Stratigraphy, Depositional Environments and Coalbed Methane Resources of Cherokee Group Coals (Middle Pennsylvanian)-- Southeastern Kansas

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Abstract

The Cherokee basin of southeast Kansas, part of the western region of the Interior Coal Province, is a hydrocarbon-bearing foreland province. Middle Pennsylvanian Cherokee Group coals form a large portion of an estimated 48 billion metric tons of deep coal resources (greater than 30 meters) in eastern Kansas. Cherokee coals are of high-volatile bituminous A and B rank. With sufficient overburden and thick seals they have high potential for coalbed gas production. In Kansas, economic coalbed gas production requires coals of higher quality (low ash, high Btu, and high gas content), seams generally thicker than 0.3 meters, and multiple coals within close proximity to pipeline infrastructure.

Structure and isopach maps, along with cross sections constructed from cores, outcrops and well logs, provide a better understanding of the lateral variability and extent of the major coal bearing sequences. Integration of core descriptions with well logs was used to correlate depositional environments across the Cherokee basin. Cherokee Group coals accumulated in a variety of depositional settings such as, marshes, non-barred and back barrier coastlines, estuaries, and fluvial flood basins. Variations in coal quality, thickness, and lateral distribution can be understood by placing Cherokee Group coals within a sequence stratigraphic framework. Thicker and laterally extensive coals developed toward the end of the transgressive systems tract, and beginning of the highstand systems tract. Pre-existing topography played a major role in the growth, distribution and quality of peatlands that developed into coal.

Desorption of coal and shale samples from core holes within the study area determined total gas content. Gas contents varied from 3 to more than 300 standard cubic feet/ton (scf/ton). Black shale gas contents range from 3 scf/ton to 35 scf/ton. Within the study area, an estimated 6.6 trillion cubic feet of original gas in place is estimated from twelve coals and two black shales. An improved geologic understanding of the Cherokee Group coals can aid in coalbed gas exploration and development in southeastern Kansas.

The Cherokee basin of southeast Kansas, part of the western region Interior Coal Province, is a hydrocarbon-bearing foreland province with abundant resources of deep coal (>100 ft; >30 m burial depth), predominately within the Cherokee Group (Desmoinesian Stage, Middle Pennsylvanian Series). Estimates of total deep coal resource within eastern Kansas are on the order of 48 billion metric tons of predominately bituminous coal (Brady, 1990). The major Cherokee Group coal beds make up the largest portion of this resource and include the Riverton, “Aw” (informal subsurface name), Weir-Pittsburg, Mineral, and Bevier coals (Brady, 1997; Figure 1.01). Typical Cherokee Group coals are of high-volatile A and B bituminous rank. Medium-volatile bituminous coal is the ideal rank for coal bed generated methane (Stoeckinger, 1989). Sufficient overburden, and a competent seal provided by thick shale, generated and trapped quantities of methane in the high-volatile A and B bituminous Cherokee Group coals (Stoeckinger, 1989).

This study of major Cherokee Group coals in southeast Kansas addresses the following:

- distribution of coals within the Cherokee basin;
- the location of coals within a sequence stratigraphic framework;
- depositional environments of the coals;
- gas content of Cherokee Group coals;
- linkage between depositional environment and coal quality;
- potential for coalbed methane exploitation in southeast Kansas.

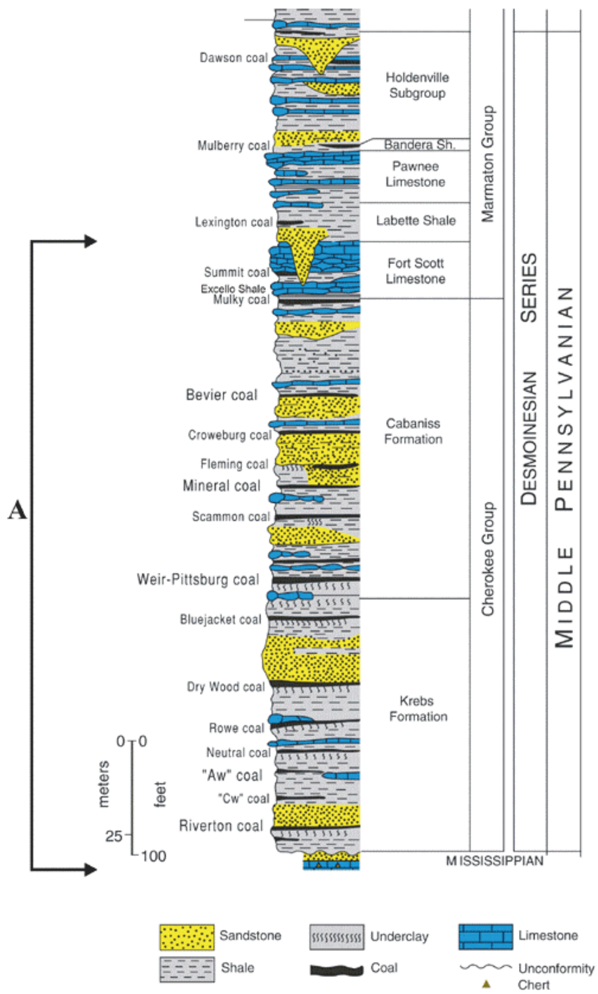


Figure 1.01 - Stratigraphic classifications of the Desmoinesian Series (modified from Zeller, 1968). (A) Stratigraphic limits of this study

1.2 Hydrocarbon Significance

Conventional petroleum production in the Cherokee basin began in the late 19th century and continues to present. Production has been in decline for the past fifty years and is presently dominated by stripper production (Newell et al., 2002). Production of shale gas in eastern Kansas from carbonaceous black shales from the Fort Scott member of the Marmaton Group dates back to 1910, where wells are reported to have produced more than 200 million cubic feet (MMCF; Charles and Page, 1929). Today, these carbonaceous black shales are known as the Little Osage and Excello Shale, and occur in association with thin underlying coals (Summit and Mulky, respectively; fig. 1.01). Exploration for shale and coal gas briefly resurged in the late 1980's due to tax incentives and then subsided in the early 1990's during persistent low commodity prices. In the first three years of the 21st century, recent demands for natural gas, increased price, and new technologies have turned unconventional gas in the Cherokee basin into an active energy play (Figure 1.02). Up to 14 relatively thin coals beds may be encountered in any one well (Brady, 1997). The key to a successful coalbed play is to identify numerous coals of sufficient thickness with higher adsorbed gas contents (greater than 100 standard cubic feet per ton) located near pipeline infrastructure (Figure 1.02).

Coals in the Cherokee basin are generally less than 2,500 feet deep (760 m), so drilling costs are relatively low. Top reported completion intervals are in the Mulky coal and overlying Excello Shale, Weir-Pittsburg coal, and Riverton coal.

Many producers are producing gas from coals that are less than 2 feet (0.6 m) thick with promising results. Current unconventional gas production in southeast Kansas is rapidly increasing and exceeds 1.5 BCF per year (billion cubic feet; Priestman, 2003).

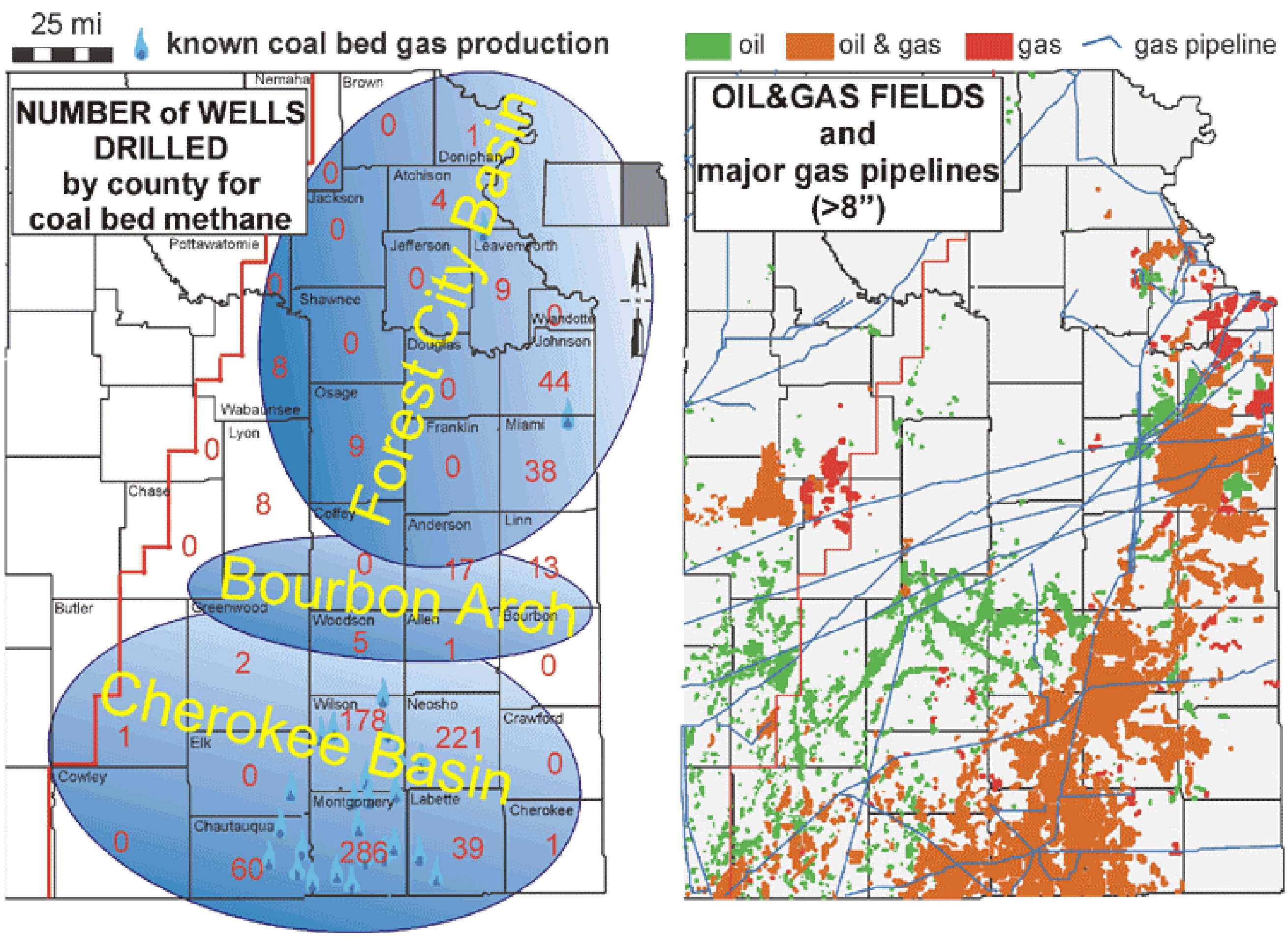


Figure 1.02 Coalbed methane wells drilled and major pipeline infrastructure

1.3 Area of Investigation

The study area covers approximately 4,000 square miles (approximately 10,300 sq km) within an eight-county area in southeastern Kansas (Figure 1.03). It includes all of Cherokee, Crawford, Neosho, Labette, Wilson, Montgomery, Elk and Chautauqua counties. Cherokee Group rocks are present in the subsurface throughout most of the study area and crop out in a northeast-southwest-trending belt along the southeastern edge of the study area. For over 145 years coal deposits of eastern Kansas have been mined with a total production of approximately 300 million short tons (272 million metric tons; Brady, 1997). During this time major peaks in production corresponded with World War I and II (Brady, 1997). For the past 25 years coal production has followed a steady decline due to low commodity prices and the demand for higher quality coal from other regions.

1.4 Previous Investigations

Previous studies have dealt with the stratigraphy and distribution of coal beds or sandstones within the Cherokee Group (Abernathy, 1936; Searight et al, 1953; Howe, 1956; Branson, 1957; and Searight and Howe, 1961). The first reference to the Cherokee Group concerned outcrops along the banks of the Neosho River in southeastern Kansas (Haworth and Kirk, 1894). Subsequently, the Cherokee Group was subdivided into fifteen cyclothems (Abernathy, 1936). Howe (1956) subdivided the Cherokee Group from the top of one coal bed to the next overlying coal bed and designated these units as formations. These earlier works, supplemented by the work of others, were the basis of the current accepted stratigraphic classification (Jewett et al., 1968; Figure 1.01). Previous work on the Cherokee Group centered on the major sandstones that formed the traditional “shoestring” oil reservoirs of southeastern Kansas and northeastern Oklahoma.

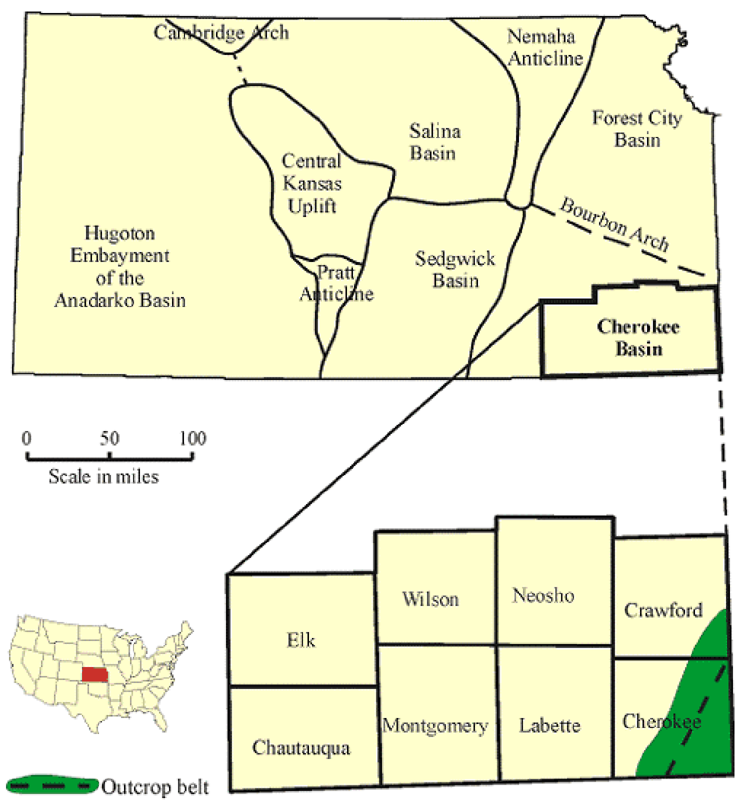


Figure 1.03 - Location of study area in state of Kansas

Recent studies have focused on the stratigraphy and/or depositional environments of the Cherokee Group relating to strippable coal reserves, and conventional sandstone petroleum reservoirs. Early work calculated the strippable coal reserves of eastern Kansas (Brady et al., 1976), while more recent work involved the first identification of coalbed methane resources (Brady, 1990, 1997). Harris (1984) examined the Krebs Formation in southeastern Kansas, and described the stratigraphy and depositional environments. Staton (1987) completed a similar study for all of the Cherokee Group in the central Cherokee basin. Walton (1995) applied sequence stratigraphic concepts to the Cherokee Group, and identified twenty-two sequence boundaries, of which some have a regional extent while others are only considered to be local. This study overlaps the areas of both Staton (1987) and Harris (1984). However, the focus is on coal deposits as a nonconventional gas reservoir, whereas previous work was centered on major sandstone deposits of the Cherokee Group (Figure 1.04).

Interpretation of depositional environments for units of the Cherokee Group (primarily sandstone deposits) have evolved and changed many times since the original interpretations (Bass, 1934). Bass (1934) concluded that the major "shoestring" sandstones were deposited in offshore barrier-bar environments. Following this interpretation, Hayes (1963) re-interpreted the sandstone units that crop out in Missouri as tidal-flat or tidal channel environments based on the presence of bi-directional cross-bedding. Cole (1969), and Visher et al. (1971) interpret most of the Cherokee Group sandstones to be fluvial-deltaic environments

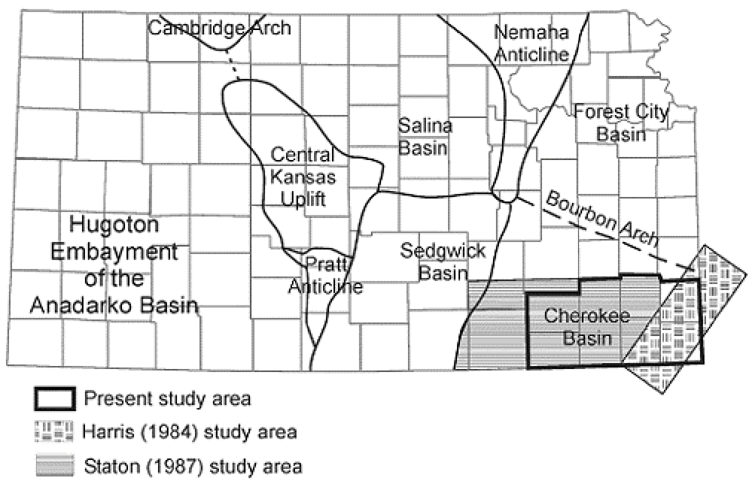


Figure 1.04 - Location of study area in relation to the study area of Harris (1984) and Staton(1987), and to the major structural features of Kansas.

1.5 Regional Geology

1.5.1 Geological Setting

The Cherokee basin is located on the western flank of the Ozark dome, which is part of the northward extension of the elongated Oklahoma platform (Cole, 1969; Moore, 1979; Figure 1.05). The Cherokee basin is bounded by the Bourbon arch to the north, the Nemaha uplift to the west, and the Ozark dome to the east. During the early to mid-Desmoinesian, the Cherokee basin was influenced by the orogenic activity of the convergent Ouachita system in present-day southeastern Oklahoma (Ham and Wilson, 1967; Harris 1984; Figure 1.05). During the Pennsylvanian, sediment of the Cherokee Group was deposited disconformably upon the karst surface of the Mississippian limestone in southeastern Kansas and adjacent areas (Saueraker, 1966). The Cherokee Group was deposited while the area was part of a slowly subsiding, intracratonic basin (Staton, 1987). Since onset of Cherokee deposition, approximately 4,900 feet (1,500 m) of Pennsylvanian and Permian sediments were deposited in the Cherokee basin (Barker et al., 1992). The Cherokee Group gradually thickens to the south into the deeper Arkoma foreland basin (Gould, 1927; Ham and Wilson, 1967; Jewett, 1951; Figure 1.05). Today, parts of these late Paleozoic deposits are stripped away leaving a homoclinal middle and upper Pennsylvanian succession dipping less than 0.5 degrees to the west (Walton, 1995).

