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STRATIGRAPHIC DISTRIBUTION AND INTERPRETATION OF A PENNSYLVANIAN "TIME SLICE" (CROWEBURG COAL TO VERDIGRIS LIMESTONE)

by

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ABSTRACT

The interval studied, the Croweburg coal through the Verdigris limestone, exposed in northeastern Oklahoma, southeastern Kansas, across Missouri, and into Iowa, has been correlated within three basins across Kansas: the Cherokee, Sedgwick, and the Hugoton Embayment of the Andarko Basin. These basins are separated by the Nemaha Anticline and the Central Kansas Uplift.

Facies changes within and between basins are the result of changes in climate, eustasy, and tectonics. In the Cherokee Basin, the interval studied appears to have been strongly influenced by changes in climate and subsidence. The sequence (up to 7 m thick) consists of, in ascending order: a mudrock (a lithology interpreted here as a vertic-like paleosol), coal, a grey mudrock, a carbonaceous black shale and an argillaceous limestone. In the Sedgwick Basin, the sequence is a variegated shale, black shale, and cherty, less argillaceous limestone. There appears to have been very little tectonic activity in the Sedgwick Basin during this time, and the basin was probably similar to a carbonate platform. West of the Central Kansas Uplift, in the Hugoton Embayment, the study interval is underlain by channel deposits, probably cut by streams flowing off the Central Kansas Uplift prior to deposition of a sandstone at the base of the study interval. Detritus

eroded from the uplift also affected the lithologies in the sequence studied. Farther west, a paleosol, containing calcareous nodules is overlain by black shale, and the sequence is capped by a "clean", fossiliferous limestone.

Considering the paleolatitude of Kansas during the Late Paleozoic, it appears that climate played a major role in the facies distribution of this interval across the state. The vertical and lateral stratigraphic relationships between all of the facies in the interval suggest a possible climatic spectrum from wetter to drier, combined with eustatic changes. The Cherokee Basin was near the equatorial region with a predominantly wet environment. At slightly higher latitudes, the Sedgwick Basin and the Hugoton Embayment were subject to drier conditions.

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INTRODUCTION

GENERAL STATEMENT

Most work on the stratigraphy of Carboniferous rocks has focused on glacio-eustatic and tectonic influences as controls on deposition. Although climate often is overlooked as a possible control on sedimentation (Cecil et al., 1985), it is regarded as a factor influencing the deposition of rocks occurring in "cyclothems" (Schutter and Heckel, 1985; Roth, 1991; Archer and West, 1993).

The premise of recent climate-based studies concerns vertical changes in geochemistry and lithofacies (Donaldson et al., 1985, Cecil et al., 1985; Cecil, 1990) and the characterization of climatic changes in rock cycles (Archer and West, 1993). Such studies tend to omit the lateral component of the rock record when discussing the role of climate. The lateral distribution of the record offers a comprehensive view of the climate at a particular time, over a given area.

Examination of rocks using a lateral perspective may aid in the understanding of continental plate configurations during the early and middle Phanerozoic. Such a study requires laterally persistent rock units and accurate temporal correlations.

Wanless and Wright (1978) attempted to map and explain the lithologic distribution of Middle Pennsylvanian rock units throughout the northern midcontinent and Illinois Basin. Their work addressed factors that controlled deposition of a part of the Upper Cherokee (and other Mid-Pennsylvanian "cyclothems") and associated paleoenvironments. Their generalized paleoenvironmental maps extended from western Indiana to central Kansas.

The Upper Cherokee interval studied, in detail, by Wanless and Wright (1978) consisted of the Croweburg coal through the Verdigris limestone (Figure 1) in Kansas. This interval is correlated throughout the northern midcontinent (Howes, 1984), the Illinois and Appalachian basins (Wanless and Weller, 1932) (Figure 2), and the Pedregosa Basin in southeastern Arizona (Connolly and Stanton, 1992). The lateral persistence of this interval and its lithologic variability may provide important information about the climate of the Desmoinesian (Middle Pennsylvanian).

Cycles of alternating sandstones, limestones, and shales, and occasionally thin beds of coal, dominate the Pennsylvanian sequence in Kansas. The Croweburg coal through the Verdigris limestone is one such cycle (Figure 3). Cyclic repetition of lithologies reflects a variety of the frequent and abrupt changes of facies and depositional environments. Investigation of the Croweburg coal though Verdigris limestone (Cherokee Group) in Kansas and other regions may provide a better understanding of the stratigraphic distribution of coal.

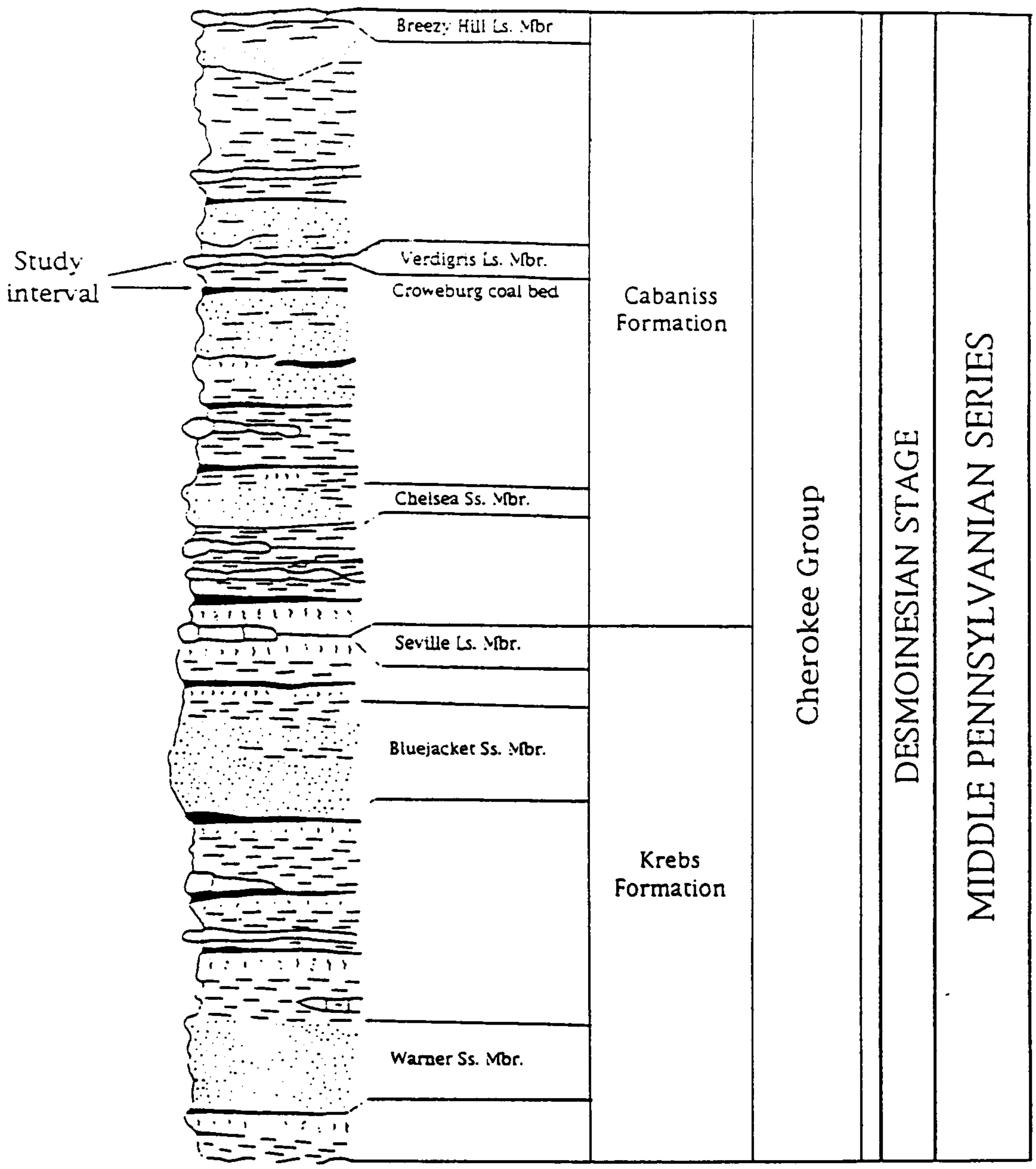


Figure 1. Stratigraphic position of Croweburg coal-Verdigris limestone. From Zeller (1968).

Figure 2. List of stratigraphically equivalent units from regional basins. From Wanless (1975).

KANSAS	OKLAHOMA	MISSOURI	IOWA	ILLINOIS	INDIANA
Verdigris limestone	Verdigris limestone	Ardmore	Ardmore	Oak Grove limestone	Oak Grove limestone
V-shale	black shale	black shale	Oakly shale	Mecca Quarry shale	Mecca Quarry shale
gray mudrock	gray shale	gray shale	Gray shale	Francis Creek shale	Francis Creek shale
Croweburg coal	Broken Arrow	Croweburg coal	Whitebreast (coal # 7)	Colchester (no. 2)	Colchester coal IIIA
underclay	underclay	underclay	underclay	underclay	underclay

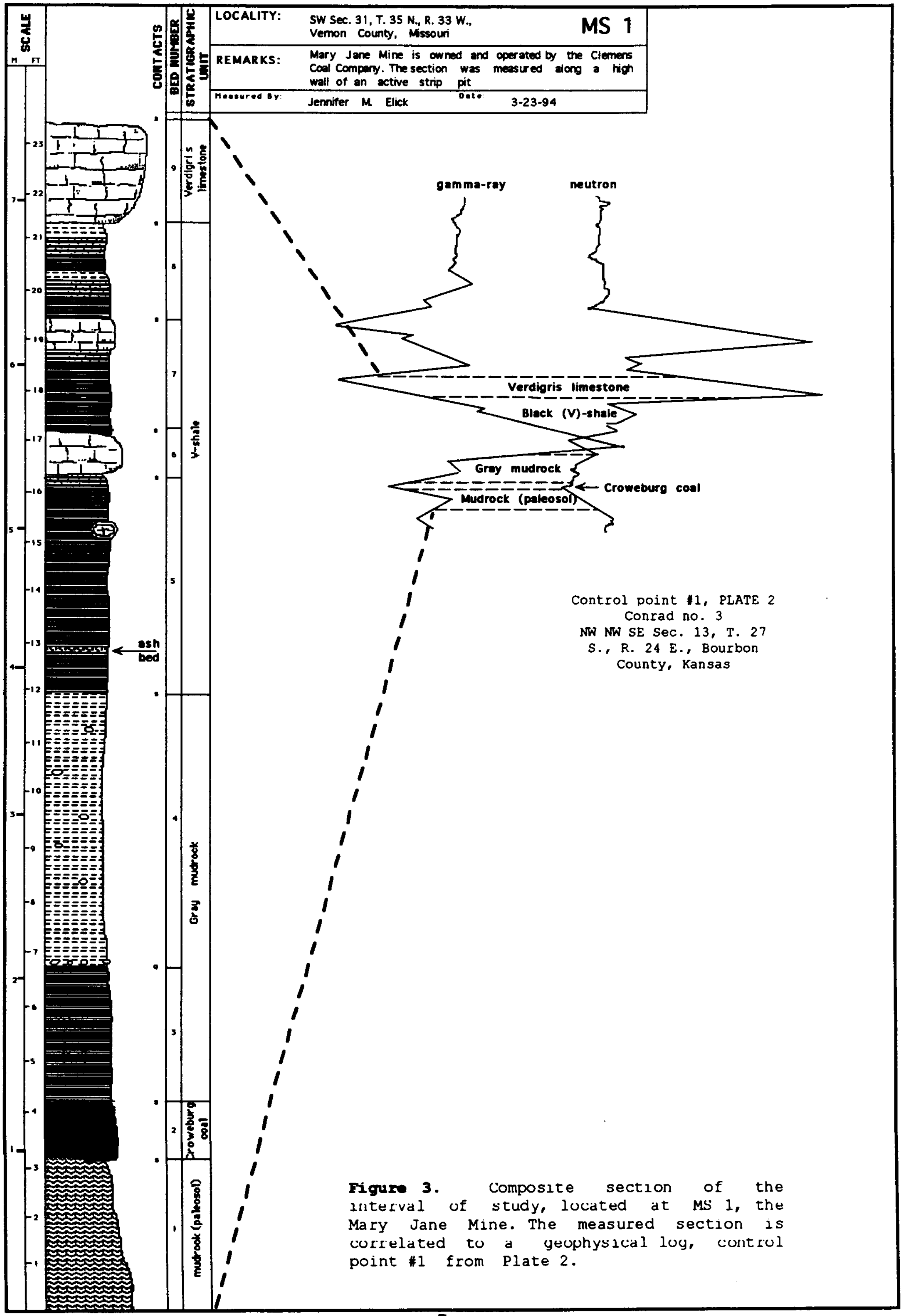


Figure 3. Composite section of the interval of study, located at MS 1, the Mary Jane Mine. The measured section is correlated to a geophysical log, control point #1 from Plate 2.

It may also enhance our understanding of the climatic factors that influenced the deposition of both persistent and nonpersistent rock units in this and other parts of the stratigraphic record.

PURPOSE OF STUDY

The purpose of this investigation is to examine a "time-slice" of the Middle Pennsylvanian across the state of Kansas, namely the Croweburg coal-Verdigris limestone interval (Figure 3). Such a study necessitates description of vertical and lateral lithologic changes within the interval, and inferences as to the depositional environments. The inferred role of climate, as reflected by the different rock units in the Croweburg-Verdigris interval also will be discussed.

In addition to reporting the lithologic changes of surface exposures, this investigation examines inferred lithologic changes in the subsurface across and among three depositional basins: the Cherokee, Sedgwick, and the Hugoton Embayment of the Anadarko Basin.

AREA AND METHODS OF STUDY

The study interval is exposed in western Missouri, southeastern Kansas, and northeastern Oklahoma (Figure 4). Fieldwork for this study was concentrated along the

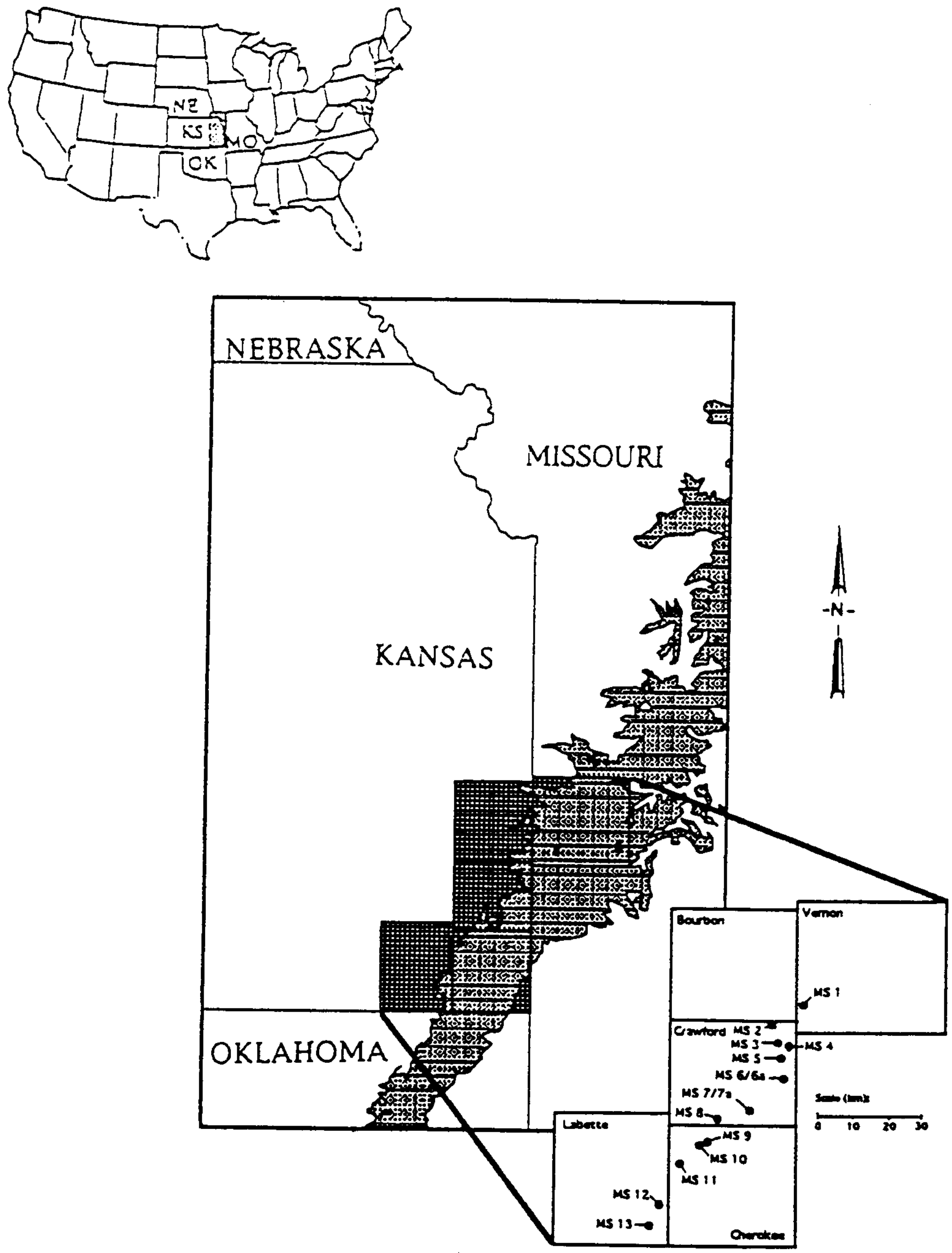


Figure 4. Map of study area and measured section (MS) localities. Modified from Moore (1949).

southwestern border of Missouri into southeastern Kansas (Figure 4); some exposures in northeastern Oklahoma also were examined. Surface data consisted of fourteen measured and described sections (Appendix 1); careful attention was paid to lithologic features, including sedimentary structures and textures; fossil diversity, density, and taphonomy, and the contacts between lithologic units.

Geophysical data, from the Oil and Gas Library at the Kansas Geological Survey, were collected to trace the Croweburg coal-Verdigris limestone interval from the outcrop area in southeastern Kansas, into the subsurface, and across the state of Kansas (Figure 5). Bore holes from which wire-line logs were available were used as control points between surface exposures and cores. These data were used to record any and all lithologic changes along this transect, and they were useful in identifying the lithologic succession and its lateral variability in the study.

Descriptions of the following units: mudrock, coal, gray mudrock, black (V)-shale, and Verdigris limestone (see Figure 3) are from six available cores (see Appendix 2). These cores were provided by the Kansas Geological Survey and the United States Geological Survey. Driller's reports from well sites also were used to provide lithologic descriptions and information not available from geophysical logs. Descriptions

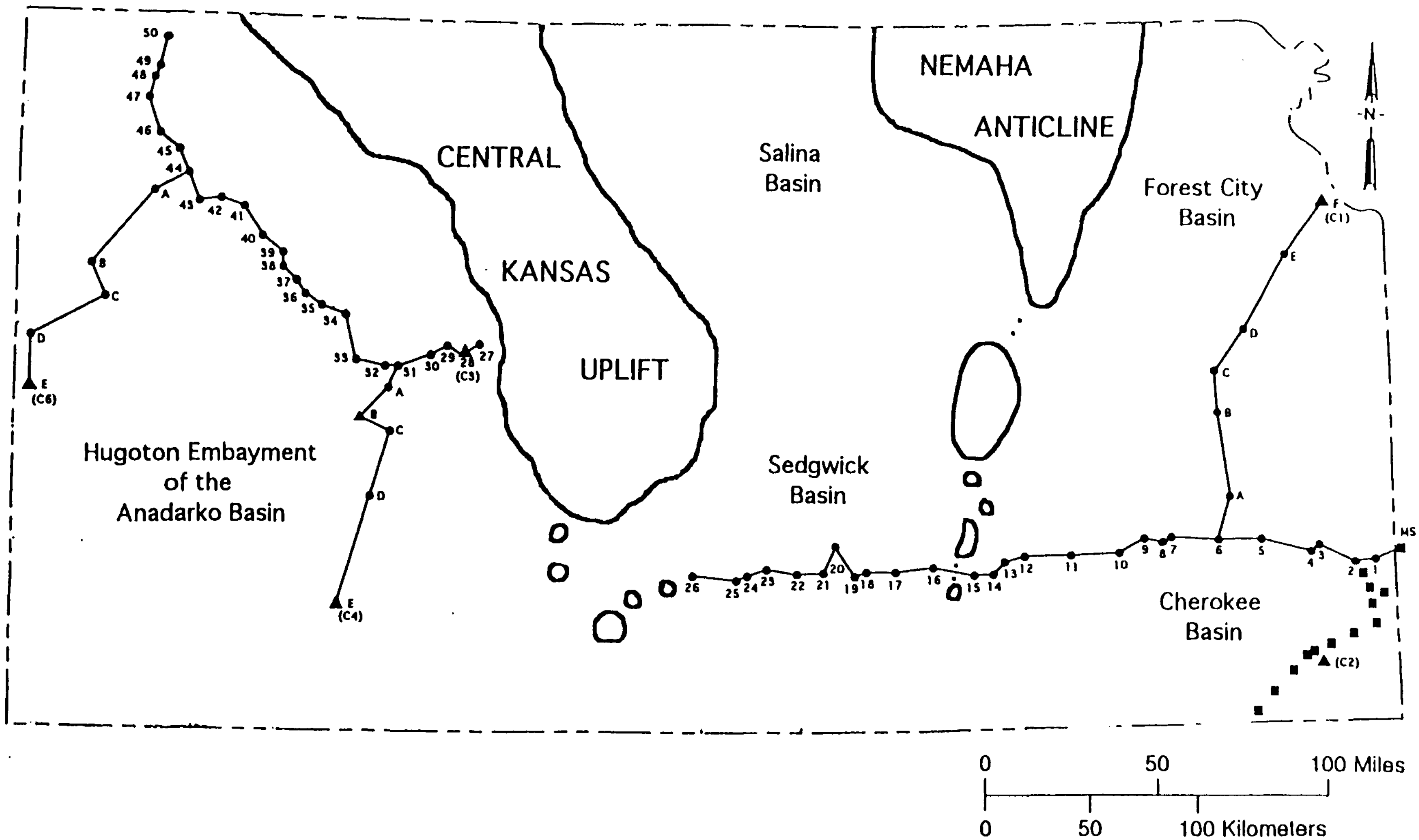


Figure 5. Distribution of subsurface control points. Dots represent geophysical well sites, triangles represent cores localities, and squares represent outcrop.

included: color, texture, type of bedding, and fossils (Appendix 2).

Gamma-ray and neutron logs were useful primarily because the black shale (V-shale of the subsurface) is highly radioactive. The logs are reliable indicators of particular lithologies and aid in the correlation of lithologies. They were useful when inferring the lithologic composition of all units in the interval, especially the limestones and paleosols. When these logs were unavailable for study, other types of logs were used, such as electric conductivity and resistivity logs. Ideally, one well log per township was used, but there were areas where this was not possible. Numerous subsurface data points were scrutinized for control of the interval within and between basins across the state of Kansas (Appendix 4).

It was possible, using geophysical logs, to identify lithologies as thick or thicker than 30.5 cm (1 foot). Units less than 30.5 cm were not considered in this study unless they were in measured sections or cores. Generally, the coal (30.5 cm thick) was the thinnest unit of the interval.

Biostratigraphic control, using conodonts, and fusulinids, from surface and subsurface samples was made available by Bruce Wardlaw (U. S. Geological Survey) and Merlynd Nestell (University of Texas, Arlington), respectively. Recognition of a thin ash bed (Triplehorn and Brady, 1991) provided stratigraphic control at two of the measured sections and in one of the cores (see Appendices 1 and 2). The biostratigraphic data, along with the ash bed, provided a useful temporal framework in the construction of a "time-slice" over the study area.

Cross sections (Plates 2-7) were made (Figure 5) using data from outcrops, geophysical logs, and core descriptions. Identification of the Excello shale, another widespread, radioactive, black shale, situated stratigraphically above the study interval, ensured correlations were consistent and at the correct cycle. The datum for the wire-line sections is the Verdigris limestone.

The sections across Kansas was chosen after it was determined that the study interval could be correlated across the Nemaha Anticline, from the Cherokee Basin into the Sedgwick Basin. The transect crossed the Sedgwick Basin toward the Central Kansas Uplift until the interval was no longer present. Because the study interval does not overstep the Central Kansas Uplift, the transect was re-established on the western limb of the structure where the study interval is once again recognized. A transect through the Hugoton Embayment, from Ness to Rawlins Counties, Kansas, was selected based on cores judged to contain the stratigraphic interval.

PREVIOUS WORK

INTRODUCTION

Research on Cherokee rocks in Kansas initially was confined to the southeastern part of the state, where the strata are exposed and contain coal beds. Initially, exploration for coal was the reason for study. Later, exploration for oil and gas in Cherokee sands inspired subsurface investigation by cores and geophysical logs. Refined subsurface lithologic correlation and improved deep coring methods allowed workers to explore for hydrocarbons farther west.

The geographical extent of the study necessitates distinction between the basins in which this interval has been encountered or studied. The following is a brief outline of the early work on the Cherokee and the recent work on the Croweburg-Verdigris interval in the three main basins: the Cherokee, Sedgwick, and Hugoton Embayment of the Anadarko.

Early Work.--Cherokee rocks in Kansas were first described along the Neosho River in Crawford County by Haworth and Kirk (1894). Cherokee strata were later described using thin beds of coal as stratigraphic markers (Haworth and Crane, 1898). Because the Cherokee was the chief coal-bearing interval of the Pennsylvanian in this area (Moore, 1936), other studies focused on its occurrence and distribution (Abernathy, 1936; Pierce and Courtier, 1937; Abernathy et. al., 1947; and Moore, 1949) for economic purposes.

Ohern (1914) was the first to correlate the Verdigris limestone in Oklahoma with its equivalent in southeastern Kansas and Missouri. In his work he described the southward thickening of this unit.

Other studies focused on the cyclicity of Cherokee strata (Weller, 1930; Moore, 1949). The Croweburg-Verdigris cycle was not highlighted in these investigations.

In 1953, a conference of geologists from Kansas, Iowa, Missouri, Nebraska, and Oklahoma met to discuss problems of interstate correlation of Pre-Marmaton (Desmoinesian) rocks. From this conference, the division, classification, and nomenclature of the Cherokee Group was established (Searight et al., 1953).

A detailed stratigraphic study of the Cherokee in southeastern Kansas by Howe (1956) addressed the repetitious nature of persistent lithologic units throughout the Cherokee. His work led to the subdivision of pre-Marmaton strata based on lithologic cycles bound by coal seams. Based on the occurrence of the Croweburg and Bevier coals, he described the Croweburg and Verdigris cycles. Howe (1956) also was responsible for dividing the Cherokee into the Cabaniss and Krebs subgroups. Much of his work was conducted in strip pits and along roadside exposures. Since the publication of his work (1956), many of these strip pits and exposures have been backfilled or overgrown.

Cherokee Basin.--*The Cherokee Basin, in southeastern Kansas and northeastern Oklahoma, is separated from the Forest City Basin in the north by the Bourbon Arch and from the Sedgwick Basin to the west, by the Nemaha Anticline. It is confined on the east by the Ozark Dome in southwestern Missouri. Part of the basin extends into southwestern Missouri* (Figure 6).

The energy crisis of the 1970s led to the exploration of heavy-oil-bearing sandstones (Ebanks, 1979; Hulse, 1979; Walton et al., 1986; and Brenner, 1989) coal-bed methane, and coal (Brady, 1988; Huffman, 1991) in Cherokee strata. Several masters theses focused on the depositional environments of the Upper Cherokee units within the Cherokee Basin (Harris, 1985; Staton, 1987) and along the Bourbon Arch (Huffman, 1991). These studies correlated the Upper Cherokee throughout southeastern Kansas. Most of this work focused on the stratigraphic distribution of the Lagonda, Burgess, and Bartlesville sandstones. Consequently, the lithologic units situated between the Cherokee sands have not been studied in detail, even though they are the most persistent in the Cherokee

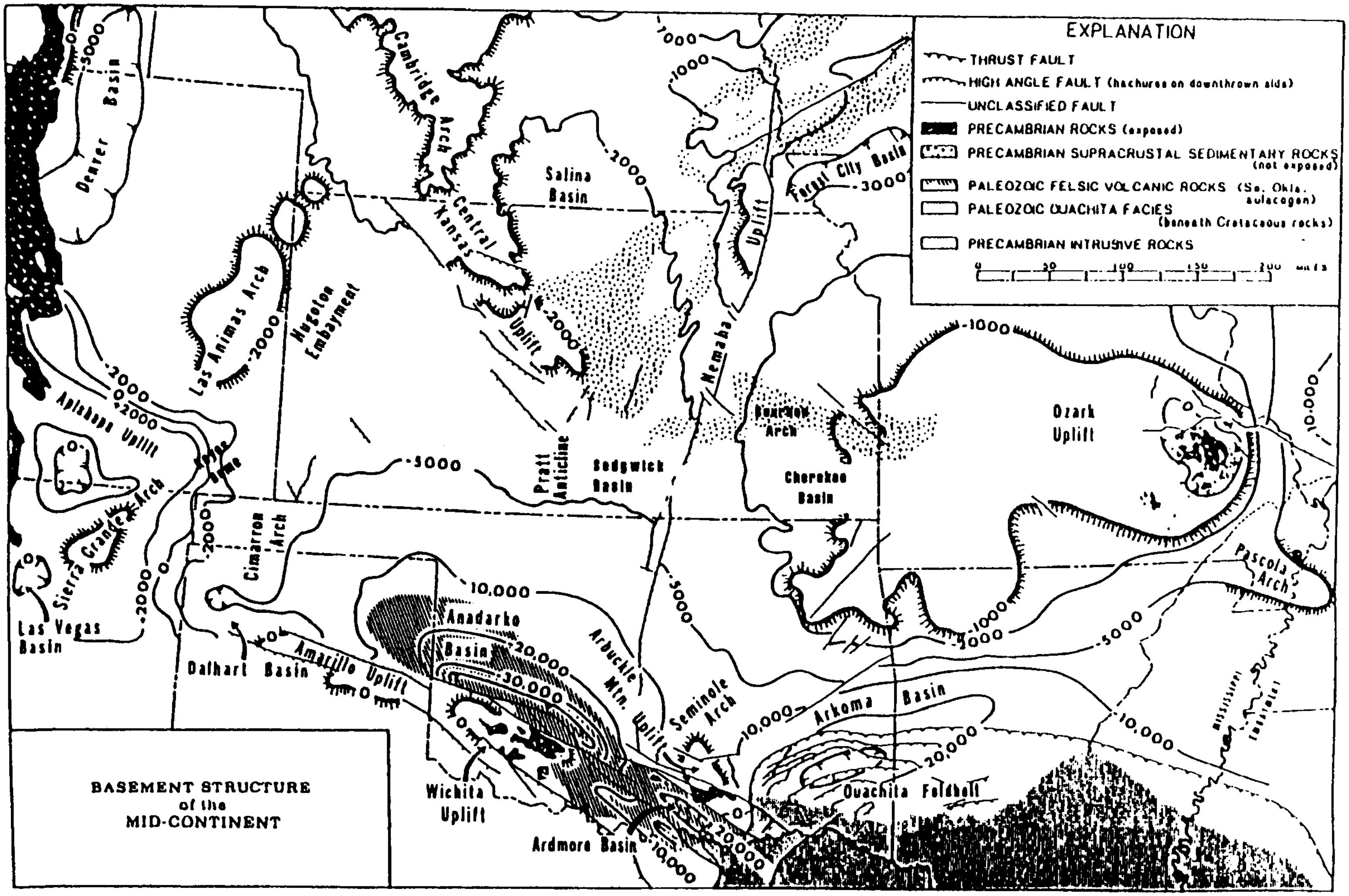


Figure 6. Generalized map of structure in Kansas. Modified from Rascoe and Adler (1983).

Basin (Howe, 1956; Harris, 1985) and can be recognized throughout most of Kansas.

A single, conspicuous layer of kaolinitic-rich volcanic ash (Brady and Triplehorn, 1991), approximately 0.5 to 1.0 cm thick, was reported in the V-shale. This ash layer occurs in cores from southwestern Iowa, Leavenworth County, Kansas, and in outcrops in Crawford County, Kansas, Vernon County, Missouri, and in northeastern Oklahoma (Triplehorn, personal communication, 1994). Because of its distribution, this may be useful in correlating the study interval between the Forest City and Cherokee basins.

Sedgwick Basin.--*The Sedgwick Basin is bounded on the east by the Nemaha Anticline and on the west by the Central Kansas Uplift and Pratt Anticline. It is separated from the Salina Basin to the north by a low, indistinct arch that extends northeast-southwest (Adkison, 1963)* (Figure 6).

Detailed work on the Cherokee Group in the Sedgwick Basin has been minimal. Early work correlated the lithologic units of the Cherokee, but did not distinguish among these units (Lukert, 1949; Goeble and Merriam, 1957; and Adkison, 1963).

Of particular interest to this study is the work of Adkison (1963), who correlated Paleozoic rocks across the northern part of the Sedgwick Basin. He described Cherokee strata from well cuttings and noted the occurrence of a trace of coal underlying a black shale. Although he did not differentiate among the members of the Cherokee, the detail of his work was useful to this study. He provided descriptions of lithologic units from the Sedgwick Basin which may be stratigraphically equivalent to units in the Cherokee Basin.

More recently, Killen (1986) subdivided the Cherokee into eight stratigraphic units on the basis of laterally widespread, radioactive black shales. The only black shale more persistent than the black (V)-shale in the Sedgwick Basin is the Excello shale (Killen, 1986). Killen recognized the black (V)-shale as a marker horizon and used it as the datum for his cross sections.

Of the three limestones recorded by geophysical logs, below the Excello shale, Killen (1986) designated the lowermost as stratigraphically equivalent to the Verdigris limestone of the Cherokee Basin. Combining the work of Killen (1986) and Huffman (1991) it is possible to correlate the Upper Cherokee from the Cherokee Basin across the Nemaha Uplift and into the Sedgwick Basin.

Hugoton Embayment of the Anadarko Basin.--*The Hugoton Embayment is an extension of the Anadarko Basin into western Kansas and eastern Colorado. It is bound on the east by the Pratt Anticline and Central Kansas Uplift and to the northeast by the Cambridge Arch. The Las Animas Arch and the Ancestral Rockies define it on the west, and the Keyes Dome on the southwest (Rascoe and Adler, 1983)* (Figure 6).

Study of Cherokee strata in the Hugoton Embayment of the Anadarko Basin has centered around exploration for oil and gas (Maher, 1947; Collins, 1947; Rascoe, 1962; Howard, 1990; Cuzella et al., 1994). Other work has focused on structures in the Hugoton Embayment (Rascoe and Adler, 1983; Youle, 1992) in search of possible hydrocarbon accumulation.

Sections across the Hugoton Embayment (Maher, 1947 and Collins, 1947) identify the Cherokee Group but do not differentiate formations or members. According to Zeller (1968), west of the Central Kansas Uplift, the Cherokee Group is not divisible into formations. It has been common practice for subsurface geologists to "lump" all Cherokee beds together (Merriam, 1963).

Later, Nodine-Zeller (1981, p. 29) said "...the deposition of the transgressive-regressive marine limestones and shales of middle to late Cherokee age, containing a fauna typical of the Verdigris Limestone..." may have occurred in the Hugoton

Embayment. The Verdigris limestone may be recognizable through biostratigraphic examination. Her study used paleontological evidence to differentiate units from the Marmaton through the Mississippian. Data from Thompson (1945) allowed her to distinguish lower Desmoinesian (Cherokee) beds from the Marmaton based on the presence of *Wedekindellina*. Several other fusulinids with ranges into the Desmoinesian were also used. Nodine-Zeller was the first to recognize the Verdigris west of the Central Kansas Uplift.

