; clayey; platy; numerous flattened inch diameter suboval grayish black phosphate nodules 0.5 (0.15)

8. Clay shale; grayish black (N2) to dark gray (N3) weathers to grayish red (5R 4/2) and brownish gray (5YR 4/1); soft; blocky; carbonaceous; gray yellow (5Y 8/4) streaks 0.5 (0.15)

7. Black shale; black (N1) to grayish black (N2) mottled with grayish red (10R 4/2) weathers to grayish orange (10YR 7/4) and very pale orange (10YR 8/2); fissile; soft; lower part carbonaceous; strongly bedded; phosphate nodules 2.0 (0.6)

6. Clay shale; grayish red (5R 4/2) banded with pale brown (5YR 5/2) weathers to dark yellowish brown (10YR 4/2) and medium dark gray (N4); numerous thin jet black (N1) glassy coal streaks; blocky; soft; weathered; carbonaceous 0.5 (0.15)

5. Weir-Pittsburg coal; black (N1) 0.6 (0.18)

KREBS SUBGROUP

BOGGY FORMATION:

4. Underclay; light gray (N7) mottled with orange weathers to very light gray (N8) 3.0 (0.9)

3. Limestone; grainstone; medium gray (N5) weathers to moderate yellowish brown (10YR 5/4), grayish red (10R 4/2), and grayish orange (10YR 7/4); hard; silty; ferruginous; crystalline; thickness variable along outcrop; slightly micaceous; fossiliferous, numerous degraded fusulinids, productid brachiopods, and other shell fragments 0.6 (0.18)

2. Shale; brownish gray (5YR 4/1); silty; carbonaceous 1.8 (0.54)

1. Sandstone; light yellowish gray with greenish hue; thick-bedded with thin-bedded shaly units; very fine grained; ripple marks; flow rolls and other soft sediment deformation; bluffs over Coal Creek 9.0 (2.7)

TOTAL: 19.5 (5.85)

Sequence with the Weir-Pittsburg taken from core. Taken from core designation C-RM-2, cored by Oklahoma Geological Survey and described by Leroy A. Hemish.

SE1/4SW1/4NW1/4SE1/4 Sec. 12, T21N, R16E

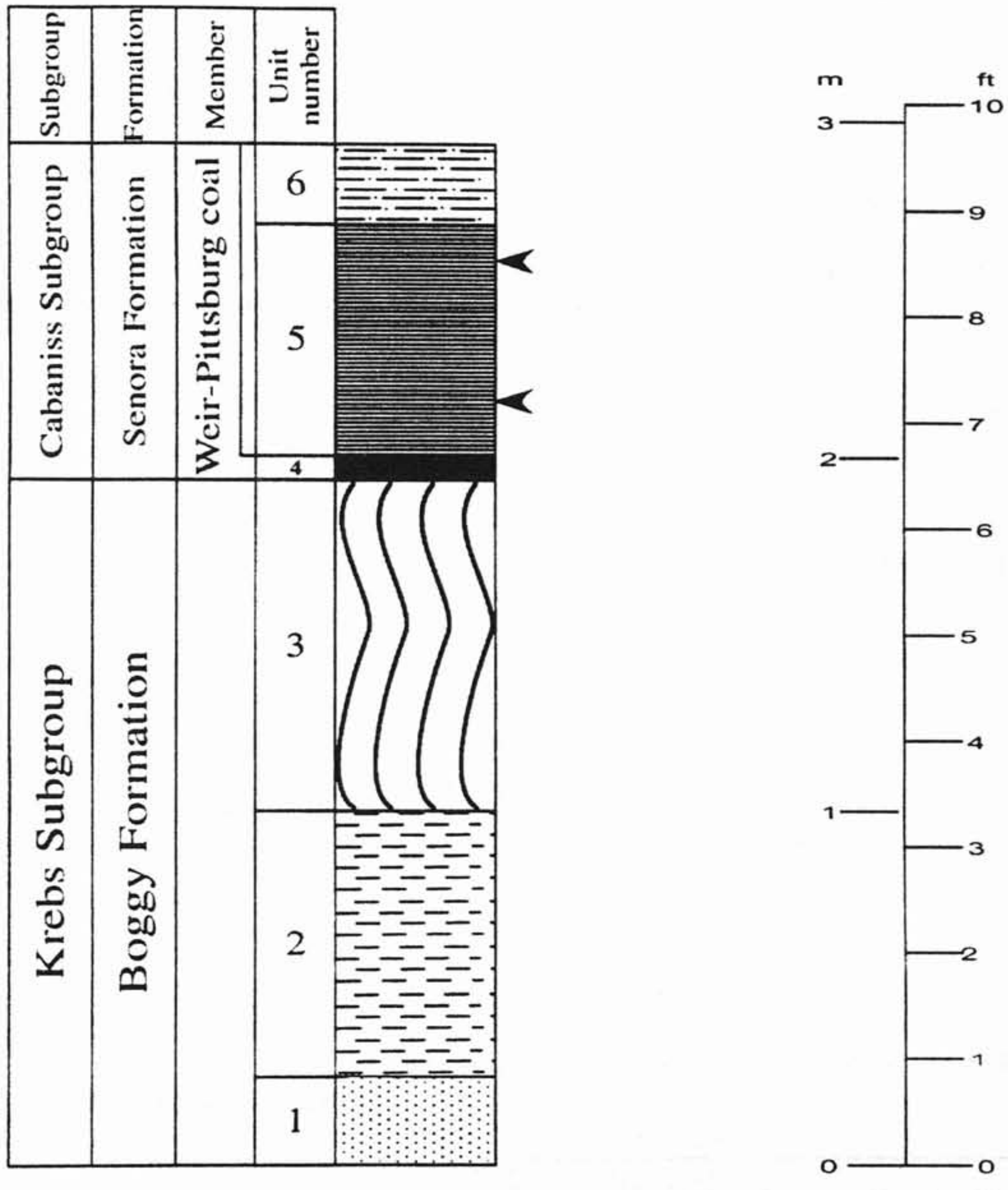


FIGURE 54. Drafted interval of the core section described by Measured Section #24, This is the same cycle noted in the last measured section but in core.

MEASURED SECTION #24

Sequence with the Weir-Pittsburg Taken from the RAMM Core (OGS designation C-RM-2).

SE1/4SW1/4NW1/4SE1/4 Sec. 12, T21N, R16E

Based upon core descriptions by Leroy Hemish, Hemish, L.A., 1997, *Lithologic descriptions of Pennsylvanian strata north and east of Tulsa, Oklahoma*: Oklahoma Geological Survey Special Publication 97-2, pp 36, Core-Hole Log 6, Rogers County.

CHEROKEE GROUP
CABANISS SUBGROUP

SENORA FORMATION: Depth: feet (meters) Thickness: feet (meters)

6. Shale; medium dark gray (N4); fissile; silty; numerous plant (possibly fern) impressions; also brachiopods and possibly pelecypods
187.3 (56.2) 0.7 (0.21)

5. Black shale; grayish black (N2); fissile; hard; dime sized phosphate nodules; sparsely fossiliferous, poorly preserved ostracods
188.0 (56.4) 2.1 (0.63)

4. Weir-Pittsburg coal; black (N1); soft; friable; pinkish gray (5YR 8/2) spots and streaks
190.1 (57.0) 0.2 (0.06)

KREBS SUBGROUP

BOGGY FORMATION:

3. Underclay; light brownish gray (5YR 6/1); clayey; silty; upper contact interbedded with chunks of degraded coal; gradual contact with clay shale below
190.3 (57.1) 3.0 (0.9)

2. Clay shale; medium gray (N5); massive; soft
193.3 (58.0) 2.4 (0.72)

1. Sandstone; medium dark gray (N4); fine grained; dark yellowish orange (10YR 6/6) and grayish red (10R 4/2) staining
195.7 (58,7) 0.8 (0.24)

TOTAL: 9.2 (2.8)

2. Oxidized clay shale; medium gray (N5) weathers to medium gray, light olive gray (5Y 6/1), and dark yellowish orange (10YR 6/6); light brown (5YR 6/6) oxidation; blocky; silty; hackly 4.0 (1.2)

1. Clay shale; pale olive (10Y 6/2) to medium gray (N5) weathers to medium light gray (N6), light olive gray (5Y 6/1), and pale yellowish brown (10YR 6/2); light (5YR 5/6) to moderate (5YR 3/4) brown and dark yellowish orange (10YR 6/6) oxidation; blocky; thin-bedded to massive; silty; dikes of tan shale; fractures; lower contact below water level 4.0 (1.2)

TOTAL: 25.3 (7.6)

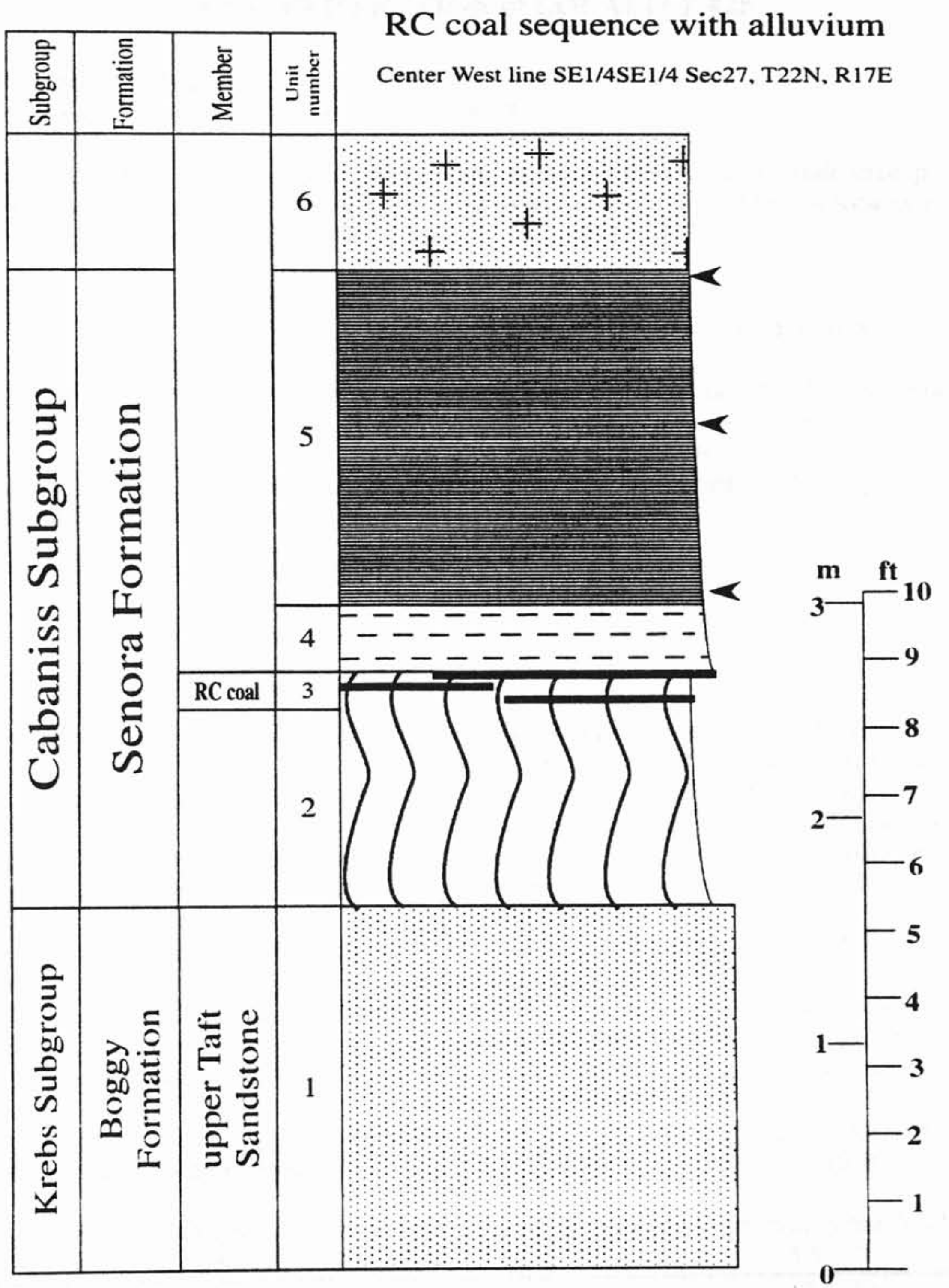


FIGURE 56. Drafted section of Locality #25

MEASURED SECTION of LOCALITY #25

RC coal sequence

Center East Line SE1/4SE1/4 Sec 27, T22N, R17E

Measured along road cut on west side of road. Measured from small roadside shale pit along bluff of small hill around curve in road to hillside exposure. Most of locality is very poorly exposed.

Thickness in feet (meters)

6. Alluvium (recent); dark yellowish orange (10YR 6/6), moderate brown (5YR 4/4), and grayish black (N2) streaks weathers to grayish orange (10YR 7/4); sandy; massive; chunks of fissile dark gray (N3) and dark yellowish orange (10YR 6/6) shale; moderate brown (5YR 8/4) plant fragments; yellowish gray (5Y 7/2) fragments of fine grained sandstone or siltstone; crumbly 4.0 (1.2)

CHEROKEE GROUP
CABANISS SUBGROUP

SENORA FORMATION:

5. Shale; grayish black (N2) weathers to light brownish gray (5YR 6/1) and pale yellowish brown (10YR 6/2); moderate brown (5YR 4/4), very pale orange (10YR 8/2), and grayish purple red (5RP 4/2) oxidation; quarter-inch to half-inch grayish black (N2) suboval to circular phosphate nodules; fissile; weathers to flakes on surface of outcrop; contains a few very poorly preserved unidentifiable fossils, probably gastropods and brachiopods, unidentifiable orthid brachiopods on bedding planes 5.0 (1.5)

4. Clay shale; fissile; mostly covered 1.0 (0.3)

3. RC coal equivalent; black (N1); numerous thin discontinuous carbonaceous stringers in upper part of underclay; occupies stratigraphic interval of the RC coal; weathered; smutty; poorly exposed 0.04 (0.01)

2. Underclay; medium gray (N5) mottled with dark yellowish orange (10YR 6/6); massive; silty; poorly exposed 3.0 (0.9)

1. Upper Taft Sandstone; massive bedded; covered by trees and vegetation; forms bluff on top of small hill adjacent to road 5.5 (1.7)

TOTAL: 18.5 (5.6)

Sequence with the RC taken from core.
Taken from core designation C-RM-2,
cored by Oklahoma Geological Survey and
described by Leroy Hemish.

SE1/4SW1/4NW1/4SE1/4 Sec. 12, T21N, R16E

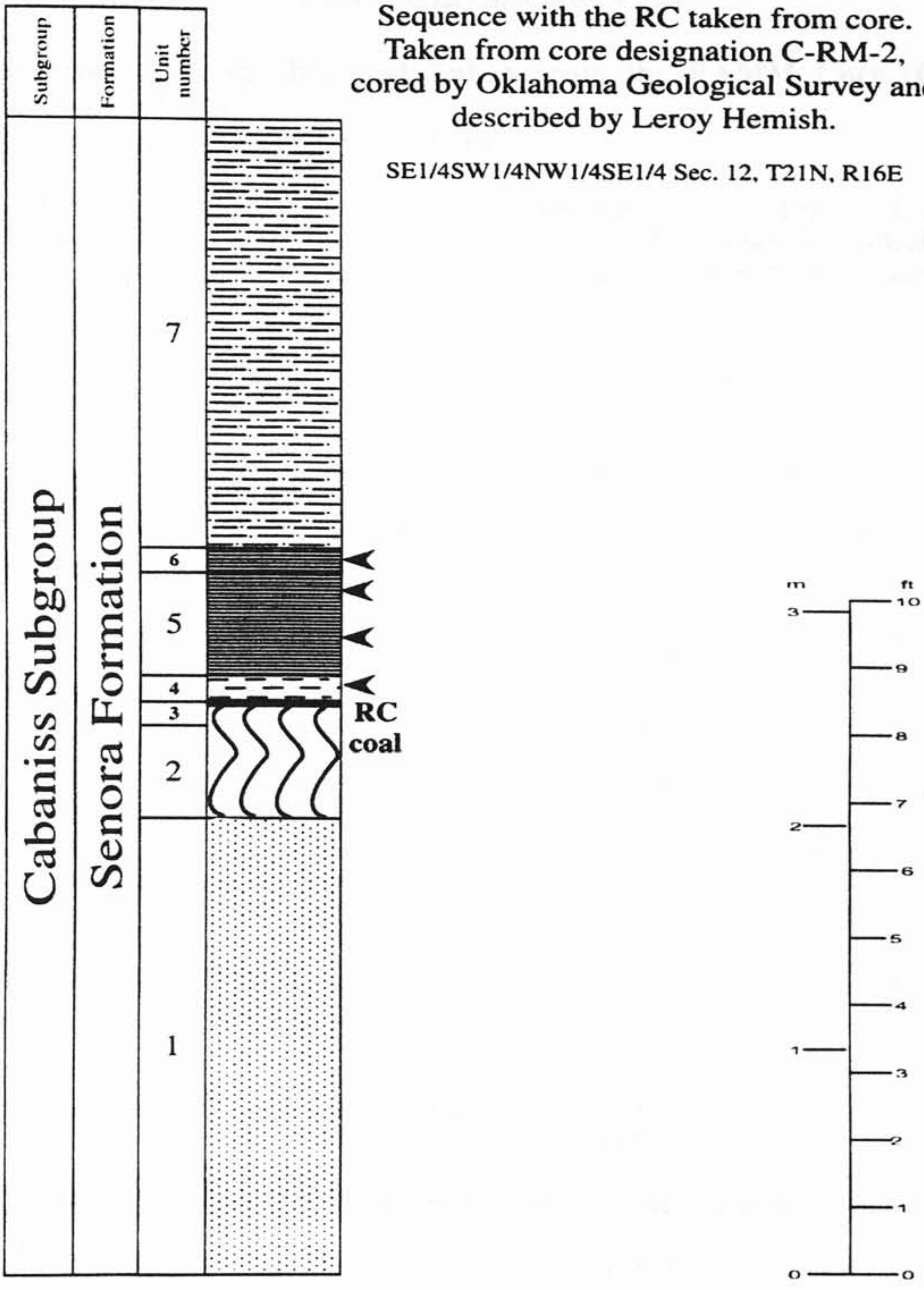


FIGURE 57. Drafted interval of the core section described in Measured Section #26

MEASURED SECTION #26

Sequence with the RC coal Taken from the RAMM Core (OGS designation C-RM-2).

SE1/4SW1/4NW1/4SE1/4 Sec. 12, T21N, R16E

Based upon core descriptions by Leroy Hemish, Hemish, L.A., 1997, *Lithologic descriptions of Pennsylvanian strata north and east of Tulsa, Oklahoma*: Oklahoma Geological Survey Special Publication 97-2, pp 35, Core-Hole Log 6, Rogers County.