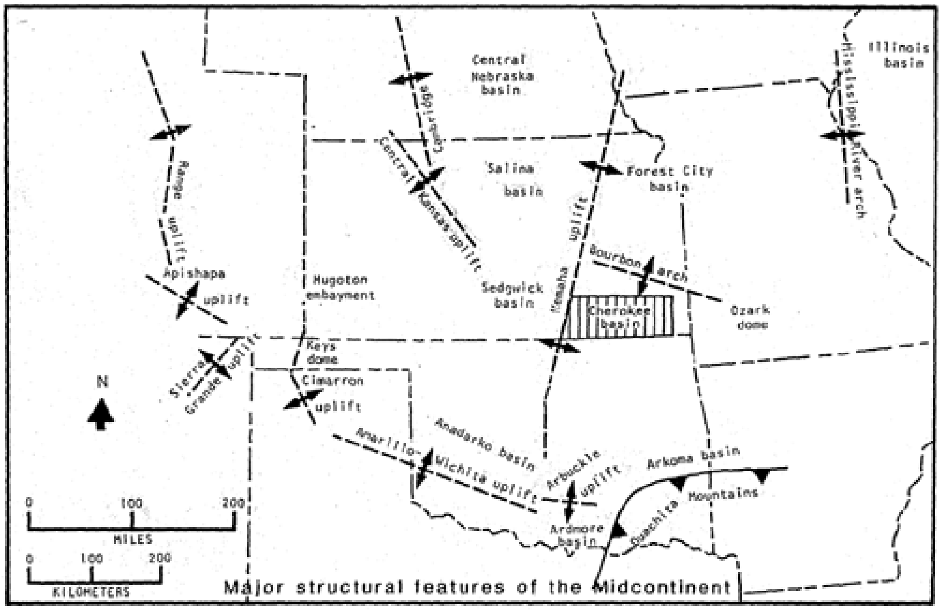


Figure 1.05 - Location of Cherokee basin and major structural features of the Midcontinent (modified from Wanless, 1969)

1.5.2 Stratigraphy

In southeastern Kansas, the Cherokee Group (Desmoinesian Stage, Middle Pennsylvanian Series) is divided into the Krebs Formation and the overlying Cabaniss Formation (Jewett et al., 1968; Figure 1.01). It is composed of numerous repetitive successions of interbedded gray to dark gray shale, rippled sandstone and siltstone, underclay, thin coal, and thin argillaceous limestone that have been interpreted as classic megacyclothems (Moore, 1931) and Illinois cyclothems (Wanless, 1931). The Cherokee Group is interpreted as consisting of a number of cyclothems that onlap positive structural features (Ham and Wilson, 1967; Visher et al., 1971, and Rascoe and Adler, 1983). Cherokee Group cyclothems were interpreted as deposited during minor progradational pulses of sedimentation that punctuate a major transgression during the Desmoinesian (Staton, 1987).

A typical Pennsylvanian cyclothem includes beds of nonmarine transitioning to marine sediments in the lower half of the cyclothem, with beds of marine transitioning to nonmarine sediments dominating the upper half of the cyclothem (Heckel, 1977). A transgressive-regressive sequence comprising a typical “Kansas” cyclothem consists of:

1. relatively thick, nearshore to terrestrial, sandy “outside” shale, and localized coal;
2. thin, transgressive “middle” limestone;
3. thin, offshore, nonsandy dark gray to black “core” shale;
4. thicker, upward grading regressive “upper” limestone; and
5. thick, nearshore to terrestrial, sandy “outside” shale (Heckel, 1977; Figure 1.06).

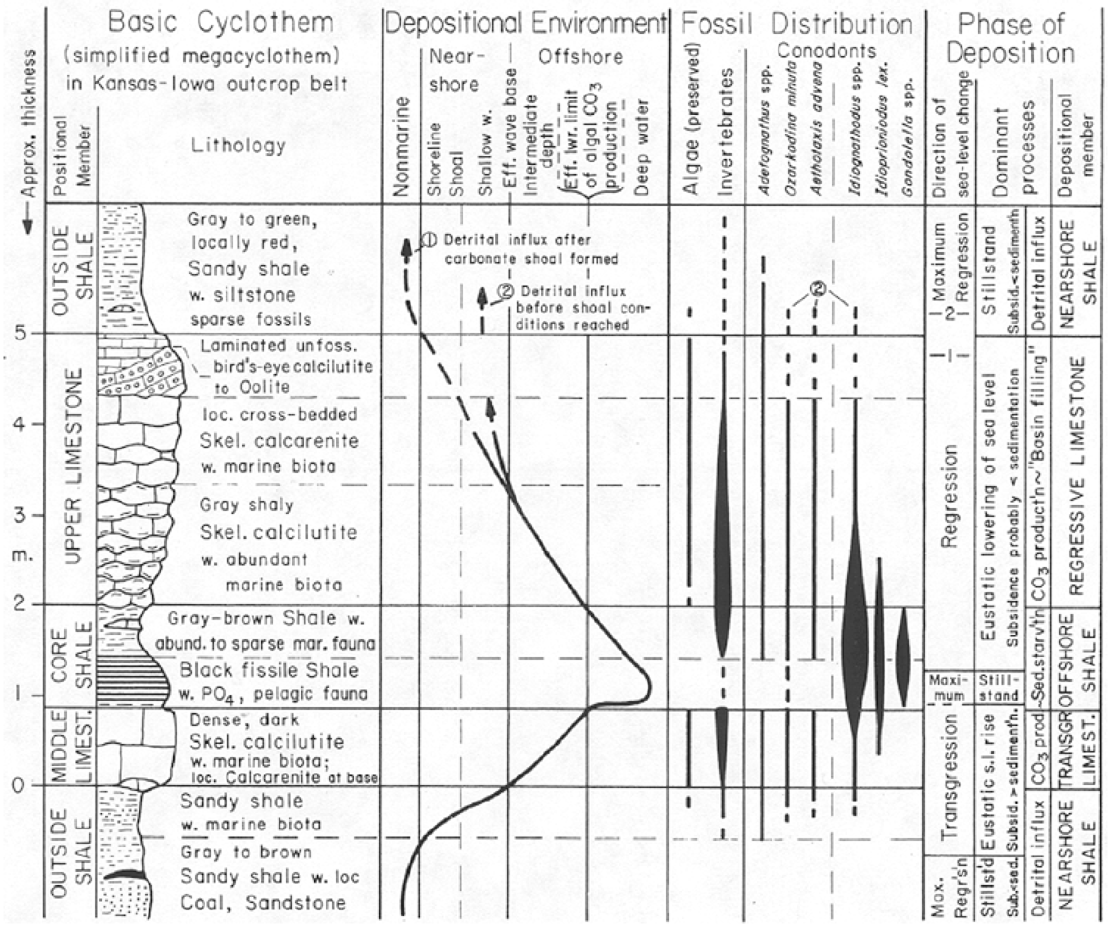


Figure 1.06 - The major components of a typical "Kansas" cyclothem and their relation to geologic properties such as depositional environment, fossil distribution, and phase of deposition (from Heckel, 1977).

1.6 Methodology

Data from the Kansas Geological Survey, including well logs, cores, and driller's logs were used to generate structure and isopach maps, and cross sections to study the geographic variability and stratigraphic geometries of coals and related facies in the Cherokee Group. A subsurface geographic information system (GIS) program was used to digitally map the structure and thickness of the main lithologies and to build a series of regional sequence stratigraphic and structural cross sections. Cores were described and tied to well log response for a well-by-well analysis. Cores of coals were sampled and desorbed to determine total gas content. After termination of the desorption process, samples were selected for proximate and sulfur analyses.

1.6.1 Well Log Analysis

The bulk of the subsurface data available for this project are geophysical well logs. Logs from a total of 930 wells, with an average spacing of eight wells per township, were interpreted and correlated (Figure 1.07). Since neutron-density is the preferred logging tools for identification and evaluation of coal, all available neutron/density porosity logs were used. Due to the paucity of neutron/density logs, gamma ray/neutron logs (the dominant geophysical well logs within the study area), were used to broaden the aerial coverage. Gamma ray/neutron logs were found to have a distinct and correlatable response that could be used to identify lithologies and sequence stratigraphic packages and surfaces.

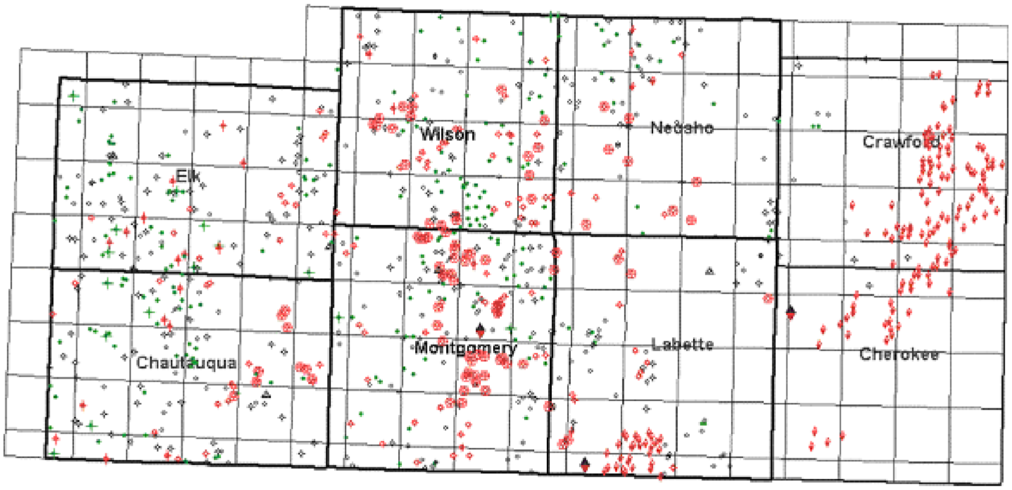


Figure 1.07 - Locations of examined and analyzed well logs in this study exceeds 930. 150 drillers logs (♦), 3 cores (♦), cbm wells (⊛), all other symbols are oil and gas wells.

A combination of gamma ray and gamma ray/neutron porosity logs were used to identify coals and provide a qualitative evaluation. Low-ash coals, lacking naturally occurring radioactive elements, exhibit a low gamma-ray count, while high ash coals contain clay minerals that register a moderate gamma-ray count. The gamma ray/neutron tool is sensitive to both high-energy captive gamma rays and thermal neutrons. The response of the tool is primarily to the amount of hydrogen in the formation that is interpreted as porosity. The high hydrogen content of coals is reflected as a high apparent porosity on the neutron log since hydrogen is regarded as an indication of porosity (Table 1.1; Scholes and Johnston, 1993). Interpretations of coal seams were made using the coincidence of low gamma-ray deflections with higher neutron porosity deflections (Figure 1.08). In addition, stratigraphic position was helpful in recognizing coals. Many Kansas coals are located just below black phosphatic “core” shales with very high gamma radiation counts (Figure 1.08). Radioactive black “core” shales were used as marker beds to focus the evaluation of possible coal development.

Density and neutron/density porosity logs are the most dependable for coal identification, and were used to provide a guide to interpretation of the much more abundant gamma/ray neutron logs. Coals generally have a low matrix density (1.33 gm/cc) and density logs will read relatively low density, which translates to very high apparent porosity (Figure 1.09). With increasing ash content (eg., clay minerals), density will increase and apparent porosity will decrease (see Table 1.1; Scholes and Johnston, 1993).

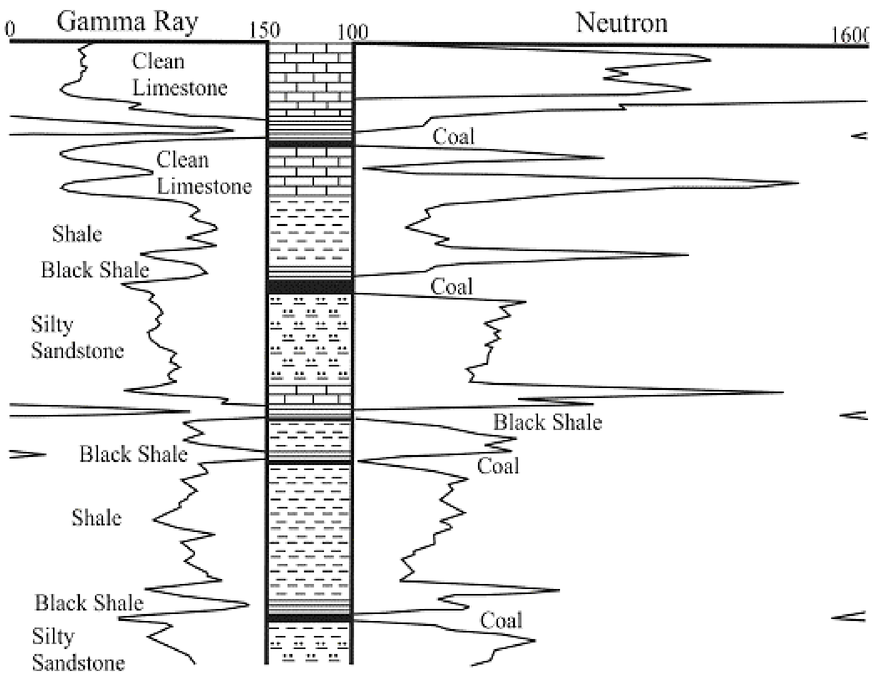


Figure 1.08 - Lithologic responses on a typical gamma-ray - neutron log from the Hinthorn CW#1 well 14=T32S-R16E. Coals are typically located beneath black phosphatic "core" shales with high gamma-ray counts (180-300 API units). Coals have relatively low gamma-ray counts (<100 API) and high apparent porosity resulting from the high hydrogen content measured by the gamma-ray/neutron log.

	Gamma Ray	Neutron	Density	Density Porosity
Low Ash Coal	Low API ~ 45 - 75 API	High Porosity ~ 35 - 45 %	Low Density < 1.75 g/cc	High DPHI > 40 %
High Ash Coal	Moderate API ~ 75 - 105 API	High Porosity < 35 %	Low Density < 2.0 g/cc	High DPHI ~ 30 - 40 %

Table 1.1 Log responses for low and high ash coals from southeastern Kansas

During the 1910's and 1920's coal exploration and extraction companies drilled numerous shallow core holes primarily in Cherokee and Crawford counties to evaluate potential for mineable coal. To supplement the sparse coverage of oil and gas wells in the eastern part of the study area, approximately 150 driller's logs from shallow borings were examined (Figure 1.07). Drillers logs from shallow borings were tied to outcrop maps and wells logs in order to better interpret the lithologies and stratigraphic position. The shallow borings provided a link between the stratigraphy from the deeper oil and gas wells and the surface stratigraphy in extreme eastern Cherokee and Crawford counties.

1.6.2 Lithologic Analysis

To supplement sparse natural outcrops and coal mines in the study area, two surface-to-total-depth cores were drilled and logged by the Kansas Geological Survey (KGS). The KGS core holes provide sedimentological, stratigraphic, and coal quality information. A total of two cores (KGS), representing the entire Fort Scott Formation and Cherokee Group, were described. Detailed descriptions of cores are in Appendix One. Another previously described core, the P&M core #20

(SE NE NE, sec.8-T23S-R22E) was reviewed and compared against the other two cores (description in Harris, 1984). Cores were examined for lithology, color, texture, cement(s), bedding, sedimentary structures, and fossil content.

Selected intervals of the core were slabbed and polished due to their brittle nature in order to better study and identify sedimentary features and fossil content. Underclays were slabbed by placing them in cardboard mailing tubes cut to length and filled with casting resin. Once the resin set up, the underclay sample was slabbed and described.

During the drilling process, cores of coals were measured and photographed before quickly placing the coals in pressurized canisters to determine gas content. Following termination of gas release, the coals were decanistered, examined for mineral and cleating development, and crushed for proximal analysis.

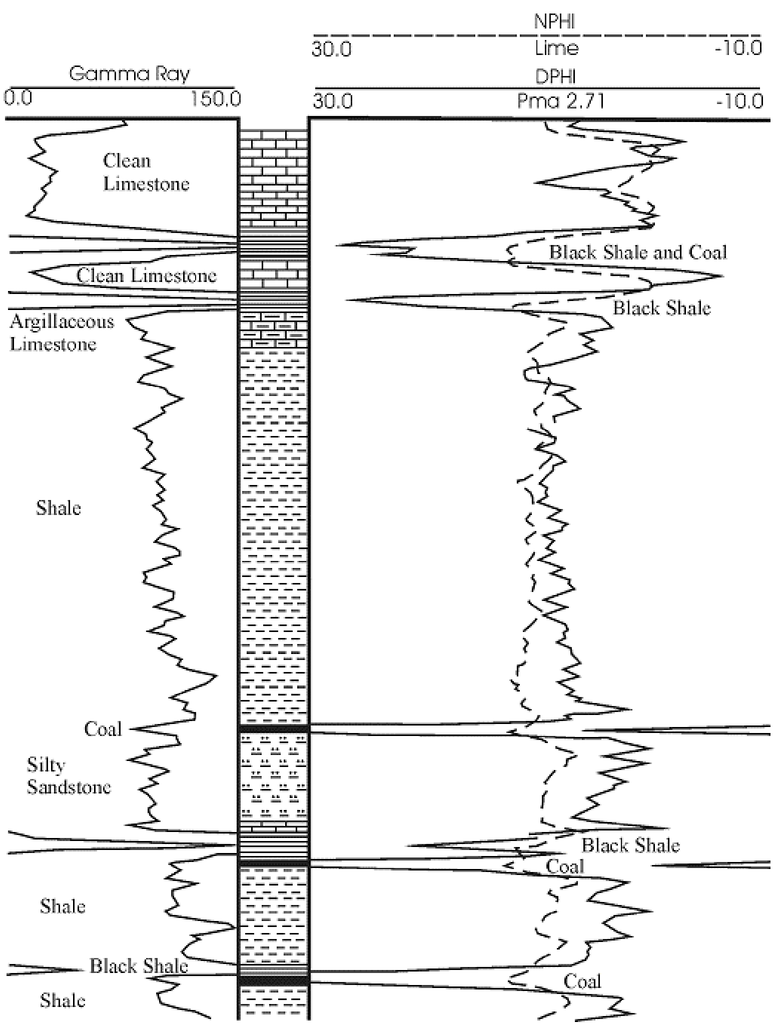


Figure 1.09 - Lithological responses on a typical gamma-ray - neutron density porosity log from southeastern Kansas. Coals have relatively low gamma-ray counts in combination with very high apparent porosity (low density). Apparent porosity in many typical coals exceeds 30 percent.

1.6.3 Computer Applications

A subsurface geographical information system (PETRA) was used to map the structure and thickness of the main stratigraphic units along with constructing regional sequence stratigraphic and structural cross sections. A digital dataset project, consisting of a series of spreadsheets (Microsoft Excel), was built through custom queries to the KGS relational database management system using Microsoft Access 2000 to generate special query language (SQL). Data selected includes general well data (eg., well name, location, elevation), producing formation, formation tops, and production for coalbed methane wells. In order to map the main lithologies and build cross sections over the study area, paper logs were selected and scanned (Neurolog scanner). Raster images of the logs were calibrated and imported into a GIS workstation for lithologic analysis. Spreadsheets were used to record and analyze all coal desorption data such as the volume, time, temperature, and barometric pressure of each measurement. Desorbed gas was summed over the time period for which the coal samples evolved all of their gas. All data generated or modified as part of this study, including horizon tops, raster wells images and identification of coalbed methane wells was uploaded into the Kansas Geological Survey’s online databases.

1.6.4 Desorption Method

In cooperation with local independent oil and gas companies, cuttings and core samples of coals were obtained from wells within the major areas of coalbed methane exploration and production. Additional coal core samples were obtained by the Kansas Geological Survey’s core drilling operations (Figure 1.10). Dave Newell and I collected and placed coal samples in desorption canisters immediately following extraction from the well bore (Figure 1.11). Cutting samples were caught with a kitchen strainer at the end of the buoy line. Core samples were obtained and quickly moved from the boring to the surface by use of a wire-line core barrel.