Differences in the underlying lithology has caused workers to position the Cherokee above the Atokan (McManis, 1956), Morrowan (Maher, 1947; Rascoe, 1962), and Pre-Cherokee to Arbuckle (Ordovician)(Collins, 1947) strata. Although their work dealt with different parts of the Anadarko Basin and these differences are expected, comparison of their designations for the top of the Cherokee Group also varied. This suggests that there was little control in the determination of the top of the Cherokee Group.

In Ness County the Cherokee overlies Mississippian limestone; a Pennsylvanian conglomerate is present at the base of the Cherokee (Nodine-Zeller, 1981; Howard, 1990). The Cherokee Group can be traced basin-wide using two prominent limestone markers (Howard, 1990; Cuzella et al., 1994).

Recently, Youle et al. (1994) stated that Cherokee strata were conformable to rock units of the upper Atokan in the southeastern region of the Hugoton Embayment in Kansas. The "...continuous succession of strata onlap either the Kearney Formation (Morrowan) or the pre-Pennsylvanian unconformity surface as they onlap the Central Kansas Uplift." (Youle et al., 1994, p. 268). They recognized thirteen fourth-order (0.1 to 1.0 m.y.) depositional sequences between the "V" shale and the base of the "Gray Group." The succession of units in this study would constitute one of their fourth-order sequences. Youle et al. (1994) used both the "V" and Excello shales as datums in their cross sections. Their work was based largely on wire-line log correlations and a few cores.

REGIONAL STRUCTURAL SETTING

The structural framework of the northern midcontinent, including Kansas (Figure 6), is inherited from the continental collision of the North and South American plates (McKee and Crosby, 1975). This collision resulted in the Marathon and Ouachita orogenies in Texas and Oklahoma, and the emergence of the Ancestral Rocky Mountains in Colorado (Rascoe and Adler, 1983). In Kansas the Nemaha Anticline emerged during the Wichita Orogeny (Early Pennsylvanian) as a response to the continental suture (Merriam, 1963; McKee and Crosby, 1975; Rascoe and Adler, 1983); the Central Kansas Uplift is a remnant of a pre-Morrowan epeirogeny (Rascoe and Adler, 1983). These positive features became barriers, which isolated basins throughout the state.

The Nemaha Anticline is a north-northeast to south-southwest trending feature (Jewett, 1951), plunging south-southwestward based on the dip of Mississippian rocks (Merriam, 1963). Middle Pennsylvanian strata are flat-lying and onlap Mississippian units (Merriam, 1963) along an extensive unconformable contact.

East of the Nemaha Anticline are the Forest City and Cherokee basins and to the west are the Salina and Sedgwick basins (Figure 6). The axes of the Forest City and Cherokee basins are nearly subparallel with the Nemaha, and this is where the thickest strata (Cherokee) occur (Merriam, 1963).

The Central Kansas Uplift trends north-northwest to south-southeast (Jewett, 1951) (Figure 6). In the north, the Central Kansas Uplift becomes the Cambridge Arch and in the south the Pratt Anticline. These features combine to form a segment of the Transcontinental Arch (Rascoe and Adler, 1983).

There are many minor structures along the flanks of the Nemaha Anticline and Central Kansas Uplift (Merriam, 1963); these probably affected the depositional and lithofacies patterns of Pennsylvanian units. Lee and

Merriam (1954) and Merriam (1963) provided structural cross sections of eastern Kansas which demonstrate how the Cherokee strata filled basinal areas across the irregular, pre-Pennsylvanian surface. Early Cherokee units were confined to basins, with Upper Cherokee units overstepping the higher elements of the irregular basin floor (Merriam, 1963). Depending on the relief of the underlying surface, the Cherokee Group varies in thickness from 70 to 170 m (Lee and Merriam, 1954).

Merriam (1963) also provided cross sections in the Hugoton Embayment showing the stratigraphic relationship of Cherokee rocks to older and younger strata; his sections record a variable thickness for Cherokee rocks overlying both the basal Pennsylvanian conglomerate and Morrowan rocks. Merriam's sections also show an irregular topography between Pennsylvanian and Mississippian rocks. A structure contour map of the top of the Mississippian surface, constructed by Cuzella et al. (1994, p. 31), depicts the surface as a system of "...knobs (highs) and valleys (lows)...."

The irregular topography of the Pennsylvanian surface may have affected the deposition of Upper Cherokee rocks, namely the interval of study. Lows are thought to represent the afore-mentioned basinal areas and may also have been where subsidence occurred, while highs were stable features that did not subside. Remnant highs and lows on the Cherokee Basin floor are interpreted as platforms and troughs and will be referred to in a later section.

At the crest of both the Nemaha Anticline and Central Kansas Uplift, Precambrian and pre-Pennsylvanian rocks are unconformably overlain by rocks of Desmoinesian age (Rascoe and Adler, 1983). This suggests that activity along this feature was not restricted to the Early Pennsylvanian.

LITHOLOGIC INDICATORS OF CLIMATE

Glacio-eustasy is often cited as a control on the deposition of rock units (Heckel, 1977); Milankovitch orbital forcing mechanisms are popular in explaining this control. Climatic fluctuation, as a result of changes in eccentricity, precession, and obliquity is the direct result of orbital forcing. Thus, changes in climate are responsible for glacio-eustasy, and determine terrestrial ice volume (Crowley and North, 1991). Orbital variation is only one of several types of cycles that may affect climate (Figure 7). Other cycles include the movement of continents through latitudes (Cecil, 1990), sun spot cycles, and El Nino cycles.

Climatic cycles have been expressed as having long, intermediate, and short-term durations (Cecil, 1990). Long-term cycles may occur over millions of years.

Figure 7. Types and Duration of Climate Cycles. Modified from Cecil et al. (1995).

RELATIVE DURATION	CAUSE	TIME (years)
Long-term	Movement of continents through latitudes	10^6-10^8
	Orogenesis, and "green house" gases(?)	10^5-10^7
Intermediate-term	100 and 400 ka cycles of term of orbital eccentricity	10^5
Short-term	Cycles in axil tilt and precession	10^4
Very-short-term	Solar variation (?)	10^3
Episodic	Weather systems	10^{-2}(months,weeks, days, hours)

Schutter and Heckel (1985) attributed the presence of coal in the Desmoinesian (Cherokee Group) and the absence of coal in the Missourian as a result of long-term climatic change. Intermediate-term cycles occur between 100-400 ky and are thought to be due to variations in the earth's orbital eccentricity. Short-term cycles may require tens of thousands of years to occur or may be shorter (Cecil, 1990).

The climatic shift associated with the Croweburg coal-Verdigris limestone interval is probably an intermediate-term cycle. As mentioned earlier, Youle et al. (1994) recognized it as one of their thirteen fourth order (0.1 to 1.0 m.y.) depositional sequences. Based on the work of Schutter and Heckel (1985), Roth (1991), and Archer and West (1993), the general shift in climate should involve a transition from a tropical, rainy climate to one that is seasonally wet-dry.

Cecil's (1990) and Cecil et al. (1995) model (Figure 8) is simplistic and will be referred to frequently in this study. It can be used to describe both long- and short-term climatic changes. Models that describe the characteristics of soil features and properties (Retallack, 1990; Mack and James, 1994) also will be considered.

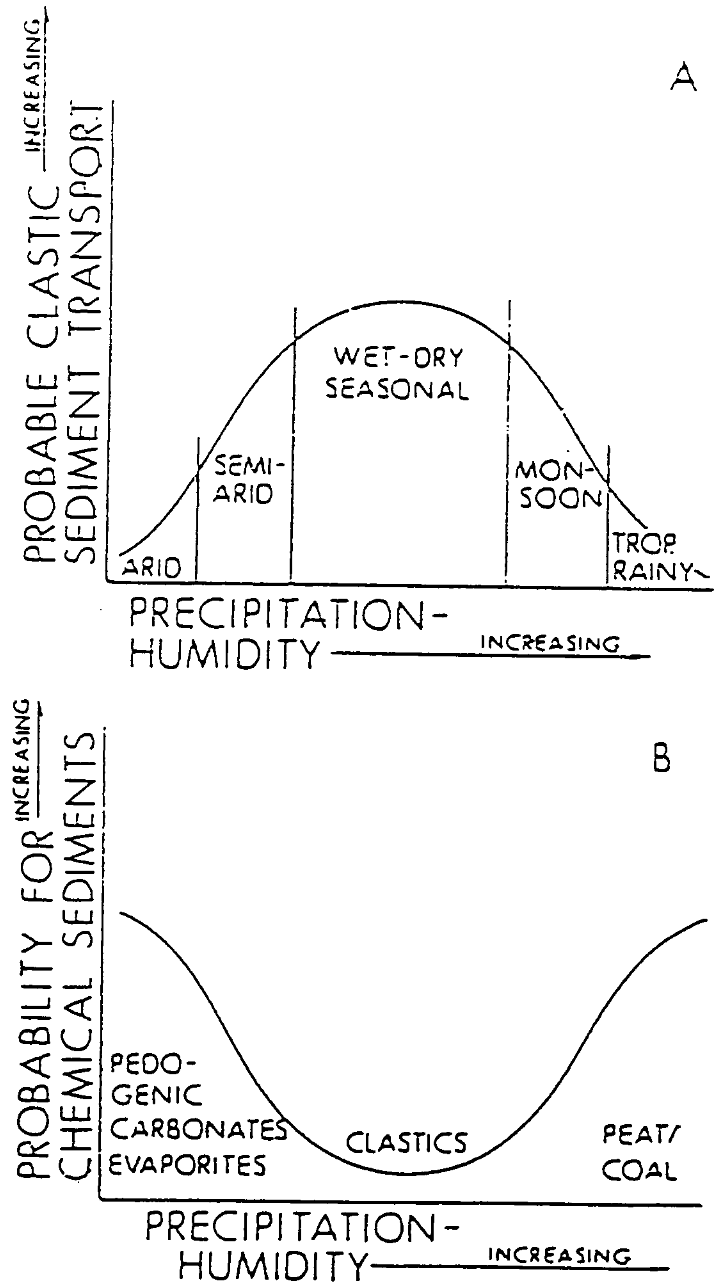


Figure 8. Model of Sedimentological Response to Climate Change. From Cecil et al. (1995)

Paleosols.--The idea that certain soils, peats, and calcretes could be used as indicators of paleoclimate was first recognized and used by Quaternary researchers. Conditions necessary for the accumulation of different kinds of soil matter, such as vegetal, mineral, and aggregations of both, are related to climate.

Processes influencing the accumulation and removal of cations in the soil also are related to climate. Features discernible in modern soils may occur in ancient soils (Retallack, 1990; Mack and James, 1994). Recognition of these features can lead to the general identification (classification) of paleosols, and from this identification, certain climatic conditions can be inferred.

Climate is regarded as a key factor in the formation of the physical and chemical properties of soils (Jenny, 1961). In a general sense, the intensity of radiant energy and the amount and distribution of precipitation control the occurrence of soil-types on a global scale (Buol et al., 1980).

There is a positive correlation between the modern climatic spectrum, including the amount of precipitation received (Buol et al., 1980) and the soil types between the equator and higher latitudes (Mack and James, 1994) (Figure 9). Mack and James (1994) classified paleosols to soil order along a latitudinal gradient that

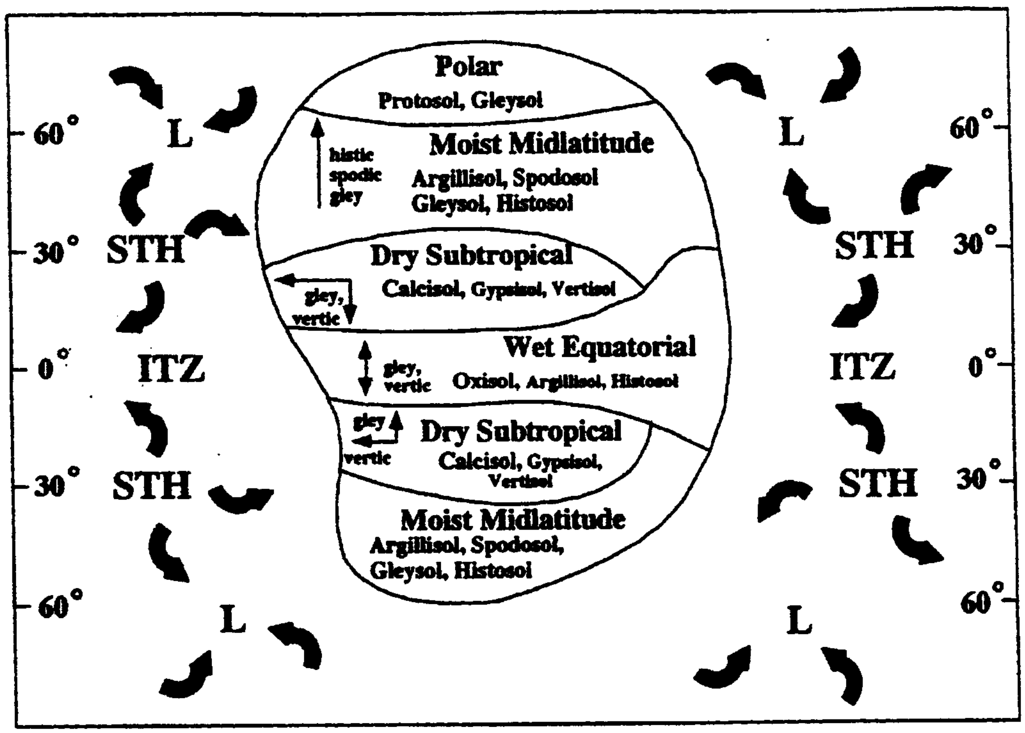


Figure 9. Distribution of soil types based on latitude. The paleoclimatic zones and the predicted paleosols were present during the widespread appearance of vascular land plants (Devonian). From Mack and James (1994).

corresponded with variations in climate/precipitation (Figure 9).

Modern soil classifications (Soil Survey Staff, 1975; Buol et al., 1980) have been revised to describe soil features preserved in paleosols (Retallack, 1990; Mack et al., 1993; Mack and James, 1994) (Figure 10). These features, including organic matter content, horizonation, redox conditions, insitu mineral alteration, illuviation of soluble and insoluble minerals and compounds, and soil texture, are generally the only reliable means of determining the original soil order, which conveys processes related to soil formation.

Soil structure, the size and shape of individual soil units or peds, also reveal the potential processes under which soils may have formed (Retallack, 1990). The size and shape of peds yield information concerning the ratio of clay to silt and sand, as well as the types of clay in the soil. Diagenesis may destroy or overprint colors, mineralogical, chemical, and biotic properties of the original soil; therefore, soil features must be used carefully to infer a soil order.

Some of the important soil types and features observed in this study are as follows:

Coal, the lithified remains of peat, is considered a hydromorphic paleosol (histosol) (Retallack, 1988; Retallack, 1990; Mack et al., 1994; Tandon and Gibling,

Figure 10. Climatic conditions and the associated soil characteristics.

type of soil	number of wet months	associated soil features
entisol	0.5-11.5	slight degree of formation, variable topographic setting
inceptisol	0.5-11.5	show relict features from parent material, some clay accumulation
aridosol	1.0-2.5	shallow, pedogenic carbonate horizons and nodules, alkaline
mollisol	2.5-6.0	high base level, granular texture, fine root systems
alfisol	2.5-6.0	very clayey, deep carbonate nodules, high base levels
vertisol	3.5-7.5	clayey, form deep cracks, smectite clays, humid to semi-arid
histosol	5.5-12	peat, underlying gleyed horizon, waterlogged, low-lying
spodosol	7.0-12.0	sandy near surface (quartz), subsurface horizon iron oxide deposits
oxisol	7.0-12.0	deeply weathered, kaolinte, hematite, goethite common, micropeds
ultisol	7.0-12.0	low base levels, kaolinite and gibbsite, no calcareous material

Data for number of wet months are from Cecil et al. (1995). Data for associated soil features are taken from Retallack (1990), Mack et al. (1993), and Buol et al. (1980).

1994). Accumulation of peat may occur under a variety of hydrologic conditions (McCabe, 1984). A majority of modern peats are found in tropical regions where precipitation is evenly distributed (Cecil, 1990; Cecil et al., 1993; Lottes and Ziegler, 1994) throughout the year. According to Cecil et al. (1995), peat may accumulate when precipitation exceeds evapotranspiration at least 6 or more months per year (Figure 11). Other types of peat may accumulate at high latitudes, but they are not thought to be responsible for extensive coal accumulations (Tandon and Gibling, 1994).

Vertic-like paleosols, herein referred to as vertisols, form under a range of different climates, from humid (when precipitation exceeds evapotranspiration for over 7 months per year) to semi-arid (precipitation exceeds evapotranspiration for 3 months per year) (Cecil et al., 1995) (Figure 12). Generally humid, or wet vertisols, have uniform, thick clayey profiles that develop wide cracks during part of the year (Retallack, 1990) and may be acidic (pH less than 7) (Soil Survey Staff, 1975). The cracks are the result of shrinking and swelling of the smectitic clays in these soils and may produce a hummock and swale topography (gilgai) on the surface and in the subsurface; thus the cracks appear as a series of mukkara structures. Vertisols which form under semi-arid conditions, or dry vertisols, are usually alkaline,

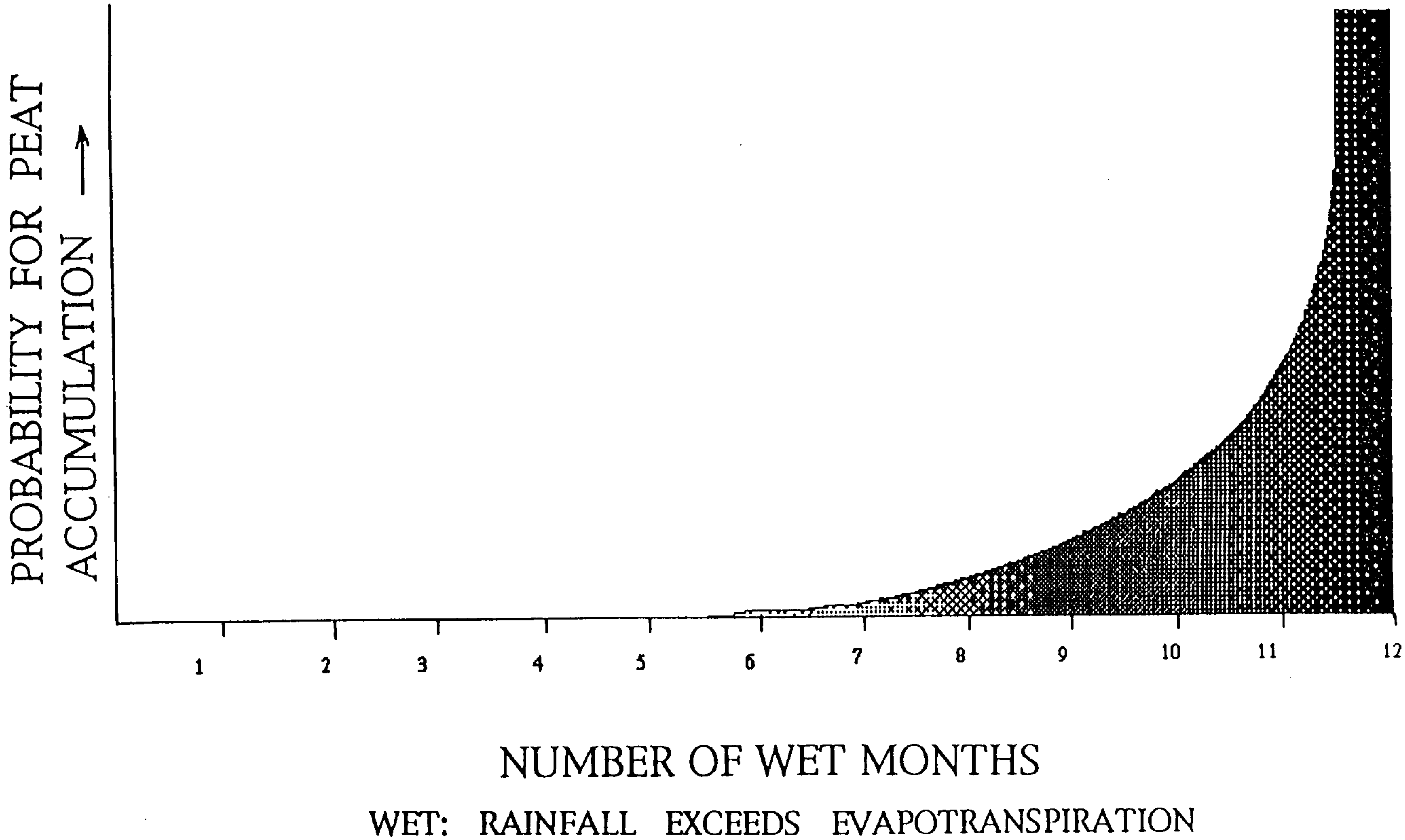


Figure 11. Precipitation needed for peat accumulation. From Cecil et al.(1995).

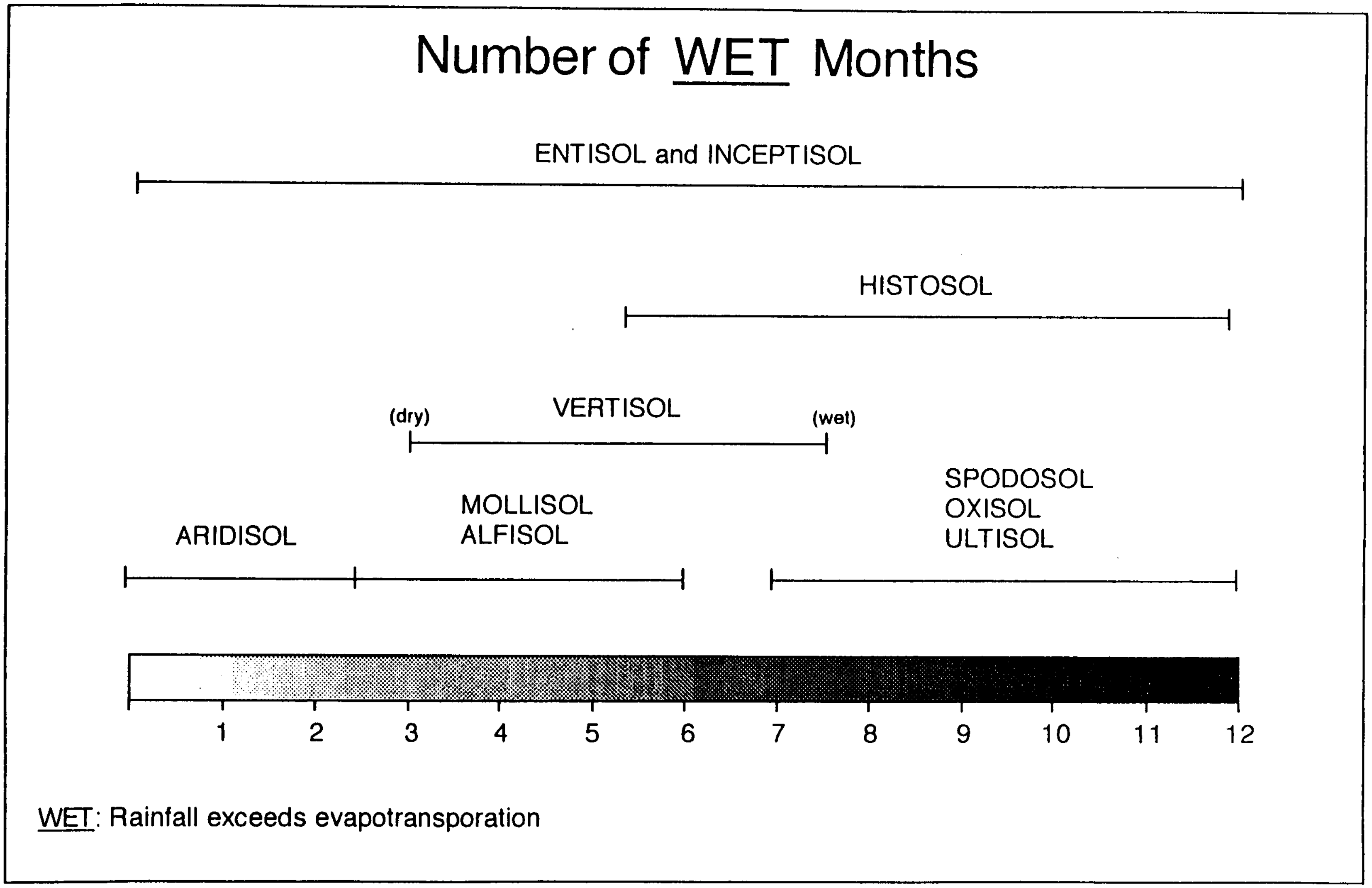


Figure 12. Different soil types may develop under a range of climate regimes. The amount and distribution of precipitation during the year corresponds to the formation of these soils. The following figure represents the soil order types (Retallack, 1990) and the number of months during formation that precipitation exceeds evapotransporation. (from Cecil et al. 1995) .

with sparse vegetation, and good reserves of exchangeable cations (Retallack, 1990). Vertisols are capable of forming from a variety of different parent materials and generally form on flat terrain (Retallack, 1990).

Paleosols, such as aridosols, vertisols, mollisols, and alfisols, may exhibit calcic features (calcretes, caliches, and calcareous nodules) and will be regarded as having formed under dry to periodically dry conditions (Figure 12). Calcareous features are retained near the surface of modern soils when precipitation is typically 400-600 mm/yr or unevenly distributed throughout the year (Tandon and Gibling, 1994). More precipitation will dissolve pedogenic carbonate and translocate it deeper in the soil profile.

Entisols may form under any climate regime (Figure 12); this type of soil usually exhibits only a slight degree of soil formation because of time constraints or unfavorable conditions (Retallack, 1990). Unfavorable conditions consist of variability in the topographic settings on which the soil form, such as young geomorphic surfaces and steep slopes. "Entisols may be penetrated by roots and show some mineral weathering and surface accumulation of organic material..." (Retallack, 1990, p. 107). They may also retain some of the original structures, like sedimentary features of their parent materials. Although not good climate indicators, entisols may be indicators of topographic position and the types of conditions affecting soil formation.

Siliciclastics.--Gray mudrock and other siliciclastic units have been recognized by Wanless and Wright (1978) as "clastic wedges" and by Heckel (1977) as "outside shales".

Climate is believed to be one of the factors involved in the erosion and deposition of siliciclastic sedimentary sequences (Cecil et al., 1985; Donaldson et al., 1985; Cecil, 1990). Input of siliciclastic sediments into a basin can be controlled by seasonality in climate (Figure 13).

Cecil (1990) stated that ideal conditions for the erosion and deposition of siliciclastic sediments occur in climates with seasonal rainfall. Seasonality, he contends, "...restricts vegetative cover in upland areas..." (p. 354, 1990), which increases the amount of surface area exposed to the influence of climate. For example, a phase of long-wet/short-dry periods may induce erosion and increase clastic transport into sedimentary basins (Cecil, 1990).

Donaldson et al. (1985) presented an overview of the sedimentological conditions of Pennsylvanian rock units from the Pocahontas and Dunkard Basins in the central Appalachians. They noted that indicators of wet

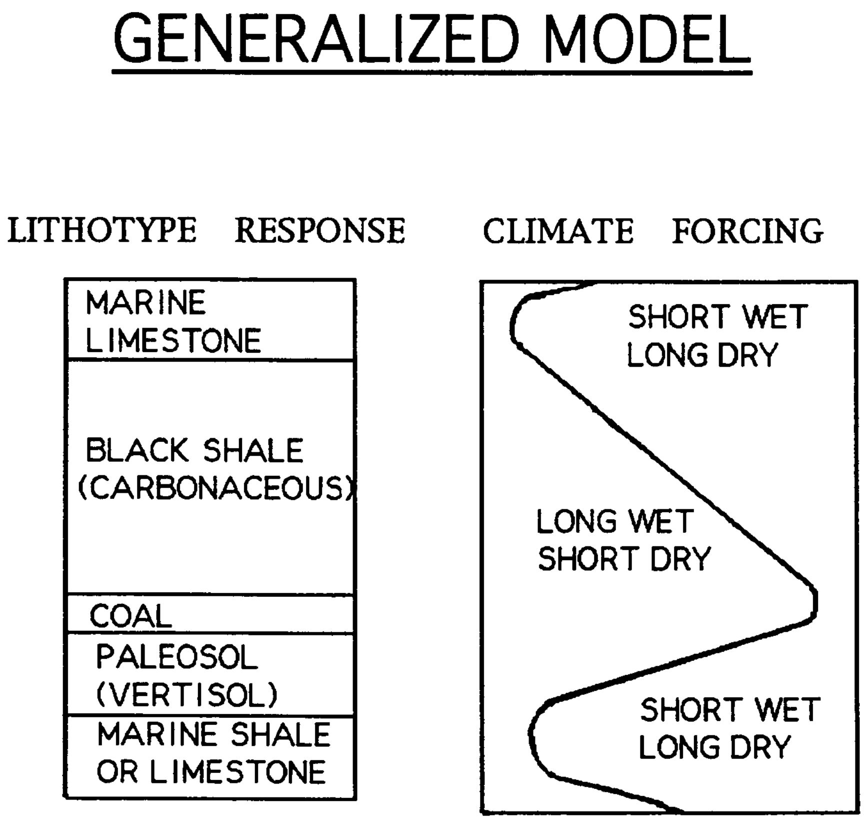


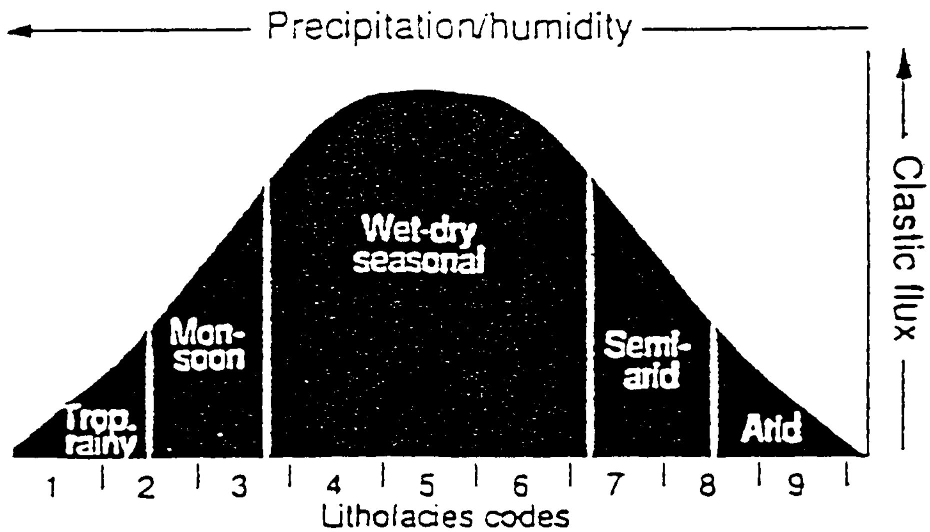
FIGURE 13. Sedimentary response to climate seasonality. The basin response is similar to that recorded by the study interval. Modified from Cecil (1990).

climates are reflected in terms of vegetation, runoff, weathering, relief, changes in base level, type of source rock, and the erodability of the source material. Lithologic indicators of a wet, tropical climate would include an abundance of quartz, lack of feldspar, increase in preserved organic matter, and presence of aluminum-rich clays (Donaldson et al., 1985).

Archer and West (1993) characterized cycles from the Cherokee Group on the basis of lithology (Figure 14). They concluded that the sequence of lithologies in the Cherokee cyclothem: coal, gray mudrock, black shale, and carbonate, is consistent with a predominantly wet, equatorial climate. The coal and carbonate of the sequence represented less seasonality, whereas siliciclastics such as mudrocks and shales represented a stronger seasonality in climate.

Siliciclastic units in the study interval consist of gray mudrock and black, (V)-shale. Black shale is discussed in greater detail below. The gray mudrock is a nonpersistent unit containing between 35-40% quartz (F. Dulong, personal communication, 1995), marine fossils, and some organic debris. The gray mudrock may represent a transitional facies between equable wetter and drier conditions.

14a.



14b.

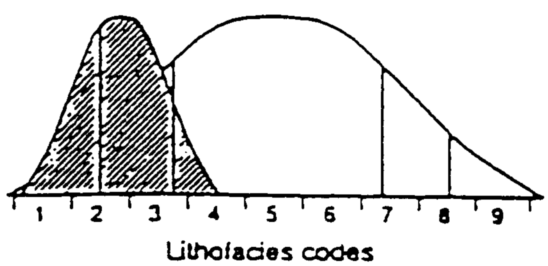


Figure 14. Climatic curve for Cherokee Group based on the vertical distribution of lithofacies. Figure 14a. shows the climatic range spectrum based on Cecil (1990). The shaded region in Figure 14b. shows where a Cherokee cyclothem has been placed relative to the climatic spectrum. From Archer and West (1993).

Black shales.--Depositional conditions associated with carbonaceous, fissile, black shales have been the focus of much controversy. Two contrasting views have gained wide support in the midcontinent and will be discussed in this section.

Early studies of black shales were conducted by Weller (1930), Wanless and Shepard (1936) and Wanless (1950); they proposed that fissile, black shales were deposited in shallow water. Black shales, often stratigraphically above a coal, led to the suggestion that marine transgression drowns the coal swamp resulting in a shallow, possibly restricted, lagoon. The presence of organic debris and coal-like appearance of the Mecca Quarry- and V-shales led some to believe they were failed peat swamps (McCabe, 1984; Cecil, personal communication 1994). Drowning of the peat-forming environment and an increase in siliciclastic detritus are thought to have stopped the accumulation and preservation of coal forming-peat; thus, the black shale could be viewed as a "failed coal."

Weller (1930) used an "algal flotant" in his scenario, to describe the rich organic content of the shales and the lack of disturbed, underlying sediments. Wanless (1950) proposed that the water level was shallower and more restricted for the black shales than for the overlying limestones.

Later, Zangerl and Richardson (1963) hypothesized the depositional environment for the black shale as a shallow water (less than 10 m deep), nearshore (fresh to brackish water), lagoonal environment. The focal point of Zangerl and Richardson's (1963) study were two shales, the Mecca Quarry and Logan shales (The Mecca Quarry shale is stratigraphically equivalent to the carbonaceous, fissile "V" shale in the study interval).

Evidence of well-preserved, articulated fish fossils demonstrated that deposition of the Mecca Quarry shale in the Illinois Basin was rapid. Also vitric and humic debris in the shale, and the presence of abundant plant debris supported nearshore deposition. Zangerl and Richardson (1963) expanded upon Weller's (1930) proposal of an "algal flotant" to explain the "sheety" character of the shale and lack of bioturbation.

Geochemical analyses also have shed some light on the origin of some black shales. Coveney et al. (1991) found that Mecca-type shales were enriched in Mo, V, U, and Se, and were slightly phosphatic. These black shales contained abundant terrestrial organic matter and were probably formed nearshore.

Wenger and Baker (1986) analyzed the Excello and Little Osage shales (Marmaton Group) and found that the terrestrial and humic constituents of the shales decreased upward. This indicated that peat swamps were probably flooded during a marine transgression. Influx of marine water could have washed land derived nutrients into the basin, stimulating algal activity. This would temporarily increase the oxygen content of the water.

In the midcontinent, many of the intervals studied did not include the coal-black shale combination. Black shales are situated between marine limestone units. Consequently, a deep-water model was developed to explain the origin of these black shales (Schenk, 1967; Heckel, 1977).