CHEROKEE GROUP
CABANISS GROUP

SENORA FORMATION: Depth: feet (meters) Thickness: feet (meters)

7. Shale; medium dark gray (N4); silty; iron nodules; carbonized plant fragments
65.0 (19.5) 6.2 (1.9)

6. Black shale; grayish black (N2); blocky; non-calcareous; scattered white shell fragments on surface, brachiopods, sparse *Idiognathodus* conodont elements, and possibly gastropods, gradational contact with lower unit
71.2 (21.3) 0.3 (0.09)

5. Black shale; black (N1) to grayish black (N2); blocky; dime to pea sized phosphate nodules; light brownish gray (5YR 6/1) calcareous stringers from 72.3 to 72.6 feet; stringers consist mainly of brachiopod and pelecypod shells; microfauna consists of pyritized pelecypod shells
71.5 (21.5) 1.5 (0.45)

4. Shale; dark gray (N3) to medium gray (N5); fissile; soft; carbonaceous; gradational contact with overlying shale
73.0 (21.9) 0.37 (0.11)

3. RC coal; black (N1); soft, degraded; friable; whitish staining
73.37 (22.0) 0.021 (0.006)

2. Underclay; light gray (N7); sandy; interbedded with lenticular siltstone; organic and rust staining
73.4 (22.02) 1.6 (0.48)

1. Sandstone; very light gray (N8); cross-bedded with greenish gray (5GY 6/1) sandstone; wavy; upper part of sandstone extensively fractured, fractures filled with dark reddish brown (10R 3/4); fracturing decreases downward

	75.0 (22.5)	6.7 (2.0)
	TOTAL:	16.7 (5.0)

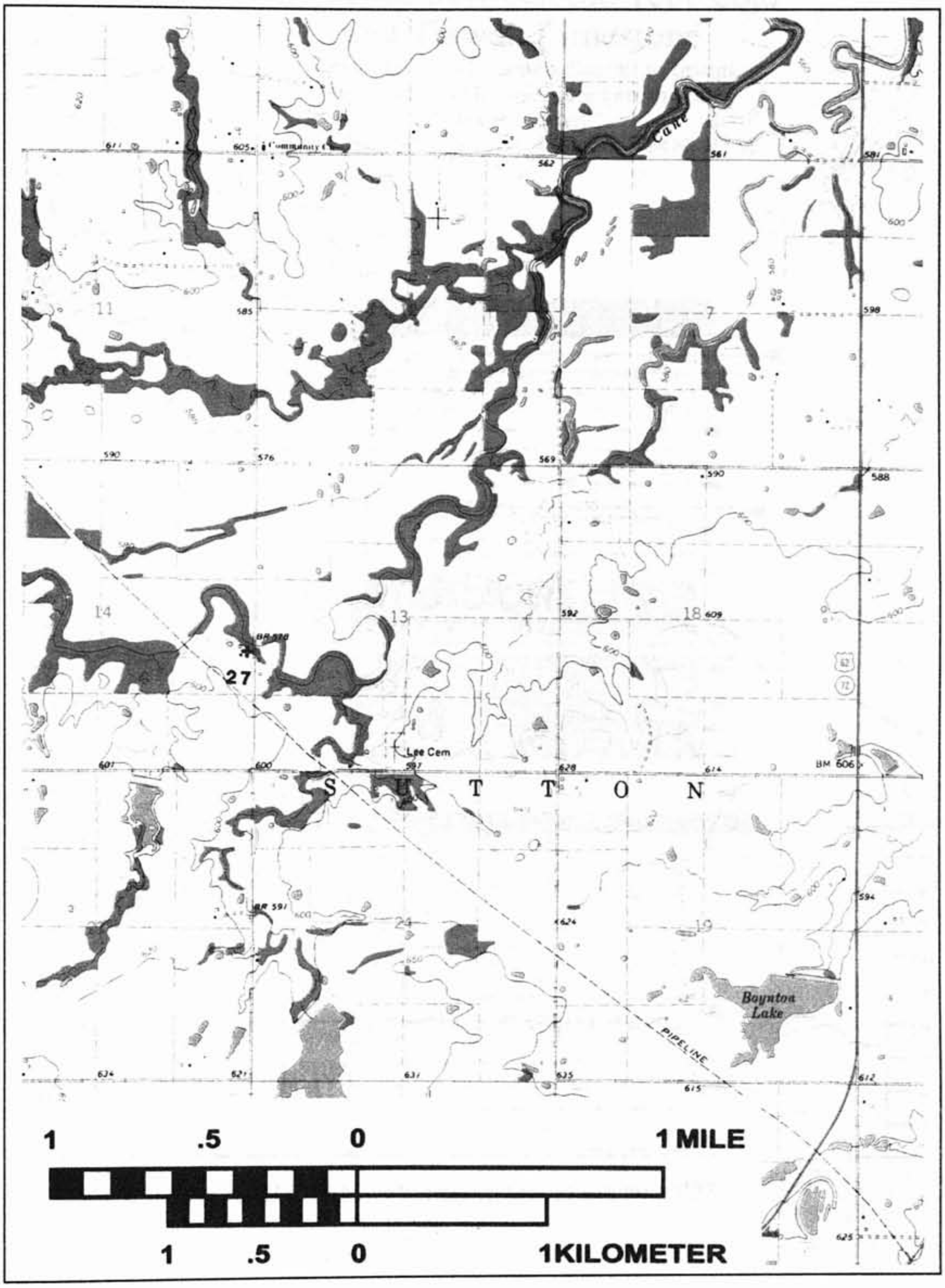


FIGURE 58. Topographic map of Locality #27, Muskogee County

Sequence between the Tebo coal and Tiawah Limestone

Measured on hill slope adjacent to bridge over Cane Creek. Measured from water level to road

SE1/4NE1/4NE1/4SE1/4 Sec14, T14N, R15E

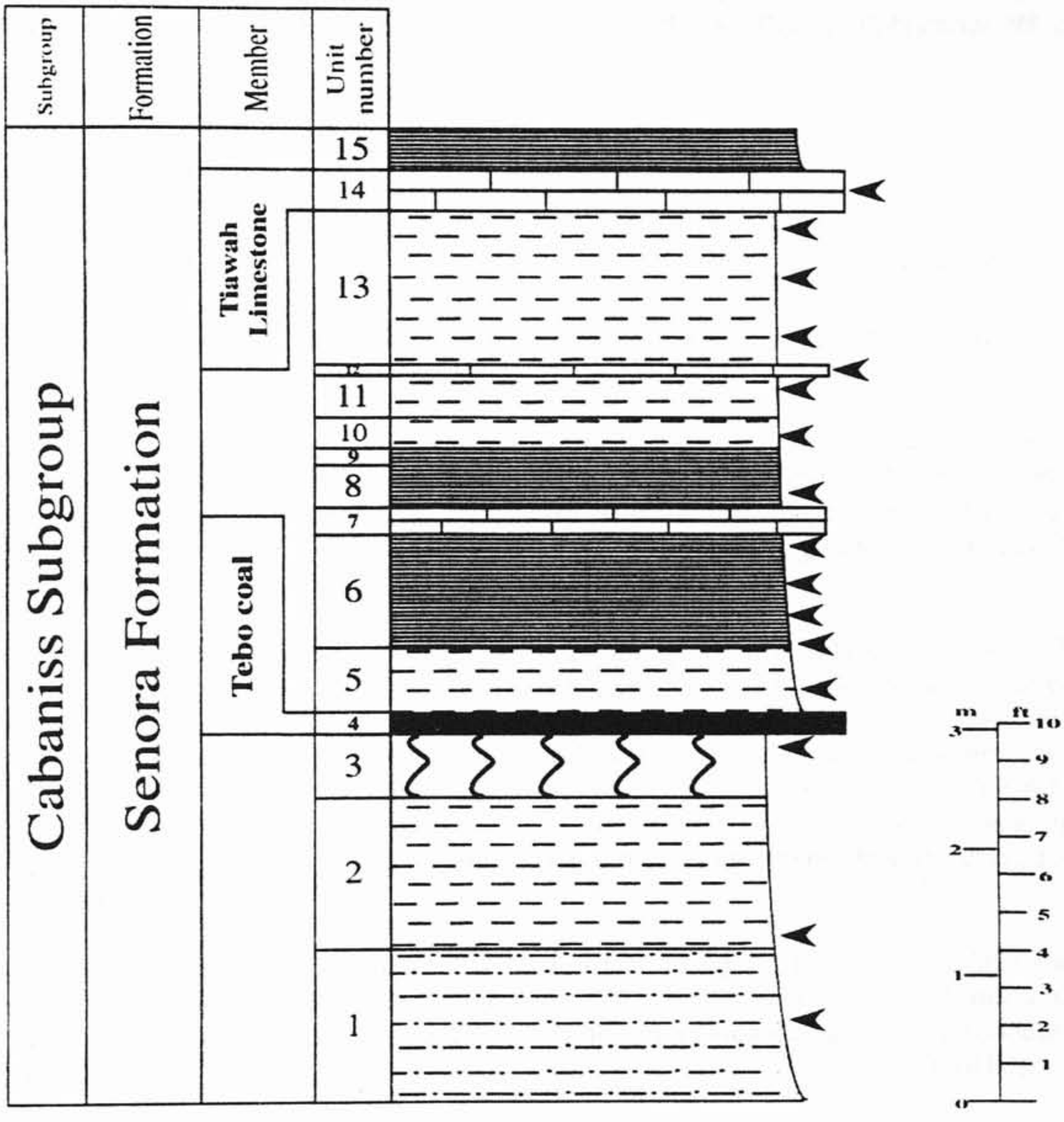


FIGURE 59. Drafted section of Locality #27

MEASURED SECTION of LOCALITY #27

Sequence between the Tebo coal and Tiawah Limestone
SE1/4NE1/4NE1/4SE1/4 Sec 14, T14N, R15E

Measured on hill slope adjacent to bridge over Cane Creek. Measured from water level to field next to bend in road above bridge. Based on Hemish, L.A.,1998, *Coal geology of Muskogee County, Oklahoma*: Oklahoma Geological Survey Special Publication 98-2, pp. 55, Measured Section 55.

CHEROKEE GROUP
CABANISS SUBGROUP

SENORA FORMATION: Thickness in feet (meters)

15. Black shale; grayish black (N2); fissile; hackly; phosphate nodules; very poorly exposed 1.0 (0.3)

14. Tiawah Limestone; wackestone; brownish gray (5YR 4/1) and medium dark gray (N4) weathers to brownish gray (5YR 4/1), moderate yellowish brown (10YR 5/4), and pale yellowish brown (10YR 6/2); shaly; hard; fossiliferous, brachiopods, gastropods (including *Platyceras*), pyritized ostracods, fish teeth, and *Idiognathodus* conodonts; forms prominent bench at top of outcrop 1.0 (0.3)

13. Shale; dark gray (N3) weathers to medium dark gray (N4), light olive brown (5Y 5/6), dark reddish brown (10R 3/4), and pale brown (5YR 5/2); dark yellowish orange (10YR 6/6) oxidation; fissile; hard; platy; ferruginous; grayish yellow (5Y 8/4) spots and streaks; numerous inch thick cubic light olive brown ironstone stringers at around two feet above lower contact; inch thick black (N1) and dark yellowish orange (10YR 6/6) hackly, nodular ironstone stringers at upper contact; tabular gypsum crystals on bedding planes; fossiliferous, *Reophax* and other foraminifera, and broken, heavily degraded gastropods 4.25 (1.3)

12. Limestone; mudstone; dark gray (N3) weathers to light olive gray (5Y 5/2) and medium dark gray (N4); dark yellowish orange (10YR 6/6) oxidized rind; hard; massive; nodular; discontinuous stringer in outcrop; *Glaphyrites* ammonoids, and sparse conodont fragments 0.10 (0.03)

11. Shale; grayish black (N2) to dark gray (N3) weathers to grayish blue (5PB 5/2), brownish gray (5YR 4/1), and dark gray (N3); dark yellowish orange (10YR 6/6) and pale yellowish brown (10YR 6/2) oxidation; fissile; soft; crumbly; weathered; tabular gypsum crystals on bedding planes; broken iron crusts in upper part of unit 1.0 (0.3)

10. Shale; dusky yellowish brown (10YR 2/2) weathers to brownish gray (5YR 4/1), medium dark gray (N4), and grayish orange pink (5YR 7/2); pale yellowish orange (10YR 8/6) and dark yellowish orange (10YR 6/6) oxidation; grayish yellow (10YR 6/6) streaks; fissile; hard; platy with sharp edges, fossiliferous, poorly preserved ostracods, gastropods, and *Idiognathodus* conodonts 0.83 (0.25)

9. Shale; grayish black (N2) weathers to dark gray (N3) and light olive gray (5Y 6/1); dark yellowish orange (10YR 6/6) and moderate yellowish brown (10YR 5/4) oxidation; fissile; soft; calcareous; carbonaceous; light brownish gray (5YR 6/1) scattered shell fragments; tabular gypsum crystals on bedding planes 0.33 (0.10)

8. Shale; grayish black (N2) to dark gray (N3) weathers to dark gray (N3), brownish gray (5YR 4/1), and medium dark gray (N4); fissile; platy; somewhat soft; calcareous; bedding planes covered with radial and tabular gypsum crystals; fossiliferous, pelecypods, archaeogastropods, mesogastropods, and *Idiognathodus* conodonts 1.25 (0.38)

7. Limestone; mudstone; dark gray (N3) rind; crystalline interior; flattened nodular appearance in outcrop; discontinuous unit; ammonoids common, mostly *Glaphyrites* ammonoids 1.0 (0.3)

6. Black shale; grayish black (N2) weathers to dark gray (N3) and brownish gray (5YR 4/1); grayish red purple (5RP 4/2), light brown (5YR 5/6), and dark yellowish orange (10YR 6/6) oxidation; fissile; hard; platy; lower contact blocky and thick-bedded becomes increasingly more fissile upward; numerous suboval half-inch to inch diameter grayish black phosphate nodules around ten to eleven inches about lower contact; very fossiliferous, gastropods, pelecypods, and *Gondolella* and *Idiognathodus* conodonts; *Gondolella* nearly constitutes half of the conodont fauna of this unit 3.0 (0.9)

5. Shale; dark gray (N3) weathers to medium dark gray (N4), pale olive (10Y 6/2), and pale yellowish brown (10YR 6/2); moderate yellowish brown (10YR 5/4), pale yellowish orange (10YR 8/6), and dark yellowish orange (10YR 6/6) oxidation; unit becomes less oxidized towards upper contact; fissile; platy; hard; ferruginous; gypsum and pyrite on bedding planes at lower contact; upper five inches of unit fossiliferous, pyritized brachiopods and pelecypods; plant fragments found about a foot above lower contact; diagonal fracture patterns on surface of outcrop 1.5 (0.45)

4. Tebo coal; black (N1) weathers to dark gray (N3); light brown (5YR 5/6) oxidation; glassy surface; fine cleated; hard; resistant; crumbly; thin layer of gypsum above coal 0.5 (0.15)

3. Underclay; medium dark gray (N4) with light brown (5YR 5/6) mottling weathers to medium gray (N5) with very light gray (N8) flecks; grayish yellow (5Y 8/4) sulfur staining; massive; hard; silty; dark carbonaceous streaks; soil nodules 1.58 (0.5)

2. Oxidized clay shale; medium gray (N5) weathers to medium gray, light olive gray (5Y 6/1), and dark yellowish orange (10YR 6/6); light brown (5YR 6/6) oxidation; blocky; silty; hackly 4.0 (1.2)

1. Clay shale; pale olive (10Y 6/2) to medium gray (N5) weathers to medium light gray (N6), light olive gray (5Y 6/1), and pale yellowish brown (10YR 6/2); light (5YR 5/6) to moderate (5YR 3/4) brown and dark yellowish orange (10YR 6/6) oxidation; blocky; thin-bedded to massive; silty; dikes of tan shale; fractures; lower contact below water level 4.0 (1.2)

TOTAL: 25.3 (7.6)

PHOTOGRAPH 7

Photograph of Locality #27

The Tiawah Limestone can be seen just above the center of the photograph; the black fissile shale below the Tiawah Limestone can be seen in the left corner of the photograph. The Tiawah Limestone at this locality is a regressive limestone, but farther north in Rogers County, the Tiawah Limestone thickens and has both a regressive and transgressive facies separated by an intraformational conglomerate.

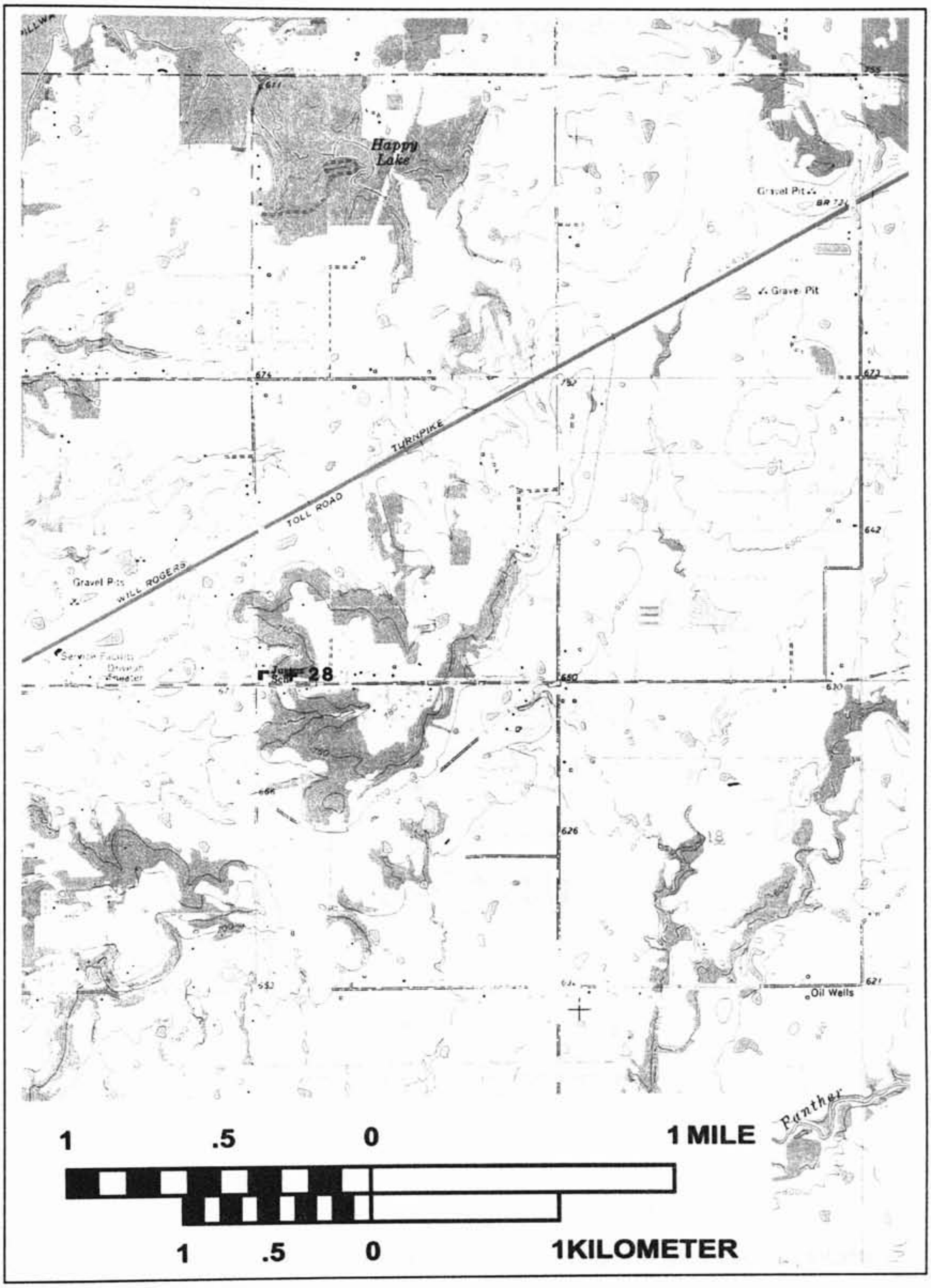


FIGURE 60. Topographic map of Locality #28, Rogers County

Interval from the Tiawah Limestone to the Chelsea Sandstone

Roadcut measurement on S.H. 20
about 2.5 miles east of Claremore, OK.
Measured on northern roadcut.

SE1/4SW1/4 Sec12, T21N, R16E

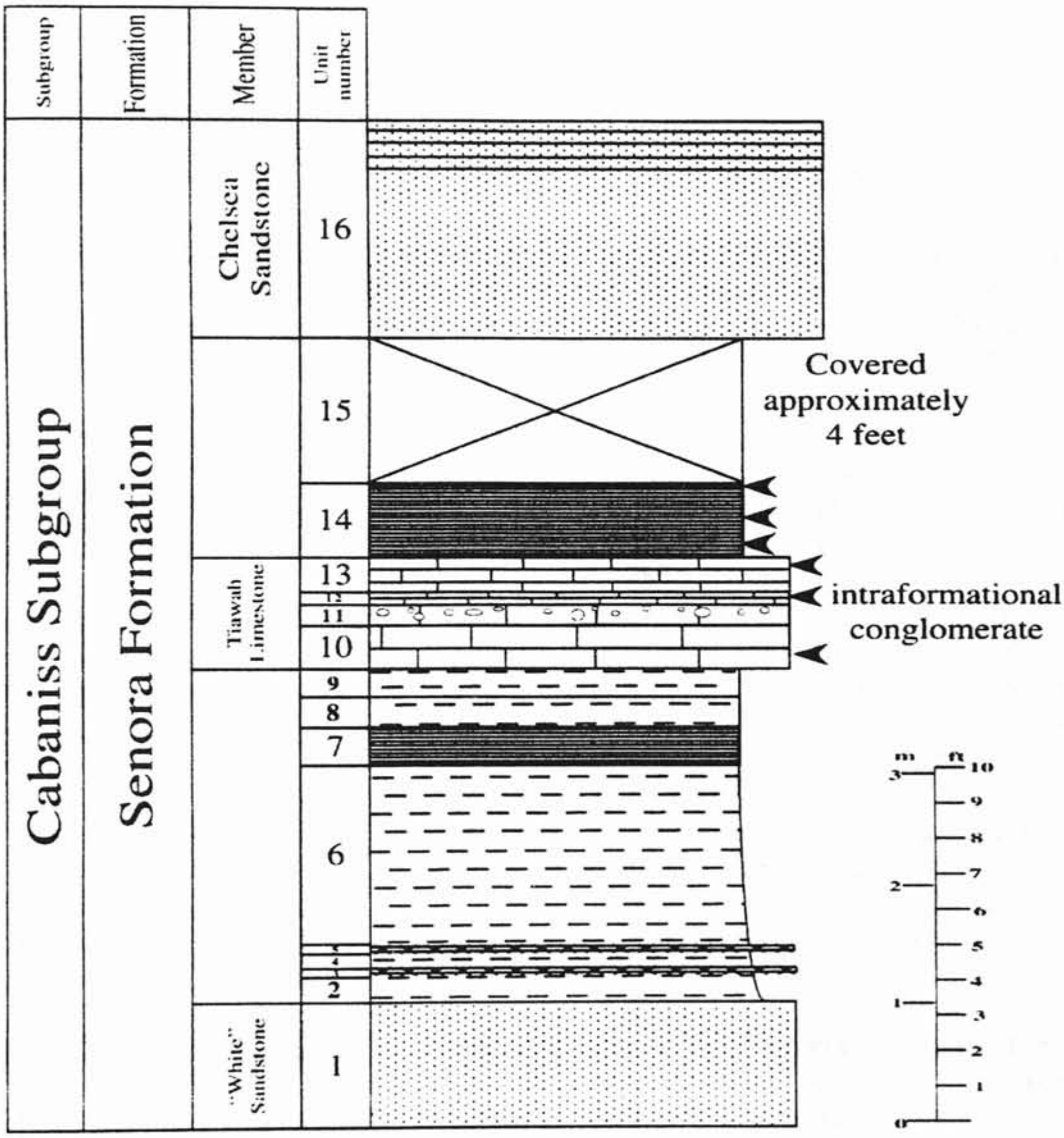


Figure 61. Drafted section of Locality #28, This represents nearly the entire cyclothem involving the Tiawah Limestone.