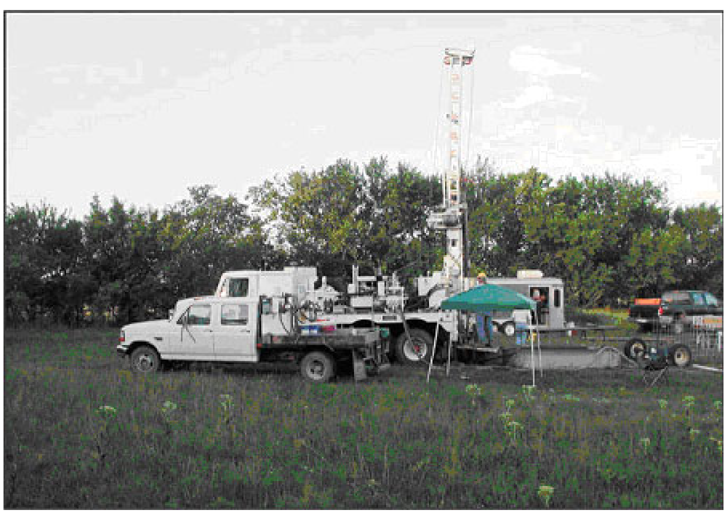


Figure 1.10 - Kansas Geological Survey's core drilling operations

Figure 1.11 Collection and canistering of coal core samples

Desorption canisters were made at the KGS, using PVC pipe and plumbing materials available at hardware stores, or purchased commercially (SSD, Inc. in Grand Junction, CO). On average, the canisters were approximately 12.5 inches long (32 cm), 3 1/2 inches (9 cm) in diameter, and enclosed a volume of approximately 150 cubic inches (2450 cm3; Figure 1.12).

Standard methods and equipment were used for measuring desorbed gas (McLennan et al., 1995). I measured evolved gas with a volumetric displacement apparatus, consisting of a set of connected dispensing burettes, one of which measures the gas evolved from the desorption canister. The other burette compensates for the compression effects that occur when the desorbed gas displaces the water in the measuring burette (Figure 1.12). The amount of gas evolved is determined by first adjusting the water levels in the two cylinders to the same level, then after releasing the gas from the desorption canister, reading the difference in water level using the volumetric scale on the side of the burette.

Desorbed gas collected in the desorption canisters was periodically released into the volumetric displacement apparatus and measured as a function of time, temperature and atmospheric pressure. Ideally, original temperature at the formation depth should be maintained for the period of desorption. To control temperature, desorption samples were placed in isothermal baths immediately after being canistered. Isothermal baths were constructed using plastic and Styrofoam coolers filled with water. For measurements in the field, original formation temperature was maintained using ice, or water heated either by an aquarium heater and/or boiling pot

Figure 1.12 - Desorption apparatus and canisters

For measurements in the lab, water was heated with aquarium heaters and circulated with aquarium pumps for formation temperatures greater than 70 °F. For temperatures less than 70 °F, the samples were kept in a room with an ambient temperature varying from 65 to 68 °F.
I measured time and atmospheric pressure in the field and laboratory using a portable weather station (Oregon Scientific, model BA928). The atmospheric pressure was measured in millibars. However, this measurement was not the actual barometric pressure, but rather an altitude-compensated barometric pressure, automatically converted to a sea-level-equivalent pressure within the instrument. In order to translate this measurement to actual atmospheric pressure, a regression correlation was determined by recording and comparing barometric readings displayed from a pressure transducer in the Petrophysics Laboratory in the Kansas Geological Survey in Lawrence, Kansas. The regression equation, corrected the millibar reading to barometric pressure.

Barometric pressure for the desorption measurements was used in a spreadsheet (written by K.D. Newell, Kansas Geological Survey) to determine gas volumes at standard temperature and pressure. Conversion of gas volumes to standard temperature and pressure was applied by the ideal-gas equation (Equation 1).

$$n = PV/RT \qquad (1)$$

where n is moles of gas, T is degrees Kelvin (i.e., absolute temperature), V is in liters, and R is the universal gas constant, which has a numerical value depending on the units in which it is measured (for example, in the metric system R = 0.0820 liter atmosphere per degree mole). The number of moles of gas (i.e., the value n) is constant in a volumetric conversion. Therefore the conversion equation is derived from the ideal gas equation (Equation 2).

$$(P_{stp}V_{stp})/(RT_{stp}) = (P_{obs}V_{obs})/(RT_{obs}) \quad (2)$$

Customarily, standard temperature and pressure for gas volumetric measurements in the oil industry are 60° F and 14.7 psi (Dake, 1978). P_{stp}, V_{stp}, and T_{stp}, respectively, are pressure, volume and temperature at standard temperature and pressure, where standard temperature is degrees Rankine (° R = 460 + ° F). P_{obs}, V_{obs}, and T_{obs}, respectively, are ambient pressure, volume and temperature measurements observed on well site or in the desorption laboratory.

Universal gas constant R drops out as this equation is simplified and the determination of V_{stp} becomes (Equation 3):

$$V_{stp} = (T_{stp}/T_{obs})\ (P_{obs}/P_{stp})\ V_{obs} \quad (3)$$

Conversion calculations in the spreadsheet were carried out in the english-metric system, as this is the standard measure system used in U.S. coal and oil industry. V is therefore converted to cubic feet; P is psia; T is ° R.

Desorbed gas was summed over the time period for which the coal samples continued to evolve gas. In the case of cores, this time could be six or more months. Cuttings desorbed faster, typically in a matter of days or weeks. Lost gas (i.e., the gas lost from the sample from the time it was drilled, brought to the surface, to time of canistering) was determined using the direct method (Kissel et al., 1975; McLennan et al., 1995). Cumulative gas evolved is plotted against the square root of elapsed time. I carefully recorded time zero during drilling operations and assumed it be the instant the core sample is lifted from the bottom of the hole, or in the case of cuttings, when the drilled rock is cut and circulated off bottom. Characteristically, the cumulative gas evolved from the sample, when plotted against the square root of time, is linear for a short time period after the sample reaches ambient pressure conditions. As a result, lost gas can be estimated by a line projected back to time zero. The period of linearity generally is 4 to 6 hours for a core sample, and less than an hour for cuttings samples.

The termination of evolved gas was defined as two consecutive weeks of zero volume of desorbed gas. After termination of gas evolution, the canisters were opened and coal samples were removed. Samples were weighed for their wet weight and allowed to dry for one to two weeks. At the end of the drying period, samples were weighed again to obtain dry weight. A portion of the dry coal sample was crushed and sent to a commercial laboratory to determine moisture, ash, sulfur, calorific value (BTU), fixed carbon, and volatile matter (Luman’s Laboratories).

Chapter 2: Coal Deposits of the Cherokee Basin

Previous work by Harris (1984) and Stanton (1987) divided the Cherokee Group into ten stratigraphic intervals using laterally persistent dark-gray to black "core" shales as stratigraphic markers (Figure 2.01). These highly radioactive black shales (150-300+ API units) are readily identifiable on gamma-ray well logs and are correlatable throughout eastern Kansas and into adjacent states. These "hot" gamma-ray shales serve as marker beds for the major coals within the study area. A composite section illustrates the stratigraphic relationship between marker beds and other units used in the study (Harris, 1984; Figure 2.02). In this study, an additional interval (Little Osage interval) was added above the Cherokee Group. The Little Osage interval contains the Summit coal of the Fort Scott Limestone a significant coal and important exploration target in southeast Kansas (Figure 2.01). Depositional environments in the Cherokee Group range from relatively deep, low energy marine environments to shallow, marginal marine and nonmarine environments. Due to significant hiatus before and after peat development, depositional environments of coals may not be directly related to the environments of the overlying or underlying sediments (McCabe, 1984). Depositional environments of coals may be better reflected by their geometry, average thickness, areal extent, orientation, ash content, and sulfur content (Flores, 1993, McCabe and Shanley, 1992).

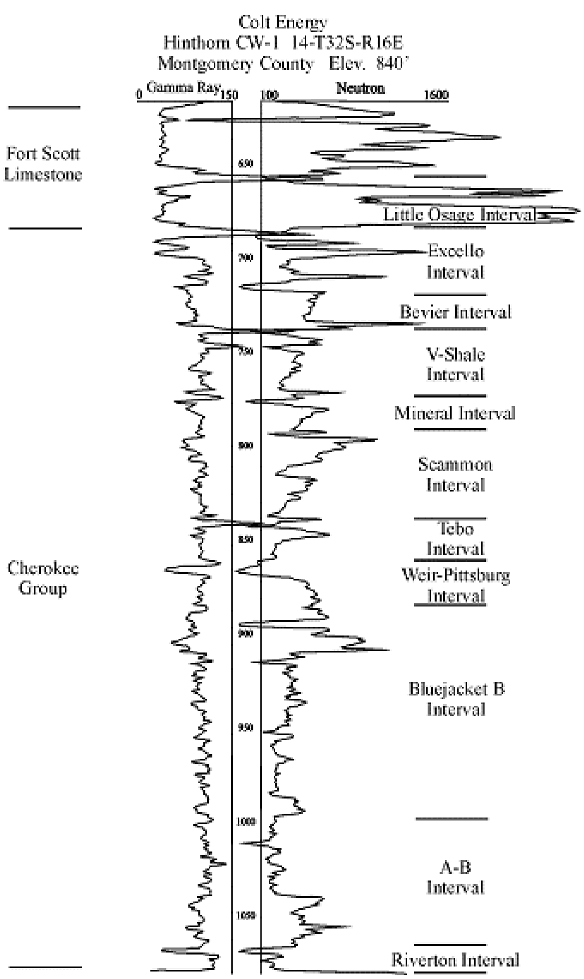


Figure 2.01 - Type log of the Cherokee Group and lower Fort Scott Limestone in the Cherokee Basin with designated intervals defined by marker beds, which are primarily dark gray to black shales (after Staton, 1987).

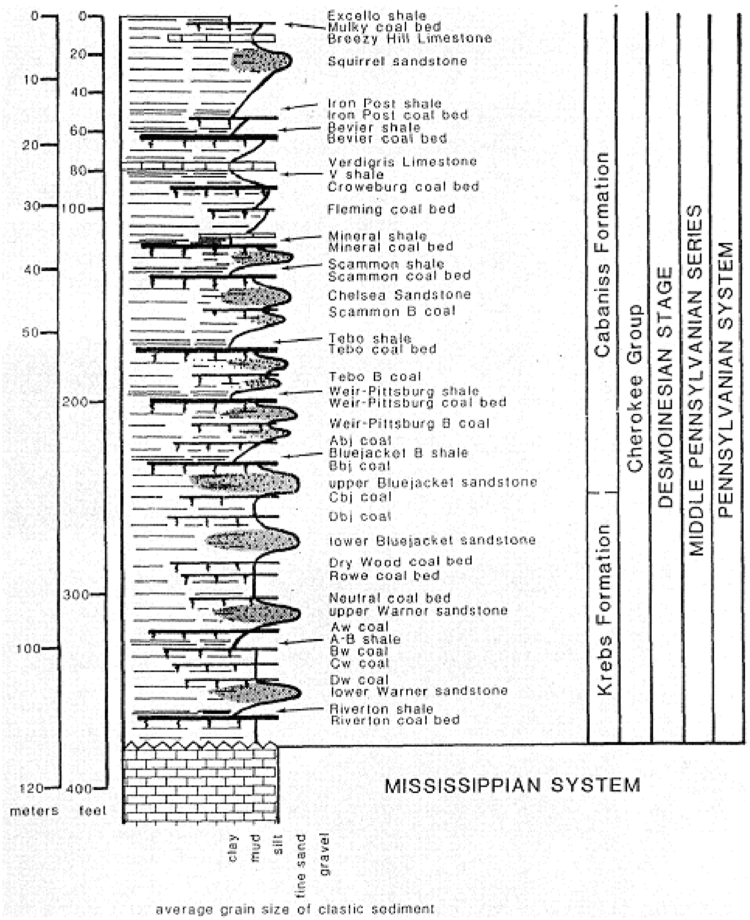


Figure 2.02 - Composite section of the Cherokee Group in southeastern Kansas showing relationship of marker beds, which are primarily dark gray to black radioactive shales and major named coals (modified from Harris, 1984)

2.1 Lithofacies and Depositional Environments of the Cherokee Group

Ten lithofacies were recognized in the Cherokee Group of southeast Kansas (Table 2.1). The depositional environment of each lithofacies was interpreted based on mineralogy, sedimentary structures, ichnology, log response and stratigraphic position of described cores (Table 2.1; Appendix 1). Individual lithofacies are listed below, along with an interpretation of the depositional process and sedimentary environment.

Table 2.1 - Facies scheme for the Cherokee Group in the Cherokee basin.

Lithofacies	Depositional Process	Sedimentary Environment
Coal to carbonaceous shale	Peat growth	Mire
Blocky mudstone	Pedogenesis	Paleosol
Pyritic shale	Sediment fallout	Coastal marsh-swamp
Interlaminated sandstone and siltstone	Tidal currents and slack-water sediment fallout	Marginal marine
Sideritic gray shale	Sediment fallout and low-energy tidal currents	Marginal marine
Laminated muddy sandstone	Tidal currents and slack-water sediment fallout	Muddy tidal flat
Bioclastic packstone to grainstone	Reworking by waves or tides and bioturbation	Marine, above fair-weather wave base
Bioclastic mudstone to wackestone	Bioturbation	Open marine, below fair-weather wave base
Dark gray shale	Storm action and sediment fallout	Offshore transition
Phosphatic black shale	Sediment fallout	Low oxygen shelf

2.1.1 Coal Facies

Description
The coal facies vary from low ash coal to high ash coal to carbonaceous shale. Diagnostic features of the coal are black color, moderately bright luster, laminations (3-10 mm), and moderate to well developed cleats (Figure 2.03). Diagnostic features of the carbonaceous shale are black color, moderately bright luster, and laminations (3-10 mm). Cleat spacing can vary widely (0.25 to 2 inches; 0.6 to 5 cm). Cleats are typically mineralized with calcite, pyrite and sulfur. Plant fragments are found throughout the facies. No trace or body fossils were observed in the coal facies. The coals facies ranges in thickness up to 6 feet (1.8 m). Lower and upper contacts are consistently sharp.

Paleoenvironmental Interpretation
The close association with marine detritus or marine carbonate sediments can explain the high-ash and carbonaceous nature of a coal. Peat growth exposed to the marine or fluvial environment is interpreted to be the cause of the carbonaceous shale or high-ash coals, while low-ash coal develops in mires protected from marine and fluvial influence. Coal splits are an indication of the margin of a coal seam and the margin of the mire. High sulfur contents are an indicator of increased marine influence during the coalification process. Historically, the coal facies would be interpreted as part of the “outside shale” in the cyclothem model (Heckel, 1977).

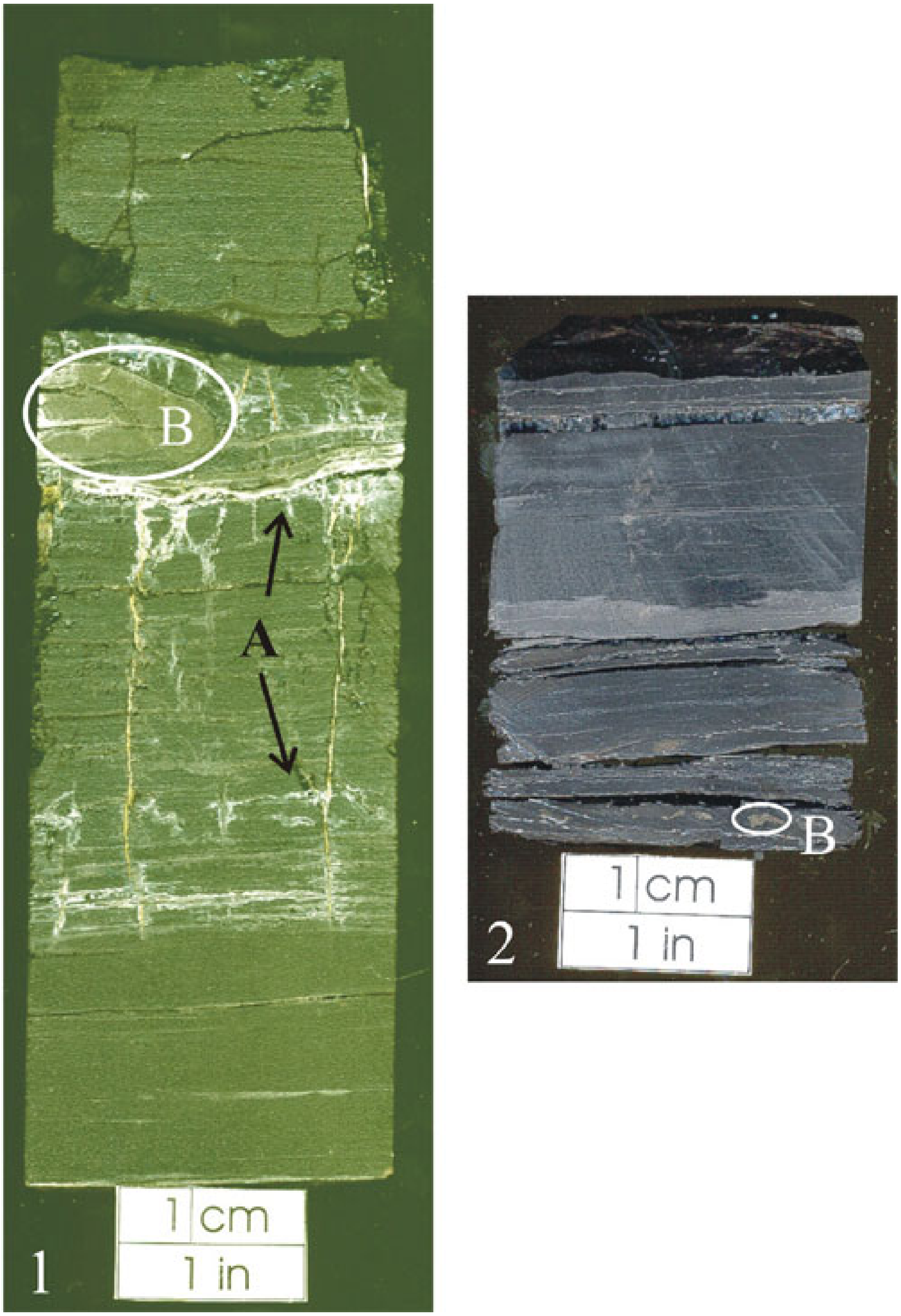


Figure 2.03 - Polished core section showing the coal facies of the Riverton coal. Coal is laminated with variations in lithotypes and macerals. Note mineralization of calcite (A) and pyrite (B) along cleats and laminations. Sample 1 from 850' in the Cooper CW#1 well, 11-T35S-R18E, Labette County, Kansas. Sample 2 from 895' in the Hinthorn CW#1 well, 14-T32S-R16E, Montgomery County, Kansas

2.1.2 Blocky Mudstone Facies

Description

The blocky mudstone facies consists of micaceous shale that is light gray to medium gray. Other features that characterize the blocky mudstone facies include slickensides, blocky and mottled texture, and plant fragments (Figure 2.04). Clay ironstone nodules (siderite) are usually present in the lower portion and decrease in abundance upwards. When the blocky mudstone facies is associated with an underlying limestone, caliche nodules may be present that are 0.25 inches in diameter (8 mm). Plant fragments and rhizoliths increase in abundance upwards toward the top of the blocky mudstone facies. No trace or body fossils were observed in the blocky mudstone facies. Thickness of the blocky mudstone ranges from 0.25 to 10 feet (.1 to 3 m). The lower contact is typically gradational with the underlying facies, while the upper contact is sharp.

