A MICROFAUNAL ANALYSIS OF AN UPPER PENNSYLVANIAN DARK SHALE (HEEBNER) AND SEVERAL LOWER PERMIAN DARK SHALES (LOWER COUNCIL GROVE GROUP) FROM THE NORTHERN MIDCONTINENT, U.S.A.

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I.

INTRODUCTION

Black shales from the Pennsylvanian of the Midcontinent have been studied by numerous geologists. Dark shales also are found in Lower Permian strata (including the Council Grove Group) of the same region. Although they have not been studied as extensively as the Pennsylvanian black shales, they appear to have many similarities with their older counterparts.

However, one notable difference is the absence of non-skeletal phosphate in Permian shales. Phosphate nodules and laminae in the Pennsylvanian black shales suggest that nutrient-rich water upwelled onto the Midcontinent from deep basins. The absence of this phosphate in the Lower Permian black shales indicates that either different factors affected their formation or that the origin was different altogether.

Several dark gray to black shales are present in the Council Grove Group, but only the Bennett Shale Member of the Red Eagle Limestone (Figure 20) is given a formal name. The others are contained within members of the formations in this group. Non-skeletal phosphate is absent from these shales. Some of the shales are laterally-extensive and others are not.

Purpose

The purpose of this study was to characterize the paleoenvironment of the Lower Permian dark gray to black shales described, notably those from the Council Grove Group. Different types of black shale were identified, based on their microfaunal content and stratigraphic extent. Because megafossils are sparse in dark gray to black shales, study of microfauna should contribute significantly to any paleoecological interpretation.

Methodology

This study was accomplished by reviewing the literature, measuring and collecting selected samples of dark gray to black shales, disaggregating the shales using standard laboratory methods, picking microfossils from each collected sample, identifying genera of microfossils, interpreting the diversity and abundance of these microfossils and comparing paleoecological interpretations with previous interpretations, notably those of Pennsylvanian black shales.

An extensive review of the literature is necessary for understanding current views on formation of black shale in the Midcontinent region. This study of mostly Lower Permian rock-stratigraphic units draws upon previous work, much of which is concerned with Upper Pennsylvanian units of the same region.

In the field, the selected shale units were measured and selected intervals were sampled. In the laboratory, each sample was soaked in kerosene, then in hot water. In a few cases the samples soaked in bleach for several weeks or months in order to weaken cement. Formic acid was not used in the disaggregation process because it would have destroyed calcareous fossils. The samples were sieved through 35-mesh and 80-mesh screens.

Residue from the 35-mesh screen was scanned for its general megafossil content. Residue of the 80-mesh screen was examined with a binocular microscope; microfossils were extracted.

Although the standard quantity of 1000 grams of shale was processed, only half of the residue from most of the shale intervals was actually sampled for microfossils. The data from intervals where more than half of the residue was picked were adjusted to equivalent counts of 500 grams. In this way, the data contain better ratios of microfossils between intervals of one shale and between shales. This method, though unconventional, was deemed necessary due to the large amount of residue from most of the samples. Raw and adjusted data are included in this report.

Darwin R. Boardman II assisted considerably in identifying most of the conodonts, foraminifers and ostracodes and many megafossils to generic level. Some genera were double-checked against sources that contained scanning electron microscope (SEM) images (Melnyk and Maddocks, 1988b; Boardman et al., 1995; Hoare, 1961; Moore, 1961).

The final counts, especially those of conodont platform elements, foraminiferan tests and ostracode carapaces, were used in the paleoenvironmental interpretations of data compiled in this study. Recognition of different types of black shale was based on microfaunal assemblages and stratigraphy.

Note on terminology: Black vs. dark gray

Dark gray or black shale is commonly interpreted as indication of low oxygen and toxic conditions in the depositional environment. Black color may be an indication of high organic carbon content or pyrite content or both (Twenhofel, 1939). Generally, a lighter gray shale is believed to have been deposited where more oxygen was present. The average black shale contains about 3% organic carbon (Myrow, 1990; Vine and Tourtelot, 1970).

The Pennsylvanian “black” shales are not completely black; indeed, a lighter facies may be present above and below the darkest part of the unit. Nevertheless, these units are often referred to as “black shales” throughout the literature.

The sampled intervals of the shales in this study range in color from grayish black to medium gray (range N2 to N5 according to Munsell® color charts). Although to refer to these shales as “dark gray to black shales” is fairly accurate, it is cumbersome and unnecessary to do so continually when an understanding is implied by the one term “black shales.” Therefore, the dark gray to black shales referenced or analyzed in this study will be referred to as “black shales,” regardless of how black they truly are.

II.

GEOLOGIC SETTING

The Late Paleozoic was a time of general worldwide emergence of land surfaces from the oceans as the supercontinent Pangea was being assembled. Gondwana, which was moving northward and rotating clockwise, collided with Laurasia in the Carboniferous Period forming the Appalachian and Ouachita ranges (Scotese et al., 1979, pp. 222-223).

Regions of Gondwana passed through the south polar latitudes during the Carboniferous and Permian Periods. These polar regions were covered by ice sheets that peaked in areal expansion in the Late Pennsylvanian and Early Permian. This period of glaciation waned in the Permian as Gondwana, concurrently a part of Pangea, continued to move northward away from the polar latitudes (Veevers and Powell, 1987; Scotese et al., 1979; Crowell, 1978).

During the Pennsylvanian and Early Permian the North American Midcontinent region was north of equatorial latitudes in the trade winds belt, between 20 degrees north latitude and the equator. Furthermore, the North American continent was oriented about 35 to 40 degrees in the clockwise direction from its current orientation with respect to the equator (Heckel, 1977) (Figure 1).

The North American Midcontinent is divided by the Wichita Uplift in southern Oklahoma. The southern midcontinent incorporates northern Texas and southern Oklahoma, and the northern midcontinent includes western and northern Oklahoma, Kansas, western Missouri, southern Iowa, southern Nebraska, eastern Colorado and parts of the Texas Panhandle. The current study is about part of the northern

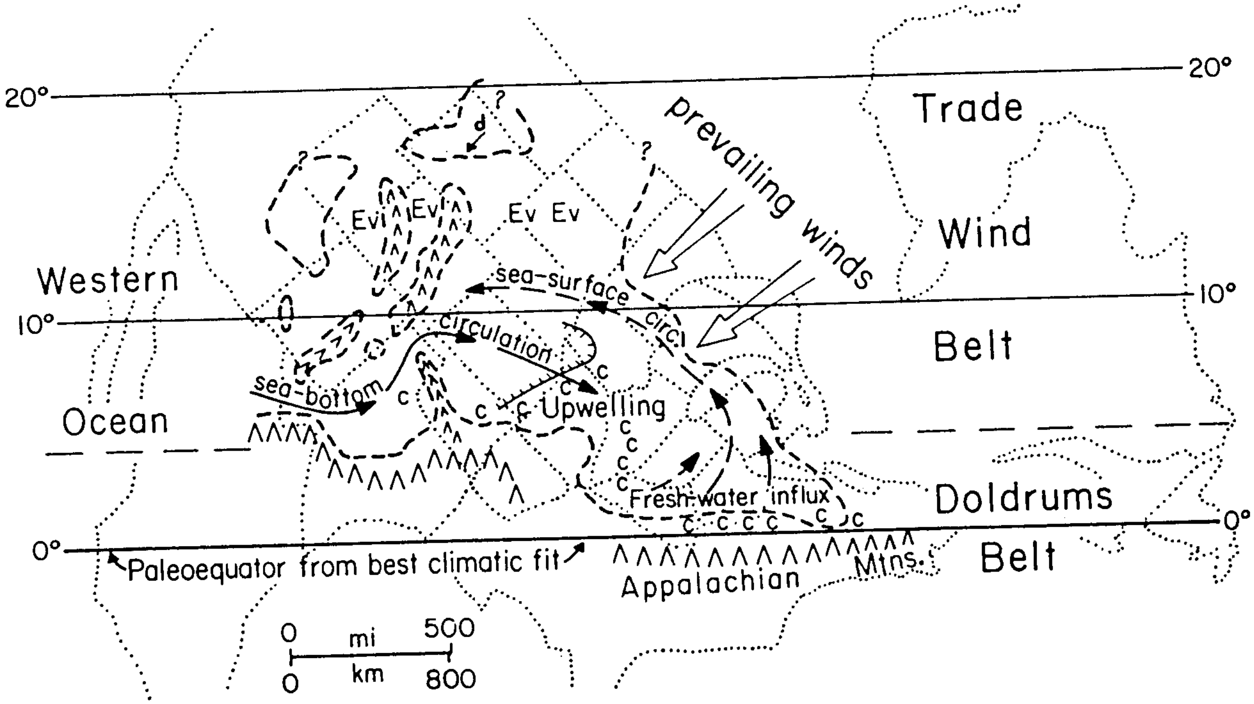

Figure 1. Paleogeography of North America in Late Pennsylvanian. Bottom water, originating from the ocean and deeper oceanic basins in the west, moved eastward and upwelled in the Midcontinent region to replace surface water that was blown westward by trade winds (from Heckel, 1977, p. 1056).

midcontinent region. Throughout this study the term “Midcontinent” will refer to “northern midcontinent.” Additionally, nomenclature of the northern midcontinent Pennsylvanian System (Desmoinesian, Missourian, Virgilian) will be used (Boardman et al., 1994b), as will modern nomenclature of the Permian System (Asselian and Sakmarian in lieu of the older term, Wolfcampian) (Figure 16).

The Midcontinent was terrain mostly of low relief. An epicontinental sea often covered it before the late Early Permian. The tectonically active Anadarko Basin occupied western Oklahoma, the Texas Panhandle and parts of southwestern Kansas. This basin was connected to a western ocean through West Texas (Rascoe, 1962).

Throughout the Late Pennsylvanian and Early Permian, the Midcontinent region was bounded along the south by the Wichita Uplift and the Appalachian-Ouachita foldbelt. The Ozark region was a positive structure at that time. The area north of Nebraska and Iowa might have been topographically too high to have been covered by marine deposits. Deposits that might have formed there were removed by post-Permian erosion. The ancestral Rockies bordered the region in the west (Rascoe and Adler, 1983; Rascoe, 1962; Heckel, 1980).

The Nemaha Uplift is a topographically positive feature that extends from southeastern Nebraska to south-central Oklahoma. It is structurally higher in southeastern Nebraska and northeastern Kansas (Rascoe and Adler, 1983, p. 981). Rascoe and Adler (ibid., p. 984) postulated that the structure formed during the Atokan “as a product of the ... collision between the North American craton and the northern margin of the South American plate.”

Sea level in the Midcontinent fluctuated in response to waxing and waning of Gondwanan continental glaciation in the southern hemisphere (Wanless and Shepard, 1936; James, 1970; Crowell, 1978; Veevers and Powell, 1987). These fluctuations, coupled with general subsidence of the entire area, produced numerous cyclic sequences of sedimentary rock.

Most subsidence was concentrated in the deeper Anadarko Basin. Rascoe (1962, p. 1369) divided the time of deposition of Midcontinent sedimentary units into two phases that reflect different rates of subsidence of the Anadarko Basin. These rates in turn reflect the overall degree of inundation of the Midcontinent shelf region. Rascoe noted that the Anadarko Basin subsided at a faster rate during the Morrowan, Atokan, Desmoinesian and Missourian Stages. The rate of subsidence decreased in the Virgilian Stage and the Early Permian and resulted in overall regression of the sea from the Midcontinent and an increased occurrence of non-marine units. Ultimately, the Midcontinent region and the Anadarko Basin were filled.

The current study area incorporates eastern Kansas and southern Nebraska, which were on the eastern shelf of the Midcontinent (Figure 2). General subsidence and widely fluctuating sea levels during much of the Pennsylvanian resulted in cyclic sequences of non-marine shales, thin coals, marine shales, limestones and black shales. Many of these units, especially the limestones and black shales, are laterally-continuous over much of the Midcontinent (Rascoe, 1962; Heckel, 1977).

Schenk's (1967) explanation and Heckel's (1977, 1980, 1983) refined model for deposition of Pennsylvanian cyclothems, specifically the black shales and associated limestone units, apply especially to sequences ranging from upper Desmoinesian to lower Virgilian (Figure 3). During transgressive events water was deep enough for a thermocline to develop. This prevented oxygenated surface water from reaching the bottom. Trade winds blew the surface water westward, and "cold, deep, oxygen-poor, phosphate-rich water from the western ocean was drawn in along the bottom through the basins of West Texas" to replace that surface water (Heckel, 1977, p. 1045). This circulation pattern at high sea-level stand allowed formation of black muds to occur. Phosphate-rich water aided the formation of non-skeletal phosphate nodules in the shales that formed from these muds (Schenk, 1967; Heckel, 1977).

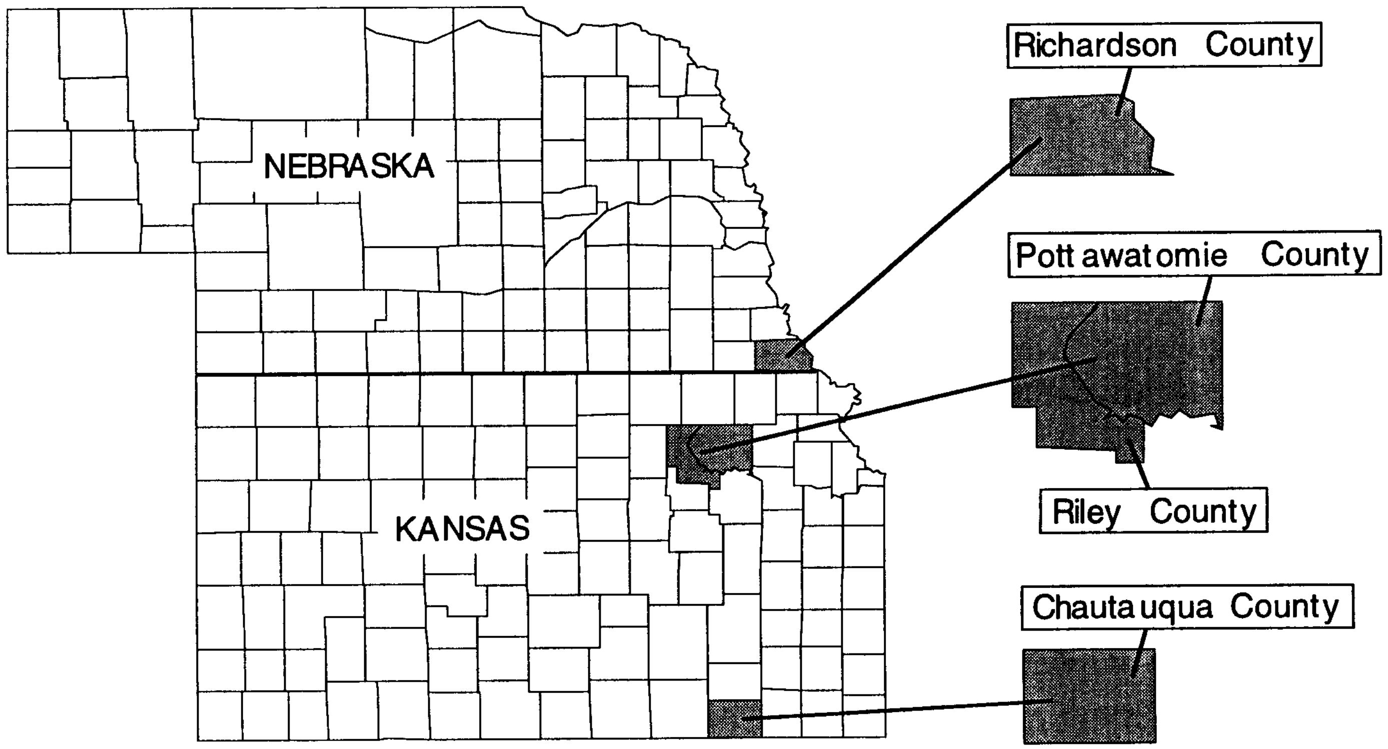

Figure 2. Study area of thesis

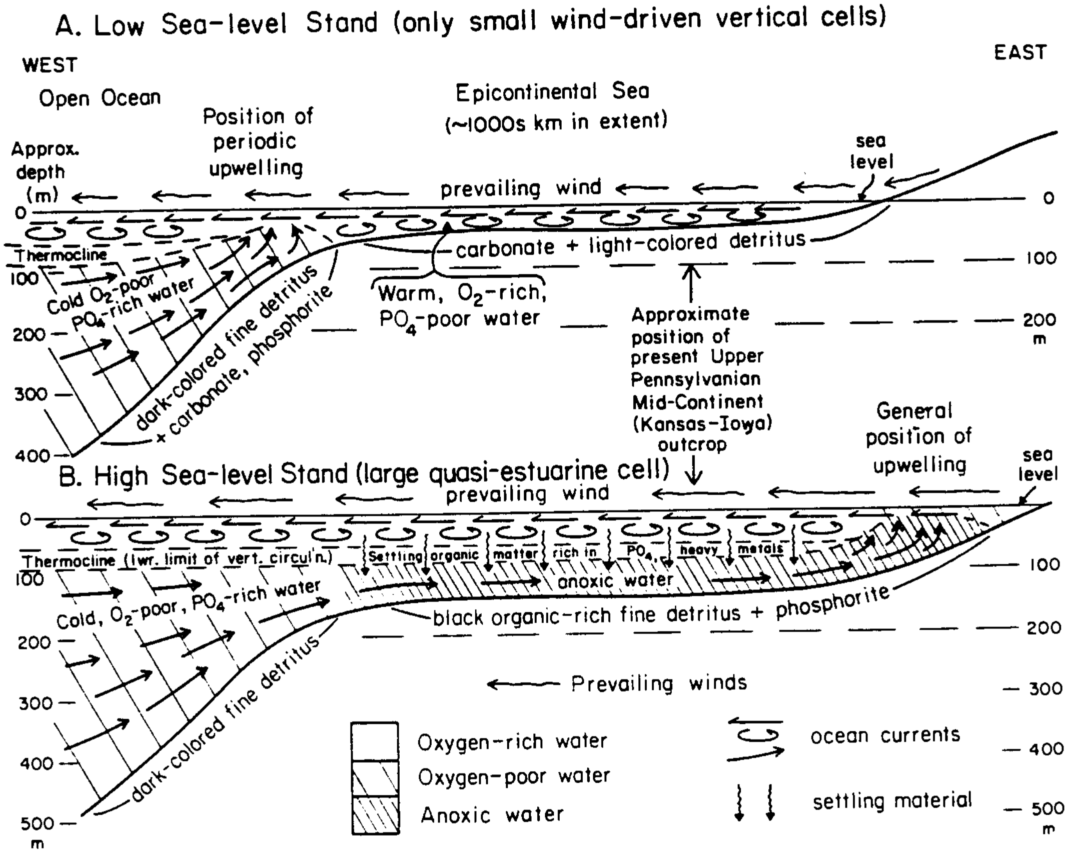

Figure 3. Vertical circulation patterns in Midcontinent seas of the Late Pennsylvanian during (A) low and (B) high stands of sea level (from Heckel, 1977, p. 1054).

During regressions, limestones developed as the thermocline was dissipated in shallow water. Deltaic and shoreline deposits of clay, sand and peat developed between the Appalachians and Kansas. Shales dominate in the Kansas deposits due to the great distance from the source areas in the east and south. Coal beds and sandstones are less common than shales and limestones. Cyclothems continued to develop throughout the Virgilian and the Early Permian; however, the scarcity of black shales in these sequences may suggest that water was shallower than it was during the Early and Middle Pennsylvanian (Heckel, 1977; Boardman and Nestell, 1993; Rascoe and Adler, 1983) (Figure 4).

Cyclic sedimentation continued in the Early Permian. Calcareous material and mud filled the Anadarko Basin while calcareous material, marine muds and non-marine deposits, including red muds and silt, were deposited on the Midcontinent shelf (Rascoe and Adler, 1983, p. 996). Heckel (1977, p. 1064) said that "a greater abundance of non-marine deposits in Kansas ... suggests shallower water deposition for the more marine phases."

Shallow water may explain why deep-water black shales are uncommon in the Lower Permian sequences. Apparently, the water was deep enough for thermoclines to develop at times. The Anadarko Basin was largely filled by this time, and deep basinal water from the west did not enter the Midcontinent along the bottom (Rascoe and Adler, 1983) (Figures 5 and 6). Cool nutrient-rich water that supported deep-water conodont species (*Gondolella*, *Neogondolella* and *Idioprioniodus*) apparently did not enter the Midcontinent in the Permian. These species are elsewhere in the world in coeval strata. The absence of non-skeletal phosphate nodules in the Permian black shales suggests that upwelling of deeper water from the west was no longer possible (Boardman et al., 1995).

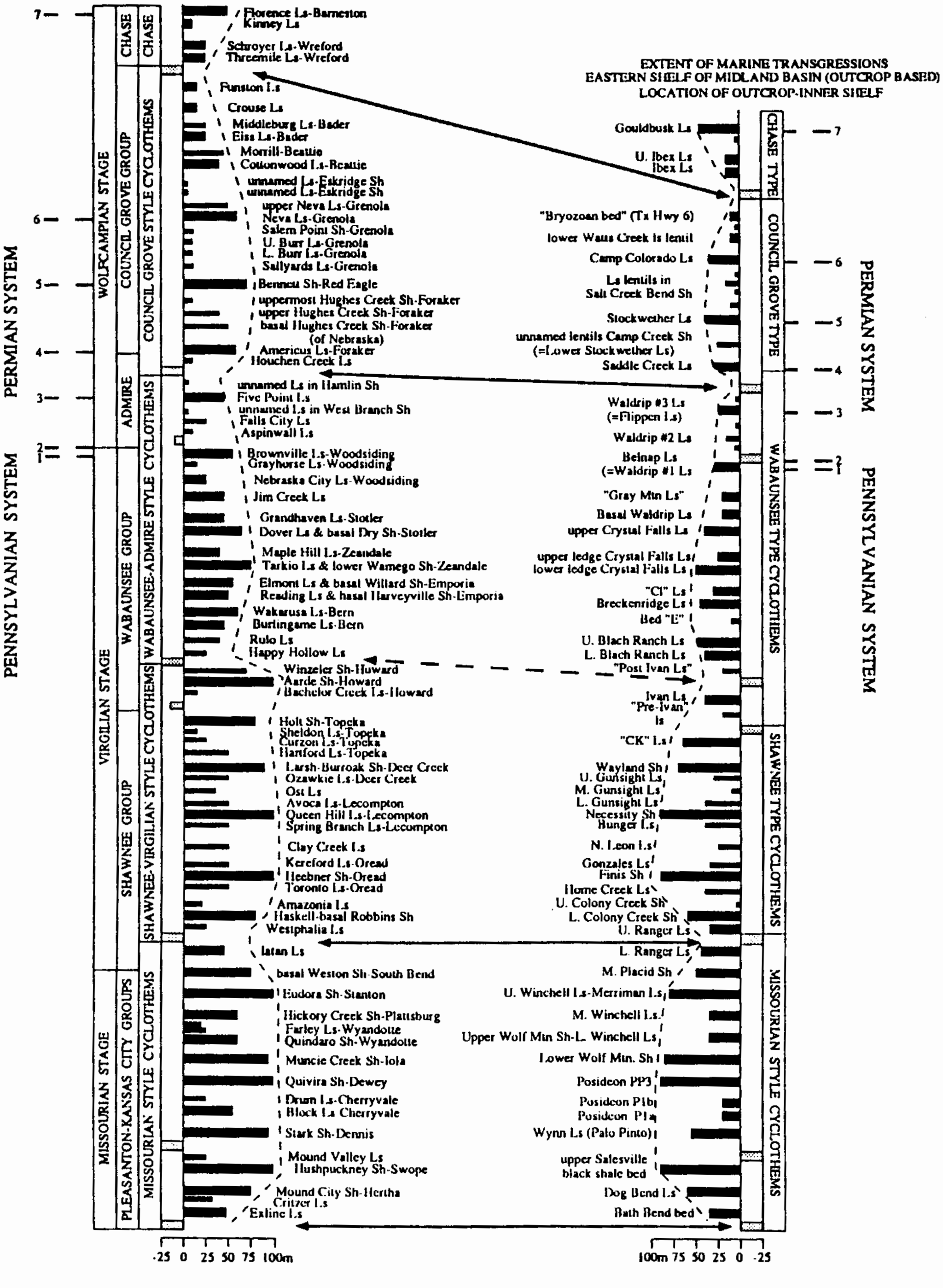

Figure 4. Sea-level fluctuations during deposition of Missourian to Lower Permian strata of the Midcontinent and the Midland Basin. Younger strata contain fewer deep-water intervals (from Boardman and Nestell, 1993, p. 23).

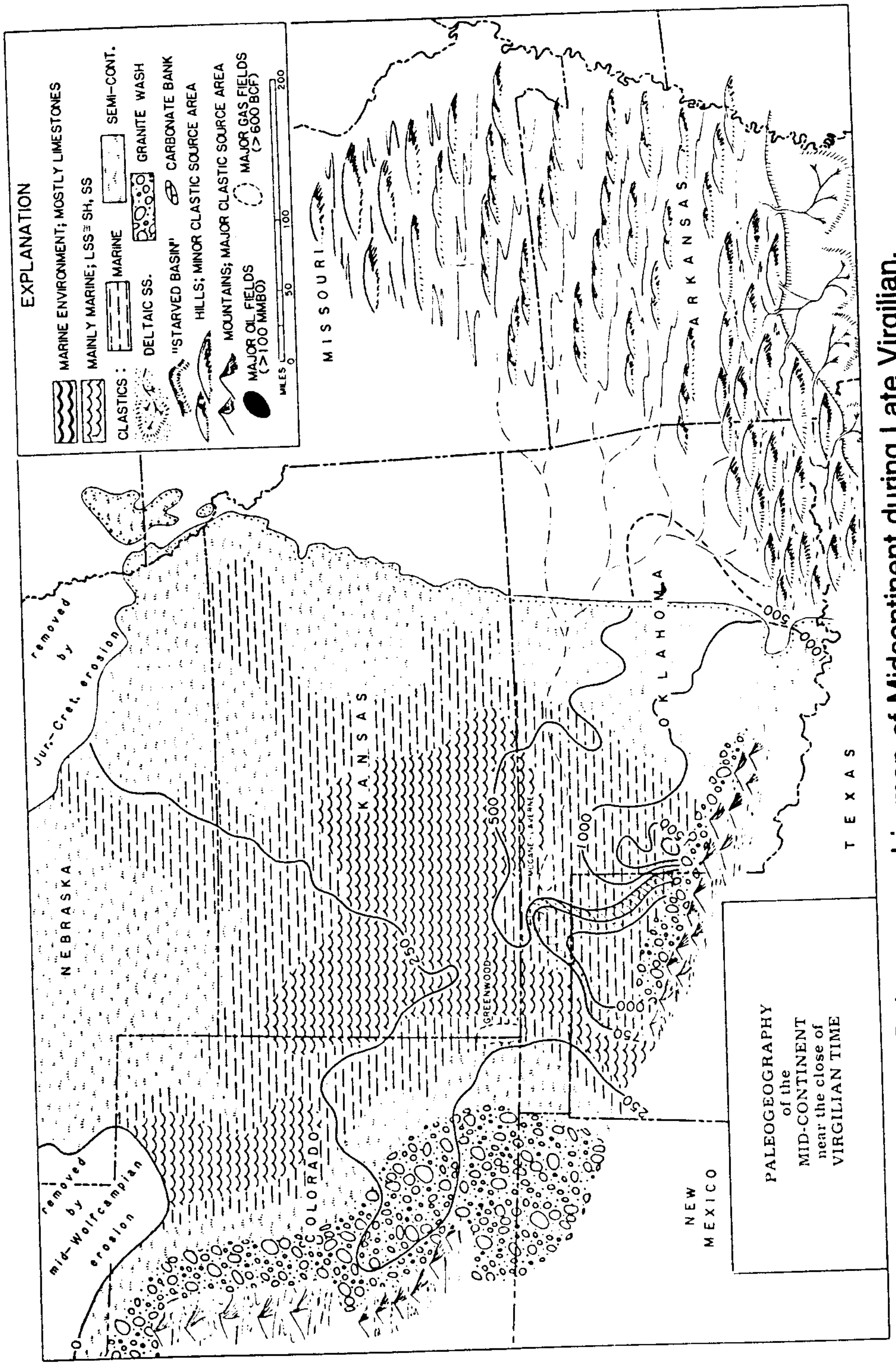

Figure 5. Paleogeographic map of Midcontinent during Late Virgilian. Connection to deeper basins via Texas Panhandle became shallower as the Anadarko Basin filled with clastics and carbonates (from Rascoe and Adler, 1983, p. 997).

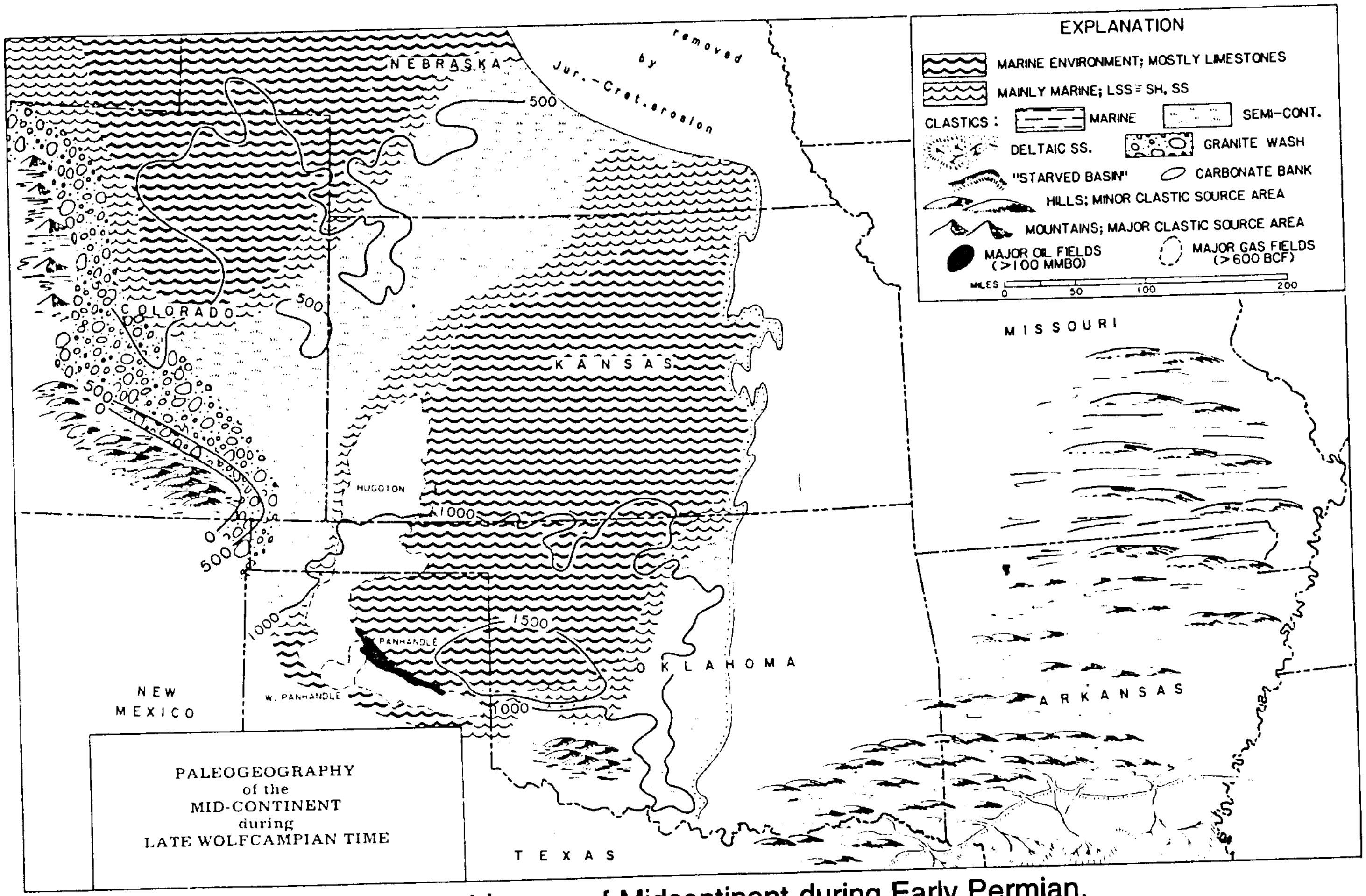

Figure 6. Paleogeographic map of Midcontinent during Early Permian. Midcontinent was unable to receive nutrient-rich bottom water from deeper basins in the southwest (from Rascoe and Adler, 1983, p. 999).
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III.