MEASURED SECTION of LOCALITY #28

Interval from the Tiawah Limestone to the Chelsea Sandstone

SE1/4SW1/4 Sec 12, T21N, R16E

Measured from Taft Sandstone to Chelsea Sandstone on northern roadcut on State Highway 20, about 2.5 miles (4.02 km) east of Claremore, OK. Measured from bottom of hill to top.

CHEROKEE GROUP
CABANISS SUBGROUP

SENORA FORMATION: Thickness in feet (meters)

16. Chelsea Sandstone; quartz arenite; brown; medium-bedded to thin-bedded; fine grained; moderately sorted; hematite and silica cement; scattered organic material; lower contact exhibits planar bedding; hematitic plant material in lower part of unit; forms bluff at top of hill 9.9 (3.0)

15. Covered 4.0 (1.8)

14. Clay shale; black (N1) to dark gray (N3) interbedded with dark yellowish orange (10YR 6/6) weathers to brownish gray (5YR 4/1) and olive gray (5Y 4/1); very soft; wet; fissile to blocky; plastic; some very pale orange (10YR 8/2) mottling on some bedding planes; up to two inch diameter oval and irregular shaped brownish gray phosphate nodules in lower foot of unit; light brown (5YR 5/6) oxidation; very slightly calcareous; fossiliferous with *Bairdia* and *Sansabella* ostracods, *Idiognathodus* and *Idioprioniodus* conodonts, and *Ammodiscus* and *Bigeneria* foraminifera, orthid brachiopods, and gastropods 2.0 (0.6)

13. Tiawah Limestone; wackestone; medium gray (N5) mottled with dark reddish brown (10R 3/4) weathers to grayish red (5R 4/2), brownish gray (5YR 4/1), and grayish orange (10YR 7/4); hard; ferruginous; massive; dense; thick-bedded; very fossiliferous, large pelecypods (clams), productids, fenestrate bryozoans, rugose corals, crinoid columnals, and calcareous shell hash 0.92 (0.27)

12. Tiawah Limestone; wackestone; flooding surface; light brownish gray (5YR 6/1) weathers to grayish brown (5YR 3/2), and pale yellowish brown (10YR 6/2); shaly; hard; slightly silty; grayish red (5R 4/2) oxidation; scattered productid brachiopod shell fragments, fish teeth, and calcareous foraminifera 0.33 (0.1)

11. Tiawah Limestone; intraformational conglomerate; very pale orange (10YR 8/2) with well rounded brownish gray (5YR 4/1) limestone clasts; some clasts up to two inches in diameter; weathers to light brownish gray (5YR 6/1) and grayish brown (5YR 3/2); hard; massive; calcareous; somewhat silty; hackly surface; reworked shattered brachiopod shells, calcareous foraminifera, and sparse fragmentary *Idiognathodus* conodonts, and other reworked unidentifiable fossils 1.7 (0.50)

10. Tiawah Limestone; packestone; greenish gray (5GY 6/1) mottled with pale red (5R 6/2) weathers to pale red, medium light gray (N6), and pale yellowish brown (10YR 8/2); dark yellowish orange (10YR 6/6), grayish orange pink (5YR 7/2), and moderate brown (5YR 4/4) banded oxidation; ferruginous; massive; hard; crystalline; dense; fossiliferous with spiriferid and strophomenid brachiopods 1.75 (0.52)

9. Shale; medium gray (N5) mottled with light olive gray (5Y 5/2) weathers to light brownish gray (5YR 6/1), medium light gray (N6), and pale olive (10Y 6/2); grayish orange (10YR 7/4) to dark yellowish orange (10YR 6/6) oxidation; blocky; silty; massive bedding; bedding planes covered in radial gypsum crystals; weathered surface riddled with concentric rings or bands of dark gray (N3) and medium gray discoloration; some discoloration rings or regions have gypsum crystals in the middle; white gypsum streaks 0.75 (0.23)

8. Clay shale; medium dark gray (N4) mottled with olive gray (5Y 4/1) weathers to medium gray (N5), grayish orange pink (5YR 7/2), and light olive gray (5Y 5/2); moderate yellowish brown (10YR 5/4) and light brown (5YR 5/6) oxidation; hard; blocky; massive; weathered; silty; nodular; very slightly micaceous; breaks off into shards with sharp edges; mostly covered 0.83 (0.25)

7. Black shale; dark gray (N3) to grayish black (N2) weathers to medium dark gray (N4) and pale yellowish brown (10YR 6/2); moderate reddish brown (10R 4/6) oxidation; blocky; massive; swaly; nodular; numerous large (up to two inch diameter) irregular shaped grayish black phosphate nodules in lower part of unit; greasy feel to shale surface; shale becomes less dark towards upper contact, going from grayish black to dark gray; *Lingula* brachiopods present on bedding planes; gastropods, and *Idiognathodus* conodonts; mainly conodonts are sparse and fragmentary; mostly covered 1.0 (0.3)

6. Shale; grayish black (N2) weathers to medium dark gray (N4), brownish gray (5YR 4/1), pale yellowish brown (10YR 6/2), and grayish red purple (5RP 4/2); becomes olive gray (5Y 4/1) in upper part of shale; medium to thick bedded; blocky; very slightly micaceous; brachiopods present; breaks off into flakes with sharp surfaces; very poorly exposed, upper contact of shale not visible 4.0 (1.02)

5. Ironstone; dark gray (N3) with reddish brown rind; singular massive bed; poorly exposed 0.25 (0.08)

4. Shale; dark gray (N3) weathers to medium gray (N5); silty; micaceous; one inch thick moderate yellowish brown (10YR 5/4) and pale yellowish orange (10YR 8/6) iron nodules; fissile; soft; severely covered with soil and vegetation 0.33 (0.10)

3. Ironstone; dark gray (N3) with reddish brown rind; massive bedding; calcareous; silty; poorly exposed 0.21 (0.06)

2. Shale; dark gray (N3) weathers to medium gray (N5); micaceous; silty; fissile; soft; carbonaceous; one inch thick moderate yellowish brown (10YR 5/4) and pale yellowish orange (10YR 8/6) iron nodules 0.67 (0.2)

1. Taft Sandstone; quartz arenite; brownish gray (5YR 4/1) mottled with dark yellowish orange (10YR 6/6) weathers to pale yellowish brown (10YR 6/2) and light brownish gray (5YR 6/2); dark yellowish brown (10YR 4/2) and dark yellowish orange staining; very fine grained; angular quartz grains; calcareous; hard; shaly to massive; includes clasts of up to one inch diameter of shale or limestone; fossiliferous, brachiopods and crinoid columnals 3.4 (1.02)

TOTAL: 32.0 (9.61)

PHOTOGRAPH 8

Photograph showing close-up of the Tiawah Limestone at Locality #28 on Highway 20. The intraformational conglomerate is visible in the middle of the unit. The intraformational conglomerate marks the boundary between the regressive and transgressive facies within the Tiawah at Locality #28. (yard ruler for scale)

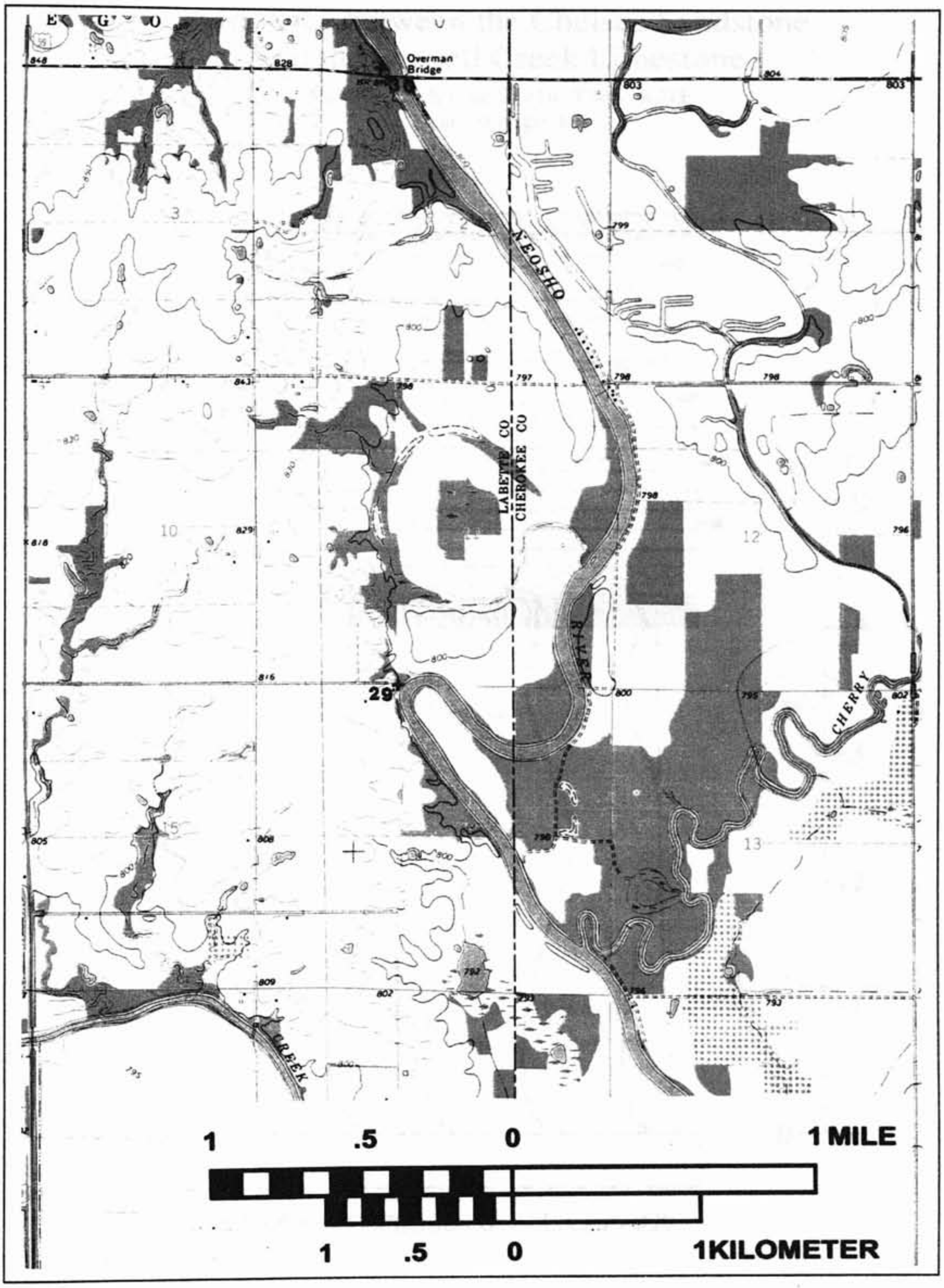


FIGURE 62. Topographic map of Localities # 29 and 30, Labette and Cherokee counties, Kansas

Sequence between the Chelsea Sandstone and the Russell Creek Limestone
Middle North Line Sec14, T34S, R21E
Near Oswego, KS

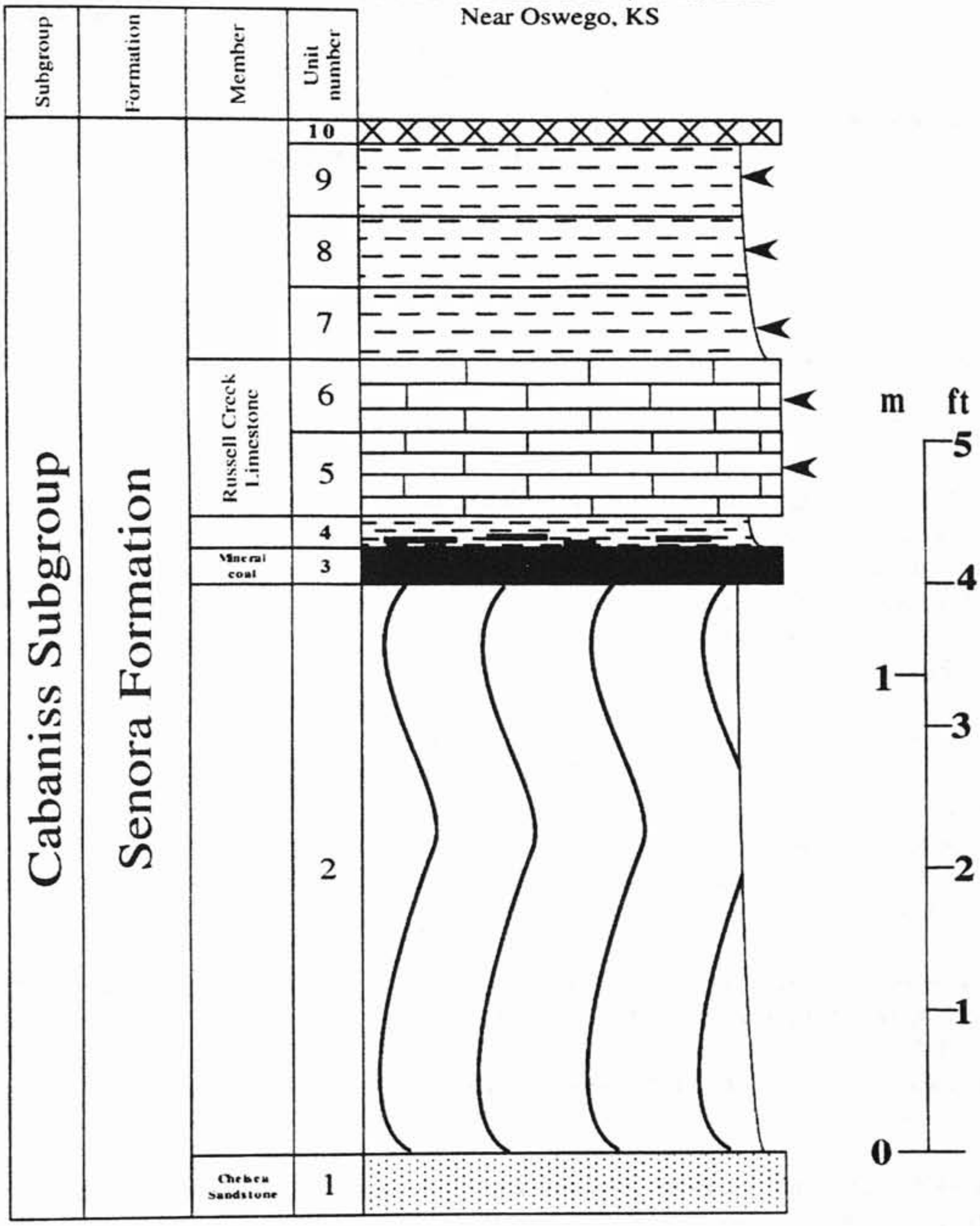


FIGURE 63. Drafted section of Locality #29

MEASURED SECTION of LOCALITY #29

Exposure from the Chelsea Sandstone to above the Russell Creek Limestone

Middle North Line Sec 14, T34S, R21E

Measured along road ditch south side of the road, near bend in the Neosho River. Measured east to west from bottom to top of small hill along road.

CHEROKEE GROUP
CABANISS SUBGROUP

SENORA FORMATION: Thickness in feet (meters)

10. Ironstone 0.17 (0.05)

9. Clay shale; moderate yellowish brown (10YR 5/4), light brownish gray (5YR 6/1), and grayish orange (10YR 7/4) weathers to very pale orange (10YR 8/2); soft; blocky; silty; dark gray (N3) carbonaceous streaks; calcareous; prominent bench in ditch; highly fossiliferous with a diverse fauna, pelecypods, *Chonetes* and productid brachiopods, *Trepospira* gastropods, ostracods, holothurian sclerites, and echinoid plates 0.5 (0.15)

8. Clay shale; bluish white (5B 9/1) to light gray (N7) banded with grayish orange (10YR 7/4) weathers to grayish orange, yellowish gray (5Y 7/2), and very light gray (N8); soft; blocky; crumbly; thin-bedded; thin carbonaceous streaks; ferruginous; calcareous; very fossiliferous, rugose corals, *Worthenia* and *Bellerophon* gastropods, echinoid spines, crinoid columnals, ostracods, holothurian sclerites, and *Idiognathodus* conodonts; chert fragments; poorly exposed 0.5 (0.15)

7. Shale; medium (N5) to dark (N3) gray banded with light olive gray (5Y 5/6) weathers to light brownish gray (5YR 6/1), brownish gray (5YR 4/1), very pale orange (10YR 8/2), and grayish orange (10YR 7/4); blocky; soft; clayey; numerous half inch to inch diameter brownish gray phosphate nodules; wavy bedded; *Idiognathodus* and *Idioprioniodus* conodonts; very poorly exposed 0.5 (0.15)

6. Russell Creek Limestone (upper bed); packestone; medium dark gray (N4) with grayish orange (10YR 7/4) rind weathers to pale yellowish brown (10YR 6/2), grayish orange, pinkish gray (5YR 8/1), and medium gray (N5); crystalline; dense; hard; massive; fossiliferous, brachiopods, *Idiognathodus* conodonts, and fusulinids; top part of prominent bench in ditch 0.5 (0.15)

5. Russell Creek Limestone; medium dark gray (N4) weathers to medium light gray (N5) and grayish orange (10YR 7/4); grayish red (5R 4/2) oxidation staining; massive; hard; crystalline; fossiliferous, brachiopods, crinoids, fusulinids, *Idiognathodus* conodonts 0.6 (0.17)

4. Shale; dark yellowish orange (10YR 6/6); black (N1) near lower contact; carbonaceous; soft; heavily weathered 0.21 (0.06)

3. Mineral coal; black (N1); crumbly 0.25 (0.08)

2. Underclay; light gray mottled with orange; plastic 4.0 (1.2)

1. Chelsea Sandstone; heavily covered; unable to measure or describe

TOTAL: 7.23 (2.2)

The Fleming and Verdigris cycles of an exposure at the Overman Bridge on the banks of the Neosho River near Oswego, KS

Center of south line SW1/4SW1/4 Sec35, T33S, R21E

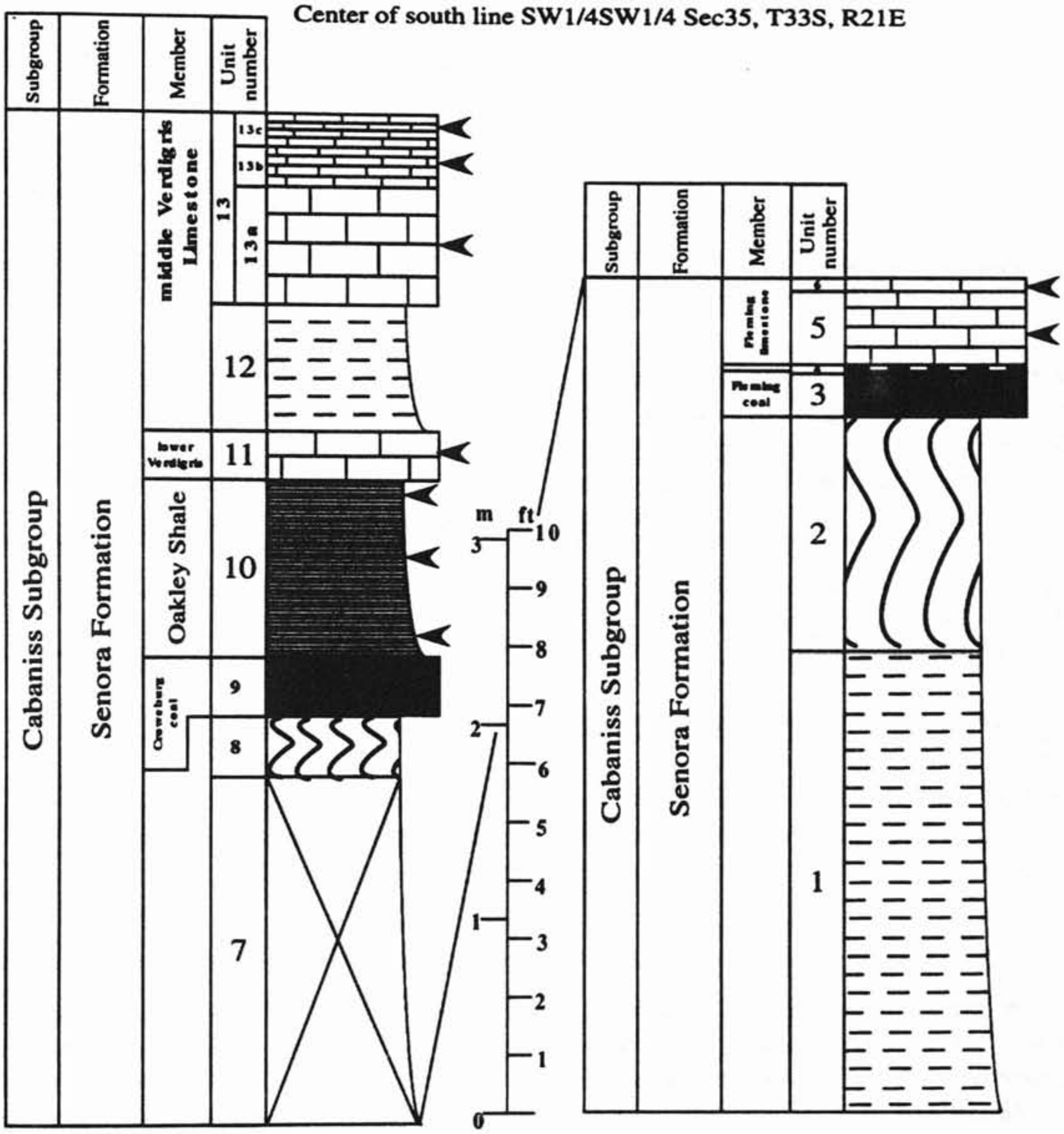


FIGURE 64. Drafted section of Locality #30, Two cyclothems are present in this interval.