Research on the Heebner (Virgilian) and Lake Neosho (Desmoinesian) black shales was conducted by Evans (1967) and Schenk (1967), respectively. Their studies resulted in deep-water, offshore models.

James (1970) and James and Baker (1971) preferred a deep-water depositional environment for the Excello shale. Their models utilized a thermocline, which formed during a marine transgression, resulting in anoxic bottom conditions that inhibited decomposition of organic matter. When sea level dropped, normal marine conditions returned, and the thermocline was destroyed.

Heckel (1977) recognized two different black shales. Black shales that overlie a coal and underlie a limestone, which commonly have a low gamma-ray response, lack phosphatic nodules, and contain sand, and land-derived (humic) organic matter. Heckel did not give a precise depth for these shallow-water, black shales.

The second type of black shale recognized by Heckel (1977) is characterized by a high gamma-ray response, phosphatic nodules, little sand, and marine (sapropelic) organic matter. This type of shale was deposited in deep-water (up to 100 meters), with cold, oceanic upwelling currents providing phosphate. The phosphate was later incorporated into nodules.

Heckel's (1994, p. 66) most recent explanation of the occurrence of the shales stated:

> "The black-shale facies was deposited in water deep enough to develop a pycnocline that inhibited vertical circulation and prevented bottom oxygenation long enough to eliminate benthic organisms and preserve large amounts of organic matter that accumulated on the bottom over a long period of time."

The pycnocline was a thermocline that, stressed by wind currents, led to "quasi-estuarine circulation and episodic upwelling" (Heckel, 1994, p. 69) of the sea.

Several points are common to both deposition models: (1) black shales probably were deposited in restricted environments, (2) black shales were subject to both dysoxic and anoxic conditions, and (3) the anoxic conditions are responsible for the preservation of high concentrations of organic material.

Currently, models for the depositional environment of the black shale are disputed. There is no evidence that water depths ever reached 100-200 meters or were less than 10 meters. Furthermore, there is no evidence that conditions were so anoxic as to exclude the presence of benthic organisms from the system.

Depending on the geographic position, the black (V)-shale has characteristics of both the shallow- and deep-water models. The V-shale contains phosphatic nodules in the Cherokee Basin however, it does not contain phosphatic nodules elsewhere in the study area. Other properties of the V-shale include a low gamma-ray response, a siliciclastic texture along structural features, and the shale occurs between nonmarine and marine units. Therefore, the preceding models are inadequate in describing the depositional environments of this and other black shales from the Middle Pennsylvanian because it is difficult to determine the depth, rate, or conditions of deposition of the unit. Association with the underlying Croweburg coal and overlying limestone indicate however that the black (V)-shale in southeastern Kansas probably was deposited in relatively shallow water.

Marine limestones.--Carbonates often are regarded as indicators of warm tropical to subtropical climates; cold water tends to dissolve fine-grained carbonate particles. Marine carbonates are dominant in clear, warm, shallow, tropical to subtropical seas, generally between 30° north and south latitudes (Prothero, 1990).

In a model developed by Cecil (1990), pedogenic and nonmarine carbonates (lacustrine) are considered to have formed during dry conditions (Figure 13). During long-dry/short-wet periods, there is a reduction in eroded sediment and siliciclastic transport, which may correspond to an increase in carbonate generation (Cecil, 1990). Increased influx of siliciclastic detritus into a carbonate-producing system would diminish the photic zone, resulting in a decrease or termination of carbonate production.

Cecil (1990) and Cecil et al. (1995) used this model to explain the spectrum of lithologic changes in the vertical succession of Pennsylvanian and Mississippian rocks of the Appalachian Basin. Carbonates and coals are lithotypes that may accumulate under long dry and wet (equable) conditions, respectively (Figure 13). Deposition of each also is dependent on elevation of: (1) the water table and (2) base-level. Pedogenic carbonates precipitate when the water table is low. Lacustrine carbonate forms when the water table is high (Cecil, 1990).

Archer and West (1993) utilized this model and included marine limestones and dolomites, cherty carbonates, chert, and evaporates as "dry" lithologies. They described the Upper Cherokee Group as consisting of both large and small cycles with paleosols, coals, siliciclastics, and thin limestone units. The siliciclastics were deposited under wet conditions, whereas the carbonates were thought to have been deposited under less wet conditions. Archer and West (1993) described a gradual paleolatitudinal transition of cycles from wet, equatorial Cherokee strata to drier, northerly conditions in the Guadalupian units (Permian).

Schutter and Heckel (1985) attributed climate as a possible cause of the transition from an equatorial Desmoinesian rainforest to arid Missourian (Upper Pennsylvanian) conditions. They stated that "...the mere presence of abundant marine ooids at a local horizon implies a warm climate that is also relatively dry" (p. 124, 1985). In modern marine environments, ooids are being produced in saline, tropical to subtropical zones (Schutter and Heckel, 1985).

RESULTS

SURFACE STRATIGRAPHY

Mudrock.--Early descriptions of the mudrock (Bed 1, Figure 3), consisted of the color and texture of the clay; it was interpreted as a paleosol. In this study, the mudrock was examined for soil horizons, structure and texture, and plant/root traces. Other features such as color and possible diagenetic alteration were also recorded.

Two types of horizons were recognized in the mudrock at one of the measured sections (Refer to Appendix 1 for this, MS 1, and other measured sections): (1) a light gray (N7) layer with a silty texture, interpreted to be a gleyed horizon, and (2) a carbonaceous, slightly clayey layer, interpreted to be an "O-A" horizon. The gleyed horizon was found at MS 1 (approximately 15 cm below the contact with the Croweburg coal); the "O-A" horizon was also found at MS 1 directly below the Croweburg coal and is approximately 0.5 to 1.0 cm thick.

Soil structures in the mudrock generally are a function of soil texture. Where the mudrock was chiefly composed of clay, pedogenic slickensides, structures caused by the compaction of peds (MS 1, 2, and 9), and mukkara structures (MS 1 and 2) were observed. Slickensides and mukkara structures (commonly found in soils that shrink and swell) are believed to be partly responsible for destroying the bedding of the original soil (Retallack, 1990).

At measured sections 1, 2, 6, 6a, 7a, and 9, the mudrock contained carbonized plant debris. Some of these plant remains occurred in vertical position (Howe, 1956) and were observed at MS 1, 2, and 6. Fossil plant rootlets, including *Stigmaria* from lycopods (Howe, 1956), are present at many of the exposures.

The mudrock was noncalcareous except at one locality (MS 2). At MS 2, the mudrock was measured to the top of the underlying, argillaceous limestone. The lower 15 cm was calcareous; the remainder of the unit was noncalcareous. The following fossils were collected from the lower part of the mudrock: *Mesolobus*, *Composita*, marginiferids, productid spines, and crinoid columnals.

Some of the mudrock exposures, (MS 2 and 9), exhibited secondary weathering and are stained by iron-oxide. Secondary deposits of gypsum coat slickensides and surfaces of mukkara structures.

The color of the mudrock varied between medium to dark gray, greenish-gray and bluish-gray. The significance of soil colors may be related to depositional environment and will be discussed later.

Brady (1988) observed a topographic irregularity at MS 9, where the mudrock forms a positive feature. Along an exposed highwall, the upper contact of the mudrock at MS 1 and 2 undulates slightly, but more subtly than the occurrence at MS 9.

Based on the range of pedogenic characteristics the mudrock has been interpreted as a paleosol. A paleosol at surface exposures probably resembles a: soil that formed under hydromorphic conditions (Fastovsky and

McSweeney, 1987), a vertisol (Retallack, 1990), or a vertisol with some characteristics of a gleysol (Mack et al., 1993). In this study, the paleosol will be referred to as a vertisol; the vertisol has been subdivided into two types: (1) a wet, clayey vertisol and (2) a dry, calcareous vertisol (Figure 12). The mudrock located along the outcrop belt (Plate 1 and Figure 4) is considered a wet, clayey vertisol.

Croweburg coal.--The Croweburg coal (Bed 2, Figure 3) is one of the most persistent beds of the Cherokee Group. It is recognized in Kansas, Oklahoma, and Missouri (Pierce and Courtier, 1937; Howe, 1956). Indeed, it, and its correlative equivalents: the Broken Arrow, Whitebreast (coal #7), Colchester (no. 2) and (IIIA), and Lower Kittanning coals, is the most widespread Pennsylvanian coal in North America (Wanless, 1975) (Figure 2).

The Croweburg coal is hard, banded, and blocky. It contains calcite cleats (MS 6) and abundant pyrite lenses (MS 1) in the upper 7-9 cm. Pyritized plant debris, including bark, has been found oriented parallel to bedding (MS 1). Occurrence of pyrite makes the Croweburg "impure," and not viable for mining (Howe, 1956). Weathering of the pyrite causes the surface of the coal to appear dark reddish brown (10 R 3/4) (MS 1 and 2).

A thin dark-gray to black shale parting, bone coal, sometimes occurs near the top of the unit (Howe, 1956) (MS 6). The thickness of the Croweburg ranges from 30 to 40 cm. In Cherokee and Crawford Counties, Kansas and Vernon Co., Missouri (MS 1, 2, and 9), both upper and lower surfaces have been observed to undulate (Brady, 1988).

Based on the accumulation of peat necessary for the development of coal, the Croweburg coal has been interpreted to have been a histosol.

<u>Gray mudrock.</u>--In southeastern Kansas, the gray, clayey mudrock (Beds 3 and 4, Figure 3) has no formal name, but it is correlated with the Francis Creek shale in the Illinois Basin (Figure 2). It is situated between the Croweburg coal and overlying black (V)-shale. The contact between the coal and the base of the gray mudrock is sharp, and carbonaceous debris is incorporated in the overlying mudrock (MS 1, 2, 5, and 9), suggesting reworking along an erosional contact.

The medium-gray to greenish-gray mudrock, which is variably distributed throughout southeastern Kansas, ranges from 1 to greater than 3 meters thick. Howe (1956) reported that the gray mudrock may reach a thickness of 12 meters in Rogers County, Oklahoma, or it may be absent. In this study, it was absent from two of Howe's localities (MS 7 and 7a), but it is present at all of the other exposures.

Laminations in the lower meter of the gray mudrock decrease upward, and slickensides are more common in the upper meter (MS 1, 2, and 6). Laminations above the coal are sometimes organic-rich and clayey, containing carbonized plant remains. In Vernon County, Missouri, a carbonized, compacted tree, extending 56 cm upward into the laminated shale, was found in vertical position, apparently growing in the peat that formed the coal. Howe (1956) also described possible rootlets in this gray mudrock. The mudrock is hard and breaks into blocks near the top.

Pectenid bivalves (Howe, 1956), clams and chonetid brachiopods are the common fossils. Shells and shell fragments of *Dunbarella, Edmondia, Astartella, Paralledon, Phestia, Lingula, Crurithyris, Mesolobus,* and productids have been found throughout the unit, predominantly in the upper two meters (MS 1, 2, and 12). *Pseudorthoceras* and holothurian remains also were collected (MS 1). Pyrite coats many of the fossils, fills both vertical and horizontal burrows, and occurs as framboids and nodules.

Black (V)-shale.--The black (V)-shale (Beds 5-8, Figure 3) became known as "V" by workers in Kansas because of its location below the Verdigris limestone. It is stratigraphically equivalent to the Mecca Quarry and Oakey shales in the Illinois Basin and Iowa, respectively (Wanless and Weller, 1932) (Figure 2). Its high radioactivity and persistence makes it an important datum that is often used in construction of subsurface sections (Killen, 1986; Huffman, 1991).

The black (V)-shale (henceforth referred to as the V-shale) is hard, fissile, and contains rounded, nonskeletal, phosphatic concretions. It ranges from 1 to 3 meters thick, and it may be subdivided into fissile, blocky, and platy beds (see MS 1, 2, or 10 for best examples).

Several discontinuous concretionary layers of dense, dark-gray micritic limestone are separated by layers of black to very dark gray shale (MS 1, 2, 3, 5, 6, 8, 9, 10). In Crawford County, Kansas, and Vernon County, Missouri, there are two concretionary layers (MS 1 and 2), but only one layer has been observed in Cherokee County, Kansas (MS 9 and 10). Some of the concretions are septarian with dolomite fillings (Howe, 1956) and some have a pyritic rind.

The lower layer is made up of individual, rounded concretions (30-90 cm wide). Some connect to form dumbbell-shaped forms (Howe, 1956). This concretionary layer is approximately 24 cm thick (MS 1, bed 6).

The second layer consists of concretions that form a nearly continuous bed (up to 20 cm thick) (MS 1, top of bed 7). It is separated from the lower concretion layer by 1.2 meters of black, fissile shale. Shapes of these concretions also are round and flat.

The concretions often have a fossil nucleus. Fossils often found in the V-shale are: *Crurithyris, Derbyia, Mesolobus, Composita, Antiquatonia,* productid-, spirifer- and chonetid-type brachiopods, orbiculoids, *Lingula, Dunbarella, Phestia, Edmondia,* conodonts, fish and shark scales, and crinoid columnals (MS 1, 2, 8, and 10). Howe (1956) reported finding Goniatite-like ammonoids and simple corals, but these are not commonly encountered. The V-shale also is rich in organic matter; plant debris has been found near the top and bottom of the unit.

Shales above and below the concretionary layers are slightly calcareous, dark gray, and fossiliferous; many of the fossils are pyritized. Pyrite-filled vertical and horizontal burrows and pyritic framboids also are present.

Triplehorn and Brady (1991) discovered a kaolinitic-rich volcanic ash layer (approximately 0.5-1.0 cm thick) in the V-shale. The ash layer was found in two exposures described in this study: MS 1, the Mary

Jane Mine in Vernon County, Missouri (SW Sec. 31, T. 35 N., R. 33 W.), and MS 2, the CATO Mine-22, in Crawford County, Kansas (Sec. 28, T. 27 S., R. 25 E.). The ash layer occurs (approximately 30 cm) above the gray-mudrock/V-shale contact.

Verdigris limestone.--The Verdigris limestone (Bed 9, Figure 3), also known as the Ardmore limestone in Missouri (Gordon, 1896), is a very persistent unit in the northern mid-continent (Figure 2).

The Verdigris limestone is a prominent unit in Crawford and Cherokee Counties, but Howe (1956) interpreted a thin, argillaceous limestone (MS 12 and 13) to be its equivalent in Labette County, Kansas. The Verdigris is from 40 to 105 cm thick, the upper surface is irregular (MS 2, 4, and 6), and it is often overlain by a fossiliferous mudrock (MS 1).

Howe (1956) described the Verdigris limestone as three limestone beds interbedded with shale. His description included the uppermost, massive limestone and the two discontinuous concretionary layers of the V-shale. Based on the fossils and character of the intervening dark-gray to black fissile shale, all of the strata below the upper, massive, ledge-forming limestone (including the concretionary layers) are considered V-shale. Only the upper limestone is referred to here as Verdigris (Figure 3).

This upper bed, the Verdigris, is medium gray to yellowish-gray (fresh surface), often with light brown mottling. Fossils include: *Crurithyris, Derbyia, Juresania, Mesolobus, Punctospirifer, Neospirifer,* linoproductids, marginiferids, *Antiquitonia, Lophophyllidium,* rugose corals (solitary and in life position), fenestrate bryozoans, echinoid spines, crinoid fragments, and algal filaments. A thin shale parting separates a bed of fusulinids and broken shell debris at the top of the unit at MS 2.

SUBSURFACE STRATIGRAPHY

Mudrock.--The following description of the mudrock is based on cores and associated data from each of the three basinal areas.

In the Orville Edmonds core (C1), from the Forest City Basin, the mudrock is a light olive-gray (5 Y 6/1) clayey unit. Slickensides are abundant near the base, where the mudrock is very clayey, and the clay expands when wet. No fossils were observed, and small carbonate nodules (0.5 to 1 cm in diameter) occurred in the noncalcareous clay matrix. A carbonaceous and clayey layer, interpreted as an "O-A" horizon (1.5-2 cm thick), occurs at the top of the unit.

The mudrock in the Cherokee Basin (C2) is very similar to that observed on outcrop, because C2 was drilled nearby (3.2 km from MS 11). One difference, however, is that the mudrock in the core is slightly calcareous, possibly from surface weathering. It is a light, bluish-gray (5 B 7/1) crumbly clay, with slickensides, carbonized plant debris, roots, and small pyritic concretions. The clay expands when wet and is calcareous near the base.

The mudrock has been traced from the surface into the subsurface using geophysical logs. A transect across the Cherokee and Forest City Basins (Plates 2 and 3) reveals that the mudrock is absent at several of the control points and is inferred to become siltier closer to the Nemaha Anticline.

There were no available cores containing the interval of study in the Sedgwick Basin. In this situation, field geologist reports were used for descriptions of the mudrock. Along the western limb of the Nemaha Anticline and the northeastern flank of the Central Kansas Uplift, the mudrock is silty to sandy, slightly pyritic, and mottled gray-green and red-brown.

Based on their descriptions, stratigraphic position, and biostratigraphic controls, quartz arenite and a mudstone (from cores C3 and C4, respectively) are thought to be equivalent to the mudrock. These cores are both situated on the highlands of the western limb of the Central Kansas Uplift (Ness County) and have been described by Howard (1990) and Nodine-Zeller (1981).

At C3 (Thompson A-2, SW NW NE Sec. 3, T. 17 S., R. 21 W.) Howard (1990) described a fine-grained, nonfossiliferous quartz arenite that is variegated with maroon and green mottling, bioturbated, and interlaminated. Nodine-Zeller (1981) described a greenish-gray, burrow-mottled, nonfossiliferous calcareous mudstone unit with disseminated pyrite in C4 (No. 1 Collins core, C NW NW Sec. 24, T. 20 S., R. 26 W.).

Farther west in the Hugoton Embayment, at C5 (Pendleton Scauf #1, Sec. 16, T. 27 S., R. 29 W.), a light olive-gray calcareous mudrock with some rhizoliths underlies the V-shale. Rootlets were observed in the core, but fossils and slickensides were not apparent. The description at C6 (Rebecca K. Bounds core, NE SE NE Sec. 17, T. 18 S., R. 42 W.) was taken from a geologist report; only a general description of the units was noted. The mudrock at C6 is calcareous, moderately clayey, and contains rhizoliths.

Croweburg coal.--The Croweburg coal was not present in the Leavenworth County, Kansas, core (Orville Edmonds 1-

A). Although there were no descriptions of the Croweburg coal in the Forest City Basin, a coal reported by Huffman (1991), occurs at the appropriate stratigraphic level on the Bourbon Arch.

The greatest thickness of Croweburg coal in Kansas is in the Cherokee Basin. Using geophysical logs, Huffman (1991) observed the coal to vary from 30 to 60 cm in thickness. He described the coal as "...found intermittently throughout the study area (Cherokee and Forest City basins)..." (p. 71, 1991). This coal overlies the mudrock and is overlain by either a gray mudrock or the V-shale. Gamma-ray log response of the coal in the Cherokee Basin is low, deflecting to the left.

The coal from C2 is bright, blocky, and fractured. It contains, plant debris, calcite cleats, and light brown iron oxide stains between fractures.

Adkison (1963) noted a thin trace of coal (less than 1 ft thick) in several of the well logs and drill cuttings he examined from the Sedgwick Basin. Adkison did not acknowledge that this was the Croweburg coal, but it is likely that it is the Croweburg equivalent, based on the reported stratigraphic position.

Killen (1986) did not report coal in the Sedgwick Basin; his research was chiefly in the southern part of the basin. Conditions were probably not conducive to significant peat accumulation and preservation (Killen, 1986).

Coal was not found in the Hugoton Embayment. However, coaly fragments were reported from C3 in Ness County.

Gray mudrock.--The gray shale facies is not a persistent unit across Kansas. It was traced from exposures into the subsurface (using geophysical logs) in both the Forest City and Cherokee Basins. The gray mudrock was observed to be medium dark gray (N4), platy, and noncalcareous (although the basal 7 cm did react slightly with hydrochloric acid), at C2. Some pyritized shell fragments thought to be *Dunbarella* also were reported. The gray mudrock was not described in any field reports and was not available in any cores outside of Cherokee County, Kansas.

V-shale.--The V-shale is the most widely distributed and easily identified unit of the Croweburg coal-Verdigris limestone interval on geophysical logs. Characteristically, it is a "hot," radioactive, black shale, but it does exhibit some variation between the different basins, especially near inferred shorelines, such as along the flanks of the Nemaha Anticline and Central Kansas Uplift (Killen, 1986; Huffman, 1991).

In the Forest City Basin, the V-shale thins to approximately 40 cm (C1, beds 2 and 3). Although it is referred to as a shale, it is a greenish-gray (5 GY 6/1) crumbly, calcareous mudrock. It contains slickensides and fossils: *Mesolobus,* crinoid columnals, scattered shell fragments, and some plant debris. The base is marked by phosphatic nodules (less than 2 cm in diameter) and abundant organic matter. The volcanic ash layer discovered by Triplehorn and Brady (1991) from MS 1, was recognized in C1.

The V-shale becomes thicker in the Cherokee Basin (up to 81 cm thick at C2). It also resembles a blocky, dark gray, calcareous mudrock. Fossils include: bivalve fragments, *Derbyia*, and high spired gastropods. Some small horizontal burrows also were observed.

The two concretion layers described in outcrop can be traced in the subsurface for a short distance (from MS 1 to control point 2 on Plate 1). Because the lower layer is continuous along the trend of the outcrop, it is also thought to occur sporadically in the subsurface of the Cherokee Basin and throughout the Sedgwick Basin.

In the Sedgwick Basin, the V-shale has a strong radioactive signal. It is noted as being a black, carbonaceous (almost coaly), and fissile shale. The radioactive signal wanes near the Central Kansas Uplift, where the V-shale is moderate to dark gray and becomes more silty and calcareous. Drill cuttings examined by Killen (1986) contain some pyrite and a few crinoid columnals. The lower concretion layer, described from the Cherokee Basin, is present across the entire Sedgwick Basin.

Wire-line log correlations, based on biostratigraphic control, indicate that an interlaminated maroon and green fissile shale from C3 appears to be the V-shale equivalent on the western limb of the Central Kansas Uplift. Howard (1990) described the unit as ripple laminated, maroon at the base and green at the top. Near the base, the unit is friable, mottled, and Howard (1990) reported coal fragments (these may be related to the Croweburg coal). There is a gradational contact with the overlying red mudstone lenses.

Farther west, the V-shale grades laterally from this variegated shale to the characteristic black, carbonaceous shale (see C4, 5, and 6). In the Hugoton Embayment the color of the V-shale has been reported in driller's logs to vary from dark gray to black, and the shale has a strongly radioactive gamma-ray response.

A thin shell lag (10 cm thick), reported in driller's logs, occurs in two cores: C4 and C6, Greeley and Gray Counties, respectively. The shell bed occurs at about the same stratigraphic level in each of the cores.

<u>Verdigris limestone.</u>--The Verdigris limestone is thin (58.5 cm) where it was measured in the Forest City Basin (C1). It is composed of small, rounded, light olive-gray (5 Y 6/1) limestone nodules in a greenish-gray (5 GY 6/1) slightly calcareous mudrock. Some bivalves were found and plant debris occurs near the top of the unit.

Subsurface descriptions of the Verdigris limestone in the Cherokee Basin are similar to those reported for surface exposures. It is relatively uniform across the basin until a decrease in the gamma-ray log response near the Nemaha Anticline (control points 12-15) reveals a sandy carbonate. In western Butler County, the Verdigris limestone and an overlying carbonate grade into one, thick, sandy carbonate. This is considered the Verdigris limestone because of the position of the underlying V-shale.

Geologist reports from well sites located on the Nemaha Anticline report the Verdigris limestone as light brown to brown and very silty to sandy. Fossils have been reported but not distinguished. Closer to the Central Kansas Uplift, the Verdigris is described as cherty and silty to slightly argillaceous. Killen (1986) described the limestone as a shaley limestone in the northern part of the Sedgwick Basin and as a clean, cherty limestone in the south.

On the western limb of the Central Kansas Uplift, the Verdigris limestone is equivalent to a siltstone (C3 and 4). This siltstone is poorly sorted, fine to medium sized, angular to subrounded grains. Some fossils (pelecypods, foraminiferids, blastoid fragments and echinoid spines) were reported by Nodine-Zeller (1981) at C4.

Westward, the Verdigris grades into a cherty, chalky, oolitic limestone. From geologist reports, it is described as dense, well cemented, and varies from gray to brown and white to cream. The Verdigris found at C6, is bioturbated, and contains crinoid fragments. Other reports describe the Verdigris as having green trace fossils, a fine to very fine crystalline texture, and a chalky base just above the V-shale.

DISCUSSION

FACIES DISTRIBUTION AND INTERPRETATION

Cherokee Basin.--The lowest member of the interval, the mudrock, which has been interpreted as a paleosol, has a patchy distribution in the study area. In the Cherokee and Forest City basins (Plates 2 and 3), it generally overlies an argillaceous limestone or a siltstone and may be overlain by the Croweburg coal, the gray mudrock, or the V-shale.

Topographic irregularities, highs and lows, appear to control lithologic distribution. Lee and Merriam (1954) constructed sections across the Cherokee and Forest City basins; their sections show the variation in thickness of the Cherokee Group throughout the region. It is suggested here, that these same topographic irregularities affected the deposition of the study interval.

The topographic irregularities of the Cherokee and Forest City basins are proposed to have affected all of the lithologies below the V-shale. This is because the V-shale overstepped all of the positive structures encountered in the study area with no apparent change in lithotype or thickness, except the Central Kansas Uplift.

Distribution of the paleosol was predominantly, but not always limited to topographic highs (see Plates 1, 2, and 3). Paleosols located on the highs are overlain by coal (Plate 2, control points 3 and 4, 8 through 10); paleosols located in lows are overlain by the gray mudrock (control points 7 and 12).

Topographic highs were exposed and pedogenically altered as base level lowered at the end of an earlier cycle. The lows may not have been exposed, subsequently; soils did not readily form in them. Parts of the basin that had a higher topographic relief, such as C1 in Leavenworth County, Kansas, and areas along the flanks of the Nemaha Anticline (control points 13 to 15), are located where the paleosol is directly overlain by the V-shale.

The Croweburg coal also has a patchy distribution throughout the Cherokee and Forest City basins (Plates 2 and 3). Throughout this part of the study area, the coal has an average thickness of 30.5 cm, and in each well examined the coal was observed to overlie the paleosol (see Plates 1, 2, and 3).

In the Cherokee Basin, the coal may be overlain by the gray mudrock or the V-shale. In the east (Plate 1, control points 1-4) the coal occurs in lower areas and is overlain by the gray mudrock. Where the coal occurs on highs (control points 5, 8-10; Plate 2), it is overlain by the V-shale (Plate 2, control points 5, 8-10).

The Bourbon Arch separated the Cherokee and Forest City basins (Plate 3). Huffman (1991) speculated that the Bourbon Arch might have affected the deposition of coal in the Upper Cherokee. Indeed, the Croweburg coal occurs on the Bourbon Arch in this study (Plate 3, control points 6b and 6c), and the coal occurs as far north as control point 6D in the Forest City Basin.

Coal did not form on or near the Nemaha Anticline along the transect (Plate 2) and was not observed in any of the wells near this structure. The western extent of the Croweburg coal in the Cherokee Basin is at control point 10. Conditions near the Nemaha Anticline were probably not conducive to coal formation because of erosional runoff from the Nemaha Anticline. Influx of sediment from the structure might produce a "failed-coal" or carbonaceous shale (McCabe, 1984). In addition, fresh water runoff, derived from the land, would create oxygenated conditions, which would speed decomposition of organic matter.

The gray mudrock, in the Cherokee and Forest City basins (Plates 1, 2, and 3) occurs between the overlying V-shale and the underlying coal or paleosol. It was deposited in the topographically low troughs, between raised platforms (see Plates 1,2, and 3).

Deposition of the gray mudrock began following the accumulation of peat, and, in certain instances, it may have been contemporaneous with the peat. In Plate 2, the gray mudrock directly overlies the coal; deposition of the gray mudrock presumably immediately followed the peat. At control points 5 and 8 through 10, the coal is not overlain by the gray mudrock, which suggests that peat may have continued to accumulate on high platforms while the gray mudrock was being deposited in lower areas.

The gray mudrock did not overstep the coal entirely. This explains the contact between the

Croweburg coal and overlying V-shale. As the transgression continued, peat accumulation continued on higher areas. Consequently, in some areas, such as control points 8-10 on Plate 1 and 6C-D on Plate 3, the accumulation of coal-forming peat may have been contemporaneous with deposition of the gray mudrock.

The gray mudrock probably was deposited rapidly because the roots of lycopods (*Stigmaria)* have been found in vertical position (MS 1, Plate 1 and 2). In addition, an abundance of plant debris is integrated into the lower part of the mudrock at the coal-mudrock contact. This is suggestive of mixing by a transgressive sea.

The V-shale is ubiquitous throughout the study area and always underlies the Verdigris limestone. It is a very persistent and recognizable unit, exhibiting a highly radioactivity gamma-ray/neutron signature.

In the Cherokee Basin, the V-shale overlies the gray mudrock, coal, or paleosol, as noted above. Two discontinuous concretionary limestone units in the V-shale occur at control points 1 and 2 (see Plate 2 and 3). The occurrence of the lower concretionary layer is sporadic (control points 3, 4, 6, and 13-15), yet it appears more persistent than the upper concretionary unit.

The V-shale was deposited across the Bourbon Arch, the first unit to be deposited over this subtle structural feature (Huffman, 1991). Northward, at C1, the V-shale is dark gray and becomes silty.

The V-shale is recognized on the Nemaha Anticline (Plates 1 and 2). In the south, the Nemaha appears to be uneven with high ridges and low saddles. At the time the V-shale was deposited, the transgressing sea circulated between the Cherokee and Sedgwick basins through the low saddles, and the V-shale was deposited in these lower areas. Prior to this transgression, the Nemaha formed a barrier between the Cherokee and Sedgwick basins.

Facies of the Cherokee and Sedgwick basins merge along the flanks of the Nemaha Anticline. Evidence for this is: (1) a similar radioactive signature, and (2) the continuation of the lower concretionary layer, which crosses the Nemaha Anticline and continues across the Sedgwick Basin transect (Plate 2) to the Central Kansas Uplift.

In this study, the persistence of the Verdigris limestone is equal to the V-shale. It is present at all control points and overlies the V-shale.

In the Cherokee Basin (Plate 2), the Verdigris limestone becomes thicker (increasing from 65 to 100 meter thick) toward the Nemaha Anticline. It also gradually becomes a more siliceous carbonate along the transect (209 km), from east to west.

To the north (Plate 3, C1), in the Forest City Basin, the Verdigris thins to 40 cm. The pedogenic appearance of the Verdigris at C1 suggests evidence of subaerial exposure (see core description). Pedogenesis probably occurred when sea level lowered sufficiently to expose the limestone although other parts of the basin apparently remained submerged because the Verdigris limestone was not pedogenically altered along the outcrop belt (Plate 1).

Sedgwick Basin.--Lee and Merriam's (1954) cross section through part of the Sedgwick Basin (east to west) shows little variation in the thickness of the Cherokee Group and no topographic irregularities. In this sense, the Sedgwick Basin is different from the Cherokee Basin.

The paleosol extends across the Sedgwick Basin (Plate 4) and is overlain either by a trace of coal (control point 20)(Adkison, 1963) or the V-shale. The occurrence of coal is spotty and confined to the north, near the center of the basin.

The presence of coal suggests that conditions in the northern Sedgwick Basin may have been similar to those in the Cherokee and Forest City basins. Influx of sediment from erosion of surrounding structures (Figure 6) may have resulted in a scarcity of coal deposits. Similar conditions have been suggested along the Nemaha

Anticline in the Cherokee Basin. Killen (1986) reported that sediment derived from the Central Kansas Uplift and the Nemaha Anticline was deposited in the northern part of the basin. This deposition may have led to "failed-coal" swamps (McCabe, 1984). It also explains the silty texture of the study interval in this basin (see Plate 4).

In the northern Sedgwick Basin, the V-shale thins to approximately 2 meters (Plate 4). It grades upward into the overlying limestone, and the radioactive signal, on geophysical logs, diminishes. Although the V-shale appears dark to medium gray in this section, Killen (1986) reported a more radioactive V-shale in the southern part of the basin.

The Verdigris limestone is very sandy on the Nemaha Anticline (Plates 2 and 4). Farther west, in the Sedgwick Basin, the Verdigris becomes a cherty limestone nearly two meters thick and it is split by a shale parting.

Hugoton Embayment of the Anadarko Basin.--In the Hugoton Embayment (Plates 5, 6, and 7), distribution of the paleosol is erratic. Near the Central Kansas Uplift it overlies a quartz arenite (C3) or mudrock (C4), which were probably the parent materials. Farther west in the Hugoton Embayment, the paleosol overlies a carbonate (C5 and 6), which is likely the parent material. The V-shale directly overlies the paleosol at all control points where the paleosol is present.

Uneven topographic relief and the topographic relationship of it to the other basins are thought to be partly responsible for the scattered distribution of the paleosol in the Hugoton Embayment. Merriam's (1963) sections across the Hugoton Embayment and structure contour maps from Cuzella et al. (1994) show how the Cherokee varies in thickness over an irregular lower surface. This irregular relief is probably a remnant of the tectonism from movement along the Central Kansas Uplift early in the Pennsylvanian Period (Youle, 1992).

Coal was not found in the Hugoton Embayment. Coaly fragments were described by Howard (1990) near the base of the V-shale (Plate 3, point 28). The presence of these fragments suggests reworking of organic detritus. Sediment eroding from the structure would have inhibited the formation of coal.

Farther west (Plate 6 and 7), the V-shale again becomes more radioactive and conspicuous. On the Central Kansas Uplift (C3), it is silty (Nodine-Zeller, 1981; Howard, 1990) and has a green and maroon color (Howard, 1990). It overlies a sandy paleosol on the western limb of the uplift and becomes more calcareous westward in the basin.

A thin limestone unit is present in two cores (C5 and C6) near the base of the black shale (Plates 6 and 7). Black shale overlies and underlies the bed; a shell lag is also noted in the geologist's report from C6, and one was found at the same stratigraphic level in C5, the Pendleton core. It is possible that these may be related to the limestone concretionary layers observed in the Cherokee and Sedgwick basins, although there is no evidence for a this presumption.

The Verdigris maintains a thickness of 2-3 meters and is split by a thin, calcareous shale (Plate 6) along the transect.

THE LITHOLOGIC CHANGES

The lithologic changes of the study interval occur on two scales: (1) as local compositional changes that occur on and near prominent structural features, and (2) as regional changes across the study area. To understand the depositional controls on the units of this interval, it is necessary to investigate both the local and regional changes.

<u>Local changes.</u>--Local compositional changes tend to be subtle and restricted to small areas, generally around

structural features or where the unit approaches an inferred shoreline. Examples of these types of changes within and between each basin will be discussed in the following section.

The Bourbon Arch controlled deposition of the lithologies beneath the V-shale, forming a topographic high on which the paleosol and Croweburg coal developed. South of the positive structure (Plate 3), the gray mudrock was deposited in a low-lying area.

North of the Bourbon Arch, in the Forest City Basin, the interval becomes shallower (Plate 3, point 6F). This interpretation is based on: (1) thinning of the interval, (2) lithologic changes of the units, and (3) pedogenesis of the Verdigris limestone. Lithologic changes in the interval are most apparent in the V-shale. The shale is both calcareous and silty, grading upward into the overlying limestone. Pedogenesis of the Verdigris limestone occurs in this part of the basin, but not in the outcrop belt (Plate 1), suggesting that when base level lowered, one part of the basin was subaerially exposed (C1), while the rest of the basin was under water (Plate 1). This indicates that C1 was located in a shallower part of the basin, possibly near a shoreline. It may also suggest that there was a lag during regression between the Forest City Basin and the Cherokee Basin.