PREVIOUS INVESTIGATIONS

Introduction

During the Pennsylvanian and Early Permian, the Midcontinental United States was covered periodically by epicontinental seas as made evident by marine deposits of limestones, shales and, in lesser volumes, sandstones. Among these deposits are dark gray to black shales, which lack megafossils or contain few of them. Some are fissile and laterally-extensive. These shales, which defy easy explanation of their origins, suggest that anoxic to near-anoxic bottom water, unaffected by carbonate deposition and high to average sedimentation rates, periodically composed parts of the epicontinental seas.

Those who studied the stratigraphic occurrence and the paleontological aspects of these black shales arrived at different hypotheses concerning their origin. Before such a history on the interpretation of black shale formation can be attempted, it is first necessary to review the early studies of cyclical sedimentation, which began in Illinois.

Early studies of cyclical sedimentation

Early work on Pennsylvanian strata was concentrated predominantly on stratigraphy and was born of the economic advantages gained from a better understanding of numerous coal deposits in the Eastern Interior Basin of the United States.

Udden (1912) examined rock sequences in Illinois. He was one of the first group to suggest an explanation for the cyclical pattern of Pennsylvanian rock units. His cycles consisted, from bottom to top, of coal, black shale, limestone, sandstone and shale

(Figure 7). The upper shale was usually topped by an erosional surface, overlain by coal of the next sequence. Udden (1912, p. 49) attributed these cycles to "recurrent interruptions in a progressive submergence" in which sediment from a distant source rapidly filled the region to sea level, thereby allowing extensive vegetation to accumulate before inundation recurred.

Weller (1930) synthesized data into a comprehensive paper on Pennsylvanian cyclical sedimentation. He believed that diastrophism was the predominant controlling factor over transgression and regression in the area. He suggested that the Pennsylvanian epicontinental seas were most likely connected to the open ocean basin through a southwest corridor. According to his theory, rapid subsidence resulted in transgression over coal swamps, followed by the deposition of calcareous material, sand and mud. Uplift resulted in a regression, which resulted in exposure and subsequent erosion of some of these units.

Weller essentially dismissed Udden's suggestion of steady transgression interrupted by aggradation of sediments, and supported the idea of a steady sea level that only appeared to fluctuate as the region was subjected to cyclical subsidence and uplift. Weller believed that his explanation accounted for the extensive erosional surfaces he noted below the coal units. He defended his views in subsequent papers (notably, Weller, 1956).

In the meantime, Moore (1931) studied Pennsylvanian cyclical sequences in the Midcontinent region. These units are generally more marine than those in the Illinois region, and the pattern of cyclicity is dominated by the alternation of shales and limestones. The units form sequences with distinctive divisions, from bottom to top, of non-marine shale, massive limestone, clayey shale, compact limestone, black shale, fine-grained limestone, sandy shale, another limestone and non-marine shale (Figure 8). This general sequence occurs throughout the Middle and Upper Pennsylvanian stratigraphic column of the Midcontinent. Although Moore (1931, p. 255) did not propose

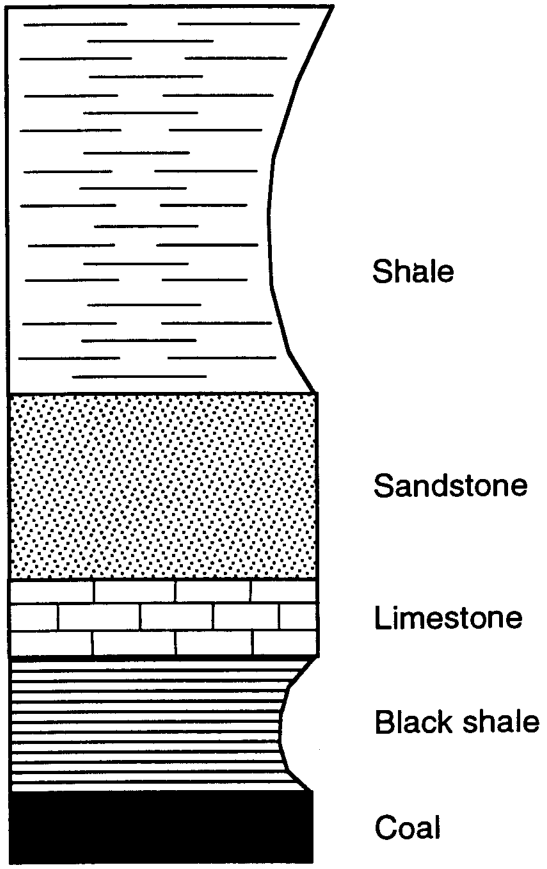

Figure 7. A typical cycle of deposition in Pennsylvanian rocks of Illinois and Indiana (Eastern Interior Basin). This cycle represents one advance and retreat of the sea (after Udden, 1912).

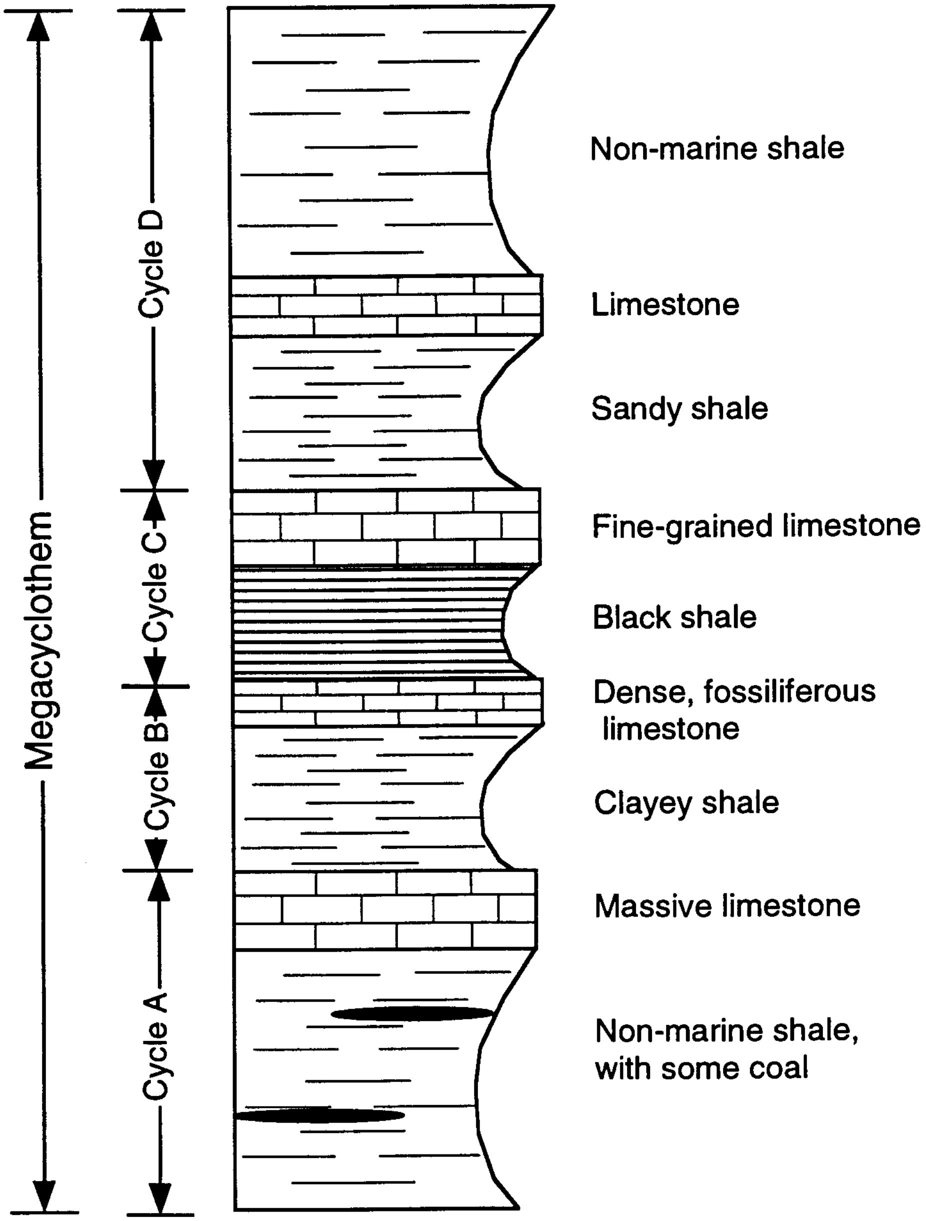

Figure 8. A typical cycle ("megacyclothem") of deposition in Pennsylvanian rocks of the Midcontinent. Each cycle represents one advance and retreat of the sea. This group of cycles ("megacyclothem") is repeated in other Pennsylvanian sections (after Moore, 1931 and 1936).

a mechanism to explain the cyclicity of the rock sequences, he did recognize that the "repetition of the described succession of beds is not fortuitous and meaningless."

Wanless and Weller (1932) noted that the Pennsylvanian cycles of the Illinois region are extensive enough to be correlatable with cycles in the Midcontinent region. The term "cyclothem" was introduced by them to "designate a series of beds deposited during a single sedimentary cycle," which represents a single major advance and retreat of the sea (Wanless and Weller, 1932, p. 1003). They concluded that whatever controlled the cycles was extensive enough to have simultaneously affected both the Illinois area and the Midcontinent region. Weller (1958, p. 199) called the unique fissile black shale unit of each cyclothem the "key to the cyclical relations of Pennsylvanian strata in Illinois and Kansas."

Moore (1936, 1949), interpreting more than one cyclothem in the repeating set of the more complex Midcontinent sequences, introduced the term "megacyclothem" to refer to the entire repeated sequence (Figure 8). A cyclothem represents one sea level advance and retreat, and Moore's (1936, p. 29) megacyclothem represents a "repeated succession of cyclothems of different character."

Cyclical sedimentation was also observed in rocks of the Late Mississippian and the Early Permian. Jewett (1933) noted that Lower Permian units also display cyclical sedimentation. Among the rocks he studied are those of the Council Grove Group, Asselian and Sakmarian Stages, exposed in Riley County, Kansas.

Wanless and Shepard (1936) addressed the several hypotheses that were put forth to explain the apparent sea level fluctuations of the Late Mississippian, the Pennsylvanian and the Early Permian. Their objections to the "alternate subsidence and uplift" hypothesis included the lack of crustal wrinkling that would be present in the case of regional diastrophism. Wanless and Shepard favored rhythmic changes in sea level to large-scale rhythmic movements of the Earth.

They were also among the first workers to seriously suggest variation of climate, manifested by glaciations, as the controlling factor of Late Paleozoic cyclical sedimentation. They noted the approximate time-synchronous glacial deposits in the southern hemisphere and cyclic deposits in North America and elsewhere.

Meanwhile, differences in Lower Permian cyclothems and Pennsylvanian cyclothems were documented by Elias (1937, p. 405). These differences include

> (1) still greater persistency and uniformity of ... limestones and shales, (2) the nearly total disappearance of sands and conglomerates, (3) the disappearance of coals (except a few thin, locally developed beds), (4) the prominent development of red and green shales, and (5) the introduction of some gypsum and salt

in the Permian units. The fauna and general character of the Early Permian epicontinental seas also differed from those of the Pennsylvanian seas. Faunal diversity decreased, indicating a "general decrease in extension or gradual shallowing of the last marine invasions" (Elias, 1937, p. 408).

Weller also commented upon these differences and noted that

> some of the Mississippian and Permian cycles that have been recognized differ more or less notably from the ordinary Pennsylvanian cyclothems. Good reasons, however, are believed to exist for concluding that these are all related in their origin and that they differ mainly because they represent somewhat different environments. Any adequate theory must take into account whatever evidence is provided by each variety of the cycle (Weller, 1964, p. 615).

Shallow-water interpretations of black shale origin

Black shales form from black muds, and those of the Pennsylvanian and Permian do not appear to have been exceptions. Twenhofel (1939) noted that either poor circulation or rapid accumulation of organic material is a prerequisite condition in the environment of deposition of original black muds. Analogous modern environments indicate that restricted oxygen is the more common condition. These conditions guided most workers who made attempts to determine the environment of deposition of Permian and, especially, Pennsylvanian black shales. Any study of one or a group of these black shales from either the Midcontinent or around Illinois has proved useful to other similar studies because the origin of these shales is believed to be similar.

Early workers viewed these black shales as shallow-water (i.e. nearshore) deposits for two reasons: 1.) The shales, specifically those in Illinois, are associated with non-marine deposits and other shallow-water deposits, and 2.) no reasonable explanation could account for water having become quite deep within a geologic time-frame inferred to have been brief by such close stratigraphic association.

The stratigraphic position of the "dark laminated shales" immediately above the coal deposits in Illinois and Indiana naturally led Udden (1912, p. 48) to assume a shallow-water origin for these black shales. "This [black shale] was formed during the beginning of the inundation of the swamp while the water was not deep enough to prevent vegetable accumulation but allowed a gentle influx of slightly muddy water."

Moore (1929, p. 466) noted that, while the source of carbonaceous material in the Illinois black shales might have been derived from a "reworking of the very shallow sea that drowned the coal swamp, ... [reworking] seems scarcely applicable to the numerous widely distributed black muds between limestones" in the Midcontinent region.

Weller (1930, 1956) noted that the black fissile shales contain marine fossils, although not abundant, and formed in undisturbed water. A mechanism was needed to explain the stillness of the water above the site of black shale deposition. Weller (1930, p. 127) suggested that surface-water plants or algae were possibly "present in sufficient abundance to prevent the development of waves." This explanation, he noted, accounts for both the uniform carbonaceous content of the shale and the fact that the plants themselves left practically no trace.

Other workers continued to assume that these black shales were deposited in stagnant shallow water. Moore (1931) noted plant debris and fossil insects in black shales of the Midcontinent, and Wanless and Shepard (1936) described the

Midcontinent black fissile shales as resembling the black shales above the coal deposits in Illinois and Indiana.

Twenhofel (1939), though not writing specifically about Pennsylvanian black shales, stated that, among other possibilities, black shales could develop in shallow, extensive epicontinental seas providing that tidal influence was minimal or non-existent.

It is imperative to note that most workers accepted the idea that the presence of fusulinids represented the deepest phase of these cyclothems. Elias' (1937, p. 411) idealized cycle of deposition depicted fusulinid-bearing rock units in the middle of the cycle with an order of other depth-related phases mirror-imaging each other above and below the fusulinid-bearing strata.

Mudge and Yochelson (1962) did an extensive paleontological and stratigraphic study of Upper Pennsylvanian and Lower Permian rocks in Kansas, including units of the Council Grove Group, which are part of the current study. Several black shales with inarticulate brachiopods near their bases and abundant *Crurithyris* brachiopods just above the bases were noted. *Crurithyris*, where present with few other kinds of fossils, is commonly abundant, suggesting harsh environmental conditions. These brachiopods "may have lived under environmental conditions intermediate between brackish and marine" (Mudge and Yochelson, 1962, p. 104).

Each of these dark shales overlies a fusulinid-bearing limestone unit and is overlain by a bed of grayer shale that contains a fauna predominantly of brachiopods. This led Mudge and Yochelson (1962, p. 110) to interpret "a change from marine to brackish conditions and back to more marine conditions through the *Crurithyris* beds."

McCrone (1963) did a detailed paleontological study of the Red Eagle Formation of the Council Grove Group (see Figure 20 for stratigraphic column). The Red Eagle Formation contains a black shale, the Bennett Shale Member, which is included in the current study. McCrone (1963, p. 56) noted that shallowing of water at the start of Bennett Shale deposition "could have left shoals between the area of study [northeast

Kansas] and the open seas to south and west." However, he cautioned that this black shale is practically always present above the fusulinid-bearing limestone, and this "could indicate that the same basin pattern persisted in the region during the accumulation of the two."

Nevertheless, McCrone (1963, p. 69) was inclined to believe that the sea was shallow at the time of Bennett Shale deposition and that "free circulation of water with the open ocean was restricted by an unknown barrier." Also, "the sea shallowed quickly from 30 or 40 feet [9 or 12 meters] to less than 10 feet [3 meters]." He does not, however, imply that sea level necessarily dropped between the formation of the limestone and the deposition of the shale. McCrone (1963, p. 57) suggested instead that "uplift or climatic change in distant source areas," and not necessarily water depth, may have been a major controlling factor of the stratigraphic and paleontological changes.

Mudge and Yochelson (1962, p. 115) made similar comments regarding factors (other than water depth) that might have affected the distribution of faunal assemblages: "The relation between the rock types and the faunal assemblages of the midcontinent area ... might be explained ... by combinations of other physical and chemical factors."

McCrone (1963) further believed that the upper grayer part of the Bennett Shale Member represents a progressive deepening, and thus freer circulation, of water. This is evident by a deeper-water fauna of articulate brachiopods and bryozoans (e.g. Moore, 1964). However, to account for the formation of the limestone above the shale, McCrone (1963) believed that sea level dropped once again, although this time without the unknown barrier to restrict circulation.

Above the Red Eagle Formation is the Grenola Formation, which was studied by Lane (1958; 1964). The lower part of the Neva Limestone Member of the Grenola contains at least one black shale in northern Kansas. This zone is possibly equivalent to the gray and dark gray zone in more southern exposures of the lower Neva

Limestone (Lane, 1958). Lane (1964, p. 21) analyzed microfossil assemblages in all Council Grove Group shales and concluded that "the accumulated data seems [sic] to form relatively shallow water deposition for most of the marine rocks." However, he cautioned that absolute depth could not be easily determined from the paleoecology of Permian beds.

Zangerl and Richardson (1963) studied many aspects of two black fissile shales from the Desmoinesian Stage in the Illinois region: the Logan Quarry Shale from the Staunton Formation and the Mecca Quarry Shale from the Linton Formation. They measured different facies within the black shales; performed chemical, spectrographic and mineralogical analyses on shale samples; studied the microscopic components contained in them and documented the flora and fauna horizontally and vertically in the shale units.

Not only did Zangerl and Richardson (1963, p. 228) assume a shallow water origin of the black shales, they believed that water depth ranged from a few inches to a few feet (less than a meter). Their reasons for such interpretation of shallowness included the facts that the marine shales overlie non-marine coals and that evidence for tectonic activity was lacking. Other conclusions reached by the authors had already been reached by others who had previously studied similar black shales; namely, the bottom water was toxic and very still, and water higher in the column was inhabited by fauna. Furthermore, Zangerl and Richardson (1963, p. 174) calculated a rapid rate of sedimentation, based on biostratonomic evidence, that averaged one millimeter every five days.

However, to account for both the stillness of such widely-extended shallow water and the high organic content of the shales, the authors (1963, p. 24) proposed "the concept of an intricate archipelago-bayou topography with a cover of vegetation (*flotant*) on the water." The flotant concept was later supported and expanded by Merrill (1975). According to Zangerl and Richardson (1963, pp. 217-219), an initial transgressive thrust, represented by a deposit of pectinid (*Dunbarella*) shell debris, covered the swamp with a blanket of shallow water topped with a vegetative mat. Four years of seasonal volumes of rainwater, which fluctuated only slightly due to decreased run-off, produced a subtle alternation of four pairs of black and gray layers in the lower part of the shale. The water eventually deepened to where seasonal cycles could not leave their marks, and a marine assemblage of shells characteristic of dark shales in restricted environments was deposited.

However, the flotant hypothesis is considered unreasonable by some investigators. It is unlikely, for instance, that a mat of floating vegetation would allow driftwood to accumulate in the water to the extensive degree implied by the findings of Zangerl and Richardson (1963, p. 122 and pp. 145-147). Also, the extensive biota documented by these authors does not reasonably compare well with their hypothesis that only a few feet (about one meter) of water were stratified, from top to bottom, with a flotant, a narrow range of habitable water and a narrow range of anoxic bottom water.

The application of the flotant model to Midcontinent black shales is met with further difficulty on account of a dense limestone member that is below the shale. Heckel (1977, p. 1058) noted that "such a shallow-water environment for black shale deposition cannot reasonably apply to widespread black shales that are underlain as well as overlain by demonstrably fully marine limestones."

Deep-water interpretations and models of black shale origin

Up to the mid-1960s, most workers considered a deep-water (i.e. offshore) origin of these black shales unlikely and improbable. Even the prospect of water as deep as 450 feet (140 meters), suggested by Wanless and Shepard (1936) in their glacial control theory, was considered improbable by Weller (1956). Moore (1929, pp. 484 and 487) believed that depths of Pennsylvanian epicontinental seas never exceeded 600 feet (180 meters) and that the seas were "not only very shallow but ... excessively fluctuating." Elias (1937) believed that water depth never exceeded 180 feet (55 meters) in the Pennsylvanian and 90 feet (27 meters) in the Permian. Most workers believed that the fusulinid zone of limestone units represented the deepest phase of the cyclothems (Elias, 1937; Mudge and Yochelson, 1962).

Under the assumption that black fissile shales formed in shallow, undisturbed water, the best plausible explanation appeared to rest on the additional assumption that a mass of floating vegetation stilled the water and contributed organic material to the mud. This explanation, not without its difficulties, did little to elucidate the origin of black shales. Deep-water interpretations of the origin of these black shales became plausible as more and more studies related cyclothem development to Gondwanan glaciation (Heckel, 1977; Crowell, 1978; Heckel, 1980; Watney, 1985; Ross and Ross, 1985; Heckel, 1986; Veevers and Powell, 1987; Cecil, 1990; Crowley and Baum, 1991; Boardman and Nestell, 1993).

Schenk (1967) was among the first to suggest that black shales are a deeper-water facies than the carbonate rocks in Midcontinent sequences. He studied the Altamont megacyclothem in the Marmaton Group, Desmoinesian Stage, which contains the black Lake Neosho Shale Member of the Altamont Limestone. Schenk based his conclusion on the presence of phosphate nodules and fossils.

> Primary phosphorites are marine deposits never associated with lagoonal or fresh-water sediments. The phosphorite facies is usually confined to the shelf on one side of a large, deep basin which has ample connection with the open ocean. ... The fauna and lithology of the Lake Neosho Shale cannot be confused with those of the deltaic deposits, and undoubtedly are not the result of an advance of this detrital complex ... The fauna of the black shale is marine with restricted and very tolerant forms (Schenk, 1967, pp. 1379-1380).

Schenk further postulated that maximum water depth was at least 200 meters (656 feet) in parts of the basin. He based his calculation on the depth where modern phosphate is precipitated, the height of channels cut from overlying formations and the gentle westward slope of the shelf edge at the line of outcrop of the studied formation.

> Water circulation must have been from the southwest, upwelling on the shelving eastern flank of the Western Interior basin [Midcontinent region]. Phosphate was precipitated chemically between depths of approximately 50 and 200 m [164 and 656 feet] under conditions of ... slow but continuous circulation, and extremely slow sedimentation (Schenk, 1967, p. 1379).

Finally, he suggested that a rapid transgression and a slow regression accounted for the differences in the limestones below and above the black shale.

Whereas Schenk studied several units in a single Middle Pennsylvanian megacyclothem, Evans (1967) concentrated only on the black shale unit of an Upper Pennsylvanian megacyclothem from the same region. Like Schenk, his conclusions were the opposite of the generally accepted idea that black shales were shallow-water deposits.

Evans (1967, p. 49) studied the Heebner Shale Member of the Oread Limestone in the Shawnee Group, Virgilian Stage, and noted that it contains phosphorites in the form of “discontinuous phosphatic laminae and associated nodules of phosphate.”

He used the conformable stratigraphic occurrence of this shale between two marine limestones and its large lateral extent to point out the unlikelihood of paludal conditions during deposition. Evans believed that quiet, oxygen-restricted water below “wave base” was the condition required. “The black shale represents accumulation in the central part of the depositional basin rather than at its periphery” (Evans, 1967, pp. 120-121).

James (1970) arrived at similar conclusions about a Middle Pennsylvanian black shale that overlies coal in Illinois and Missouri. He studied the Excello Shale Member of the Calvin Formation of the Cherokee Group, Desmoinesian Stage, which contains an interval of dark gray to black, phosphatic, fissile shale.

James interpreted the shale as an offshore deposit that formed during maximal high-water stand brought about by the melting of Gondwanan glaciers to the south.

James (1970, pp. 37-38) suggested that a thermocline developed in the waters of the Excello sea. This density gradient, a contrast between high surface water temperatures and cold, deep water, inhibited circulation of bottom water and resulted in the development of anoxic bottom water conditions. Organic decomposition was accomplished with nitrates and was followed by sulfate reduction, which resulted in acidic conditions and sulfide toxicity. According to James (1970, pp. 80-81), this restricted the diversity and abundance of organisms capable of living on the bottom and inhibited their decay.

Heckel and Baesemann (1975) developed a paleoecological model for the deposition of the units of Midcontinent sequences, based on the distribution of conodont genera throughout the megacyclothem. Their model closely follows the ecological model for conodonts proposed by Seddon and Sweet (1971), who studied Ordovician and Devonian conodont faunas in eastern North America and Western Australia in order to understand the ecological preferences of different species.

The model Seddon and Sweet developed is based on the assumption that most conodonts are planktonic or nektonic. Their reasoning is based on "the occurrence of representatives of the same species in a variety of lithofacies, including black shales of various ages that otherwise yield the remains only of planktonic or nektonic organisms" (Seddon and Sweet, 1971, p. 869).

Furthermore, their model "views conodonts as small planktonic organisms .... with different species segregated by vertical stratification" (ibid., p. 879). This model implies that knowing the depth preferences of certain conodont species, to determine the general depositional environment of units containing these conodonts would be fairly simple. According to the model, a shallow-water deposit contains only shallow-water conodont species, whereas a deep-water deposit contains both deep-water and shallow-water conodont species (Figure 9).

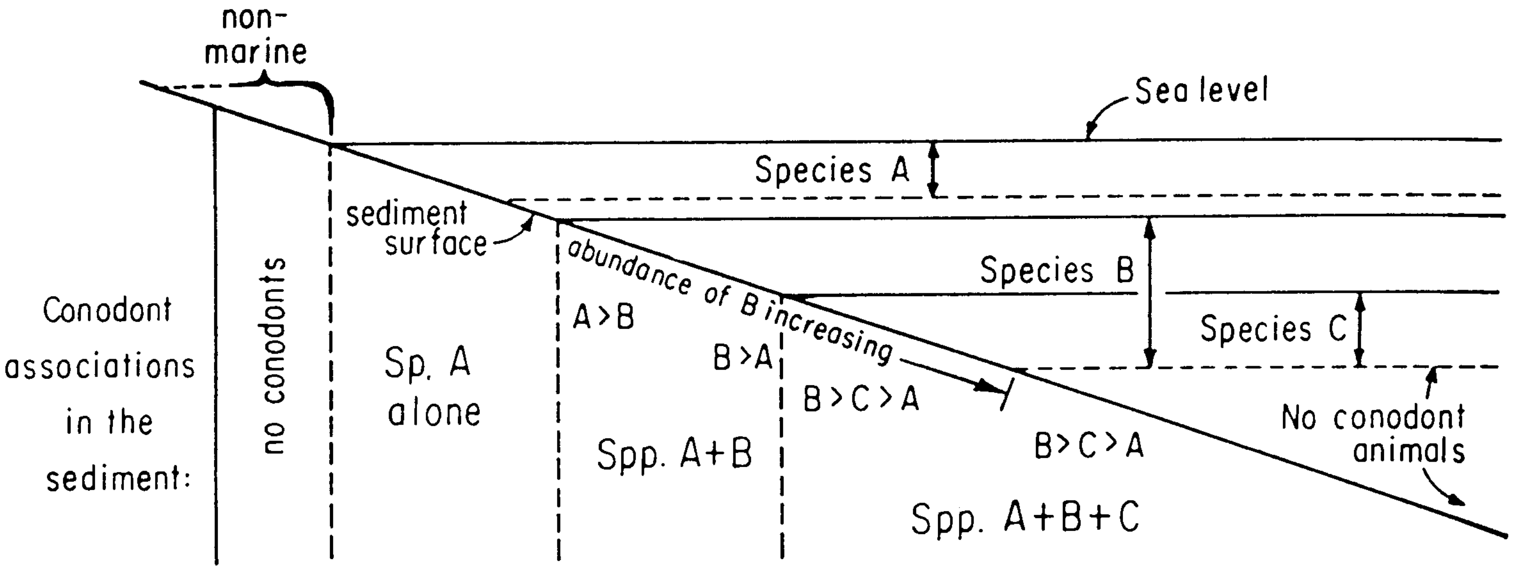

Figure 9. Conodont distribution assuming a pelagic mode of life. Distribution of conodont species in sedimentary units is a result of conodonts living at different depths (from Heckel and Baesemann, 1975, p. 498, after Seddon and Sweet, 1971).

Heckel and Baesemann (1975, p. 490) believed that the black shale units of Missourian sequences were the deepest-water deposits, based on vertical distribution of conodont species throughout the megacyclothem. The authors refer to the black shale, and sometimes also to the limestone members above and below it, as the "core" of the Midcontinent megacyclothem (Figure 10). The core contains a diverse conodont fauna with *Streptognathodus* (called *Idiognathodus* in their paper) species being most abundant. Species of *Gondolella* and *Idioprioniodus* are associated with and almost exclusive to the core.

When Heckel's and Baesemann's data are applied to Seddon's and Sweet's conodont ecology model, the core of the megacyclothem is recognized as the deepest-water deposit of the sequence (Figure 11). Likewise, other members of the sequence fit well with the conodont model. The shale members away from the core (called "outside shales" by the authors) "are characterized by either absence or low abundance of conodonts ... and low diversity of conodonts" (Heckel and Baesemann, 1975, p. 491). Some of these outside shales and some parts of the limestones closer to the core "have conodont faunal characteristics transitional between those of the core and those of the outside shales." In these units species of *Adetognathus* are generally dominant where conodonts are present. *Streptognathodus* species are present, too; however, their number per unit volume of rock decreases away from the core.

As a matter of course for the remainder of this discussion, the "megacyclothem" sequence of rocks defined by Moore (1936) and referred to by Heckel and Baesemann (1975) will be referred to simply as a "cyclothem." Heckel (1977) proposed this change because he and other workers believed that the "megacyclothem" sequence actually represented only one major advance and retreat of the sea (Figures 10 and 11).