MEASURED SECTION of LOCALITY #30

The Fleming and Verdigris Sequences of an Exposure at the Overman Bridge on the Banks of the Neosho River near Oswego, KS

Center South Line SW1/4SW1/4 Sec 35, T33S, R21E

Measured from ditch just below bridge to hill face above driveway.

CHEROKEE GROUP
CABANISS SUBGROUP

SENORA FORMATION: Thickness in feet (meters)

13. Verdigris Limestone (middle unit); divided into three subunits

13c. Upper subunit; mudstone; medium dark gray (N4) weathers to brownish gray (5YR 4/1), medium dark gray, pale yellowish brown (10YR 6/2), and light olive gray (5Y 5/2); flaggy to shaly; hard; pale red purple (5RP 6/2) chonetid brachiopods, *Idiognathodus* conodonts, encrusting and calcareous foraminifera, possibly *Tetrataxis* and *Cornuspira* among others 0.4 (0.12)

13b. Middle subunit; medium gray (N5) and pale yellowish brown (10YR 6/2) weathers to grayish orange (10YR 7/4) and very pale orange (10YR 8/2); hard; ferruginous; dense, nodular 0.83 (0.25)

13a. Lower subunit; wackestone; medium light gray (N6) with grayish orange (10YR 7/4) silty rind weathers to grayish orange and grayish red (10R 4/2) and bluish white (5B 9/1); dense; hard; massive, fossiliferous, rugose corals, brachiopods, crinoids, fragmented and poorly preserved encrusting and calcareous foraminifera, degraded holothurian sclerites, and very sparse *Idiognathodus* conodonts 2.02 (0.61)

TOTAL 3.25 (0.98)

12. Calcareous shale; dark gray (N3) and pale yellowish brown (10YR 6/2) weathers to grayish orange (10YR 7/4); clayey; somewhat fissile; blocky near upper contact; silty near lower contact, slightly fossiliferous, poorly preserved ostracods, *Idiognathodus* conodonts, and poorly preserved *Reophax* foraminifera 2.16 (0.65)

11. Verdigris Limestone (lower unit); mudstone; medium dark gray (N4) with a silty grayish orange (10YR 7/4) rind weathers to grayish orange; massive bedded; dense; hard; scattered brachiopod shells, *Idiognathodus* conodonts, and possible fish teeth 0.83 (0.25)

10. Oakely shale; dark gray (N3) to grayish black (N2) weathers to brownish gray (5YR 4/1) and pale yellowish brown (10YR 6/2); grayish red purple (5RP 4/2), moderate brown (5YR 3/4), and moderate yellow (5Y 7/6) oxidation; middle of unit heavily oxidized; fissile; platy; breaks off into sheets with sharp edges; hard; slight pinkish gray (5YR 8/1) mottling at lower contact; half inch diameter spherical and irregular shaped brownish gray phosphate nodules; large four inch diameter flattened iron nodules near upper contact; *Idiognathodus* and *Idioprioniodus* conodonts in upper foot of shale; coal streaks at lower contact 3.0 (0.9)

9. Croweburg coal, black (N1) 1.0 (0.3)

8. Underclay; medium light gray (N6) mottled with light brownish gray (5YR 6/1), dark yellowish orange (10YR 6/6), and pale yellowish orange (10YR 8/6); grayish yellow (5Y 8/4) spotting; black (N1) coal fragments and dark gray (N3) carbonaceous streaks; plant fragments; plastic; clayey 1.0 (0.3)

7. Covered (probably underclay) 6.0 (1.8)

6. Fleming limestone (upper unit); packestone; concentric banding of brownish gray (5YR 4/1) (core), light brown (5YR 5/6), dark reddish orange (10R 3/4), and dark yellowish orange (10YR 6/6) (outer layer) weathers to grayish orange pink (5YR 7/2), grayish orange (10YR 7/4), dark reddish brown, and moderate reddish brown (10R 6/6); very ferruginous; hard; thin-bedded; fossiliferous, large spiriferid brachiopods, gastropods, crinoid stems, and poorly preserved foraminifera 0.2 (0.06)

5. Fleming limestone (lower unit); grainstone; medium gray (N5) weathers to light brownish gray (5YR 6/1) and grayish orange pink (5YR 7/2); massive bedded; very hard; crystalline; carbonized fragments; fossiliferous, brachiopods, crinoids, *Idiognathodus* conodonts, and poorly preserved fish debris; forms caprock in ditch embankment 1.25 (0.38)

4. Clay shale; light brownish gray (5YR 6/1) mottled with grayish orange (10YR 7/4) weathers to brownish gray (5YR 4/1), dark yellowish orange (10YR 6/6), and grayish yellow (5Y 8/4) streaks; crumbly; soft; carbonaceous; somewhat calcareous 0.08 (0.02)

3. Fleming coal; black (N1) mottled with dark reddish brown (10R 3/4) and light brown (5YR 5/6); dark yellowish orange (10YR 6/6) and grayish yellow (5Y 8/4) streaking; weathered; soft; crumbly; cubic cleats 0.84 (0.25)

2. Underclay; very light gray (N8) to bluish white (5B 9/1) mottled with pale yellowish orange (10YR 8/6), light brown (5YR 5/6), and grayish orange (10YR 7/4) weathers to pale yellowish brown (10YR 6/2); dark yellowish orange (10YR 6/6) spots; clayey; plastic; silty; 0,12 inch black (N1) cubic coal fragments; incorporated rock fragments and tabular gypsum crystals 4.0 (1.2)

1. Clay Shale; grayish black (N2) to dark gray (N3) banded with light olive gray (5Y 5/2) weathers to medium gray (N5), pale yellowish orange (10YR 6/2), grayish orange (10YR 7/4), and very pale orange (10YR 8/2); massive; blocky; swaly; nodular; becomes increasingly more micaceous towards upper contact; grayish orange streaks and lines criss-crossing shale face; large (up to half foot) calcareous clay ironstone nodules, very dark red (5R 2/6), light brown (5YR 5/6), pale yellowish brown (10YR 6/2), and medium gray (N5); purplish-black calcareous nodules with aragonite crystals; limonite stringers; weathers to flakes; tabular gypsum crystals	8.0 (2.4)
TOTAL:	31.6 (9.5)

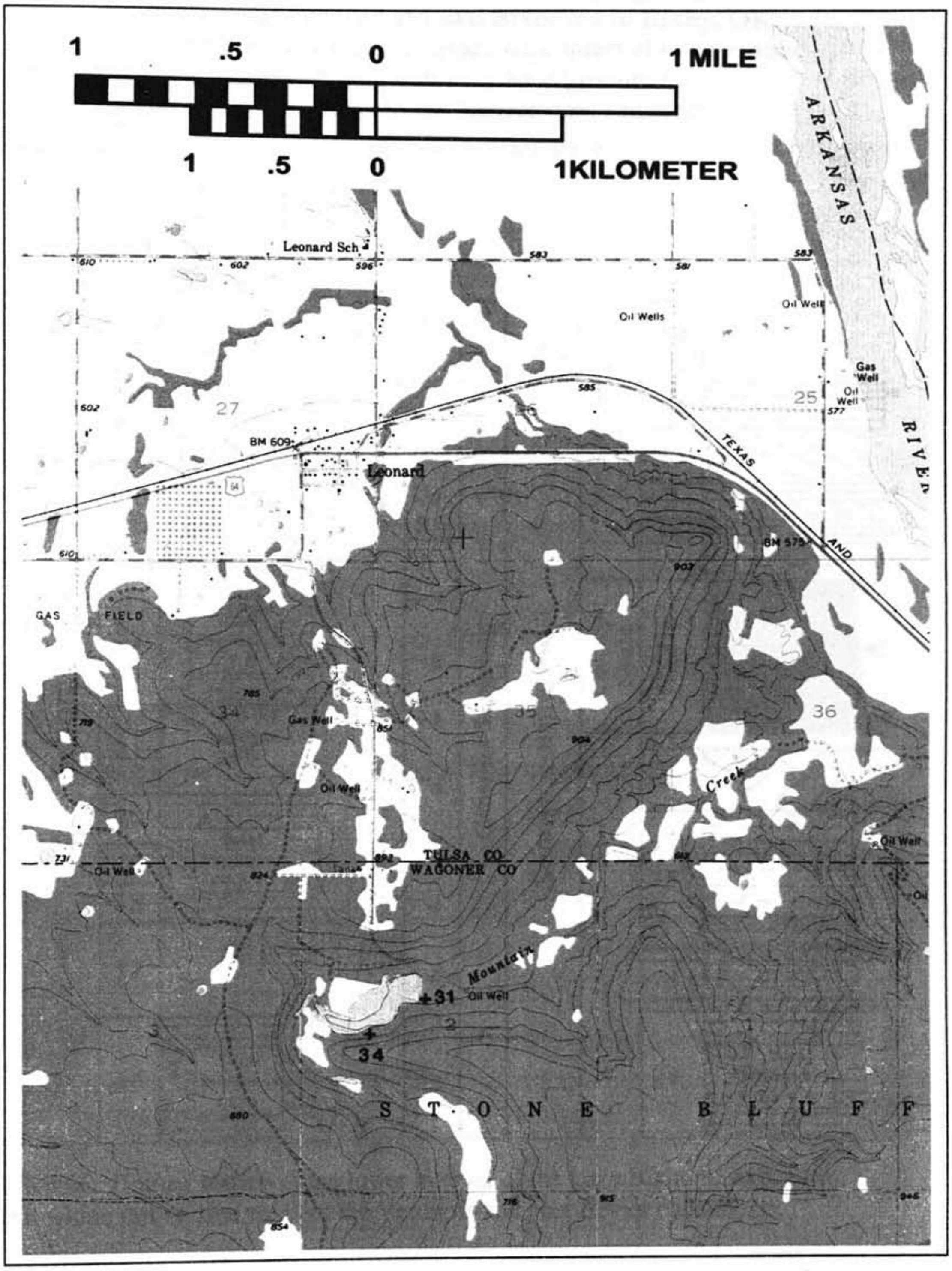


FIGURE 65. Topographic map of Localities # 31 and 34, Lake Bixhoma, Wagoner County

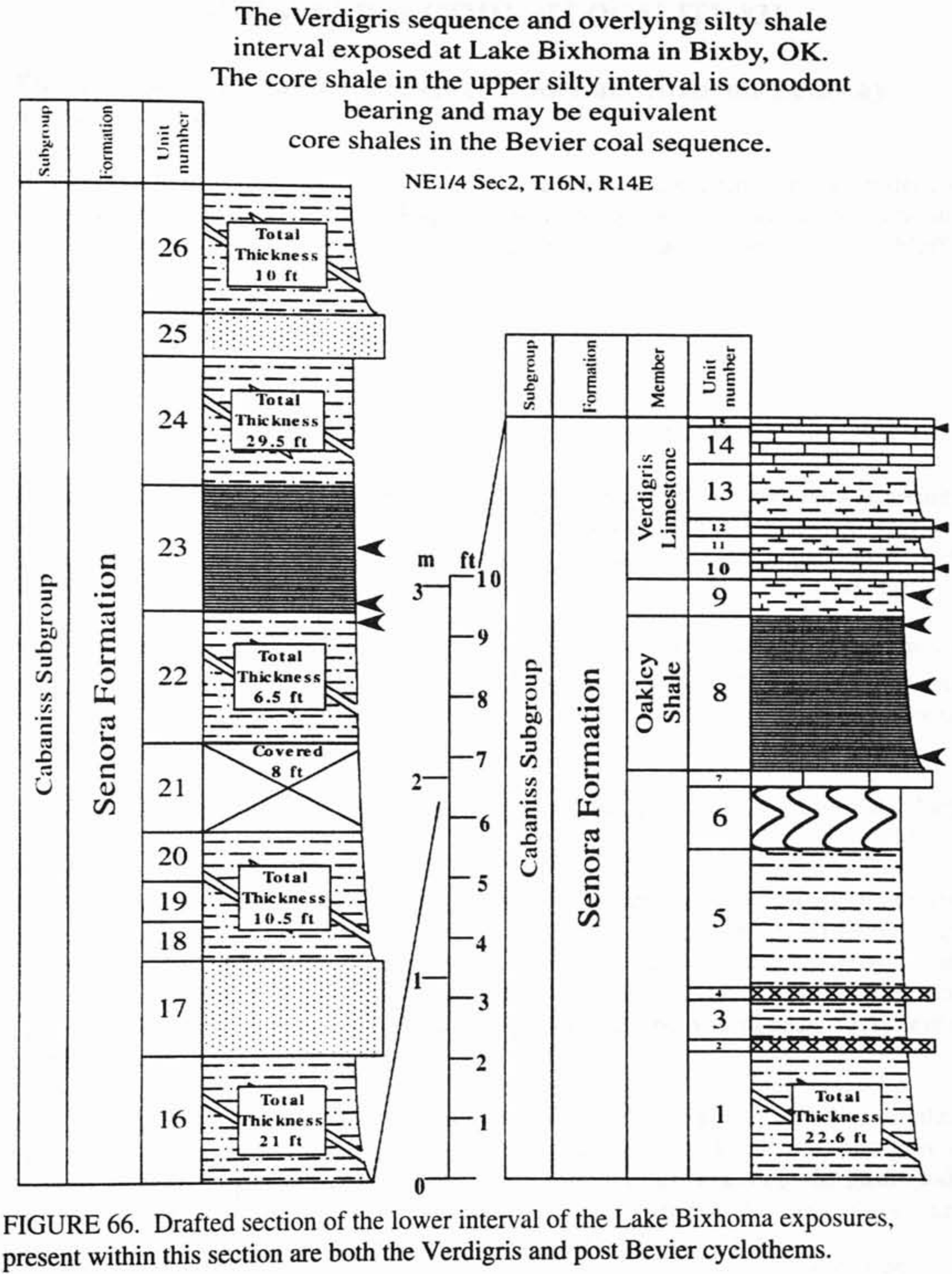


FIGURE 66. Drafted section of the lower interval of the Lake Bixhoma exposures, present within this section are both the Verdigris and post Bevier cyclothems.

MEASURED SECTION of LOCALITY #31

The Verdigris and Bevier Sequences from Lake Bixhoma Spillway

N1/2SE1/4NW1/4 Sec 2, T16N, R14E

Measured in deeply cut stream just east of Lake Bixhoma, approximately two miles (3.2 km) south of Leonard, Oklahoma. Exposure is in the spillway and along the slope of a hill adjacent to the spillway. Measured from streambed to road exposure to top of bluff.

CHEROKEE GROUP
CABANISS SUBGROUP

SENORA FORMATION: Thickness in feet (meters)

26. Shale; medium gray (N5) banded with light olive gray (5Y 6/1) weathers to medium light gray (N6) and dusky yellow (5Y 6/4); grayish orange (10YR 7/4) chunks scattered throughout shale; slightly fissile to blocky; calcareous; scattered mica flakes; soft; weathers to flakes on the surface; poorly exposed 10.0 (3.0)

25. Sandstone; quartz arenite; medium gray (N5) with dark yellowish orange (10YR 6/6) banding weathers to yellowish gray (5Y 7/2), grayish orange (10YR 7/4), and pale yellowish brown (10YR 6/2); shaly; micaceous; calcareous; fine grained; ferruginous; interbedded with two thin shales 0.7 (0.21)

24. Shale; medium dark gray (N4) weathers to medium gray (N5); fissile; platy; hard; very calcareous; micaceous 29.5 (8.85)

23. Black shale; grayish black (N2) and black (N1) to dark gray (N3) weathers to dark gray and medium dark gray (N4); fissile; platy; micaceous; hard; becomes increasingly more calcareous towards upper contact; oxidized surfaces at upper contact: dark yellowish orange (10YR 6/6) and moderate reddish brown (10R 4/6); fossiliferous, *Idiognathodus* and *Idioprioniodus* conodonts, ammonoids, and brachiopods; equivalent to post Bevier coal shale 2.0 (0.6)

22. Shale; medium dark gray (N4) banded with moderate olive brown (5Y 4/4) weathers to medium light gray (N6); streaks of dark yellowish orange (10YR 6/6) and grayish yellow (5y 8/4); silty; calcareous; blocky; very fossiliferous, brachiopods, gastropods, crinoids, ostracods, pelecypods, conodonts, and foraminifera; *Idiognathodus* and *Idioprioniodus* conodonts; *Endothyra* foraminifera; strong bedding planes 6.5 (1.95)

21. Covered; probably gray silty shale 8.0 (2.4)

MEASURED SECTION of LOCALITY #31

The Verdigris and Bevier Sequences from Lake Bixhoma Spillway

N1/2SE1/4NW1/4 Sec 2, T16N, R14E

Measured in deeply cut stream just east of Lake Bixhoma, approximately two miles (3.2 km) south of Leonard, Oklahoma. Exposure is in the spillway and along the slope of a hill adjacent to the spillway. Measured from streambed to road exposure to top of bluff.