Along the Nemaha Anticline (Plate 1), each of the lithologies is affected by eroded detritus; sediment shed from the structure is most likely the source of this detritus. The paleosol, located between points 12-15 was observed to be sandier, on geophysical logs, than the paleosol underlying the coal at control points 1 to 5 on Plate 1. In addition, siliciclastics increase in the V-shale and Verdigris limestone near the Nemaha.

Composition of the paleosol is not affected by erosion of sediment shed from the Nemaha Anticline in the Sedgwick Basin (Plate 4). Descriptions from geologist reports indicate that it may have had a similar texture and composition to the paleosol underlying the Croweburg coal in the Cherokee Basin.

The trace of coal described by Adkison (1963) lies directly over the paleosol in the middle of the transect (point 20). Adkison (1963) reported several occurrences of coal (No. 1 Peltzer, NE NE SE Sec. 15, T. 26 S., R. 3 W., No. 1 Haines C SW SE Sec. 24, T. 24 S., R. 8 W., and No. 1 Milburn SE SE SW Sec. 5, T. 25 S., R. 5 W.) in this part of the basin; he also noted an increase in siliciclastics to the north. From examination of drill cuttings, Killen (1986) observed an increase in siliciclastics in the north and attributed this detritus to erosion from the Nemaha Anticline and the Central Kansas Uplift. The section in the west (Plate 4, control points), along the limb of the Central Kansas Uplift, contains more siliciclastics.

The V-shale thins over the Nemaha Anticline, and gamma-ray response indicates that the V-shale is less radioactive farther to the west in the Sedgwick Basin (Plate 3). Construction of the transect (Plate 2) through the Cherokee Basin may have been at a different topographic position than the transect through the Sedgwick Basin. The Cherokee Basin was slowly sagging (Huffman, 1991), creating a basin with greater accommodation space for deposition of V-shale. The northern part of the Sedgwick Basin was generally shallow with less accommodation space because the basin did not sag (Killen, 1986). This explains both the thinning of the V-shale and its diminished radioactivity.

The V-shale tends to be dark to medium gray and more calcareous in the upper part, near the base of the overlying Verdigris limestone. The change is most noticeable closer to the Central Kansas Uplift where it onlaps, but does not overstep the Central Kansas Uplift.

The Verdigris limestone is sandy on the Nemaha Anticline and grades into a cherty carbonate in the west into the Sedgwick Basin. The chert may be a secondary deposit, precipitating from ground water rich in dissolved silica. The transition between sand and chert is marked by a thickening of the limestone and thinning of the V-shale to the west. Eroded sediment from the Central Kansas Uplift was deposited with the limestone (Killen, 1986), along the eastern limb of the structure (Plate 4, point 23-26).

Sediment from the Central Kansas Uplift also was deposited along its western limb (Plate 5, point 27-29). The paleosol in this area is very sandy (C3), considered a quartz arenite by Howard (1990), and may have developed from a channel deposit cut by streams flowing off the uplift. This interpretation is based on its lithology as well as the reported sedimentary structures (see core description).

Elsewhere in the basin, the paleosol probably developed from a carbonate (C4, C5, and C6). This was determined by examination of wire-line logs (Plate 5). Where the carbonate underwent pedogenesis, the V-shale overlies a calcareous paleosol (Plate 5, points 35, 37, 39-42, 45-50; Plate 6, points 31C and E; and Plate 7, points 44D-44E). In places where the paleosol was not recognized, the V-shale overlies a thick limestone unit.

On the highlands of the western limb of the Central Kansas Uplift (Plate 5, control points 27 and 28), the V-shale is silty with a low gamma-ray signature. The diminished radioactivity of the shale is probably due to an influx of eroded sediments from the Central Kansas Uplift.

South of the Hugoton Embayment (Plate 6, C5), gamma-ray logs show the V-shale to be less radioactive, and it is thin at control point 31D (Plate 5), grading upward into the overlying Verdigris limestone (point 31E). A similar phenomenon was noted in the Sedgwick Basin. Gradation of the V-shale into the Verdigris limestone may be indicative of a rise in base-level, change in climatic conditions, increased circulation throughout the basins, or some combination of these. Each of these would result in a change in water chemistry, and possibly an increase in carbonate productivity.

On the flanks of the Central Kansas Uplift, the Verdigris limestone resembles a calcareous sandstone (Plate 5, point 27). Westward along the transect, the unit grades from a sandy carbonate (points 28 and 29) into a cherty limestone. This lateral gradation in composition appears to occur along the flanks of both the Central Kansas Uplift and the Nemaha Anticline in the Sedgwick Basin (Plate 4) and Hugoton Embayment (Plate 5). Driller's logs report an oolitic texture in the Verdigris limestone between control points 35 and 42.

Regional changes.--Regional changes are readily identifiable across Kansas. Lithologies most affected are the paleosol(s) and the Verdigris limestone. These units appear to be most sensitive to fluctuations in base level and climate.

Lowering of base level may expose parts of a basin to pedogenesis; subsequently, a rise in base level may flood exposed surfaces. Fluctuation in base level may move the photic zone, change the circulation and chemistry of sea water, and alter productivity.

Using the classification scheme from Retallack (1990), several types of soil were interpreted from paleosol features in this study.

In this study the paleosol(s) was/were interpreted to exhibit a range of characteristics associated with vertisols, entisols, and a histosol. From the descriptions of paleosol outcrops and cores throughout the study area, the vertisol was categorized as a wet, clayey vertisol or a dry, calcareous vertisol (Figure 12). The Croweburg coal is represented by a histosol, and the presence of an entisol was interpreted from core data, combined with the response of geophysical logs near the core location. Paleosols examined in outcrop and core were readily categorized; descriptions from field reports and wire-line log data required inference as to possible soil order.

The wet vertisol and the histosol are exposed in southeastern Kansas and western Missouri (Plate 1) in the Cherokee Basin. The outcrops (see measured sections) are thick, clayey, and contain long (up to 1 meter) mukkara structures. The wet vertisol is predominantly composed of quartz, illite, and kaolinite; samples taken from outcrop "show very little down-section variation" in content (F. Dulong; personal communication, 1995). This vertisol probably formed from a mudstone.

The wet vertisol and the histosol are thought to extend from the outcrop in southeastern Kansas (Plate 2) to control point 10 in the Cherokee Basin. On Plate 3, the vertisol is inferred to extends north from the Bourbon Arch (control point 6B) to the Orville Edmond core (C1, control point 6F). The texture of the vertisol changes slightly along this transect (Plates 1) from a silty claystone to mudstone. In northeastern Oklahoma, the texture is that of a very sandy mudstone.

The wet vertisol is unaffected by any large structures in southeastern Kansas with the exception of the Nemaha Anticline. Driller's logs report a lithologic change from a predominantly clayey to sandier texture at control points 11 through 16 (Plates 2 and 4), which may indicate the influence of the Nemaha on soil development. This sandier paleosol is inferred to be an entisol, which could have formed on the eroding flanks of the Nemaha Anticline.

In the north and central part of the Sedgwick Basin (Plate 2, points 16 through 24), geologist reports and driller's logs describe a mudrock with features similar to those of the wet vertisol described in the Cherokee Basin. Closer to the Central Kansas Uplift, the wet vertisol in the Sedgwick Basin may grade into an entisol. This transition was not directly observed, but based on a high gamma-ray response from points near the Central Kansas Uplift, it is not unlikely. Retallack (1990) described entisols as forming in variable topographic settings, such as young geomorphic surfaces and steep slopes.

Characteristics exhibited by an entisol, such as very slight degree of soil formation, little-altered sedimentary features (cross bedding and laminae), and some mineral weathering, are apparent on the western limb of the Central Kansas Uplift (Plate 5, points 27 through 30) and from C3. The entisol is presumed to have developed from a channel sand on the highlands. Possible evidence for a higher topographic position, is based on the silicic character of the study interval at C3 on and near the Central Kansas Uplift. In this study entisols are associated with prominent structural features.

Where the paleosol overlies a carbonate in the western part of the Hugoton Embayment (Plates 3, 5, and 6), it resembles a dry, calcareous vertisol because it is a calcareous mudrock containing rhizoliths, inferred root traces, large, rounded peds, and no slickensides

(Plates 6 and 7, C5 and C6). Rhizoliths are indicative of a well-developed soil (Klappa, 1980; Retallack, 1990).

In terms of thickness and composition, the Verdigris limestone is the most variable of all the units in the study interval. From MS 1 (Mary Jane Mine, Plate 1) in western Missouri to the Rebecca Bounds core in northwestern Kansas (Plate 6, C6), the interval increases from 0.65 to 3 meters. It gradually changes from a slightly argillaceous limestone in the east to a cherty, "cleaner" limestone in the west.

Over much of the transect, the Verdigris is affected by prominent structural features; in these situations the limestone displays local compositional changes (see previous section on Local Changes).

The top of the Verdigris shown in Plate 5 (point 31E) is pedogenically altered much like at C1, the Orville Edmonds core (Leavenworth County, Kansas). Thus, it is possible that the top of the Verdigris in some parts of the study area was exposed during the subsequent regression.

THE DEPOSITIONAL HISTORY AND ENVIRONMENTS

Initial exposure.--Deposition of the Croweburg coal-Verdigris limestone interval began with the exposure, and subsequent pedogenesis, of a mudrock in the Cherokee Basin, a siltstone near the Nemaha Anticline and in the Sedgwick Basin, a sandstone on the Central Kansas Uplift, and a carbonate in the Hugoton Embayment. As base level lowered, exposure, combined with climate (discussed in the next section), led to the development of several different soil types across the study area: a wet vertisol, a dry vertisol, and an entisol.

Of the paleosol types inferred over the study area, the wet and dry vertisols had the widest distribution. Presumed root traces observed in the vertisols located in the Cherokee Basin and Hugoton Embayment suggest a vegetated surface in both basins. In addition, the presence of an "O-A" horizon (MS 1 and C1) in the Cherokee and Forest City basins suggests that there was a thick accumulation of organic debris at the top of the wet vertisol.

In eastern Kansas, the vertisol is very clayey, yet there is some carbonate, probably from the original parent material (a fossiliferous mudrock). Brachiopod shells and crinoid columnals were found near the base of the mudrock at MS 1. The dry vertisol in the west is more calcareous and less clayey, having formed from a limestone. The entire paleosol distribution can be explained in terms of clay content of parent material and paleotopography.

Pedogenesis of the parent material in the west may have followed the pedogenic development in the Cherokee Basin. This may be due, in part, to a lag in the timing of regression in the Hugoton Embayment. Extended exposure in the Cherokee and Sedgwick basins may have resulted in greater pedogenic development of soil features. Therefore, it is suggested that the Hugoton Embayment may have been topographically lower, and submerged while paleosols in the Cherokee and Sedgwick basins were forming. No evidence, however, exists to prove this presumption.

Pedogenic alteration of the mudstone was probably rapid, but pedogenesis of more resistant units, like the limestone in the Hugoton Embayment, may have required more time. According to Retallack (1990, p. 109), a vertisol "...may form in only a few hundred years on claystones, shales, or marls...it may take longer for them to form on limestones...". Consequently, it is not unreasonable to expect the early maturation of the vertisol in the east (Plates 1, 2, and 3) compared to slow development in the west (Plates 5, 6, and 7).

Exposure surfaces on the topographic highs were most likely affected by erosion. The lack of strong soil features in C3 implies that erosion and possibly addition of sediment to the entisol were important factors in formation of the soil on the Central Kansas Uplift. Formation of soil features in entisols is generally slight (Retallack, 1990); the features noted in the entisols from the study area were very cryptic (see C3 and C4).

Peat accumulation probably began in the east while the calcareous vertisol in the west was still forming (Plates 3,5, and 6). Pedogenesis in the Hugoton Embayment reached a level of maturity with the formation of rhizoliths, observed in C5 and C6.

Paleopeat swamp.--Accumulation, and preservation of organic debris requires rapid burial in reducing environments, such as found in swamps and marshes. According to Cecil (1990, p. 85), "...the formation of peat requires low suspended and dissolved sediment loads, and large, flat areas that are uninterrupted by contemporaneous clastic sediments and associated channels." As a result, regions of high sedimentation rates are not favorable to the formation of peat.

The Croweburg peat was situated far enough away from detrital sediment sources that it was largely unaffected by sedimentation. As mentioned earlier, topographic irregularities on the depositional surface in the Cherokee Basin are partly responsible for the accumulation of peat. In fact, deposition of sediment, detrimental to the formation of coal, in the low-lying areas may have been coeval with the accumulation of peat on topographic highs.

Vegetation may have accumulated on higher areas. Wright (1975, p. 78) described "...a broad platform on which the swamp could develop." The broad platform Wright mentioned was formed by channel and deltaic sand deposits. In addition, Wright mentioned that topographic irregularities may have influenced the accumulation of peat.

Two types of swamps characterize peat-forming environments: (1) raised peat mires (ombrogenous), and (2) low-lying, "blanket" mires (topogenous) (Cecil et al., 1985). Raised peat deposits, like those found in the modern tropics of Malaysia and Indonesia, are protected from clastic deposition (Cecil et al., 1993). Low-lying, topogenous peats are unprotected and may be easily inundated by coastal flooding. The Croweburg coal probably accumulated in a topogenous mire due its high ash content (20.5 %) and the presence of syngenetic minerals: calcite and pyrite (Cecil et al., 1985; F. Dulong, personal communication, 1995). However, lycopods, generally thought to be associated with the acidic, ombrogenous swamps (Cecil et al., 1985), were reported by Howe (1956).

Although it is considered a topogenous mire in this study, the Croweburg coal formed on slightly raised areas (Plates 2 and 3). This is evident from geophysical data and the stratigraphic position of the members in the study interval across the Cherokee Basin. Brady (1988) documented a positive feature associated with the Croweburg coal (Figure 15) from the high wall of the Big Brutus Mine (MS 9) in Cherokee County, Kansas. At this locality, the overlying gray mudrock thins over the positive feature and varies in thickness (from 0.3 to 2.6 m). At the top of the positive structure, the gray mudrock contains carbonaceous debris, probably reworked from the peat swamp.

Climate is an important factor in the formation of peat. McKee and Crosby (1975, p. 18) speculated that the climate during deposition of the Croweburg peat was "persistently humid" with little variation in temperature. Lycopods (*Stigmaria)* grew among the dense vegetation of the Croweburg peat swamp (Howe, 1956).

An important aspect of climate for this period concerns base level. During development of the paleosols, base level was low; as the Croweburg peat accumulated, base level rose. A combination of high amounts of precipitation and an increase in base level resulted in a high water table. Waterlogged conditions, resulting from a high water table, preserved organic debris, forming the Croweburg peat.

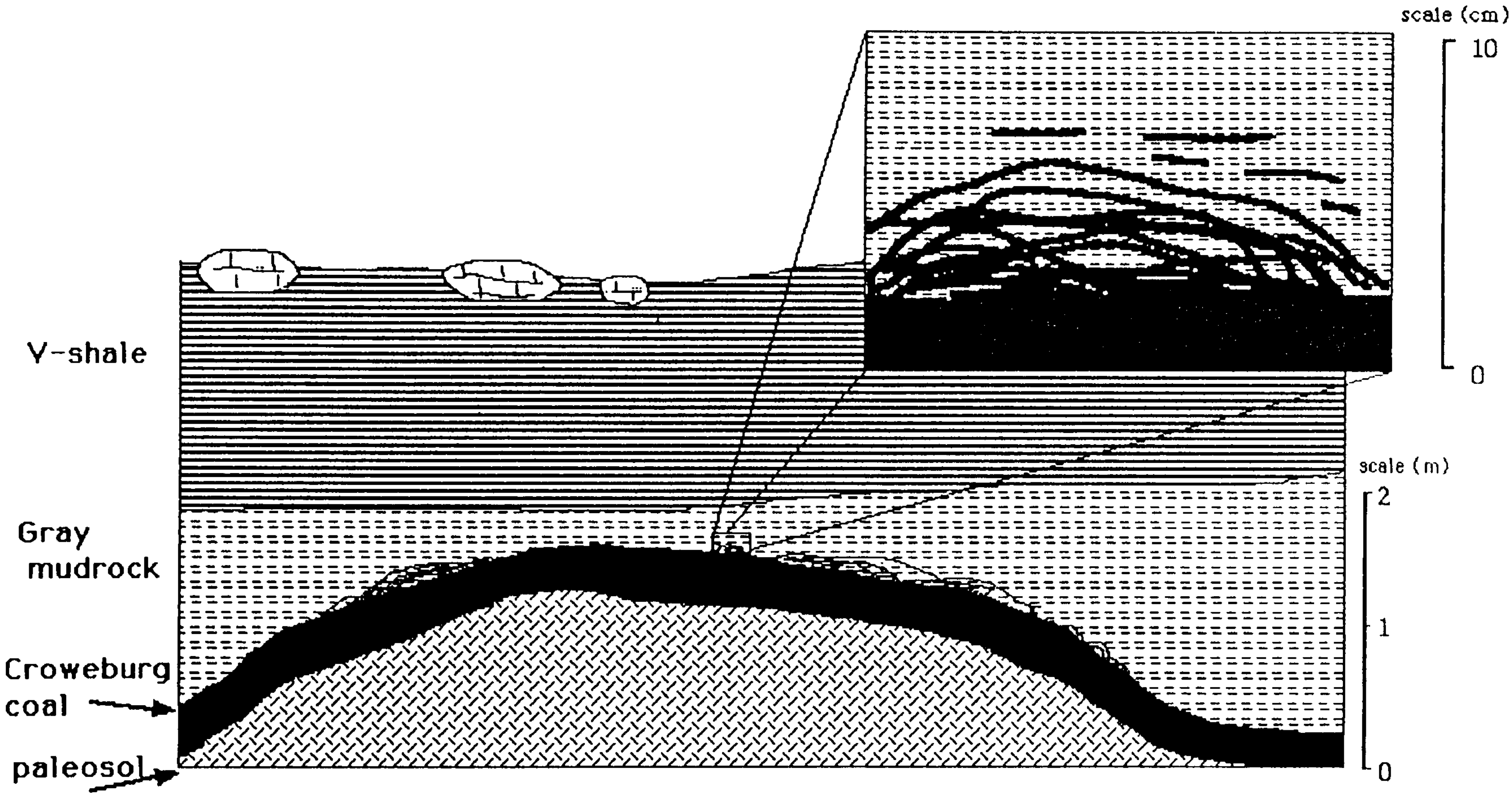


Figure 15. Schematic diagram of the positive Croweburg coal feature (MS 9), measured along the highwall of Mine 19, also known as the Big Brutus locality (NE SE NE Sec. 7, T. 32 S., R. 23 E., Cherokee County., Kansas). The boxed area shows carbonaceous debris that has been reworked during the deposition of the gray mudrock.

Tidal Influence.--Based on marine fossils, laminations, and association with peat deposits, the gray mudrock could have been deposited in a nearshore tidal environment. Rise of sea level drowned swampy inlands, flooding low-lying basinal areas, and exerting a tidal influence on the deposition of sediment.

The gray mudrock was deposited over the uneven floor of the Cherokee Basin in low-lying areas which accommodated the inundating sea. As the Cherokee Basin slowly sagged, the gray mudrock filled topographic lows, being deposited on the Croweburg coal. Along an extensive tract of the Mary Jane Mine (strip pit), MS 1, (approximately 200 meters), the "pod-like" or lenticular shape associated with tidally deposited, gray shales, as noted by Archer and Kvale, (1993) is apparent.

Deposition of the mudrock is thought to have followed peat accumulation (Plate 2, control points 1-4), and in some cases, it may have been deposited contemporaneously with the peat (Plate 2, control points 5, and 8-10; MS 9). Reasons for this are listed below.

(1) The mudrock was observed to form in response to topographically irregular structures (Figure 15). Thick deposits accumulated at some localities (MS 1), but thin over topographically higher, positive features (MS 9). This geometry was observed in the field at MS 1, MS 2, and MS 9 (see figure 15).

(2) The Croweburg coal directly underlies both the mudrock and the V-shale. This is thought to be a result of basin floor irregularities (Plates 1, 2, and 3). Both the Croweburg and Bevier coals tend to be confined to highs (see Plates 2 and 3).

(3) Increase in accommodation space due to subsidence is apparent in the Cherokee Basin in southeastern Kansas and northeastern Oklahoma. The gray shale ranges between 0.3 and 2 meters thick at outcrops in Kansas; the same gray mudrock increases to nearly 16 meters in northeastern Oklahoma. In places where subsidence was occurring, deposition of the mudrock may have been contemporaneous with the coal, which was forming elsewhere in the basin. Overall, rocks between the Excello shale and Verdigris limestone thicken in lows and thin on highs (see Plate 2).

Compaction of the peat combined with sagging of the basin floor provided space for the gray mudrock. Some areas of the peat swamp (located at "highs") were not subject to burial and peat continued to accumulate contemporaneously with deposition of the gray mud (Plate 2, control points 5, 8-10).

Sedimentation rates were high and thick deposits of the mud prograded over the topographically low-lying regions of the study area. Rates for tidalite sedimentation may vary from 1 cm/yr to 1 m/yr (Kvale and Archer, 1990). Trees from the peat swamps were buried in place, and carbonaceous debris was reworked between the underlying Croweburg coal and the gray mudrock contact.

Archer and Kvale (1993) have postulated that some gray muds may have been deposited during the onset of a transgression. The rise in sea level submerged the low-lying areas and as base level continued to rise, the peat swamp was drowned.

Chemical conditions in the basin were acidic. Periodic flooding and runoff from the peat mires lowered the pH of the water in low-lying areas. This attracted a marine invertebrate biota consisting chiefly of mollusks (notably *Dunbarella*) and brachiopods adapted to brackish conditions.

The dry, calcareous vertisol in the west (Plates 5,6, and 7) was probably still forming while the coal and gray mudrock were being deposited in the east(Plates 1,2, and 3). This is supported by the fact that the V-shale directly overlies the dry vertisol in the Hugoton Embayment. There were no other units deposited between the initial exposure and the transgression that deposited the V-shale. The dry vertisol was probably submerged as base level rose and conditions developed that led to the deposition of gray mudrock to the V-shale. The gray mudrock may have been deposited along some of the topographically low areas of the Hugoton Embayment, south of the study area.

Silicilastic Swamp.--McCabe (1984) proposed that peats accumulating adjacent to areas of active sedimentation would be transformed into carbonaceous shales or high-ash coals. Following the deposition of the gray mudrock, transgression drowned the remaining patches of peat swamps and partially oxidized the organic matter. Fine-grained sediment was deposited over the former swamp, which led to the development of carbonaceous shale.

Shortly thereafter, a lack of circulation transformed the shallow sea again into a reducing environment and preserved land-derived organic matter. The V-shale was probably deposited in shallow water based on the association of the black, organic shale with the underlying coal and the concentration of land-derived material.

The high radioactive signature of the shale, especially the uranium content, is believed to be the result of a reducing environment (Doveton, 1988). High concentration of organic matter in reducing environments favor the fixing of uranium. The reducing environment of V-shale preserved organic detritus, resulting in the carbonaceous composition of the black shale; it may have also favored the fixing of the elements responsible for the strong radioactive signature of the V-shale.

The origin of organic matter in the black shale is unknown. Much of it may have been land-derived. Wenger and Baker (1986) suggested that the organic matter in the Excello and Little Osage shales was land-derived. This suggests that peat swamp conditions may not have been completely eradicated at the onset of transgression. Reworking of peat from the exposed swamp coupled with other types of productivity (algal?) may have contributed to the organic content (Zangerl and Richardson, 1963). The Excello shale is the first widespread, carbonaceous, black shale stratigraphically above the V-shale.

Conditions probably fluctuated between anoxic and dysoxic, based on the different shades of gray associated with calcareous and noncalcareous horizons in the shale. During shifts to more dysoxic conditions, benthic organisms, like the corals Howe (1956) reported finding in the V-shale, may have existed, but low pH during anoxia dissolved much of this evidence. Brachiopods, bivalves, and burrowing organisms were common under both conditions. The upper meter of the V-shale in outcrop records a transition from a low-oxygen to a more oxidized, and open marine environment (MS 1, 8, and 9). This is suggested by changes in color (from black to dark gray), bedding (from fissile to blocky), and an upward increase in calcareous content and fossils.

Carbonate Shelf/Lagoon.--Effects of high concentrations of dissolved solids and the low pH associated with the anoxic black shale may have diminished with a rise in base level. Increase of base level aerated the stagnant seas, improved circulation, and greatly increased productivity. In the Cherokee Basin brachiopods, bivalves, corals, and echinoderms were very prevalent and phylloid algae thrived, possibly binding some of the skeletal grains. The energy and productivity of the Cherokee Basin during the deposition of the Verdigris limestone is reflected in the density and diversity of the biota.

Killen (1986) described the Sedgwick Basin as a shallow carbonate platform to the south and a mud flat in the north. Along the transect (Plate 4) in this basin, the Verdigris limestone thickens, suggesting that the transect is south of Killen's proposed mudflat. There are only a few descriptions available from the Sedgwick Basin that mention fossils in the Verdigris limestone. From his sedimentologic study, Killen (1986) described the Sedgwick Basin as a low-energy environment, basing this conclusion on the ratio of mud to larger grains associated with Cherokee rocks and the amount of energy that might have distributed sediment throughout the basin.

The Hugoton Embayment was a shallow carbonate platform. Thick carbonate deposits in the basin suggest that productivity was very high. Oolites found within the basin (Plate 5, control points 35-42) indicate that the energy within the Hugoton Embayment also was high, and that this part of the basin was shallow. Descriptions from cores (C5 and C6) indicate that the limestone in the Hugoton Embayment contained many of the same fossils found in the Cherokee Basin: *Crurithyris*, *Mesolobus*, marginiferids, gastropods, fusulinids, and crinoid columnals.

Although the limestone from the Cherokee Basin and Hugoton Embayment may have had a similar biota, several differences distinguish them. In eastern Kansas, the Verdigris is thin, coarse-grained, and contains abundant phylloid algae; in western Kansas the Verdigris is massive, fine-grained, and lacks phylloid algae. Comparison of these limestones suggests a difference in energy and productivity and possibly a difference in water depth between the basins.

THE ROLE OF CLIMATE

Data collected in this study from measured sections, cores, and geophysical logs, make it possible to infer the role of climate.

The influence of climate is apparent in both vertical and lateral successions of lithologies. It has been proposed that some lithologic changes can possibly be explained by climatic fluctuations (Donaldson et al., 1985; Schutter and Heckel, 1985; Cecil et al., 1985; Cecil, 1990; Roth, 1991; Archer and West, 1993).

The lithologic changes discussed herein are thought to have developed as a shift in a climate gradient occurred, from wet to drier conditions. This shift may be related to the overall movement of North America throughout the Pennsylvanian-Permian periods away from an equatorial position to higher (northerly) latitudes (Cecil, 1990).

Vertical Succession.--The vertical succession of changing lithologies suggests a strong influence of climate. This statement can be made about the vertical succession anywhere along the transect. From Cecil's (1990) model, climate curves of the study interval in each basin (Figures 16a, b, and c) were constructed. Each curve illustrates a trend consisting of long-wet and short-dry seasons grading into short-wet, longer-dry periods. Influence of the structural features on compositional changes are not reflected in the climate curves.

The paleosols in this study formed from either mudrocks or carbonates. These parent materials are interpreted as the last units to be deposited prior to exposure and pedogenesis, and thus record the initial

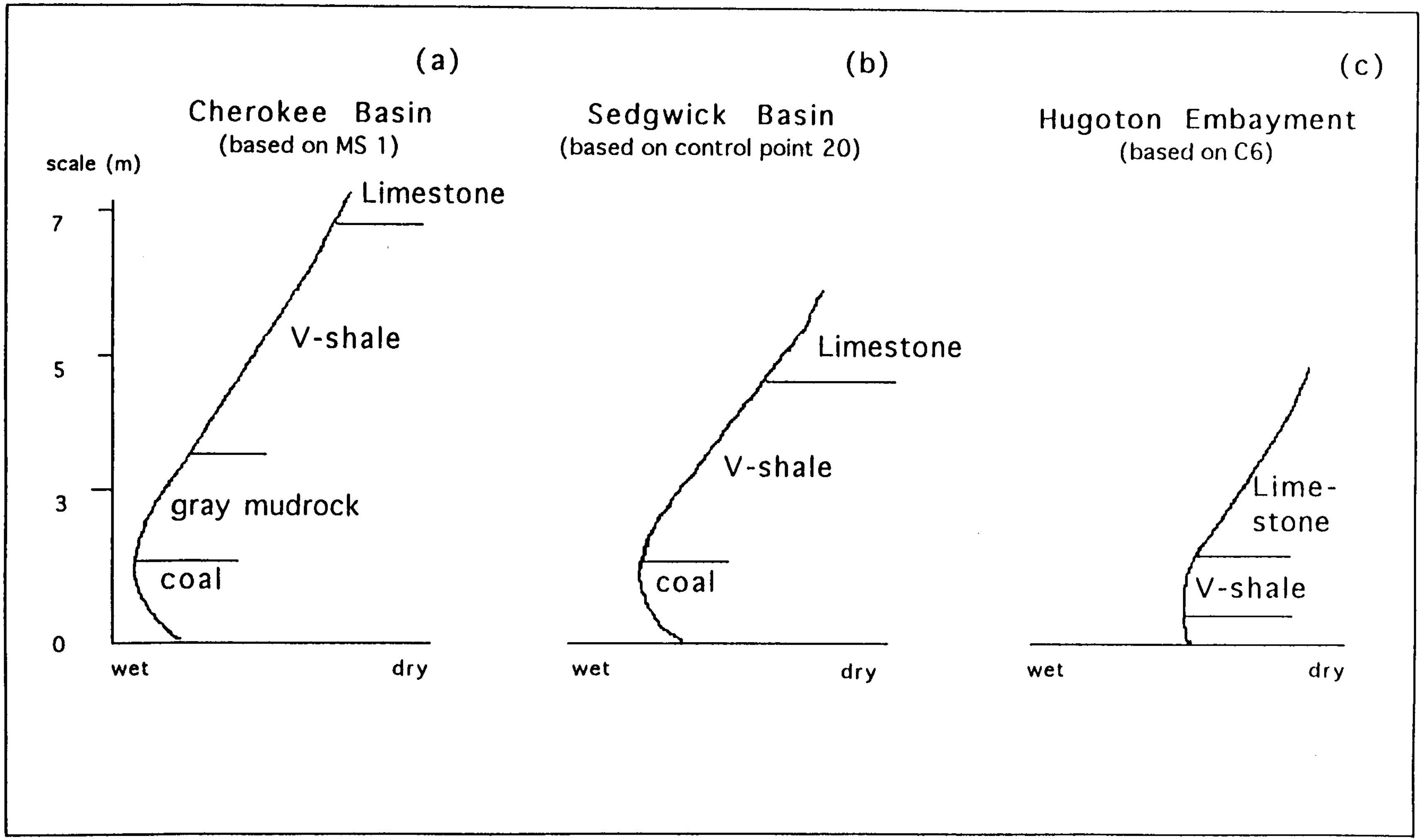


Figure 16. Relative Wet-Dry climate curves for (a) Cherokee Basin, (b) Sedgwick Basin, and (c) Hugoton Embayment, constructed from lithologic changes in the vertical succession of the study interval. Based on Cecil (1990) and Cecil et al. (1995) model of sedimentological response to climate.

climate phase for the region. In the east (Cherokee Basin), the initial climate was probably seasonal in that a fossiliferous mudrock begins the cycle as the parent material for the wet vertisol. According to Cecil (1990) a mudrock is indicative of long wet and short dry conditions. Farther west, in the Hugoton Embayment, the presence of a carbonate parent material suggests a drier initial climate.

The vertical succession of lithologies in the Cherokee and Sedgwick basins are alike and suggest that the basins probably experienced similar climatic conditions. Therefore, the following section will refer to the combination of the basins and the respective climate curves (Figures 16a and 16b).

Formation of a clayey vertisol from a fossiliferous mudrock marked the lowering of sea level and the partial exposure of the floors of the Cherokee and Sedgwick basins. Development of the paleosol was rapid as the amount and distribution of precipitation increased.

As precipitation continued to increase, certain types of vegetation adapted to waterlogged conditions, like lycopods and possibly *Calamites*, took advantage of the higher water table. This led to the development of an "O-A" horizon at the top of the vertisol; the "O-A" horizon documents the accumulation and preservation of organic matter under waterlogged conditions (Soil Survey Staff, 1975; Retallack, 1990).

A more equable distribution of precipitation is evident from the development of a histosol, or the Croweburg peat, on top of the wet vertisol. The climate phase was probably long-wet with short-dry periods. Cecil (personal communication, 1995) proposed that the "wet" phase, number of months that rainfall exceeded evapotranspiration, associated with the Croweburg coal was between 9-10 months. Under favorable conditions, the histosol probably accumulated to a thickness of 2.5 to 6 meters (estimated from a 10:1 compaction ratio for peat to coal).

Transition from wet equable to a more seasonal phase (Figure 16a and 16b) is represented by the siliciclastic units between the Croweburg coal and the Verdigris limestone. The gray mudrock may have been contemporaneous with peat accumulation; although it represents a transition to more seasonal conditions. The climate during deposition of the upper part of the V-shale probably was less "wet" because the V-shale underlies and grades upward into the Verdigris limestone. According to Cecil's (1990) model (Figure 8), the V-shale would have been deposited under monsoonal conditions with fewer wet months than the tropical rainy climate of the coal. Transition of this is recorded by an increase of small scale, calcareous (less anoxic conditions) and noncalcareous beds in the upper part of the V-shale (Figure 17). These calcareous-noncalcareous beds may represent small scaled cycles also related to climate change.

A meter below the Verdigris limestone contact, the V-shale consists of interbedded calcareous and noncalcareous layers (Figure 17). Because of the fossils collected at some of the exposures (MS 1, 2, 8, and 10), these horizons are believed to be indicative of greater circulation and open marine conditions. A rise in base-level may have temporarily raised the pH of the stagnant, anoxic sea, improved circulation, and oxygen conditions in the environment, making it more conducive to productivity.