Heckel (1977) expanded Heckel's and Baesemann's (1975) paleoecological model to account for oceanic circulation, the occurrence of phosphate nodules in the black shales, lateral variation of major Pennsylvanian cyclothems and the rarity of black shales

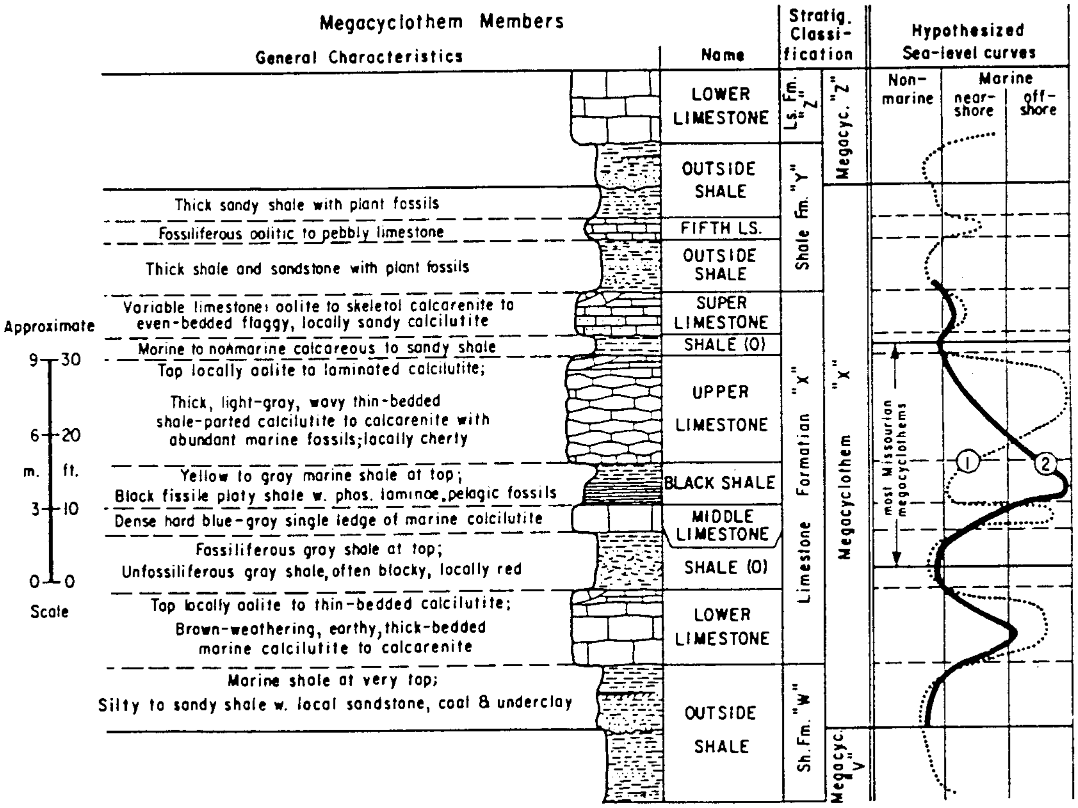

Figure 10. Ideal Upper Pennsylvanian megacyclothem (=cyclothem) of Midcontinent. Dotted sea-level curve (1) based in part on Moore (1936); solid sea-level curve (2) based in part on Evans (1967) and Schenk (1967) with black shale interpreted as the deepest-water deposit (from Heckel and Baesemann, 1975, p. 487).

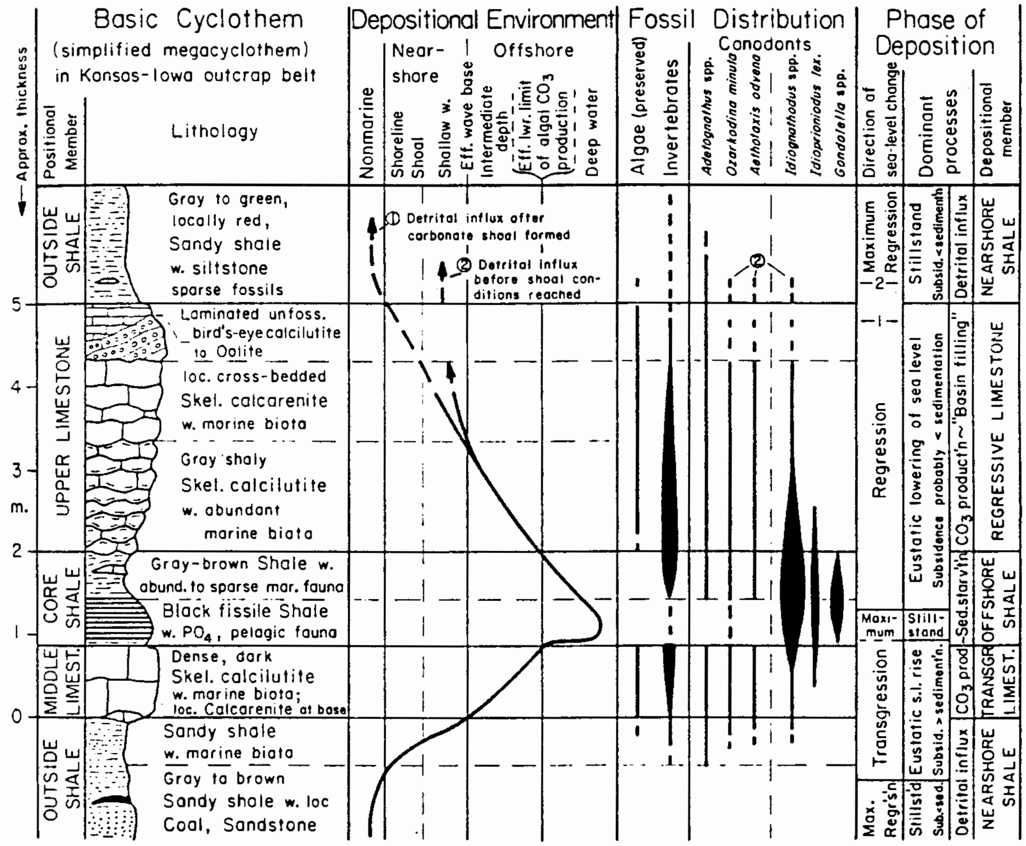

Figure 11. Basic Upper Pennsylvanian cyclothem of Midcontinent showing relative water depth and conodont distribution throughout the sequence (from Heckel, 1977, p. 1047, after Heckel and Baesemann, 1975).

in slightly younger Midcontinent cyclothems. Whereas the earlier model essentially revolves around water depth and the depth-preference of certain conodont species, the newer model centers on the factors that controlled oceanic circulation and oxygenation of bottom waters in the Pennsylvanian Midcontinent epeiric seas (Figure 12).

Heckel (1977) suggested that a thermocline developed during high sea-level stand. The Pennsylvanian Midcontinent was located north of the paleoequator in the trade wind belt, and prevailing wind direction was from the east. This westward flow of surface water pulled deeper oceanic water eastward from West Texas basins. This deeper oceanic water was colder, lower in oxygen, and richer in phosphate than the surface water, and the temperature contrast produced a thermocline in waters deeper than 50 meters (164 feet). The thermocline did not develop during low sea-level stand.

According to the model (Heckel, 1977, p. 1054), the thermocline "was strong enough to prevent local wind-driven cells of vertical circulation from replenishing oxygen to the sea bottom." The phosphate-rich bottom water surfaced nearer the eastern shorelines and produced planktonic blooms that ultimately generated more organic matter. The organic matter was carried westward on surface currents and eventually settled below the thermocline where it removed even more of the already sparse oxygen as it decayed (Figure 12).

An alternative model of black shale deposition in Pennsylvanian strata of the Midcontinent invokes a sill in West Texas that restricted circulation of bottom water in the Midcontinent region. Evans (1967, p. 123) suggested that detrital sedimentation at the mouth of the Midcontinent sea may have "constituted a shallow sill which effectively blocked normal circulation between the inland sea and a more open marine environment ... to the south." A sill in the Baltic Sea of today results in salinity stratification, greater stagnation of deeper water and the accumulation of fine-grained black organic mud (Manheim, 1961). Although a sill might explain low-oxygen conditions in the Midcontinent during high sea-level stands, its effectiveness as a barrier to free circulation with open

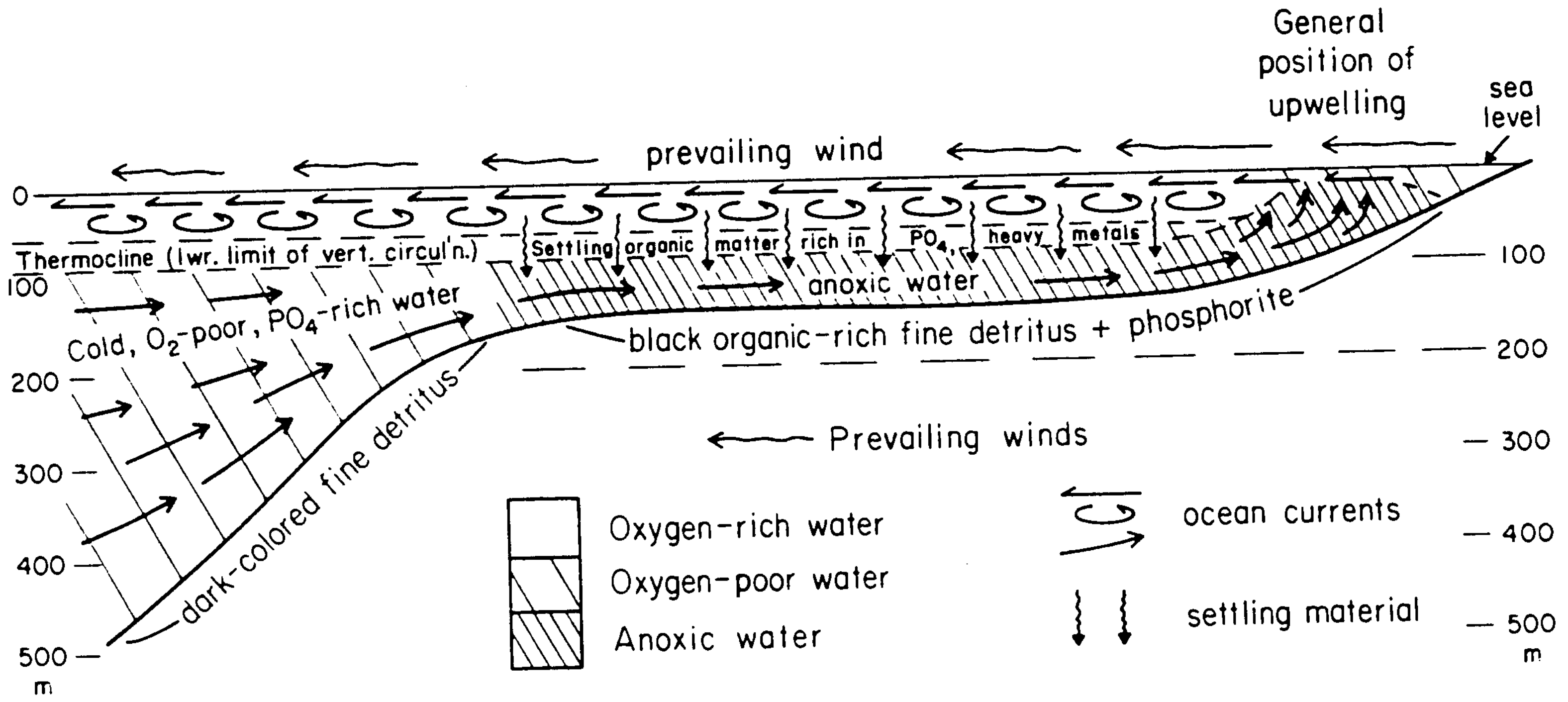

Figure 12. High-stand vertical circulation pattern in the Late Pennsylvanian Midcontinent. West is to the left in figure. A thermocline developed in waters deeper than 50 meters (164 feet). Nutrient-rich bottom waters upwelled in the east. (from Heckel, 1977, p. 1054).

sea water would have increased during regressions until the Midcontinent sea became a closed basin, evidence of which has not been observed. Heckel (1977, p. 1058) addressed this scenario and added that "black shale members are overlain conformably by thick limestone members with diverse marine biotas that record continued good connection with the open sea."

The bottom water of a high sea-level stand, therefore, remained low in oxygen and rich in phosphate and organic matter. Conditions did not favor formation of calcite-rich sediment, perhaps due to acidity from organic decay or to very low oxygen conditions in the water. In any case, only fine detritus and organic debris reached the quiet bottoms of Pennsylvanian Midcontinent seas during maximal sea-level stand to produce black mud. Phosphate in the water apparently reached concentrations high enough to precipitate directly or, possibly, to replace any carbonates that might have formed.

Modern examples of phosphorite formation off the coast of Peru (Veeh et al., 1973; Manheim et al., 1975) tend to support Heckel's upwelling model despite differences in oceanic sea-floor topography. Recent phosphate nodules were found in "laminated anaerobic sediments associated with coastal upwelling off Peru and Chili" and were dated by uranium-series methods (Veeh et al., 1973). Manheim et al. (1975) listed four requirements necessary for phosphorite formation: organic-rich sediment, low oxygenated waters, low sedimentation rates and low calcium carbonate concentration.

Veeh et al. (1973) found that the phosphate nodules seem to form at the upper and lower limits of the oxygen minimum layer, between 100 and 400 meters (328 and 1312 feet). Although the sea-floor topography is much steeper off Peru than it was beneath the Pennsylvanian Midcontinent epicontinental seas, it is conceivable that similar conditions, though at lesser depths, affected the Pennsylvanian seas.

Black shales of the Illinois region are analogous and correlatable with black shales of the Midcontinent region. However, the absence of an underlying limestone unit in the cyclothems of the Illinois region, where coal is present, required an explanation. Heckel (1977, pp. 1059 and 1061) noted that rapid transgression over Illinois coal swamps, coupled with cut-off of detrital sources, could result in deep water without significant deposition. Low pH or low-oxygen conditions may have contributed to "an environment unfavorable to carbonate production." Although coals are uncommon in Midcontinent sequences, the limestones underlying the black shales are thin, implying conditions that were not as unfavorable for the production of calcium carbonate sediment as conditions in the Illinois region.

Heckel (1983) used his earlier model in conjunction with diagenetic data to develop a diagenetic model for formation of limestones above and below black phosphatic shales of the Midcontinent. Heckel (1986, 1991) applied his models to more of the Midcontinent cyclic record and supported their correlation with Illinois cyclothems. He also supported Gondwanan glaciation as the ultimate cause of eustatic sea-level fluctuations in the Pennsylvanian.

Boardman et al. (1984) summarized arguments supporting a deep-water origin of these black shales. These shales are continuous over most of the Midcontinent and underlying relief is preserved after the shales were compacted by overlying deposits.

The authors pointed out that the symmetry of cyclothemic sequences would be compromised if a shallow-water interpretation of these shales were accepted. As shallow-water deposits, "the black, fissile, phosphatic shales should be present in at least two other positions within the cyclothem" (Boardman et al., 1984, p. 151). Furthermore, such shales have never been found "in regions that can be conclusively demonstrated to represent shallow, nearshore environments" (ibid., p. 153).

These black shales grade updip (i.e. in the direction of the paleoshoreline) into fossiliferous offshore marine deposits. Boardman et al. (1984) regarded this observation to be the strongest evidence that these shales are deep-water deposits. The authors pointed out that a shallow-water model requires that the black shales grade into shoreline and terrestrial deposits, a situation that was not observed.

The asymmetry of limestone thicknesses within the Midcontinent sequences also supports a deep-water origin for black shales because it supports sea-level fluctuation as the major control over the formation of cyclothems. A thin "transgressive" limestone below the black shale and a thick "regressive" limestone above it suggests that each transgressive event was several times faster than the subsequent regressive event (Boardman et al., 1984, pp. 152-153). This observation is consistent with studies of marine Pleistocene deposits which demonstrate this same pattern of rapid transgression/ slow regression during concurrent episodes of glaciation (Broeker and vanDonk, 1970).

Another line of evidence includes restricted occurrence of phosphate nodules in these black shales, which is analogous to modern phosphate formation (Boardman et al., 1984). Phosphate nodules are more common at the boundary between the black fissile shales and the dark gray, non-fissile, clay-rich shales of the Midcontinent, a zone that may represent the anaerobic-dysaerobic boundary of the ancient sedimentary environment.

Boardman and Malinky (1985) studied Virgilian strata of north-central Texas along the eastern shelf of the Midland Basin and applied a modified glacial-eustatic sea-level fluctuation model to the sequences. Dark gray and black shales containing deep-water faunas developed over deltaic sequences on the shelf during intervals of high sea-level stand. "During the transgressive phase, ... the oxygen-minimum zone responsible for the black shales in the Midland basin rose to a position well up on the shelf area..." (Boardman and Malinky, 1985, p. 13). As regression followed maximal sea-level stand, this oxygen-minimum zone and its associated dark shales retreated toward the Midland Basin, where they were confined during maximal regression. This stratigraphic evidence supports a deep-water origin of these shales.

Individual black shales merge basinward and thicken upon the shelf toward the paleoshoreline and the source of clastic material (ibid.). Facies within these black shales record oxygen gradients ranging from anoxic to dysaerobic to aerobic, based on faunal communities defined by Boardman et al. (1984) (see following section "Paleontological studies of black shales" and associated Figure 14 for more detail). Phosphate nodules are more abundant where black fissile shales grade into dark gray, clay-rich shales. In the regressive phase, the paleogeography of prograding deltas influenced the composition of shales deposited over the black muds. These units ranged from carbonate sediment, uninfluenced by the deltas, to thick fossiliferous clay, adjacent to the deltas, to thick deltaic sequences of various facies (Boardman and Malinky, 1985).

The transgressive sequences studied by Boardman and Malinky (1985) correlate with sequences of the Midcontinent. The correlation of sea-level curves developed from north-central Texas strata and from Midcontinent strata supports glaciation as the driving mechanism of sea-level fluctuations in the Pennsylvanian (Boardman and Heckel, 1989; Boardman et al., 1984). These laterally-continuous, phosphatic, fissile black shales were deposited in deep water during maximal sea-level highstand.

Watney (1985) noted that the marine shales which overlie thin transgressive limestones of four Midcontinent Missourian cyclothems completely cover the western Kansas study area. The black facies of this shale, which is developed in only three of the four cyclothems studied, may by interpreted as the deepest-water facies because it did not develop over structurally-positive areas.

Geochemical studies indicate that the black phosphatic shales of the Midcontinent, as well as some non-phosphatic black shales of the Illinois basin (Mecca Quarry and Logan Quarry shales), "are universally enriched in organic matter and trace elements including such heavy metals as molybdenum, vanadium, zinc, and uranium" (Coveney, 1985, p. 247; also Coveney et al., 1991). Cubitt (1979) identified a number of trace elements associated with Upper Pennsylvanian and Lower Permian black shales. These elements include cadmium, chromium, copper, molybdenum, nickel, lead, vanadium and zinc. Hatch and Leventhal (1985) also observed high heavy metal contents in laminated offshore shales of Middle and Upper Pennsylvanian rocks of the Midcontinent.

Adlis et al. (1988) studied oxygen isotopes in the calcite of *Crurithyris planoconvexa*, a brachiopod that is found in all levels of the studied shales in north Texas. Maximum oxygen-18 isotopes were recorded in shale levels representing "the deepest faunal zone, defined by the occurrence of the conodont *Gondolella*" (ibid., p. 487). These values could mean one of two opposing interpretations: 1.) low bottom temperatures associated with greater depth from a high sea-level stand, or 2.) oxygen-18 isotope concentration in seawater from the tie-up of the lighter oxygen isotopes in continental glaciation. The latter interpretation necessitates a low sea-level stand and shallow depths, which are conditions opposite the first interpretation. Despite these two opposing interpretations, the authors supported the interpretation of cold, deep-water based upon supporting fossil evidence.

Using studies of modern sea temperatures, they further postulated a minimum depth change of 70 meters (230 feet) within the history of one of the north Texas cycles studied. "The data indicate even larger depth changes if a glacial effect on the isotopic composition of the ocean occurred" (ibid., p. 501). Greater depth changes would have been necessary to counter the lower oxygen-18 isotope concentrations that would have been present during interglacial periods.

Coveney et al. (1991) used abundances of molybdenum to differentiate between nearshore and offshore black shales. Their model accounts for some of the differences between black shales of the Midcontinent region and those of the Eastern Interior Basin. Non-skeletal phosphate and molybdenum-rich black shales of the Desmoinesian Stage in Indiana contain fish fossils and abundant terrestrial organic matter. According to the authors, deposition occurred in a nearshore environment influenced by a wet climate, high sedimentation rates and a high influx of terrestrial organic debris. This made the bottom water acidic and promoted molybdenum fixation. Coeval black shales of the Midcontinent contain more phosphate and less molybdenum. Upper Pennsylvanian black shales of Indiana, on the other hand, are more transitional in nature and contain more phosphate and less molybdenum than their older counterparts of the same area. The climate was drier during this time, and some transgressive events reached higher sea-level stands (Coveney et al., 1991; Heckel, 1986; Cecil, 1990) (Figure 13).

Teo (1991, pp. 104-107) noted that the total organic carbon (TOC) content of Pennsylvanian Midcontinent core shales varied due to redox conditions in the original sedimentary environment. Core shales with a high TOC also contain abundant vanadium, zinc and chromium. These elements accumulate in low redox conditions and suggest that the original sedimentary environment was anaerobic. Core shales with low TOC do not show correlation between TOC and certain essential transition metals (V, Zn, Cr, Ni, Cu, Co). This may be due to some oxidation on the sediment-surface layer in a dysaerobic environment. Marine-marginal shales also show no correlation between TOC and these elements; however, this is due to several factors, including fluctuating quantities of original organic carbon and essential transition metals and fluctuating redox conditions.

Baker (1995) related elemental and microfaunal distributions to redox conditions and rates of sedimentation in a section of Upper Pennsylvanian units in southeastern Kansas. The core of the Haskell-Cass cyclothem is the lower part of the Robbins Shale in the Lawrence Formation of the Douglas Group. This shale contains high concentrations of vanadium, *Gondolella* conodonts, some trace elements, a greater abundance of TOC than much of the cyclothem and a limited benthic fauna. A gray-to-black transition, which corresponds with differences in geochemistry and faunal

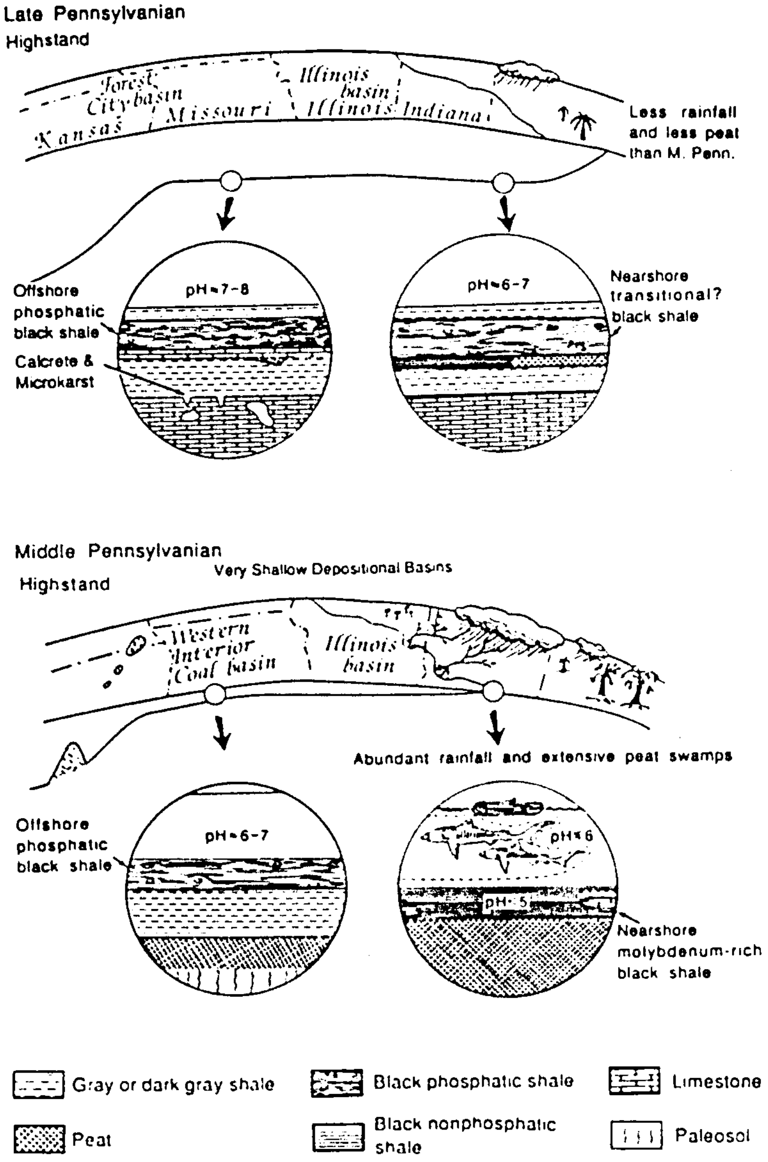

Figure 13. Model for black shale deposition differentiating offshore and nearshore shales based on relative abundance of molybdenum. Distance from upwelling source of phosphate-rich waters, climate, depth at maximum highstand and distance from terrestrial organic sources affected deposition and composition of these shales (from Coveney et al., 1991, p. 149).

distributions, occurs forty centimeters (16 inches) above the base of the shale. This interval is enriched in sulfide and contains a greater abundance of TOC and trace metals than the core of the cyclothem. "Conodont abundances decrease, with offshore faunas dominating. Holothurian sclerites completely disappear, and the overall fauna is restricted to only those organisms that tolerate dysoxic conditions" (Baker, 1995, p. 111). Baker believes this interval, which "is not a typical phenomenon described in Heckel's cyclothem model, ... probably was deposited during a pulse of humic organic matter" which lowered redox conditions and concentrated certain trace metals (ibid.).

Baker concluded that "faunas seem to be affected by the same conditions affecting elemental distributions," and that both elemental and faunal sources should be studied when original depositional and diagenetic conditions are sought (ibid., p. 114).

The purpose behind reviewing models of Pennsylvanian black shale deposition is to apply these models to interpretation of Lower Permian black shales, which are the central subject of the current study.

Miller and West (1993, p. 2) recognized the problem of applying Heckel's (1977) model to explanation of Lower Permian black shales of the Midcontinent. Heckel's model relies heavily on the black shale for "defining the position of transgressive maxima on cyclothemic sea-level curves..."

As pointed out previously, the absence of phosphatic nodules and laminae in the few widespread black shales in Lower Permian strata suggests that Heckel's (1977) model is not completely applicable even to those apparent deep-water deposits (i.e. to those widespread Permian black shales). Nevertheless, several dark gray to black shales are in the Lower Permian of the Midcontinent; some of these shales are laterally-extensive and others are much less widespread or only local.

Miller and West (1993) concentrated on discontinuity surfaces and meter-scale cycles bounded by flooding surfaces and concluded that eustatic factors that affected Pennsylvanian rocks no longer dominated facies development in Permian rocks. The authors suggested that regional climatic change, coupled with lower amplitude glacio-eustatic sea-level fluctuations which affected facies development less strongly, produced the Lower Permian cyclic sequences they studied in northeastern Kansas (Miller and West, 1993, p. 22). The climate-control portion of their model, adapted from Cecil (1990), predicts that clastics were generally deposited during wet climates when salinity was low and terrigenous debris was high due to excess runoff, and that carbonates were generally deposited during arid climates for opposite reasons (Miller and West, 1993, p. 20).

The common occurrence of limestone-shale sequences in the Lower Permian strata, bounded by paleosols and flooding surfaces, suggested to Miller and West (1993) that the sequences might have formed from shallowing upward cycles. The authors analyzed units in the Council Grove and Chase Groups, including black shales of the following members of the Grenola Formation used in the current study: Legion Shale, Burr Limestone, Salem Point Shale and Neva Limestone. When applied to limestone-black shale cycles, "the limestones would represent deepest water conditions with the overlying black to dark-gray shales deposited during subsequent shallowing." These shales are interpreted as "lagoonal or estuarine" deposits, and the presence of "lingulid brachiopods, pectinid and myalinid bivalves, and ostracodes in these shales is also consistent with a nearshore, possibly brackish-water setting" (ibid., p. 18).

The conclusions of Miller and West (1993) bring the interpretations of black shale origin to a full circle. The black shales of the Pennsylvanian were first viewed as shallow-water deposits and then later as deep-water deposits. Those of the Lower Permian were believed to have formed in conditions similar to those of the Pennsylvanian. Miller and West (1993) recently proposed that the black shales of the Lower Permian are shallow water deposits.

Paleontological studies of black shales

Since the focus of this study essentially is paleontological, it is appropriate to review exclusively this aspect of studies of Pennsylvanian and Lower Permian black shales. Numerous authors studied the paleontology of black shales and related gray shales (Moore, 1929; Mudge and Yochelson, 1962; McCrone, 1963; Zangerl and Richardson, 1963; Evans, 1967; Grenda, 1969; Heckel and Baesemann, 1975; Schutter, 1983; Schram, 1984; Malinky, 1984; Boardman et al., 1984; Boardman et al., 1995).

Moore (1929) noted conodonts, a few species of foraminifers and brachiopods including *Derbyia*, productids and lingulids in his early studies of the Midcontinent Pennsylvanian black shales. "Poorly preserved plant fragments" and "a few fossil insects" were also noted by Moore (1931, p. 253). Moore's (1936, p. 34) general description of the black shale unit in a typical Missourian megacyclothem (cyclothem of today) was as follows: "shale, black fissile, contains conodonts, scanty brackish water molluscan fauna and abundant macerated plant fragments."

Moore's (1936) descriptions of Pennsylvanian rocks in Kansas contain cursory paleontological descriptions. The lower black portion of the Stark Shale Member of the Dennis Formation of the Bronson Group, Missourian Stage, contains conodonts, plant debris, and phosphatic nodules. The upper lighter portion of the Stark commonly contains the brachiopod *Derbyia crassa* and the pelecypod *Aviculopectin.* The upper grayer portion of the Muncie Creek Shale Member of the Iola Limestone of the Kansas City Group, Missourian Stage, contains phosphatic specimens of the conulariid *Conularia crustula*. The lower black portion of the Heebner Shale Member of the Oread Limestone of the Shawnee Group, Virgilian Stage, "contains conodonts but mostly lacks megascopic fossils." The upper grayer part of the Heebner "contains numerous fossils, chiefly molluscoids" (Moore, 1936, p. 166). Only conodonts are mentioned in connection with the Queen Hill Shale Member of the Lecompton Limestone and the Larsh-Mission Creek Shale Member of the Deer Creek Limestone, both of the Shawnee Group;

however, the upper lighter portion of the Larsh-Mission Creek contains brachiopods and bryozoans in some places. The Holt Shale Member of the Topeka Limestone of the Shawnee Group contains "conodonts and some corneous brachiopods in the lower part and in places pelecypods and some calcareous brachiopods and bryozoans in the upper part" (ibid., p. 198). The Aarde Shale Member (Shanghai Creek) of the Howard Limestone of the Wabaunsee Group, Virgilian Stage, despite the presence of some coal, does contain a black fissile shale in some places "with very abundant ostracodes [and] some corneous brachiopods and pelecypods" (ibid., p. 206).

Mudge and Yochelson (1962), when describing paleontology of the Lower Permian strata, excluded algae, bryozoans, ostracodes and conodonts. They also excluded all foraminifers except fusulinids. The inarticulate brachiopods *Lingula carbonaria* and *Orbiculoidea missouriensis* are also in these black shales. *Crurithyris expansa*, an articulate brachiopod, is common in argillaceous beds and is "commonly abundant in thin layers just below or just above unfossiliferous beds" (Mudge and Yochelson, 1962, p. 77). This suggested to the authors that these brachiopods may have lived in brackish water. Several *Lissochonetes geronticus* and *Wellerella osagensis* specimens are in black shales; however, these brachiopods are more common in the calcareous shales.

McCrone's (1963) study of the Red Eagle Limestone of the Council Grove Group included a detailed analysis of the black Bennett Shale Member. McCrone (1963, p. 23) noted abundant *Orbiculoidea missouriensis* and rarer *Lingula* sp. brachiopods in the lower part of the Bennett. Conodonts, dominantly *Streptognathodus*, are in the black shale and are accompanied by minute fish teeth. Ostracodes are absent. *Crurithyris* is throughout the Red Eagle Limestone, including parts of the Bennett Shale Member.

Lane (1964) analyzed microfossils in shales of the Council Grove Group in northern Kansas. However, his data are difficult to apply to the current study because he identified fossil assemblages with little regard for shale type or color, properties that can be indicators of paleoenvironment. Nevertheless, Lane (1964, p. 10) noted "a fauna restricted to fragments of *Orbiculoidea*, fish teeth and scales, and conodonts" in black shale in the upper half of the Hughes Creek Shale Member. He observed fish remains and inarticulate brachiopods, but no conodonts, in the lower part of the Bennett Shale Member, and holothurian sclerites and *Bairdia* ostracodes in the upper part. Fish remains, orbiculoid brachiopods and a few *Tetrataxis* foraminiferans were recorded from the black part of the Legion Shale Member. The upper part of the Legion contains several ostracode genera, including *Hollinella*. The Salem Point Shale Member includes *Carbonita* and *Geisina* ostracodes and fish teeth and scales. A lower black shale in the Neva Limestone Member, "contains abundant conodonts, fish teeth, and orbiculoid fragments similar to the assemblage in the black shales in the Hughes Creek" (ibid., p. 11).