CHEROKEE GROUP
CABANISS SUBGROUP

SENORA FORMATION: Thickness in feet (meters)

26. Shale; medium gray (N5) banded with light olive gray (5Y 6/1) weathers to medium light gray (N6) and dusky yellow (5Y 6/4); grayish orange (10YR 7/4) chunks scattered throughout shale; slightly fissile to blocky; calcareous; scattered mica flakes; soft; weathers to flakes on the surface; poorly exposed 10.0 (3.0)

25. Sandstone; quartz arenite; medium gray (N5) with dark yellowish orange (10YR 6/6) banding weathers to yellowish gray (5Y 7/2), grayish orange (10YR 7/4), and pale yellowish brown (10YR 6/2); shaly; micaceous; calcareous; fine grained; ferruginous; interbedded with two thin shales 0.7 (0.21)

24. Shale; medium dark gray (N4) weathers to medium gray (N5); fissile; platy; hard; very calcareous; micaceous 29.5 (8.85)

23. Black shale; grayish black (N2) and black (N1) to dark gray (N3) weathers to dark gray and medium dark gray (N4); fissile; platy; micaceous; hard; becomes increasingly more calcareous towards upper contact; oxidized surfaces at upper contact: dark yellowish orange (10YR 6/6) and moderate reddish brown (10R 4/6); fossiliferous, *Idiognathodus* and *Idioprioniodus* conodonts, ammonoids, and brachiopods; equivalent to post Bevier coal shale 2.0 (0.6)

22. Shale; medium dark gray (N4) banded with moderate olive brown (5Y 4/4) weathers to medium light gray (N6); streaks of dark yellowish orange (10YR 6/6) and grayish yellow (5y 8/4); silty; calcareous; blocky; very fossiliferous, brachiopods, gastropods, crinoids, ostracods, pelecypods, conodonts, and foraminifera; *Idiognathodus* and *Idioprioniodus* conodonts; *Endothyra* foraminifera; strong bedding planes 6.5 (1.95)

21. Covered; probably gray silty shale 8.0 (2.4)

20. Shale; medium dark gray (N4) weathers to medium dark and medium (N5) gray; silty; micaceous; blocky; calcareous; massive; gradational contact with underlying unit 4.4 (1.32)

19. Shale; medium dark gray (N4) weathers to medium dark and medium (N5) gray; silty; micaceous; fissile; very calcareous; massive; fossiliferous, brachiopods, pelecypods, and gastropods; fossils poorly preserved 3.6 (1.1)

18. Shale; medium dark gray (N4) weathers to medium gray (N5) and medium light gray (N6); very micaceous; blocky; silty; massive; hard; very calcareous; sparsely fossiliferous 2.5 (0.75)

17. Sandstone; quartz arenite; light brownish gray (5YR 6/1) weathers to yellowish gray (5Y 7/2), dark yellowish orange (10YR 6/6), and grayish orange (10YR 7/4); grayish red purple (5RP 4/7) and grayish red (10R 4/2) staining; fine grained; angular quartz grains; micaceous; calcareous; hard; shaly; ferruginous 1.5 (0.45)

16. Clay shale; medium gray (N5) with pale yellowish brown (10YR 6/2) banding at lower contact; becomes medium dark gray (N4) to medium gray (N5) higher up; weathers to medium gray (N5), yellowish gray (5Y 7/2), and medium light gray (N6); blocky; silty; heavily micaceous; noncalcareous at lower contact becomes increasingly calcareous higher up; large light brown (5YR 5/6) flattened clay iron nodules at lower contact; numerous thin ironstone stringers; vertical fractures filled with siltstone; carbonaceous flecks and streaks; pyrite fragments at lower contact 21.0 (6.3)

15. Limestone; packestone; pale yellowish brown (10YR 6/2) mottled with grayish orange (10YR 7/4) weathers to medium gray (N5), light brownish gray (5YR 6/1), and dark yellowish orange (10YR 6/6); thin bedded to shaly; very silty; micaceous; slightly calcareous; jointed appearance in stream; fossiliferous, crinoids, mollusks, ostracods, brachiopods, and *Idiognathodus* conodonts 0.2 (0.06)

14. Upper Verdigris Limestone; packestone to grainstone; medium light gray (N6) weathers to grayish orange (10YR 7/4), light gray (N7), and light olive gray (5Y 6/1); grayish red purple (5RP 4/2) oxidation; massive bedding; thin rust streak about one inch above lower contact; ferruginous; scattered crinoid fragments, corals, ostracods, gastropods, fish debris, and *Idiognathodus* conodonts 0.5 (0.15)

13. Shale; brown; calcareous; very fissile; numerous yellow and black bands; oxidation staining near upper contact 0.9 (0.27)

12. Middle Verdigris Limestone; wackestone; brownish gray (5YR 4/1) weathers to medium light gray (N6), grayish orange (10YR 7/4), and very pale orange (10YR 8/2); shaly; jointed; fossiliferous, brachiopods predominate, crinoids, encrusting foraminifera, *Idioprioniodus*, *Neognathodus*, and *Idiognathodus* conodonts 0.25 (0.08)

11. Clay shale; brown; fissile; calcareous 0.3 (0.09)

10. Lower Verdigris Limestone; wackestone; dark (N3) to medium dark (N4) gray mottled/banded with brownish gray (5YR 4/1) weathers to grayish orange (10YR 7/4), very pale orange (10YR 8/2), and pale yellowish brown (10YR 6/2); wavy bedded; nodular surface; fossiliferous, crinoids, brachiopods, encrusting foraminifera, calcareous foraminifera (possibly *Orthovertella*), *Idiognathodus* conodonts, and possible nautiloids; jointed; lowermost of three steep benches in stream bed 0.4 (0.12)

9. Calcareous shale; medium gray (N5) intermixed with moderate olive brown (5Y 4/4) weathers to pale yellowish orange (10YR 6/2); massive; very hard; gradational contact with underlying unit; fossiliferous, crinoids, brachiopods, echinoid spines, gastropods, pelecypods, and *Idiognathodus*, *Idioprioniodus*, and *Neognathodus* conodonts; recessed into outcrop 0.6 (0.18)

8. Oakely Shale; grayish black (N2) weathers to dark gray (N3); middle foot of unit heavily oxidized: moderate yellow (5Y 7/6), grayish red purple (5RP 4/2), and pale yellowish brown (10YR 6/2); large 3 to 4 inch flattened brownish gray (10YR 6/2) and grayish orange (10YR 7/4) clay iron nodules; bluish white (5B 9/1), light bluish gray (5B 7/1), and greenish gray (5G 6/1) staining; fissile; hard; paper-like; platy; 0.5 to 1.5 inch oval, suboval, to irregular shaped phosphate nodules (N2); middle foot has benches of resistant shale; clayier and more massive near upper contact; very fossiliferous, crinoid columnals, ostracods, brachiopods, *Reophax* foraminifera, and *Idiognathodus*, *Idioprioniodus*, *Neognathodus*, and *Gondolella* conodonts; middle foot of shale barren of microfossils 2.5 (0.75)

7. Limestone; mudstone; medium dark gray (N4) weathers to medium dark gray, light brownish gray (5YR 6/1), and light olive gray (5Y 6/1); shaly; hard; slightly micaceous; pyritized brachiopod shells; scattered very small pyrite flakes on surface of hand samples 0.25 (0.08)

6. Underclay; yellowish gray (5Y 7/2) mottled with light gray (N7) and pale yellowish orange (10YR 8/6); stained with dark yellowish orange (10YR 6/6); moderate brown (5YR 4/4) oxidation surface; plastic; fissile appearance in outcrop; contains numerous dikes of silty shale; virtually indistinguishable from underlying shale 1.0 (0.3)

5. Shale; medium gray (N5) with numerous moderate brown (5YR 3/4) and grayish red (10R 4/2) oxidation surfaces weathers to light olive gray (5Y 6/1); blocky; silty; strong bedding planes; soft; very slightly micaceous; waxy surface; not as resistant as overlying underclay 2.3 (0.69)

4. Ironstone; dark gray (N3) stained with brownish black (5YR 2/1) and black (N1) weathers to pale yellowish brown (10YR 6/2) and medium gray (N5); hard; nodular; silty; micaceous; moderate reddish brown (10R 4/6) oxidation; numerous *Lingula* brachiopod fossils; organic staining 0.2 (0.06)

3. Shale; medium dark gray (N4) weathers to medium gray (N5), medium bluish gray (5B 5/1), and light olive gray (5Y 6/1); very dusky red purple (5RP 2/2) oxidation surfaces; fissile; silty; slightly micaceous; slightly calcareous; sparse light brownish gray (5YR 6/1) ostracode and brachiopod shells 0.6 (0.18)

2. Ironstone; dark gray (N3) weathers to pale yellowish gray (10YR 6/2) and medium gray (N5); hard; nodular; micaceous; moderate reddish brown (10R 4/6) oxidation; hand samples resemble massive blocky shale; *Lingula* brachiopods present 0.2 (0.06)

1. Shale; medium dark gray (N4) weathers to medium gray (N5) and light olive gray (5Y 6/1); very dusky red purple (5RP 2/2) oxidation surfaces; silty; diagonal fracture pattern in stream bed; fractures and joints filled with siltstone; six inch band of sandy shale approximately two feet above water level; strong bedding planes; sparse light brownish gray (5YR 6/1) ostracode and brachiopod shells; lower contact not present; measured down to water level 22.6 (6.78)

TOTAL: 122.5 (36.75)

PHOTOGRAPH 9

Photograph of the Verdigris interval exposed at the spillway of Lake Bixhoma, N1/2SE1/4NW1/4 Sec. 2, T16N, R14E (Locality #31), Wagoner County, Oklahoma

The shoulders of the man standing near the waterfall are approximately level with the lower contact of the Oakley Shale. The Oakley Shale is a black phosphatic fissile shale containing deep-water conodonts (such as Gondolella). All three beds of the Verdigris Limestone are present here, but only the lower two are visible in the picture. As evidenced by the waterfall, the Verdigris Limestone forms a major bench in the outcrop. Silty and clayey shales are present below and above the Verdigris Limestone.

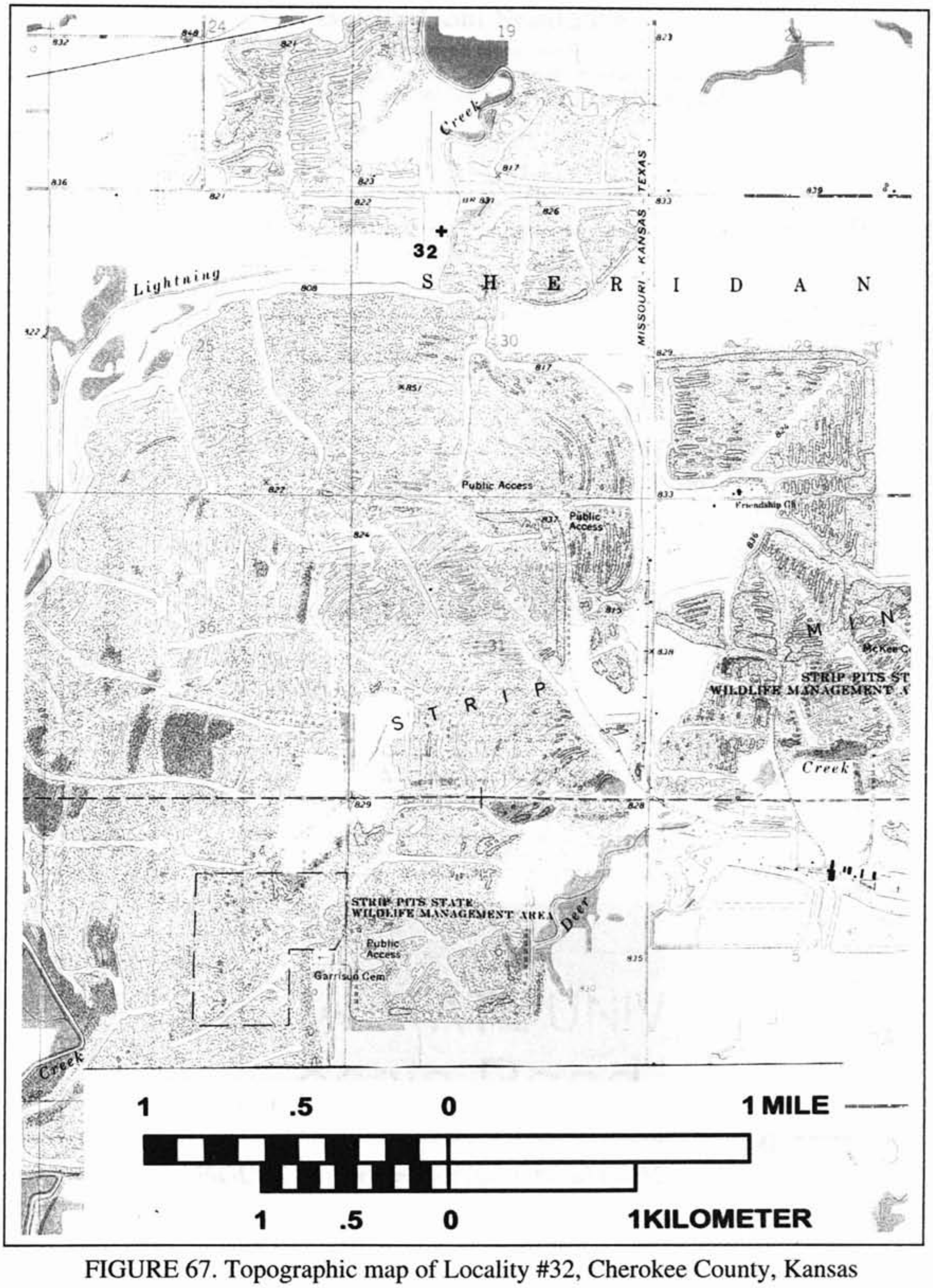


FIGURE 67. Topographic map of Locality #32, Cherokee County, Kansas

Bevier Coal Sequence

Measured along bluff
overlooking Lightning Creek, near Oswego, Kansas
W1/2NE1/4NW1/4 Sec 30, T32S, R22E

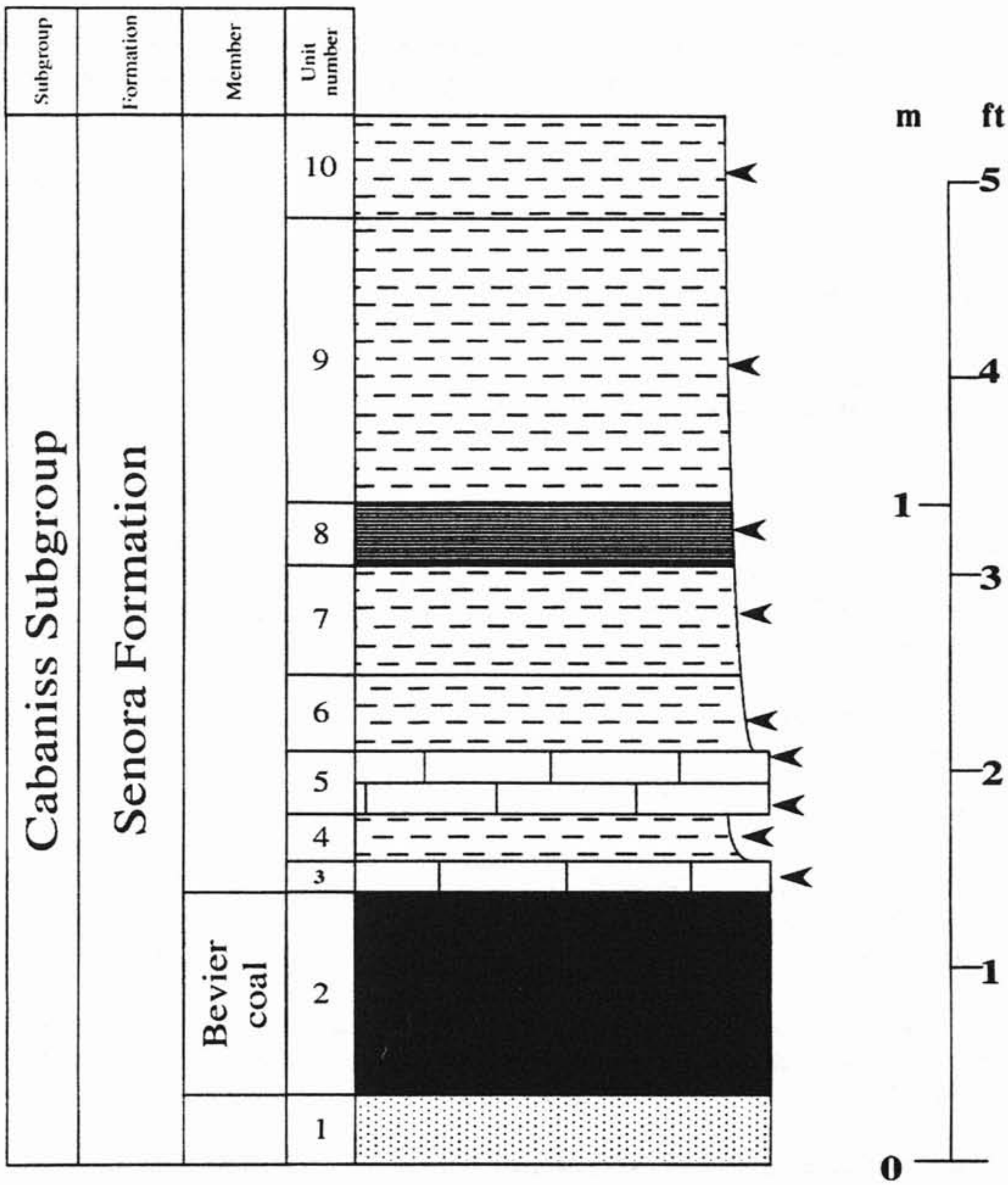


FIGURE 68. Drafted section of Locality #32

MEASURED SECTION of LOCALITY #32

Bevier coal Sequence

W1/2NE1/4NW1/4 Sec 30, T32S, R22E

Measured along bluff overlooking Lightning Creek, near Oswego, Kansas.
Measured from sandstone at stream level to top of bluff.

CHEROKEE GROUP
CABANISS SUBGROUP

SENORA FORMATION: Thickness in feet (meters)

10. Shale; moderate olive brown (5Y 4/4) weathers to yellowish gray (5Y 7/2) and moderate olive brown; earthy; massive; very fossiliferous, numerous brachiopods and some gastropods; some brachiopods are dark yellowish orange (10YR 6/6) 0.5 (0.15)

9. Shale; dark gray (N3) weathers to medium dark gray (N4); blocky; slightly silty; some minor oxidation; breaks up into flakes with sharp edges; very few scattered mica flakes on surface; strophomenid brachiopods, crinoid stems, and rare *Idiognathodus* conodont elements 1.58 (0.47)

8. Shale; grayish black (N2) to black (N1) weathers to medium dark gray (N4) to dark gray (N3); dark yellowish orange (10YR 6/6) and pale yellowish brown (10YR 6/2) staining; fissile; hard; slate-like; phosphate nodules, sparse *Idiognathodus* conodonts 0.33 (0.10)

7. Shale; grayish black (N2) weathers to dark gray (N3) and pale yellowish brown (10YR 6/2); fissile; micaceous; brachiopod shell impressions and unidentifiable shell fragments, sparse *Idiognathodus* conodonts, and poorly preserved foraminifera 0.583 (0.17)

6. Clay shale; dark gray (N3) weathers to medium dark gray (N4); dark yellowish orange (10YR 6/6) staining; fissile; soft; carbonaceous; gypsum and pyrite crystals on surface; crumbly; very sparse *Idiognathodus* conodont elements 0.416 (0.12)

5. Limestone; dark gray (N3) weathers to brownish gray (5YR 4/1) and pale brown (5YR 5/2); crystalline; packestone to grainstone; shaly; fossiliferous, pelecypods, brachiopods, rugose corals, crinoid ossicles; upper portion of limestone produced several thousand conodont elements from 3 kg of sample, mostly *Idiognathodus* and some *Idioprioniodus* conodonts; bryozoan fragments, gastropods, ostracods, and fish teeth 0.33 (0.10)

4. Shale; grayish black (N2) weathers to dark gray (N3); reddish brown, moderate brown (5YR 4/4), and light brown (5YR 5/6) oxidation surfaces; pyrite crystals on shale surface; very carbonaceous; soft; fissile; *Idiognathodus* conodont fragments 0.25 (0.08)

3. Limestone; grayish black (N2) weathers to medium dark gray (N4) and medium gray (N5); mudstone; whitish flecks (N9) on limestone surface; nodular; hard; impure; carbonaceous; fossiliferous, crinoids, corals, brachiopods, pyritized gastropods and ostracods, *Idioprioniodus* and *Idiognathodus* conodont fragments 0.167 (0.05)

2. Bevier coal; jet black (N1) with white (N9) streaks; plant impressions 1.1 (0.33)

1. Sandstone; outcrops at water level; mostly covered by water

TOTAL: 5.25 (1.6)