Paleoenvironmental Interpretation

Blocky or mottled texture with soil slickensides, and plant fragments are evidence that the blocky mudstone lithofacies is a paleosol. Marine fossils were not observed. Development of slickensides indicates frequent shrink-swell cycles. These cycles are directly tied to paleoclimate. A higher frequency of cycles is expected in a subhumid temperate climate (Gustavson, 1991). Factors such as parent rock mineralogy, paleoclimate, duration of exposure, and rainfall played a major roll in soil development (Gustavson, 1991). The facies was probably formed in either an overbank area within an interfluve setting, or in swampy conditions of a mire, with the sediment of the facies being derived from pedogenic process acting on the underlying sediment, and wind derived sediment. The gradational contact with the underlying facies is interpreted as a C zone of a paleosol (Retallack, 1990). Historically, the blocky mudstone facies would be interpreted as part of the “outside shale” in the cyclothem model (Heckel, 1977).

Figure 2.04 - Polished core section showing blocky mudstone facies. Note pedogenic nature and weathered appearance of the mudstone. Soil slickensides are also observed within the blocky mudstone. Sample 1 from 780' and sample 2 from 870' in the Hinthorn CW#1 well, 14-T32S-R16E, Montgomery County, Kansas

2.1.3 Pyritic Shale Facies

Description

The pyritic black shale facies consists of micaceous dark gray to black shale. Diagnostic features include poorly developed irregular laminations (3 mm), and abundant pyritized wood and plant fragments (Figure 2.05). Angular pyrite concretions are approximately 0.25 inches in diameter (8 mm). Trace or body fossils were not observed in the pyritic black shale facies. Thickness of the pyritic shale facies ranges from 5 to 20 feet (1.5 to 6 m). Contacts with the overlying and underlying facies are gradational.

Paleoenvironmental Interpretation

The abundance of pyrite concretions, pyritized plant material and poorly developed laminations suggest deposition from sediment fallout in a brackish water marginal marine environment. An abundance of pyrite nodules and associated plant fragments appears related to swamp or marsh environments (Ho and Coleman, 1969). No marine fossils were observed. The pyritic black shale facies is interpreted as being deposited in a brackish water, coastal marsh or swamp environment. Historically, the pyritic shale facies would be interpreted as part of the "outside shale" in the cyclothem model (Heckel, 1977).

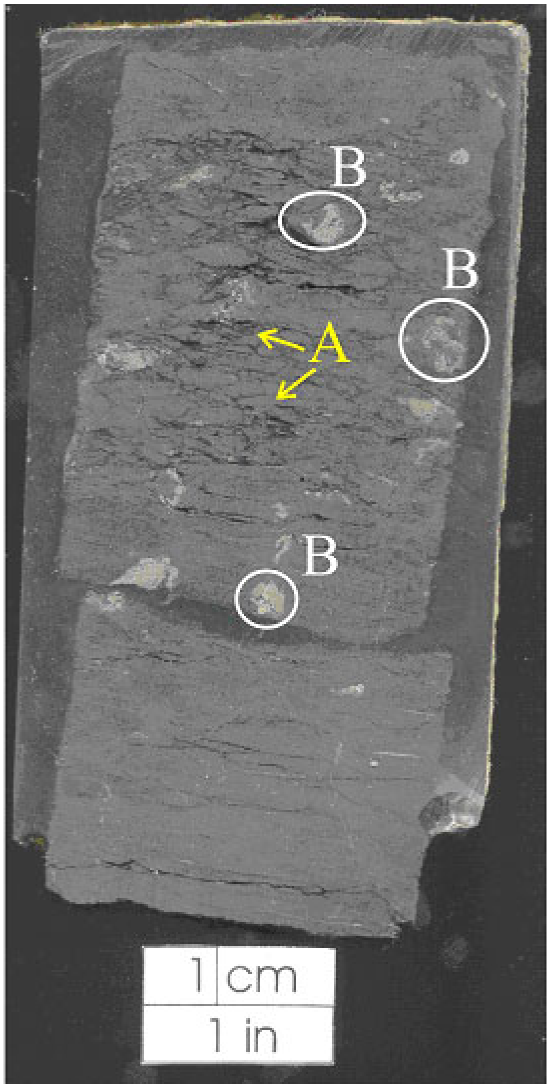


Figure 2.05 - Polished core section of the pyritic black shale facies. Note the development of irregular laminations (A) and angular pyrite concretions (B) of apporximately 0.25 inches in diameter (90 mm). The black appearance is due to a high organic content (i.e. carbonized wood fragments). Sample from 1,076' in the Hinthorn CW#1 well, 14-T32S-R16E, Montgomery County, Kansas

2.1.4 Interlaminated Sandstone and Siltstone Facies

Description
The interlaminated sandstone and siltstone lithofacies consists of light gray to brown medium- to fine-grained sand laminae intercalated with medium gray silt to mud laminae (3-10 mm; Figure 2.06). Diagnostic features include soft sediment deformation, clay ironstone nodules that are 0.5 inches in diameter (12 mm), mud laminations (3-10 mm) and scattered rip-up clasts that are 0.25 inches in diameter (6 mm), and wave ripples. The facies displays numerous fining upward packages (1-5 cm;

approx. 24 packages) over approximately 3 feet (1 m). The upper portion of the facies is commonly massive, fine-grained sandstone with minor mud drapes, while the lower portion is medium- to fine-grained sandstone with abundant intercalated mud and silt laminae. Individual sand laminae have unidirectional ripples, while mud drapes have a bimodal orientation. Wavy, flaser and lenticular bedding are also common. A low diversity trace fossil assemblage is dominated by actively filled horizontal (cf. Paleophycus), and passively filled vertical burrows (cf. Skolithos). No body fossils were observed. The interlaminated sandstone and siltstone facies ranges in thickness from 10 to 30 feet (3 to 9 m). The lower contact with underlying facies is typically erosional, while the upper contact with overlying facies is gradational.

Paleoenvironmental Interpretation

The presence of mud drapes dipping in opposite directions and numerous fining upward packages indicates sediment fallout during slack-water intervals from tidal influence (Buatois et al., 1999). The low trace fossil diversity indicates a stressed brackish-water marginal marine or deltaic environment. Erosional basal contacts, unidirectional flow alternating with bimodal flow, and upward fining packages suggest channel-fill deposition that may be tidally influenced. This facies is interpreted as a marginal marine environment. Historically, in the cyclothem model, the interlaminated sandstone and siltstone facies would be interpreted as part of the "outside shale" (Heckel, 1977).

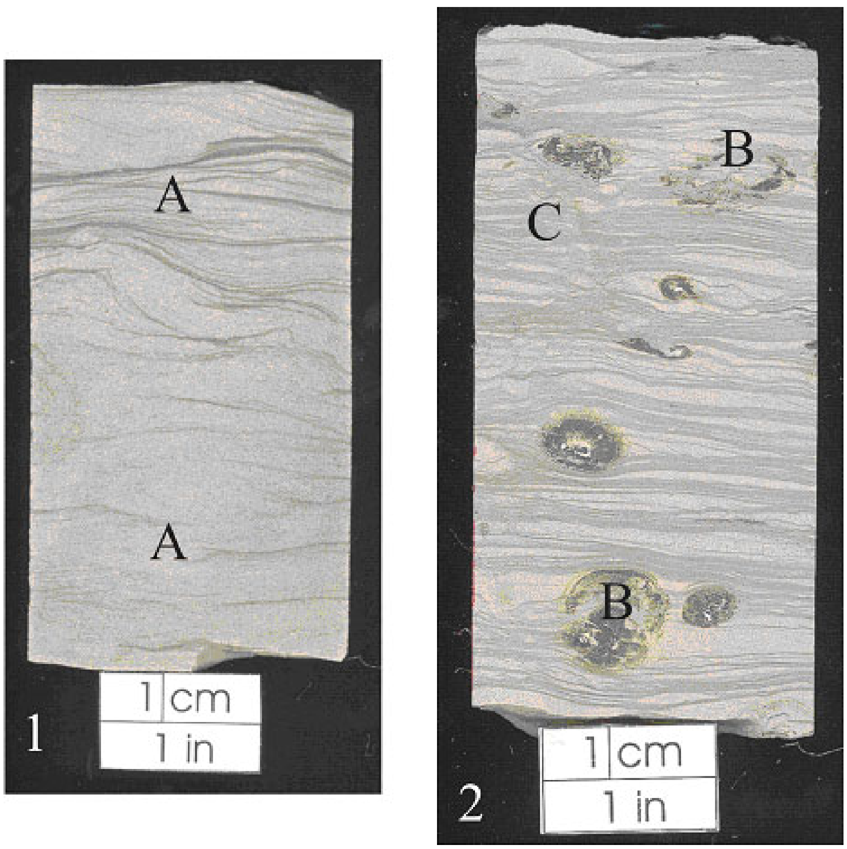


Figure 2.06 - Polished core section showing of the interlaminated sandstone and siltstone facies . 1) Rippled fine-grained sandstone laminae with minor mud drapes. Individual sandstone laminae are characterized by unidirectional cross-stratification (A). Cross-stratification orientations among sandstone laminae are bi-directional. 2) Medium- to fine-grained sandstone and interclated mudstone to siltstone laminae with soft sediment deformation, clay ironstone (B), vertical burrows (C). Sample 1 from 904' and sample 2 from 899' in the Hinthorn CW#1 well, 14-T32S-R16E, Montgomery County, Kansas

2.1.5 Sideritic Shale Facies

Description

Diagnostic features of the sideritic shale facies include quartz silt, parallel fissile laminae (less than 3 mm), dark gray to black color, and abundant clay ironstone bands (cf. siderite) that are approximately 1 inch in height (2.5 cm; Figure 2.07). Carbonaceous plant material are found throughout the facies. Body fossils were not observed, but actively filled horizontal burrows (cf. Planolities) are present. Overall, the intensity of bioturbation is relatively low. Thickness of the sideritic shale facies ranges from 6 to 12 feet (1.8 to 3.6 m). Contacts with overlying and underlying facies are gradational.

Paleoenvironmental Interpretation

Consistency of parallel laminated shale indicates sediment fallout in a low energy environment possibly due to upwelling or pseudo-estuarine circulation (Heckel, 1977). Fissility, plant material, and the dark gray to black appearance suggest a relatively high organic content. The low trace fossil diversity may indicate a stressed brackish-water, hypersaline, or anoxic environment (Buatois et al., 1999; Reineck and Singh, 1980). Presence of abundant siderite bands supports the presence of a marginal marine environment receiving fresh water input (Postma, 1982). This facies is interpreted as having been deposited in a marginal marine environment. Historically, the sideritic shale facies would be interpreted as part of the “outside shale” in the cyclothem model (Heckel, 1977).

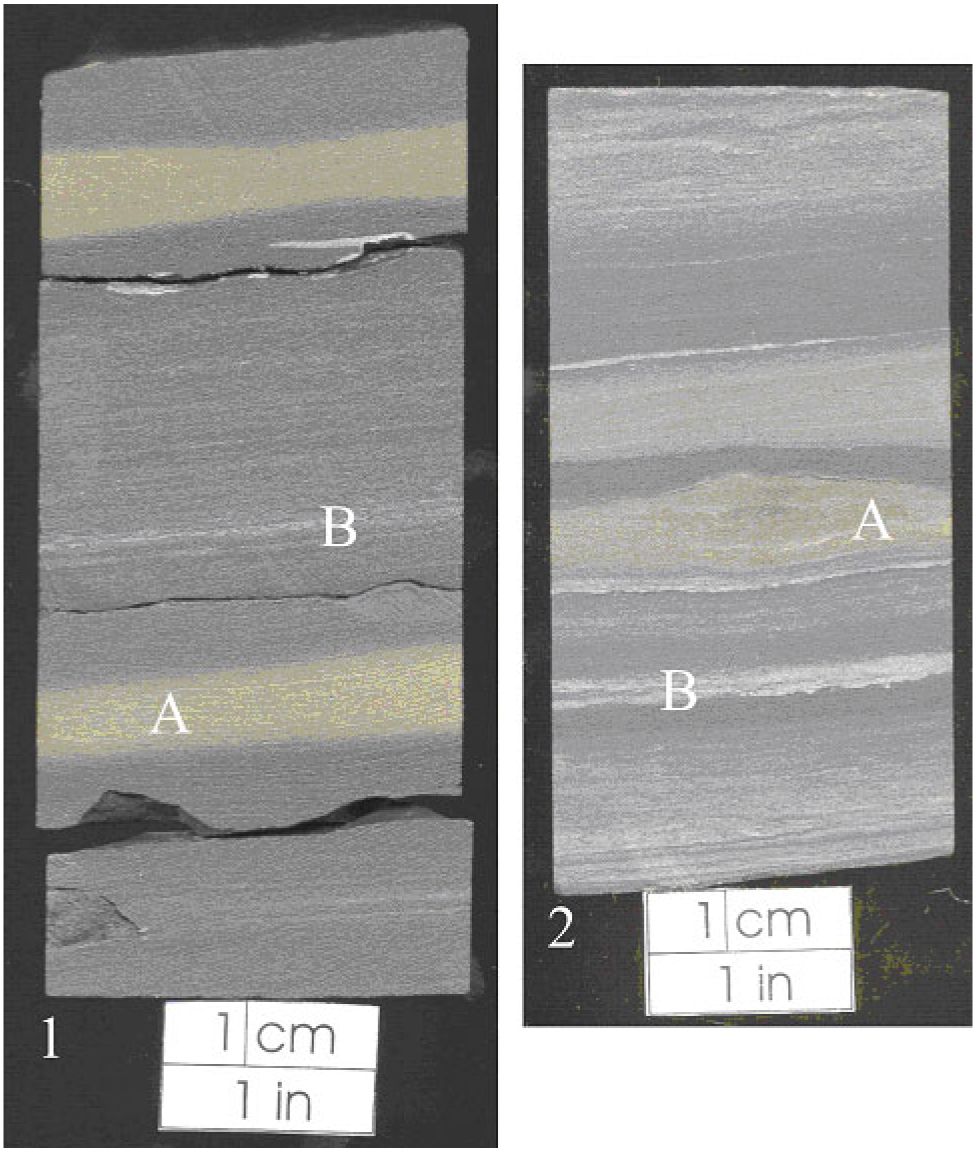


Figure 2.07 - Polished core section showing the sideritic shale facies. Note the abundance of siderite bands (A), minor amount of quartz silt (B), and absence of trace of body fossils. Sample 1 from 417' in the Cooper CW#1 well, 11-T35S-R18E, Labette County, Kansas. Sample 2 from 893' in the Hinthorn CW#1 well, 14-T32S-R16E, Montgomery County, Kansas

2.1.6 Laminated Muddy Sandstone Facies

Description

The laminated muddy sandstone facies is composed of dark-gray silt and mud and light-gray fine-grained sand (Figure 2.08). Diagnostic features of the facies are intervals (0.5-1 cm) of thin laminae (3 mm) of siltstone and sandstone that are separated by intervals (0.5-1 cm) dominated by bioturbated to laminated mudstone (1-3 mm). Many of the laminated intervals are cross-stratified, and have bimodal orientations. Contacts between the top of the mudstone and the bottom of the sandstone may be reactivation surfaces. Minor amounts of plant fragments are scattered through the facies (Figure 2.08). Body fossils were not observed, although bioturbation is prevalent along with sparse actively filled vertical and horizontal burrows. Thickness of the facies ranges from 5 to 12 feet (1.5 to 3.7 m). Contacts with the overlying and underlying facies are gradational.

Paleoenvironmental Interpretation

The laminated muddy sandstone facies is interpreted as having been deposited in a tidal-flat environment. Alternating fine-grained sand cross laminations and thicker mudstone laminations indicate bedload transport during variable tidal flow and sediment fallout during slack-water (Reineck and Singh, 1980). Presence of reactivation surfaces and cross lamination dipping in opposite directions indicates changes in flow direction and suggests tidal influence. Open-marine tidal flats often have an abundant and diverse trace fossil assemblage (Buatois et al., 1999). The paucity of trace and body fossils preserved in this setting may be due to the muddy system or freshwater influence from tidal channels. Historically, the cross-laminated muddy sandstone facies would be interpreted as part of the "outside shale" in the cyclothem model (Heckel, 1977).