As described previously, Zangerl and Richardson (1963) completed an extensive paleontological analysis of two black shales from the Pennsylvanian Eastern Interior Basin. Above a transgressive shell breccia composed of innumerable productid brachiopods, the basal Mecca Quarry Shale "consists of countless individuals of the pectinoid *Dunbarella*, a very few orbiculoid and linguloid brachiopods, fairly abundant conodonts," some cephalopods and some vertebrates. (Zangerl and Richardson, 1963, p. 184). The grayer facies above the basal shale is dominated by vertebrates, including shark fossils. Similarly, the corresponding grayer facies of the Logan Quarry Shale contains many vertebrate fossils.

In the Midcontinent, the *Ammovertella* foraminiferan biofacies of the Altamont Limestone of the Marmaton Group, Desmoinesian Stage, observed by Schenk (1967, p. 1377) "includes the phosphate-bearing black shale interval of the Lake Neosho [Shale]." It consists of the foraminiferans *Ammovertella* and *Ammodiscus*, conodonts, ostracodes and minor echinoid debris. Fragments of *Orbiculoidea missouriensis* brachiopods form the nuclei of many phosphatic nodules.

The Heebner Shale in Kansas, studied in detail by Evans (1967), contains black fissile shale, with a sparse fauna, that separates two lighter calcareous shale units that contain more abundant fauna. Fossils in the black fissile shale "are generally limited to numerous ... conodonts, fair numbers of orbiculoid brachiopods, and a few scolecodonts and thin-shelled pectinoid clams" (Evans, 1967, p. 61). The calcareous shales contain productid brachiopods, crinoid columnals, bryozoans, a few corals, abundant pelecypods and gastropods and many foraminifers.

Heckel and Baesemann (1975) and Heckel (1977; 1991) concentrated primarily on conodonts when they studied the Midcontinent black shales from the Upper Desmoinesian to the Lower Virgilian. They noted that conodont faunas are most diverse in the black fissile shale sequences of the Midcontinent cyclothems and "are dominated strongly in numbers of individuals by species of *Idiognathodus* ... which equals *Streptognathodus* spp. of [other] authors." *Idioprioniodus* and *Gondolella* conodonts occur exclusively in shales "closely associated with the black shale facies" (Heckel and Baesemann, 1975, p. 490).

Later, Heckel presented a more detailed description of the fauna within the shales:

> The grey facies contains an abundant to sparse benthic fauna dominated by crinoid debris and brachiopods, particularly *Crurithyris* and *Chonetes*, and an abundant conodont fauna that ranges from hundreds to thousands of elements per kilogram of rock ... The black facies, which is typically sandwiched within the grey facies, contains mainly conodonts of similar high abundance, fish debris, conularids in places, radiolarians ..., and ammonoids (Heckel, 1991, pp. 261-262).

Schram (1984) noted benthic crustaceans from three Pennsylvanian black shales, including the Heebner Shale, in outcrops along the Nebraska-Iowa border. These "bottom-dwelling types" of crustaceans are marine organisms that are "not completely compatible with the interpretation of stagnant, poisonous deep-water habitats envisioned in the Heckel-Baesemann [1975] model" (Schram, 1984, p. 199).

Compatibility could be possible if the creatures had "additional tolerance for low oxygen conditions" and occupied a part of the basin where the edge of the anoxic bottom waters fluctuated. Schram concluded that these crustaceans "lived in some proximity to anoxic conditions" and "may represent a catastrophic kill" (ibid., pp. 199-200).

If Schram is correct, the fauna he observed in outcrops along the Nebraska-Iowa border is representative of the northern, shallower tract of the Midcontinent region during maximal transgression. Furthermore, one might expect to find benthic fossils in black shale outcrops in southern Kansas and northern Oklahoma along the corresponding southern tract of the Midcontinent region.

Malinky (1984) studied extensively the macrofauna of Pennsylvanian black shales across their lines of outcrop from Nebraska to Oklahoma. Essentially, he sampled the dark gray facies of these units to determine diversity trends and document "stratigraphic and geographic changes among faunas" (Malinky, 1984, p. 2).

Because his data are excessive, the faunas from only three shales are treated here. The Eudora Shale of the Stanton Limestone of the Lansing Group, Missourian Stage, contains "common *Crurithyris*, *Chonetinella* and less common *Derbyia*, *Composita*, *Rhipidomella*, spiriferids [all brachiopods], bryozoans and corals" in Nebraska and Iowa. Mollusks are absent (ibid., pp. 70-71). The Eudora contains only a "few fragmentary brachiopods and crinoid columnals" in the central part of the basin, in northwestern Missouri and northern Kansas (ibid., p. 71). The Nebraska-Iowa fauna reoccurs in southern Kansas along with gastropods and bivalves. The Heebner Shale contains rare *Crurithyris*, spiriferids and crinoid columnals in Nebraska and is unfossiliferous in northern Kansas. Fauna are present but unidentifiable in southern Kansas, and molluscan faunas are present in northern Oklahoma (ibid., p. 72). The Queen Hill Shale is unfossiliferous in northern Kansas. Rare *Crurithyris*, derbyid and productid brachiopods, bryozoans and crinoid columnals are present in southwestern Iowa. Mollusks of the sort that are in the Eudora Shale are absent (ibid., p. 73).

Schutter (1983) studied two Pennsylvanian black shales and associated calcareous shales above and below them. The black Stark Shale Member of the Dennis Formation of the Bronson Group, Missourian Stage, contains a basal gray transitional shale which “typically includes myalinid pelecypods, fish fragments, and inarticulate and a few articulate brachiopods” (Schutter, 1983, p. 75). The phosphatic fissile black facies, which is prominent throughout the Stark Shale, almost exclusively contains fish fragments, inarticulate brachiopods and conodonts. The upper grayer facies contains *Crurithyris* and pectinoids.

The black Eudora Shale contains “inarticulate brachiopods, pectinoids, conodonts, *Conularia* [a conulariid], low-spired gastropods, and land plants,” but whether this fauna comes from the black phosphatic facies or from the gray facies or represents the entire Eudora Shale is unclear (ibid., 1983, p. 108).

Boardman et al. (1984) recognized several deep-water communities in the Pennsylvanian cyclothemic sequences of the Midcontinent (Figure 14). The deepest-water community, which is in the fissile black shales, “is characterized by *Caneyella* and *Dunbarella* bivalves, ammonoid and nautiloid cephalopods, sharks, conodonts, radiolarians and conulariids” (Boardman et al., 1984, p. 141). These organisms are believed to have been pelagic, epipelagic, nektonic and nektobenthic; no benthic organisms are present.

The community of the dark to medium gray, clay-rich, non-fissile shales, which are more developed in Oklahoma, consists of “the same taxa that are prominent [above], plus a high diversity of molluscan and nonmolluscan stenohaline benthic invertebrates” (ibid., p. 160). This suggests that more-oxygenated conditions were present in the environment of deposition of these shales than were present in the environment of deposition of black fissile shales.

The above-mentioned biofacies model is concerned primarily with megafossils, specifically ammonoids and mollusks. However, Boardman et al. (1995) recently

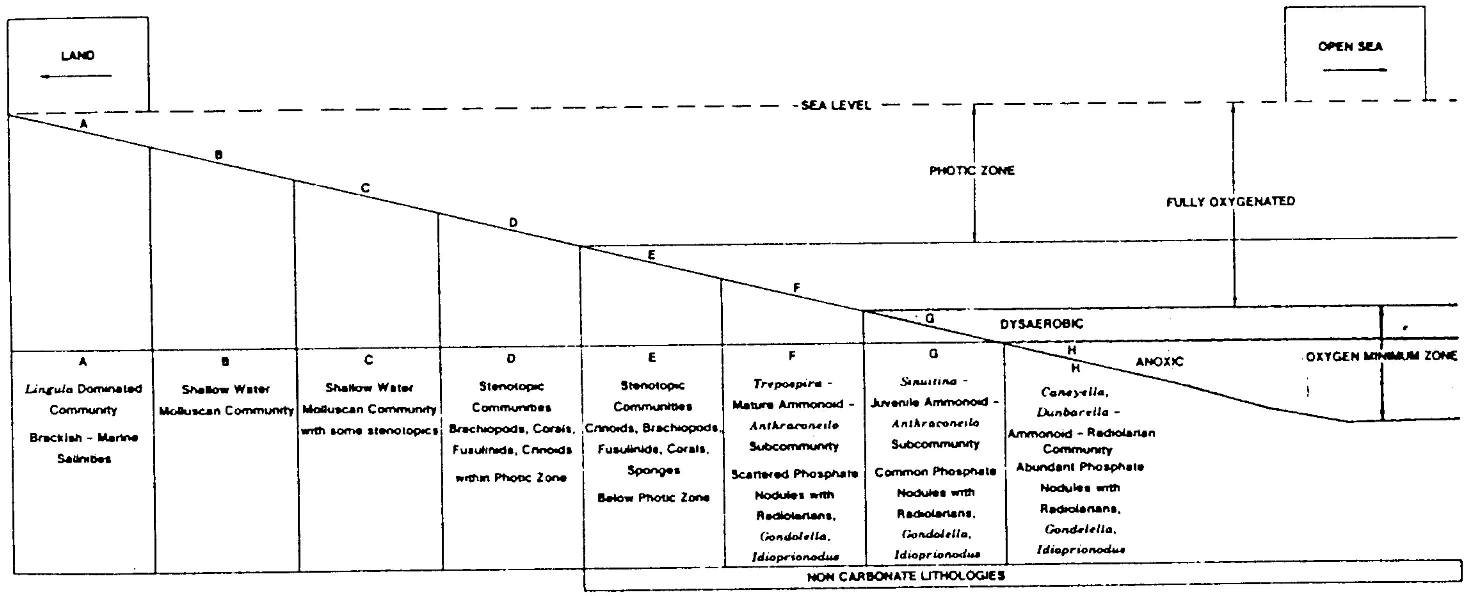

Figure 14. Model for community succession versus water depth in Pennsylvanian cyclothems (from Boardman et al., 1984, p. 171).

described a depth-related biofacies model based upon distribution of microfossils (Figure 15).

According to this model, deep-shelf marine strata of the Midcontinent generally contain *Gondolella*, *Idioprioniodus* and *Neogondolella* conodonts, *Healdia* and *Mammoides* ostracodes, and *Reophax* and *Ammodiscus* foraminifers. Although these biofacies are independent of lithology, they are common in black shales of the Midcontinent. Intermediate depths are represented by *Idiognathodus* and *Streptognathodus* conodonts, *Amphissites* ostracodes, and *Tetrataxis*, *Globivalvulina* and *Endothyranella* foraminifers. These biofacies are also independent of lithology, but are common in carbonate and siliciclastic rocks. Nearshore normal marine strata contain *Adetognathus* and *Sweetognathus* conodonts, *Cavellina* ostracodes and *Ammodiscus* foraminifers. Finally, marginal marine facies contain no conodonts, *Geisina* ostracodes and rare foraminifers (Boardman et al., 1995).

Some of the shale units of the Council Grove Group addressed in this study were described by Miller and West (1993). A black shale within the Burr Limestone Member of the Grenola Formation "is bounded below by a thin lag of skeletal and phosphatic debris and above by a skeletal lag including abundant tiny pyramidellid gastropods and fish teeth" (Miller and West, 1993, p. 7). The black shale in the lower Neva Limestone Member of the Grenola Formation "contains lingulid brachiopods and plant debris and is marked at its base by a condensed phosphatic bed ... containing brachiopod shell debris and abundant fish bone and conodonts" (ibid., p. 8).

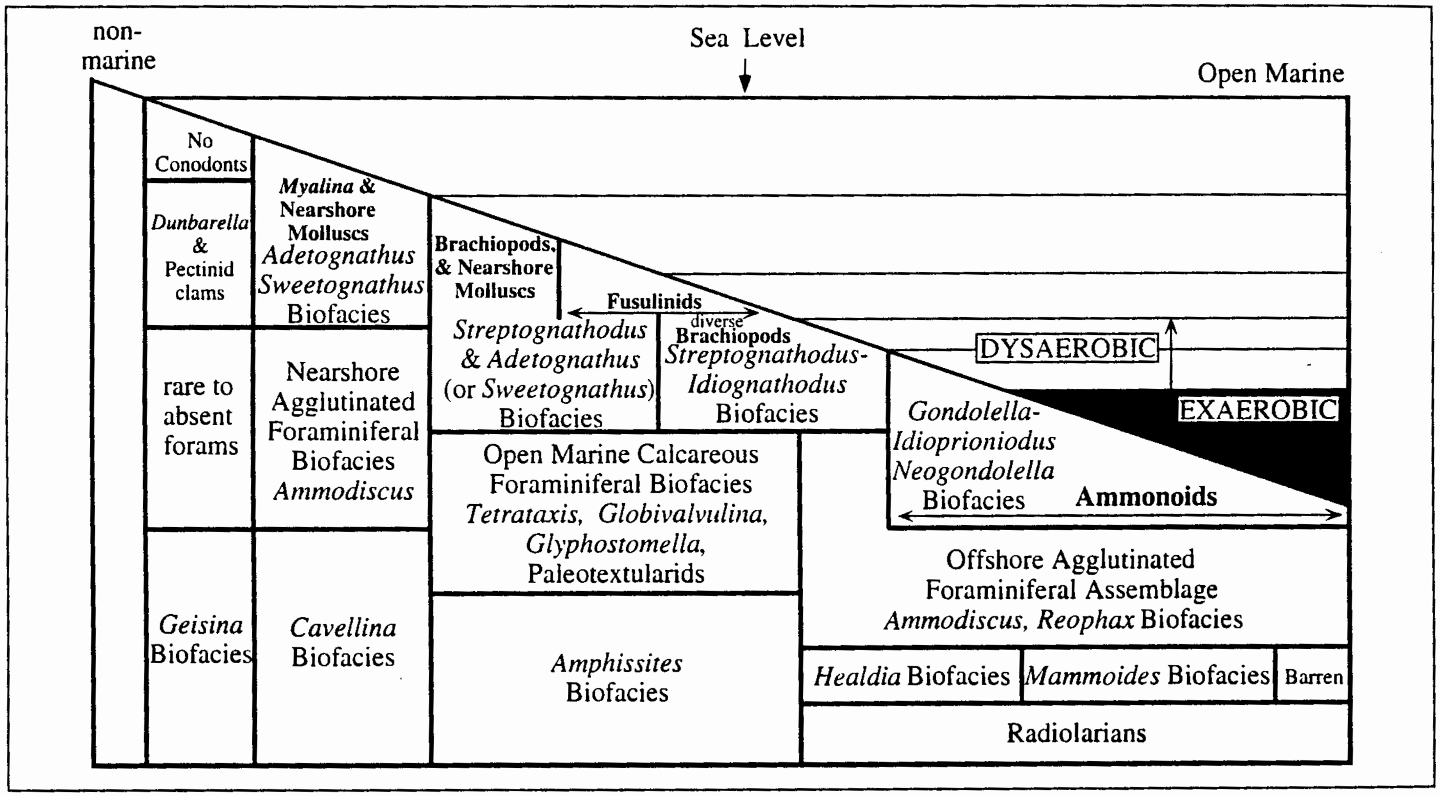

Figure 15. Onshore-offshore model for Pennsylvanian depth- and oxygen-related biofacies associations related to water depth (from Boardman et al., 1995, p. 116, after Boardman and Nestell, 1993).

IV.

STRATIGRAPHY

Pennsylvanian and Permian rocks that outcrop in eastern Kansas and southeastern Nebraska dip gently to the west. The units sampled for this study were taken from outcrops across this area. One sample was from a black shale of the Shawnee Group of the Pennsylvanian Virgilian Stage, and the remaining eight samples were from the lower portion of the Council Grove Group of the Pennsylvanian Virgilian Stage and the Permian Asselian Stage (Figure 16). However, because the recently proposed change of the Pennsylvanian-Permian boundary is still unofficial, the Council Grove Group has been and will be referred to as Lower Permian strata for this study.

Stratigraphic descriptions of sampled units

Shawnee Group: Oread Limestone

The type locality of the Shawnee Group is in Shawnee County, Kansas. In ascending order, it contains the following formations: Oread Limestone, Kankawa Shale, Lecompton Limestone, Tecumseh Shale, Deer Creek Limestone, Calhoun Shale and Topeka Limestone (Figure 17). The Oread Limestone formation is about 45 feet (14 meters) thick near its type locality in the town of Lawrence in Douglas County, Kansas. It forms a prominent escarpment, traceable across much of eastern Kansas in a southerly trend. In ascending order, this formation contains the following members:

SERIES	STAGE	GROUP
Lower Permian	Artinskian	Chase
	Sakmarian	Council Grove*
	Asselian	
Upper Pennsylvanian	Virgilian	Admire
		Wabaunsee
		Shawnee *
		Douglas
	Missourian	Lansing
		Kansas City
		Pleasanton
Middle Pennsylvanian	Desmoinesian	Marmaton
		Cherokee
	Atokan	Atoka

Figure 16. Stratigraphic column (including groups) of Middle Pennsylvanian to Lower Permian units of the Midcontinent. Asterisks (*) indicate groups from which black shales were sampled for the current study.

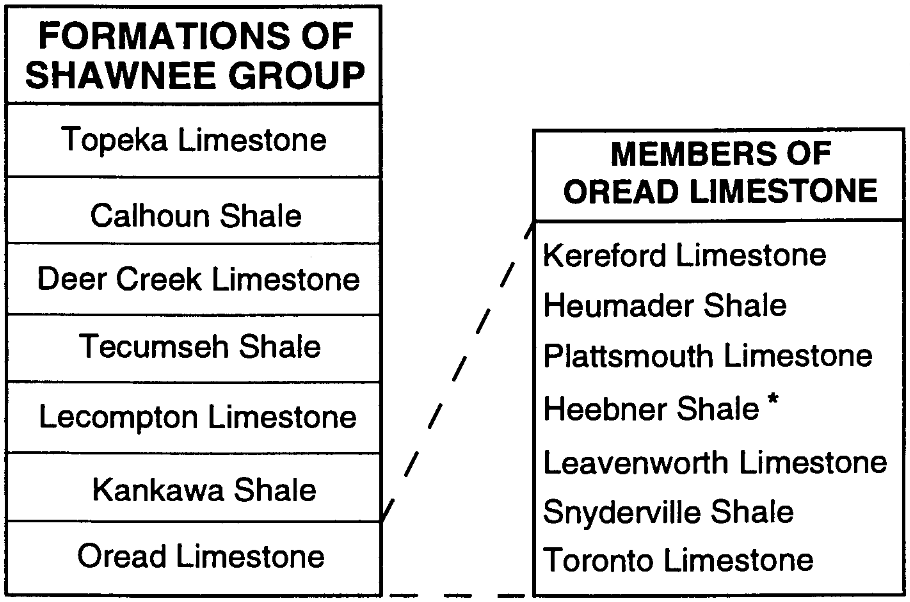

Figure 17. Stratigraphic column of the Shawnee Group, Virgilian Stage. Asterisk (*) indicates black shale.

Toronto Limestone, Snyderville Shale, Leavenworth Limestone, Heebner Shale, Plattsmouth Limestone, Heumader Shale and Kereford Limestone (Moore, 1936).

Black Heebner Shale

The black Heebner Shale Member of the Oread Limestone is about 5 feet (1.5 meters) thick throughout Kansas and Nebraska. Its type locality is along Heebner Creek west of Nehawka, Nebraska, in Cass County. Although it was first described by Condra (1927), Moore (1936, p. 166) describes it as "black, carbonaceous, hard and very fissile" in the lower portion, and "bluish to yellowish gray" and clayey in the upper portion. For the current study, the Heebner was sampled in southeastern Kansas in Chautauqua County just west of Sedan where its thickness and its description do not differ significantly from Moore's (ibid.) thickness and description (Figures 18 and 19).

Evans (1967) divided this shale into three units: a thin lower calcareous shale with numerous small brachiopods and pelecypods, a distinctive black fissile shale with many phosphatic laminae and nodules and a well-developed upper calcareous shale that generally resembles the lower calcareous shale and contains phosphatic nodules at its base. The intervals sampled for this study are described in Appendix A.

Council Grove Group: Foraker Limestone

The Council Grove Group of the Upper Pennsylvanian and Lower Permian is about 320 feet (98 meters) thick across the Kansas outcrop area. In ascending order, it contains the Foraker Limestone, Johnson Shale, Red Eagle Limestone, Roca Shale, Grenola Limestone, Eskridge Shale, Beattie Limestone, Stearns Shale, Bader Limestone, Easly Creek Shale, Crouse Limestone, Blue Rapids Shale, Funston Limestone and Speiser Shale (Zeller, 1968). The remaining eight samples for this study were taken from the Foraker, Red Eagle and Grenola Limestone formations of this group (Figure 20). The Nemaha Uplift is higher in Nebraska and northern Kansas;

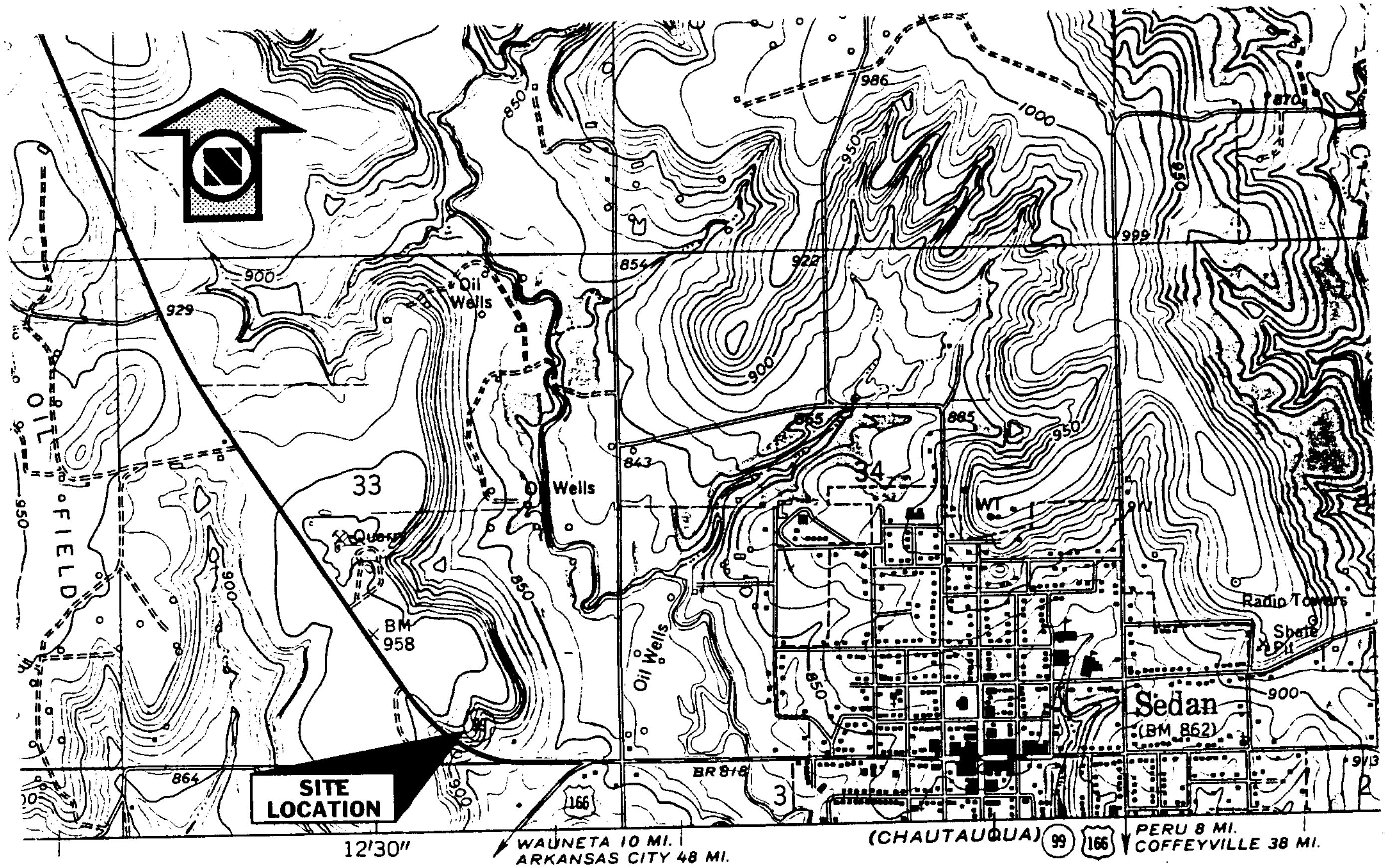

Figure 18. Map locality of Heebner Shale. Roadcut on east side of Highway 99, 0.4 miles north of Highway 166 intersection. SW/4, SE/4, sec. 33, T33S, R11E, Sedan Quadrangle (7.5 minute series), Kansas, 1962.

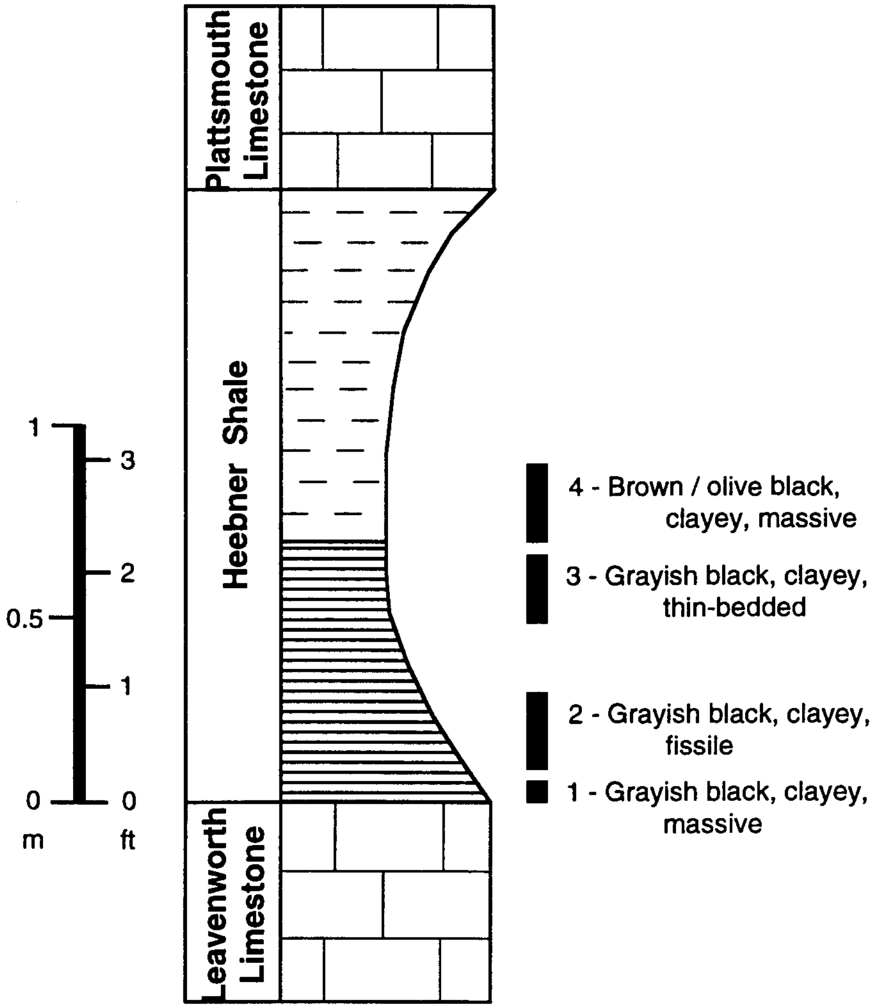

Figure 19. Locations of intervals sampled in the Heebner Shale. Further descriptions are in Appendix A.

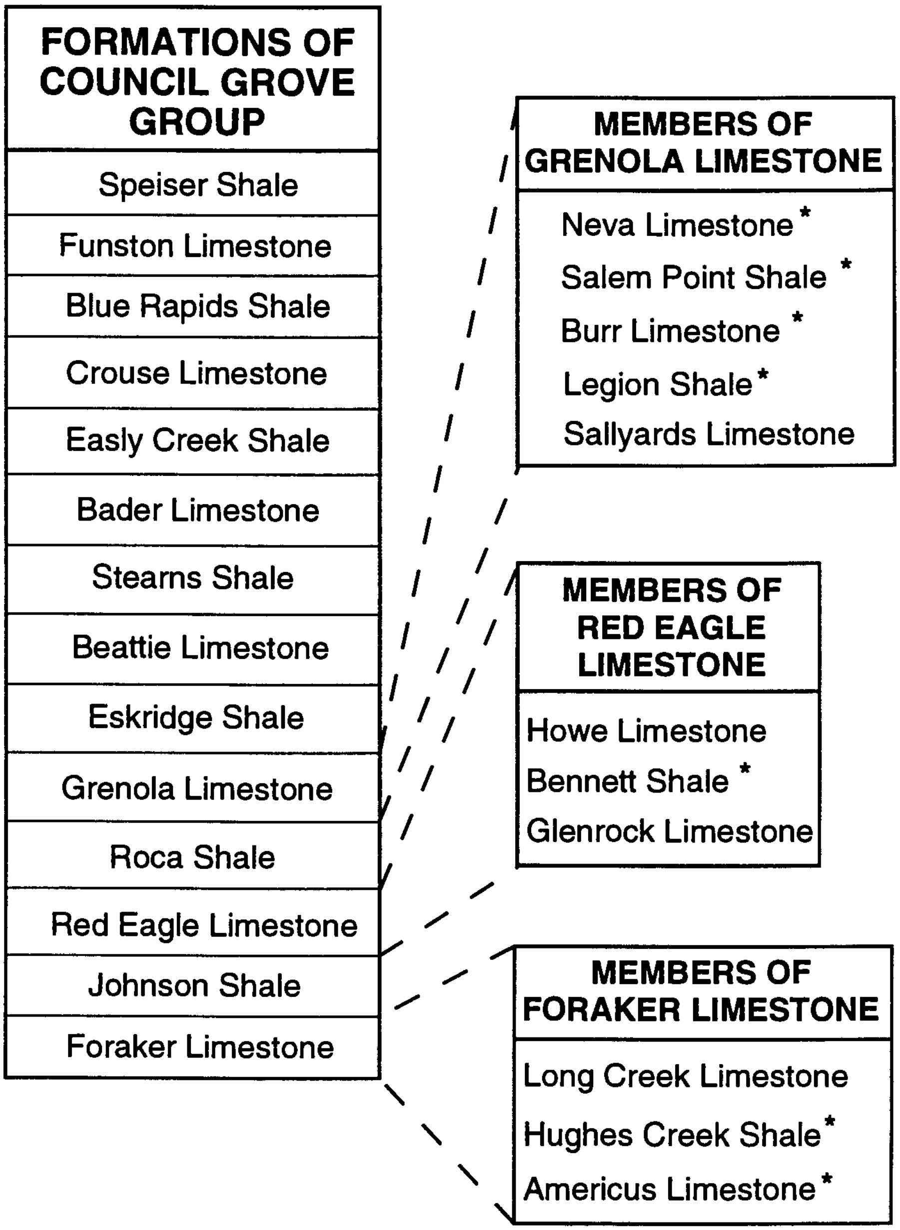

Figure 20. Stratigraphic column of the Council Grove Group. Asterisks (*) indicate black shales in the member.

consequently, some of the units that outcrop over this positive structure are thinner along this uplift.

The Foraker Limestone is about 70 feet (21 meters) thick in southern Kansas and about 30 feet (9.1 meters) thick in northern Kansas. The type section of the Foraker is in Osage County, Oklahoma. In ascending order, this formation contains the following members: Americus Limestone, Hughes Creek Shale and Long Creek Limestone (Mudge and Yochelson, 1962).

Black shale unit of Americus Limestone

The Americus Limestone Member is named for exposures near Americus in Lyon County, Kansas. It ranges in thickness from 1.5 to 20 feet (0.5 to 6.1 meters) and averages 4 feet (1.2 meters) thick in northern Kansas. The member is essentially "two gray to bluish-gray limestone beds separated by a medium-gray to very dark-gray shale bed" (Zeller, 1968, p. 45; also Mudge and Yochelson, 1962). The separating dark shale unit was sampled from an outcrop in Richardson County, Nebraska, several miles south of Humboldt, along the crest of the Nemaha Uplift where the Americus is less than 2 feet (0.6 meter) thick (Figures 21, 22 and 23). Intervals sampled are described in Appendix A.