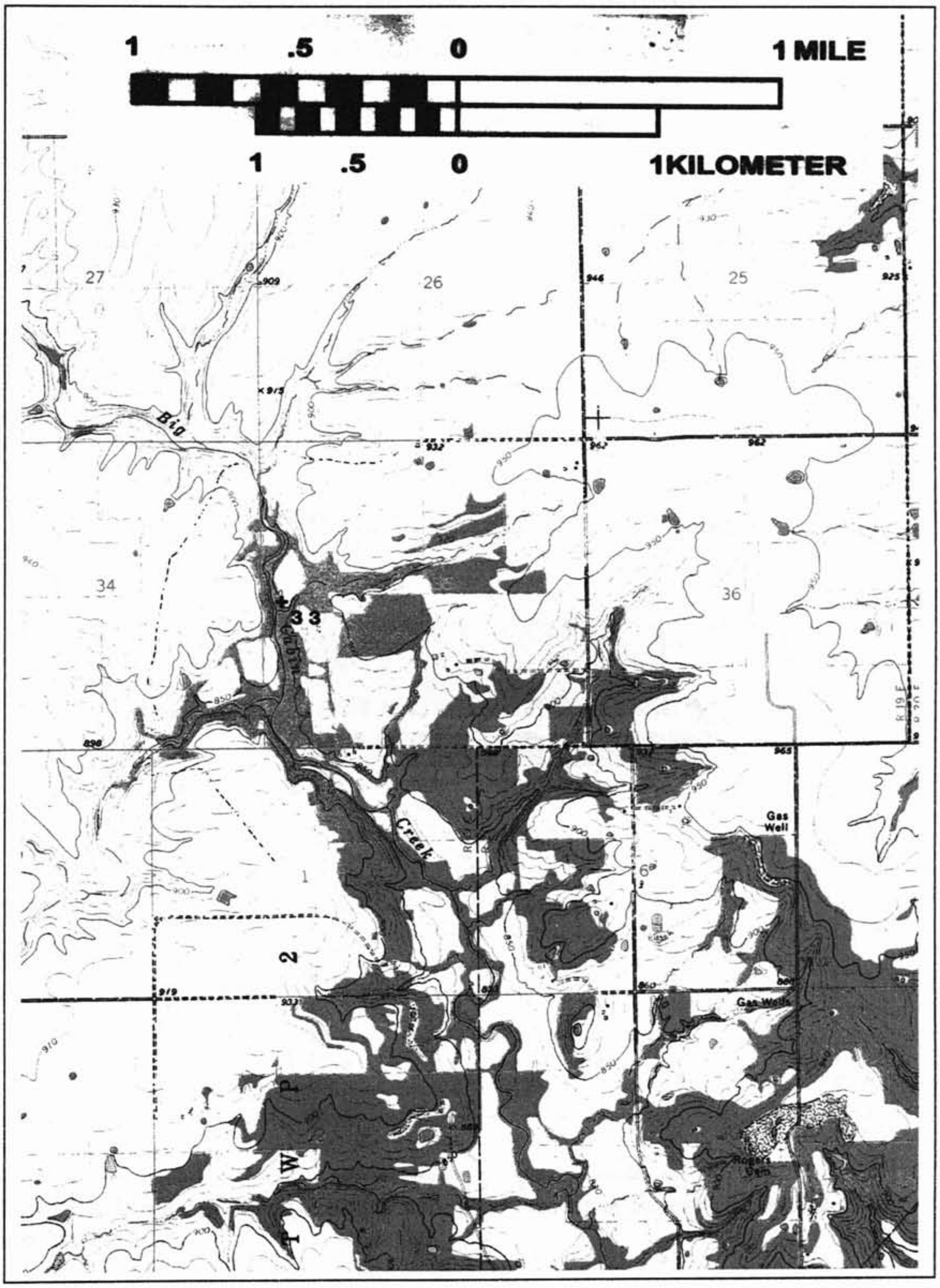


FIGURE 69. Topographic map of Locality #33, Craig County

Type Kinnison Shale Locality

Measured in an old coal mine in a
cattle pasture 5 miles north of
Welsh, OK and 8 miles west of
S.H. 2.
W1/2SW1/4 Sec. 35, T29N, R19E

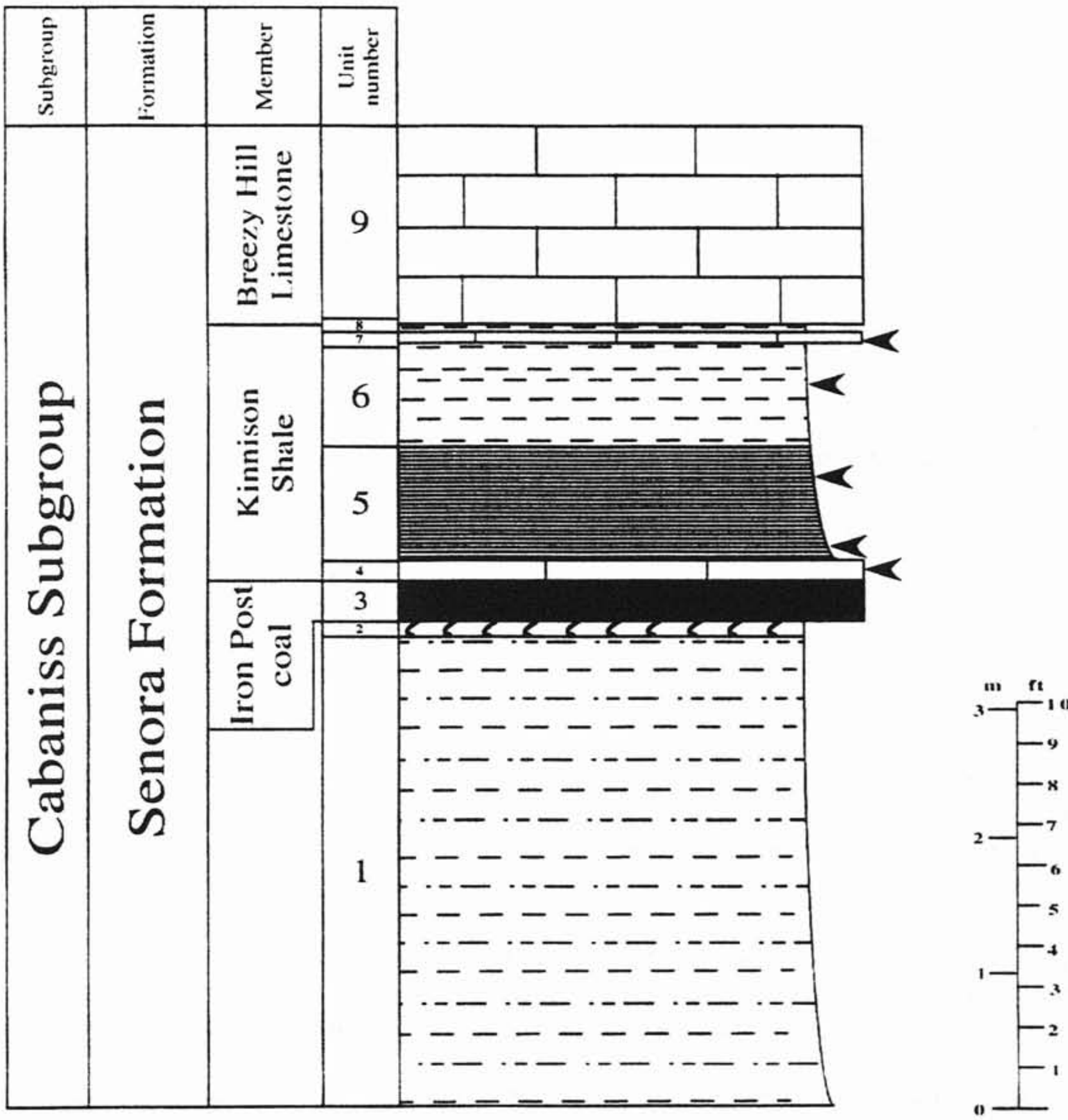


FIGURE 70. Drafted section of Locality #33, nearly the entire Breezy Hill cyclothem is present here

MEASURED SECTION of LOCALITY #33

Type Kinnison Shale Locality

W1/2SW1/4 Sec 35, T29N, R19E

Measured in old coal mine in cattle pasture 5 miles (8 km) north of Welsh, OK and 8 miles (13 km) west of State Highway 2. Measured from stream cut up hill slope.

CHEROKEE GROUP
CABANISS SUBGROUP

SENORA FORMATION: Thickness in feet (meters)

9. Breezy Hill Limestone; pale yellowish brown (10YR 6/2); partly dolomitized; fossiliferous with productids; contact with Breezy Hill and upper Kinnison unconformable 5.0 (1.5)

Kinnison Shale Member:

8. Clay shale; pale yellowish brown (10YR 6/2) mottled with dark yellowish orange (10YR 6/6) weathers to grayish orange (10YR 7/4) and light brownish gray (5YR 6/1); massive; earthy; hard; very calcareous; crumbly; fossiliferous, crinoids, brachiopods, poorly preserved ostracods and foraminifera, *Idiognathodus* conodonts fragments, fish teeth, and holothurian sclerites 0.17 (0.05)

7. Limestone; grainstone; light brownish gray (5YR 6/1) mottled with dark gray (N3); shaly; very hard; fossiliferous, brachiopods, crinoids, fish teeth, and conodonts 0.10 (0.03)

6. Clay Shale; very light gray (N8) weathers to pale yellowish orange (10YR 8/6) and very pale orange (10YR 8/2); dark yellowish brown (10YR 4/2), grayish red purple (5RP 4/2) and moderate brown (5YR 4/4) oxidation; blocky; soft; silty; poorly preserved foraminifera and fusulinids, gradational contact with lower unit 2.8 (0.84)

5. Black shale; grayish black (N2) weathers to pale yellowish brown (10YR 6/2) and medium gray (N5); fissile; clayey; becomes calcareous towards lower contact; poorly preserved foraminifera (probably *Reophax*), poorly exposed 2.9 (0.87)

4. Limestone; wackestone; grayish black (N2) weathers to light brownish gray (5YR 6/1); hard; somewhat shaly; coal fragments; fossiliferous, crinoids, pyritized brachiopods, *Idiognathodus* and *Idioprioniodus* conodonts, *Ammodiscus* foraminifera, fish teeth, and carbonized ostracods; lowermost unit of the Kinnison Shale Member at this locality 0.5 (0.15)

3. Iron Post coal 1.0 (0.3)

2. Underclay	0.25 (0.08)
1. Shale; brownish gray (5YR 6/2); interbedded with siltstone; silty; prominently exposed in banks of stream	12.0 (3.6)
TOTAL:	24.6 (7.38)

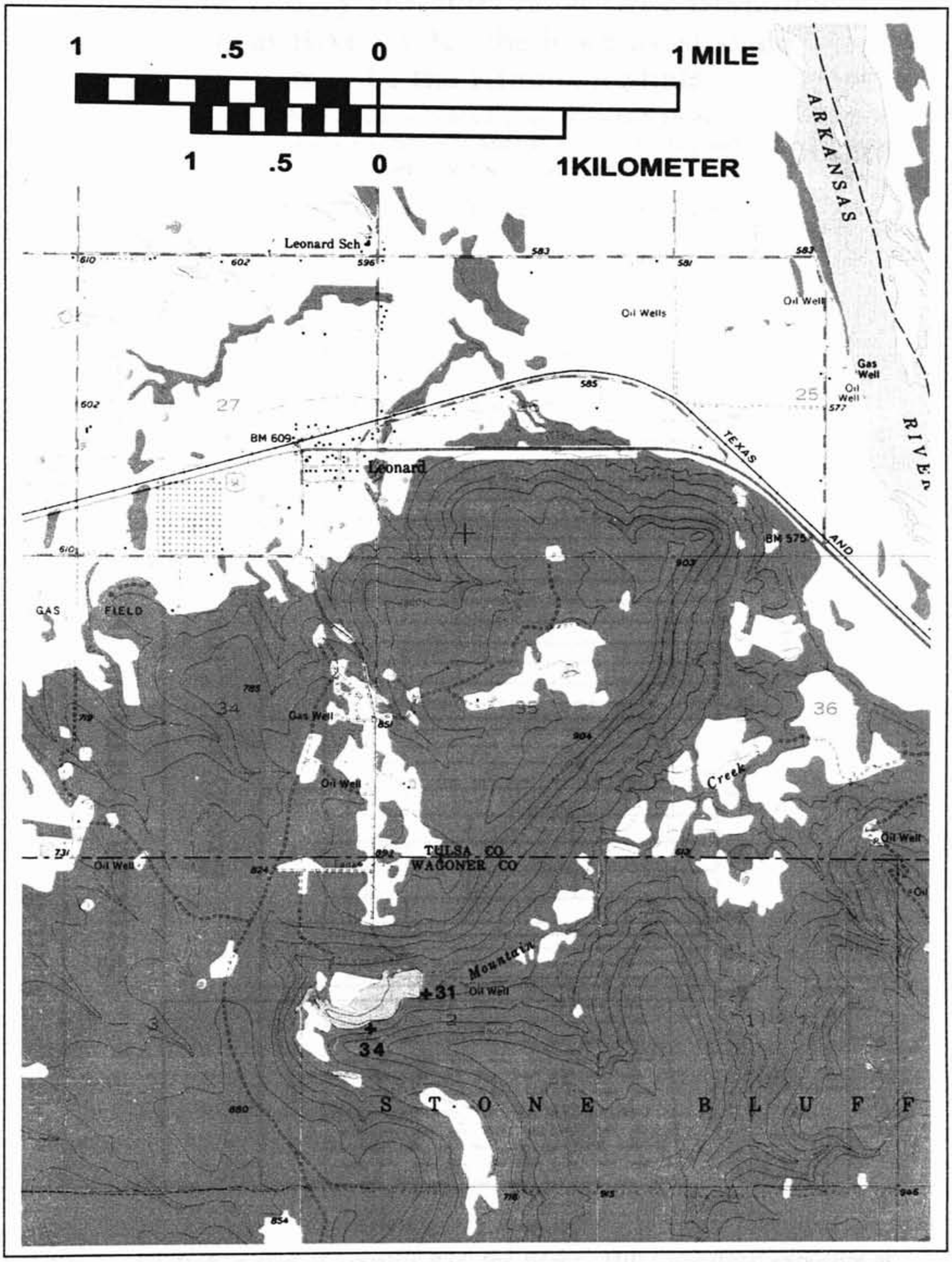


FIGURE 71. Topographic map of Localities # 34 and 31, Lake Bixhoma, Wagoner County

The Breezy Hill interval at Lake Bixhoma near Bixby, OK, the lowermost shale may be the Kinnison Shale.

Measured on a roadcut on the south shore of Lake Bixhoma. Outcrop is cut by a normal fault near the western end.

Center N1/2N1/2SW1/4 Sec2, T16N, R14E

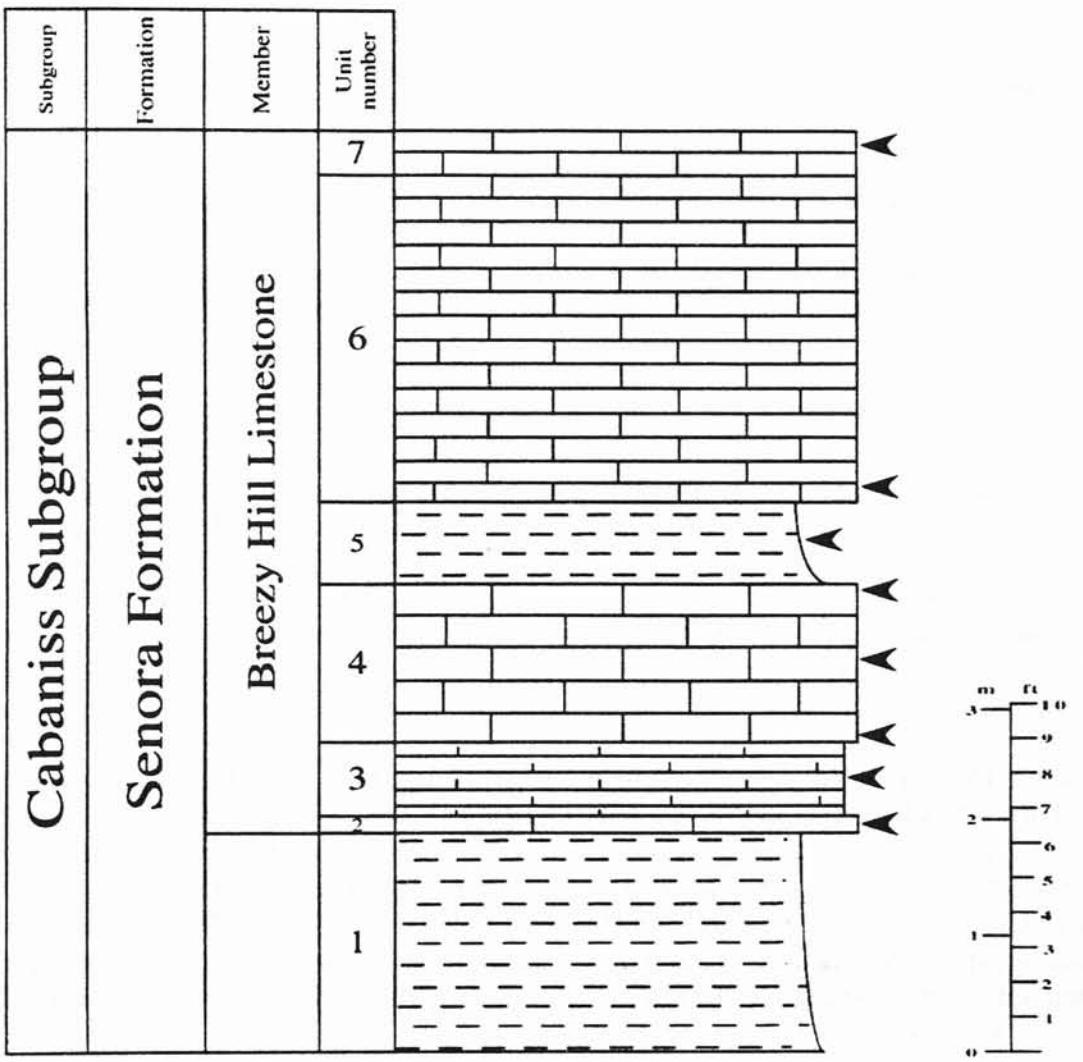


FIGURE 72. Drafted section of Locality #34, the Breezy Hill Limestone exposure at Lake Bixhoma

MEASURED SECTION of LOCALITY #34

Breezy Hill Exposure at Lake Bixhoma
Center N1/2N1/2SW1/4 Sec 2, T16N, R14E

Measured on a roadcut on the south shore of Lake Bixhoma. Outcrop is cut by a normal fault at the western end.