Although the climate was becoming drier (Figures 16a and 16b), base-level was rising. Rise in base level may have been a glacio-eustatic response to global warming or tectonically driven. The change from wet to dry climates may be attributed to a shift in climatic gradient. This shift records the demise of wet conditions in or near the Intertropical Convergence Zone to drier conditions in the Cherokee and Sedgwick basins. Eastern Kansas experienced wet conditions during the deposition of the wet, clayey vertisol, Croweburg coal, and siliciclastics, and drier climatic conditions during the deposition of the Verdigris limestone. The climatic

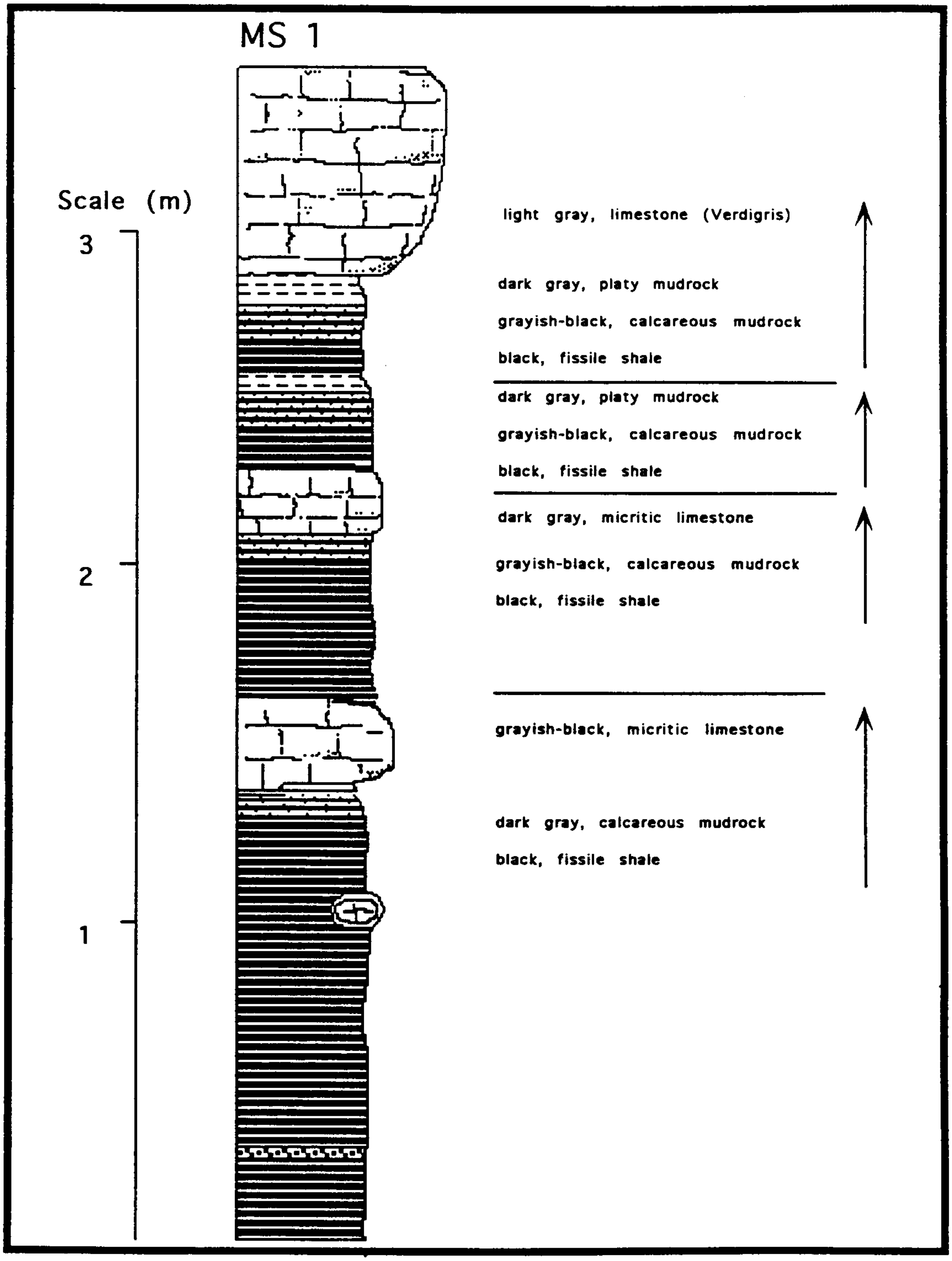


Figure 17. Small scale calcareous/noncalcareous cycles in the Black (V)-shale. These cycles probably represent changing environmental conditions, from anoxic to more oxygenated, possibly of wetter to drier conditions. Arrows delineate where the cycles occur. This section was measured in the Mary Jane Mine, MS 1 (SW Sec. 31, T. 35 N., R. 33 W., Vernon County, Missouri).

phase for this cycle consists of long-wet to short-wet conditions (Figures 16a and 16b).

The end of the cycle is marked by a shift in the climatic gradient. Pedogenesis of the fossiliferous mudrock directly overlying the Verdigris signifies the onset of a new climatic cycle.

From the data collected in the Hugoton Embayment, it is reasonable to assume that the western part of the state did not receive the same amount of precipitation as eastern Kansas. In fact, the climate curve (Figure 16c) for the Hugoton Embayment records a drier initial climate than eastern Kansas. This is suggested by the presence of the dry, calcareous vertisol and the absence of the Croweburg coal and gray mudrock from the vertical succession of lithologies.

The Hugoton Embayment was a site of drier climates prior to the start of the Croweburg coal-Verdigris limestone cycle. Evidence of this is conveyed in the thick limestone deposits beneath the study interval. Also, the dry vertisol is proposed to have formed from this underlying carbonate. Drier conditions in western Kansas were probably due to its initial distance from the Intertropical Convergence Zone.

Prolonged development of a calcareous vertisol from a resistant carbonate parent material is indicative of lower regional precipitation. Given that vertisols may develop in semi-arid environments (Retallack, 1990; Mack et al., 1994), it is reasonable to assume that the dry, calcareous vertisol of the Hugoton Embayment represents a drier initial climate.

An increase in base level affected the basin about the time the V-shale was being deposited. Marine transgression submerged the paleosol and buried it under dark gray to black mud. As in the Cherokee and Sedgwick basins, deposition of siliciclastics signified a transition from a longer wet phase to drier conditions.

The stagnant, anoxic V-shale records a gradational vertical change similar to that observed in the Cherokee and Sedgwick basins. Climate changes in the Hugoton Embayment may have occurred earlier and may have lasted longer than changes in eastern Kansas. Evidence for this is based on the low gamma-ray response near the top of the V-shale, a notable, westward thinning of the shale and the thickening of the Verdigris limestone. The tremendous accumulation of Verdigris limestone in the Hugoton Embayment is due to a transition from wet (deposition of V-shale) to drier conditions associated with the carbonate.

In the Hugoton Embayment, the Verdigris limestone reached a thickness of nearly 3 meters. Reports of oolites in the carbonate suggest that the climate was warm and dry during deposition of the Verdigris. This accumulation occurred as western Kansas moved from a dry seasonal climate to a drier climate at higher (northerly) latitudes. Eventually, sea level dropped again, exposing and pedogenically altering the limestone along the margins of the basins (C1 and C5). This marked the end of the cycle and the advent of a new one.

Lateral Succession.--Comparison of individual lithologies from the time-slice reveals subtle changes (Figure 18) from east to west. These changes are significant because they show trends that are visible over an extended area and at a particular time. The lateral component of the rock record shows the transitional lithologic changes occurring between data control points. This produces a more complete stratigraphic understanding of the study interval and may reveal the possible processes affecting deposition.

Major differences between the Cherokee and Sedgwick Basins and the Hugoton Embayment consist of a spectrum of paleosol types across the transect, decreased distribution in the thickness and extent of coal in the west, lack of gray mudrock in the west, and a westward thickening of the Verdigris limestone. These differences are attributed to unevenly distributed precipitation and water table position. The absence of gray mudrock in the Sedgwick Basin and Hugoton Embayment is probably due to the selection of transects across topographically higher parts of the basin. The gray

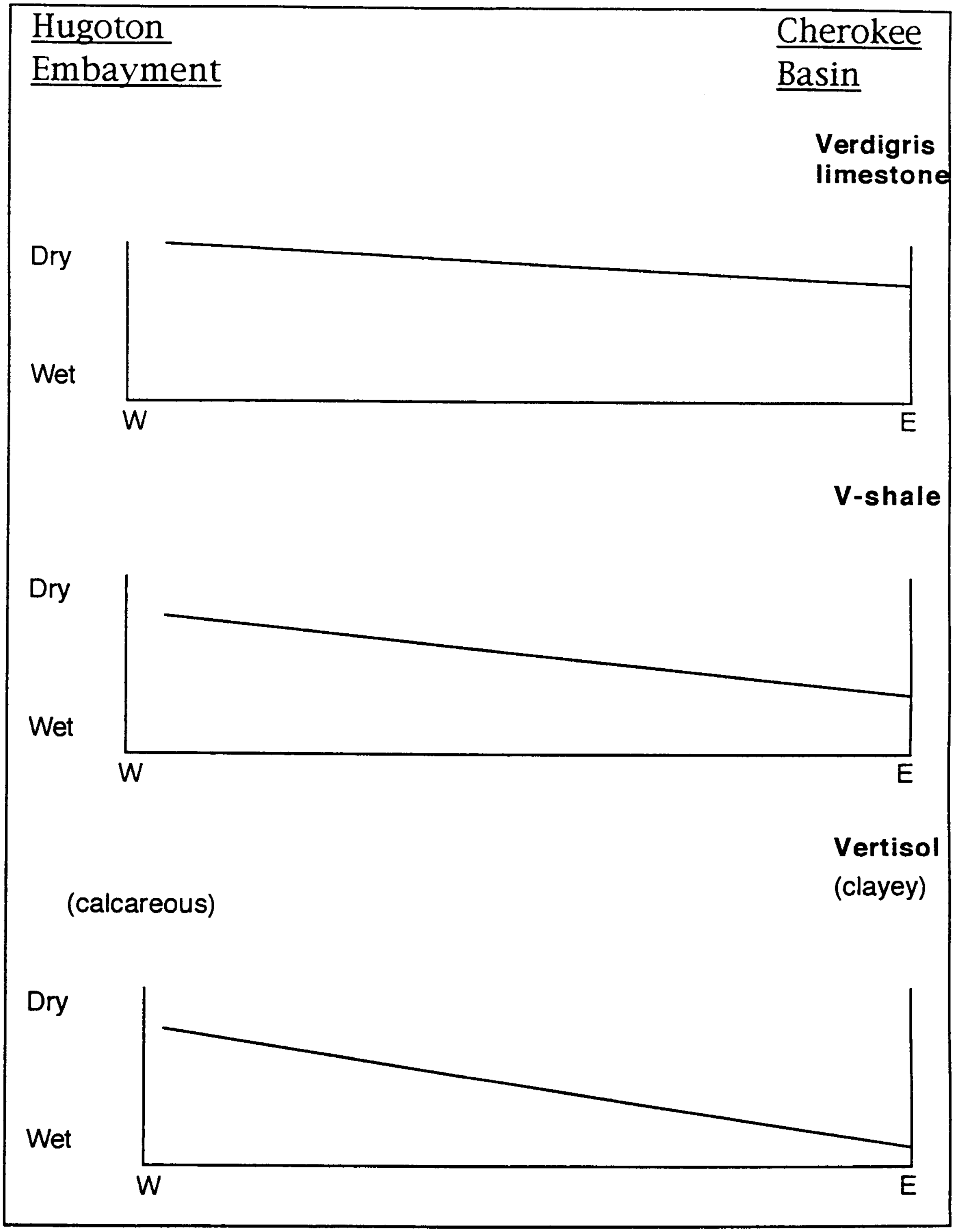


Figure 18. Gradation of relative Wet-Dry conditions for individual lithologies from the Cherokee Basin to the Hugoton Embayment of the Anadarko Basin. Based on the regional lithologic changes using Cecil's (1990) model.

mudrock was probably deposited as the basin sagged, in low-lying areas, and in some instances, contemporaneously with the coal.

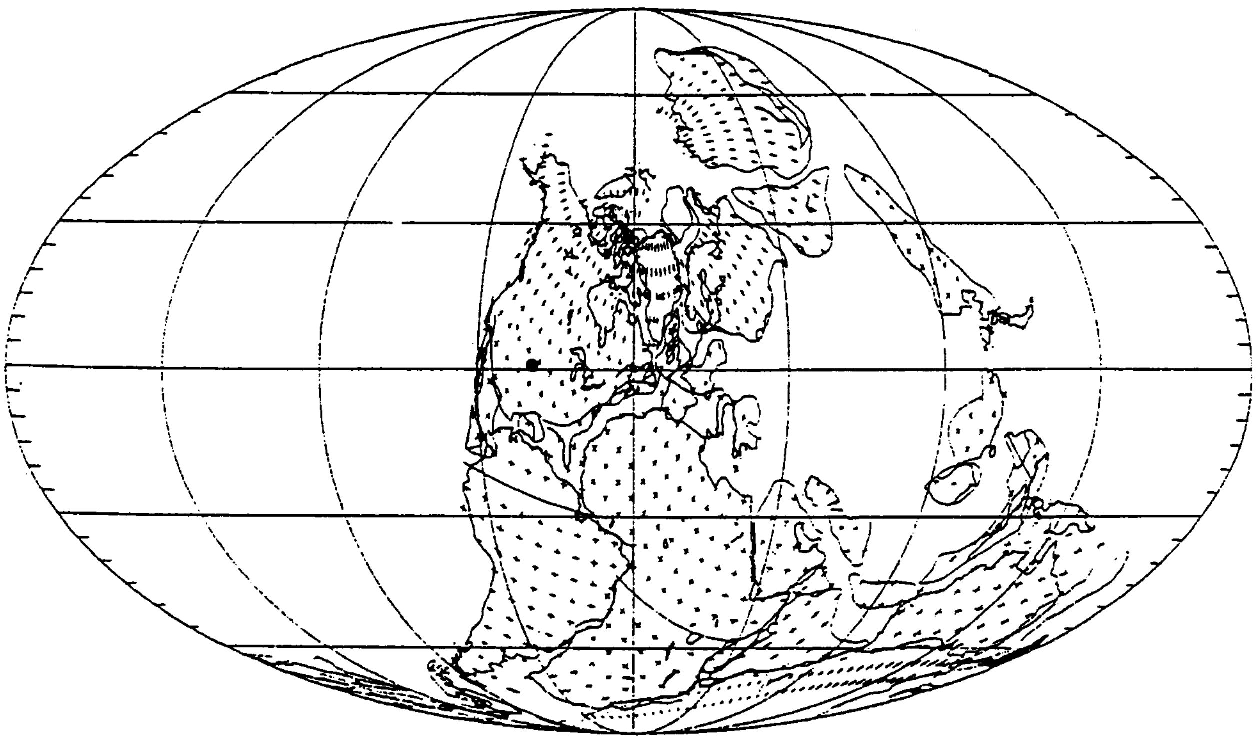
Across the transect, the paleosols record a spectrum of characteristics. Composition of the wet, clayey vertisol in the east is different from the dry, calcareous vertisol from the west. The wet vertisol probably received an equable distribution of precipitation throughout the year (Figure 12). This resulted in an increase in cation exchange, and consequently, a lower soil pH. The dry vertisol from the west received less precipitation throughout the year and as a result, it underwent less cation exchange; this explains the alkaline composition of the vertisol as well as the lack of soil structures (see core descriptions C5 and C6). Given equal exposure time for the development of wet and dry vertisols, the dry vertisol probably would have reached a more mature stage prior to the marine transgression.

Although there is a trace of coal in the Sedgwick Basin, conditions were not as favorable for accumulation and preservation of peat as in the east. There is no coal or gray shale in the Hugoton Embayment. This also suggests less favorable coal-forming conditions. Vegetation growing on the dry vertisol may have been too sparse to accumulate as peat deposits.

Thickening of the Verdigris limestone across the transect is associated with thinning of the V-shale. Western Kansas probably was situated far enough north of the Intertropical Convergence Zone that it experienced a drier climate throughout the deposition of the entire interval.

As base-level rose, the climate gradient across Kansas changed from wet in low latitudes (southeast Kansas) to drier in high latitudes (northwest Kansas). This change resulted in the gradational change from V-shale into the overlying, thick carbonate unit. In some cases, deposition of the V-shale in eastern Kansas may have been contemporaneous with the Verdigris limestone in western Kansas.

Summary.--Given the paleolatitudinal position of Kansas during the Middle Pennsylvanian (Scotese and McKerrow, 1990) (Figure 19), it is reasonable to suggest that climate may have played a large role in the deposition of rock units. In the case of the study interval, increase in base level, regional water-table variability, and tectonics were agents that controlled deposition. Of these controls, changes in climate influenced both rise in base level and water-table variability.



Late Carboniferous (Westphalian)

Figure 19. Paleolatitudinal position of Kansas (marked with black dot) during the Middle Pennsylvanian. From Scotese and McKerrow (1990).

Fluctuations in the water table are indicative of the amount and distribution of precipitation in a region. Eastern Kansas received a great deal of precipitation throughout the year. This led to the accumulation and preservation of the Croweburg peat. Based on the development of tropical peats, the Croweburg peat probably experienced 8-9 "wet" months (out of the year) in which rainfall exceeded evapotranspiration (Cecil, personal communication, 1995). This would raise the water table to a level which would cause a region to become waterlogged; and provide ideal conditions for certain vegetal growth.

Distribution of precipitation in western Kansas was lower than in the east. It may have experienced less than 6 "wet" months (Figure 11) of which precipitation was greater than evapotranspiration. The number of wet months in the Hugoton Embayment is based on the alkaline composition of the dry vertisol. A dry environment, combined with a calcareous parent material, would result in an alkaline soil composition with high reserves of exchangeable cations (Retallack, 1990). A dry environment may have prolonged the development of the dry vertisol, because a lack of cation exchange results in the slow chemical break-down of the parent material.

In describing the role climate played in the vertical and regional succession of lithologies, Cecil (1990) suggested that movement of the North American continent away from the equator produced a shift in climatic belts. In this study, it appears that deposition of certain lithologies was controlled, in part, by a climate gradient from low latitudes (southeastern Kansas) to higher latitudes (northwestern Kansas) from wet to drier, respectively. Given the paleolatitude of the North American continent during this time (Scotese and McKerrow, 1990), it is estimated that this movement was no greater than 5° to the north. Overall, the movement of Kansas during the Pennsylvanian was from the northern limits of the Intertropical Convergence Zone (ITCZ) to a northerly latitude, monsoonal zone (Figure 20). This may explain, in part, the gradual decrease in coal beds upward through the Pennsylvanian in Kansas.

Given the data collected from cores, geophysical logs, as well as the presence of a dry vertisol and the absence of coal in the Hugoton Embayment, it is reasonable to suggest that western Kansas was initially drier at the start of the cycle (Figure 20). The Hugoton Embayment was probably situated north of the equatorial region, thus it did not receive as much precipitation as eastern Kansas. This conclusion is based on the lithologic character of the units in western Kansas and climate curve data (Figures 16a, 16b, and 16c).

Climate in the west was initially drier than in the east; the climate in western Kansas gradually became more seasonally wet when the V-shale was deposited. In the Hugoton Embayment massive carbonate accumulation of the Verdigris limestone and the gradation of V-shale into the limestone suggests that western Kansas was drier earlier and longer than eastern Kansas. This climate trend was due to the original paleolatitudinal position of Kansas.

The role of tectonism in this study is difficult to evaluate. Many of the major tectonically active areas (the sediment source areas) are located far from the study area (Figure 6). Subsidence or sagging of basinal floors was the only effect of tectonism that was apparent in the Cherokee Basin (Huffman, 1991). Uplift of tectonically active structures in the region may have contributed to the sediment deposited in the study area. Erosion from these areas would be regarded as a function of seasonality and could be explained by Cecil's (1990) climate model.

Structural features such as the Nemaha Anticline and the Central Kansas Uplift were inactive during the deposition of the study interval (McKee and Crosby, 1975; Rascoe and Adler, 1983), even though they contributed to the local compositional change of lithologies. Sediment shed from these features was probably in response to climate. Huffman (1991) and

Wanless (1975) stated that these structures did not contribute much sediment into the basins during deposition of the study interval. This is true relative to the regional scale, but on a local scale, erosion of sediment from these structures changed the lithologic composition of some units.

A final perspective lends credence to the contributions of climate on a regional scale. This involves the distribution of lithologies from distant basins. The interval of study has been correlated with evaporite deposits in the Paradox Basin (B. Wardlaw, personal communication, 1995) and the thick limestone deposits from the Pedregosa Basin (Connolly and Stanton, 1992). According to Cecil's (1990) model, thick carbonate and evaporite accumulations are indicative of arid conditions. Considering these lithologies and the results from this study and adjacent basins, a rough estimate of the paleolatitudinal position of North America can be constructed.

The accuracy of this paleolatitudinal reconstruction is strongly affected by the lack of available data. As more data become available, better reconstructions will be possible. This type of research will generate a better understanding of the role of climate during the Middle Pennsylvanian.

CONCLUSIONS

This study reports the stratigraphic distribution of lithologies from the Croweburg coal-Verdigris limestone interval, and it explains the role of climate in the deposition of these rocks. A "time-slice" of the Middle Pennsylvanian across Kansas shows where the lithologic compositional changes occur over an extensive region. Based on the lithologic differences observed, explanation of these changes was possible. Listed below are some of the important contributions from this study:

1. Eastern Kansas (the Cherokee Basin) was in or near the Intertropical Convergence Zone during the deposition of the vertisol, Croweburg coal, and gray mudrock facies. Evidence of high precipitation rates and an even distribution of precipitation throughout the year are recorded by these lithologies.

2. At the start of the Croweburg coal-Verdigris limestone cycle, western Kansas was near the Intertropical Convergence Zone but received less overall precipitation compared to the east.

3. Irregular topography and a high number of "wet" months/year favored accumulation and preservation of peat in the Cherokee Basin. It is believed that the gray mudrock was deposited both contemporaneously with and following the Croweburg coal. The gray mudrock possibly was deposited under tidal conditions in

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Key to Measured Sections and Core Descriptions

clayey mudrock (interpreted as a wet vertisol)

calcareous mudrock (interpreted as a dry vertisol)

gray mudrock

laminated gray mudrock

silty mudrock/siltstone

calcareous mudrock

platy, fissile, carbonaceous shale

calcareous, dark gray mudrock

blocky, dark gray or brown mudrock

argillaceous limestone

limestone

clay

quartz arenite

ripple laminated shale

phosphatic nodules

ash bed

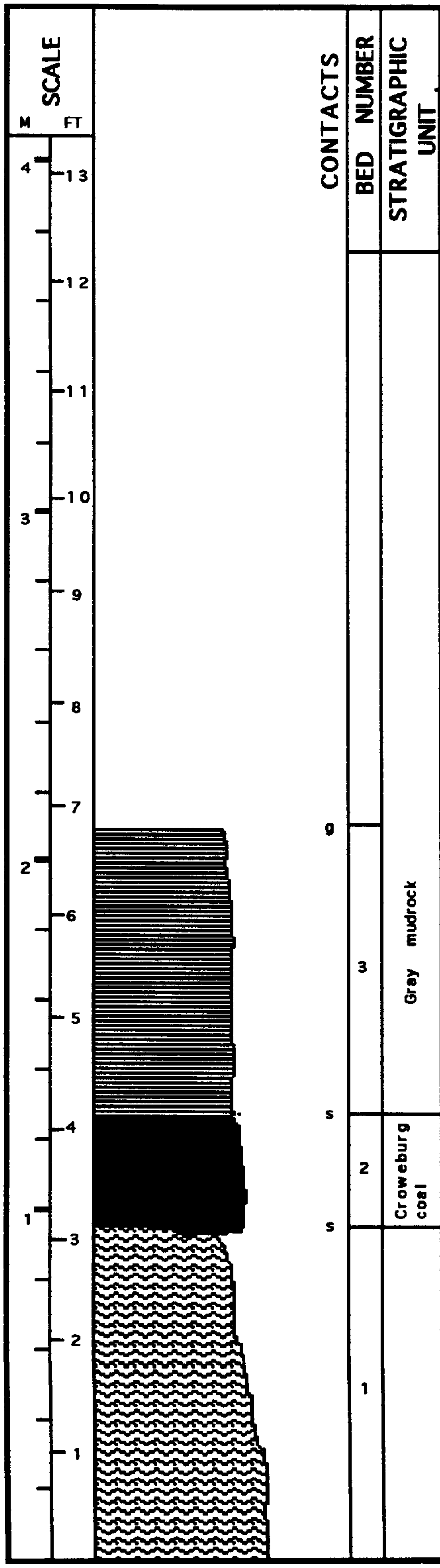
rhizoliths

shell fragments
and crinoid columnals

Contacts between units:

s - sharp
g - gradational

MS 1



LOCALITY: SW Sec. 31, T. 35 N., R. 33 W., Vernon County, Missouri

REMARKS: Mary Jane Mine is owned and operated by the Clemens Coal Company. The section was measured along a high wall of this active strip pit

Measured By: Jennifer M. Elick **Date:** 3-22-94

STRATIGRAPHIC DESCRIPTION

* unit 3 is differentiated from unit 4 based on nodules (pyritic) and the lack of visible laminations.

3 - Mudrock, medium dark gray (N4), abundant plant debris 5 cm from base (very condensed and carbonized- (gradual transition from coal), *Spirorbis* and *Dunbarella*, plant debris dominates at base, color becomes light- medium grey (N5), laminated (tidal environment ?), dicontinuous concretionary layer, *Lingula* (1), *Crurithyris* , slickensides look wet-waxy; 81 cm thick .

2 - Coal (Croweburg), bright and blocky, undulating surface, pyritic lenses (2-3 cm in thickness and up to a meter in length), pyritized plant remains, calcite in cleats, weathered surface is very dusky red (10 R 2/2), pyrite is olive gray (5 Y 4/1); 29-38 cm.

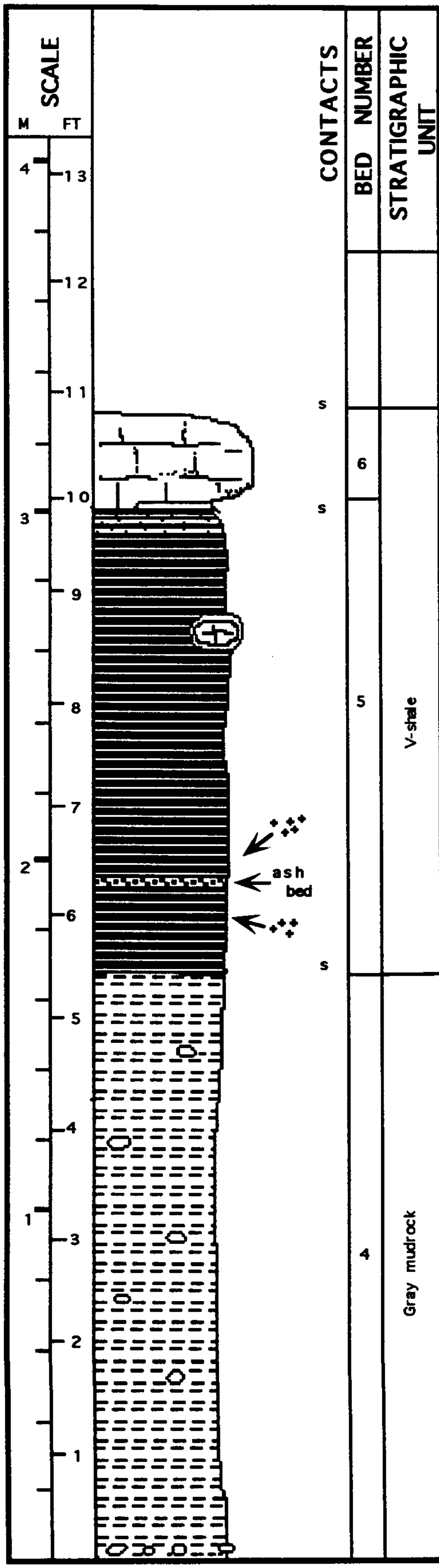
1 - Underclay, medium bluish gray (5 B 5/1), some silt, slickensides, mukkara structures (approximately 1 meter long), plant debris (carbonized) and rootlets (?), "O-A" horizon (.5 to 1 cm thick-carbonaceous/clay), gleyed horizon- light gray (N7), slightly silty (approximately 15 cm below contact with coal), noncalcareous (except basal 15 cm where fossils (3 unidentified) were collected), overlies an argillaceous limestone; 95 cm thick.

MS 1

LOCALITY: SW Sec. 31, T. 35 N., R. 33 W., Vernon County, Missouri

REMARKS: Mary Jane Mine is owned and operated by the Clemens Coal Company. The section was measured along a high wall of this active strip pit

Measured By: Jennifer M. Elick **Date:** 3-23-94



STRATIGRAPHIC DESCRIPTION

6 - Limestone concretionary layer (micritic), black (N1), discontinuous, shale that wraps around concretions, pyritized *Phestia,* clams, burrows; 30 cm thick.

5 - Shale, black (N1), fissile, (measured from lower contact to first continuous concretionary layer); 12 cm shale, black, blocky with increase of silt stringers upwards; 6 cm phosphatic nodule bed, nodules are small and spherical; 7 cm shale, fissile, *Dunbarella, Crurithyris, Mesolobus,* some pyrite; 0.5-1 cm ash bed, pale yellowish brown (10 YR 6/2); 11 cm shale, blocky, orbiculoids; 5 cm phosphatic nodule bed (small and spherical); 12 cm shale, black, blocky, calcareous, increase: in pyritized *Dunbarella, Mesolobus, Crurithyris,* some plant debris, weathered surface is coated with oxidized pyrite, silt stringers, larger, sporadic phosphatic nodules (vary in length 10-15 cm) with pyrite rinds; total thickness is 133 cm.

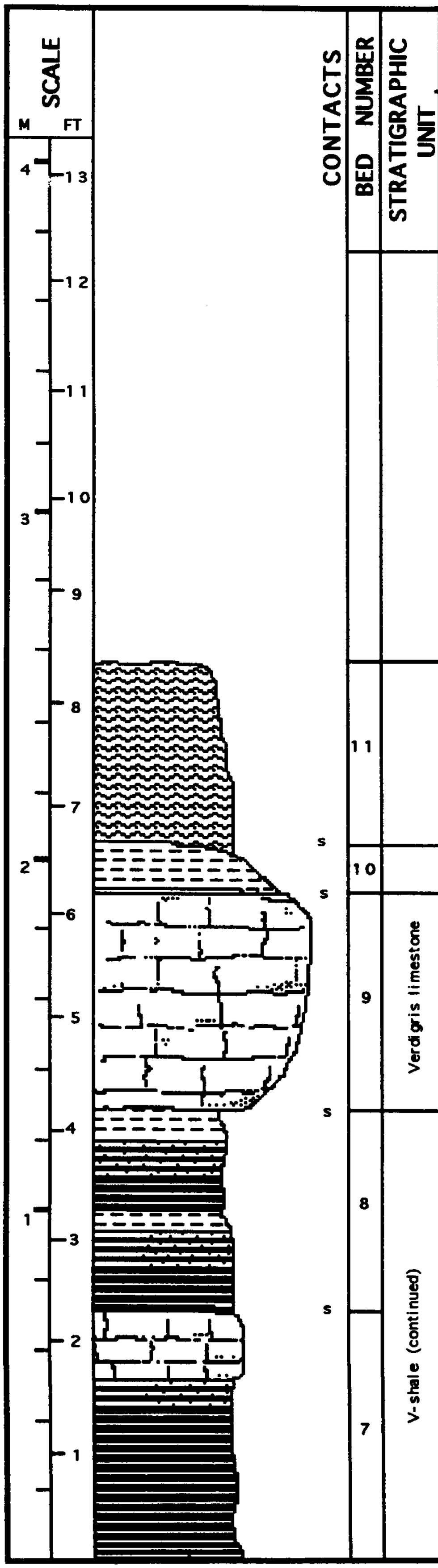
4 - Mudrock, medium dark gray (N4) to dark gray (N3) (color varies with compaction), bed of pyritic nodules marks base, slickensides, pyritic framboids and chondrites, *Dunbarella,* articulated, butterflied valves of *Edmondia* c.f. *E. crata* (a burrower, mobile), single valves of *Astartella* (a shallow burrower, mobile), single articulated valves of *Paralledon* c.f. *P. carbonacious* (an endo- to epibyssate form-attached), articulated *Phestia* c.f. *P. bellistrata* (an infaunal, burrowing deposit feeder-mobile), single valves of *Dunbarella* (an epibyssate form-attached), very small globose, medium-spired, smooth-shell snail like *Ianthonopsis*; upper part of unit contains plant debris, pyritic chondrites and fragmented *Dunbarella* (whole shells scarce), productids (shells are moderately deformed), shells are arranged in a hydrodynamically stable position (convex up), possible holothurian, *Pseudorthoceras,* large burrow trace fossils (1.5 cm in width and up to 20 cm long), slickensides; total thickness is 150 cm.

MS 1

LOCALITY: SW Sec. 31, T. 35 N., R. 33 W., Vernon County, Missouri

REMARKS: Mary Jane Mine is owned and operated by the Clemens Coal Company. The section was measured along a highwall of this active strip pit

Measured By: Jennifer M. Elick **Date:** 3-23-94



STRATIGRAPHIC DESCRIPTION

11 - Claystone, medium gray (N5) with moderate yellowish brown (10 YR 5/4) and grayish orange (10 YR 7/4) mottling, also contains (5 YR 5/6) iron stains, noncalcareous, *Mesolobus*, marginiferids, ostracodes, burrows (near base); 56 cm thick.

10 - Clay, moderate yellowish brown (10 YR 5/4) to dark yellowish orange (10 YR 6/6), *Mesolobus*, *Composita*, marginiferids, crinoid columnals; 15 cm thick.

9 - Limestone (Verdigris), dark gray (N3) (fresh surface), massive, hard and dense, *Antiquatonia*, *Crurithyris*, *Mesolobus*, *Composita*, marginiferids, linoproductids; 60 cm thick.

8 - Mudrock, dark gray (N2) to black (N1), blocky, becomes clay-rich upward (at least two possibly three "cycles" of low fossil content, black shale to high density, calcareous and fossiliferous, dark gray mudrock), orbiculoids, *Crurithyris*, *Mesolobus*, marginiferids, *Composita*, brachiopod spines, crinoid columnals; 59 cm thick.

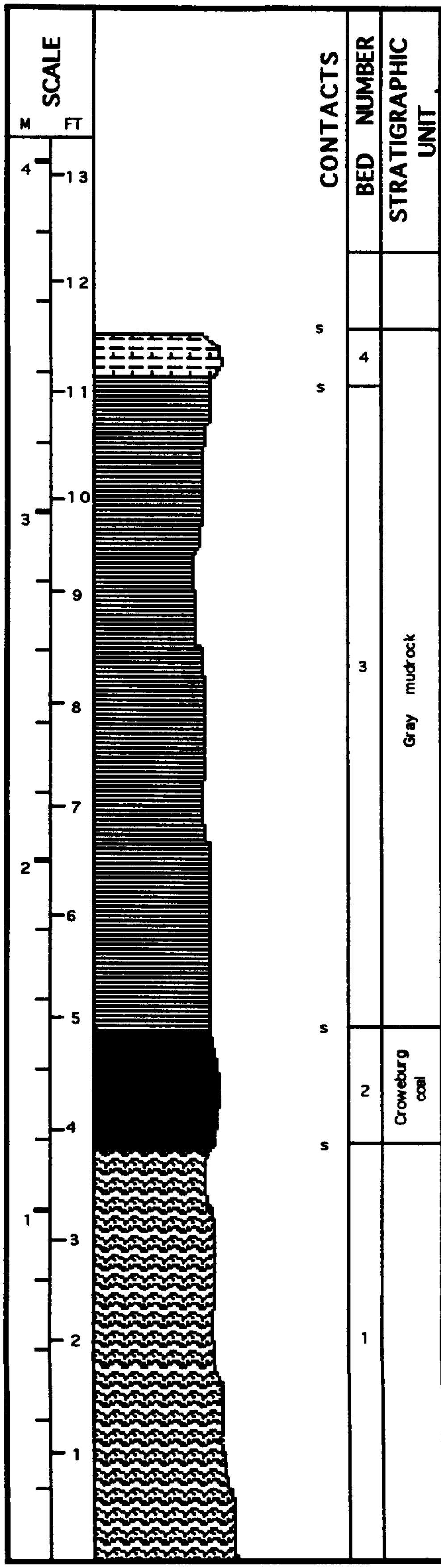
7 - Shale, blocky and continuous limestone concretionary layer (micritic), fissile near base becoming blocky upward, increase in fossils near concretionary layer: orbiculoids, *Crurithyris*, *Mesolobus*, smashed *Composita* shells, chonetids and worm burrows; 73 cm thick.