Two black shale units of Hughes Creek Shale

The Hughes Creek Shale Member grades from mostly limestone in southern Kansas to mostly shale in northern Kansas. It ranges from 20 to 36 feet (6.1 to 11 meters) in thickness and generally thickens southward. Typically it is a thick dark gray shale with thin beds of fusulinid-rich limestone. The type locality for this member is along Hughes Creek in Nemaha County, Nebraska (Mudge and Yochelson, 1962; Zeller, 1968). This member contains two black shales that were sampled in the Tuttle Creek spillway near Manhattan in Pottawatomie County, Kansas (Figures 24, 25, 26 and 27).

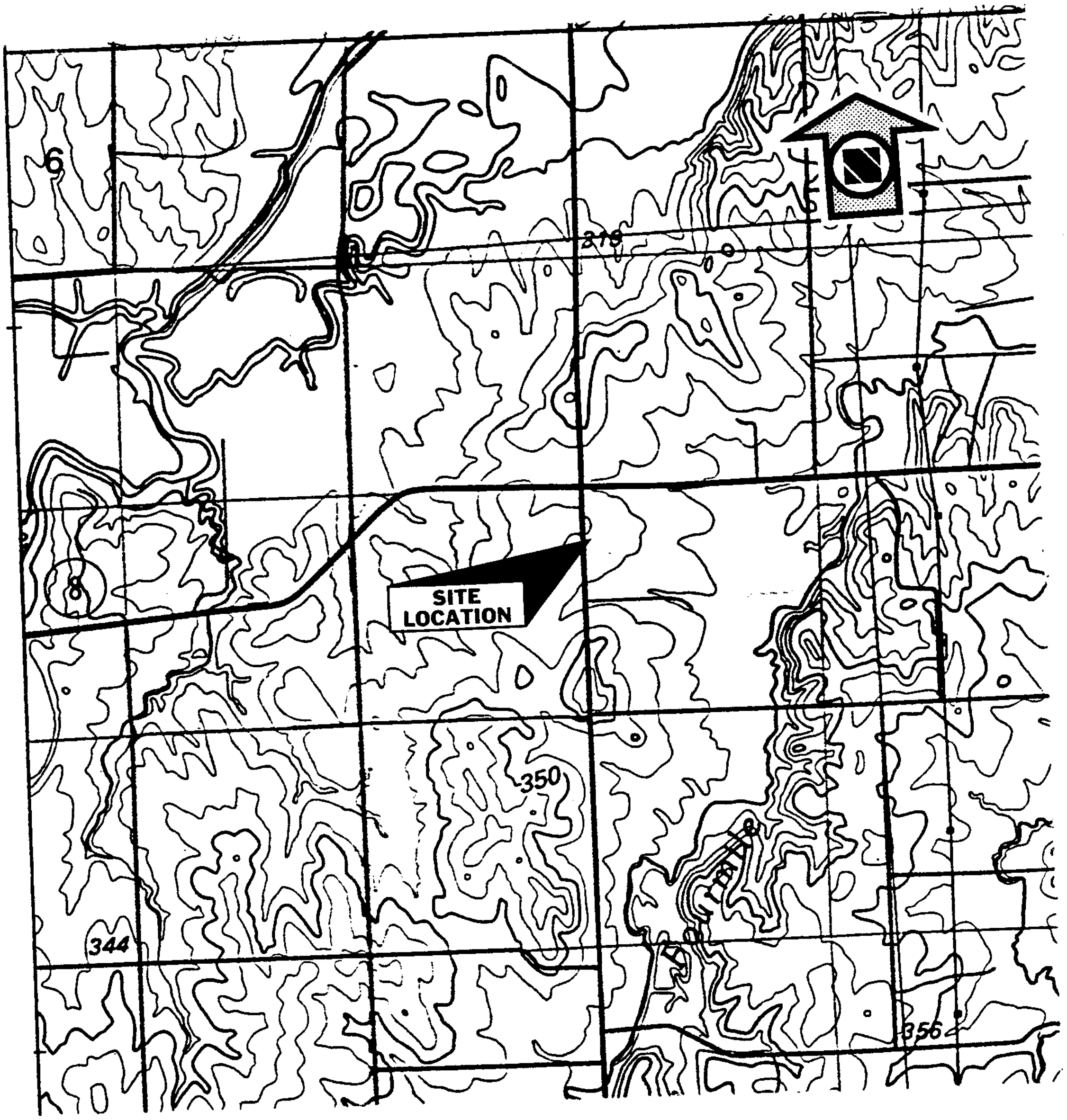

Figure 21. Map locality of Americus Limestone. Roadcut on east side of Highway 105, 0.2 miles south of Highway 8 intersection. NW/4, NW/4, sec. 15, T1N, R13E, Falls City, Nebraska-Missouri (30 x 60 minute series), 1986. (Figure enlarged 2x from original.)

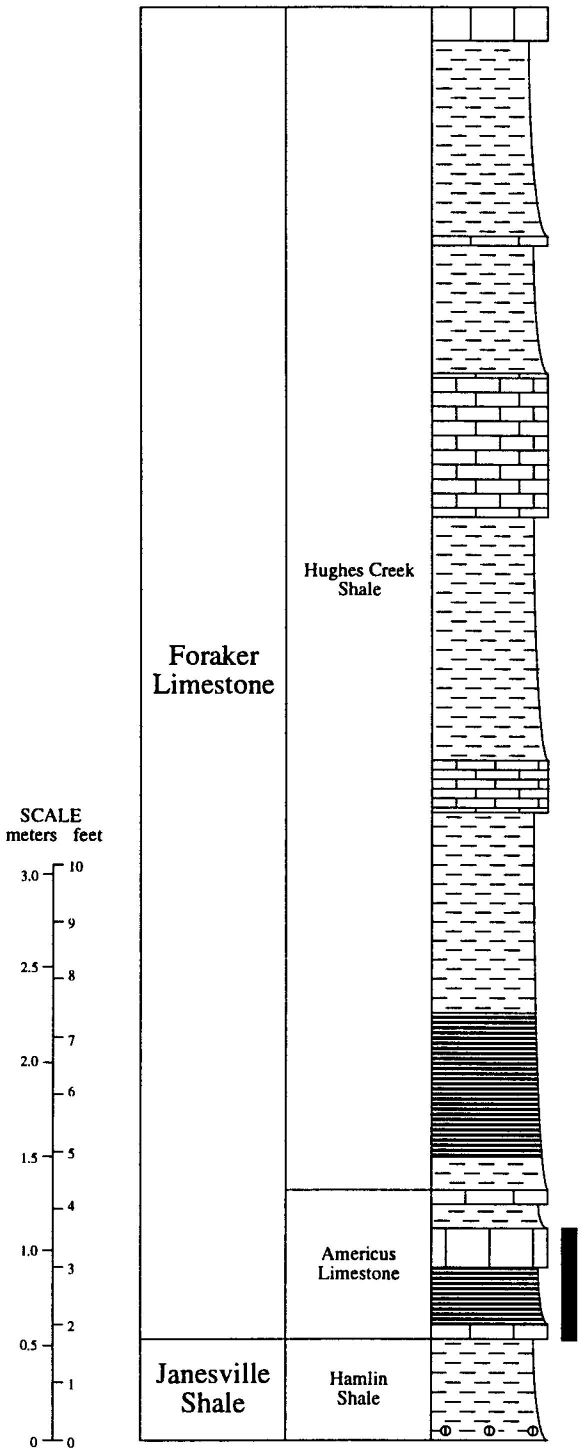

Figure 22. Stratigraphic section of Highway 105 outcrop in southeastern Nebraska at location shown in Figure 21. Marked section is the black shale of the Americus and is expanded in Figure 23. Black shale of basal Hughes Creek was not used in this study. Diagram courtesy of Darwin R. Boardman II.

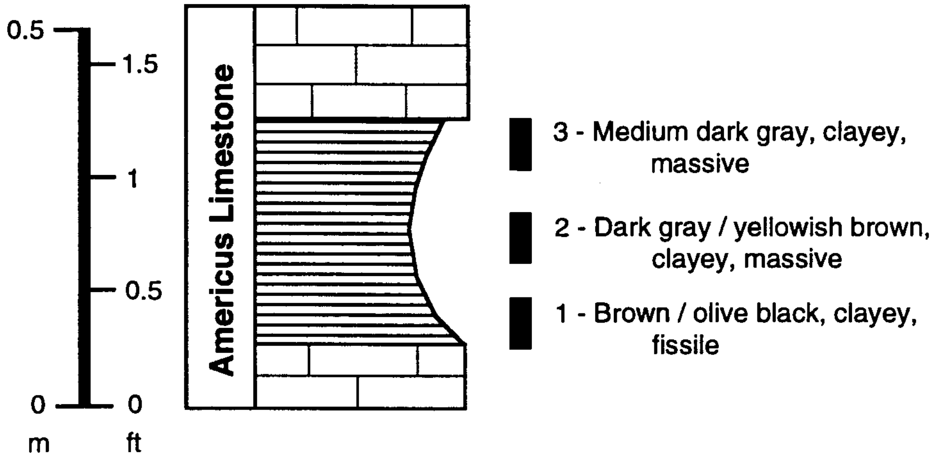

Figure 23. Locations of intervals sampled in black shale unit of Americus Limestone. Further descriptions are in Appendix A.

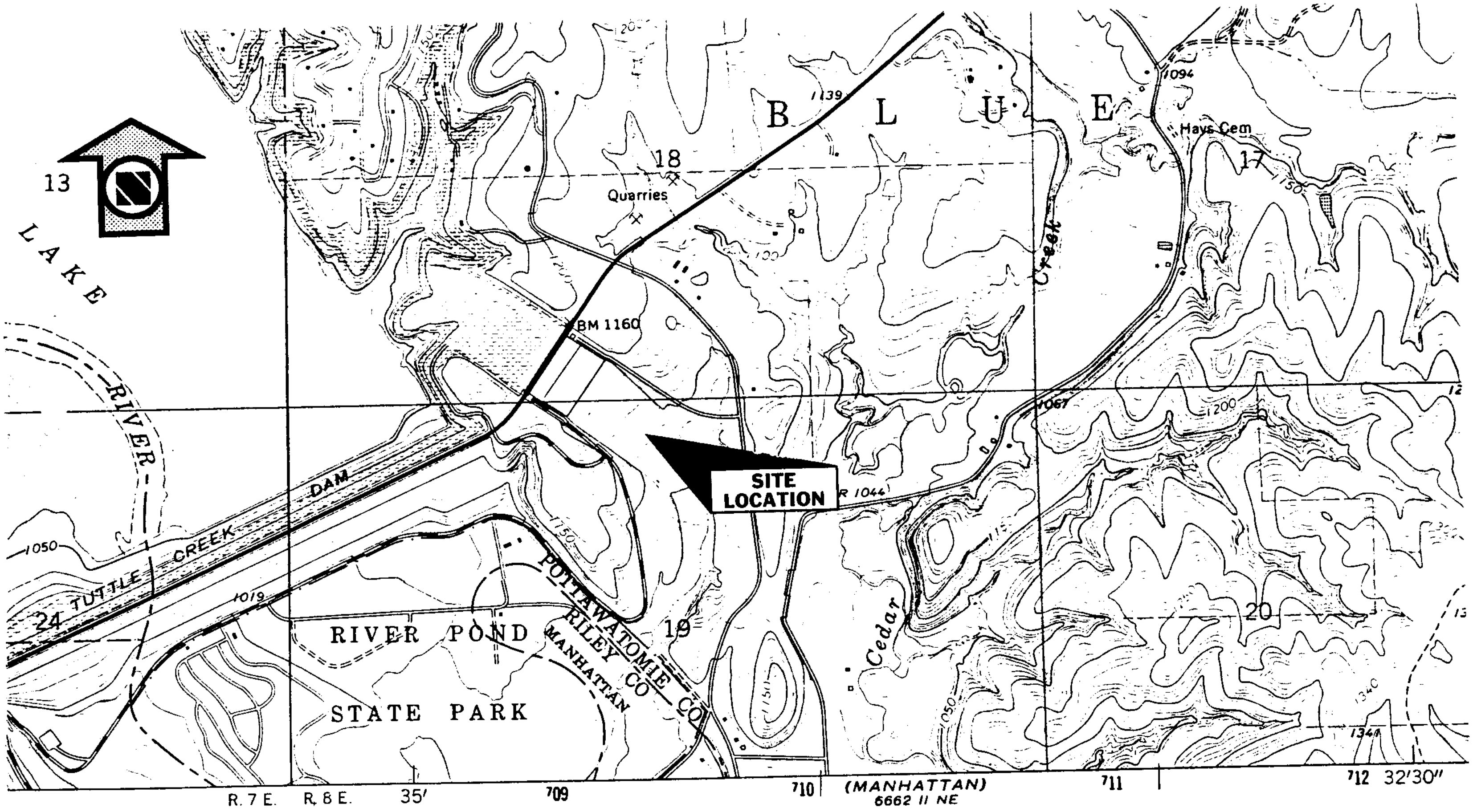

Figure 24. Map locality of Hughes Creek and Bennett Shales. Tuttle Creek spillway. SE/4, SW/4, sec. 18 and NE/4, NW/4, sec. 19, T9S, R8E, Tuttle Creek Dam Quadrangle (7.5 minute series), Kansas, 1964.

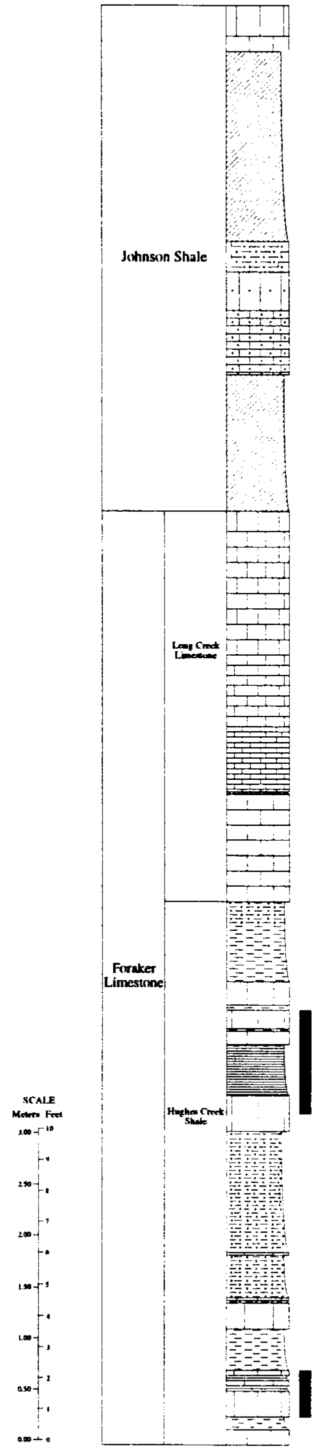

Figure 25. Lower stratigraphic section of outcrop in Tuttle Creek spillway north of Manhattan, Kansas, at location shown in Figure 24. Marked sections are the lower and upper black shales of the Hughes Creek and are expanded in Figures 26 and 27, respectively. Diagram courtesy of Darwin R. Boardman II.

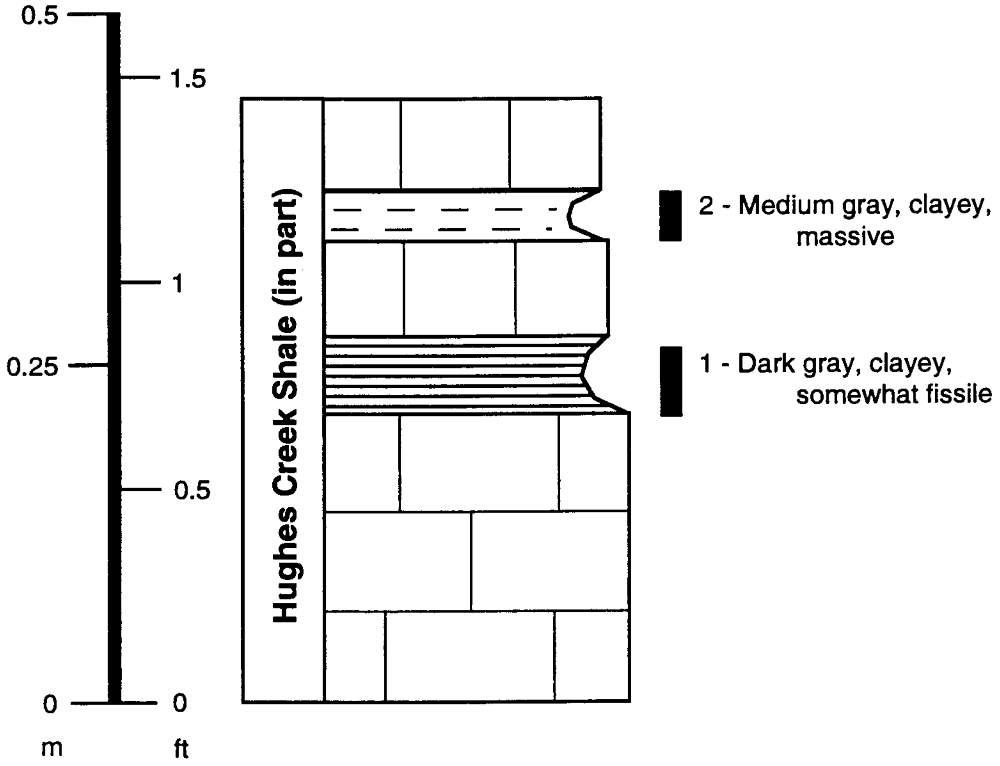

Figure 26. Locations of intervals sampled in lower black shale unit of Hughes Creek Shale. Further descriptions are in Appendix A.

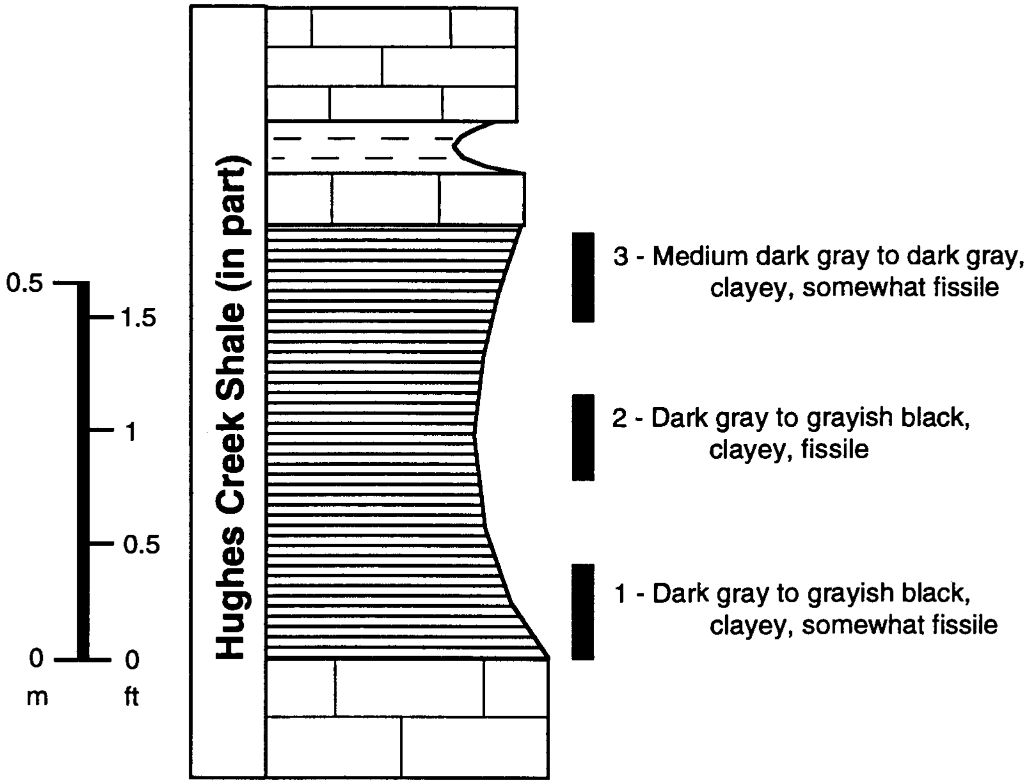

Figure 27. Locations of intervals sampled in upper black shale unit of Hughes Creek Shale. Further descriptions are in Appendix A.

Only about 21 feet (6.4 meters) of the upper Hughes Creek was exposed at this locality (Boardman et al., 1994a). The two sampled units grade from thick cherty limestone in southern Kansas to thin dark gray shale in northern Kansas. These shale units are likely the same *Orbiculoidea / Crurithyris* zones (Units 2 and 4) identified by Mudge and Yochelson (1962, p. 34). Intervals sampled from each shale are described in Appendix A.

Council Grove Group: Red Eagle Limestone

In Kansas, the Red Eagle Limestone ranges in thickness from 6 to 33 feet (1.8 to 10 meters). It was named for a school (Red Eagle) near Foraker in Osage County, Oklahoma. The formation mostly is limestone in northern Oklahoma and southern Kansas. It contains a distinctive black shale unit in northern Kansas and southern Nebraska. In ascending order, the Red Eagle is composed of the following members: Glenrock Limestone, Bennett Shale and Howe Limestone (Mudge and Yochelson, 1962; Zeller, 1968; McCrone, 1963) (Figures 20 and 28).

Black Bennett Shale

In northern Kansas the Bennett Shale is dark gray, fissile shale, but in southern Kansas this “shale” is light gray limestone with common fossils. This member was named for exposures south of Bennet (spelling correct) in Lancaster County, Nebraska. The member ranges from 4 to 27 feet (1.2 to 8.2 meters) thick and generally thins toward the north (Mudge and Yochelson, 1962; Zeller, 1968). Mudge and Yochelson (1962) and Condra (1927) observed the same *Orbiculoidea / Crurithyris* zone in the lower part of this member in northern Kansas and southern Nebraska, respectively. The Bennett was sampled in the Tuttle Creek spillway in Pottawatomie County, Kansas, where it is just over 4 feet (1.2 meters) thick (Boardman et al., 1994a) (Figures 24, 28 and 29). Intervals sampled are described in Appendix A.

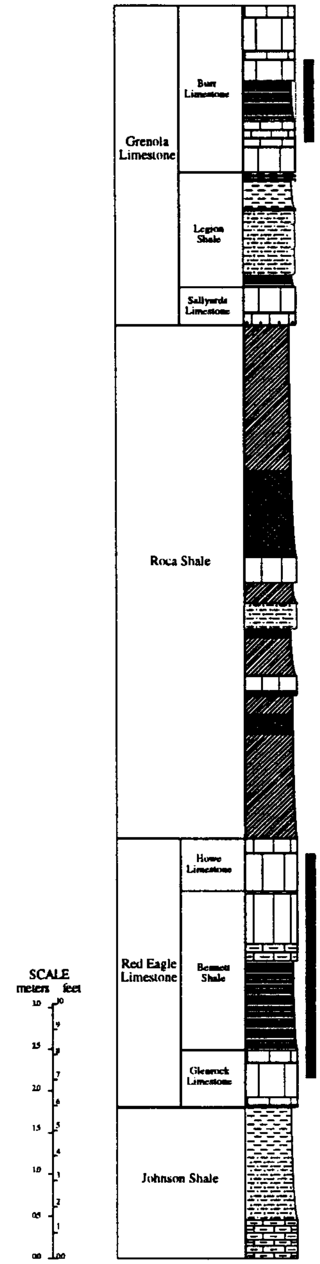

Figure 28. Upper stratigraphic section of outcrop in Tuttle Creek spillway at location shown in Figure 24. Marked sections are the Bennett Shale and the black shale of the Burr, and are expanded in Figures 29 and 33, respectively. The black shale in the Legion at this locality was not used in this study. Diagram courtesy of Darwin R. Boardman II.

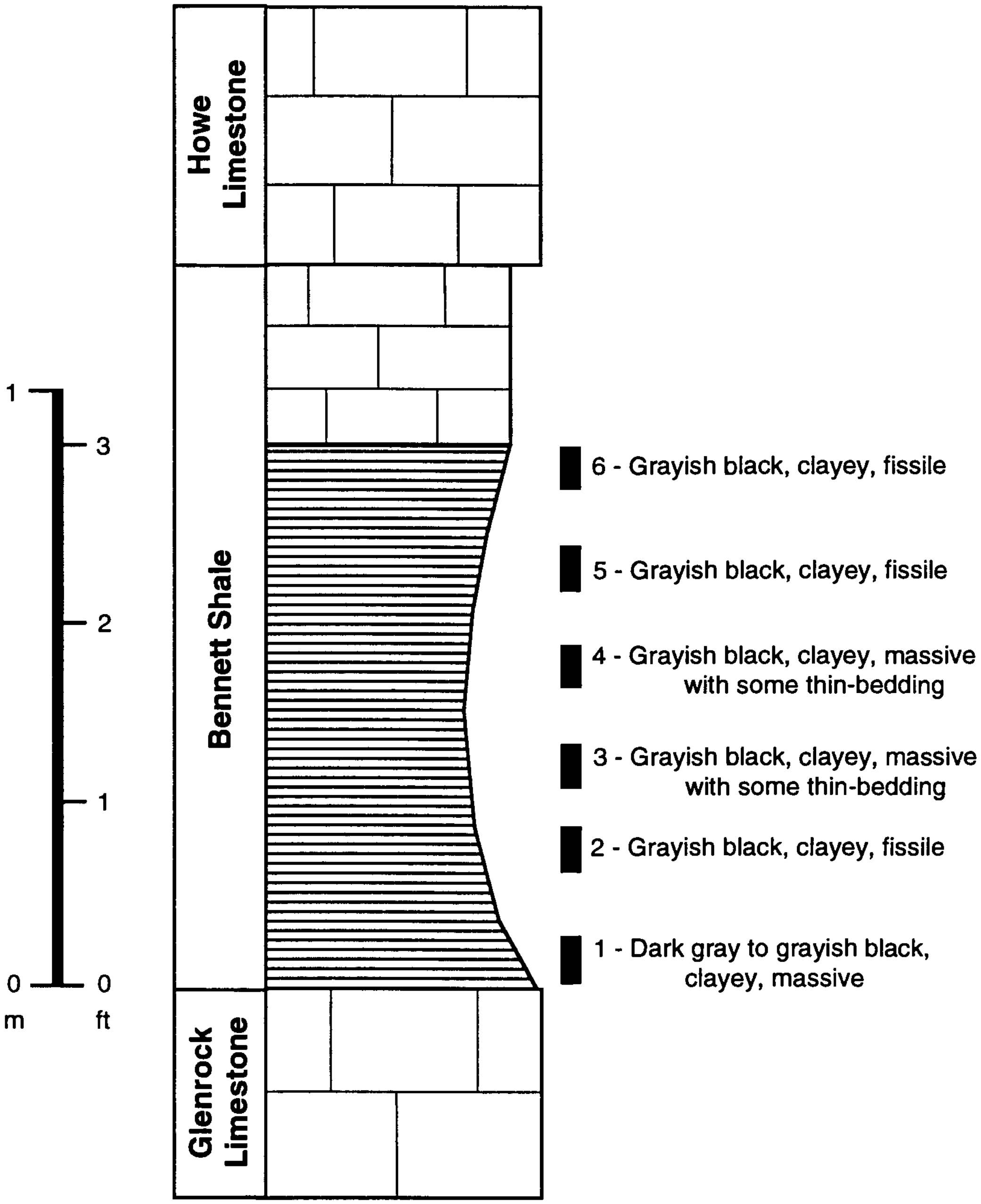

Figure 29. Locations of intervals sampled in Bennett Shale. Further descriptions are in Appendix A.

Council Grove Group: Grenola Limestone

The Grenola Limestone was named for exposures west of Grenola in Elk County, Kansas. It ranges in thickness from 32 to 54 feet (9.8 to 16 meters). In ascending order, the following members make up the formation: Sallyards Limestone, Legion Shale, Burr Limestone, Salem Point Shale and Neva Limestone (Mudge and Yochelson, 1962). The latter four members each contain a black shale unit that was sampled for this study (Figures 20 and 31).

Black shale unit of Legion Shale

The Legion Shale Member generally is gray and clayey and contains some black fissile shale. It ranges in thickness from 1.4 to 13 feet (0.4 to 4.0 meters) and generally thickens southward. This member was named for exposures southwest of the American Legion grounds in Manhattan in Riley County, Kansas (Mudge and Yochelson, 1962). The type section describes black fissile shale near the top of the member; however, Miller and West (1993) depict black shale at the base of the Legion in a stratigraphic section along Highway 18 southwest of Manhattan. Because the same Miller and West (1993) outcrop was used for the current study, this shale unit was sampled from the base of the Legion where it is mostly light olive gray (Figures 30, 31 and 32). Dark fissile shale was not found at this locality. Intervals sampled are described in Appendix A.

Black shale unit of Burr Limestone

The Burr Limestone Member was named for exposures northwest of Burr in Otoe County, Nebraska. It ranges in thickness from 2.3 to 15 feet (0.7 to 4.6 meters) and generally thickens southward. This member is described as two limestone units separated by gray clayey shale that is black and fissile in some exposures. This middle shale unit is in Nebraska and northern Kansas but is less distinctive in southern Kansas

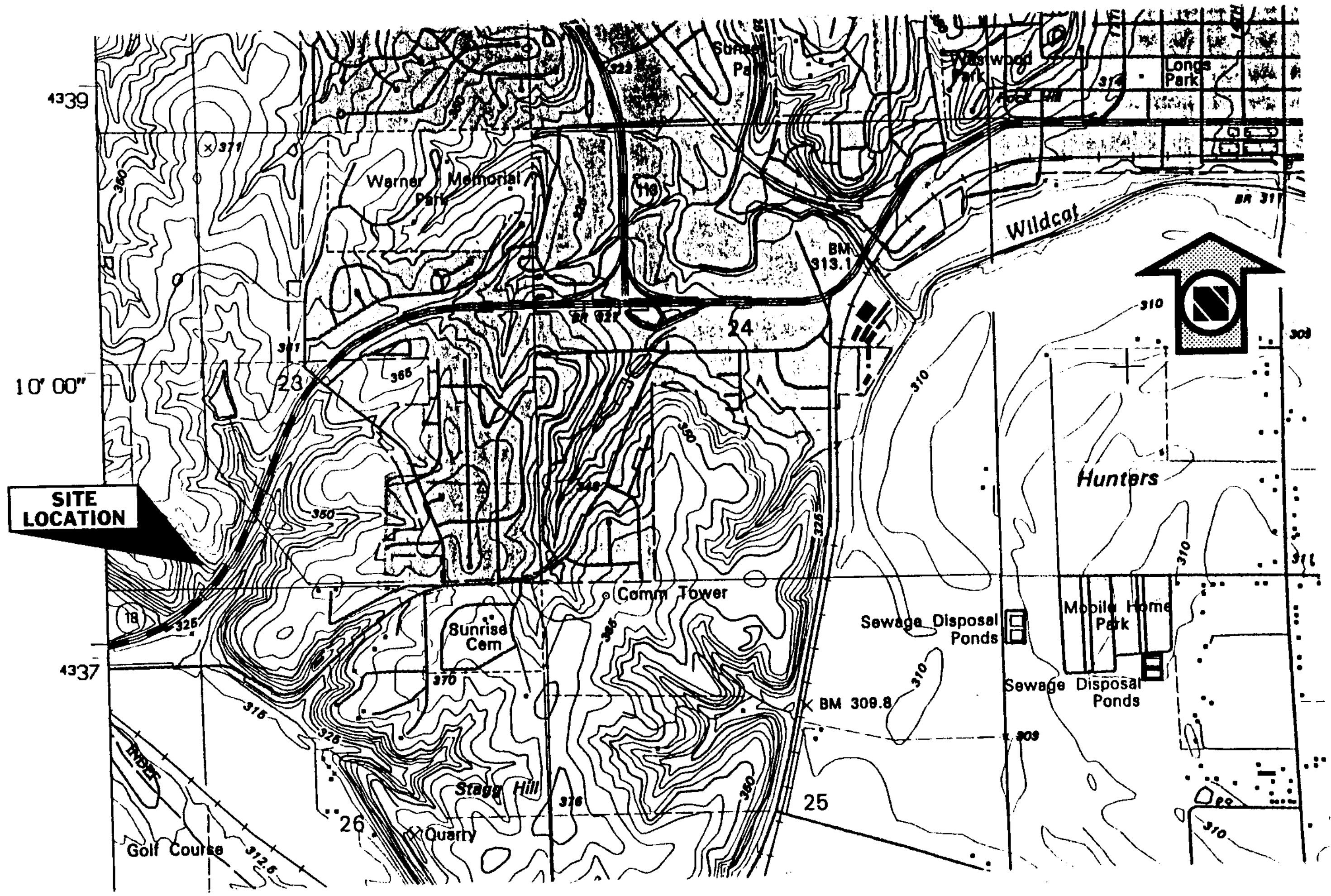

Figure 30. Map locality of Legion Shale-Neva Limestone. North side of Highway 18 in E/2, SW/4, sec. 23, T10S, R7E, Manhattan Quadrangle (7.5 minute series), Kansas, 1991.