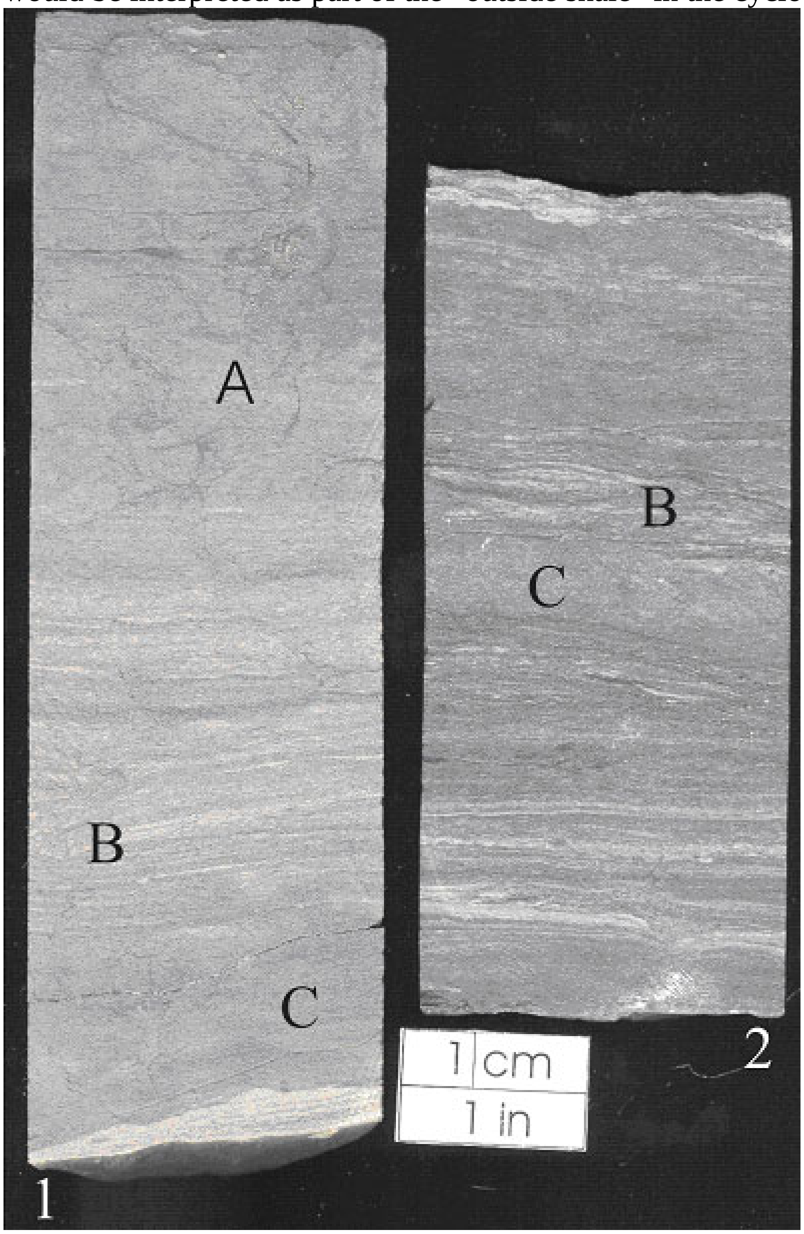


Figure 2.08 - Polished core section of laminated muddy sandstone facies. 1) Intercalated intervals of cross-stratified muddy sandstone (B) and laminated to bioturbated and burrowed mudstone (C). At top of core section abundant rooting has disrupted primary sedimentary structures (A). 2) Inercalated intervals of cross-stratified sandstone and mudstone (B) separated by intervals of laminated to bioturbated mudstone. Sample 1 from 881' and sample 2 from 851' in the Hinthorn CW#1 well, 14-T32S-R16E, Montgomery County, Kansas

2.1.7 Bioclastic-Packstone-to-Grainstone Facies

Description

The bioclastic-packstone-to-grainstone limestone lithofacies is light to medium gray. Diagnostic features of the lithofacies include medium bedding (10-30 cm), and well-preserved sparse marine bioclastic fragments (Figure 2.09). Stylolites are distributed throughout the facies, while caliche and rhizoliths are observed approaching the top of the facies. The dominant texture is packstone, although a peloidal, non-fossiliferous grainstone may also present in the facies. Identified fossils include disarticulated bryozoans, brachiopods, crinoids and fusulinids. Trace fossils are sparse, however the facies appears to be heavily bioturbated. Thickness of the bioclastic-packstone-to-grainstone facies ranges from 5 to 30 feet thick (1.5 to 9 m). Contacts with the overlying and underlying facies are gradational.

Paleoenvironmental Interpretation

Peloidal grains, the lack of abundant trace fossils, and disarticulation of body fossils are evidence that the bioclastic-packstone-to-grainstone facies was deposited in a high to moderate energy environment, probably above fair weather wave base. Fragmentation of bioclasts is due to reworking by wave or tidal processes in a relatively shallow-water environment and from extensive bioturbation. Bryozoans, brachiopods, and crinoids indicate a normal salinity marine environment (Heckel, 1972). Presence of caliche and rhizoliths in the upper portion of the facies suggests post depositional alteration by pedogenic processes. The combination of texture, peloidal grains, and fauna present suggests that the bioclastic-packstone-to-grainstone was deposited in a relatively normal marine, higher energy, and shallow environment. Historically, the bioclastic-packstone-to-grainstone facies would be interpreted as part of the “upper limestone” in the cyclothem model (Heckel, 1977).

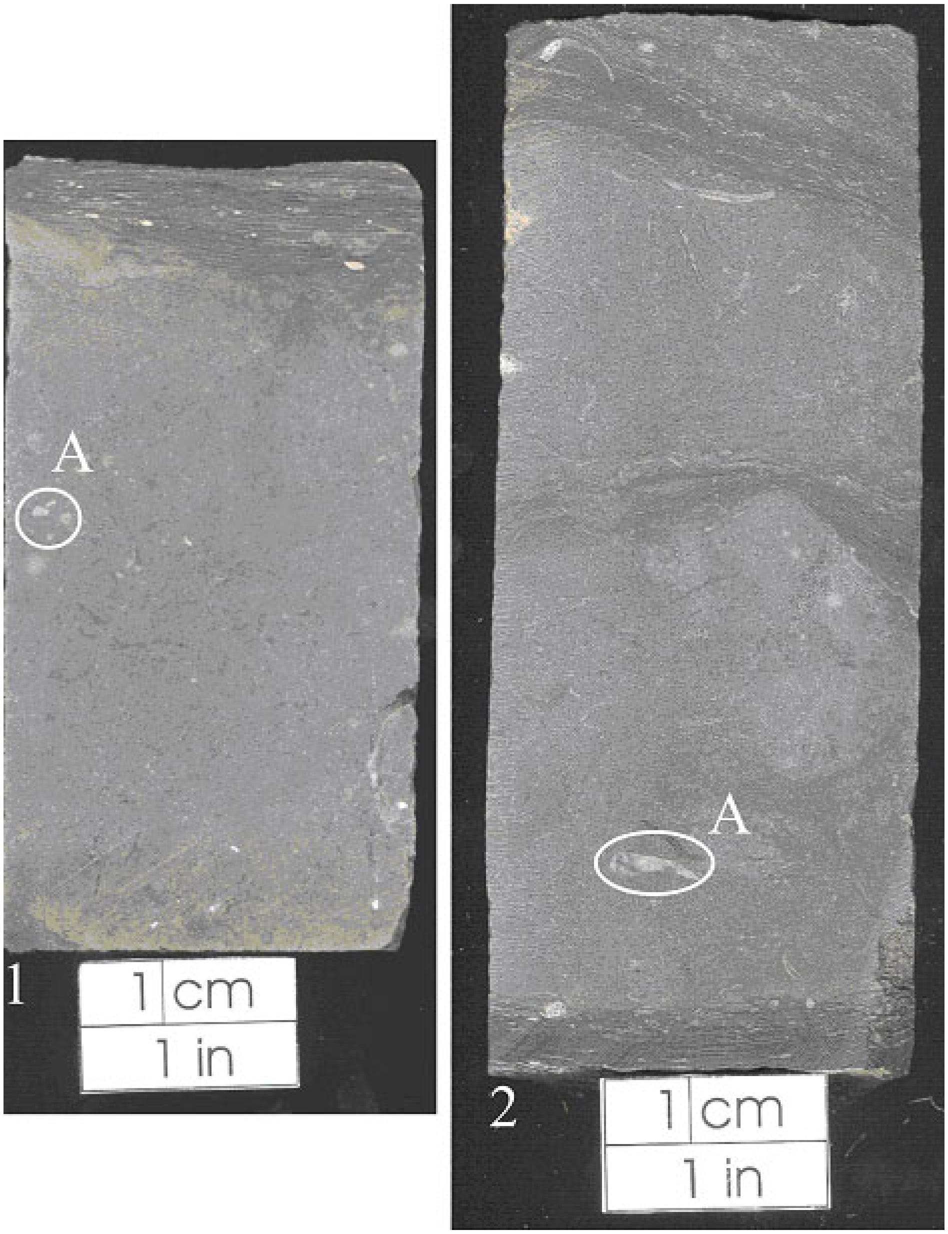


Figure 2.09 - Polished core section of bioclastic packstone to grainstone facies comprised of marine fossil fragments (A). Sample 1 from 623' and sample 2 from 625' in the Hinthorn CW#1 well, 14-T32S-R16E, Montgomery County, Kansas

2.1.8 Bioclastic Mudstone to Wackestone Facies

Description

The bioclastic mudstone to wackestone facies is typically medium to dark gray in appearance with a micritic matrix. Diagnostic features include medium bedding (10-30 cm), abundant well-preserved whole-fossil marine bioclasts, and high-degree of bioturbation (Figure 2.10). Stylolites are commonly observed in the upper portion of the facies. Identified fossils include bryozoans, crinoids, brachiopods, mollusks, foraminifera, phyloid algae, and chaetetids. Thickness of the bioclastic-mudstone-to-wackestone facies ranges from 1 to 20 feet with an average of 12 feet (0.3 to 6 m; average of 4 m). Upper and lower contacts of the bioclastic-mudstone-to-wackestone facies with adjacent facies are gradational.

Paleoenvironmental Interpretation

Bryozoans, brachiopods, phyloid algae, formainfera, chaetetids and crinoids indicate a normal salinity marine environment (Heckel, 1972). The presence of a micrite matrix is evidence of a low energy environment. Presence of well-preserved whole body fossils suggests a low-energy environment, probably below fair weather wave base. Disarticulation of bioclasts is due to bioturbation or storm activity. The combination of abundant and fragmented marine fauna, a micritic matrix, and texture suggests that the bioclastic-mudstone-to-wackestone facies was deposited in an open marine environment, probably below wave base. Historically, the bioclastic mudstone to wackestone facies would be interpreted as part of the "upper limestone" in the cyclothem model (Heckel, 1977).

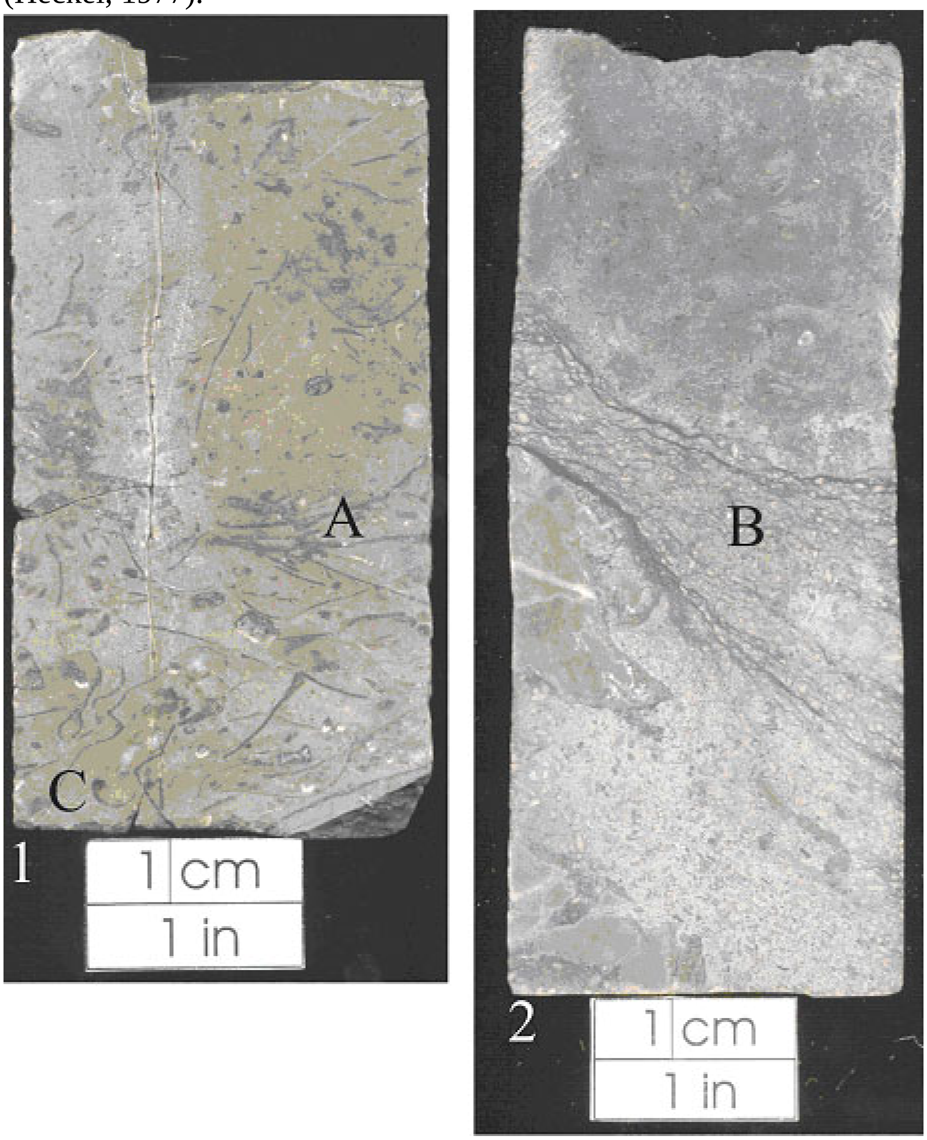


Figure 2.10 - Polished core section of bioclastic mudstone to wackestone facies with abundant whole fossil bioclasts. Note well persevation of bryozoans (A), chaetetes (B) and brachiopods (C). Sample 1 from 650' and sample 2 from 645' in the Hinthorn CW#1 well, 14-T32S-R16E, Montgomery County, Kansas

2.1.9 Dark Gray Shale Facies

Description

Diagnostic features of the dark gray shale facies include thin laminations (3 mm), fissility, parallel bedding, and minor amounts of quartz silt. The facies is dark gray to black changing gradually upwards to medium gray (Figure 2.11). Minor amounts of clay ironstone (cf. siderite) or pyrite nodules are observed in the middle to upper portion of the facies. Identified fossils, when present, include small fragments of brachiopods, fusilinids and crinoids. Fossil shells are commonly concave down and fossil material is concentrated in thin layers that are normally graded. The dark gray shale facies ranges in thickness from 10 to 15 feet (3 to 4.5 m). Upper and lower contacts of the dark gray shale facies are gradational.

Paleoenvironmental Interpretation

The parallel laminated shale indicates sediment fallout in a low energy environment possibly deep marine with little bioturbation. A gradual change from dark gray upward to light gray color indicates a change from anaerobic to more aerobic conditions. Thin intervals of normally graded and concave downward bioclastic fragments (5-10 cm) may represent higher energy storm deposits that are periodically introduced into offshore deeper water environments. The presence of minor amounts of pyrite and siderite in the upper portion of the facies also suggests the influence of freshwater and shift to aerobic conditions. This lithofacies is interpreted as a offshore transitional environment. Historically, the dark gray shale facies would be interpreted as part of the “core shale” in the cyclothem model.

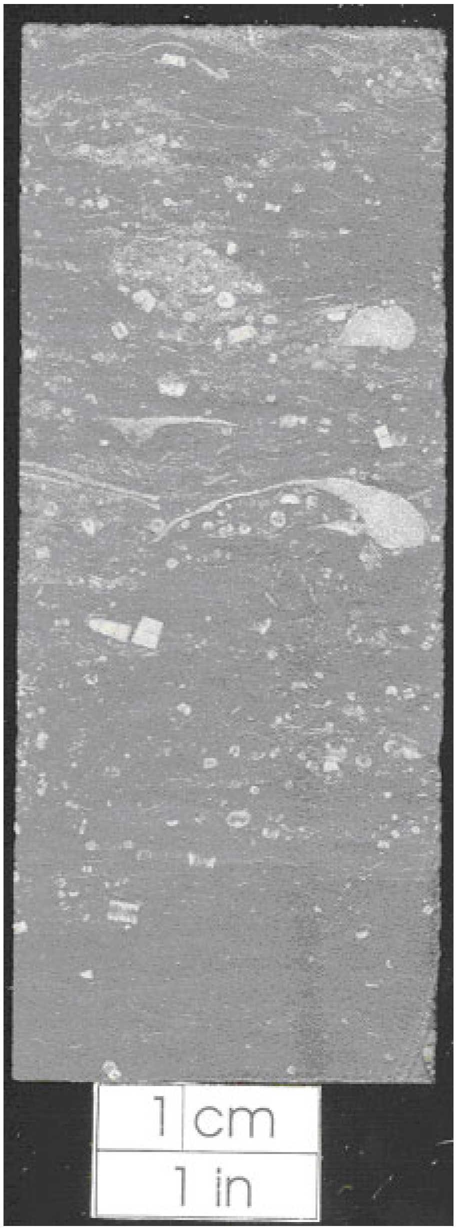


Figure 2.11 - Polished core section showing dark gray shale facies. Note small scattered fossil fragments and absence of bioturbation. Sample from 713' in the Hinthorn CW#1 well, 14-T32S-R16E, Montgomery County, Kansas

2.1.10 Phosphatic Black Shale Facies

Description

Very thin laminations (less than 3 mm), fissility, black color, and phosphatic nodules, characterize this facies (Figure 2.12). Phosphatic nodules are abundant and also vary in size (0.1 to 1 inch; 0.2 to 2.54 cm). Sparse pyrite and calcite concretions are also present. Planktonic organisms (such as conodonts) and disarticulated brachiopods are the only fauna observed in the black shale facies. No trace fossils or bioturbation were observed. The phosphatic black shale facies ranges in thickness from 1 to 10 feet with and average of 5 feet (0.3 to 3 m; average of 1.5 m). Upper and lower contacts are usually sharp, but the upper contact can be gradational.

Paleoenvironmental Interpretation

The black shale facies was deposited by sediment fallout in either low energy shallow marginal marine or deep marine environments. The dark black color, fissility, absence of bioturbation and presence of phosphatic nodules are indicative of anoxic conditions. Heckel (1977) proposed that upwelling or pseudo-estuarine circulation would support anoxic conditions in relatively shallow water. The widespread occurrence of the black shale facies across the Cherokee basin and into adjacent states suggests a relatively deep marine environment. The presence of normal marine planktic fauna (i.e. conodonts) supports an anoxic deep-water environment. This facies is interpreted as deposited in a shelf environment under anoxic conditions and far removed from sources of sediment supply. Historically, the phosphatic black shale facies would be interpreted as part of the "core shale" in the cyclothem model (Heckel, 1977).

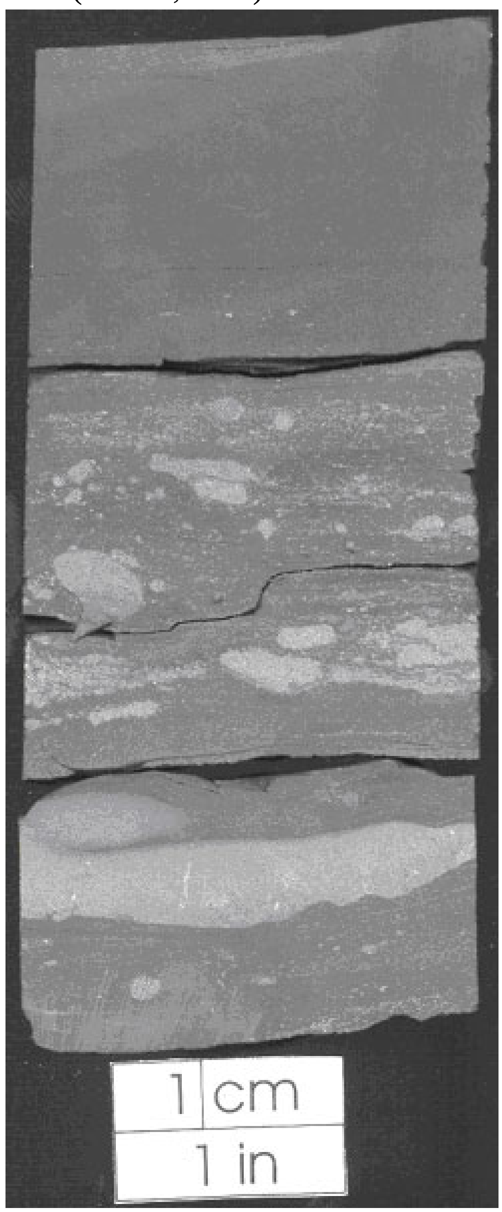


Figure 2.12 - Polished core section showing the phosphatic black shale facies. Note the abundance of authigenic phosphate nodules (light gray) that widely vary in size. Sample from 414' in the Cooper CW#1 well, 11-T35S-R18E, Labette County, Kansas

2.2 Distribution and Vertical Relationships of Facies

The Cherokee Group is composed of numerous repetitive successions of interbedded gray to dark gray shale, rippled sandstone and siltstone, underclay, thin coal, and thin argillaceous limestone. The following table lists a typical succession starting with marine facies progressively transitioning to marginal marine to non-marine facies (Table 2.2).