MS 2

LOCALITY: NW NW sec. 28, T. 27 S., R. 25 E., Crawford County, Kansas

REMARKS: "CATO " is also known as Clemens Mine #22. Section is in an active strippit.

Measured By: Ronald R. West (1993) and Jennifer M. Elick (1994) **Date:** 3-22-94



STRATIGRAPHIC DESCRIPTION

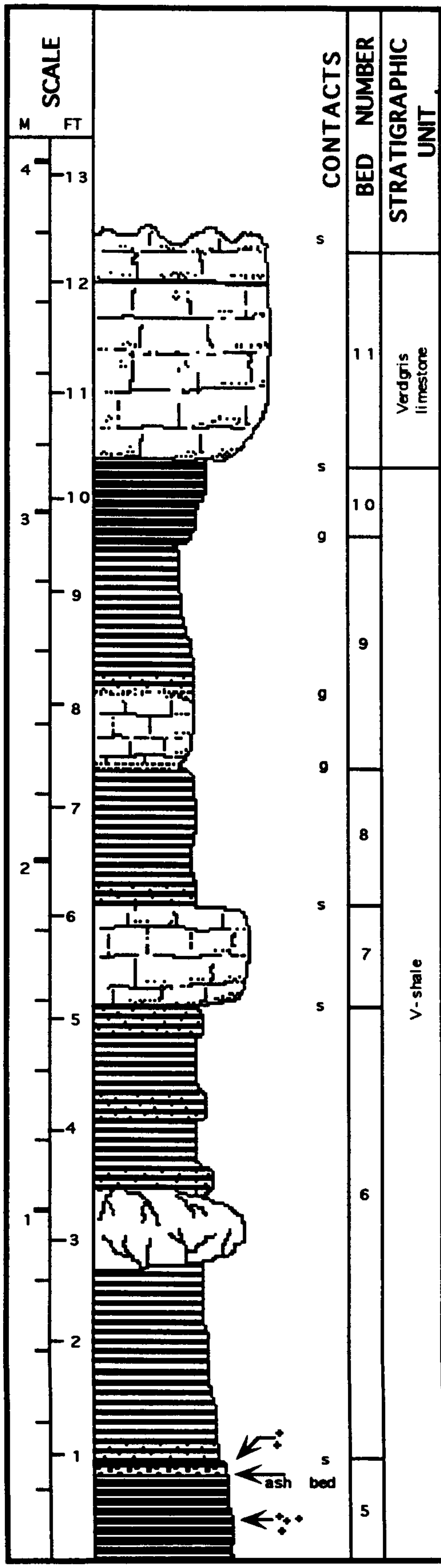
4 - Limestone, dark gray (N3), clayey to calcareous shaley-limestone, hard, dense, contains phosphatic nodules; 15 cm thick.

3 - Mudstone, light (N7) to medium light gray (N5) fresh, thinly laminated (rhythmites?), poorly bedded with laminations 20 cm above the coal-conspicuous reworked carbonaceous detritus in gray mudrock, small pyrite nodules, possible burrow filling, possible herringbone structure in upper part; 182 cm thick.

2 - Coal (Croweburg), bright, blocky, with pyrite layer (1cm), calcite and pyrite filled cleats, pyrite nodules: massive (2x5cm), pyritized bark parallel to bedding; 25 to 32 cm thick.

1 - Claystone, dark gray (N3) weathered and medium dark gray (N4) fresh, some diagentic staining (dark yellowish-orange (10 YR 6/6) and light brown (5 YR 5/6), both contacts sharp, no bedding, calareous up to 15 cm above base with *Mesolobus*, *Composita*, marginiferids, productid spines, and crinoid columnals near base (it overlies a limestone), upper part is silty and noncalcareous, carbonized rootlet structures, small pisoliths olive gray (5 Y 3/2), less than 1 cm in diameter, slickensides with secondary gypsum coating, mukkara zone is developed between 60-100 cm, some carbonate nodules at 80-110 cm; 120 cm thick.

MS 2



LOCALITY: NW 1/4 NW 1/4 sec. 28, T. 27 S., R. 25 E., Crawford County, Kansas

REMARKS: "CATO" is also known as Clemens Mine #22. Section is in an active strip pit.

Measured By: Ronald R. West (1993) and Jennifer M. Elick (1994) **Date:** 3-22-95

STRATIGRAPHIC DESCRIPTION

11 - Limestone, medium gray (N5) fresh, olive gray (5Y4/1) weathered, upper surface with 5-8 cm relief; contains a layer with fusulinids, crinoids, and productid shell fragments; 70 cm thick.

10 - Shale, laminated, *Mesolobus* and marginiferids in life position, also *Crurithyris* and productid shell fragments, *Dunbarella*, and crinoid columnals, plant debris; 15 cm thick.

9 - Mudstone/shale, dark gray (N3) to black (N1), well bedded (platy to thin), calcareous, fossils are abundant in calcareous layer directly above #8 bed), *Mesolobus*, *Derbyia*, *Crurithyris*, *Orbiculoidea*, *Lingula*, marginiferids in life position, crinoid columnals, coiled cephalopod, *Hibbardella*, possibly some plant debris; 65 cm thick.

8 - Mudstone/shale, color grades upward from medium gray (N5) to light gray (N 7), fossil content increases upward: *Derbyia*; 38 cm thick.

7 - Limestone (micritic), dark gray (N3), dense, continuous bed , no obvious fossils; 28 cm thick.

6 - Mudstone/shale with sporadic limestone (micritic) concretions (90 cm below upper contact), dark gray (N3), thin bedded with several calcareous horizons, fossiliferous: pyritized *Crurithyris* and *Dunbarella*, *Edmondia* (?), and framboids; 128 cm thick.

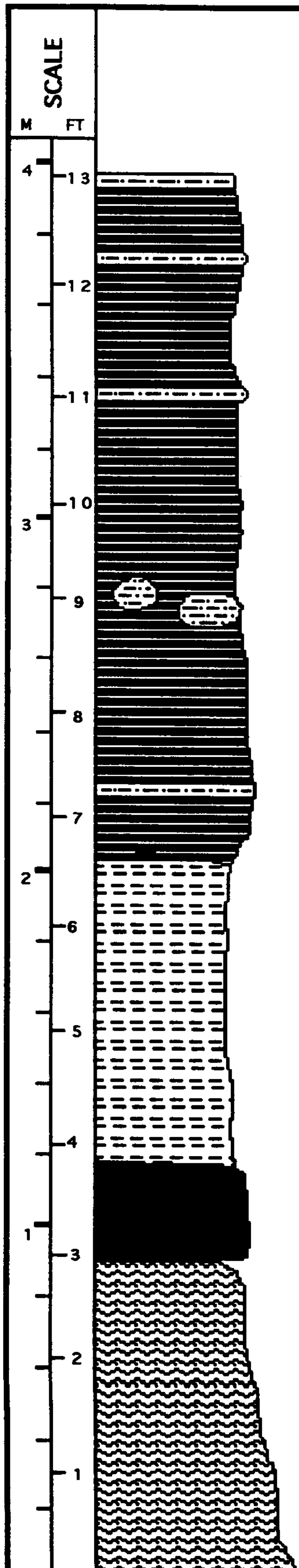
5 - Shale, black (N1), platy to fissile contains thin phosphatic nodule layers, ash bed (0.5-1 cm thick) is yellowish-gray (5Y 7/2) and located 38 cm above lower contact, shale contains a zone of pyritized *Mesolobus*, *Dunbarella*, *Crurithyris*, and marginiferids (10 cm above the base); 31 cm thick.

MS 3

LOCALITY: SW SW NW Sec. 15, T. 28 S., R. 25 E., Crawford County, Kansas.

REMARKS: Section at Clemens Mine # 22, highwall; measured near MS 2.

Measured By: unknown **Date:** 3-24-76



CONTACTS (CONTACTS WERE NOT DESCRIBED IN REPORT)

BED NUMBER	STRATIGRAPHIC UNIT
4	V-shale
3	Gray mudrock
2	Croweburg coal
1	

STRATIGRAPHIC DESCRIPTION

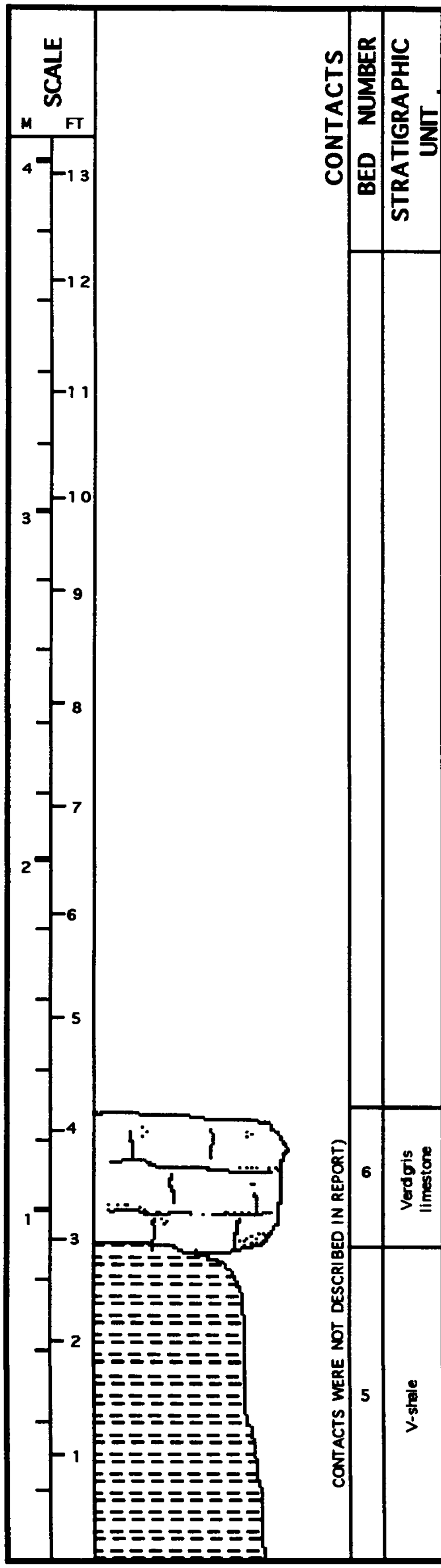
4 - Shale, carbonaceous, well bedded, hard, with several calcareous siltstone beds up to 30 cm thick and large calcareous siltstone concretions, upper part is dark gray with brownish gray to dark gray siltstone; 1.8 m thick.

3 - Shale, greenish-gray, well bedded, breaks into blocks 15 cm thick, hard; 90 cm thick.

2 - Coal (Croweburg), banded, mainly vitrin, thin pyrite partings along some bedding planes, gypsum in cleats; 32 cm thick.

1 - Claystone, greenish-gray, no bedding, slakes readily; 90 cm thick.

MS 3



LOCALITY: SW SW NW Sec. 15, T. 28 S., R. 25 E., Crawford County, Kansas.

REMARKS: Section at Clemens Mine # 22, highwall; measured near MS 2.

Measured By: unknown **Date:** 3-24-76

STRATIGRAPHIC DESCRIPTION

6 - Limestone (Verdigris) (micrite), gray with light brownish gray mottling micrite, fossiliferous, one bed; 40 cm thick.

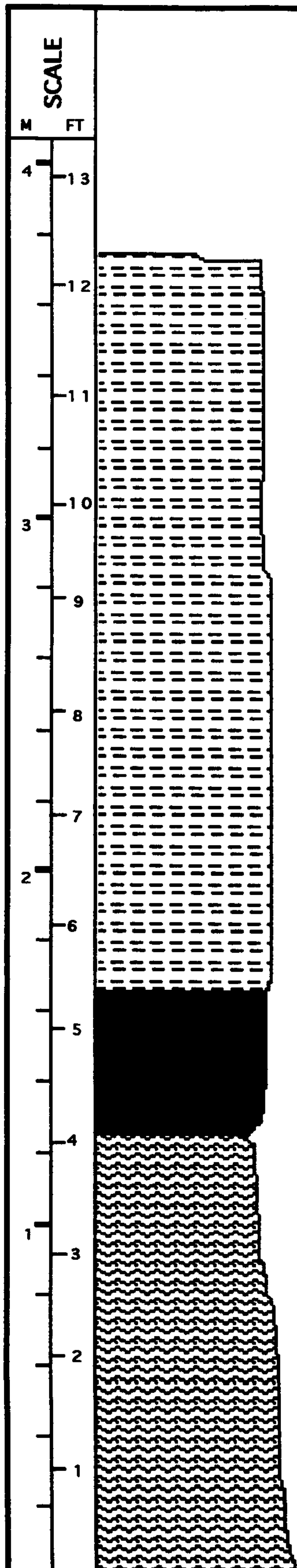
5 - Shale, gray with light brownish staining, well bedded; 90 cm thick.

MS 4

LOCALITY: NW NE C Sec. 24, T. 28 S., R. 25 E., Crawford County, Kansas

REMARKS: Abandoned strip pit about 2.5 miles north of Mulberry, Kansas.

Measured By: Wallace B. Howe **Date:** 6-11-48



CONTACTS: (HOWE DOES NOT DESCRIBE CONTACTS BETWEEN UNITS)

BED NUMBER	STRATIGRAPHIC UNIT
3	Gray mudrock
2	Croweburg coal
1	

STRATIGRAPHIC DESCRIPTION

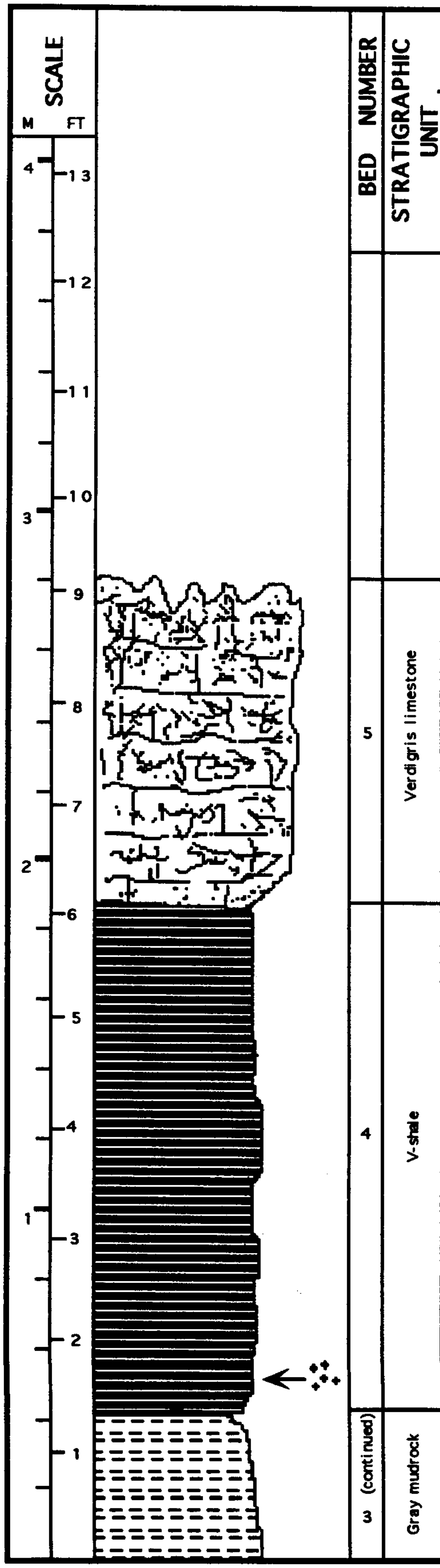
Based on Howe's Description:

3 - Shale, gray weathers brown, upper 30 cm very light and clayey; 2.54 m thick.

(unit 3 is continued on page 2)

2 - Coal (Croweburg), mostly weathered; 30-38 cm thick.

1 - Clay, dark gray, hard, crumbly; 1.3 m thick.



LOCALITY: NW NE C Sec. 24, T. 28 S., R. 25 E., Crawford County, Kansas

REMARKS: Abandoned strip pit about 2.5 miles north of Mulberry, Kansas.

Measured By: Wallace B. Howe **Date:** 6-11-48

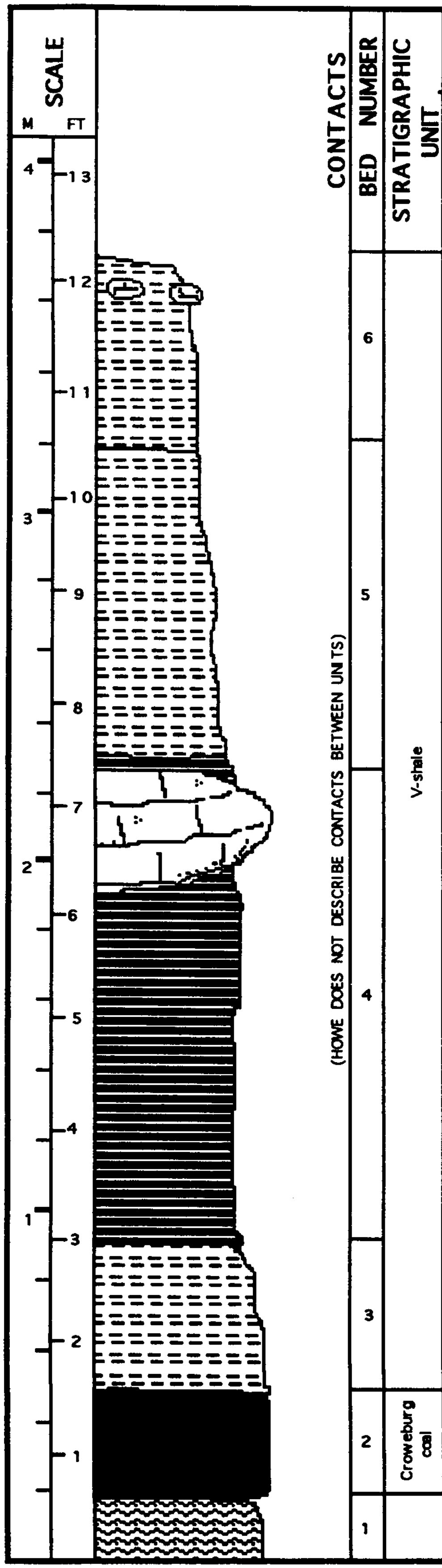
STRATIGRAPHIC DESCRIPTION

<u>Based on Howe's Description:</u>

5 - Limestone ; 81 cm thick.

4 - Shale, black but lighter color in upper part, fissile, hard, contains many small, round, phosphatic concretions about 90 cm above the base; 1.52 m thick.

MS 5



LOCALITY: SW SW C Sec. 34, T. 28 S., R. 25 E., Crawford County, Kansas

REMARKS: Strip pit in corner just northeast of main jct. at Croweburg, Kansas. Probably the type Croweburg locality.

Measured By: Wallace B. Howe **Date:** 6-10-48

STRATIGRAPHIC DESCRIPTION

Based on Howe's Description:

6 - Clay and shale, light gray, soft; fossiliferous, mostly productids (small); upper part persistent zone of limestone concretions, similar to those in bed # 4, but smaller; 46 cm thick.

5 - Shale, dark brown, softer than bed # 4; 90 cm thick.

4 - Shale, black, thinly laminated; hard, fissile, coarse blocky fractures; upper part contains very large limestone concretions, some up to 76 cm in diameter; concretions confined to zones; very hard, and appear to be unfossiliferous; 130 cm thick.

3 - Clay and shale, many plant (root?) impressions and some carbonized plant debris; 46 cm thick.

2 - Coal (Croweburg), hard, blocky fracture, some is bony and pyrite is common; 32 cm thick.

1 - Clay, underlies coal; thickness unknown.

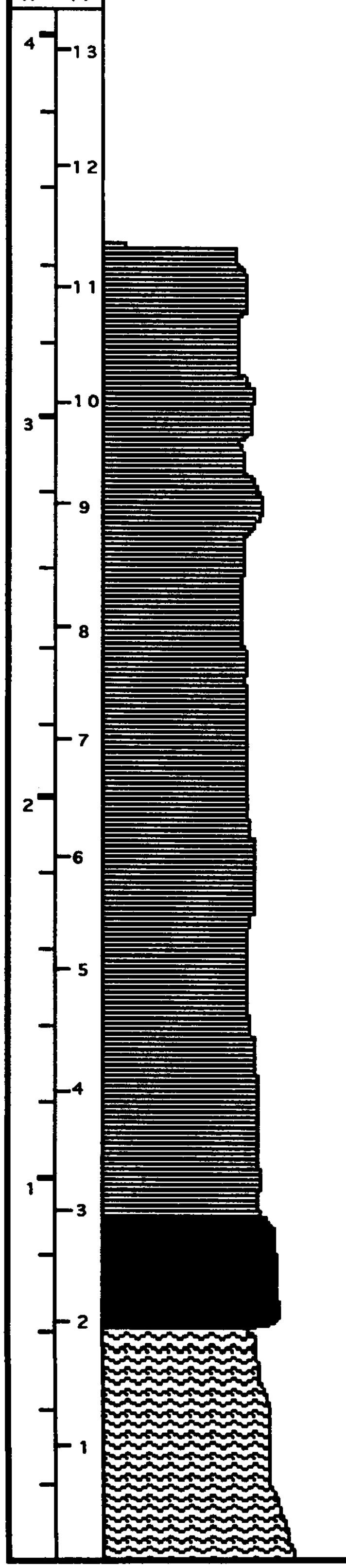
MS 6

LOCALITY: NW SE C Sec. 28, T. 29 S., R. 25 E., Crawford County, Kansas

REMARKS: Operating coal stripping of Mackie-Clemens Coal Company.

Measured By: Wallace B. Howe **Date:** 6-13-49

SCALE (M, FT) | CONTACTS | BED NUMBER | STRATIGRAPHIC UNIT



(HOWE DOES NOT DESCRIBE CONTACTS BETWEEN UNITS)

BED NUMBER	STRATIGRAPHIC UNIT
3	Gray mudrock
2	Croweburg coal
1	

STRATIGRAPHIC DESCRIPTION

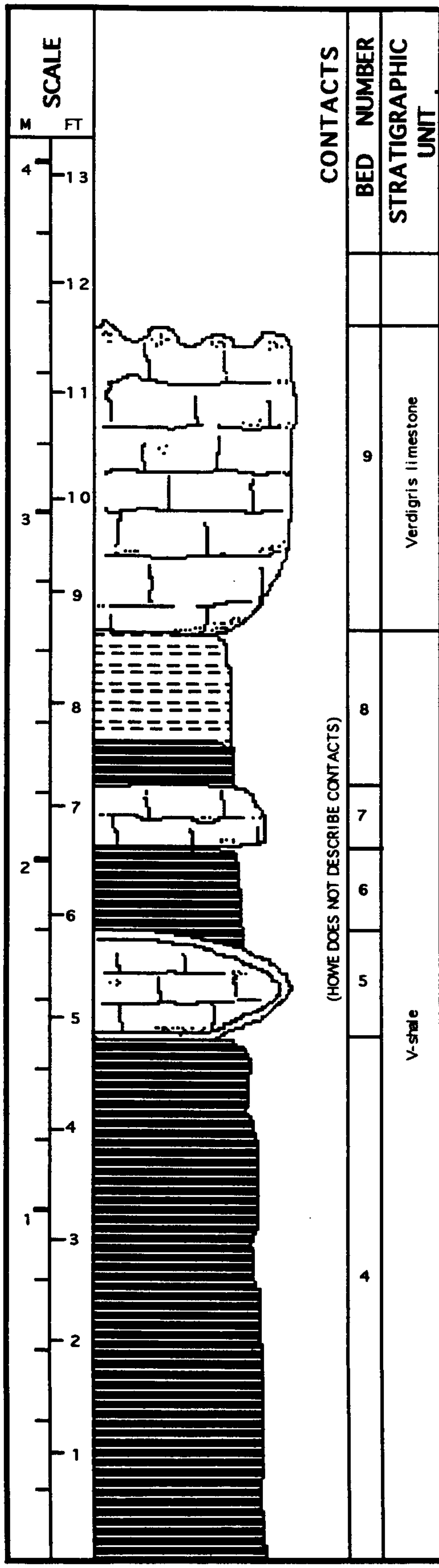
Based on Howe's Description:

3 - Shale, medium gray, thinly laminated; three beds (13-15 cm thick) occur at top, but are apparently a similar lithology; 2.6 m thick.

2 - Coal (Croweburg), bright, blocky; calcite in cleats and abundant pyrite in upper part; in places thin (3-5 cm thick) bed of impure, bony, coal, 7-10 cm above a gray to black shale parting; 30.5 cm thick.

1 - Clay, mud, gray, silty to sandy throughout, with abundant plant remains; fossils are presumed in life (vertical) position; 66 cm thick.

MS 6



LOCALITY: NW SE C Sec. 28, T. 29 S., R. 25 E., Crawford County, Kansas

REMARKS: Operating coal stripping of Mackie-Clemens Coal Company.

Measured By: Wallace B. Howe **Date:** 6-13-49

STRATIGRAPHIC DESCRIPTION

Based on Howe's Description:

9 - Limestone, mottled dark gray and brown, weathering light gray to tan; very hard, forming single massive bed; upper surface very uneven and apparently very deeply leached; Fossils: *Punctospirifer, Neospirifer, Composita, Ambocoelia, Squarmlaria, Marginifera, Mesolobus, Eumpygas,* horn corals; Ardmore limestone (main bed). This limestone is made up in large part by preserved algal (?) debris; has large fragments or impressions of plants; 81 cm thick.

8 - Shale, black but lighter, possibly leached in upper part; hard, and fissile at base; 46 cm thick.

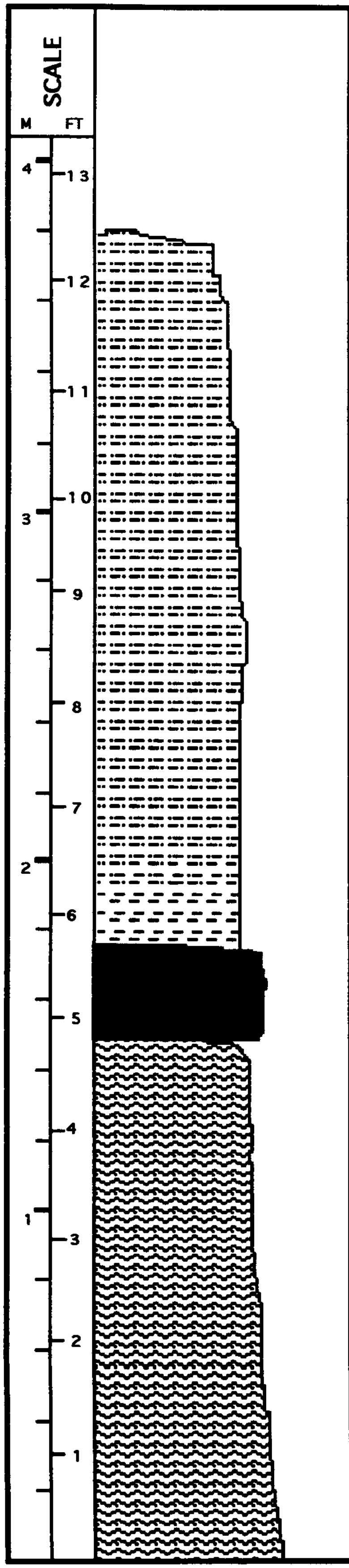
7 - Limestone, black; 23 cm thick.

6 - Shale, black and fissile; 25 cm thick.

5 - Zone of massive concretonary limestone; much of it is septarian with dolomite fillings; most masses (30-90 cm) in diameter; have a pyrite rind; marginifera; 30. 5 cm thick.

4 - Shale, black, fissile, slaty; abundant, rounded to lenticular phosphatic concretions; black shale below Ardmore limestone; fossils: *Marginifera, Composita, Goniatite*-like cephalopds; spirifer-type brachiopods, orbiculoids, horn corals; 1.5 m

MS 6a



LOCALITY: NW NE SW Sec. 28, T. 29 S., R. 25 E., Crawford County, Kansas

REMARKS: "Makie-Clemens pit No. 13 (?). Approximately 2.5 miles north of main junction at Frontenac, Kansas. Very good exposure to date."

Measured By: Wallace B. Howe **Date:** 6-09-48

BED NUMBER	STRATIGRAPHIC UNIT
3	Gray mudrock
2	Croweburg coal
1	

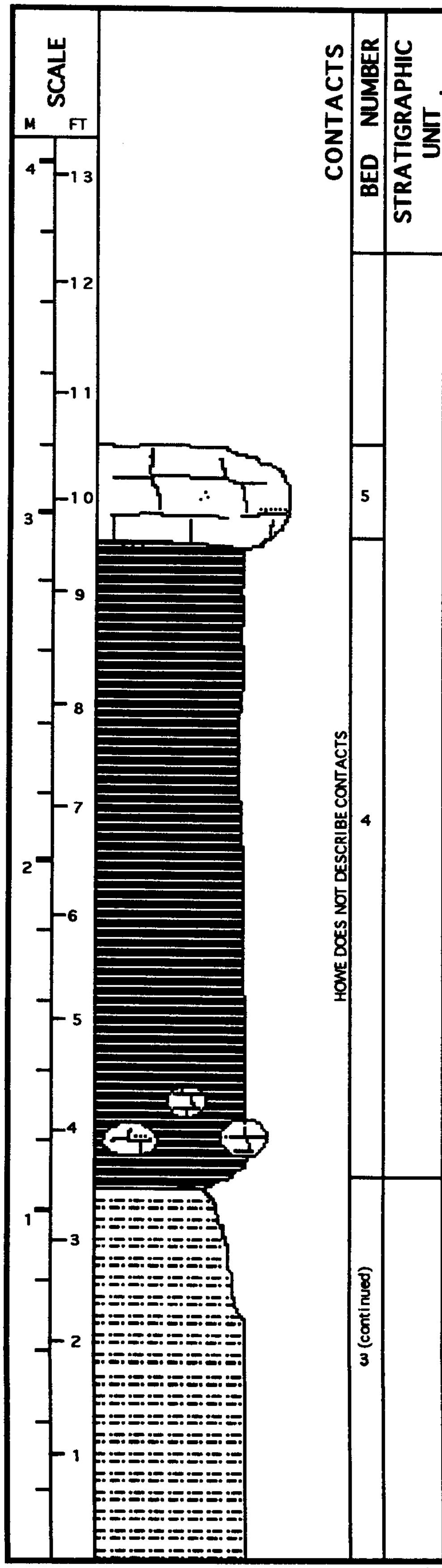
STRATIGRAPHIC DESCRIPTION

Based on Howe's Description:

3 - Shale, very silty, hard, clayey at base, but very uniform for most part; 3.0 m.

2 - Coal (Croweburg); 30.5 cm thick.

1 - Clay, containing abundant root (?) markings; 1.5 m thick.



LOCALITY: NW NE SW Sec. 28, T. 29 S., R. 25 E., Crawford County, Kansas

REMARKS: "Makie-Clemens pit No. 13 (?). Approximately 2.5 miles north of main junction at Frontenac, Kansas. Very good exposure to date."

Measured By: Wallace B. Howe **Date:** 6-09-48

STRATIGRAPHIC DESCRIPTION

Based on Howe's Description:

5 - Concretionary limestone layer; 30.5 cm thick.

4 - Shale, black, thin zone of black limestone concretions at base; 1.8 m thick.

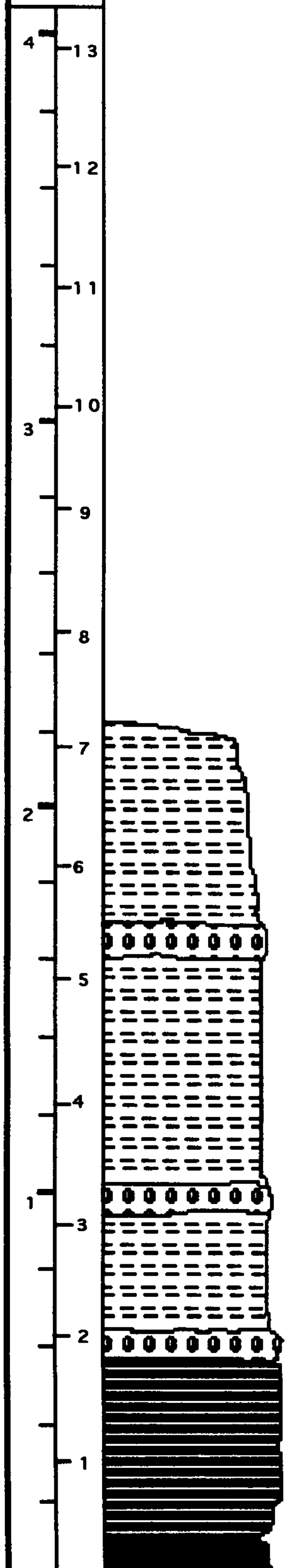
MS 7

LOCALITY: NW NW sec. 27, T. 30 S., R. 24 E., Crawford County, Kansas

REMARKS: Section 66 is exposed in abandoned strip pit.

Measured By: Wallace B. Howe **Date:** 6-18-48

SCALE (M, FT) | CONTACTS | BED NUMBER | STRATIGRAPHIC UNIT | STRATIGRAPHIC DESCRIPTION



(HOWE DOES NOT DESCRIBE CONTACTS BETWEEN UNITS)

BED NUMBER	STRATIGRAPHIC UNIT
3	V-shale
2	V-shale
1	C. coal

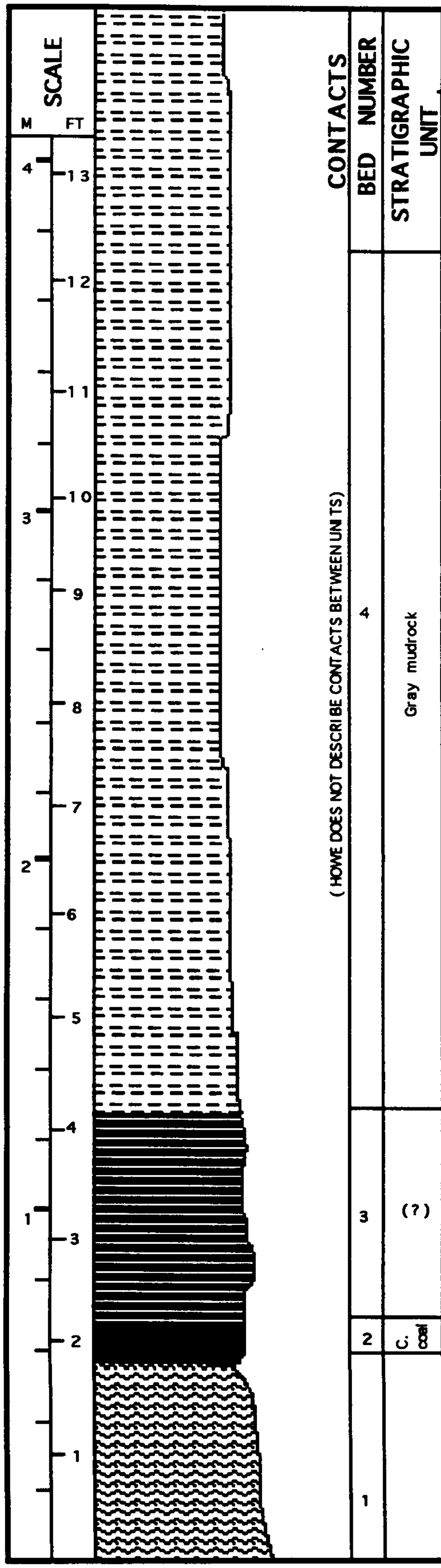
<u>Based on Howe's Description:</u>

3 - Mudrock, Drab to tan, several clay-ironstone layers, one marking the base; 1.6 m thick.