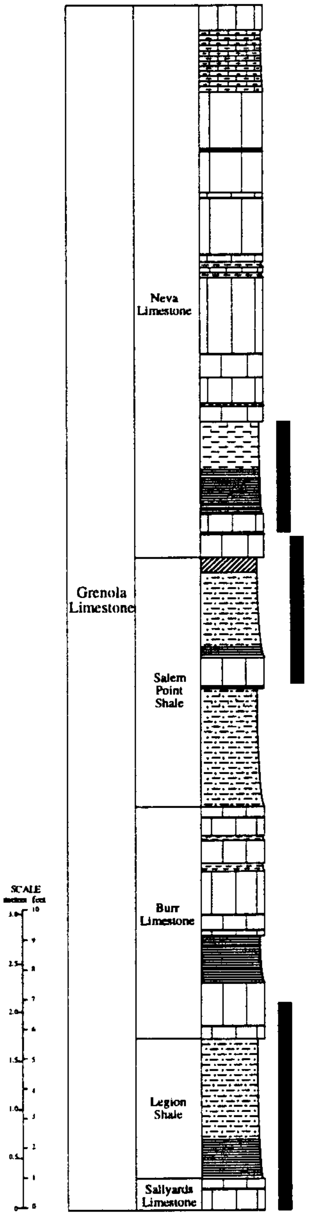

Figure 31. Stratigraphic section of Highway 18 outcrop southwest of Manhattan, Kansas, at location shown in Figure 30. Marked sections are black shales of the Legion, the Salem Point and the Neva and are expanded in Figures 32, 34 and 35, respectively. The black shale of the Burr at this locality was not used in this study. Diagram courtesy of Darwin R. Boardman II.

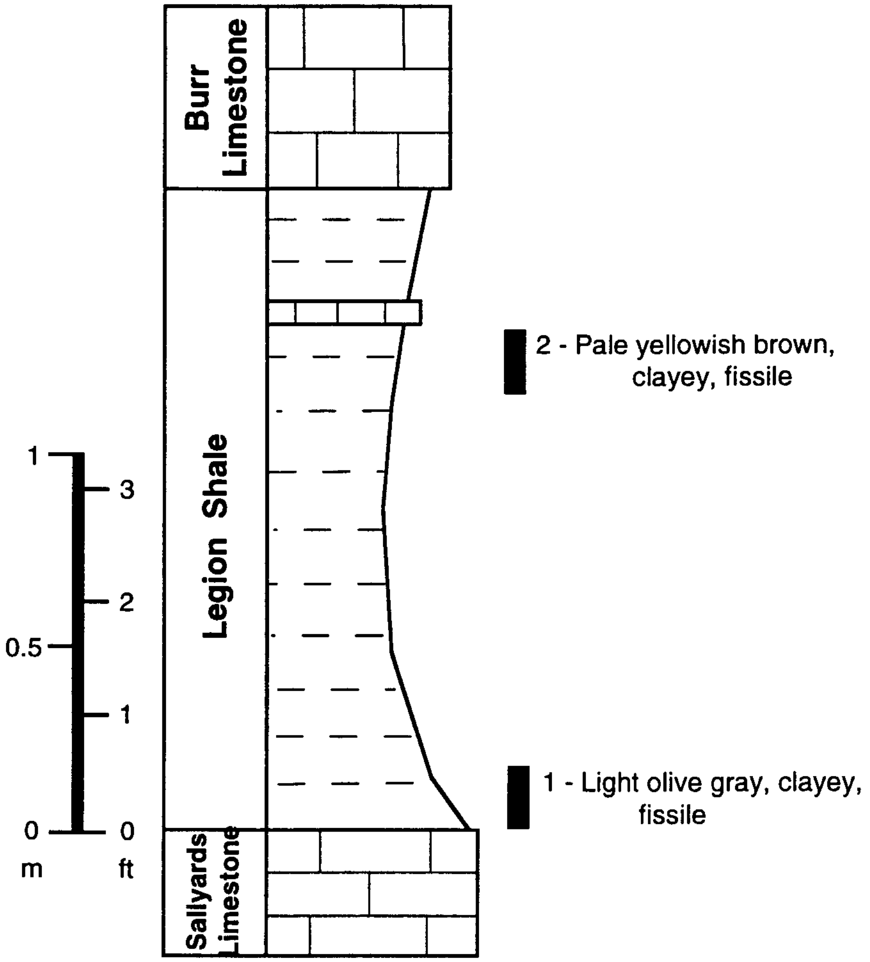

Figure 32. Locations of intervals sampled in Legion Shale. Further descriptions are in Appendix A.

(Mudge and Yochelson, 1962). This dark shale unit was sampled in the Tuttle Creek spillway in Pottawatomie County, Kansas, where it is about 1.5 feet (0.5 meter) thick (Figures 24, 28 and 33). Intervals sampled are described in Appendix A.

Black shale unit of Salem Point Shale

The Salem Point Shale Member averages about 8 feet (2.4 meters) in thickness across Kansas with greatest thickness in the southern half of the state. The Salem Point was named for exposures northwest of Salem in Richardson County, Nebraska. This member "is mostly silty, calcareous gray to olive-drab to gray-green shale" and generally is thin-bedded to blocky with fissile beds at some places (Mudge and Yochelson, 1962, p. 45). At the sampled locality along Highway 18 in Riley County, Kansas, the Salem Point contains a middle limestone unit which is 1 foot (0.3 meter) thick (Miller and West, 1993) (Figure 30 and 31). The dark shale sampled for this study lies immediately above this middle limestone at this locality. The upper shale is 3 feet (0.9 meter) thick and is topped by a calcareous paleosol. The dark gray shale is mottled with olive and brown (Figures 34). Intervals sampled are described in Appendix A.

Black shale unit of Neva Limestone

The Neva Limestone Member was named for exposures near Neva in Chase County, Kansas. The Neva is composed of limestone beds interbedded with gray and grayish-green shales. It averages about 17 feet (5.2 meters) thick and thickens to the south (Zeller, 1968; Mudge and Yochelson, 1962). The lower part of this member contains a dark gray shale traceable across most of Kansas. This shale unit averages 1.2 feet (0.4 meter) thick and thickens toward the north. An *Orbiculoidea / Crurithyris* zone is noted in the lower part of this shale at some exposures (Mudge and Yochelson, 1962). This dark shale was sampled at the same Highway 18 locality in Riley County,

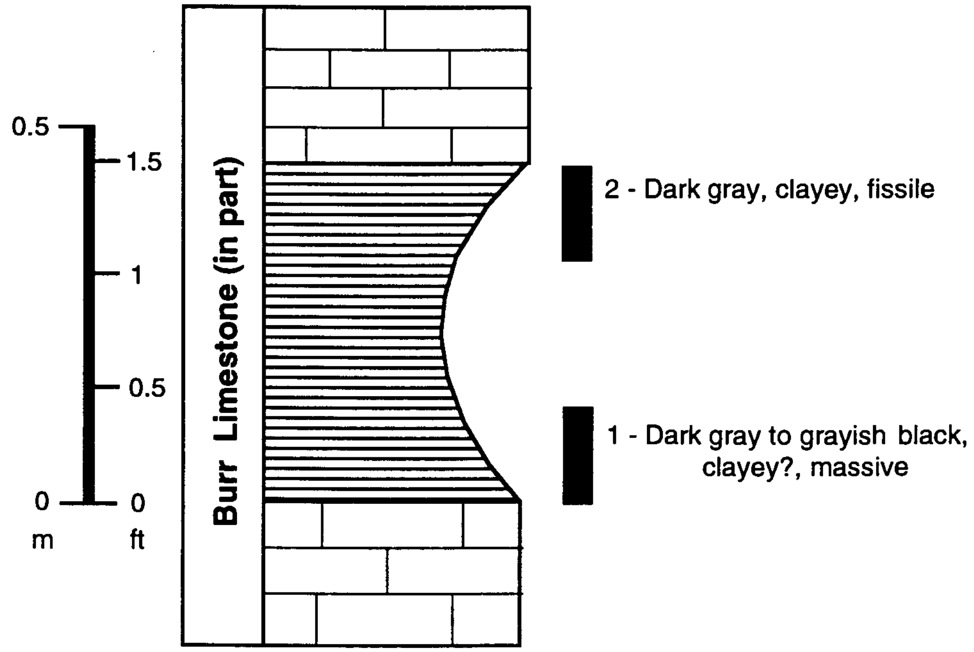

Figure 33. Locations of intervals sampled in black shale unit of Burr Limestone. Further descriptions are in Appendix A.

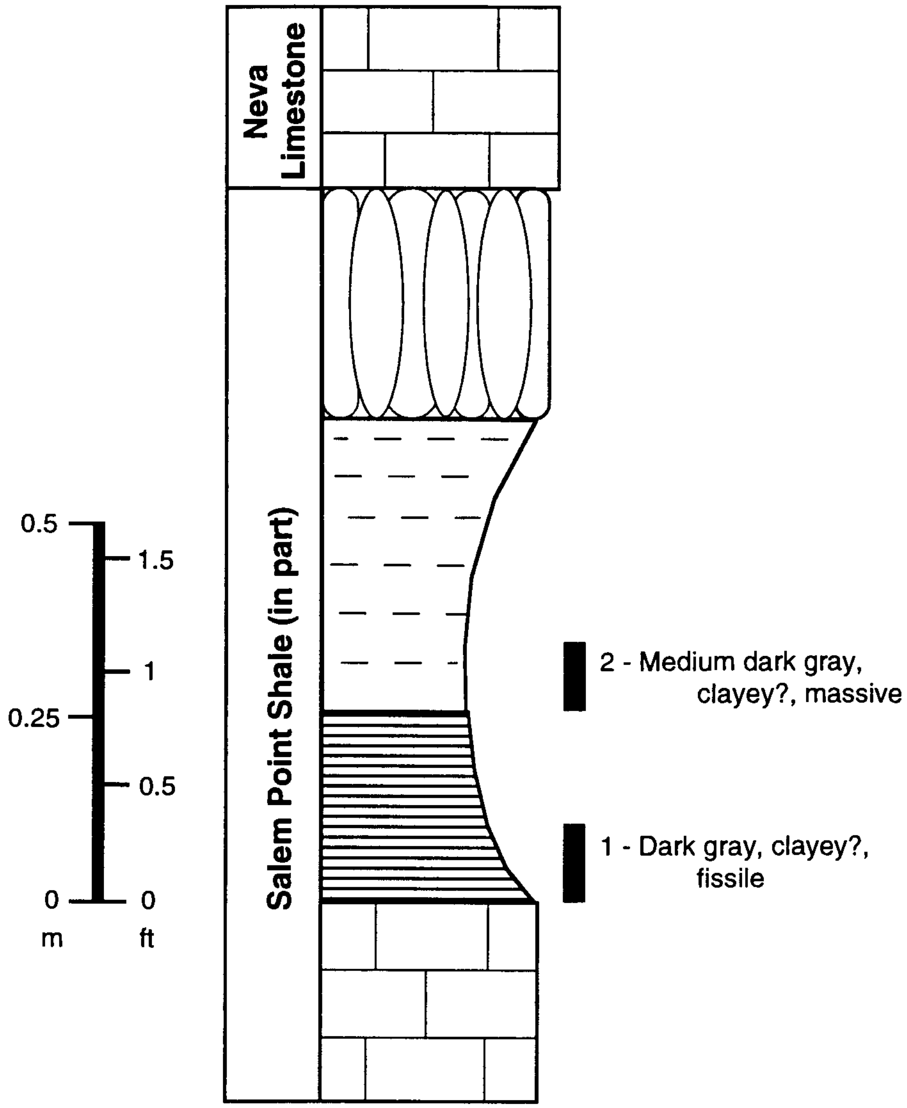

Figure 34. Locations of intervals sampled in black shale unit of Salem Point Shale. Further descriptions are in Appendix A.

Kansas, where it is less than 2 feet (0.6 meter) thick (Figures 30, 31 and 35). Intervals sampled are described in Appendix A.

Lateral uniformity / variation of sampled units

The line of outcrop of Midcontinent Pennsylvanian and Permian units extends roughly north and south and, notwithstanding proximity to paleoshorelines, represents a cross-section of more or less equal depth across the Midcontinent region. The ancient seas deepened westward and shallowed eastward from the line of outcrop. The northern paleoshoreline was generally passive, and the southern paleoshoreline was affected by the Ouachita Uplift in Oklahoma. Thicker deposits in the southern part of this region indicate that subsidence was an additional factor there.

Assuming that the line of outcrop represents an ancient seafloor of roughly equal depth during the deposition of any unit, it follows that water depth controlled the lateral variation or the lateral uniformity of that unit. In other words, shallow-water deposits are less consistent across a large area than deep-water deposits are, because shallow water is less prevalent. Conversely, deep water deposits remain persistent over a wide area.

Shale deposited in shallow water would either pinch out locally or grade into shoreline and terrestrial deposits, and shale deposited in deep water would grade into fossiliferous offshore marine deposits before pinching out (Boardman et al., 1984). The latter situation has indeed been observed among many of the Pennsylvanian black shales of the Midcontinent that are considered deep-water deposits, as based upon other evidence.

The black Heebner Shale is continuous over an extensive area. It changes little in thickness or lithology from its type locality in southeastern Nebraska to southern Kansas where it was sampled for this study (Moore, 1936; Evans, 1967). This suggests that the Heebner is a deep-water deposit.

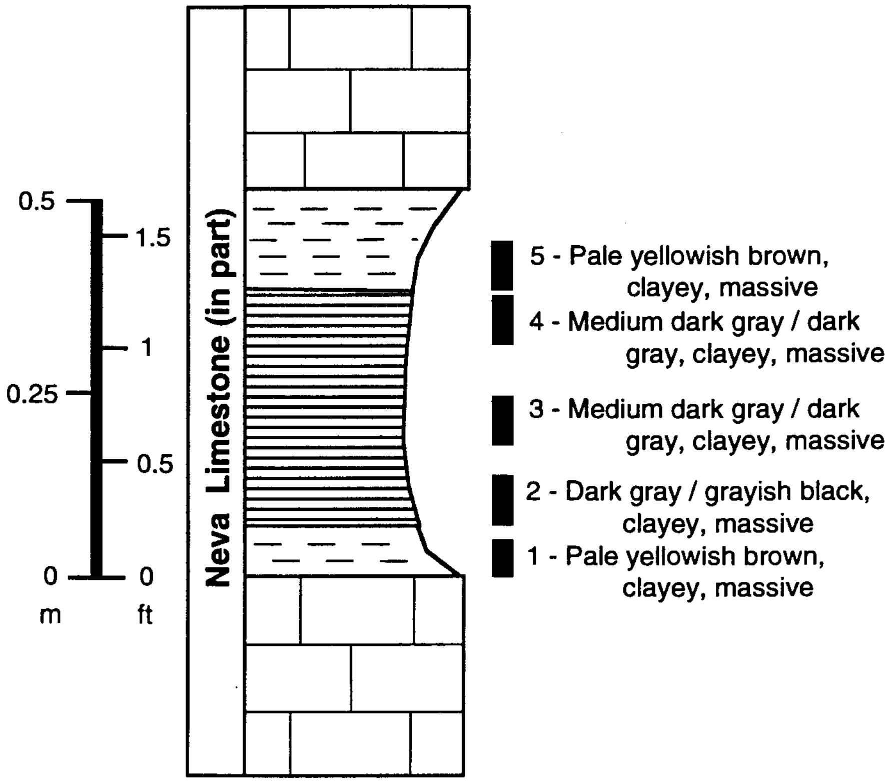

Figure 35. Locations of intervals sampled in black shale unit of Neva Limestone. Further descriptions are in Appendix A.

The black Bennett Shale and both black shale units of the Hughes Creek Shale grade from thin black shales in northern Kansas to thick limestones in southern Kansas (Mudge and Yochelson, 1962). This suggests that the shales formed in a deep-water environment far from shoreline while the limestones concurrently formed closer to the southern paleoshoreline in shallower, more oxygenated, water. The lower black shale unit of the Hughes Creek Shale grades into limestone upon the Nemaha Uplift in Richardson County, Nebraska (where the Americus was sampled for this study). This suggests that the shallower depth over this structurally positive feature resulted in the formation of limestone instead of black shale (Boardman, personal communication).

The black shale unit of the Neva Limestone does not grade into limestone in southern Kansas; however, it does grade from a non-calcareous, clayey shale in the north to a calcareous, silty shale in the south. Furthermore, an *Orbiculoidea / Crurithyris* faunal zone is in this shale unit. This same faunal zone is in the Bennett Shale and the two thin black shales of the Hughes Creek Shale (Mudge and Yochelson, 1962). This evidence suggests a similar origin for all four shales.

The black shale of the Americus Limestone is continuous across the outcrop area. It varies from a featheredge to 2.5 feet (0.76 meters) thick and varies from silty to clayey. In southern Kansas the Americus Limestone Member thickens, and the upper and lower contacts of the separating shale are gradational with the limestones above and below (ibid.). This stratigraphic information by itself is insufficient to determine whether this shale was deposited in deep water or in shallow water.

The black shale of the Burr Limestone, like the shale of the Neva Limestone, is mostly clayey, though silty in some places, and is calcareous in southern Kansas. Unlike the shale of the Neva, however, the shale of the Burr contains pelecypods, bryozoans, gastropods and some stromatolites in southern Kansas (ibid.). Stromatolites indicate very shallow water, and this suggests that the shale of the Burr Limestone was deposited in shallow water.

The black shales within the Legion and the Salem Point Shales may be limited to exposures in northern Kansas. The Legion Shale contains various facies across the outcrop area. The Salem Point Shale consists of red shale in parts of Oklahoma (ibid.). The local occurrence of black shales, the lateral variation of lithologies within the Legion Shale and red shale in the Salem Point Shale suggest that these two shale members, and therefore the black shales locally contained within them, are shallow water deposits.

In conclusion, stratigraphic data can be used to make initial-depth assessments for most of the black shales of this study. According to that data, deep-water shales include the Heebner Shale, both black shales of the Hughes Creek Shale, the Bennett Shale and the black shale of the Neva Limestone. Shallow-water shales include the black shales of the Legion Shale, the Burr Limestone and the Salem Point Shale. Stratigraphic data for the black shale of the Americus Limestone are inconclusive to make an assessment of relative water depth.

V.

PALEOECOLOGIC INTERPRETATIONS

Three groups of microfossils (conodonts, foraminifers and ostracodes) are important in the interpretation of paleoecology of the black shales. Background information concerning each group's optimal environment supports the interpretation of the origins of black shales from which each group is recorded. Other microfauna were picked or simply noted, and the sparse megafossils were only noted. However, the paleoecology of these fossils provides only ancillary support to the interpretations suggested by the presence of the three major groups of microfossils.

In this study, depth is stressed as the environmental condition with the most influence on distribution of microfossils in black shales. Low dissolved oxygen is assumed from the start. In lagoons salinity and perhaps nutrient availability further affected the microfauna. Offshore, at depths below the zone of carbonate production, cold temperatures prevailed and the degree of oxygenation affected the distribution of species. Although phosphate nodules in black shales decreased from Upper Pennsylvanian to Lower Permian, presence or absence does not indicate conditions that affected microfauna as much as difference in ages of shales. Nevertheless, presence or absence of non-skeletal phosphate is used as a criterion to differentiate shales.

Class Ostracoda

Ostracodes belong to Class Ostracoda of the Superclass Crustacea, Phylum Arthropoda. They range from Cambrian to Holocene. Jointed appendages and the capability to molt during growth stages, are evident in living specimens. The bivalved, calcareous carapace that protected each ostrocode is all that remains in the fossil record.

Most ostracode carapaces are less than one millimeter in diameter. The carapaces are hinged on the dorsal side, and in life the organism extends its appendages through the ventral opening to feed, walk or swim. Although sexual dimorphism is evident, fossil species are identified based on the shape and ornamentation of the carapace, the type of hinge line each possesses and the nature of muscle scars.

Some ostracodes are terrestrial, but most are aquatic and can be found in environments ranging from freshwater to hypersaline. They commonly live on or within bottom sediments, and since they are also capable of swimming, their mode of life ranges from nektobenthic to infaunal.

The ostracodes picked from the black shales of this study were identified to generic level and include *Geisina*, *Hollinella*, *Cavellina*, *Kegelites*, *Bairdia*, *Healdia* and *Amphissites.*

Paleoecological interpretations made here are based upon the work of Melnyk and Maddocks (1988a), who studied marine ostracodes of the Permo-Carboniferous in central and north-central Texas, and the work of Boardman et al. (1995) who identified biofacies of ostracodes and other microfauna in Upper Pennsylvanian - Lower Permian strata of north Texas and the Midcontinent. It is assumed that the paleoenvironments of Midcontinent ostracode genera are not much different from those of the same genera that lived contemporaneously in Texas. Melnyk and Maddocks (1988a, p. 14) believed that paleoecological characterizations of ostracodes are more useful for interpreting nearshore environments than for interpreting offshore environments, because ostracodes tend to dominate nearshore facies.

Geisina species lived in nearshore environments ranging in zones from near the paleoshoreline to carbonate banks. This was the only ostracode genus found to occupy solely a shallow-water environment (ibid.). Boardman et al. (1995, p. 106) identified a *Geisina* Biofacies that “occurs in dark gray to black non-phosphatic shales...” and that “probably [represents] lagoons of variable salinity regimes from brackish to hypersaline.”

According to Melnyk and Maddocks (1988a), *Healdia* and *Cavellina* species are generally good indicators of nearshore conditions although some species occupied deeper offshore environments. Boardman et al. (1995), however, contended that most species of *Healdia* occur in offshore environments. Their *Healdia* Biofacies occurs in “dark gray pyritic, slightly phosphatic shales that overlie and underlie the black phosphatic shales.” Furthermore, this biofacies is “restricted to the Oklahoma and north Texas region with higher siliclastic influx than northward” (ibid., p. 107). This interpretation is applicable only to the Heebner Shale of this study, which was sampled in southernmost Kansas.

Species of *Hollinella* range from near the paleoshoreline to much deeper conditions where diversity increased. Overall, this genus is a poor indicator of paleoenvironment (Melnyk and Maddocks, 1988a).

According to Melnyk and Maddocks (1988a), *Amphissites* was generally restricted to offshore environments, although a species of *Amphissites* and a species of *Kegelites* appear to have preferred shallower water. Boardman et al. (1995) described an *Amphissites* Biofacies characterized by a high diversity of ostracode species and associated with a high diversity of megafossils. This biofacies inhabited offshore environments; it is represented in the gray core shales of Midcontinent cyclothems.

Species of *Bairdia* commonly indicate offshore conditions, according to Melnyk and Maddocks (1988a). This genus attained highest diversity in offshore environments with slow sedimentation rates, but a few species of *Bairdia* are in shallow-water facies.

In summary, *Geisina* most likely indicates an environment near the paleoshoreline. *Bairdia* and *Healdia*, on the other hand, are likely indicators of offshore terrain. Although the remaining genera occupy a wide range of paleoenvironments, *Cavellina* is more common in shallow-water environments and *Amphissites* is more common in deep-water environments. *Hollinella* and *Kegelites* do not dominate any paleoenvironment and are, therefore, poor indicators of relative paleo-depth.

Finally, strict reliability of environmental interpretations based on ostracodes from this study is somewhat compromised because these ostracodes were identified only to generic level, whereas previous environmental interpretations were based on ostracode species.

Order Foraminiferida

All foraminifers belong to Order Foraminiferida of the Class Granuloreticulosa of the Subphylum Sarcodina (which also includes radiolarians), Phylum Sarcomastigophora. Unlike the other two major groups of the current study (conodonts and ostracodes of Kingdom Animalia), foraminifers belong to the Kingdom Protista because they are single-celled eukaryotes. Foraminifers are in rocks ranging from Cambrian to Holocene.

Foraminifers possess a skeleton called a test. These organisms either secrete a test of calcium carbonate or build one from sand grains, sponge spicules, other organisms and whatever else is available. The test is the hard part preserved in the fossil record. The tests of some species contain only one chamber; those of other species contain chambers that are added throughout the life of the organism. Their final form varies from coiled to elongate to globular.

Living forms extend their cell into elongated structures called pseudopods in order to gather food particles. These organisms exhibit dimorphism between the sexual forms and the more common assexual forms.

The classification of smaller foraminifers is based on external features such as the nature of the test and the walls. Internal characteristics are used to identify and classify larger foraminifers such as the fusulinids.

Prior to the Middle Jurassic all foraminifers were benthic and lived in or upon the sediment or lived attached to other objects on the seafloor. Fossil foraminifers are in rocks representing a wide range of marine depositional environments. Foraminifers are quite useful for dating subsurface rocks brought to the surface by drilling.

More than 3,000 genera and 40,000 species have been described in the literature. The foraminifers picked from the black shales of this study are identified to generic level and include *Ammodiscus*, *Endothyranella*, *Tetrataxis*, *Globivalvulina*, *Climacammina* and *Triticites* (a fusulinid).

Boardman et al. (1995, pp. 107-109) noted the difficulties associated with interpretation of paleoenvironments based on various foraminiferan species. Environmental distribution data of Upper Pennsylvanian - Lower Permian foraminifers in the context of modern cyclic interpretation are unavailable. Nevertheless, the authors drew a correlation between two species and water depth. A species of *Thurammina* occurs in marginal marine brackish water environments, and a species of *Reophax* is associated with deep-water core shales. Unfortunately, neither genus was found in the shales of the current study.

Ammodiscus and *Tetrataxis* are in a wide variety of depth-related environments. *Endothyranella*, *Globivalvulina*, *Climacammina* and some fusulinids (perhaps *Triticites*?) are in bioassemblages of intermediate depth. *Endothyranella* and *Ammodiscus* are also in deeper environments (Boardman et al., 1995).

In summary, foraminifers are poor indicators of paleoenvironments. Within the black shales of this study, their absence or rarity suggests either a stressed shallow-water environment or an unusually stressed deep-water environment. A moderate diversity of foraminifers indicates a reasonably oxygenated environment for microfauna in offshore conditions. In this latter situation, *Ammodiscus* and/or *Endothyranella* tend to dominate the foraminiferan fauna of these shales.

Phylum Conodonta

Conodonts are an extinct group of animals of uncertain affinity. They are classified as invertebrates and are in their own phylum, Conodonta. Their geologic range is from Late Proterozoic to the end of the Triassic. Only microscopic hard parts are all that remains of conodonts.

These hard parts, called elements, are composed of calcium phosphate mineral called francolite and range in shape from coniform to ramiform to pectiniform. The function of these elements is unknown, but paleontologists believe they may have served as support to the conodont animal or as food-gathering apparatuses. The consistent recurrence of assemblages of certain conodont elements is believed to represent one or a few species of conodonts. Each conodont animal contained several kinds of elements. Throughout this paper these elements have been and will be referred to as "conodonts" instead of "conodont elements."

Less data is available on the conodont animal itself; however, a Lower Carboniferous soft-bodied fossil found in Scotland contains conodont elements in the head portion. This small, elongate creature somewhat resembles modern arrowworms or amphioxus, two worm-like organisms of different phyla, yet appears different enough to justify belonging in a separate phylum (Briggs et al., 1983).

To determine whether conodonts were benthic or pelagic or nektobenthic organisms has been difficult. Since some genera appear to have been restricted to certain depth zones, depth is believed to have been a major factor in the environmental distribution of conodonts. Furthermore, the occurrence of the same genera in different lithologies suggests that conodonts were not limited to a benthic mode of life or, at least, were not dependent on the substrate.

Seddon and Sweet (1971) viewed conodonts as pelagic organisms that lived at various depths. The deepest facies would therefore contain the widest variety of conodonts since a larger number of depth zones lay above. Other workers argued that conodonts were nektobenthic organisms because some genera exhibit lateral segregation (Barnes and Fahraeus, 1975). Klapper and Barrick (1978) concluded that the mode of life of conodonts is difficult to determine based on distribution patterns alone. In other words, either mode of life could have produced the conodont distribution observed in the fossil record.

Nevertheless, known benthic foraminifers in all shales of this study that contain conodonts lends credence to the explanation that conodonts were benthic or nektobenthic. Also, the observed lack of diversity of conodonts in most of these shales suggests that conodonts probably were not solely pelagic organisms. The explanation favored in this study holds that conodonts are the remains of nektobenthic organisms and that different genera of conodonts preferred different conditions (i.e. depth, temperature, etc.). Because conodonts are rarely in nearshore facies and are practically absent from the proposed shallow-water black shales of this study, most of the conodonts discussed here represent offshore conodonts that inhabited environments of different degrees of temperature and oxygenation.

The pectiniform elements, also known as platform elements, were used for identification and counts of the Late Pennsylvanian and Early Permian conodonts within this study. All conodonts of this time frame belong to the Order Hibbardellina of the Class Conodontophorida. These conodonts are identified to generic level and include *Streptognathodus*, *Idiognathodus*, *Idioprioniodus*, *Adetognathus*, *Hindeodus* and *Ellisonia*. Conodont counts include only identifiable platform elements.

Boardman et al. (1995) recognized three major conodont biofacies: *Adetognathus* Biofacies, *Idiognathodus-Streptognathodus* Biofacies and *Gondolella-Idioprioniodus* Biofacies. The *Adetognathus* Biofacies is characterized by the dominance of *Adetognathus* and represents nearshore conditions. *Adetognathus* is not found above the Red Eagle Limestone in the Midcontinent. This biofacies was replaced by the *Sweetognathus* Biofacies. Neither the *Adetognathus* Biofacies nor (above the Bennett Shale) the *Sweetognathus* Biofacies is identified in this study. *Adetognathus* species are significantly less prevalent in deeper biofacies.

The *Idiognathodus-Streptognathodus* Biofacies, in addition to the nominate taxa, contains some *Hindeodus* and *Aethotaxis* (Boardman et al., 1995). This biofacies is perhaps the most widespread and diverse of conodont biofacies. Merrill and von Bitter (1984) also recognized this biofacies and used it as the standard to which other conodont biofacies were compared.

Boardman et al. (1995) recognized several subfacies of the *Idiognathodus-Streptognathodus* Biofacies, ranging from open marine offshore conditions to low-oxygen offshore conditions. It is important to note that many genera identified as *Idiognathodus* have been renamed as *Streptognathodus*. In addition, *Idiognathodus* is not in Permian rocks. This biofacies is represented in Pennsylvanian rocks by a combination of both nominate taxa, dominating the conodont microfauna. *Streptognathodus* dominates this biofacies where it occurs in Permian rocks. This Permian version of the *Idiognathodus-Streptognathodus* Biofacies is present in several of the black shales of the current study.

The third major biofacies recognized by Boardman et al. (1995) is the *Gondolella-Idioprioniodus* Biofacies. It is characterized by representatives of the nominate taxa as well as by many *Streptognathodus* and *Idiognathodus*. This biofacies represents offshore deep-water environments of low oxygen and cold water and is common in, but not restricted to, black phosphatic shales of the Midcontinent and other areas. *Gondolella* became extinct near the end of Carboniferous time and was replaced by *Neogondolella*. Nevertheless, this biofacies (with or without *Neogondolella*) is not present in Midcontinent rocks younger than Late Virgilian. Boardman et al. (1995) believe that the infilling of the Anadarko Basin in Late Virgilian greatly reduced the upwelling of deep, phosphate-rich basinal waters from the west, which supported this biofacies.