Table 2.2 – Distribution and vertical relationships of facies

		Vertical Relationships	
Lithofacies	**Distribution**	**Underlying facies**	**Overlying facies**
Phosphatic black shale	Entire basin & into adjacent states	Coal or blocky mudstone	Dark gray shale
Dark Gray shale	Across basin & throughout Cherokee Group	Phosphatic black shale	Interlam. Ss & Xs, lam. muddy shale, bio wackestone or pyrite sh
Bioclastic-mudstone to -wackestone	Observed in upper Higginsville, Black Jack Creek & Breezy Hill limestones	Phosphatic black shale	Bioclastic-packstone-to-grainstone
Bioclastic-packstone-to-grainstone	Observed in upper Higginsville, Black Jack Creek & Breezy Hill limestones	Bioclastic-mudstone-to-wackestone	Blocky mudstone or phosphatic black shale
Interlam. Ss and Xs	Observed as fill above incision surfaces and discontinuous	Phosphatic black shale or dark gray shale	Coal, sideritic gray sh or poorly developed blocky mudstone
Sideritic gray shale	Observed as fill above incision surfaces and discontinuous	Interlaminated Ss & Xs	Blocky mudstone or laminated muddy sandstone
Laminated Muddy Ss	Observed in middle and upper Cherokee Group	Dark gray shale	Poorly developed blocky mudstone or coal
Pyritic black shale	Observed in Krebs Fm and in upper Cherokee Group	Dark gray shale or sideritic shale	Blocky mudstone or coal
Blocky mudstone	Throughout basin and Cherokee Group	Pyritic black shale, cross-lam. muddy Ss, interlam. Ss & Xs, or bio-packstone-to-wackestone	Coal of phospatic black shale
Coal	Highly variable across basin & throughout Cherokee Group	Blocky mudstone	Dark gray shale or phospatic black shale

2.3 Coal Bearing Intervals of the Cherokee Group

Division of the Cherokee Group into ten intervals is based on regionally extensive marker beds, which serve to define mappable units. These marker beds are the black phosphatic shale lithofacies. Typically, the base of marker beds will be interpreted as flooding surfaces. The intervals also serve as a basis for identifying and mapping individual coals in the Cherokee Group. Coal thickness and distribution of individual coals can be related to the paleostructure reflected in the underlying units.

2.3.1 Mississippian Basement

In southeastern Kansas, Cherokee Group clastic rocks unconformably overly Mississippian limestones (Meremecian Stage; Merriam, 1963; Figure 2.13). The top of the Mississippian is characterized by a chert residue (Watney et al., 2001). Depth to the karstic Mississippian basement in the Cherokee basin ranges from 0 feet at outcrops in the extreme southeastern corner of Kansas, to more than 2500 feet (762 m) in Elk and Chautauqua counties, as the Mississippian and Cherokee Group rocks gradually dip to the west and southwest (Figure 2.14).

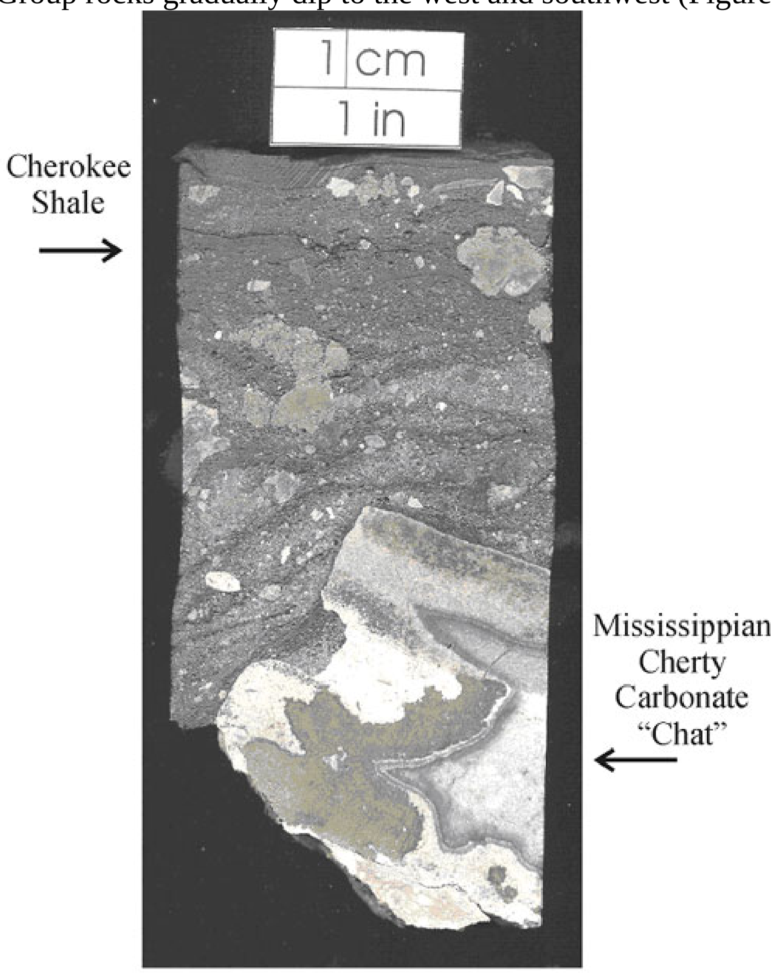


Figure 2.13 - Polished core section showing the unconformable contact between the Mississippian and Middle Pennsylvanian. The Cherokee Group shale overlies the karstic Mississippian Warsaw Limestone (Meremecian) and chert residium ("chat"). Sample from 1,081' in the Hinthorn CW#1 well, 14-T32S-R16E, Montgomery County, Kansas

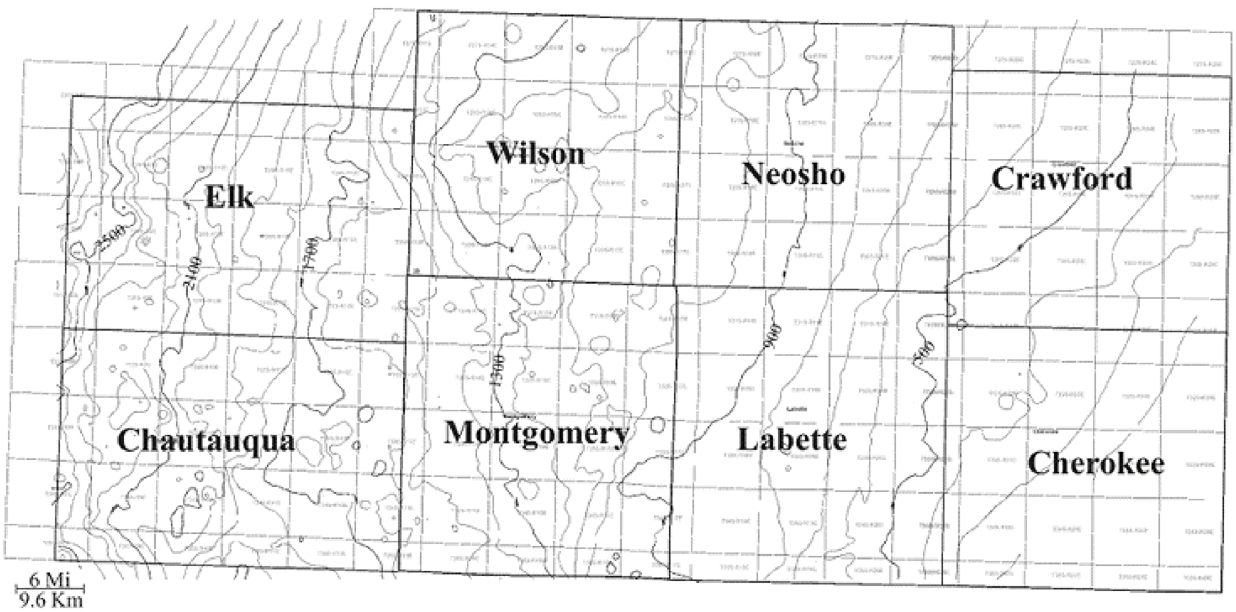


Figure 2.14 - Structure map on top of the Mississippian limestone showing regional dip to the west (CI:100 ft). The surface is characterized by extensive karst features resulting in a highly irregular topography for deposition of the overlying Cherokee Group coal bearing intervals.

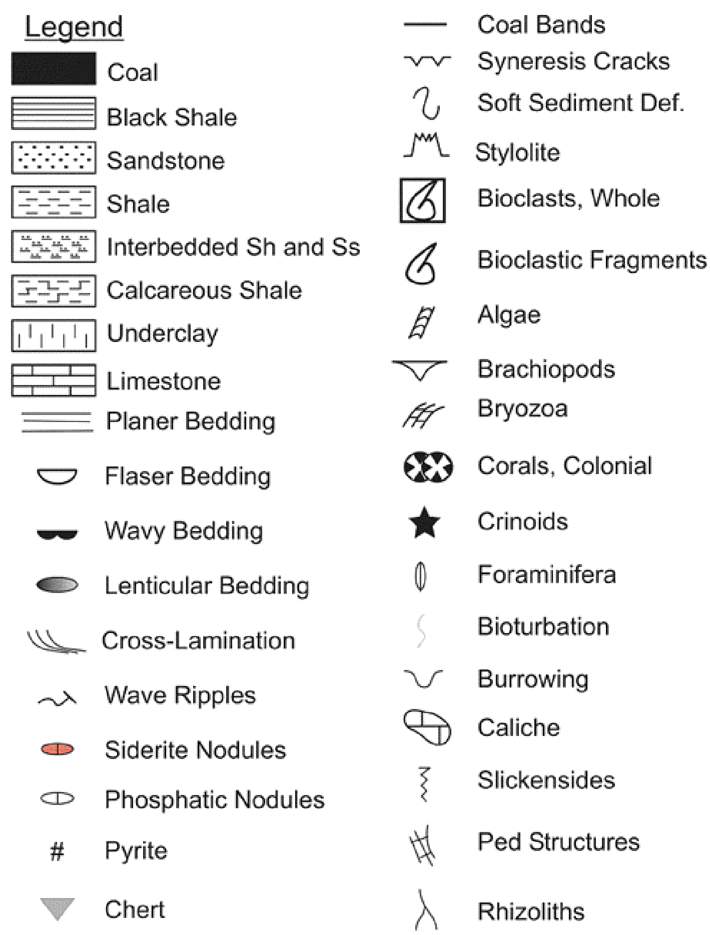


Figure 2.15a - Symbols for depositional sequences in figures 2.15, 2.17, 2.20, 2.22, 2.24, 2.28 and 2.30

2.3.2 Riverton Interval

Description

The interval from the top of the Mississippian to the top of the Riverton shale ranges in thickness from 4 to 40 feet with an average of 15 feet (1.2 to 12 m, 4.5 m; Figures 2.02 and 2.15). Variability in thickness is due to deposition of sediments on top of the high relief karstic Mississippian limestone. In ascending order, the Riverton interval consists of a pyritic shale facies and a blocky mudstone facies, which is overlain by the Riverton coal (Figure 2.15). The Riverton coal is capped by a phosphatic black shale facies (Figure 2.15). Locally, siltstone lenses, and additional coal beds are present below the Riverton coal. An additional blocky mudstone facies ranging in thickness from 1 to 3 feet (0.3 to 1 m) is locally found in the middle of the interval beneath the Riverton coal.

Riverton and Lower A-B Interval

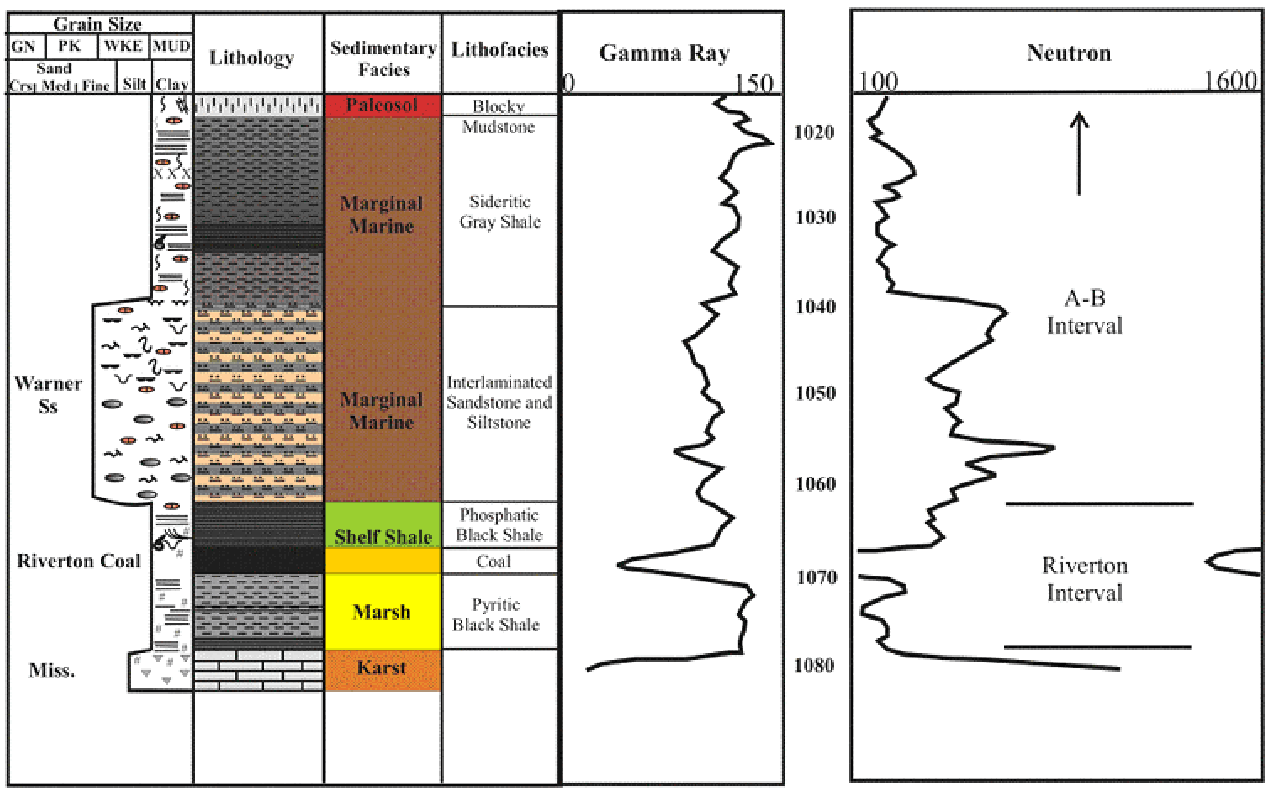


Figure 2.15 - Depositional sequence and log characteristics of the Riverton and lower A-B interval, based on core and well log from the Hinthorn CW#1 well, 14-T32S-R16E, Montgomery County, Kansas (scale in feet). See Figure 2.15a for legend

Riverton Isopach Map

The Riverton shale is recognizable on logs due to a relatively high gamma ray response (approx. 110 API units) and low neutron response (< 400 neutron counts) followed down hole by a lower gamma-ray response (< 105 API units) associated with the underlying Riverton coal (Figure 2.15). The Riverton coal is the first thick and laterally extensive coal bed encountered in the Cherokee Group in southeastern Kansas (Figure 2.16). Thickness of the Riverton coal can be up to 4.5 feet with an average of 1.8 feet and a normal distribution (1.4 m, average of 0.5 m; Appendix 2).

Detailed isopach mapping of the Riverton coal reveals a coal that stays fairly consistent in thickness over an average distance of 5 square miles (8 km2). The Riverton coal locally appears to thicken into the Mississippian lows and thin onto the highs (Figure 2.16). The Riverton coal is consistently thicker in Montgomery, Labette, and Neosho counties, while its thins to the west and east in the study area.

Riverton Coal

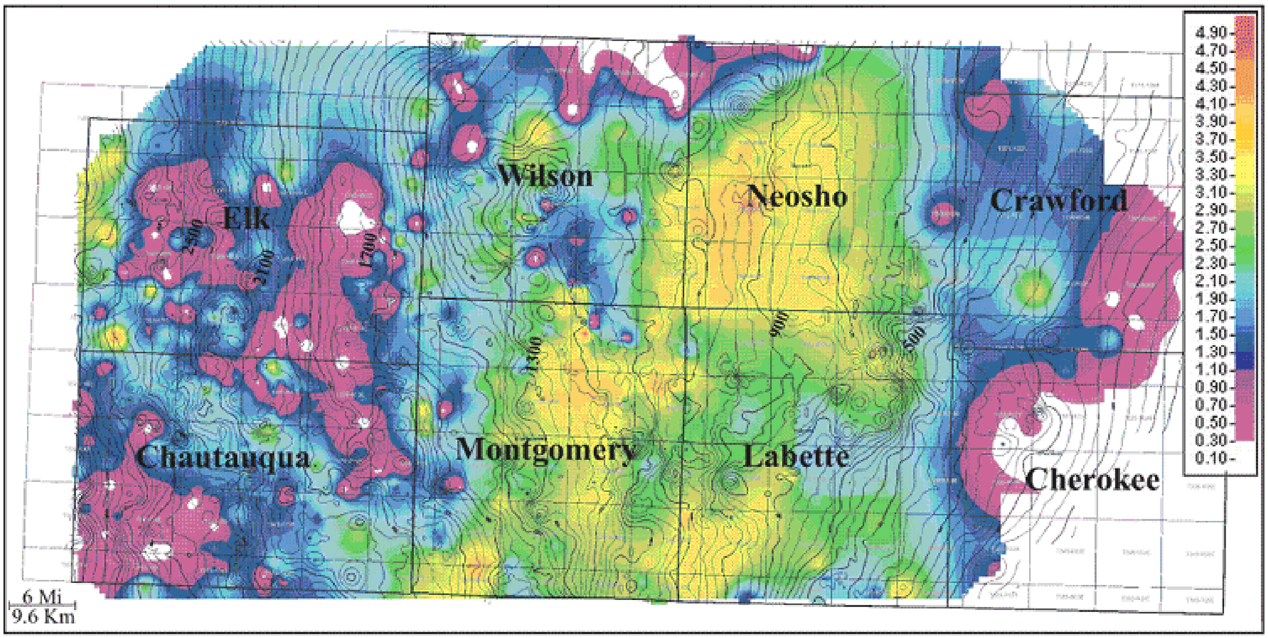


Figure 2.16 - Isopach of Riverton coal (color) overlain with contours of top of Mississippian limestone structure (isopach CI: 0.10 ft; structure CI:25 ft).