2 - Shale, black (N1), fissile; sharply defined at top and bottom, thinly laminated, blocky fracture; 52 cm thick.

1 - Coal (Croweburg), very poor, ranges from featheredge to 12 cm.

MS 7a



LOCALITY: NW SW sec. 27, T. 30 S., R. 24 E., Crawford County, Kansas

REMARKS: "Section 65" is exposed in abandoned strip pit..

Measured By: Wallace B. Howe Date: 6-13-50

STRATIGRAPHIC DESCRIPTION

Based on Howe's Description:

4 - Shale, medium gray, some limonitic streaks; non-silty "soapstone"; some nonpersistent clay-ironstone layers; 5.1 m thick.

(unit 4 is continued on the next page)

3 - Shale, black, hard, fissile; blocky; from featheredge to "Croweburg formation"; 60 cm thick.

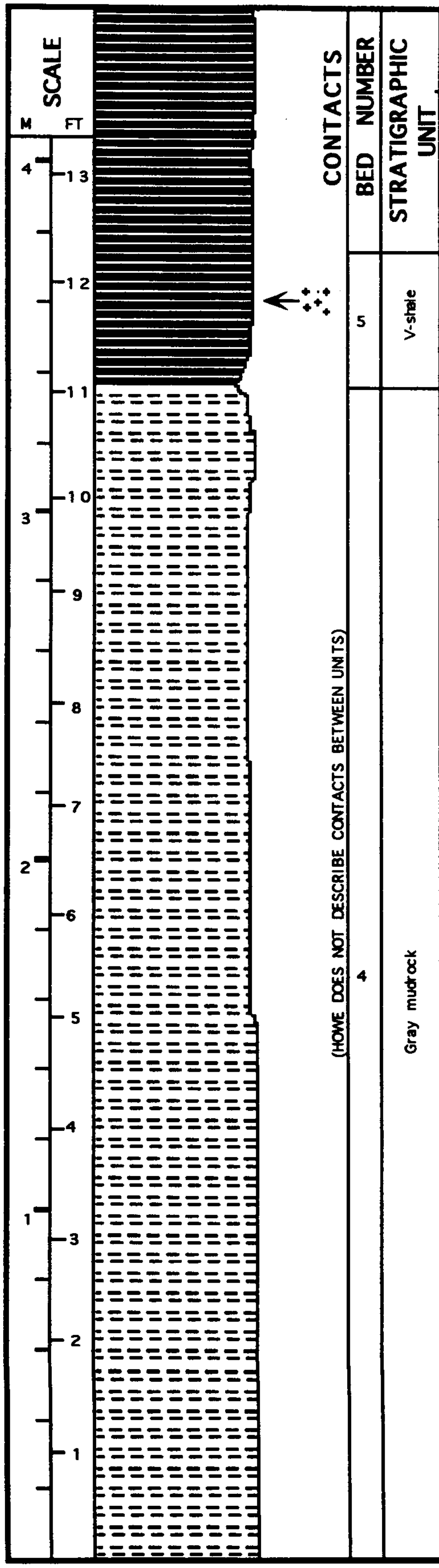
2 - Coal (Croweburg); 10 cm.

1 - Unconsolidated sand and silt; dark gray, leached; coaly debris throughout; represents underclay; 60 cm thick.

LOCALITY: NW SW sec. 27, T. 30 S., R. 24 E., Crawford County, Kansas

REMARKS: "Section 65" is exposed in abandoned strip pit..

Measured By: WALLACE B. HOWE **Date:** 6-13-50



STRATIGRAPHIC DESCRIPTION

<u>**Based on Howe's Description:**</u>

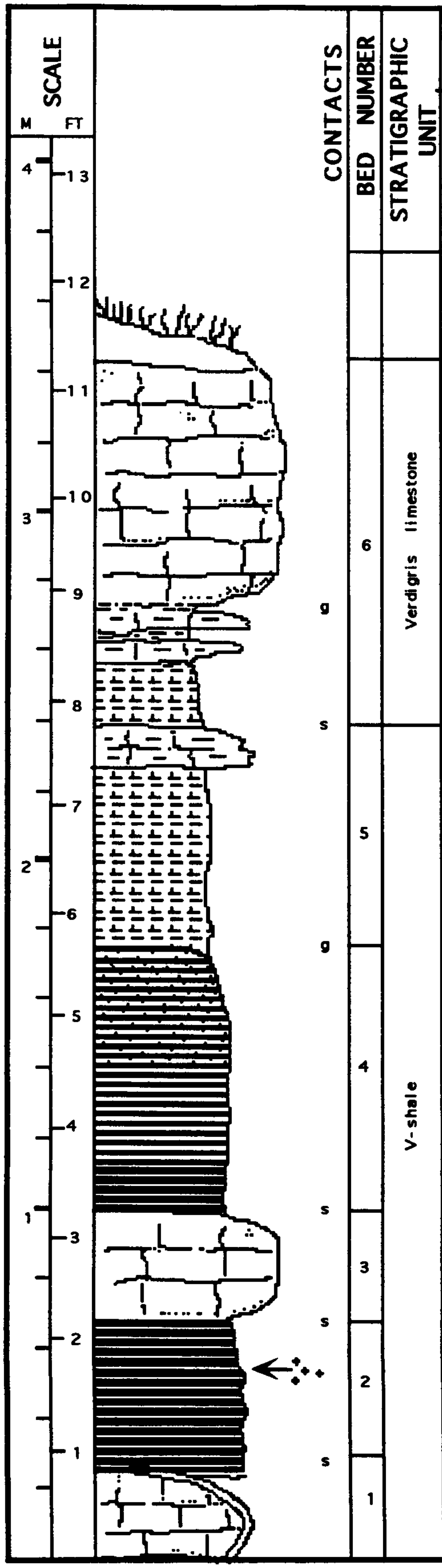
5 - Shale, black, fissile; abundant round phosphatic concretions; occurs beneath Verdigris limestone member; exposed; 1.2 m thick.

MS 8

LOCALITY: SE SE Sec. 16, T. 31 S., R. 23 E., Crawford County

REMARKS: "Wolf Creek" was measured in Wolf Creek, along Rt. 160. Howe measured an exposed highwall which is his section #55; Elick measured along the creek.

Measured By: Wallace B. Howe (1949) and Jennifer M. Elick(1994) **Date:** 3-24-94



STRATIGRAPHIC DESCRIPTION

5 - Mudrock, grayish-brown (5 YR 3/2) weathered, brownish black (5 YR 2/1) with light brown (5 YR 5/6) staining fresh, platy (alternates between fossiliferous, blocky and less fossiliferous friable), calcareous, contains rough limestone concretions in upper part, marginiferids, small *Crurithyris*, *Mesolobus*, pectin fragments; 61 cm thick.

4 - Mudrock, greyish black (N2) weathered and fresh, becomes friable near middle (chemically corroded?), some small nodules near lower contact, Calcareous contains tiny gypsum crystals, *Mesolobus*, marginiferids (*Desmoinesia*?), small *Crurithyris*, *Neospirifer* (?), *Meekella* (?), *Dunbarella*, *Parallelodon* (?), chonetids and fish scales; 78 cm thick.

3 - Limestone (micritic) concretion bed (coalesced); dark gray (N3) fresh; undulatory contacts, concretions measure up to 85 cm in diameter, grayish-orange (10 YR 7/4) with yellowish-brown (10 YR 6/2) and light brown (5 YR 5/6) spots weathered; plant impressions on upper surface; fossils rare but include coiled nautiloids; 30 cm thick.

2 - Shale; black (1) fresh and dark grayish black (N2) weathered; platy; noncalcareous nodules with same color as weathered and fresh colors, pyritized and compacted *Crurithyris* (some are articulated), *Desmoinesia* , possible arthropod (?); 40 cm thick..

1 - Limestone concretion bed, dark gray to black (N2-1); concretions are subspherical and dumbell shaped and are up to 60 cm diameter; most concretions have pyritic rind; 30 cm thick.

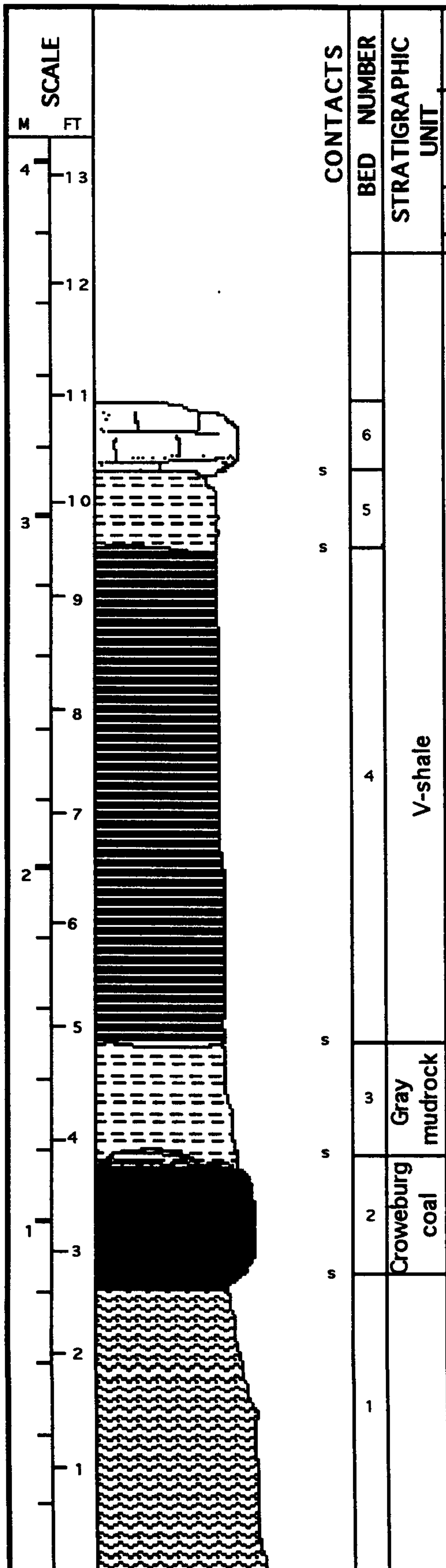
LOCALITY:	SE SE Sec. 16, T. 31 S., R. 23 E., Crawford County, Kansas
REMARKS:	"Wolf Creek" was measured in Wolf Creek, along Rt. 160. Howe measured an exposed highwall of a nearby strip pit; Elick measured along the creek.
Measured By:	Wallace B. Howe (1949) and Jennifer M. Elick (1994) **Date:** 3-24-94

STRATIGRAPHIC DESCRIPTION

soil cover

6 - Limestone, yellowish-gray (5 Y 7/2) with light brown (5YR 5/6) stains weathered, pale yellowish-brown (10 YR 6/2) fresh, massive, very dense and brittle, vertical fracture; joint system results in rhombic blocks, lots of algal debris, crinoid columnals, fenestrate bryozoans, *Mesolobus*, marginiferids, and *Composita* (many skeletal fragments); 1.0 m thick.

MS 9



LOCALITY: NE SE NE Sec. 7, T. 32 S., R. 23 E., Cherokee County, Kansas.

REMARKS: "Big Brutus" locality. Positive Structure of the Croweburg coal was measured along the highwall of a strip pit at the apex of the positive structure. Underclay and coal were both at water level.

Measured By: Jennifer M. Elick **Date:** 3-22-94

STRATIGRAPHIC DESCRIPTION

4 - Platy, fissile shale, light brownish gray (5 YR 6/1) weathered, light olive gray at top (5 YR 6/1) fresh, thin (.5-1 cm thick) black bands throughout, both contacts are sharp, noncalcareous, and no fossils were found; unit 4 is 1.44 m thick.

3 - Gray mudrock, no apparent bedding, noncalcareous, breaks off in shards, mudrock is lt gray (N7) with dark yellowish orange (10 YR 6/6) and pale yellowish orange (10 YR 8/6) banding-weathered, medium gray (N5) with light brown (5 YR 5/6), moderate yellow (5 YR 7/6), and very dark red (5 R 2/6) bands- fresh, bands are discontinuous and intersect in places, no obvious fossils, highly weathered, some carbonaceous material above lower contact has been reworked from underlying coal, unit pinches over positive structure of underlying coal; both contacts are sharp; unit 3 vaies between .3 and 2.6 m in thickness.

2 - Coal (Croweburg), banded, bright, blocky forms on positive underlying unit, both contacts are undulating, upper contact is reworked, carbonaceous material at top folds and forms ribbons interbedded with gray mudrock; unit 2 varies between 30 and 38 cm in thickness.

1 - Claystone, no bedding, blocky, some plant material, unit is yellowish gray (5 YR 7/2) with dark yellowish orange (10 YR 6/6) and pale yellowish orange (10 YR 8/6) iron stains-weathered, medium light gray (N6) with light brown (5 YR 5/6) and dark yellowish orange (10 YR 6/6) stains, canon ball-shaped concretions found on ledge, in claystone, right above water level; unit 1 is 90 cm thick where exposed above the water at the apex of the small positive structure.

LOCALITY: NE SE NE Sec. 7, T. 32 S., R. 23 E., Cherokee County, Kansas.

REMARKS: "Big Brutus" locality. Positive Structure of the Croweburg coal was measured along the highwall of a strip pit at the apex of the positive structure. Underclay and coal were both at water level.

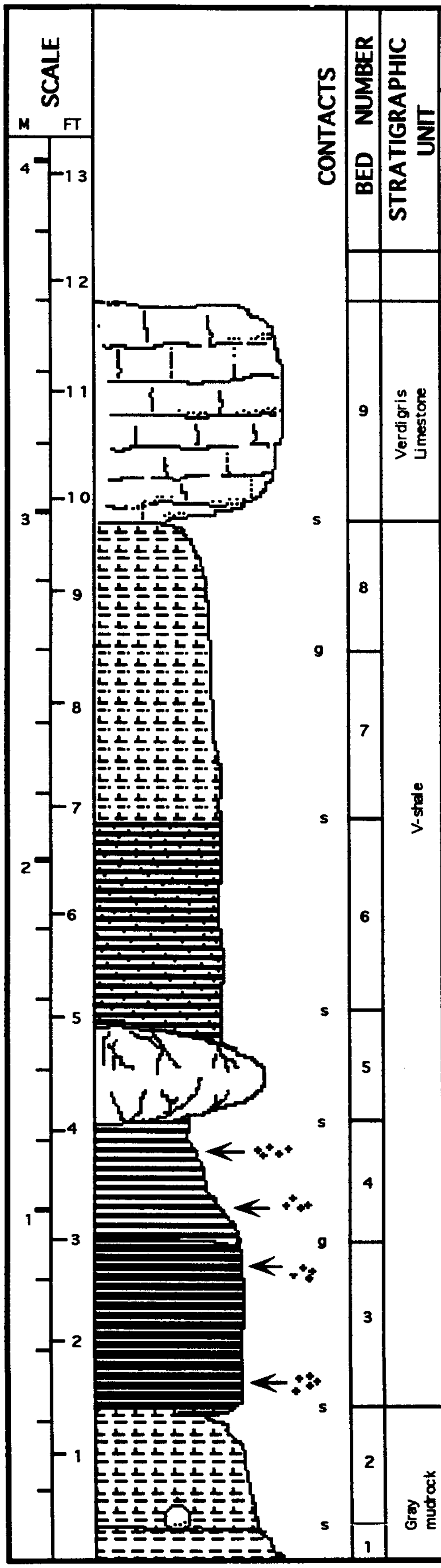
Measured By: Jennifer M. Elick **Date:** 3-22-94

STRATIGRAPHIC DESCRIPTION

6 - Micritic concretions, pale yellowish orange (10 YR 8/6) to greyish-orange (10 YR 7/4); unit is 20 cm thick (difficult to reach for description.).

5 - Noncalcareous mudrock, nodular, forms blebs, mudrock is yellowish gray (5 Y 7/2) weathered with thin, light brown (5 Y 5/6) iron stained partings, no fossils were observed; unit 5 is 22 cm thick.

MS 10



LOCALITY: NE NE NE Sec. 13, T. 32 S., R. 22 E., Cherokee County, Kansas

REMARKS: "Big Brutus" (Mine #19). Situated in an abandoned strip mine south of West Mineral in northeastern Cherokee Co. Section was measured along a mine highwall.

Measured By: Jennifer M. Elick | Date: 4-02-95

STRATIGRAPHIC DESCRIPTION

5 - Mudrock with concretions; yellowish-gray (10 Y 6/2) weathered, dark yellowish-brown (10 YR 4/2) with black clay stringers (N1) fresh; large concretions (micritic), up to 60 cm in diameter, olive gray (5 Y 4/1) with grayish-brown (5 YR 3/2) calcite filled veins, mudrock wraps around concretions), straight cephalopod, *Edmondia*, and vertical worm burrows; 28 cm thick.

4 - Mudrock; light brown (5 YR 5/6) weathered, black (N1) fresh with yellowish-gray (5 Y 7/2) phosphatic (?) nodules in dense layers; shaly; *Composita*, marginiferids, *Bellerophon* (?)- found 10 cm above lower contact (possible marine event?); 35 cm thick.

3- Shale, black (N1) with light brown (5 YR 5/6) iron stains, irredescent coloration, and moderate yellow stains (5 Y 7/6), platy, large pyritic lenses and concretions found throughout, calcite-filled joints, fish scales, compacted marginiferids, *Dunbarella*, platform and blade conodonts found above first nodule layer: *Hindeodella*; 48 cm thick.

2- Mudrock, medium gray (N5) with light brown (5 YR 5/6) and moderate olive brown (5 Y 4/4) mottling weathered, dark gray(N3) with dark greenish-gray (5 GY 4/1) and moderate brown (5 YR 3/4) mottling fresh, platy, calcareous ; and contains cannon ball-like concretions 10 cm above lower contact; 36 cm thick.

1 - Mudrock, medium dark gray (N4) weathered and fresh, moderate brown (5 YR 4/4) iron staining; blocky mudrock; 9 cm thick.

* coal is not exposed

LOCALITY:	NE NE NE Sec. 13, T. 32 S., R. 22 E., Cherokee County, Kansas
REMARKS:	Big Brutus* (Mine #19). Situated in an abandoned strip mine south of West Mineral in northeastern Cherokee Co. Section was measured along a mine highwall.
Measured By: Jennifer M. Elick	**Date:** 4-02-94

STRATIGRAPHIC DESCRIPTION

9 - Limestone; dark yellowish-orange (10 YR 5/6) with light brown linear mottling (5 YR 5/6) weathered, medium gray (N5) fresh with black "blebs" found on upper limestone surface; massive; undulating upper surface (covered), *Lophophyllidium*, rugose corals (solitary and in life position), *Composita*, *Mesolobus*, *Neospirifer*, *Crurithyris*, *Derbyia*, large linoproductids and marginiferids, crinoid columnals, echinoid spines, and phylloid algae; 65 cm thick.

8 - Mudstone; yellowish-gray (5 Y 7/2); (weather pattern distinct from unit 7) laminated and blocky; calcareous; *Crurithyris*, *Mesolobus*, marginiferids, and dark yellowish-orange (10 YR 6/6) horizontal burrows; 37 cm thick.

7 - Mudrock; grayish-orange (10 YR 7/4) with grayish-black mottling (N2) weathered, dark yellowish-brown (10 YR 4/2) with same (N2) mottling fresh; silty; calcareous; forms shards, *Crurithyris*, *Mesolobus*, *Composita*, compacted marginiferids, pectin (unidentified), crinoid columnal; 54 cm thick.

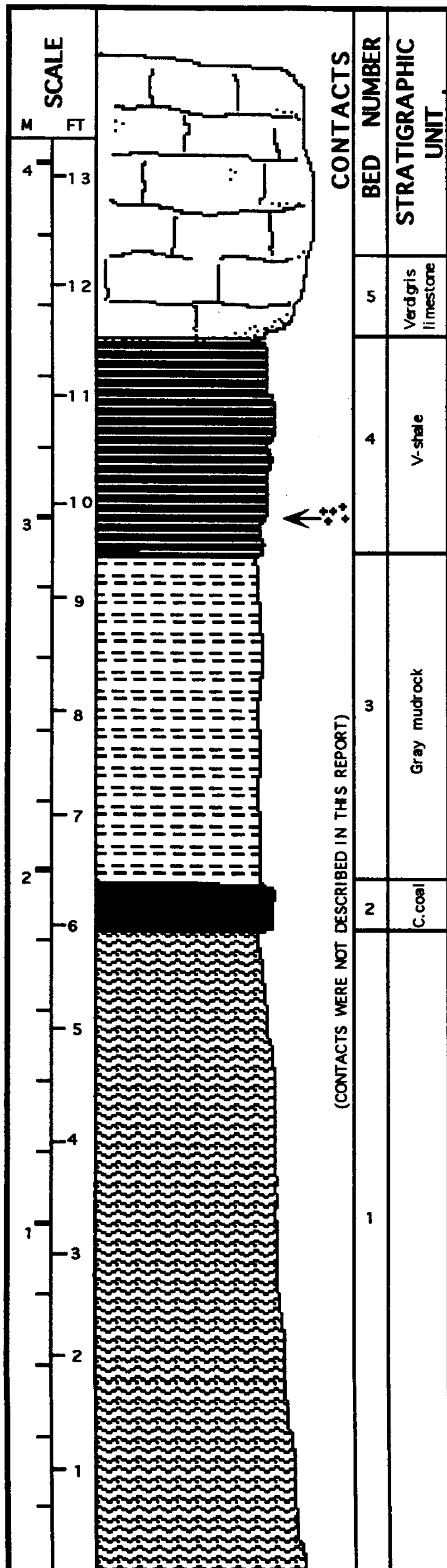
6 - Mudrock; dark gray (N2) with grayish-orange (10 YR 7/4) with grayish-black mottling (N2) weathered, dark yellowish-brown (10 YR 4/2) fresh with black stringers of platy black clay and light gray nodules (N7); platy and friable; silty, calcareous; fossils (badly weathered) occur in distinct layers: *Crurithyris*, *Mesolobus*, *Composita*, compacted marginiferids, crinoid columnals; 58 cm thick.

MS 11

LOCALITY: SW SE C Sec. 31, T. 32 S., R. 22 E., Cherokee County, Kansas

REMARKS: "Section at stop 1 (Pittsburg & Midway Coal Mining Co., Mine #19)."

Measured By: A. L. Hornbaker   Date: unknown



STRATIGRAPHIC DESCRIPTION

Based on Hornbaker's Description:

5 - Limestone (Verdigris), dark gray, weathers light gray; varies in thickness between 45 and 106 cm.

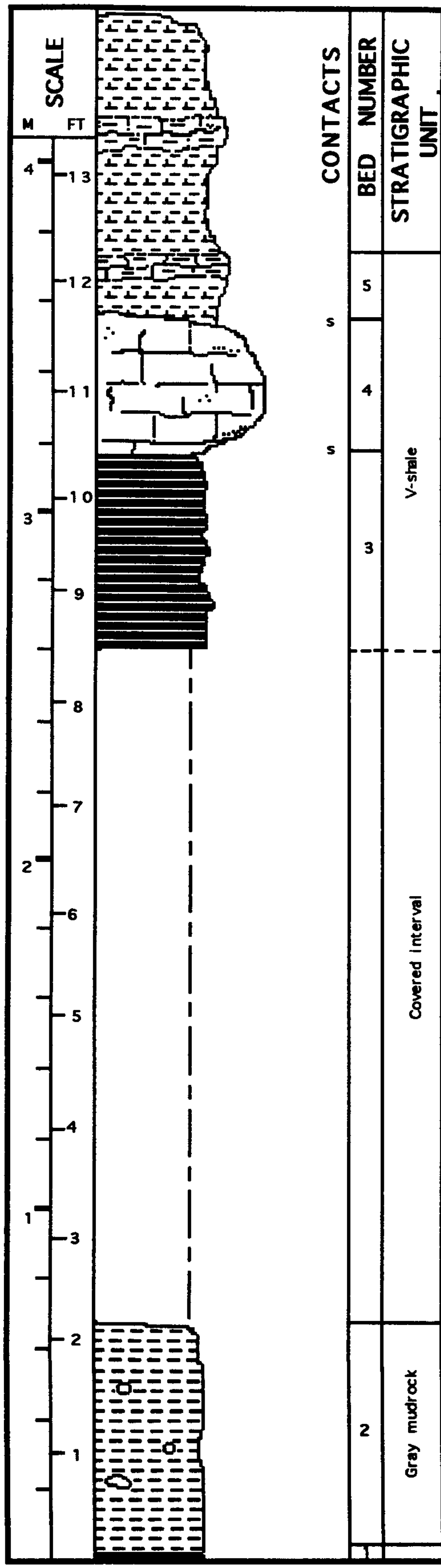
4 - Shale, black, fissile with abundant phosphatic nodules; 60 cm thick.

3 - Shale, medium gray; 60 to 1.2 m thick.

2 - Coal (Croweburg), not mined here; 15 cm thick.

1 - Shale, gray to medium gray; 1.8 m.

MS 12



LOCALITY: Sec. 13, SW 1/4 SE 1/4 sec. 27, T. 33 S., R. 21 E., Labette County, Kansas

REMARKS: "Section 13" is an abandoned strip pit and adjacent road cut.

Measured By: Wallace B. Howe **Date:** 6-22-49

STRATIGRAPHIC DESCRIPTION

Based on Howe's Description:

5 - Mudrock; thin and slabby; calcareous; fossils include: *Mesolobus*, marginiferids, *Juresania*, and *Derbyia;* 91 cm thick..

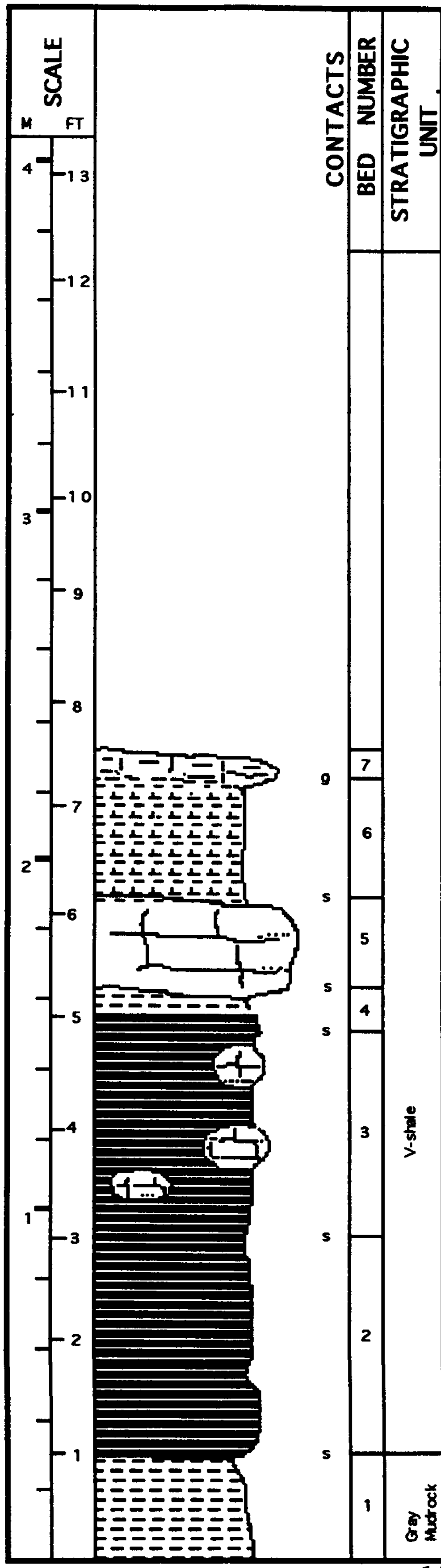
4 - Limestone (Howe's lower Verdigris unit); black (N1) weathers tan; brittle, dense; fossils include: *Mesolobus*, *Echinoconchus* *Juresania*, and marginiferids.

3 - Covered interval (2.4 m); upper 60 cm is shale; black; fissile; containing phosphatic concretions.

2 - Mudrock; contains scattered clay-ironstone concretions.

1 - Coal (Croweburg), present at base, thickness unknown.

MS 13



LOCALITY: NW NW Sec. 19, T. 34 S., R. 21 E., Labette County, Kansas

REMARKS: "Section 11" was measured in a gully by Wallace B. Howe, June 23, 1949. It has been back filled since Howe's work.

Measured By: Wallace B. Howe **Date:** 6-23-49

STRATIGRAPHIC DESCRIPTION

<u>**Based on Howe's Description:**</u>

7 - Shaly-limestone (Howe's middle Verdigris unit); gray; forms a resistant ledge; contains *Mesolobus* and marginiferids; 9 cm thick.

6 - Mudrock; gray; calcareous; 30 cm thick.

5 - Limestone (Howe's lower Verdigris unit), black (N1) fresh, weathers tan; very dense and brittle; distinctly jointed, resulting in rectangular blocks (weather round); fossils include: *Mesolobus*, *Marginifera muricatina*, and crinoid material; 24 cm thick.

4 - Clay, light to dark gray (represents weathered shale);15 cm thick.

3 - Zone of rough shaly limestone concretions; fossils include: *Marginifera muricatina*; 60 cm thick.

2 - Shale; black (N1); fissile, hard; contains abundant, rounded phosphatic concretions; 60 cm thick.

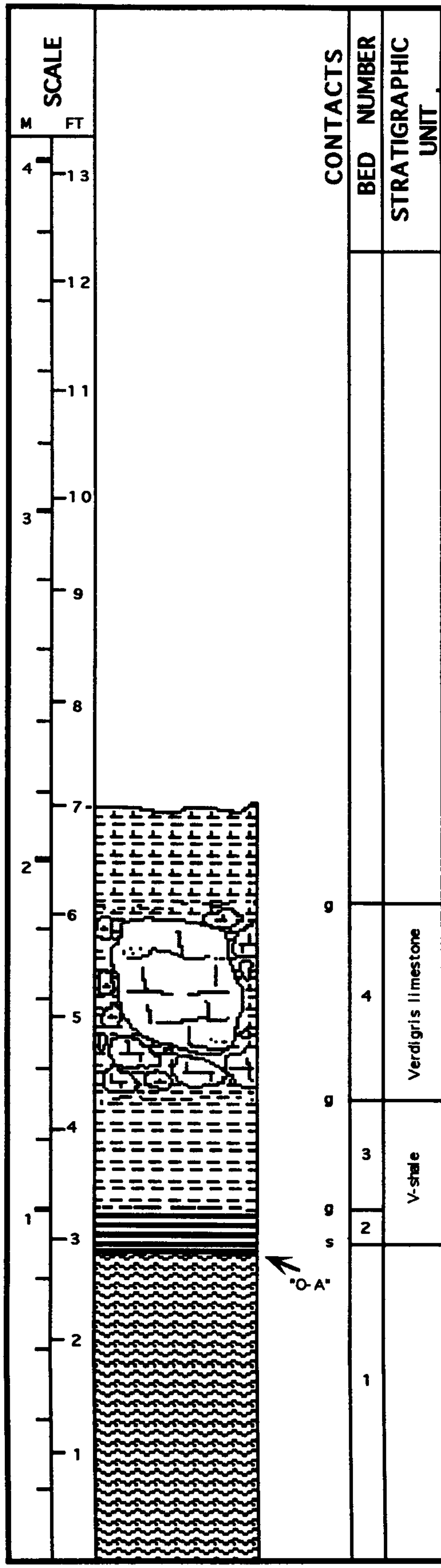
1 - Shale and clay (exposed); 30 cm thick.

C1

LOCALITY: SE NW SW Sec. 35, T. 9 S., R. 22 E., Leavenworth County, Kansas.

REMARKS: Orville Edmonds No. 1-A-KGS. Core was provided by the Kansas Geological Survey. Larry Brady was helpful in finding the core and locating the study interval.

Measured By: Jennifer M. Elick **Date:** 6-18-94



STRATIGRAPHIC DESCRIPTION

4 - Limestone;, light olive gray (5 Y 6/1) dry in a greenish-gray (5 GY 6/1) clayey matrix; very nodular, made up of large and small, rounded "ped"-like forms; no apparent fossils, clay is calcareous; (depth: 806.5-808.4 ft) 58 cm thick.

3 - Mudrock; greenish-gray (5 GY 6/1) and medium bluish-gray (5 B 5/1) dry; crumbly; noncalcareous, small slickensides, some shell material, *Mesolobus*, crinoid columnals; (depth: 808.4-809.4 ft) 30 cm thick.

2 - Shale; dark gray (N3) to grayish-black (N2); blocky; noncalcareous, carbonaceous; some pyrite nodules (up to 1 cm long); no apparent fossils, some plant debris; (depth: 809.4-809.8 ft) 10 cm thick.

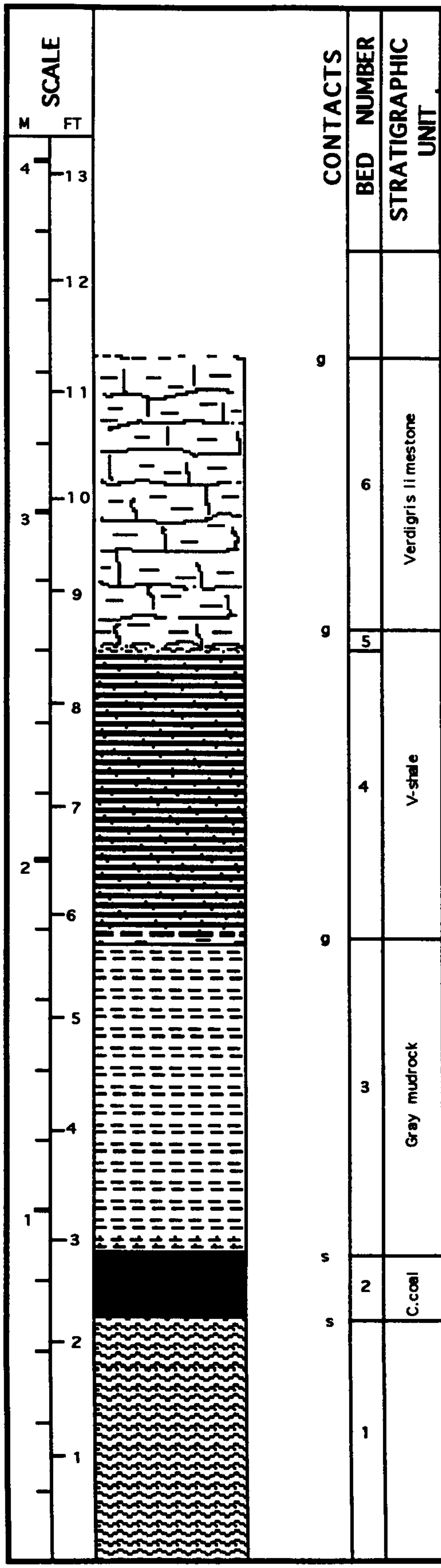
1 - Mudrock; light olive gray (5 Y 6/1); no bedding; clayey, "O-A" horizon at top composed of carbonized plant debris and clay, matrix is noncalcareous but there are small (less than 0.5 cm long), abundant, calcareous nodules 60 cm below "O-A" horizon, slickensides with medium bluish-gray (5 B 5/1) surface, becomes very clayey at base; (depth: 809.8-812.8 ft) 90 cm thick.

C2

LOCALITY: SW SW NE Sec 17, T. 32 S., R. 22 W., Cherokee County, Kansas

REMARKS: P&M #14 was provided by the Kansas Geological Survey.

Measured By: Jennifer M. Elick **Date:** 6-24-94



STRATIGRAPHIC DESCRIPTION

6 - Argillaceous limestone; medium dark gray (N4) dry, some grayish-orange (10 YR 7/4) and dusky yellowish-brown (10 YR 2/2) mottling; some pyrite nodules; brachiopod fragments, *Mesolobus*, marginiferids, crinoid columnal, bioturbated- large burrows; (depth: 831.5-833.1 ft) 77 cm thick.