Gondolella and *Neogondolella* are not present in the shales of the current study; however, *Idioprioniodus* is in the Heebner Shale. It indicates either a shallower subfacies of the *Gondolella-Idioprioniodus* Biofacies or a deeper subfacies of the *Idiognathodus-Streptognathodus* Biofacies. In either case, *Idioprioniodus* suggests an environment influenced by cold, phosphate-rich waters (Boardman et al., 1995).

Two minor genera in shales of this study but not discussed are *Hindeodus* and *Ellisonia*. *Hindeodus* lived in a wide range of paleoenvironments. It is in the shallower two of three biofacies identified by Boardman et al. (1995). Merrill and von Bitter (1984) noted that it is less common where *Idioprioniodus* is more common. Some question remains as to the environmental preference of *Ellisonia*, but it appears to have been associated with a euryhaline biofacies identified by Merrill and von Bitter (1984).

In summary, the conodont genera in the shales of this study lived in deep-water environments of low-oxygen conditions. All of the shales that contained conodonts were dominated by *Streptognathodus* or, in the case of the Heebner Shale, both *Streptognathodus* and *Idiognathodus*. *Idioprioniodus* indicates the influence of cold, nutrient-rich basinal waters; the absence of *Gondolella*, *Neogondolella* and *Idioprioniodus* implies the opposite condition. Other taxa that are fewer in the shales do not affect the paleoenvironmental interpretations made in this study.

Other microfossils

Microfossils other than conodonts, foraminifers and ostracodes are in the black shale samples; however, they were not identified to generic level. Furthermore, their paleoecology does not provide the crux upon which the black shale interpretations are based. These other microfossils include vertebrate teeth, fish scales, scolecodonts, holothurian sclerites, brittle star fragments and microgastropods.

The teeth and fish scales are the remains of pelagic vertebrates (Phylum Chordata) that lived above the muddy bottom. Because they are exotic to the shales, they imply very little about the paleoenvironment. Small phosphatic teeth, especially those of cartilaginous fishes (Class Chondrichthyes of Phylum Chordata) like sharks, are common in the fossil record because sharks continually lose teeth as they grow and feed on other organisms. Bony fishes (Class Osteichthyes of Phylum Chordata) also contribute teeth to the fossil record. Additionally, some bony fishes possessed scales that are preserved in the shales.

Scolecodonts are the hardened organic jaw elements of polychaete worms (Class Polychaeta of Phylum Annelida). The elements resemble conodonts to some degree but differ in chemical composition and microstructure. Scolecodonts are more abundant in shallow marine deposits.

Holothurian sclerites are the endoskeletal remains of echinoderms, such as sea cucumbers of modern seas. The sclerites are calcitic plates that have a small variety of forms ranging from round wheels to elongated hooks. Each individual holothurian (Class Holothuroidea of Phylum Echinodermata) contains ten to twenty million sclerites. Modern holothurians are benthic organisms that move slowly on the muddy bottoms of offshore environments. Sclerites are absent in nearshore deposits where sedimentation rates are higher, salinity is variable and currents are stronger.

Brittle star fragments belong to another mobile, benthic echinoderm (Class Ophiuroidea of Phylum Echinodermata). Like holothurians, brittle stars are more common in deep-water environments.

Microgastropods are the shells of certain mollusks (Class Gastropoda of Phylum Mollusca). Because gastropods live in all marine environments, they are not useful for analyzing paleoenvironments. However, most gastropods are benthic.

In summary, microfossils other than conodonts, foraminifers and ostracodes supply only general information about the black shales. The remains of benthic organisms such as holothurians, brittle stars, scolecodonts and most gastropods refutes the contention that anoxic conditions prevailed in the original environment of deposition of these black shales. Nevertheless, conditions may have been dysoxic, based on the low abundance and low diversity of microfauna in most of these shales. Vertebrate debris (teeth and fish scales) give no useful information about the black shales.

Megafossils

Although generally rare, megafossils are throughout the black shales of this study. They were noted in the 35-mesh residue after each shale sample was broken down. They support the contention that these shales contained some oxygen. Nevertheless, because this study focused on microfossils, the relatively few megafossils were not introduced into the paleoenvironmental analysis of the black shales.

Megafossils included numerous genera of brachiopods (*Crurithyris*, *Orbiculoidea*, *Wellerella*, *Chonetinella*, *Rhipidomella*, *Derbyia*, *Hustedia*, *Juresania*(?) and *Hystriculana*), echinoid spines, crinoid fragments, larger gastropods, larger fusulinids, bryozoans, a rugose coral and a bivalve.

Phosphate

The association of phosphatic concretions with deep-water environments is documented in the literature regarding Pennsylvanian deposits (Schenk, 1967; Heckel, 1977; Kidder, 1985) and modern environments (Veeh et al., 1973; Manheim et al., 1975). In contrast, Bushinski (1964) contends that phosphate-rich formations are common in shallow-water deposits. Some of this phosphate is reworked material.

Kidder (1985) studied the unreworked phosphate nodules of the Pennsylvanian Midcontinent and added to Heckel's (1977) upwelling model. Additional phosphorous was released to the interstitial water by the decay of dead organisms. Nodules were cemented before compaction of the shale, based on evidence of deformation around the nodules.

Phosphate is concentrated in the deepest basinal water from decay of pelagic organisms that have settled to the bottom. As described elsewhere, westward blowing trade winds resulted in a vertical circulation pattern that brought this phosphate-rich basinal water from the deeper Anadarko Basin onto the Midcontinent during highstands of sea level. Phosphate concretions in Pennsylvanian black shales appear to indicate the influence of basinal upwelling beneath a thermocline in deep water of an epicontinental sea (Heckel, 1977). The absence of these concretions in analogous Permian shales suggests that upwelling no longer occurred during similar highstands.

VI.

DISCUSSION

Five types of black shale are identified, based upon general and relative abundance of three groups of microfossils: conodonts, foraminifers and ostracodes. Non-skeletal phosphate is also a factor to differentiate shales. These five shale types are summarized in Table 1. Stratigraphic evidence supports the interpretations of relative depths, as discussed in Chapter IV (Stratigraphy).

Two types of shale are shallow-water varieties and three are deep-water varieties. Black shales from intermediate depth are not represented by any shale in this study. Shales of intermediate depth represent well-oxygenated conditions (i.e. light in color) and contain abundant macrofauna. Black shales, as indicated by their sparse macrofauna, formed in stressed environments, which include deep offshore marine areas of low oxygen and marginal marine areas influenced by extreme salinity and low oxygen.

In general, this study indicates that where conodonts and foraminifers are absent or extremely rare, a low diversity of ostracodes is either in small amounts or in great numbers. These shales are the shallow-water types.

Likewise, where conodonts (and foraminifers, except in one type of shale identified) are numerous, ostracodes are typically less abundant. The conodont and foraminiferan genera that occur typically represent genera associated with deep-water assemblages. These shales, therefore, are the deep-water types.

	Type One	Type Two	Type Three	Type Four	Type Five
Phosphate nodules	Absent	Absent	Present	Absent	Absent
Conodonts	Absent	Rare	Abundant, moderately high diversity, typically Streptognathodus, *Idiognathodus and Idioprioniodus*	Abundant, low diversity, mostly Streptognathodus	Abundant, low diversity, mostly Streptognathodus
Foraminifers	Absent	Rare	Abundant, typically Ammodiscus and Endothyranella	Abundant, typically Ammodiscus and/or Endothyranella	Rare typically Ammodiscus
Ostracodes	Rare, low diversity, typically Geisina	Very abundant, low diversity, typically Geisina and/or Hollinella	Present, including Bairdia and Healdia	Present, typically Amphissites and/or Bairdia	Absent
Interpretation	Shallow-water lagoon, possibly hypersaline	Shallow-water lagoon, possibly brackish	Deep-water, beneath a thermocline, affected by upwelling of cold, phosphate-rich basinal water	Deep-water, beneath a thermocline, unaffected by upwelling conditions	Deep-water, beneath a thermocline, unaffected by upwelling conditions, greater environmental stress due to greater depth and/or less oxygen
Examples	Black shale of Burr Limestone Member	Black shales of Legion Shale and Salem Point Shale Members	Heebner Shale Member	Black shales of Americus Limestone, Hughes Creek Shale (2), and Neva Limestone Members	Bennett Shale Member

Table 1. Summary of types of black shale identified in this study.

Tables 2 and 3 list the counts of all microfossils picked from each interval of the nine shales of this study. Tables 4 through 12 in Appendix B summarize the same data on a shale-by-shale basis. A more detailed description of each shale is in Appendix A.

Raw data are in Table 2 and adjusted data are in Table 3. Although 1000 grams of each shale interval were originally broken down in the lab, not all of the residue was picked. This was due either to incomplete disaggregation (as with the Bennett) or to an excessive amount of residue. The amount of residue picked for microfossils represents either half of the original amount (i.e. equaling residue from 500 grams of a shale interval) or more. Many counts were adjusted downward for Table 3 so that each interval of shale represents microfossil counts equivalent to 500 grams of shale. Interpretations made in this study remain valid whether raw data or adjusted data are used.

With exception of conodonts, counts of each microfossil category that equal or exceed 300 implied that this microfossil was abundant in the shale and therefore it was no longer picked from the residue. Several thousand microfossils of one category were estimated to be in some samples, but only around 300 of that category were picked.

Types of shallow-water black shales

Three of the shales studied are of shallow-water origin. The major basis for this assessment is the absence or rarity of conodonts and foraminifers in these shales. Their localized stratigraphic extent or gradation to a non-marine deposit also supports this shallow-water interpretation, as discussed in Chapter IV (Stratigraphy). Another characteristic of these shales is their lack of non-skeletal phosphate. These shales are divided into two types, based on the abundance of low-diversity ostracodes.

Type One black shales contain no conodonts and no foraminifers. Ostracodes of low diversity are few. Type One shales include the black shale of the Burr Limestone Member.

Black shale of... (followed by type)	Sample number	Field code	Conodonts								Foraminifers								Ostracodes									Other Microfossils					
			Total conodonts	*Streptognathodus*	*Idiognathodus*	*Idioprioniodus*	*Adetognathus*	*Hindeodus*	*Ellisonia*	indeterminate	**Total foraminifers**	*Ammodiscus*	*Endothyranella*	*Globivalvulina*	*Tetrataxis*	*Triticites*	*Climacammina*	indeterminate	**Total ostracodes**	*Geisina*	*Bairdia*	*Healdia*	*Cavellina*	*Amphissites*	*Hollinella*	*Kegelites*	indeterminate	holothurian sclerites	brittle star fragments	scolecodonts	microgastropods	vertebrate teeth	fish scales
Neva Type IV	5	B35	68	66				2			1	1							2					2				1				37	
	4	B34	5	5							8	8							0												4		
	3	B33	90	90							16	13		3					0													47	
	2	B32	8	8							0								0													14	
	1	B31	180	179					1		345	44			2	299			146					131			15				63	197	
Salem Point Type II	2	B22	0								0								300	300												4	11
	1	B21	0								0								300								300					7	8
Burr Type I	2	A52	0								0								9	9										1	1	6	
	1	A51	0								0								15	15											118	23	
Legion Type II	2	B3	0								1							1	350	30					320						2	6	
	1	B2	1							1	0								8	4			4						5		2	1	
Bennett Type V	6	A36	58	58							0								0													32	
	5	A35	131	131							0								0													40	
	4	A34	62	62							0								0													29	
	3	A33	50	50							4			3				1	0													19	
	2	A32	26	26							20	14		6					0													7	
	1	A31	85	85							4	4							0													4	
Hughes Creek (upper) Type IV	3	A13	145	145							33		33						7		7											18	
	2	A12	288	288							180	179	1						1		1											16	
	1	A11	583	583							179	130	45		4				32		16			16				19			45	60	
Hughes Creek (lower) Type IV	2	A4	115	110				4	1		276		211	12	53				339		330			9				302		1	1	25	
	1	A2	307	307							325		320		5				23		23							71			12	103	
Americus Type IV	3	N8	167	167							295		283	11			1		41		18	2		3	18			74			21		
	2	N7	206	206							210		210						4				2	2				7			6	41	
	1	N6	564	559			5				0								15		3		3	3	3	3		1			41	80	
Heebner Type III	4	R5	25	9	16						182	56	126						41			41						13			55		
	3	R4	17	8	7	2					147	112		35					0														
	2	R3	71	36	32	3					31	31							0														
	1	R2	48	35	11	2					40	40							11		8						3				7		

Table 2. Raw microfaunal data for all samples of shale. Sample size ranges from 500 to 1000 grams of shale.

Black shale of... (followed by type)	Sample number	Field code	Conodonts									Foraminifers									Ostracodes										Other Microfossils					
			Total conodonts	*Streptognathodus*	*Idiognathodus*	*Idioprioniodus*	*Adetognathus*	*Hindeodus*	*Ellisonia*	indeterminate		Total foraminifers	*Ammodiscus*	*Endothyranella*	*Globivalvulina*	*Tetrataxis*	*Triticites*	*Climacammina*	indeterminate		Total ostracodes	*Geisina*	*Bairdia*	*Healdia*	*Cavellina*	*Amphissites*	*Hollinella*	*Kegelites*	indeterminate		holothurian sclerites	brittle star fragments	scolecodonts	microgastropods	vertebrate teeth	fish scales
Neva Type IV	5	B35	68	66				2			1	1								2					2					1				37	
	4	B34	3	3							4	4							0												2		
	3	B33	45	45							9	7		2						0														24	
	2	B32	4	4							0									0														7	
	1	B31	180	179					1			345	44			2	299				146					131			15				63	197	
Salem Point Type II	2	B22	0									0									300	300													4	11
	1	B21	0									0									300								300						7	8
Burr Type I	2	A52	0									0									5	5											1	1	3	
	1	A51	0									0									15	15												118	23	
Legion Type II	2	B3	0									1							1		300	26					274							1	3	
	1	B2	1							1		0									4	2			2								3		1	1	
Bennett Type V	6	A36	30	30							0									0														17	
	5	A35	68	68							0									0														21	
	4	A34	33	33							0									0														16	
	3	A33	28	28							3			2				1		0														10	
	2	A32	13	13							10	7		3						0														4	
	1	A31	43	43							2	2							0														2	
Hughes Creek (upper) Type IV	3	A13	145	145							33		33						7		7												18	
	2	A12	288	288							180	179	1						1		1												16	
	1	A11	583	583							179	130	45		4				32		16			16					19			45	60	
Hughes Creek (lower) Type IV	2	A4	115	110				4	1			276		211	12	53				339		330			9					302		1	1	25	
	1	A2	154	154							163		160		3				12		12									36			6	52	
Americus Type IV	3	N8	167	167							295		283	11			1			41		18	2		3	18				74			21		
	2	N7	206	206							210		210							4				2	2					7			6	41	
	1	N6	564	559			5					0									15		3		3	3	3	3			1			41	80	
Heebner Type III	4	R5	25	9	16							182	56	126							41			41							13			55		
	3	R4	17	8	7	2						147	112		35						0																
	2	R3	71	36	32	3						31	31							0																
	1	R2	36	26	8	2						30	30							8		6						2						5		

Table 3. Adjusted microfaunal data. Raw data have been adjusted downward to represent data from 500 grams of shale.

Type Two black shales contain extremely rare quantities of conodonts and foraminifers and a large quantity of ostracodes representing very few genera. Type Two shales include the black shale of the Legion Shale Member and the black shale of the Salem Point Shale Member.

Geisina, a shallow-water ostracode genus, is in all three shales. It is, in fact, the only ostracode genus in black shale of the Burr and the upper half of the black shale of the Salem Point. It occurs, but not dominantly, in black shale of the Legion where another ostracode genus, *Hollinella*, dominates the assemblage. Unidentified ostracodes in the lower half of black shale of the Salem Point may have been affected by diagenetic processes that stripped their outer surface of detail. Although these unidentified ostracodes may belong to the *Geisina* genus, which is found above it in the same shale, their general shapes suggest that they belong to only one or two genera and represent a low-diversity assemblage.

Absence of deep-water microfaunas, presence of a shallow-water ostracode genus and narrow lateral extent of these three black shales point to a marginal marine environment of quiet deposition, such as an expansive lagoon. The faunal assemblage in these shales was influenced by shallow depth, low oxygen, variable salinity and, to a lesser degree, nutrient availability and sedimentation rate.

An initial interpretation suggests that Type One black shales formed in a hypersaline lagoon where evaporation was greater than freshwater runoff, and that Type Two black shales formed in a brackish-water lagoon where freshwater runoff mixed with marine water in a shallow bay.

Rare gypsum crystals in a sample of black shale of the Burr from a nearby section not used in this study (Highway 18 of Chapter IV, Stratigraphy) suggests that Type One black shales formed in a hypersaline environment. Although gypsum was not seen in this shale where it was sampled for this study, Boardman (personal communication) has noted gypsum crystals at other localities of this dark shale. Rare sand grains in the residue of this shale indicate that the shoreline was nearby and that the rate of sedimentation might have been greater than that of other black shales studied. An increased rate of sedimentation might lower the apparent concentration of microfossils. Microgastropods (*Donaldina*) are abundant in the lower half of this shale where it was sampled but not in the nearby section of Burr mentioned above.

Abundant plant debris in black shale of the Salem Point indicates a nearshore environment influenced by freshwater runoff from nearby terrestrial sources. Brackish conditions are more likely to have existed in the environment of this Type Two black shale than hypersaline conditions, based upon this evidence. Evidence of nearshore conditions is further supported by a paleosol immediately above the dark shale interval of the Salem Point. Carbon residue and some rare pyrite in the Salem Point samples are evidence of reducing conditions. Abundant ostracodes in this shale and in black shale of the Legion indicate optimal conditions for them. It is more likely that certain organisms would thrive, at least from time to time, in the less hostile environment of brackish conditions than those of hypersaline conditions. Rare sand grains in the Legion sample support a nearshore interpretation for this shale. Stratigraphically, the Legion Shale contains very light-colored shale zones. This observation is compatible with an interpretation of brackish-water conditions, where a shifting delta might have occasionally changed salinity conditions.

An alternative interpretation suggests that these two shales formed in the same harsh environment and that the difference between them simply is due to episodes that favored temporary, exponential growths in ostracode populations. The suggestiion for this interpretation is the manner in which ostracodes appear to be found in some field samples.

Ostracode carapaces (*Geisina* where identified) litter one or more surfaces of black shale samples in the Salem Point, and *Hollinella* carapaces litter one or more surfaces of black shale samples in the Legion. The remaining surfaces in these samples are essentially barren of ostracodes. This suggests that ostracodes periodically "bloomed" in large numbers but commonly were rare. Furthermore, this interpretation implies that the three shallow-water shales of this study formed in similar environments and that only two of the shale were affected by ostracode blooms.

Assuming a large lagoonal depositional environment of unknown salinity, conditions favoring ostracode blooms were apparently caused by one or more factors. The salinity may have been "normalized" temporarily by excess runoff of freshwater into a hypersaline lagoon or by decreased freshwater runoff and/or increased evaporation in a brackish lagoon. In any event, it seems unlikely that a large lagoon could maintain an extreme salinity for a period of time equivalent to its depositional history. Perhaps an unusual increase in runoff water favorably altered the nutrient supply in the lagoon until the nutrients were consumed by an increased abundance of certain organisms. Evidence that changes in salinity or nutrient abundance or any other factor might have initiated an organic (ostracode) bloom was not detected in the shale samples of this study. In any case, these rare blooms affected only a limited biota and possibly arose in only a portion of the lagoon.

The lower half of the black shale of the Legion resembles much of the black shale of the Burr Limestone in low diversity and low abundance of ostracodes. However, the upper half of the black shale of the Legion contains an abundance of a single genus (here *Hollinella*) as in the black shale of the Salem Point (here *Geisina* where identified). Type One and Type Two traits in the Legion samples supports the episodic, and therefore unpredictable, nature of ostracode blooms in these lagoonal environments.

This same pattern of paucity and proliferation representing a similar organic bloom yet involving microgastropods is recorded in the black shale of the Burr. *Donaldina* is abundant in the lower half of this shale but practically absent in the upper half. Littering of microgastropods on the field samples was not observed; however, the texture of the sample was highly crumbly, making an examination for such an occurrence difficult. Furthermore, *Donaldina* may be localized because the nearby section of the Burr shale unit (mentioned previously) does not contain an extraordinary abundance of *Donaldina*.

If this alternative interpretation of periodic ostracode blooms is correct, then the more barren Type One shale is representative of conditions that prevailed in the lagoon during the shale's depositional period. Type Two shales then represent a combination of Type One conditions and rare ostracode-favorable conditions. Rarity of these conditions suggests that ostracode abundance in Type Two shales does not represent the normal environment of deposition, and their abundance in the shale residue only distorts the interpretation by making one type of shale appear as two. Nevertheless, the fact remains that two shallow-water shale types are identified; one contains rare ostracodes and the other contains a plethora of ostracodes.

Caution is advised when interpreting shallow-water black shale types based on a variable (such as relative ostracode abundance) that may not be the product of the normal depositional environment of the shale. Furthermore, this variable may change locally over short distances, and the two shale types may grade into each other. Other localities of these same shale units should be examined to determine whether ostracode abundance is localized or widespread across the shale's range of deposition. Further evidence will refine or broaden the above interpretation of shallow-water black shales.

Types of deep-water black shales

The remaining six shales studied are deep-water types. The abundance of deep-water conodonts is the major basis for this assessment. Other fossil and stratigraphic data support this contention. These deep-water shales are divided into three types, based on the presence or absence of non-skeletal phosphate and the presence or near-absence of foraminifers and other benthic microfossils.

Type Three black shales contain abundant conodonts of moderately high diversity, abundant foraminifers of moderately high diversity and nodules of non-skeletal phosphate. Type Three shales include the black Heebner Shale.

Type Four black shales contain abundant conodonts of low diversity (mostly *Streptognathodus*) and abundant foraminifers of moderately high diversity. Non-skeletal phosphate nodules are absent from these shales. Type Four shales include the black shale of the Americus Limestone, the lower and upper black shales of the Hughes Creek Shale and the black shale of the Neva Limestone.

Type Five black shales contain abundant conodonts of low diversity (*Streptognathodus*) and little else. Other benthic microfossils are rare to absent, and non-skeletal phosphate nodules are absent. Type Five black shales include the black Bennett Shale.

None of these deep-water shales contains the shallow-water ostracode *Geisina*. Although this is negative evidence (i.e. the absence of an indicator genus does not necessarily suggest an absence of the condition of which it is indicative) its absence does suggest that different factors were involved in the formation of these shales. Likewise, *Streptognathodus* conodonts in all of the deep-water shales and its absence from all of the shallow-water shales is reciprocal evidence of similar factors having influenced the paleoenvironment of different black shales.

It is no surprise that the one Pennsylvanian shale of this study is in a class by itself. Indeed, the Heebner Shale was selected to represent a typical, well-studied example of a Pennsylvanian black shale, for comparison with Lower Permian black shales from the same region. A similar microfaunal analysis of other Pennsylvanian black shales might identify different types, of which the Heebner may or may not be representative. Nevertheless, the Heebner is established as a deep-water black shale affected by upwelling of cold, phosphate-rich basinal water and overall low-oxygen conditions (Heckel, 1977).

The Heebner Shale samples of this study contain more or less equal numbers of *Streptognathodus* and *Idiognathodus* conodonts and a few *Idioprioniodus* conodonts. All are genera associated with deep-water environments. *Ammodiscus* and *Endothyranella* foraminifers are abundant, and *Bairdia* and *Healdia* ostracodes and holothurian sclerites are present. These benthic organisms inhabited deep-water environments and suggest that at least low-level oxygen conditions existed there. *Idioprioniodus* and phosphate nodules indicate that cold, phosphate-rich water was in the paleoenvironment. This water upwelled onto the Midcontinent from deep basins in the west as described in Chapter III (Previous Investigations).

The Heebner Shale section's location closer to the southern paleoshoreline may indicate that water was shallower and more oxygenated there. Schram (1984) suggested a similar scenario for outcrops of the same shale believed to be located closer to the northern paleoshoreline. Malinky (1984) observed geographic changes in the fauna of the Heebner Shale; northern and southern outcrops of this shale are more fossiliferous than outcrops from the central portion. Such changes may represent different types of shale, and such differences may be applicable to Permian shale types as well.

Type Four shales are the Lower Permian equivalents of Type Three shales; however, Type Four shales differ from them mostly by the absence of phosphate nodules. The additional absence of *Idioprioniodus* suggests that the cold, phosphate-rich basinal water did not upwell on the Midcontinent in the Lower Permian as it did in the Pennsylvanian.

Another difference in Type Four shales is the absence of *Idiognathodus* conodonts in Permian black shale biofacies. The conodont fauna is dominated almost exclusively by *Streptognathodus* in Type Four shales; equal numbers of the two genera are in Type Three shales. This difference is a reflection in the age difference of the two shale types, because *Idiognathodus* became extinct prior to the end of the Pennsylvanian.

Microfossils that are present or abundant in various combinations within these Type Four shales include *Ammodiscus* and *Endothyranella* foraminifers, *Bairdia* and *Amphissites* ostracodes and holothurian sclerites. These deep-water benthic organisms suggest that at least low oxygen conditions prevailed in the paleoenvironment of these shales.

Type Five black shales (only the Bennett Shale of this study) differ from Type Four shales with respect to most microfossils except conodonts. *Streptognathodus* conodonts are abundant, similar to those of Type Four shales; however, ostracodes and holothurian sclerites are absent. Foraminifers are nearly absent, except for a few *Ammodiscus* and *Globivalvulina* in the lower portion of the Bennett Shale. Absence of phosphate nodules and *Idioprioniodus* conodonts suggests that upwelling did not occur.

In the absence of other studies, the reason for greater stress in the paleoenvironment of Type Five shales can only be surmised. The water may have been deeper than that of Type Three and Type Four black shales. Greater depth is typically associated with colder temperatures and lower oxygen conditions. This explanation might account for the near-absence of known benthic organisms; however, it fails to explain why *Streptognathodus* abundance was unaffected by these different paleoenvironmental factors.

Once more, the conodont mode of life comes into question. If conodonts were pelagic, like the phosphatic fish remains in the same shale, then their presence in the near-absence of benthic microfauna is plausible. Yet, as discussed in Chapter V (Paleoecologic Interpretations), pelagic lifestyle could have resulted in a high diversity of conodonts, and this is not the case. The nektobenthic mode of life of conodonts is still supported here, although the reason for their continued remains unclear.

One point to consider regarding Type Five shales is calcite dissolution. Low pH conditions may have inhibited the growth of calcitic organisms and at the same time allowed organisms with phosphatic hard parts, such as conodonts, to tolerate the stressed environment. If this was the case, however, it was not completely effective as the few foraminifers indicate.

Black shale of the Neva Limestone has characteristics transitional between shale Types Four and Five. With exception of fossiliferous lag deposit at the base, most intervals of this shale are like the Type Five Bennett Shale. However, instead of absence of holothurian sclerites and ostracodes, there are a couple of specimens of each present. Nevertheless, the Neva black shale is characterized as a Type Four shale based on total abundance of foraminifers and ostracodes. The possibility of transitional conditions of stress during the shale's deposition, however, is compatible with the transitional nature of the abundances of microfauna in the Neva black shale.

Similar microfaunal studies of Pennsylvanian black shales are deficient. Surely, the greater stress conditions which differentiate the Permian Type Five shales from the Permian Type Four shales affected Pennsylvanian black shales as well. Such studies might lead to the discovery of Pennsylvanian black shales that have equivalent microfaunal characteristics as Type Five shales, yet contain phosphate nodules.

On the other hand, most of the Pennsylvanian black shales may be like the Heebner Shale (Type Three). Previous studies of these shales centered upon conodonts and mostly ignored known benthic microfauna, either because it was not present or because it was destroyed in the process of disaggregating the shales. Paleoenvironmental interpretations thus assumed that anoxic conditions existed in the shales. This interpretation was supported by dark color and fissility of these shales. However, Maples (1986) showed that in at least one Indiana black shale, horizons of bioturbation are preserved in calcareous concretions and are absent in the surrounding shale. This suggests that fissility does not necessarily prove that bioturbation was absent. The diversity of benthic microfossils seen in the current study overturns the baseline anoxic assumption for a large number of black shales. Future inquiries in black shale paleoecological studies should account for at least minimal levels of oxygen in the paleoenvironment.

Earlier, the idea of geographical change in fauna was introduced regarding the Heebner Shale. Additional work at the level of microfossils in the Permian shales may identify whether shale Types Four and Five grade into each other. If so, gradations may occur relative to paleodepth, due to distance from the paleoshoreline or to location over structurally positive areas. In this scenario, Type Five shales would represent deeper environments than Type Four shales, and Type Four shales might grade into Type Five shales in subsurface units to the west and south where paleodepth was greater.

Phosphate concretions in Pennsylvanian black shales suggest that upwelling occurred beneath a thermocline in the deep water of an epicontinental sea, according to Heckel (1977). The absence of these concretions in analogous Permian shales suggests that upwelling no longer occurred during similar highstands. The Anadarko Basin, from where the basinal water upwelled onto the Midcontinent in the Pennsylvanian, was nearly filled with sediment by the Lower Permian. Deep phosphate-rich water from the open oceans no longer flowed from the west into the now shallow Anadarko Basin in the Lower Permian. Although vertical circulation as proposed for the Pennsylvanian epicontinental seas may have also occurred in the Permian, there was no phosphate-rich water to upwell onto the Midcontinent region during similar highstands.

Overall, it appears that the epicontinental seas were not as deep during Permian highstands as during Pennsylvanian highstands and, therefore, the Permian black shales should contain a richer fauna. The evidence of this study does not assuredly demonstrate that this is the case; however, only one Pennsylvanian black shale was studied. Nevertheless, similar studies that take calcareous microfossils into account should be performed on other Pennsylvanian black shales.

Finally, other studies should address problems associated with the interpretations made in this study. Geochemical studies would detect trace metals and phosphate that would yield clues to rates of sedimentation and origin of the sediments. Also, such studies might shed light on the black coloration that these shales share in common. This coloration, as pointed out in Chapter I (Introduction), could be caused by factors that indicate different conditions in the paleoenvironment. Grain-size studies may also yield valuable information about the black shales. An analysis of silt and sand abundance might determine which shale deposits were deposited near paleoshorelines and whether any relationship exists between relative water depth and grain-size distribution in these black shales.

VII.

CONCLUSIONS

- Black shales are in repetitive sequences of sedimentary rocks in the Pennsylvanian of both the Eastern Interior Basin and the Midcontinent region. Black shales are also in similar sequences in the Lower Permian Midcontinent.

- Early cyclical sedimentation studies addressed questions regarding differences between the Illinois and Kansas cyclothems and the origin of these repeating sequences.

- Pennsylvanian black shales have been regarded as both shallow-water deposits and deep-water deposits. Shallow-water interpretations of black shale origin dominated the literature throughout most of this century. Extreme sea-level fluctuations were deemed impossible by most workers. Hypotheses invoked to explain widespread, fissile, shallow-water black shales include the existence of barriers that restricted water circulation and the covering of the shallow sea surface by a vegetative flotant or algal mat.

- Deep-water interpretations of black shale origin gained support with the acceptance of the glacial-control theory. Late Paleozoic glaciation in southern polar regions of Gondwanaland caused extreme sea-level fluctuations worldwide. Deposition within the framework of these fluctuations amid a regional subsidence produced the cyclothemic sequences of mostly limestone and shale seen in Midcontinent outcrops.

- Many workers accept the interpretation that these black shales formed during high sea-level stands beneath a thermocline that restricted circulation of oxygenated surface water. Upwelling of cold, phosphate-rich water from the deeper Anadarko Basin to the west produced the phosphate nodules found *in situ* in the Pennsylvanian shales of the Midcontinent. The abundance of certain conodont genera (*Streptognathodus*, *Idiognathodus*, *Idioprioniodus* and *Gondolella*) in these shales provides paleontological evidence of the deep-water origin of these shales.