2.3.3 A-B Interval

Description

The interval from the top of the Riverton shale to the top of the A-B shale ranges in thickness from 22 to 112 feet with an average of 57 feet (6.7 to 34.1m, average of 17.4 m, Figure 2.01 and 2.15). Variability in interval thickness may be due to thick sandstone accumulations within the interval (up to 80 ft; 24 m). In ascending order, the A-B interval consists mainly of a dark gray shale facies, laterally discontinuous interlaminated sandstone and siltstone facies known as the Warner Sandstone, sideritic gray shale facies, and numerous discontinuous coal facies known informally as the Dw, Cw, and Bw (after Harris, 1984; Figure 2.15). The base of the Warner Sandstone is an unconformity. Due to the sporadic nature of coals distributed within the A-B interval, they were not mapped as part of this study. The A-B shale is recognizable on most well logs as the shale between the first split coal known as the Aw and Bw coals. When the coals are absent the A-B shale is approximately 25 feet (7.6 m) above the Warner Sandstone.

2.3.4 Bluejacket B Interval

Description

The Bluejacket B interval extends from the top of the A-B shale to the top of the Bluejacket B shale and ranges in thickness from 20 to 200 feet (6.1 to 59 m; Figures 2.01 and 2.17; Staton, 1987). Variability in interval thickness is the result of thick sandstone accumulations (up to 60 ft, 18 m). In ascending order, the Bluejacket B interval consists of a widely distributed dark gray shale facies, pyritic shale facies, coal facies, and erratically distributed sideritic shale facies. Continuing upward is an interlaminated sandstone and siltstone facies known as the Warner (upper), Bluejacket or Bartlesville sandstones. The sandstone is overlain by the Weir - Pittsburg B coal (lower Weir-Pitt coal; Figure 2.17). The base of the Warner Sandstone (upper) and Bluejacket/Bartlesville Sandstone is an unconformity.

Weir-Pittsburg and Upper Bluejacket B Interval

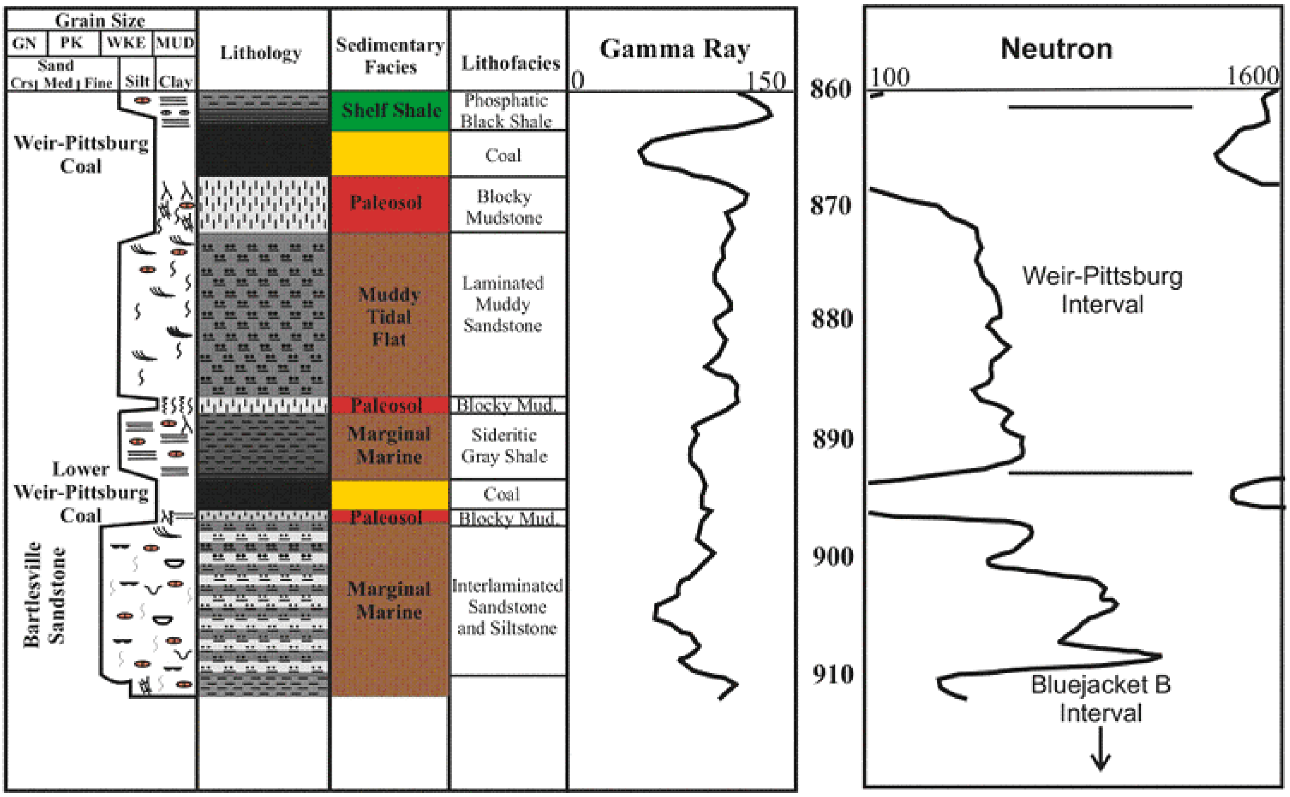


Figure 2.17 - Depositional sequence and log characteristics of the Weir-Pittsburg and upper Bluejacket B interval, based on core and well log from the Hinthorn CW#1 well, 14-T32S-R16E, Montgomery County, Kansas (scale in feet). See Figure 2.15a for legend.

Laterally continuous coal beds known as the Aw, Neutral, Rowe and Dry Wood are sporadically distributed throughout the Cherokee basin. The informally named Bbj, Cbj, and Dbj coal beds are also distributed throughout the Cherokee basin, but are very difficult to correlate over any distance.

Aw Isopach Map

The Aw coal is recognizable on most logs due to its close stratigraphic relationship with the underlying thin Bw coal. Approximately 4 feet of shale separate the coals (1.2 m). Thickness of the Aw coal can be up to 4 feet with an average of 1.7 feet and a slightly skewed distribution to the maximum (1.2 m, average of 0.5 m; Appendix 2). The Aw coal is recognizable on most logs in the central part of the Cherokee basin as the next thick coal above the Warner Sandstone (Figure 2.18). Due to the lack of Aw coal in any of the described cores, this study does not include a depositional sequence for the Aw coal.

Detailed isopach mapping of the Aw coal reveals a coal that stays fairly consistent in thickness over an average of 3 square miles (4.8 km2; Figure 2.18). When bottom contours of Aw coal structure are overlain on the isopach map, the coal appears to thicken onto local highs and thin into lows. The Aw coal exhibits an elongate geometry that is oriented parallel to depositional dip (SW), and is consistently thicker within a north-south trend through Montgomery, Wilson, and Neosho counties. Locally thin areas and linear trends in the Aw coal thickness may be due to removal by erosion (ie. channel erosion).

Aw Coal

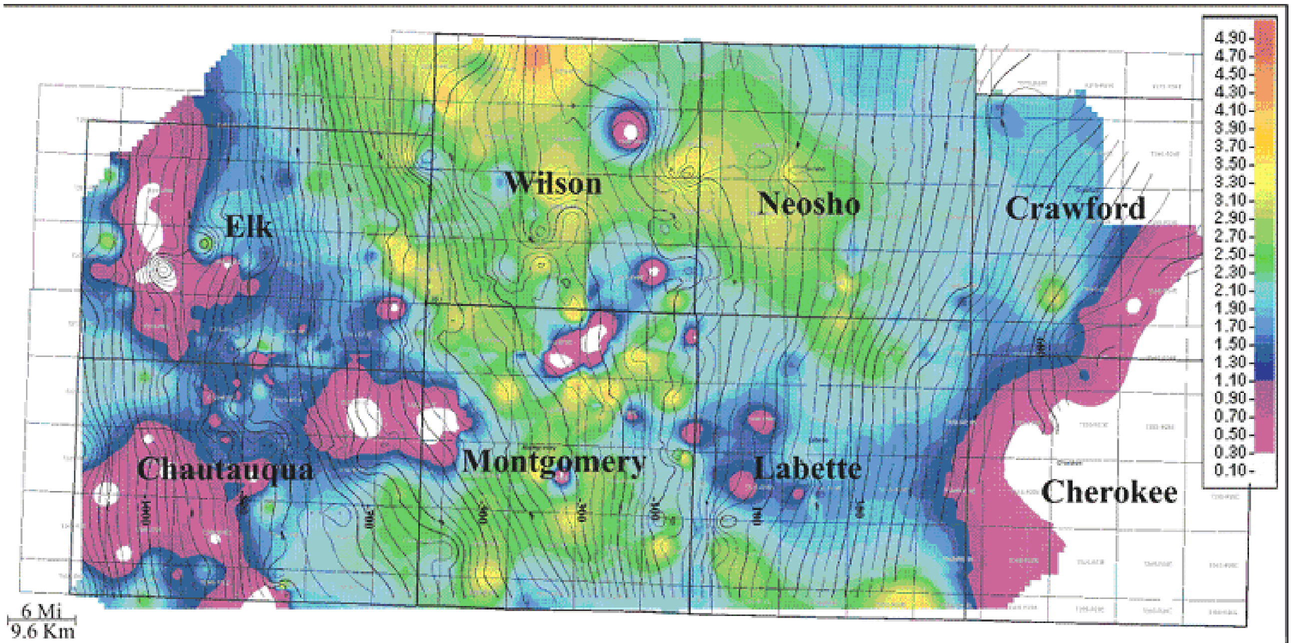


Figure 2.18 - Isopach of Aw coal (color) overlain with countours of bottom Aw coal structure (isopach CI: 0.10ft; structure CI: 25ft).

2.3.5 Weir-Pittsburg Interval

Description

The interval from the top of the Bluejacket B Shale to the top of the Weir-Pittsburg shale ranges in thickness from 5 to 60 feet with an average of 20 feet (1.5 to 18.2 m, average of 6.1 m; Figures 2.01 and 2.17). In ascending order, the Weir-Pittsburg interval consists mainly of a sideritic shale facies that passes upward into a laminated muddy sandstone facies or interlaminated sandstone and shale facies. These facies are overlain by a blocky mudstone facies followed up section by the Weir-Pittsburg coal, and capped by a dark gray shale facies (Figure 2.17). Poorly developed blocky mudstone facies can occur locally through the Weir-Pittsburg interval.

Weir-Pittsburg Coal Isopach Map

The Weir-Pittsburg coal is recognizable on logs due to a relatively high gamma ray response (> 120 API units) and low neutron response (< 200 neutron counts) from the Weir-Pittsburg shale followed down hole by a lower gamma ray response (< 75 API units) associated with the underlying Weir-Pittsburg coal (Figure 2.17). Thickness of the Weir-Pittsburg coal can be up to 6 feet with an average of 1.5 feet and distribution skewed to the minimum (1.8 m, average of 0.5 m; Appendix 2). The Weir-Pittsburg coal is recognizable on logs in the central part of the Cherokee basin as the thickest coal in the Cherokee Group (Figure 2.19). Of the many coals mined in the outcrop belt, the Weir-Pittsburg coal is known to be the thickest and best developed coal (Brady, 1997).

Weir-Pittsburg Coal

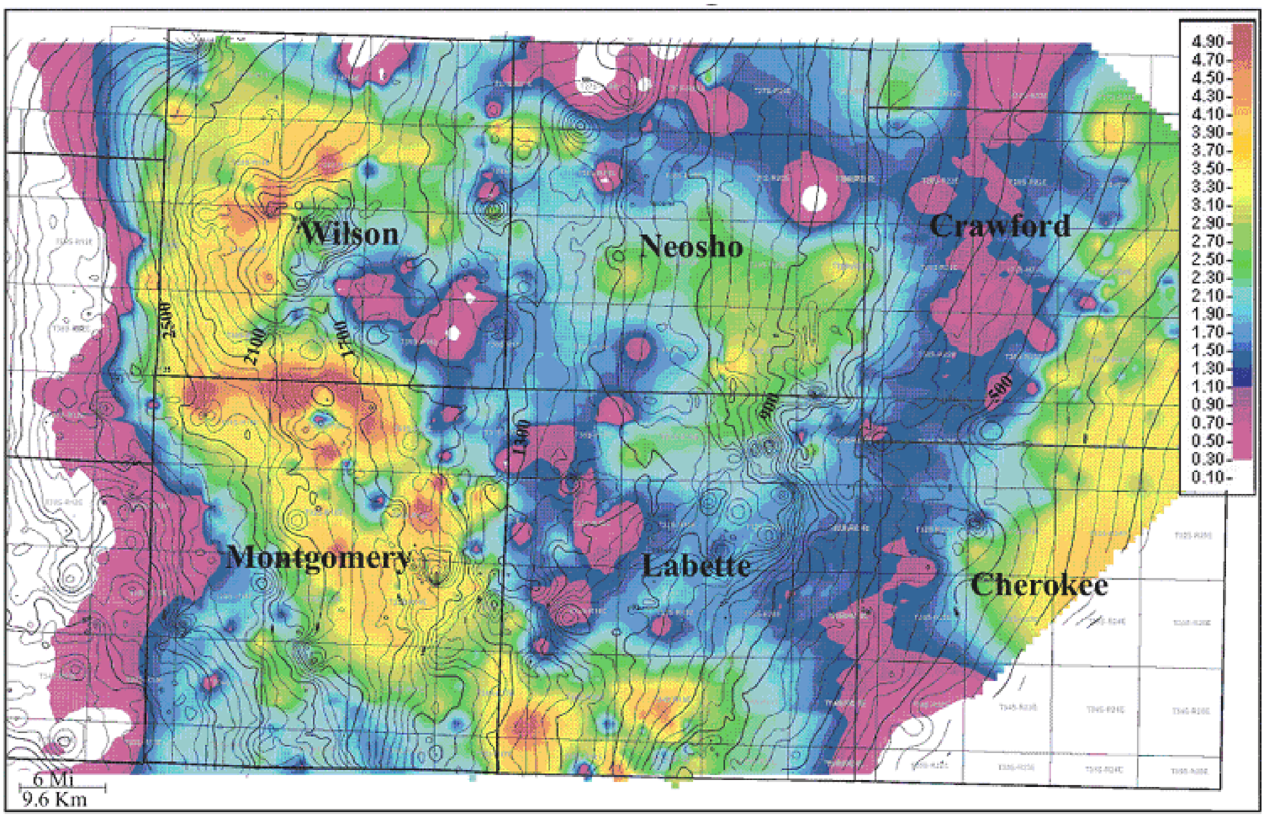


Figure 2.19 - Isopach of Weir-Pittsburg coal (color) overlain with contours of top Mississippian limestone structure (isopach CI:0.10ft; structure CI:25ft).

Detailed isopach mapping of the Weir-Pittsburg coal reveals a coal that stays fairly consistent in thickness over an average of 2.5 square miles (4 km2; Figure 2.19). When overlaying contours of top Mississippian structure on the isopach map, the coal appears to follow the structural strike. The Weir-Pittsburg coal exhibits a lenticular geometry that is oriented parallel to depositional strike (northwest), and is consistently thicker through an acute trend from southern Labette through Montgomery and Wilson counties. Localized circular areas of the Weir-Pittsburg coal may be due to removal by fire or crevasse splays (see Chapter 5).

2.3.6 Tebo Interval

Description

The interval from the top of the Weir-Pittsburg shale to the top of the Tebo shale ranges in thickness from 6 to 50 feet with an average of 25 feet (1.8 to 15.6m, average of 7.7 m; Figures 2.01 and 2.20). In ascending order, the Tebo interval consists of a dark gray shale facies passing upward into a laminated muddy sandstone facies. Overlying these facies is a regional coal facies (Tebo coal), capped by a phosphatic black shale facies (Figure 2.20). A poorly developed blocky mudstone facies locally underlies the Tebo coal.

Tebo Interval

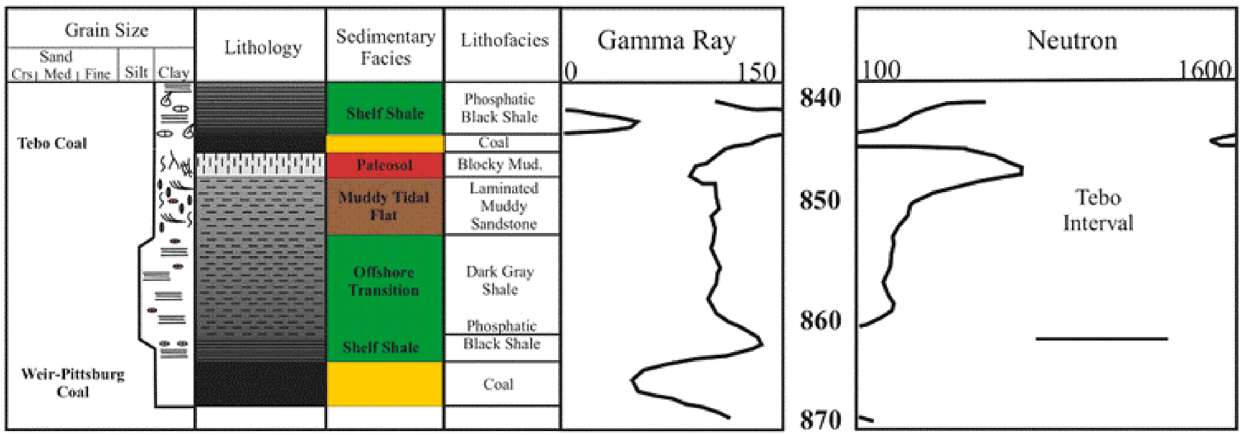


Figure 2.20 - Depositional sequence and log characteristics of the Tebo interval, based on core and well log from the Hinthorn CW#1 well, 14-T32S-R16E, Montgomery County, Kansas (scale in feet). See Figure 2.15a for legend.

Tebo Coal Isopach Map

The Tebo coal is recognizable on logs due to a high gamma ray response (> 160 API units) and low neutron response (< 625 neutron counts) from the thick radioactive phosphatic black shale marker, which is followed down hole by a lower gamma ray response (< 105 API units) associated with the underlying Tebo coal (Figure 2.21). The Tebo shale marker extends across the Cherokee basin. Thickness of the Tebo coal can be up to 3 feet with an average of 0.9 feet and a distribution slightly skewed to the minimum (1 m, average of 0.3 m; Figure 2.21; Appendix 2).

Detailed isopach mapping of the Tebo coal reveals a coal that stays fairly consistent in thickness over an average of 5 square miles (8 km2; Figure 2.21). Structural contours of bottom of the Tebo coal are overlain on an isopach of the Tebo coal (Figure 2.21). The coal appears to thicken on highs and thin into lows. The Tebo coal exhibits an elongate geometry oriented obliquely to depositional dip (southwest) and strike (northwest) with an area of thicker accumulation through Montgomery and Wilson counties. Local thin areas and linear trends in the Tebo coal thickness may be the consequence of erosion (i.e. fluvial).