5 - Shell lag; medium dark gray (N4), calcareous; *Crurithyris*, marginiferids, and fragmented shell debris, crinoid fragments; (depth: 833.1-833.3 ft) 5 cm thick.

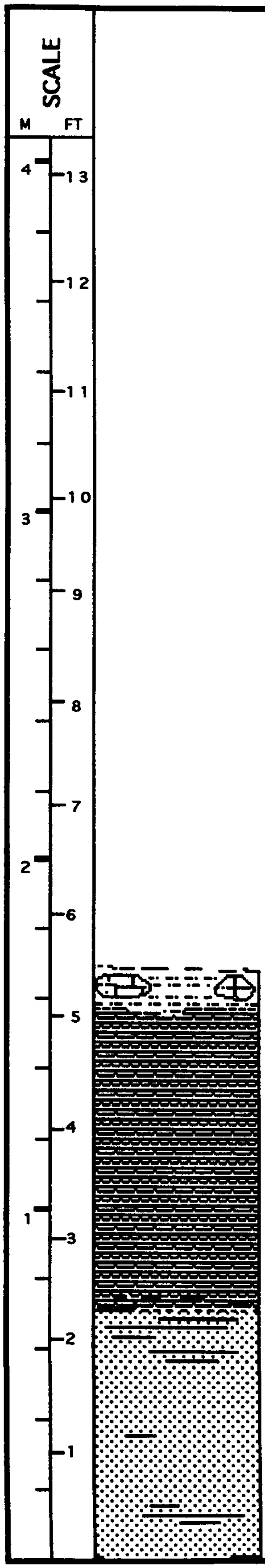
4 - Mudrock; dark gray (N3); blocky; calcareous, *Derbyia*, bivalve fragments, high spired gastropods, some small, horizontal burrows; (depth: 833.3-835.8 ft) 81 cm thick.

3 - Mudrock; medium dark gray (N4); breaks into plates; basal 7 cm is calcareous, upper part is noncalcareous; some pyritized shell fragments: *Dunbarella*(?); (depth: 835.8-838.4 ft) 88 cm thick.

2 - Coal (Croweburg); bright, vitrin, blocky; fractured; contains plant debris; grayish-black (N2) shaly partings; calcite in cleats, some fractures are stained light brown (5 YR 5/6); (depth: 838.4-839.3 ft) 20 cm thick.

1 - Mudrock; light bluish gray (5 B 7/1) to light gray (N7) dry with grayish-yellow (5 Y 8/4) with dusky brown (5 YR 2/2) pryrite(?) nodules; calcareous near base with some calcite nodules (less than 0.5 cm diameter), upper part is not calcareous; contains carbonized plant debris, slickensides-very clayey (expands when wet); (depth: 839.3-841.4 ft) 67 cm thick.

C3



CONTACTS	BED NUMBER	STRATIGRAPHIC UNIT
g	3	Verdigris limestone(?)
g	2	V-shale(?)
	1	

LOCALITY: SW NW SE Sec. 3, T. 17 S., R. 21 W., Ness County, Kansas.

REMARKS: Thompson A-2 core. Description modified from Howard 's (1990) thesis. Howard interpreted this section as supratidal.

Measured By: Stephen Howard (1990) **Date:** 1990

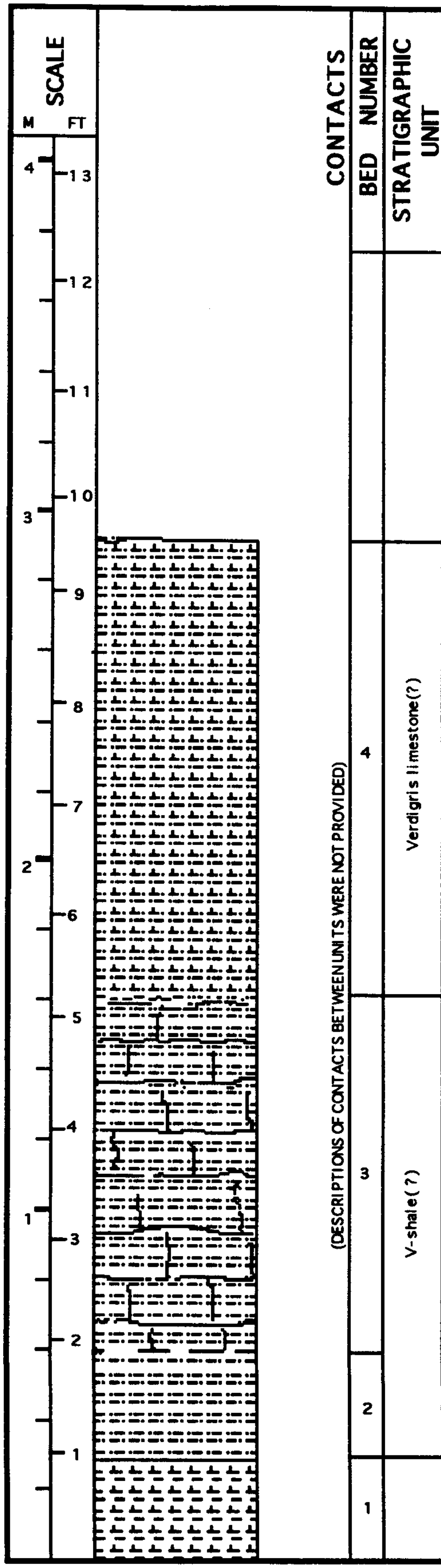
STRATIGRAPHIC DESCRIPTION

3 - Siltstone, green with bivalve casts, white limestone nodules, ripple laminations, interlaminated green shale, some quartz-rich parts, no limestone nodules or bivalves along the basal contact; (depth: 4107.0-4107.3 ft) 5 cm thick.

2 - Shale, interlaminated red and green, fissile, ripple laminated; green at top with red mudstone lenses, maroon at base; gradational contact with overlying unit; contains coal fragments near base, carbonaceous coatings near base; (depth: 4107.3-4110.0 ft) 95 cm thick.

1 - Quartz arenite, fine to very fine grained, gradational contact, mottled, bioturbated, interlaminated maroon and green, graded, planar cross bedding, light and dark gray laminations, dark laminae 2 mm thick, light laminae 10 mm thick; clay matrix, subrounded to rounded grains, porous, some biotite, coal, and light and dark green/gray laminae; (depth: 4110.0-4112.4 ft) 78 cm thick.

C4



LOCALITY: C NW NW Sec. 24, T. 20 S., R. 26 W., Ness County, Kansas

REMARKS: The Mid-continent No. 1 J. G. Collins core was measured by Nodine-Zeller (1981). She used biostratigraphic data from Thompson (1945) to locate the Cherokee Group.

Measured By: Doris E. Nodine-Zeller **Date:** 1981

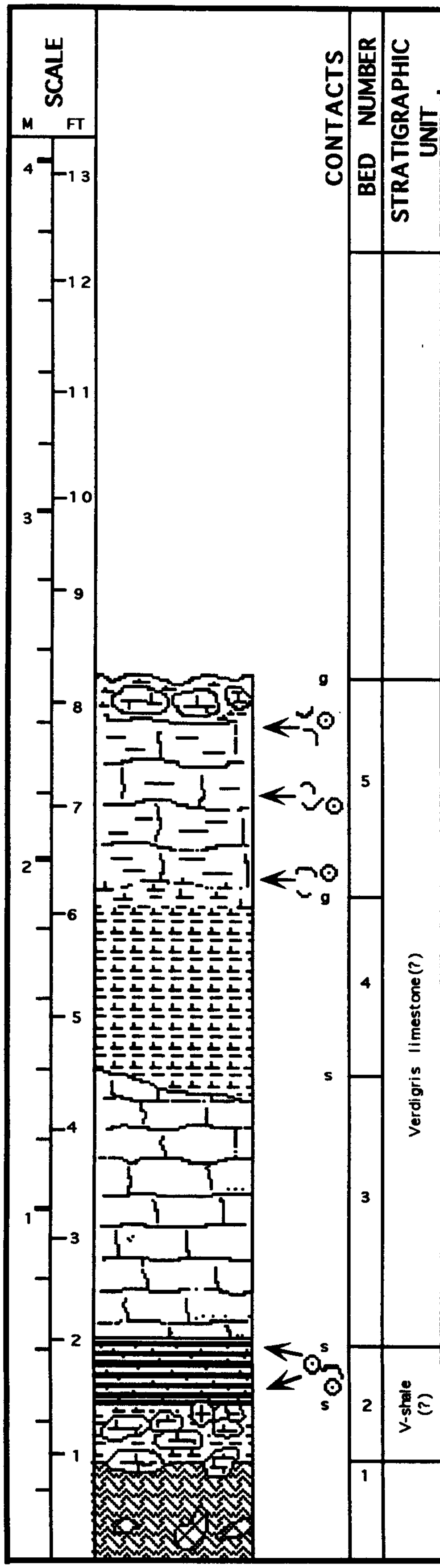
STRATIGRAPHIC DESCRIPTION

4 - Siltstone, gray, calcareous, fragmental, fusulinids (reworked?) and sandstone, green to tan, calcareous, pelecypods, tiny white opaque foraminifera, blastoids, echinoid spines; (depth: 4413.19-4418.7 ft) 1.34 m thick.

3 - Silty limestone, medium blue-gray, and fossiliferous near base, upper part dense, and pale brown; (depth: 4418.7-4422 ft) 1 m thick.

2 - Siltstone, gray-green, fine grained, disseminated pyrite, brachiopods, (depth: 4423-4424 ft) 30.5 cm thick.

1 - Mudstone, medium greenish-gray, calcareous, disseminated pyrite increases near base, unit is burrow mottled; (depth: 4424-4425 ft) 30.5 cm thick.



LOCALITY: SW SW NE Sec. 16, T. 27 S., R. 29 W., Gray County, Kansas

REMARKS: Pendleton Ld. & Ex. Inc. #1 Schauf core was provided by the Kansas Geological Survey. Lynn Watney helped locate the study interval in the core.

Measured By: Jennifer M. Elick **Date:** 7-29-94

STRATIGRAPHIC DESCRIPTION

5 - Agillaceous limestone, olive black (5 Y 2/1) and greenish black (5 G 2/1), fine-grain matrix, fossils occur along shaly partings within unit: marginiferids, *Crurithyris*, *Mesolobus*, high-spired gastropods, crinoid columnals, and fusulinds, the uppermost part of this unit appears to have been pedogenitized- becomes more argillaceous with large, rounded peds, grades into overlying unit; (depth: 4850-4852 ft) 60 cm thick.

4 - Mudrock, calcareous, breaks into plates, medium dark gray (N4) dry, dark gray (N3) wet, micaceous, pyrite nodules; fossils occur iin distinct layers: maginiferids (in life position), *Lingula*, and crinoid columnals are all mixed together, fossil hash marks base; (depth 4852-4853.6 ft) 45 cm thick.

3 - Limestone, no bedding, no apparent fossils except along basal and uppermost contacts, large, rounded ped-like strutures- light olive gray (5 Y 6/1) and greenish gray (5 GY 6/1) near top of unit, different from medium gray (N5) mottling also present neat top, some horizontal, black (N1) rootlets (?) among peds, slightly argillaceous; (depth: 4853.6-4856.3 ft) 79 cm thick.

2 - Mudrock, greenish black (5 G 2/1) and olive black (5 Y 2/1) wet with olive gray (5 Y 4/1) mottling wet; breaks into plates, grain-supported, densely packed shell lag deposit: marginiferids, *Crurithyris*, crinoid columnals, appears bioturbated, pyrite-filled burrows; (depth: 4856.3-4857.5 ft) 32 cm thick.

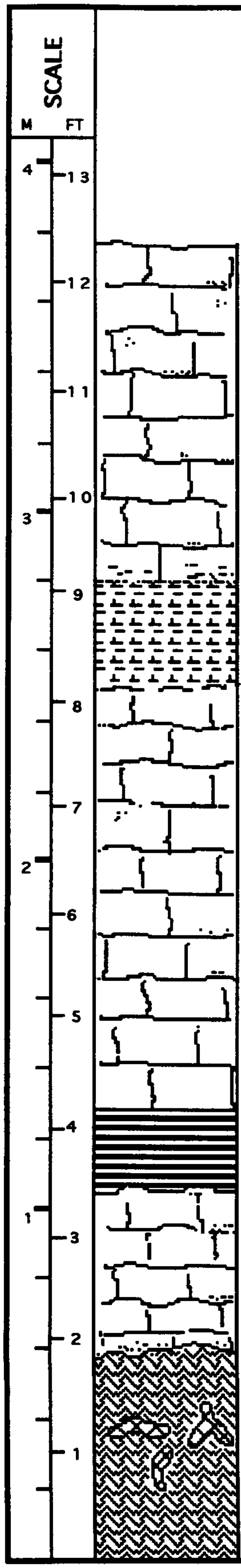
1 - Mudrock, calcareous, upper 10 cm resembles a pedogenitized limestone, composed of large, rounded peds, below are large, light olive gray (5 Y 6/1) rhizoliths (?) occurring in grayish olive green (5 GY 3/2) mudrock matrix, no fossils apparent, some greenish gray (5 GY 6/1) and dark greenish gray (5 G 4/1) roots (?), some laminae near base, no slickensides; (depth: 4857.5-4858.3 ft) 27 cm thick.

C6

LOCALITY: NE SE NE Sec. 17, T. 18 S., R. 42 W., Greeley County, Kansas.

REMARKS: Amoco drilled the Rebecca K. Bounds No. 1 core but did not release it to the KGS. A general description is found on the accompanying geophyical log. Amoco located the Cherokee at the same cycle as this study using fusulinids.

Measured By: unknown **Date:** 4-11-88



CONTACTS	BED NUMBER	STRATIGRAPHIC UNIT
	6	Verdigris limestone
	5	Verdigris limestone
	4	Verdigris limestone
	3	V-shale
	2	V-shale
	1	

STRATIGRAPHIC DESCRIPTION

6 - Limestone, burrowed, crinoid columnals; (depth: 4709-4711.0 ft) 90 cm thick.

5 - Mudrock, calcareous; (depth: 4711-4712 ft) 30 cm thick.

4 - Limestone, burrowed, crinoid columnals, corals (?); (depth: 4712-4717.4 ft) 120 cm thick.

3 - Shale, black with shell lag composed of bivalves at base of unit; (depth: 4717.4-4718.3 ft) 30 cm thick.

2 - Limestone, contains crinoid columnals; (depth: 4718.3-4719.7 ft) 45 cm thick.

1 - Mudrock, calcareous, contains rhizoliths and fossil debris (?), overlies an oolitic limestone; (depth: 4719.7-4721.7 ft) 60 cm thick.

Well Name	Location	Sec.	Twp.	Range	County
		PLATE 2			
1) Conrad No. 3	C N/2 N/2	13	27 S	24 E	Bourbon
2) Harris # 7	----	24	27 S	23 E	Bourbon
3) J-K Corp. No. 1	NW NW NW	18	26 S	22 E	Bourbon
4) Dotson 54 W.S.W	NW SW	26	26 S	21 E	Bourbon
5) Johnson W. D. W. 1	NW NW NE	10	26 S	19 E	Allen
6) Stoll W. P. W 11	NW NW	5	26 S	17 E	Woodson
7) Lauber"B" #10	----	19	26 S	15 E	Woodson
8) Ery # 1	----	24	26 S	14 E	Woodson
9) Hibbard #1	NE	14	26 S	13 E	Woodson
10) Morris # 1	NE SW NW	20	26 S	12 E	Greenwood
11) Shinkle #2	NW NW	18	26 S	10 E	Greenwood
12) Larcom # 4	NE NE NE	16	26 S	8 E	Butler
13) Simon 1-A	SW SW NE	22	26 S	10 E	Butler
14) Bolin # 1	NE NW NE	1	27 S	6 E	Butler
15) Irvine #1	NW Ne SW	11	27 S	5 E	Butler
14) Bolin # 1	NE NW NE	1	27 S	6 E	Butler
15) Irvine #1	NW Ne SW	11	27 S	5 E	Butler
		PLATE 3			
6) Stoll W. P. W 11	NW NW	5	26 S	17 E	Woodson
A) L. Cleaver #5	SW SW SE	35	23 S	17 E	Allen
B) James No. 1	NW NW NE	34	19 S	17 E	Coffey
C) Koehler No. 1	NE NE NW	9	18 S	17 E	Osage
D) Smith No. 1	C SW	35	15 S	18 E	Franklin
E) Hemphill # 1	NE NW	23	12 S	20 E	Leavenworth
F) Orville Edmonds No. 1	C SW	35	9 S	22 E	Leavenworth
		PLATE 4			
16) No. 1 Ballew	NW SW SW	1	27 S	3 E	Butler
17) Jade unit B #2	NE NW NE	3	27 S	1 E	Sedgwick
18) Donell # 1	NW NW NE	5	27 S	1 W	Sedgwick
19) Miller # 1	S/2 NE SE	13	27 S	2 W	Sedgwick
20) Peltzer # 1	NE NE SE	15	26 S	3 W	Sedgwick
21) Asendorf # 1	SW SW SW	25	27 S	4 W	Sedgwick
22) Busch # 1	NE SE NE	25	27 S	5 W	Kingman
23) # 1 Gleena	C NE NW	17	27 S	6 W	Kingman
24) Woolridge # 1	SW NW NE	21	27 S	7 W	Kingman
25) Funke # 1	C NW SE SE	25	27 S	8 W	Kingman
26) Mason B-1	SW NE NW	31	27 S	9 W	Kingman

Well Name	Location	Sec.	Twp.	Range	County
PLATE 5					
27) Jennings B-1	C NW SE	17	16 S	20 W	Rush
28) Thompson 1-A	SW NW SE	3	17 S	21 W	Ness
29) Linden # 4	NE NW NE	25	16 S	22 W	Ness
30) #3 Klitzke 5 B-32 D	E/2 NE NW	5	17 S	22 W	Ness
31) Phelps # 1	W/2 W/2 NW	9	17 S	24 W	Ness
32) # 1 ClyneB-A	SW SW NE	12	16 S	25 W	Ness
33) Thornburg "A"	NW NE NE	4	16 S	26 W	Gove
34) Cheney #1-1	SE NE SE	1	15 S	27 W	Gove
35) No. 1 Coberly	NE SW	23	14 S	28 W	Gove
36) Beesley Estate #1	----	12	14 S	29 W	Gove
37) Priefert # 1	----	28	13 S	29 W	Gove
38) Viola # 1	W/2 NE SE	2	13 S	30 W	Gove
39) Zimmerman # 1	SE NE SW	10	12 S	30 W	Gove
40) J. M. Bloom	S/2 SW SW	11	11 S	31 W	Gove
41) No. 1 Wiens "A"	NE NE SW	6	10 S	31 W	Thomas
42) Keller No. 1	NE NE SW	19	9 S	32 W	Thomas
43) Herbel "A" # 1	NW SW SE	28	9 S	33 W	Thomas
44) # 1 Dell	C SE SE	27	8 S	34 W	Thomas
45) # 1 Nickel	C NE NE	26	7 S	35 W	Thomas
46) # 1 Roulier	C SE NE	35	6 S	36 W	T homas
47) No. 1 Geneva Jenks	----	6	5 S	36 W	Rawlins
48) Kehlbeck 2-D	NW C	5	4 S	36 W	Rawlins
49) Joe Caho J D-1	SW SW SE	28	3 S	36 W	Rawlins
50) No. 1 Wilkinson	C NE NW	34	1 S	36 W	Rawlins
PLATE 6					
31) Phelps # 1	W/2 W/2 NW	9	17 S	24 W	Ness
A) Hardman No. 1	C NW SW	24	20 S	25 W	Ness
B) No.1 J. G. Collins	C NW NW	24	20 S	26 W	Ness
C) Harkness # 1	NE NE	5	19 S	24 W	Ness
D) Schlereth No. 1-36	C SE	36	23 S	26 W	Hodgemen
E) Pendleton Schauf (no log)	----	16	27 S	29 W	Gray
PLATE 7					
44) # 1 Dell	C SE SE	27	8 S	34 W	Thomas
A) # 1 Starns	C NW SE	35	9 S	36 W	Thomas
B) # 1 Mills	C SE SW	6	12 S	39 W	Wallace
C) # 1 Pilger	NW NW SE	1	14 S	39 W	Wallace
D) Sloan 1-8	----	2	16 S	42 W	Greeley
E) Rebecca K. Bounds No. 1	NE SE NE	17	18 S	42 W	Greeley

Well names	Location	Sec.	Twp.	Rng.	County
Orville Edmonds no. 1	C SW	35	9 S	22 E	Leavenworth
Orville Edmonds 1-A	SW NW C	35	9 S	22 E	Leavenworth
Hemphill no. 1	NE NW	23	12 S	20 E	Leavenworth
Moews 1	SE SE SW	34	18 S	20 E	Franklin
Trent Birkdoll 1-A	SW NW NE	13	18 S	20 E	Franklin
Smith no. 1	C SW	35	15 S	18 E	Franklin
Koehler no. 1	NE NE NW	9	18 S	17 E	Osage
James no. 1	NW NW NE	34	19 S	17 E	Coffey
Greathouse # 1	NE NE NW	5	20 S	16 E	Coffey
DW Evans 2	NE SE SE	1	19 S	14 E	Coffey
Hatch A #2	SW SW NE	2	22 S	13 E	Coffey
Mulson no. 1	NE NE NW	2	20 S	13 E	Coffey
Miller 1	center	30	22 S	21 E	Anderson
Whittman # 1	----	21	20 S	20 E	Anderson
Cones 1E	----	19	22 S	25 E	Linn
Shinkle CT-I-31	NE NE SW	31	21 S	24 E	Linn
No. 5	SE SW SW	5	23 S	24 E	Linn
Mitchell #3	C NW NE	36	21 S	21 E	Linn
Larry Cook #2		21	31 S	21 E	Labette
Hall # 3	W/2 SW SW	27	28 S	19 E	Neosho
Everit Wratchford	E SE SW	16	25 S	25 E	Bourbon
C. M. Blevins 1	----	15	24 S	25 E	Bourbon
No. 1	SW NW SW	5	26 S	25 E	Bourbon
Develan no. 1	W NE	24	24 S	24 E	Bourbon
Dotson #2	NE SW SE	27	23 S	24 E	Bourbon
O. Younggren no. 6	C SE SW NW	15	26 S	23 E	Bourbon
J-K Corp. no. 18-1	NW NW NW	18	26 S	22 E	Bourbon
Darrel George IV	NW NE NW	4	25 S	22 E	Bourbon
Honneus 31 A0	S/2 SW	11	24 S	21 E	Bourbon
WSW #1	NW NE NE	2	24 S	21 E	Bourbon

Well names	Location	Sec.	Twp.	Rng.	County
Johnson #1	NW NE NW	12	27 S	21 E	Bourbon
No . 32	SW SE NE NE	25	23 S	21 E	Allen
Stewart 1.8	SE SE SE	28	23 S	21 E	Allen
Love 7A0	S/2 E/2	36	24 S	20 E	Allen
Johnson W. D. W 1	NW NW NE	10	26 S	19 E	Allen
Colt 5-A	SE	3	24 S	18 E	Allen
Frances Mae # 13	SE NW NE	36	23 S	18 E	Allen
George no. 1	NW SE NW	6	24 S	17 E	Woodson
Stoll W. D. W. 11	NW NW	5	26 S	17 E	Woodson
Mitchell # 1	NE SE SW	19	23 S	16 E	Woodson
# 1 Knapp	SW SW NE	33	24 S	15 E	Woodson
Lauber "B" #10		19	26 S	15 E	Woodson
Kimbell no. 17	NW SE NW	18	24 S	14 E	Woodson
Ery #1		24	26 S	14 E	Woodson
J. W. Maclaskey # 24		32	23 S	14 E	Woodson
Hibbard # 1	NE SW NE	14	26 S	13 E	Woodson
Dalton no. 1	SW SW NE	12	24 S	13 E	Woodson
Berry # 3	NE SW SW	32	23 S	13 E	Greenwood
Joe Becker # 2	NE NW SW	8	25 S	13 E	Greenwood
Berry # 3	NE SW SW	32	23 S	13 E	Greenwood
W. F. Harmon no. 7	----	31	23 S	12 E	Greenwood
Bobey # 1	SE S/2	1	24 S	12 E	Greenwood
Dalton "C" no. 1-A	SW SE NE	11	24 S	12 E	Greenwood
Morris #1	NE SW NW	20	26 S	12 E	Greenwood
Carson #1	NW SW SW	33	23 S	11 E	Greenwood
Kipper # 1	NE NE NE	2	23 S	11 E	Greenwood
Elmer Hollis #1	NW NE NW	20	23 S	10 E	Greenwood
Shinkle no. 2	NW NW NW	18	26 S	10 E	Greenwood
Pixlee # 6	SE SW NW	9	22 S	10 E	Greenwood
Nixon no. 8	NE NW SE	34	24 S	9 E	Greenwood
Marshall # 3	SW NW SW	34	24 S	9 E	Greenwood
Barrier # 34	----	3	26 S	8 E	Greenwood
Barrier # 36	----	3	26 S	8 E	Greenwood
Zebold #1	NE NW NE	35	23 S	8 E	Greenwood

Well names	Location	Sec.	Twp.	Rng.	County
No. 3 "A" Eno	C N/2 S/2 NE	25	21 S	9 E	Chase
Underwood no. 1	NE NW SE	13	22 S	9 E	Chase
Evans no. 1	NE SW SW	13	22 S	9 E	Chase
Pascal Roniger # 4-1	SW SE SW	4	21 S	8 E	Chase
Rettiger no. 1	NW NW NW	20	19 S	8 E	Chase
Peak and Hatch	NW NW SE	26	18 S	8 E	Chase
Gutherie # 1	SE NW SE	11	18 S	8 E	Chase
M c Nee # 1	SW NE NW	23	20 S	7E	Chase
Frick Farms # 1-19	C SE SW	19	19 S	7 E	Chase
Childs no. 1	NE NE NW	24	19 S	7 E	Chase
Mulvane # 5	NW SW NW	26	18 S	7 E	Chase
Stauffer # 1	C NE NW	2	20 S	7 E	Chase
# 1 Schroeder *	C SE SE	8	20 S	6 E	Chase
Sauble # 2 *	NE SW SE	13	21 S	5 E	Chase
Galyardt # 1	C SE	9	26 S	8 E	Butler
Larcom #4	----	16	26 S	8 E	Butler
Galyardt # 2	C NW SE	9	26 S	8 E	Butler
Nuttle Estate #1	NW SE SW	32	24 S	8 E	Butler
Simon 1-A	SW SW NE	22	26 S	7 E	Butler
Wagner #2	CN SW	29	26 S	6 E	Butler
Bolin # 1	NE NW NE	1	27 S	6 E	Butler
Irvine # 1	NW NE SW	11	27 S	5 E	Butler
Bisagno #4	NW SE	35	26 S	5 E	Butler
Horner #2	SW NW	17	26 S	5 E	Butler
# 1 Jantzen	C SE NW	21	24 S	4 E	Butler
# 1 Ballew *	NW SW SW	1	27 S	3 E	Butler
Jade Unit B #2	NE NW NE	3	27 S	1 E	Sedgwick
Moran # 1	SE SW NE	5	27 S	1 W	Sedgwick
Cramner #1 *	SE SE SE	6	27 S	1 W	Sedgwick
Donell #1	NW NW NE	5	27 S	1 W	Sedgwick
Miller no. 1	S/2 NE SE	13	27 S	2 W	Sedgwick
Martha Weninger #1	SW SW SE	13	26 S	2 W	Sedgwick
A-9 Simon *	C SE NE	9	27 S	2 W	Sedgwick
Klausmeyer no. 1	NE NE NE	14	27 S	3 W	Sedgwick
Lorg no. 1	SE NW SE	34	26 S	3 W	Sedgwick

Well names	Location	Sec.	Twp.	Rng.	County
#1 Becker	SE NE SE	18	27 S	3 W	Sedgwick
Rosenhagen # 1	C-W/2 NW SW	26	27 S	4 W	Sedgwick
# 1 Asendorf	SW SW SW	25	27 S	4 W	Sedgwick
#1 Casad	SE SE SE	7	27 S	4 W	Sedgwick
#1 Knobvauck	C NE NW	26	27 S	5 W	Kingman
1 Moorehouse	S/2 SE NE	18	27 S	5 W	Kingman
Busch #1	NE SE NE	25	27 S	5 W	Kingman
1-A William Endicott*	SE NW C	23	27 S	6 W	Kingman
1 Endicott B *	C S/2 N/2 SE	23	27 S	6 W	Kingman
Zecha no. 1	S/2 SW NE	23	27 S	6 W	Kingman
Erwin Shrag no. 1 *	W/2 SE/4 NE/4	24	27 S	6 W	Kingman
Glenna no. 1	C NE NW	17	27 S	6 W	Kingman
Wooldridge no. 1	SW NW NE	21	27 S	7 W	Kingman
McClura # B-1	NW NW NE	10	27	7 W	Kingman
Funk no. 1	C NW SSE SE	25	27 S	8 W	Kingman
Mason "B" no. 1	SW NE NW	31	27 S	9 W	Kingman
Oelkers "A" no. 1	NE SW SW	17	16 S	19 W	Rush
Speier # 30-A1	C S/2 NE SW	30	16 S	19 W	Rush
Jennings "B" no. 1	C SW NE	17	16 S	20 W	Rush
Moran "a" no. 1	SW SE SW	10	16 S	20 W	Rush
O. Farmer no. 1	SW NE SW	21	14 S	22 W	Trego
1-6 Brauer *	C NE SE NE	6	17 S	21 W	Ness
Moore no. 1	C NW NW	34	19 S	21 W	Ness
# 1 Irvin	C SW SE	1	17 S	21 W	Ness
Thompson #1	C N/2 NW SW	3	17 S	21 W	Ness
Lamer no. 1	NW NW SW	8	16 S	21 W	Ness
V. Higgins # 1	SE NW NE	6	17 S	22 W	Ness
Linden # 3	SE NE	25	16 S	22 W	Ness
Linden # 4	NE NW NE	25	16 S	22 W	Ness
Richardson *	NW	1	16 S	22 W	Ness
Hair "A" no. 1 *	C SE SW NE	4	17 S	22 W	Ness
Northwest Bazine (11)	----	21	18 S	22 W	Ness
Endicott A-1	----	18	18 S	23 W	Ness
Bahr no. 1 *		13	18 S	23 W	Ness

Well names	Location	Sec.	Twp.	Rng.	County
Hayes no. 1-17	C SE SE	17	16 S	23 W	Ness
Phelps no. 1	W/2 W/2 NW	9	17 S	24 W	Ness
# 1 Phelps "B"	SE SE NE	8	17 S	24 W	Ness
Harkness #1	NE NE	5	19 S	24 W	Ness
Hardman no. 1	C NW SW	3	18 S	25 W	Ness
Doebbeling D #1	C SE NW	32	20 S	25 W	Ness
Carter "G" no. 1	C SE NW	4	16 S	25 W	Ness
Brown "X" A	C SE NE	2	16 S	26 W	Ness
Miner no. 1	SW SW SW	21	17 S	26 W	Ness
Mann #1	NE SW NW	33	14 S	26 W	Gove
Cheney "A" #2	C SW SE	28	14 S	27 W	Gove
Cheney "C" #4	S/2 N/2 SE	28	14 S	27 W	Gove
Becker B # 6 *	NE NW NE	34	15 S	27 W	Gove
# 1 Tustin "B"	SW SW SW	4	14 S	28 W	Gove
Davis 1 "A" *	NE NE NW	29	15 S	28 W	Gove
Lundgren "M" no. 1	C SE SE	32	14 S	29 W	Gove
O'Conner # 5	SW SW NW	31	14 S	29 W	Gove
Lundgren no. 1	C N/2 NW	32	14 S	29 W	Gove
Hockersmith no. 1	SE SE NE	36	13 S	29 W	Gove
Beoucher no. 1-10	S/2 N/2 SE	19	14 S	29 W	Gove
No. 1 Groom	E/2 SE NE	25	14 S	30 W	Gove
Martin "UU" no. 1 *	SW	23	11 S	30 W	Gove
Jensen L # 1	C NW NW	3	12 S	30 W	Gove
# 1 Zimmerman	----	10	12 S	30 W	Gove
Beoucher no. 1	C SW NE	26	13 S	30 W	Gove
Phelps "C" #1	C SW NW	32	13 S	31 W	Gove
Brockelman no. 1	C NE SW	6	10 S	30 W	Sheridan
Summers no. 68-25	SE SW SE	25	10 S	31 W	Thomas
No. 2 Ryan Twin *	E C SE	27	8 S	32 W	Thomas
Stewart "A" 1	NW NW NW	28	7 S	33 W	Thomas
Hansen # 1		16	10 S	33 W	Thomas
Curry "C" # 1	NW NW SE	2	6 S	35 W	Thomas
# 1 Starns	C NW SE	35	9 S	36 W	Thomas
Davis # 1	C NW SE	22	7 S	36 W	Thomas

Well names	Location	Sec.	Twp.	Rng.	County
Dull # 2-6	SW NW SE	6	6 S	36 W	Thomas
Waterman # 1	SE SE SE	15	4 S	33 W	Rawlins
Heble no. 1-27	SE SE	27	1 S	34 W	Rawlins
# 1 Ackerman *	NE NE NE	3	4 S	34 W	Rawlins
# 1 Lyndon McDougal	C SE SW	4	4 S	34 W	Rawlins
# 1 Reinert	C NW NE	34	3 S	34 W	Rawlins
Eueriss no. 1	C NE SE	35	5 S	35 W	Rawlins
Mayfield no. 1	C NE NE	10	4 S	35 W	Rawlins
# 1 Bessie Wright "F" *	NW NE NE	14	3 S	35 W	Rawlins
# 27-16 CAHO J	SE SE	27	1 S	35 W	Rawlins
Kehlbeck # 1-D	NW NE	5	4 S	36 W	Rawlins
# 1 Richard	C SW NE	24	9 S	37 W	Sherman
Goodland No. 5	NE NE NE	11	9 S	37 W	Sherman
# 1 Wilkens	S/2 SE SE	8	2 S	37 W	Cheyenne
Hundhenke # 1	----	18	4 S	39 W	Cheyenne
# 1 Pilger	NW NW SE	1	14 S	39 W	Wallace
# 1 Mills	C SE SW	6	12 S	39 W	Wallace
Schlereth no. 1-36	C SE	36	23 S	26 W	Hodgemen
# 1 Becker "L"	NW NE NW	31	16 S	27 W	Lane
Becker # 1	C NW NE	31	16 S	27 W	Lane
Robert # 1	SE SE	3	16 S	28 W	Lane
Roberts no. 1-5 *	NE NE SE	5	16 S	28 W	Lane
Dickey # 1 *	SW NE NE	32	16 S	29 W	Lane
Cramner "S" no. 1	C NW	22	16 S	30 W	Lane
Blumer Ardrey no. 16-19	SE SE SE	19	26 S	29 W	Gray
F. Finuup no. 1	C SW SE	33	25 S	29 W	Gray
Heyen "D" # 1 *	SE SE SW	5	11 S	32 W	Logan
Spiking no. 1	C NW SE	1	12 S	32 W	Logan
Clark "A" No. 1	SW SW SW	17	12 S	33 W	Logan
Wilton # 1	NW SW SE	8	12 S	33 W	Logan
Potter # 1	C SE SW	18	11 S	33 W	Logan

Well names	Location	Sec.	Twp.	Rng.	County
Nollette "B" #1 *	W/2 SE	11	12 S	34 W	Logan
Herl # 1	SE SW	1	12 S	34 W	Logan