- Additional studies supporting the deep-water origin of Pennsylvanian black shales include 1.) correlation of units and cycles from the Midcontinent to both the Eastern Interior Basin and north-central Texas, 2.) lateral continuity of these shales over many hundreds of miles, 3.) assymetry of cyclothemic sequences, reflecting rapid transgression and slow regression rates as inferred from studies of Pleistocene glaciation, 4.) gradation of these black shales into fossiliferous offshore deposits in the direction of paleoshorelines, 5.) stratigraphic placement of these shales over prograded deltaic sequences in north-central Texas shelf strata, 6.) absence of the black facies of some dark shales over structurally positive features and 7.) enrichment of organic matter and certain trace elements in these shales.

- The lateral uniformity or lateral variability of many black shale units can be used to make initial depth assessments. Widespread black shales were deposited beneath an epicontinental sea during highstand and include the Heebner Shale Member, the lower and upper black shale units of the Hughes Creek Shale Member, the Bennett Shale Member and the black shale of the lower Neva Limestone Member. Dark shales that occur over a limited geographic range were deposited in nearshore environments during lowstands of sea level and include the dark shale of the Legion

Shale Member, the black shale of the Burr Limestone Member and the black shale of the Salem Point Shale Member. Lateral stratigraphic data for the black shale of the Americus Limestone Member does not give enough information to infer an initial depth assessment.

- Previous paleoecologic work with ostracodes, foraminifers and conodonts suggested that certain genera of microfossils preferred particular environmental conditions. For ostracodes, *Geisina* was a shallow-water genus, and *Bairdia* and *Healdia* (and often *Amphissites*) were deep-water genera. Foraminifers are poor indicators of paleo-depth; however, abundant *Ammodiscus* and/or *Endothyranella* strongly suggest a deep-water environment. For conodonts, abundant *Streptognathodus* and/or *Idiognathodus* suggest a deep-water environment, and the presence of *Idioprioniodus* indicates the influence of phosphate-rich water in a deep-water environment.

- Five types of black shale are identified, based upon the presence or absence of phosphate nodules and the abundance and distribution of certain microfossils. Shallow-water types and deep-water types are clearly differentiated, based on distribution of microfauna.

- Type One black shales are interpreted as shallow-water shales possibly deposited in a hypersaline lagoon. They contain no conodonts and no foraminifers. A low diversity of ostracodes (typically *Geisina*) are few. Phosphate nodules are absent. Type One shales include the black shale of the Burr Limestone Member.

- Type Two black shales are interpreted as shallow-water shales possibly deposited in a brackish lagoon. They contain few conodonts and few foraminifers. Ostracodes of low diversity (typically *Geisina* and *Hollinella*) are abundant. Phosphate nodules are absent. Type Two shales include the dark shale of the Legion Shale Member and the black shale of the Salem Point Shale Member.

- Type Three black shales are interpreted as deep-water shales affected by upwelling of colder, phosphate-rich basinal water from the west. They contain abundant conodonts (typically *Streptognathodus*, *Idiognathodus* and *Idioprioniodus*), abundant foraminifers (typically *Ammodiscus* and *Endothyranella*) and some ostracodes (*Bairdia* and *Healdia*). Phosphate nodules are present. Type Three shales include the Heebner Shale Member of the Pennsylvanian.

- Type Four black shales are interpreted as deep-water shales unaffected by upwelling conditions. They contain abundant conodonts (mostly *Streptognathodus*), abundant foraminifers (typically *Ammodiscus* and/or *Endothyranella*) and some ostracodes (typically *Amphissites* and/or *Bairdia*). Phosphate nodules are absent. Type Four shales include the black shale of the Americus Limestone Member, the lower and upper black shales of the Hughes Creek Shale Member and the black shale of the Neva Limestone Member.

- Type Five black shales are interpreted as deep-water shales unaffected by upwelling conditions, yet affected by greater environmental stress than Type Four black shales. They contain abundant conodonts (*Streptognathodus*) and little else. Foraminifers (typically *Ammodiscus*) may be few. Phosphate nodules are absent. Type Five shales include the Bennett Shale Member.

- Instead of representing two environments of deposition, shallow-water shale Types One and Two may represent the same lagoonal environment where the only difference is low-diversity ostracode lag deposits in Type Two shales. It is possible that the two shale types grade into each other within the same unit if these lag deposits represent localized phenomena.

- Type Four shales appear to be the Lower Permian equivalents of Pennsylvanian Type Three shales; however, the influence of upwelling phosphate-rich water was not in the depositional environment of the Lower Permian shales. This cessation of upwelling is the result of a decreased rate of subsidence in the Anadarko Basin. Additionally, this basin was nearly filled by the Lower Permian and therefore did not possess deep water as cold or nutrient-rich as it was in the Pennsylvanian.

- Type Five shales probably formed in an environment more stressed (perhaps less oxygenated) than those of Type Four shales. These two shale types may grade into each other within the same black shale unit.

- Geochemical studies of the shales used in this study are lacking. The detection and measurement of phosphate and trace metals would shed light on the differences between the shale types identified in this study. Similar microfaunal studies conducted laterally across several outcrops of a single black shale might reveal clues about the gradational nature of shale types or about the localization of low-diversity microorganism abundance. Finally, grain-size distribution studies would help determine which shale types were affected by greater sedimentation rates.

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APPENDIX A

Descriptions of sampled intervals

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Descriptions of sampled intervals

This appendix includes a listing of the raw data of this study. It contains data that were used and data that were not used in the text and interpretations of this report. The data are included so that readers can make their own conclusions, based on the abundance of faunas and other data.

Each shale is described beginning with the oldest (i.e. stratigraphically lowest) first. Each shale contains more than one sample interval. Its location and thickness are also noted. Data listed for each sampled interval include the field code used, the percentage of the original 1000 grams picked in the laboratory, a physical description of the sample, the quantity of each microfossil picked and an estimate of the microfossils and macrofossils not picked. "Microdata" refers to data from the residue of the 80-mesh screen, and "macrodata" refers to data from the residue of the 35-mesh screen. (See Chapter I, Introduction, for more details of the shale processing techniques.) For each shale, the oldest sampled interval is described first.

Field codes were assigned to shale samples and any limestones above, below or within sampled intervals. However, because many of the limestones were not broken down in the laboratory, and because none were used in this study, limestone data are not included.

The colors used to describe the shales are based on Munsell® color charts. Colors were described in the laboratory beside a window beneath a combination of natural sky light and artificial lighting.

Verbal estimates used here are strictly arbitrary and are based on an apparent visual abundance in the residue. The use of “rare,” “common” or “abundant” is meant to be taken more relatively than absolutely and may depend on whether there is a lot of residue or a small amount.

Orbiculoid brachiopods, when present in unprocessed shale samples, are often absent in the residue data. Apparently this brachiopod breaks up easily and contributes to the “shell debris” of the microdata and macrodata.

Heebner Shale

Kansas: SW/4, SE/4, sec.33, T33S, R11E.

Roadcut on east side of Highway 99, 0.4 miles north of Highway 166 intersection.

4 feet, 0 inches thick; black interval is lower 26 inches.

1.) Field code **R2**; 67 percent picked.

Grayish black (moist), clayey, massive with relict bedding, calcareous, some iron oxide staining, no easily apparent fossils.

Microdata:

Conodonts:

Streptognathodus	35
Idiognathodus	11
Idioprioniodus	2
ramiform elements	8

Foraminifers:

Ammodiscus	40

Ostracodes:

Bairdia	8

indeterminate forms	3

other microdata:

microgastropods	7
productid spines	abundant
shell debris	rare

Macrodata:

brachiopods:

Rhipidomella	abundant
Derbyia	rare
Crurithyris	rare
Hustedia	rare
productid spines	rare
Chonetinella	very rare

2.) Field code **R3**; 50 percent picked.

Grayish black, clayey, fissile, non-calcareous, iron oxide staining on many bedding surfaces, no easily apparent fossils.

Microdata:

Conodonts:

Streptognathodus	36
Idiognathodus	32
Idioprioniodus	3
ramiform elements	17

Foraminifers:

Ammodiscus	31
Ostracodes:	none

other microdata:

shell debris	very rare
quartz grains	very rare

Macrodata:

larger quartz grains	common
productid spines	very rare
large *Streptognathodus*	very rare

3.) Field code **R4**; 50 percent picked.

Grayish black, clayey, thin-bedded but not sheety, non-calcareous, some iron oxide staining, no easily apparent fossils.

Microdata:

Conodonts:

Streptognathodus	8
Idiognathodus	7
Idioprioniodus	2
ramiform elements	8

Foraminifers:

Ammodiscus	112
Globivalvulina	35

Ostracodes:	none

other microdata:

quartz grains	very rare

Macrodata:

hematite(?)	present
larger quartz grains	very rare

4.) Field code **R5**; 50 percent picked.

Brownish black to olive black, clayey, massive with relict bedding, slightly calcareous, some iron oxide staining, no easily apparent fossils.

Microdata:

Conodonts:		
	Streptognathodus	9
	Idiognathodus	16
	ramiform elements	6
Foraminifers:		
	Ammodiscus	56
	Endothyranella	126
Ostracodes:		
	Healdia	41
other microdata:		
	holothurian sclerites	13
	microgastropods	55
	productid spines	abundant
	crinoid debris	rare
	quartz grains	rare

Macrodata:

hematite(?)		present
larger quartz grains		rare
shell debris		rare
crinoid debris		rare
gastropods		rare
brachiopods:		
	Wellerella	rare

Chonetinella	rare
Crurithyris	rare
productid spines	rare
Juresania(?)	very rare

Black shale of Americus Limestone

Nebraska: NW/4, NW/4, sec.15, T1N, R13E.

Roadcut on east side of Highway 105, 0.2 miles south of Highway 8 intersection.

1 foot, 0 inches thick.

1.) Field code **N6**; 50 percent picked.

Mottled brownish black to olive black *and* brownish gray to olive gray, clayey, fissile, lightly calcareous, lag deposits.

Microdata:

Conodonts:	
Streptognathodus	559
Adetognathus	5
ramiform elements	31
Foraminifers:	none
Ostracodes:	
Bairdia	3
Cavellina	3
Amphissites	3
Hollinella	3
Kegelites	3

other microdata:

holothurian sclerites	1
microgastropods	41
vertebrate teeth	80
productid spines	abundant
shell debris	abundant

Macrodata:

brachiopods:

Crurithyris	common
productid spines	common
Orbiculoidea	rare
crinoid debris	rare
vertebrate teeth	rare
gastropods	very rare

2.) Field code **N7**; 50 percent picked.

Moderate yellowish brown with dark gray lenses, clayey, massive but highly broken, calcareous, brachiopods.

Microdata:

Conodonts:

Streptognathodus	206
ramiform elements	8

Foraminifers:

Endothyranella	210

Ostracodes:

Cavellina	2
Amphissites	2

other microdata:

holothurian sclerites	7
microgastropods	6
vertebrate teeth	41
productid spines	common
shell debris	common
crinoid debris	rare

Macrodata:

shell debris	common
crinoid debris	common
brachiopods:	
Wellerella	common
Crurithyris	rare
productid spines	rare
Hustedia	very rare
productid fragments	very rare
turbiniform gastropods	rare

3.) Field code **N8**; 50 percent picked.

Medium dark gray but weathers yellowish brown, clayey, massive but highly broken, calcareous, brachiopods (including productids) and other fossils.

Microdata:

Conodonts:	
Streptognathodus	167
ramiform elements	4
Foraminifers:	
Endothyranella	283
Globivalvulina	11

Climacammina	1
Ostracodes:	
Bairdia	18
Healdia	2
Amphissites	3
Hollinella	18
other microdata:	
holothurian sclerites	74
microgastropods	21
productid spines	abundant
shell debris	common
crinoid debris	common
Macrodata:	
shell debris	common
crinoid debris	common
brachiopods:	
productid spines	common
Chonetinella	rare
Wellerella	rare
Crurithyris	rare
productid fragments	rare
Hustedia	very rare
Derbyia	very rare
turbiniform gastropods	rare
ramiform bryozoans	rare

Lower black shale of the Hughes Creek Shale

Kansas: SE/4, SW/4, sec. 18 and NE/4, NW/4, sec. 19, T9S, R8E.

Tuttle Creek spillway, north of Manhattan.

0 foot, 7 inches thick, lower 2 inches is black interval, 3.5 inches limestone interval in the center.

1.) Field code **A2**; 100 percent picked.

Dark gray, clayey, somewhat fissile, calcareous, *Orbiculoidea* and *Crurithyris* brachiopods

Microdata:

Conodonts:

Streptognathodus	307
ramiform elements	23

Foraminifers:

Endothyranella	320+
Tetrataxis	5

Ostracodes:

Bairdia	23

other microdata:

holothurian sclerites	71
microgastropods	12
vertebrate teeth	103
productid spines	common
shell debris	common
pyrite	rare

Macrodata:

crinoid debris	abundant

brachiopods:

Crurithyris	abundant
Chonetinella	rare
Wellerella	rare
Rhipidomella	rare
Derbyia	rare

2.) Field code **A4**; 50 percent picked.

Medium gray, clayey, massive and crumbly, calcareous, brachiopods including productids.

Microdata:

Conodonts:

Streptognathodus	110
Hindeodus	4
Ellisonia	1
ramiform elements	none

Foraminifers:

Endothyranella	211
Globivalvulina	12
Tetrataxis	53

Ostracodes:

Bairdia	330+
Amphissites	9+

other microdata:

holothurian sclerites	302
scolecodont	1
Donaldina gastropod	1

vertebrate teeth	25
productid spines	abundant
shell debris	common
pyrite	common

Macrodata:

brachiopods:	
Crurithyris	abundant
productid spines	abundant
Derbyia	rare
crinoid debris	common
fusulinids	common
echinoid spines	rare
encrusting bryozoans	rare

Upper black shale of the Hughes Creek Shale

Kansas: SE/4, SW/4, sec. 18 and NE/4, NW/4, sec. 19, T9S, R8E.

Tuttle Creek spillway, north of Manhattan.

1 foot, 11 inches thick.

1.) Field code **A11**; 50 percent picked.

Dark gray to grayish black, clayey, somewhat fissile but crumbly, calcareous, some *Orbiculoidea* and *Crurithyris* brachiopods.

Microdata:

Conodonts:

Streptognathodus	583
ramiform elements	13

Foraminifers:	
Ammodiscus	130
Endothyranella	45
Tetrataxis	4
Ostracodes:	
Bairdia	16
Amphissites	16
other microdata:	
holothurian sclerites	19
microgastropods	45
vertebrate teeth	60
productid spines	abundant
shell debris	abundant
glauconite	common
echinoid spines	rare
Macrodata:	
brachiopods:	
Crurithyris	abundant
Orbiculoidea	abundant
productid spines	abundant
productid fragments	rare
Wellerella	rare
vertebrate teeth	common
ramiform bryozoans	common
fenestrate bryozoans	rare
crinoid debris	rare
echinoid spines	rare

gastropods	very rare

2.) Field code **A12**; 50 percent picked.

Dark gray to grayish black, clayey, fissile, lightly calcareous, abundant *Orbiculoidea* and *Crurithyris* brachiopods.

Microdata:

Conodonts:	
Streptognathodus	288
ramiform elements	10
Foraminifers:	
Ammodiscus	179
Endothyranella	1
Ostracodes:	
Bairdia	1
other microdata:	
vertebrate teeth	16
productid spines	abundant
shell debris	abundant

Macrodata:

shell debris (*Orbiculoidea*?)	abundant
brachiopods:	
Crurithyris	abundant
productid spines	common
vertebrate teeth	rare
ramiform bryozoans	rare
crinoid debris	rare

3.) Field code **A13**; 50 percent picked.

Medium dark gray to dark gray, clayey, somewhat fissile, calcareous, *Orbiculoidea* brachiopods, productid spines.

Microdata:

Conodonts:

Streptognathodus	145
ramiform elements	7

Foraminifers:

Endothyranella	33

Ostracodes:

Bairdia	7

other microdata:

vertebrate teeth	18
productid spines	abundant
shell debris	common
crinoid debris	rare
echinoderm plates	rare

Macrodata:

brachiopods:

Crurithyris	abundant
Chonetinella	abundant
productid spines	common
Orbiculoidea debris	rare
Wellerella	rare
Hystriculana	very rare
Hustedia	very rare
Rhipidomella fragment	very rare

crinoid debris	common
bivalve	very rare

Bennett Shale

Kansas: SE/4, SW/4, sec. 18 and NE/4, NW/4, sec. 19, T9S, R8E.

Tuttle Creek spillway, north of Manhattan.

3 feet, 0 inches thick; sampled at 6-inch intervals.

1.) Field code **A31**; 99 percent picked.

Dark gray to grayish black, clayey, massive and dense, lightly calcareous, *Orbiculoidea* brachiopods.

Microdata:

Conodonts:	
Streptognathodus	85
ramiform elements	1
Foraminifers:	
Ammodiscus	4
Ostracodes:	none
other microdata:	
vertebrate teeth	4
shell debris	very abundant

Macrodata:

brachiopods:	
Orbiculoidea debris	abundant
vertebrate teeth	rare

2.) Field code **A32**; 99 percent picked.

Grayish black, clayey, mostly fissile, slightly calcareous, *Orbiculoidea* brachiopods.

Microdata:

Conodonts:	
Streptognathodus	26
ramiform elements	none
Foraminifers:	
Ammodiscus	14
Globivalvulina	6
Ostracodes:	none
other microdata:	
vertebrate teeth	7
shell debris	common

Macrodata:

brachiopods:	
Orbiculoidea debris	rare
vertebrate teeth	rare

3.) Field code **A33**; 91 percent picked.

Grayish black, clayey, somewhat massive with some thin bedding, lightly calcareous, *Orbiculoidea* brachiopods.

Microdata:

Conodonts:	
Streptognathodus	50
ramiform elements	3
Foraminifers:	

Globivalvulina	3
indeterminate form	1
Ostracodes:	none
other microdata:	
vertebrate teeth	19
shell debris	abundant
Macrodata:	
brachiopods:	
Orbiculoidea debris	rare

4.) Field code **A34**; 93 percent picked.

Grayish black, clayey, somewhat massive with some thin bedding, lightly calcareous, *Orbiculoidea* brachiopods.

Microdata:	
Conodonts:	
Streptognathodus	62
ramiform elements	3
Foraminifers:	none
Ostracodes:	none
other microdata:	
vertebrate teeth	29
shell debris	abundant
Macrodata:	
brachiopods:	
Orbiculoidea debris	rare

5.) Field code **A35**; 97 percent picked.

Grayish black, clayey, fissile, lightly calcareous, abundant *Orbiculoidea* brachiopods.

Microdata:

Conodonts:	
Streptognathodus	131
ramiform elements	2
Foraminifers:	none
Ostracodes:	none
other microdata:	
vertebrate teeth	40
shell debris	very abundant

Macrodata:

brachiopods:	
Orbiculoidea debris	abundant
Crurithyris	very rare

6.) Field code **A36**; 97 percent picked.

Grayish black, clayey, fissile, calcareous, common *Orbiculoidea* brachiopods.

Microdata:

Conodonts:	
Streptognathodus	58
ramiform elements	8
Foraminifers:	none
Ostracodes:	none
other microdata:	
vertebrate teeth	32

shell debris	very abundant

Macrodata:

brachiopods:

Orbiculoidea debris	abundant
Crurithyris	common
vertebrate teeth	rare

Black shale of Legion Shale

Kansas: E/2, SW/4, sec. 23, T10S, R7E.

Roadcut on north side of Highway 18, southwest of Manhattan.

4 feet, 8 inches thick; second sample is 32 inches above base of first sample.

1.) Field code **B2**; 100 percent picked.

Light olive gray, clayey, mostly fissile, calcareous, no easily apparent fossils.

Microdata:

Conodonts:	
indeterminate piece	1
Foraminifers:	none
Ostracodes:	
Geisina	4
Cavellina	4
other microdata:	
brittle star fragments	5
microgastropods	2
vertebrate teeth	1
productid spines (short)	rare

shell debris	rare
crinoid debris	rare
quartz grains	very rare
Macrodata:	none

2.) Field code **B3**; 100 percent picked.

Pale yellowish brown, clayey, fissile but crumbly, calcareous, no easily apparent fossils except ostracode lag deposits on some surfaces.

Microdata:

Conodonts:	none
Foraminifers:	
indeterminate form	1
Ostracodes:	
Geisina	30+
Hollinella	320+
other microdata:	
microgastropods	2
vertebrate teeth	6
ostracodes (still)	very abundant
productid spines	common
echinoid spines	rare
quartz grains	rare

Macrodata:

larger ostracodes	common
turbiniform gastropods (*Donaldina* ?)	rare
crinoid debris	rare
echinoid spines	very rare

Black shale of Burr Limestone

Kansas: SE/4, SW/4, sec. 18 and NE/4, NW/4, sec. 19, T9S, R8E.

Tuttle Creek spillway, north of Manhattan.

1 foot, 6 inches thick.

1.) Field code **A51**; 50 percent picked.

Dark gray to grayish black, clayey, massive but highly crumbly, non-calcareous, no easily apparent fossils.

Microdata:

Conodonts:	none
Foraminifers:	none
Ostracodes:	
Geisina	15
other microdata:	
Donaldina gastropods	118
vertebrate teeth	23
productid spines	common
shell debris	common
quartz grains	common

Macrodata:

Donaldina gastropods	abundant
other turbiniform gastropods	common
quartz grains	common
brachiopods:	
productid spines	common
Juresania(?)	very rare
larger ostracodes	rare

crinoid debris	rare
vertebrate teeth	rare
echinoid spines	very rare

2.) Field code **A52**; 100 percent picked.

Dark gray, clayey, fissile, very slightly calcareous, no easily apparent fossils.

Microdata:

Conodonts:	none
Foraminifers:	none
Ostracodes:	
Geisina	9
other microdata:	
scolecodont	1
Donaldina gastropod	1
vertebrate teeth	6

Macrodata:

shell debris	rare

Black shale of Salem Point Shale

Kansas: E/2, SW/4, sec. 23, T10S, R7E.

Roadcut on north side of Highway 18, southwest of Manhattan.

2 feet, 1 inch thick; color change 10 inches above base; capped by limey paleosol.

1.) Field code **B21**; 50 percent picked.

Mottled dark gray and moderate yellowish brown, clayey(?), fissile with thin alternations of dark and light colors, calcareous, abundant plant debris, no other easily apparent fossils.

Microdata:

Conodonts:	none
Foraminifers:	none
Ostracodes:	
indeterminate forms	300+
other microdata:	
vertebrate teeth	7
fish scales	8
carbon debris	rare
fish debris (vertebrae)	very rare

Macrodata:

larger ostracodes	abundant
shell debris	rare

2.) Field code **B22**; 50 percent picked.

Mottled light olive gray and medium dark gray, clayey(?), massive with thin alternations of two colors, calcareous, no easily apparent fossils except ostracode lag deposits on some surfaces.

Microdata:

Conodonts:	none
Foraminifers:	none
Ostracodes:	
Geisina	300+
other microdata:	

vertebrate teeth	4
fish scales	11
pyrite	rare
quartz crystals	very rare

Macrodata:

larger ostracodes	abundant
vertebrate teeth	very rare

Black shale of Neva Limestone

Kansas: E/2, SW/4, sec. 23, T10S, R7E.

Roadcut on north side of Highway 18, southwest of Manhattan.

1 foot, 8 inches thick; tan lag deposit 2 inches above base; color change 1 foot, 3 inches above base.

1.) Field code **B31**; 50 percent picked.

Pale yellowish brown with streaks of dark yellowish orange and dark gray, clayey but with coarse fossil debris, massive with some thin bedding, calcareous, phosphatic lag deposit included in sample, many brachiopods including *Orbiculoidea* and *Wellerella*, pectinid mollusks(?).

Microdata:

Conodonts:

Streptognathodus	179
Ellisonia	1
ramiform elements	none(?)

Foraminifers:

Ammodiscus	44

Tetrataxis	2
Triticites (or *Leptotriticites* ?)	299
Ostracodes:	
Amphissites	131
indeterminate forms	15
other microdata:	
microgastropods	63
vertebrate teeth	197
shell debris	abundant
productid spines	common
bryozoan debris	common
Macrodata:	
fusulinids (mostly *Triticites*)	abundant
brachiopods:	
Crurithyris	common
productid spines	common
Wellerella	rare
winged spiriferid fragment	very rare
bryozoans (all kinds)	common
shell debris	common
crinoid debris	common
crinoid calyx fragment	very rare

2.) Field code **B32**; 100 percent picked.

Dark gray to grayish black, clayey, massive with thin bedding, calcareous, *Crurithyris* and flattened *Wellerella* brachiopods.

Microdata:

Conodonts:	
Streptognathodus	8
ramiform elements	5
Foraminifers:	none
Ostracodes:	none
other microdata:	
vertebrate teeth	14
shell debris	abundant
hematite	common
gypsum crystals	common
Macrodata:	
shell debris	very abundant
brachiopods:	
Wellerella	rare

3.) Field code **B33**; 100 percent picked.

Medium dark gray to dark gray, clayey, mostly massive but somewhat fissile in parts, calcareous, no easily apparent fossils.

Microdata:

Conodonts:	
Streptognathodus	90
ramiform elements	22
Foraminifers:	
Ammodiscus	13
Globivalvulina	3
Ostracodes:	none
other microdata:	

vertebrate teeth	47
shell debris	common
Macrodata:	
brachiopods:	
Wellerella debris	rare
shell debris	rare
quartz grains	very rare

4.) Field code **B34**; 100 percent picked.

Medium dark gray to dark gray, clayey, massive, non-calcareous, some plant debris, no other easily apparent fossils.

Microdata:	
Conodonts:	
Streptognathodus	5
ramiform elements	2
Foraminifers:	
Ammodiscus	8
Ostracodes:	none
other microdata:	
microgastropods	4
Macrodata:	none

5.) Field code **B35**; 50 percent picked.

Pale yellowish brown with rare grayish orange pink and medium dark gray, clayey, massive with some traces of thin bedding, very slightly calcareous, plant debris(?), no other easily apparent fossils.

Microdata:

Conodonts:	
Streptognathodus	66
Hindeodus	2
ramiform elements	11
Foraminifers:	
Ammodiscus	1
Ostracodes:	
Amphissites	2
other microdata:	
holothurian sclerites	1
vertebrate teeth	37
shell debris	common
productid spines	common
crinoid stems	common
Macrodata:	
crinoid debris	common
shell debris	rare
brachiopods:	
Crurithyris	very rare
rugose coral	very rare

APPENDIX B

Microfaunal summaries
of each shale

APPENDIX B

Microfaunal summaries of each shale

This appendix contains the microfaunal data that is summarized in Table 2; however, the data are contained on one page for each of the nine shales of this study. The data for each shale are condensed and are easier to read than in Table 2.

Only the conodont data, foraminiferan data, ostracode data and other selected microfaunal data are included in the tables. The shale type that was identified based upon this study is also noted.

The raw data of Table 2 was used as opposed to the adjusted data of Table 3 as discussed in Chapter VI (Discussion).

Sample number	Field code	**Total conodonts**	*Streptognathodus*	*Idiognathodus*	*Idioprioniodus*		**Total foraminifers**	*Ammodiscus*	*Endothyranella*	*Globivalvulina*		**Total ostracodes**	*Bairdia*	*Healdia*	indeterminate		holothurian sclerites	microgastropods	
4	R5	**25**	9	16			**182**	56	126			**41**		41			13	55	
3	R4	**17**	8	7	2		**147**	112		35		**0**							
2	R3	**71**	36	32	3		**31**	31				**0**							
1	R2	**48**	35	11	2		**40**	40				**11**	8		3			7	

Table 4. Data: picked microfauna of the Heebner Shale (Type III).

Sample number	Field code	**Total conodonts**	*Streptognathodus*	*Adetognathus*		**Total foraminifers**	*Endothyranella*	*Globivalvulina*	*Climacammina*		**Total ostracodes**	*Bairdia*	*Healdia*	*Cavellina*	*Amphissites*	*Hollinella*	*Kegelites*		holothurian sclerites	microgastropods	vertebrate teeth	
3	N8	**167**	167			**295**	283	11	1		**41**	18	2		3	18			74	21		
2	N7	**206**	206			**210**	210				**4**			2	2				7	6	41	
1	N6	**564**	559	5		**0**					**15**	3		3	3	3	3		1	41	80	

Table 5. Data: picked microfauna of the black shale of the Americus Limestone (Type IV).

Sample number	Field code	**Total conodonts**	*Streptognathodus*	*Hindeodus*	*Ellisonia*		**Total foraminifers**	*Endothyranella*	*Globivalvulina*	*Tetrataxis*		**Total ostracodes**	*Bairdia*	*Amphissites*		holothurian sclerites	scolecodonts	microgastropods	vertebrate teeth	
2	A4	**115**	110	4	1		**276**	211	12	53		**339**	330	9		302	1	1	25	
1	A2	**307**	307				**325**	320		5		**23**	23			71		12	103	

Table 6. Data: picked microfauna of the lower black shale of the Hughes Creek Shale (Type IV).

Sample number	Field code	**Total conodonts**	*Streptognathodus*		**Total foraminifers**	*Ammodiscus*	*Endothyranella*	*Tetrataxis*		**Total ostracodes**	*Bairdia*	*Amphissites*		holothurian sclerites	microgastropods	vertebrate teeth	
3	A13	**145**	145		**33**		33			**7**	7					18	
2	A12	**288**	288		**180**	179	1			**1**	1					16	
1	A11	**583**	583		**179**	130	45	4		**32**	16	16		19	45	60	

Table 7. Data: picked microfauna of the upper black shale of the Hughes Creek Shale (Type IV).

Sample number	Field code	**Total conodonts**	*Streptognathodus*		**Total foraminifers**	*Ammodiscus*	*Globivalvulina*	indeterminate		**Total ostracodes**		vertebrate teeth	
6	A36	**58**	58		**0**					**0**		32	
5	A35	**131**	131		**0**					**0**		40	
4	A34	**62**	62		**0**					**0**		29	
3	A33	**50**	50		**4**		3	1		**0**		19	
2	A32	**26**	26		**20**	14	6			**0**		7	
1	A31	**85**	85		**4**	4				**0**		4	

Table 8. Data: picked microfauna of the Bennett Shale (Type V).

Sample number	Field code	**Total conodonts**	indeterminate		**Total foraminifers**	indeterminate		**Total ostracodes**	*Geisina*	*Cavellina*	*Hollinella*		brittle star fragments	microgastropods	vertebrate teeth	
2	B3	**0**			**1**	1		**350**	30		320			2	6	
1	B2	**1**	1		**0**			**8**	4	4			5	2	1	

Table 9. Data: picked microfauna of the black shale of the Legion Shale (Type II).

Sample number	Field code	**Total conodonts**		**Total foraminifers**		**Total ostracodes**	*Geisina*		scolecodonts	microgastropods	vertebrate teeth	
2	A52	0		0		9	9		1	1	6	
1	A51	0		0		15	15			118	23	

Table 10. Data: picked microfauna of the black shale of the Burr Limestone (Type I).

Sample number	Field code	**Total conodonts**		**Total foraminifers**		**Total ostracodes**	*Geisina*	indeterminate		vertebrate teeth	fish scales	
2	B22	0		0		300	300			4	11	
1	B21	0		0		300		300		7	8	

Table 11. Data: picked microfauna of the black shale of the Salem Point Shale (Type II).

Sample number	Field code	**Total conodonts**	*Streptognathodus*	*Hindeodus*	*Ellisonia*		**Total foraminifers**	*Ammodiscus*	*Globivalvulina*	*Tetrataxis*	*Triticites*		**Total ostracodes**	*Amphissites*	indeterminate		holothurian sclerites	microgastropods	vertebrate teeth	
5	B35	**68**	66	2			**1**	1					**2**	2			1		37	
4	B34	**5**	5				**8**	8					**0**					4		
3	B33	**90**	90				**16**	13	3				**0**						47	
2	B32	**8**	8				**0**						**0**						14	
1	B31	**180**	179		1		**345**	44		2	299		**146**	131	15			63	197	

Table 12. Data: picked microfauna of the black shale of the Neva Limestone (Type IV).

VITA

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Candidate for the Degree of

Master of Science

Thesis: A MICROFAUNAL ANALYSIS OF AN UPPER PENNSYLVANIAN DARK SHALE (HEEBNER) AND SEVERAL LOWER PERMIAN DARK SHALES (LOWER COUNCIL GROVE GROUP) FROM THE NORTHERN MIDCONTINENT, U.S.A.

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