CHEROKE GROUP
CABANISS SUBGROUP

SENORA FORMATION: Thickness in feet (meters)

7. Breezy Hill Limestone; wackestone; medium dark gray (N4) weathers to medium gray (N5), dark yellowish orange (10YR 6/6), pale brown (5YR 5/2), moderate yellowish brown (10YR 5/4), and grayish orange (10YR 7/4); hard; dense; nodular; thin-bedded; interbedded with shale; ferruginous; fossiliferous, productid brachiopods, encrusting foraminifera, poorly preserved calcareous foraminifera, and *Idiognathodus* conodonts 0.83 (0.25)

6. Breezy Hill Limestone; mudstone; light olive gray (5Y 6/1) banded with grayish orange (10YR 7/4) weathers to pale yellowish orange (10YR 8/6) and grayish orange (10YR 6/6); hard; thin to massive bedded; ferruginous; sparse scattered brachiopod shells, and *Hyperamminoides* foraminifera 9.9 (2.96)

5. Shale; medium light gray (N6) weathers to brownish gray (5YR 4/1), light olive gray (5Y 6/1), and grayish orange (10YR 7/4); hard; medium bedded; silty; slightly calcareous; strong moderate reddish brown (10YR 4/6) staining or oxidation; breaks off into sheets 2.5 (0.75)

4. Breezy Hill Limestone; mudstone to wackestone; upper part, pale yellowish brown (10YR 6/2) and dusky yellow (5Y 6/4); middle part, grayish orange (10YR 7/4); lower part, light olive gray (5Y 5/2); weathers to grayish orange, pale yellowish orange (10YR 8/6), and dusky yellow; massive; very hard; ferruginous; medium gray (N5) filled fractures; dark yellowish brown (10YR 4/2) and light olive gray staining; moderate reddish brown (10R 4/6) oxidation; fossiliferous, crinoid columnals, brachiopods, and *Idiognathodus* conodonts; in middle part of unit, brachiopod shells are oriented along thin horizontal calcareous bands indicating flow patterns 4.7 (1.41)

3. Mudrock; medium gray (N5) weathers to medium light gray (N6), very pale orange (10YR 8/2), and pale yellowish brown (10YR 6/2); blocky; nodular; calcareous; slightly micaceous; massive; very hard and sharp 2.1 (0.63)

2. Breezy Hill Limestone; wackestone; medium gray (N5) weathers to medium gray, pinkish gray (5YR 8/1), moderate olive brown (5Y 4/4), and grayish orange (10YR 7/4); massive; hard; slightly micaceous; fossiliferous, *Idiognathodus* conodonts, *Platyceras* gastropods and mesogastropods, planoconvex spiriferids and other brachiopods, encrusting and *Cornuspira* calcareous foraminifera, and crinoid columnals; small round pinkish gray intraclasts 0.5 (0.15)

1.Clay shale; medium dark gray (N4) to medium gray (N5) weathers to medium gray, medium light gray (N6), and pale brown (5YR 5/2); blocky; thin-bedded; silty; micaceous; upper part noncalcareous, lower part slightly calcareous; inch long medium light gray calcareous nodules; brachiopods at upper contact; lower contact not present
6.3 (1.9)

TOTAL: 26.8 (8.05)

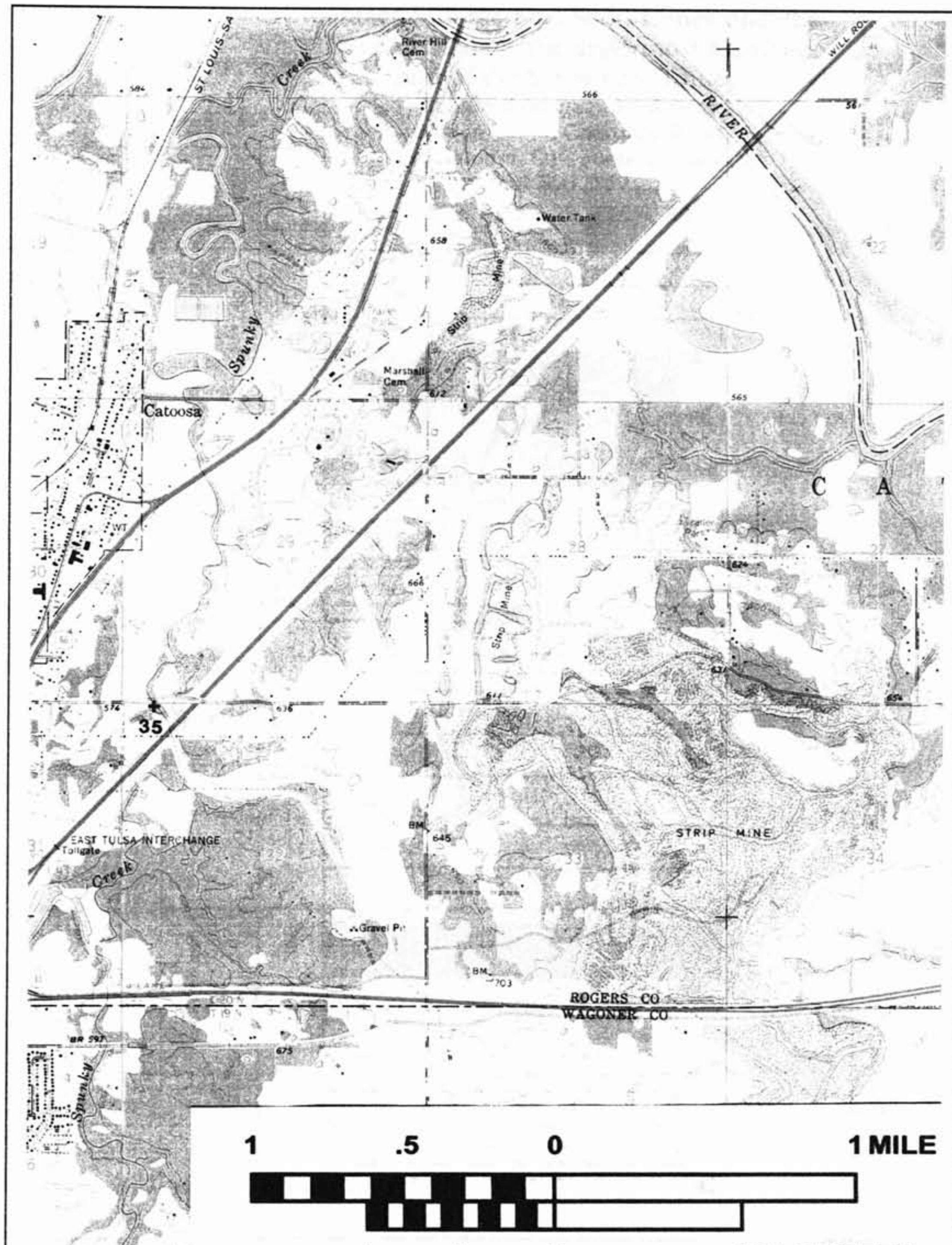


FIGURE 73. Topographic map of Locality #35, Rogers County

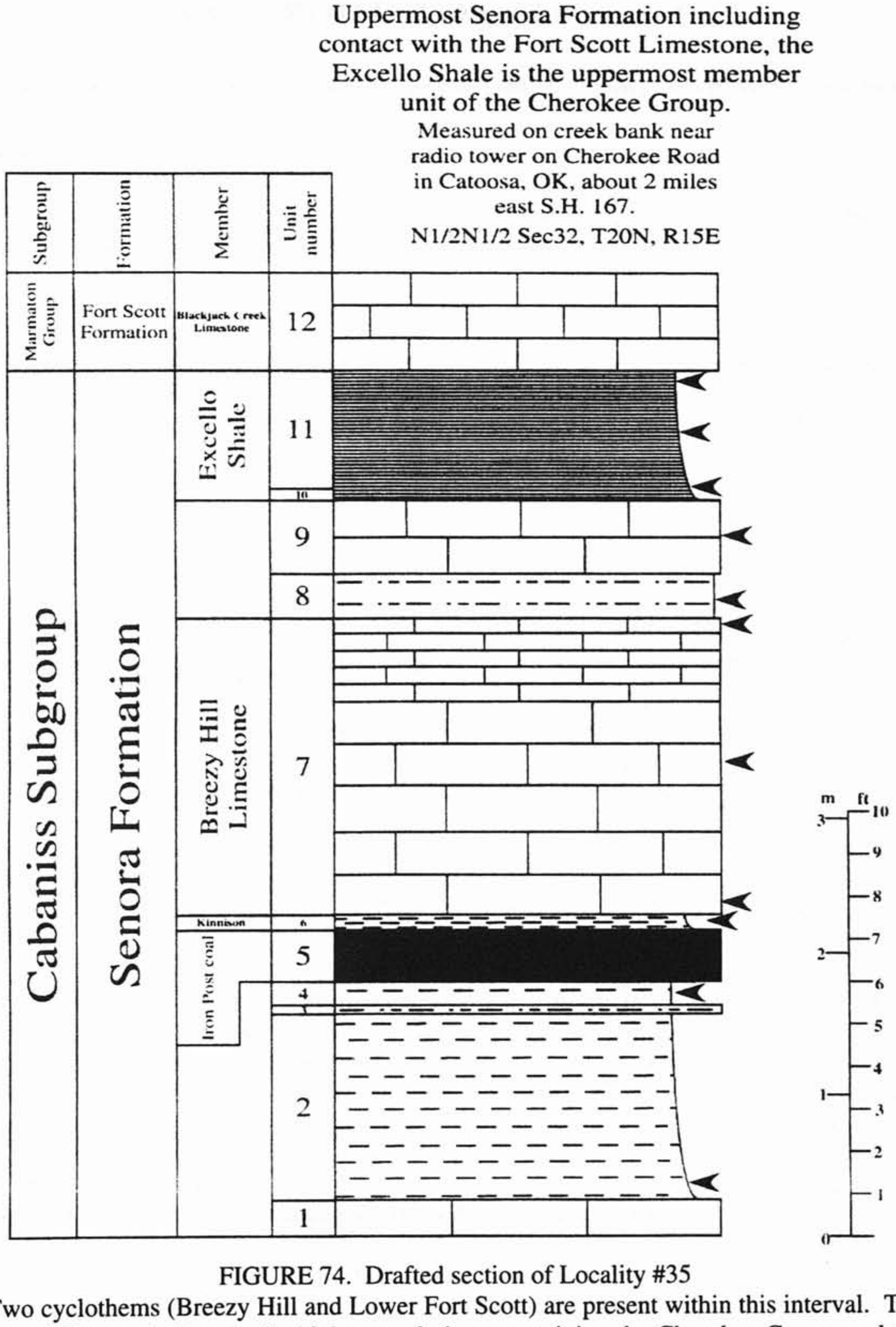


FIGURE 74. Drafted section of Locality #35

Two cyclothems (Breezy Hill and Lower Fort Scott) are present within this interval. The Lower Fort cyclothem is the highest cyclothem containing the Cherokee Group, and the Breezy Hill cyclothem is the highest cyclothem fully within the Cherokee Group.

MEASURED SECTION of LOCALITY #35

Uppermost Senora Formation Including Contact with the Fort Scott Limestone

N1/2N1/2 Sec32, T20N, R15E

Measured on creek bank near radio tower on Cherokee Road in Catoosa, Oklahoma. Locality is about two miles (3.2 km) east of State Highway 167.

MARMATON GROUP
FORT SCOTT LIMESTONE: Thickness in feet (meters)

12. Blackjack Creek Limestone 1.0 (0.3)

CHEROKEE GROUP
CABANISS SUBGROUP

SENORA FORMATION:

11. Excello Shale; grayish black (N2) weathers to grayish red (10R 4/2), pale brown (5YR 5/2), and dark reddish brown (10R 3/4); light brown (5YR 5/6), moderate brown (5YR 5/6), grayish red purple (5RP 4/2), and moderate reddish brown (10R 4/6) oxidation; fissile; paper-like with sharp edges; breaks up into flakes; iron nodules; inch diameter subcircular and irregular shaped grayish black phosphate nodules; some phosphate nodules have a dusting of light bluish gray (5B 7/1); poorly exposed 3.0 (0.9)

10. Clay; medium dark gray (N4) banded with light olive gray (5Y 6/1) weathers to olive gray (5Y 4/1) and brownish gray (5YR 4/1); thin-bedded, soft, calcareous, brachiopods 0.1 (0.03)

9. Limestone; mudstone; medium dark gray (N5) weathers to dark yellowish brown (10YR 4/2); nodular appearance in outcrop; massive; near perfect cubic pyrite crystals in processed residues, very fossiliferous, sparse brachiopods, *Idiognathodus* conodonts, poorly preserved calcareous foraminifera (probably *Cornuspira*), and holothurian sclerites 1.67 (0.5)

8. Mudrock; dark gray (N3) to medium dark gray (N4) weathers to light olive gray (5Y 6/1) and medium dark gray; massive; soft; silty; very calcareous 1.0 (0.3)

7. Breezy Hill Limestone; mudstone; medium gray (N5) to pale yellowish brown (10YR 6/2) weathers to grayish orange (10YR 7/4) mottled with medium light gray (N6) and pale yellowish brown; dusky green (5G 3/2) staining on weathered surface; massive; thick-bedded becomes flaggy in upper third of unit; very hard; fossiliferous, fish teeth, *Idiognathodus* conodonts, encrusting foraminifera, calcareous foraminifera (possibly *Tetrataxis*), sparse algae 6.8 (2.0)

6. Kinnison Shale; dark gray (N3) weathers to medium dark gray (N4) and yellowish gray (5Y 7/2); moderate yellowish brown (10YR 7/2) oxidation; fissile; very soft; heavily weathered; carbonaceous; cubic black (N1) coal chunks; *Reophax* foraminifera 0.33 (0.10)

5. Iron Post coal; black (N1) glassy surface; very pale orange (10YR 8/2) staining 1.2 (0.36)

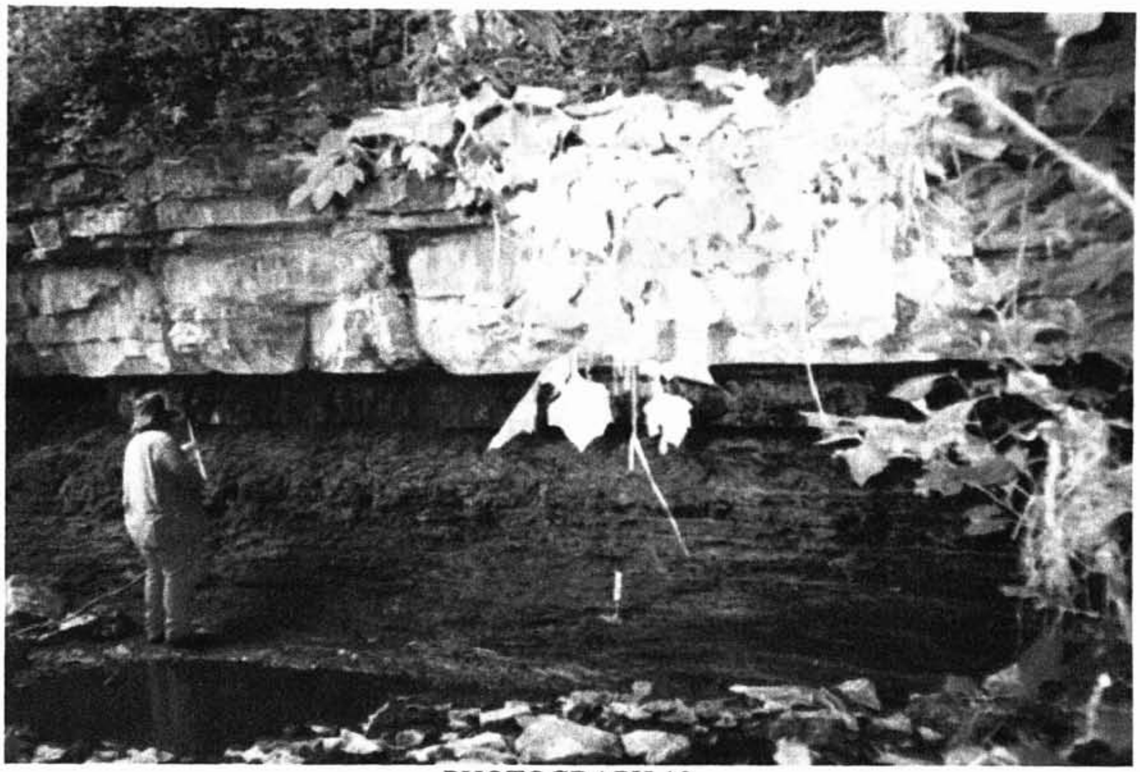
4. Clay shale; medium gray (N5) weathers to pale yellowish brown (10YR 5/4); moderate brown (5YR 4/4) and moderate yellowish brown (10YR 5/4) oxidation; blocky; massive; silty; heavily oxidized; probably a paleosol 0.5 (0.15)

3. Siltstone 0.21 (0.06)

2. Clay shale; medium gray (N5) weathers to yellowish gray (5Y 7/2), pale yellowish orange (10YR 8/6), and pale greenish yellow (10Y 8/2); moderate brown (5YR 3/4) and dark yellowish orange (10YR 6/6) oxidation; plastic; silty; breaks off into chunks; carbonate nodules; brachiopod shells; resembles underclay 4.3 (1.29)

1. Fossiliferous limestone; covered by water

TOTAL: 19.11 (5.73)



PHOTOGRAPH 10

A very good view of Locality #35 (N1/2NW1/4NW1/4 Sec 32, T20N, R15E, Rogers County, Oklahoma)

The man's shoulders are at the contact between the Iron Post coal and the underlying underclay-like shale. He is pointing towards the very thin bed of Kinnison Shale between the Iron Post and Breezy Hill Limestone. The Breezy Hill Limestone forms a massive gray bluff in the upper center of the photograph. The Excello Shale and a few underlying regressive shales are not visible. There are two cyclothems present. The lower cyclothem is the Breezy Hill cyclothem from the top of the underclay-like shale to the subaerial exposure at the top of the Breezy Hill Limestone. The upper cyclothem is the Lower Fort Scott cyclothem, extending from the top of the Breezy Hill (underclay of the Mulky coal in Kansas) to the top of the underclay below the Summit coal. The black phosphatic Excello Shale is the major transgressive shale for the Lower Fort Scott cyclothem.

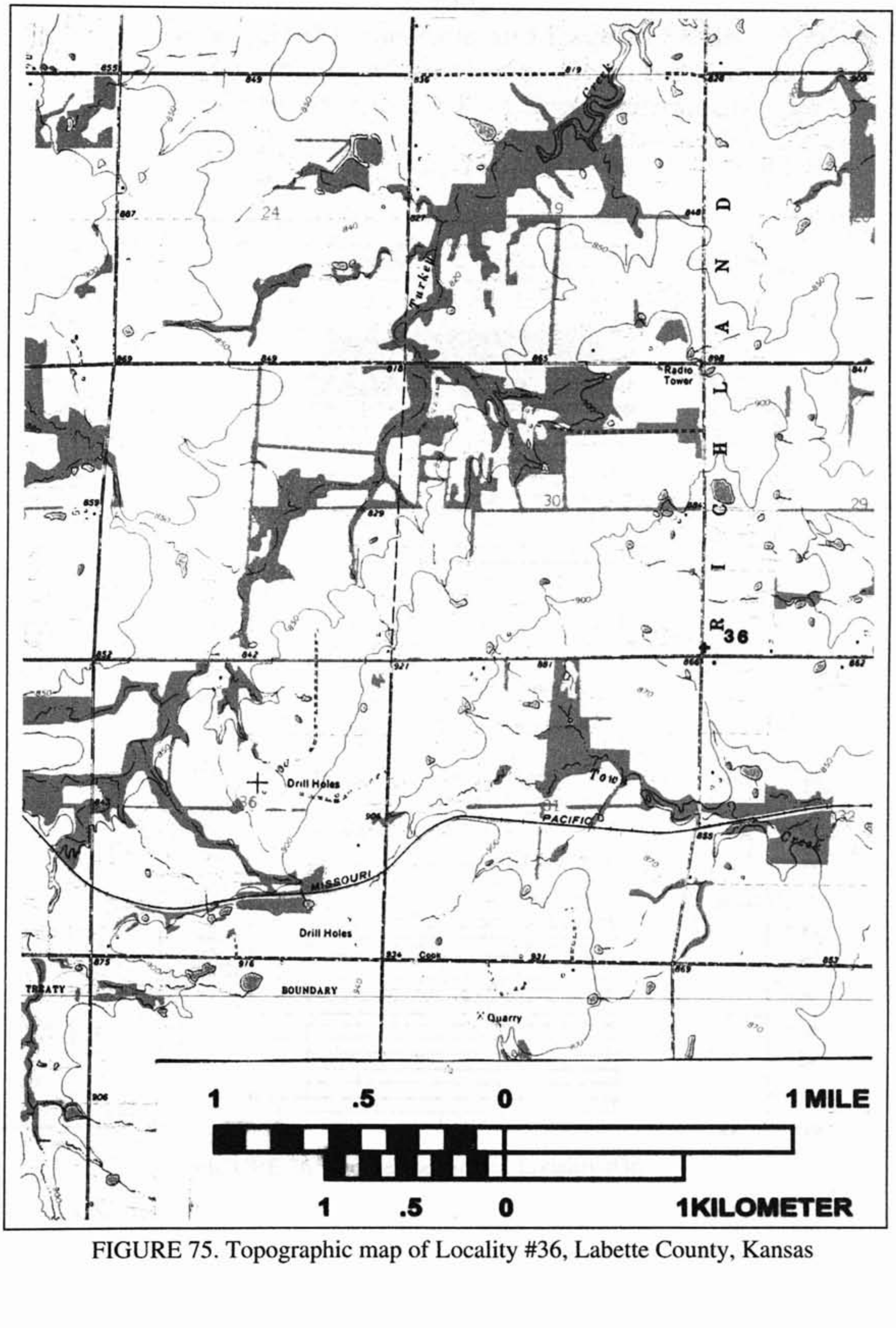


FIGURE 75. Topographic map of Locality #36, Labette County, Kansas

Uppermost Sequence of the Cherokee Group
Breezy Hill Limestone and Excello Shale
Measured along roadcut on US 166 in SE Kansas capped by Marmaton Fort Scott Formation

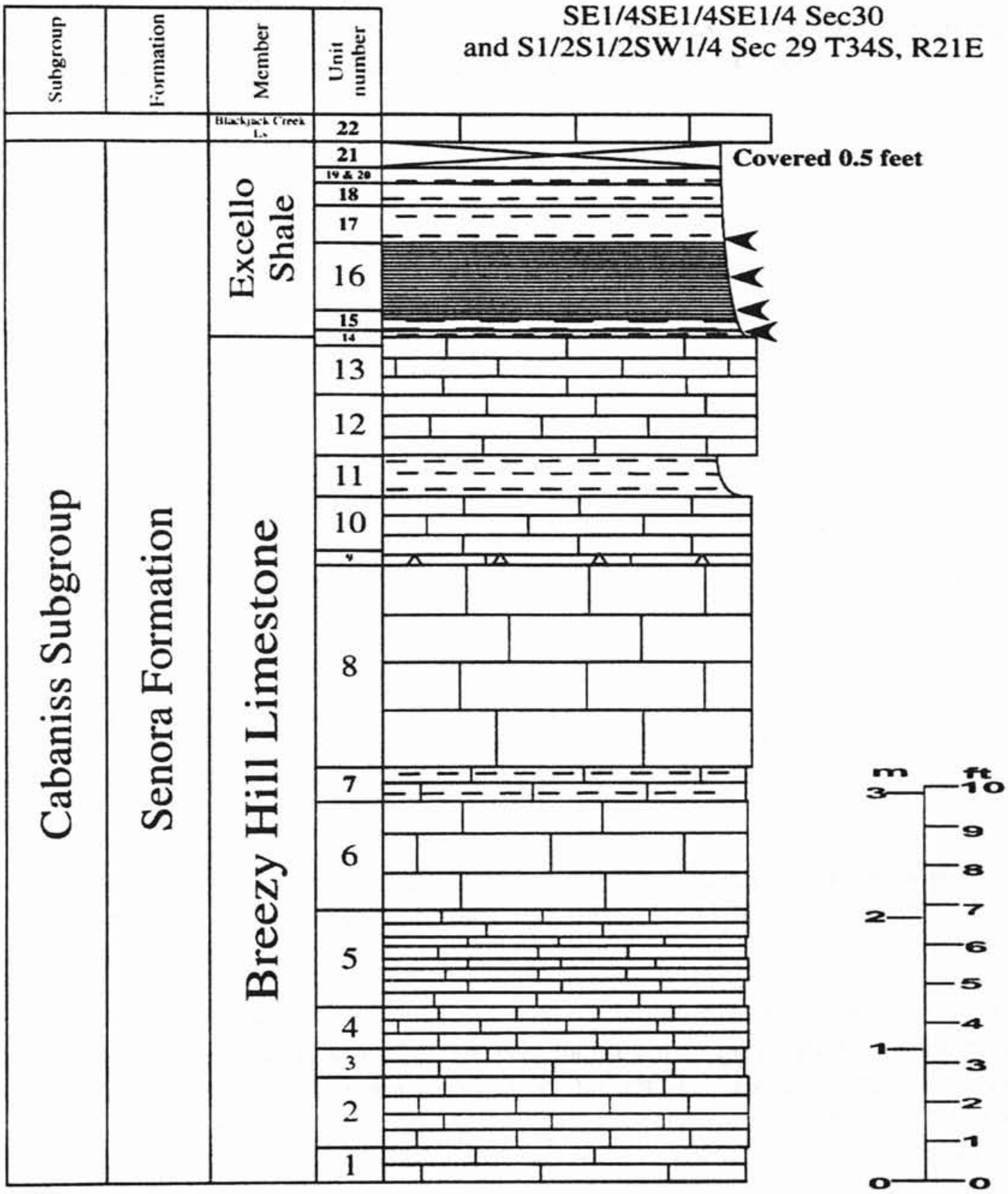


FIGURE 76. Drafted section of Locality #36

MEASURED SECTION of LOCALITY #36

Uppermost Sequence of the Cherokee Group
Breezy Hill Limestone and Excello Shale

SE1/4SE1/4SE1/4 Sec 30 and S1/2S1/2SW1/4 Sec 29, T34S, R21E

Measured along roadcut on US166 in SE Kansas capped by Marmaton Fort Scott Formation, approximately two miles (3.2 km) west of Chetopa, Kansas.

MARMATON GROUP
FORT SCOTT FORMATION:

22. Blackjack Creek Limestone 1.0 (0.3)

CHEROKEE GROUP
CABANISS SUBGROUP

SENORA FORMATION:

Excello Shale Member: Thickness in feet (meters)

21. Covered, probably clay shale 0.5 (0.15)

20. Clay shale 0.58 (0.17)

19. Clay Shale; grayish black (N2) to dark gray (N3), black (N1) carbonaceous spots, mottled with dark yellowish orange (10YR 6/6) and light brownish gray (5YR 6/1); thin-bedded; soft; plastic; incorporated chunks of platy hard black shale; calcareous; resembles underclay 0.17 (0.05)

18. Clay shale; light brownish gray (5YR 6/1) mottled with dark yellowish orange (10YR 6/6); thin-bedded; wavy bedded; plastic; soft; silty; chunks of dark gray (N3) fissile shale; slightly calcareous; resembles underclay 0.42 (0.13)

17. Clay shale; medium gray (N5) banded with moderate yellowish brown (10YR 5/4) weathers to pale yellowish brown (10YR 6/2) mottled with moderate yellowish brown and moderate olive brown (5Y 4/4); very dusky red purple (5RP 2/2), moderate brown (5YR 3/4), and dark yellowish orange (10YR 6/6) oxidation; thin-bedded, soft, blocky, silty, ferruginous 0.67 (0.2)

16. Black shale; black (N1) to grayish black (N2) weathers to light brownish gray (5YR 6/1) and moderate yellowish brown (10YR 5/4); grayish yellow (5Y 8/4) and light bluish gray (5B 7/1) streaking and staining; moderate reddish brown (10R 4/6) oxidation; very fissile; hard; paper-like with sharp edges; numerous 0.10-0.5 inch spherical to oval grayish black phosphate nodules in bedding planes; around one foot above lower contact, *Idiognathodus* conodonts; some elements are off white and heavily fractured on bedding planes; becomes clayier and softer towards upper contact 1.8 (0.54)

15. Shale; grayish black (N2) mottled with moderate yellowish brown (10YR 5/4) weathers to dark yellowish brown (10YR 4/2); fissile; soft; contorted, undulating beds; half inch to inch diameter brownish gray (5YR 4/1) spherical phosphate nodules; some phosphate nodules are flattened, irregular shaped, and up to two inches in diameter; fossiliferous with *Idiognathodus* and *Idioprioniodus* conodonts 0.25 (0.08)

14. Clay; dark yellowish orange (10YR 6/6) mottled with moderate yellowish brown (10YR 5/4); soft; crumbly; heavily oxidized; contorted, undulating beds 0.08 (0.02)

Breezy Hill Limestone Member:

13. Limestone; grainstone; pinkish gray (5YR 8/1) weathers to very pale orange (10YR 8/2), pale yellowish brown (10YR 6/2), and dark yellowish brown (10YR 4/2); pale red purple (5RP 6/2) staining; massive; thick-bedded; hard; silty; wavy, undulating beds; fossiliferous, scattered broken up shell fragments, ostracods, and poorly preserved calcareous foraminifera (possibly *Cornuspira* or *Ammodiscus*); due to undulating nature of beds, thickness varies along outcrop 0.75 to 1.5 (0.23 to 0.45)

12. Limestone; grainstone; light gray (N7) mottled with pale red purple (5RP 6/2), elongate patches (3 inches long and quarter inch thick) of light brownish gray (5YR 6/1) surrounded by grayish red purple (5RP 4/2) staining, weathers to light gray mottled with pale red purple and grayish orange (10YR 7/4); hard; massive; finely crystalline; slightly silty; scattered dark calcite crystals; wavy, undulating beds; fossiliferous, poorly preserved calcareous foraminifera and ostracods; due to undulating nature of beds, thickness varies along outcrop 1.3 to 1.4 (0.4 to 0.42)

11. Clay shale; grayish orange (10YR 7/4); soft; crumbly; noncalcareous; silty; breaks up into cubic blocks 1.0 (0.3)

10. Limestone; poorly exposed 1.0 (0.3)

9. Limestone; wackestone; pinkish gray (5YR 8/1) weathers to pale yellowish brown (10YR 6/2) and moderate yellowish brown (10YR 5/4); medium-bedded; hard; dark gray (N3) hackly calcareous nodules; calcite recrystallization around calcareous nodules; chert nodules; very fossiliferous, large pelecypod fragments, rugose corals, *Ammodiscus* and agglutinated foraminifera, nautiloids, and dark yellowish orange (10YR 6/6) brachiopods 0.17 (0.05)

8. Limestone; wackestone; grayish orange pink (5YR 7/2) with clasts of light gray (N7) weathers to grayish orange (10YR 7/4) mottled with very light gray (N7) and brownish gray (5YR 4/1); massive; hard; solution vugs; fossiliferous, crinoid stems, brachiopods, holothurian sclerites, and calcareous sponge spicules 5.0 (1.5)

7. Limestone; mudstone; pale yellowish brown (10YR 6/2) weathers to pale yellowish orange (10YR 8/6), and grayish orange (10YR 7/4); shaly; medium-bedded; blocky; ferruginous; hard; phylloid algae 0.83 (0.25)

6. Limestone; wackestone; pinkish gray (5YR 8/1) with grayish orange (10YR 7/4) banding weathers to moderate yellowish brown (10YR 5/4), dark yellowish orange (10YR 6/6), and light brownish gray (5YR 6/1); massive; hard; thick-bedded; inch long and deep solution vugs, fossiliferous, brachiopods, phylloid algae, and fusulinids; some shells have dissolved out and replaced with recrystallized calcite; upper 1.5 inches of unit is a grayish orange (10YR 7/4) chatetes sponge interval, includes other fossils, fusulinids, brachiopods, crinoids, agglutinated foraminifera, calcareous monaxon sponge spicules 2.7 (0.81)

5. Limestone; wackestone; light brownish gray (5YR 6/1) weathers to pale yellowish orange (10YR 6/2), grayish orange (10YR 7/4), dark yellowish orange (10YR 6/6), and grayish brown (5YR 3/2); upper part, very pale orange (10YR 8/2) banded with grayish orange (10YR 7/4) and lenses of brownish gray (5YR 4/1); flaggy bedded; massive; very hard; ferruginous; hackly surface; course grained; up to inch wide solution vugs lined with reprecipitated calcite crystals; upper part has numerous small vugs that may be dissolved fusulinid tests; lower part produces hollow metallic sound when struck by a rock hammer; very fossiliferous, spiriferid brachiopods, crinoid stems, phylloid algae, gastropod fragments, echinoid spines, holothurian sclerites, and calcareous monaxon sponge spicules; forms large bench in outcrop 2.4 (0.72)

4. Limestone; wackestone; pinkish gray (5YR 8/1) weathers to very pale orange (10YR 8/2), grayish orange (10YR 7/4), and dark yellowish brown (10YR 7/4); light brown (5YR 5/6) oxidation; moderate yellowish green (10GY 6/4) staining; massive; hard; medium-bedded; extensive calcite recrystallization; numerous small vugs, probably dissolved fusulinid tests; very fossiliferous, degraded foraminifera, holothurian sclerites, sponge spicules; brachiopod shells; phylloid algae; bryozoan fragments, and sparse *Idiognathodus* conodonts 1.2 (0.36)

3. Limestone; mudstone; light brownish gray (5YR 6/1) weathers to grayish orange (10YR 7/4), dark yellowish brown (10YR 4/2), and pale yellowish brown (10YR 6/2); moderate yellowish green (10GY 6/4) staining; hard; massive; nodular; medium-bedded; ferruginous; dissolved fusulinid tests; weathered; fossiliferous, scattered shell fragments, degraded fusulinids and foraminifera, brachiopod spines 0.67 (0.2)

2. Limestone; packestone, lower part to wackestone, upper part; pale yellowish brown (10YR 6/2) to light brownish gray (5YR 6/1) weathers to dark yellowish orange (10YR 6/6), moderate yellowish brown (10YR 5/4), pale yellowish orange (10YR 8/6), and grayish orange (10YR 7/4); hard; massive; thick-bedded; extensive calcite recrystallization; ferruginous; fossiliferous, phylloid algae, brachiopods, and fusulinids 1.75 (0.53)

1. Limestone; mudstone; very pale orange (10YR 8/2) banded with pale yellowish orange (10YR 8/6) weathers to pale yellowish orange (10YR 8/2), dark yellowish brown (10YR 4/2), grayish orange (10YR 7/4), and dark yellowish orange (10YR 6/6); flaggy; hard; nodular; ferruginous; light brown (5YR 5/6) oxidation, fossiliferous, numerous fusulinids, many of which have been dissolved out of the matrix, heavily degraded foraminifera, brachiopod spines, and sparse poorly preserved *Idiognathodus* conodonts 0.83 (0.25)

TOTAL: 25.9 (7.8)

C. SUMMARY OF NEWLY IDENTIFIED CONODONTS

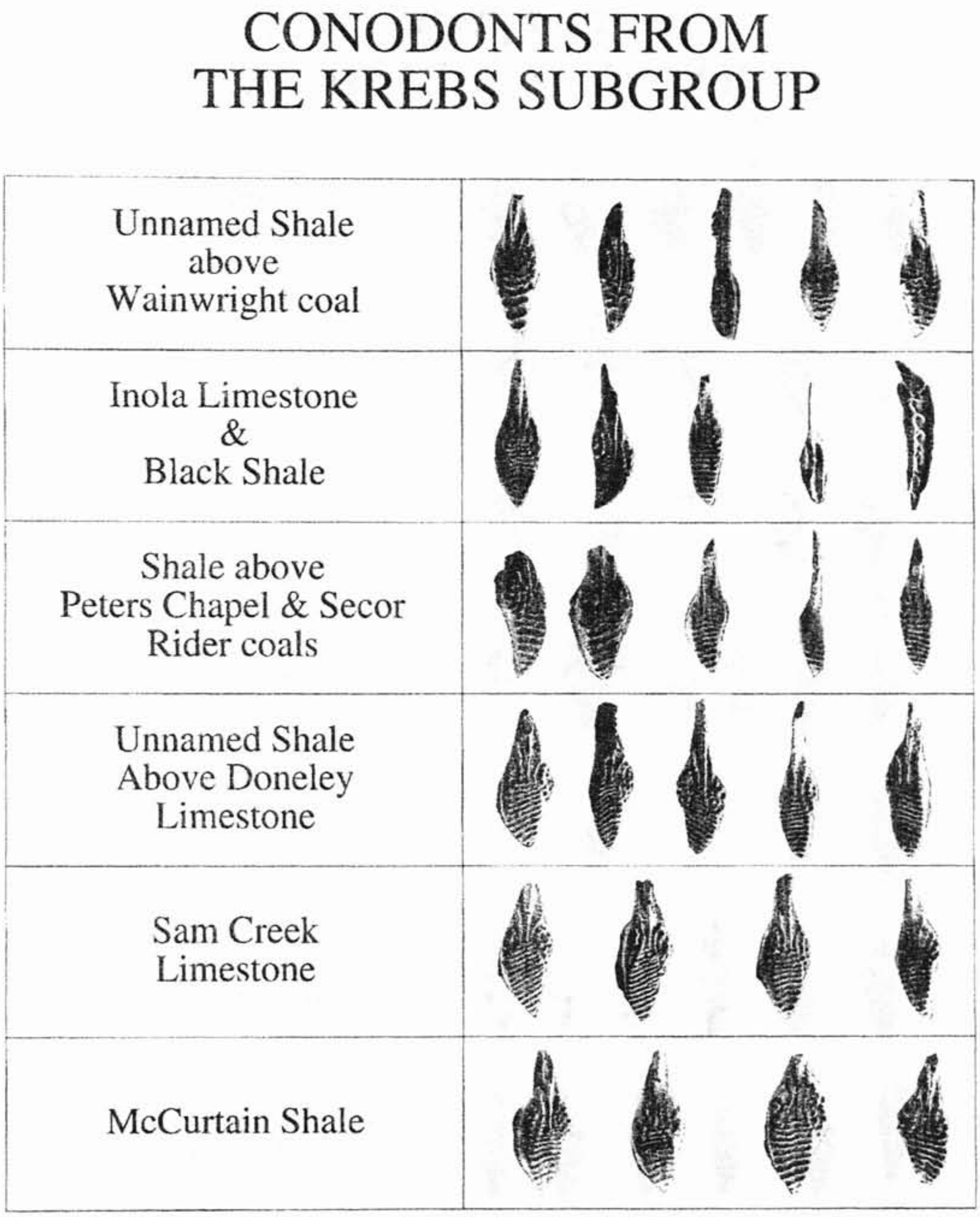


FIGURE 77. S.E.M. photomicrographs of selected conodonts from the Krebs Subgroup (Boardman and Marshall, 2002)

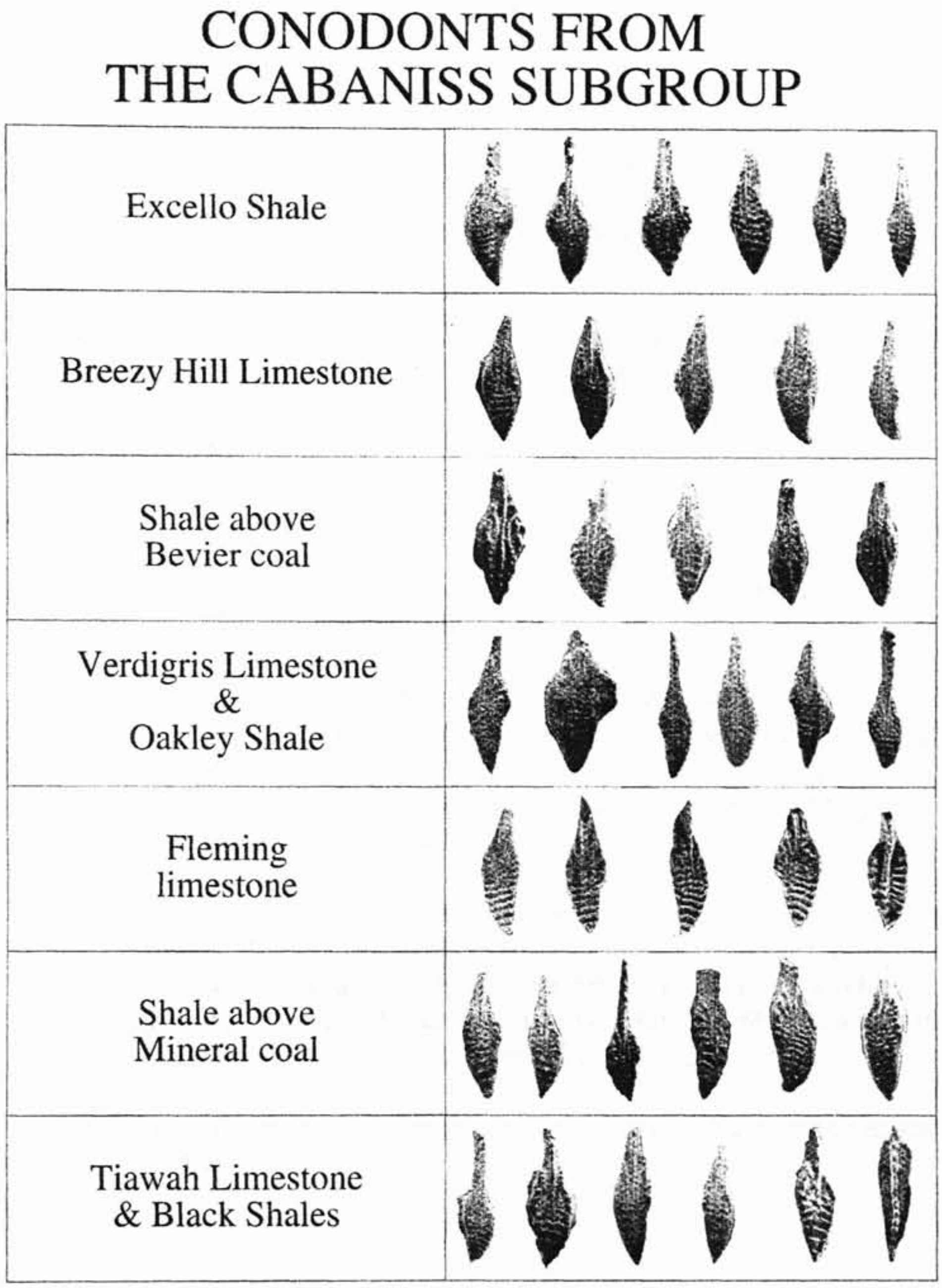


FIGURE 78. S.E.M. photomicrographs of selected conodonts from the Cabaniss Subgroup (Boardman and Marshall, 2002)

2

VITA

Thomas Robert Marshall

Candidate for the Degree of

Master of Science

Thesis: OUTCROP-BASED CYCLIC STRATIGRAPHY OF THE CHEROKEE GROUP (DESMOINESIAN, PENNSYLVANIAN)

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Biographical:

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Education: Graduated from Stillwater High School, Stillwater, Oklahoma in May 1990; received Bachelor of Science degree in Geology from Oklahoma State University, Stillwater, Oklahoma, May 1995. Completed requirements for the Master of Science degree with a major in Geology at Oklahoma State University (December, 2002).

Experience: Employed by Oklahoma State University, School of Geology as a graduate teaching assistant, 1996 to 1998, 2001; taught English for one academic year at the University of Petroleum, East China, Dongying, Shandong, People's Republic of China, 1998 to 1999; participated as an enumerator in the 2000 U.S. Census, April to July 2000.

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