Tebo Coal

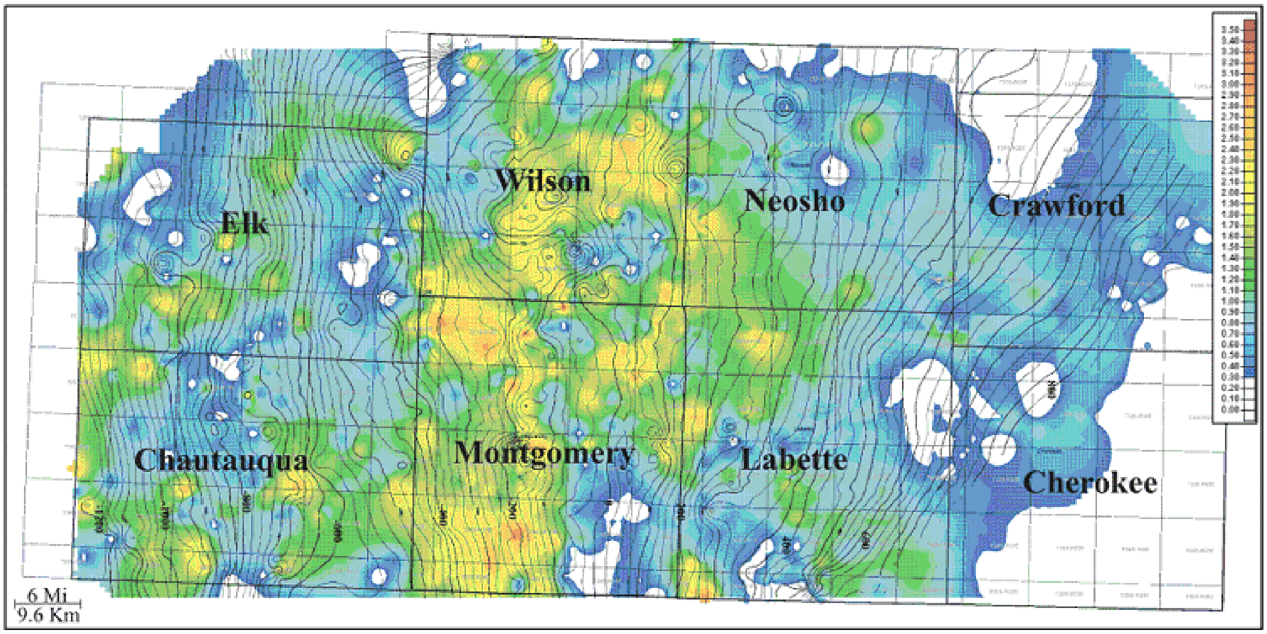


Figure 2.21 - Isopach of Tebo Coal (color) overlain with contours of bottom Tebo Coal structure (isopach CI:0.10ft; structure CI:25ft).

2.3.7 Scammon Interval

Description

The interval from the top of the Tebo shale to the top of the Scammon shale marker ranges in thickness from 8 to 80 feet with an average of 38 feet (2.4 to 24.4 m, average of 11.6 m; Figures 2.01 and 2.22). Variability in interval thickness may be due to thick sandstone accumulations within the interval (up to 40 ft, 12 m). In ascending order, the Scammon interval consists of a dark gray shale facies passing upward into interlaminated sandstone and siltstone facies known as the Skinner Sandstone or Chelsea Sandstone. A blocky mudstone facies, and the semi-continuous Scammon coal overlie the Skinner/Chelsea Sandstone. At the top of the Scammon interval is a dark gray shale facies (Figure 2.22). The bottom of the Skinner/Chelsea Sandstone is an unconformity that can erode deeply into the underlying interval (Tebo interval). Locally, a discontinuous coal facies (Scammon B coal) is present within the Skinner/Chelsea Sandstone.

Scammon Interval

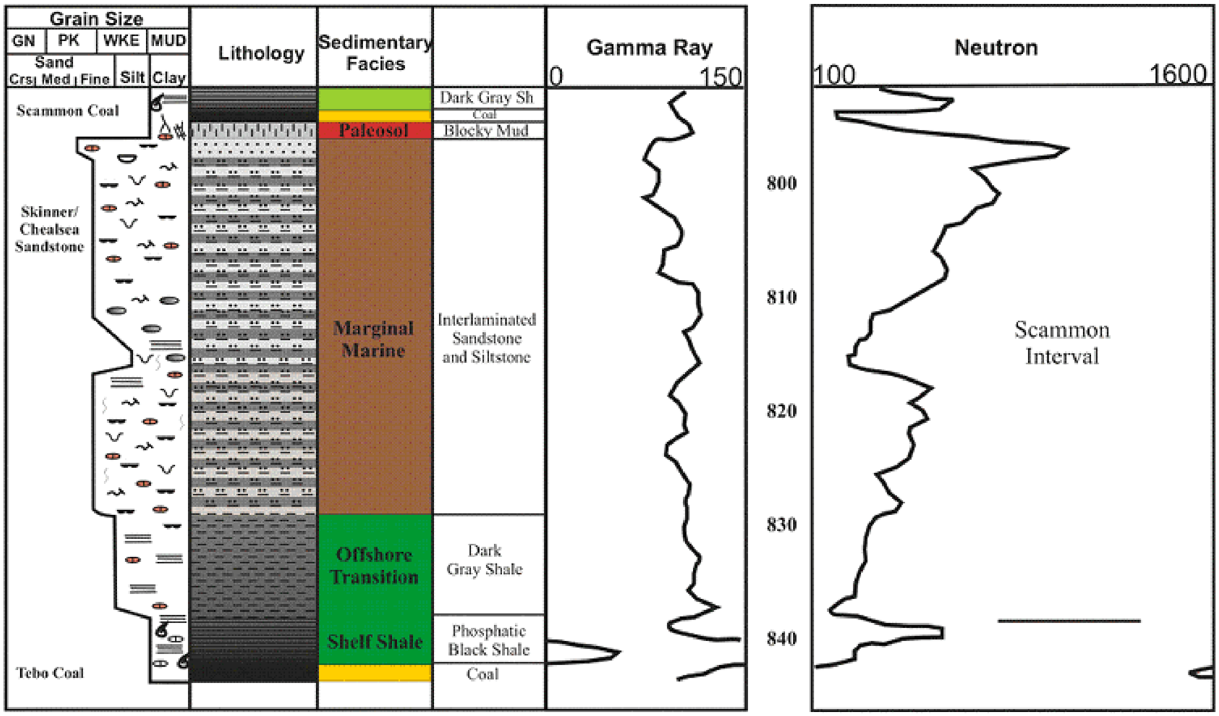


Figure 2.22 - Depositional sequence and log characteristics of the Scammon interval, based on core and well log from the Hinthorn CW#1 well, 14-T32S-R16E, Montgomery County, Kansas (scale in feet). See Figure 2.15a for legend.

Scammon Coal Isopach Map

The Scammon coal is recognizable on logs due to a relatively high gamma ray response (> 105 API units) and low neutron response (< 475 neutron counts) from the thin black shale marker followed down hole by a lower gamma ray response (< 105 API units) associated with the underlying coal (Figure 2.22). The Scammon shale marker extends across most of the Cherokee basin. Thickness of the Scammon coal can be up to 3 feet with an average of 1 foot and distribution slightly skewed to the minimum (1 m, average of 0.3 m; Figure 2.23; Appendix 2).

Detailed isopach mapping of the Scammon coal reveals a coal that remains fairly constant in thickness over an average of 6 square miles (9.6 km2; Figure 2.23). When structural contours of top of the Skinner Sandstone are overlain onto an isopach of the Scammon coal thickness, the coal appears to thicken on highs and thin into lows. Highs associated with the Skinner Sandstone may be due to differential compaction, where thicker Skinner Sandstone units provide a relatively higher topographic area. Local thin trends within thicker Scammon coal may be due to removal by fluvial erosion. The Scammon coal exhibits an irregular geometry that is oriented parallel and oblique to depositional dip (southwest), and is consistently thicker in Labette, Montgomery and Wilson counties.

Scammon Coal

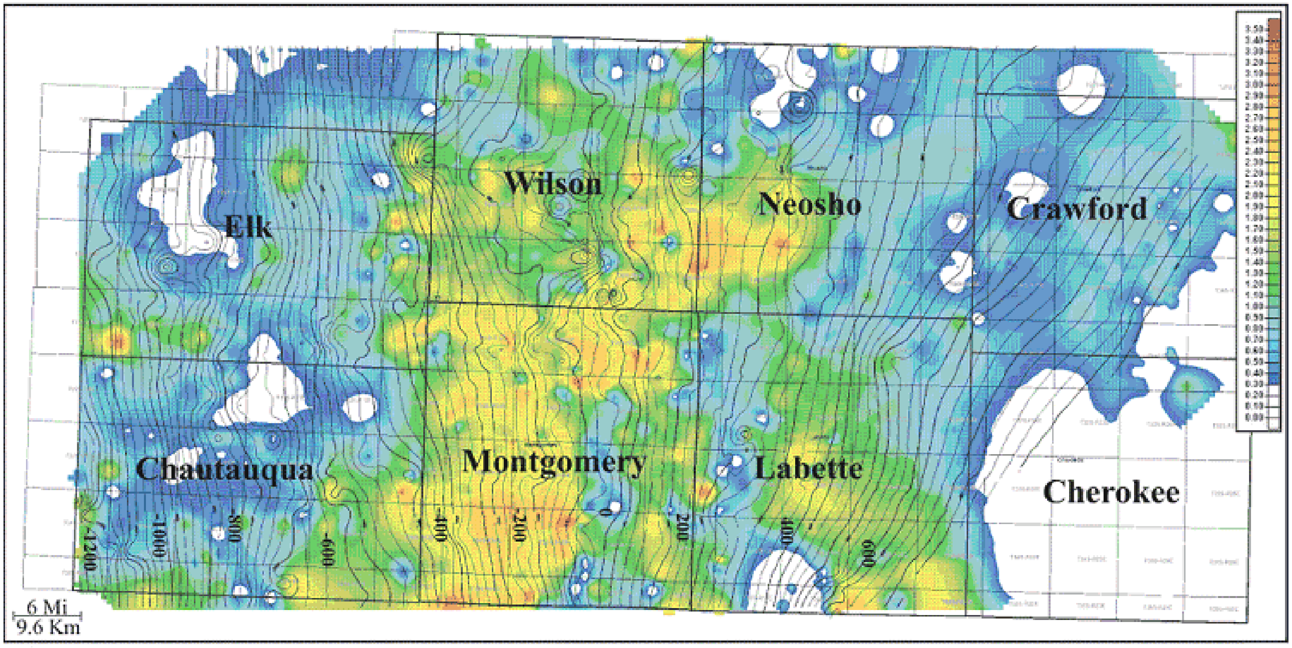


Figure 2.23 - Isopach of Scammon Coal (color) overlain with contours of bottom Skinner/Chelsea Sandstone structure (isopach CI:0.10ft; structure CI:25ft).

2.3.8 Mineral Interval

Description

The interval from the top of the Scammon shale to the top of the Mineral shale ranges in thickness from 10 to 40 feet with an average of 19 feet (3 to 12.2 m, average of 5.8 m; Figures 2.01 and 2.24). In ascending order, the Mineral interval consists mainly of a dark gray shale facies passing upward into a laminated muddy sandstone facies. A blocky mudstone facies, and the regional extensive Mineral coal overlies the sideritic shale facies. The regionally extensive Mineral coal is overlain by a phosphatic black shale facies (Figure 2.24). The blocky mudstone facies underlying the coal facies varies in thickness from 2 to 8 feet (0.6 to 2.4 m).

V-Shale and Mineral Interval

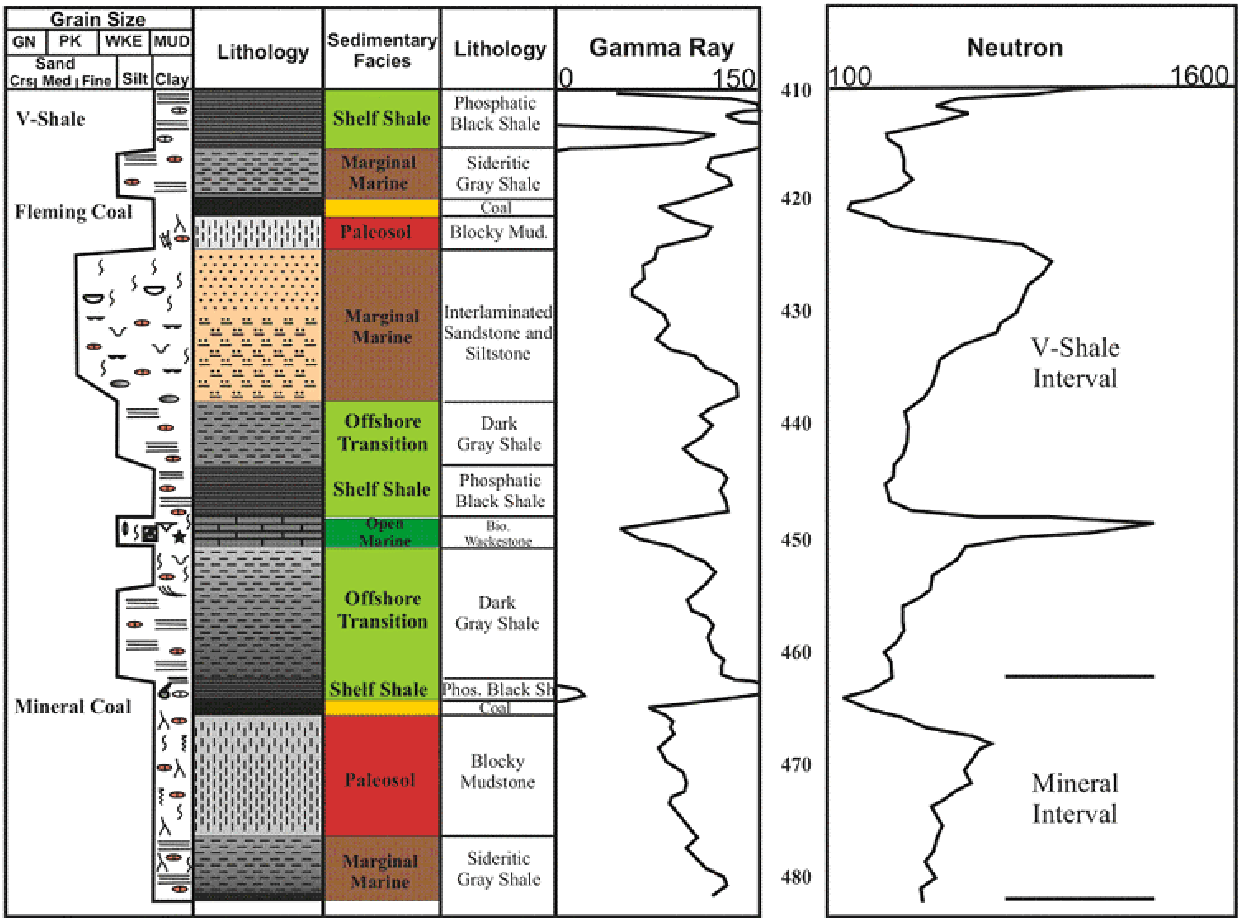


Figure 2.24 - Depositional sequence and log characteristics of theV-Shale and Mineral interval, based on core and well log from the Cooper CW#1 well 11-T35S-R18E, Labette County, Kansas (scale in feet). See Figure 2.15a for legend.

Mineral Coal Isopach Map

The Mineral coal is recognizable on most logs by the radioactive black shale marker (Mineral shale marker) present above the Mineral coal, which is due to a high gamma ray response (> 140 API units) and a lower neutron response (< 475 neutron counts). This black shale marker is followed down hole by a lower gamma ray response (< 100 API units) associated with the underlying coal (Figure 2.24). The Mineral coal marker extends throughout the Cherokee basin. Thickness of the Mineral coal ranges up to 4 feet with an average of 1.4 feet, and is normal in distribution (1 m, average of 0.4 m; Figure 2.25; Appendix 2).

Detailed isopach mapping of the Mineral coal reveals a coal that stays fairly constant in thickness over an average distance of 6 square miles (9.6 km2; Figure 2.25). The Mineral coal is the next laterally extensive and thick coal above the Weir-Pittsburg coal. Paleotopography reflected in structure appears to influence coal thickness. When structural contours of bottom of the Mineral coal are overlain onto an isopach of Mineral coal thickness, the coal appears to thicken on highs and thin into lows (Figure 2.25). The Mineral coal exhibits a lenticular geometry that is oriented parallel to depositional strike (northwest), and is consistently thicker in Labette, Neosho, Montgomery, Wilson, and Cherokee counties. Localized thin areas in the Mineral coal are usually circular in map view, and may be due to removal by erosion (see Chapter 5).

Mineral Coal

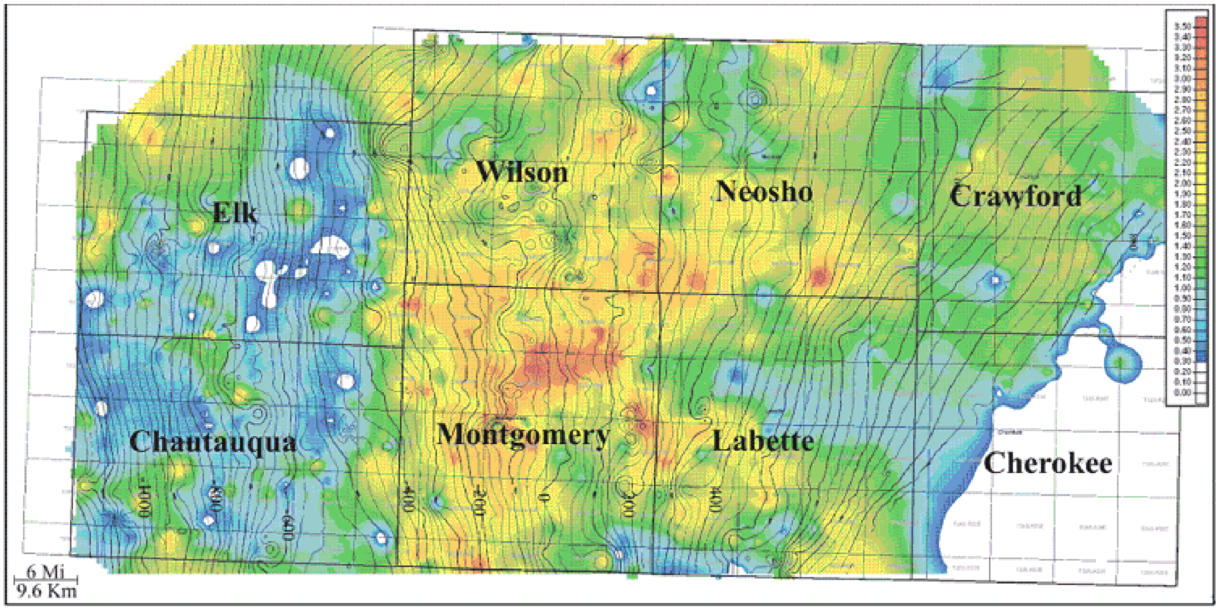


Figure 2.25 - Isopach of Mineral Coal (color) overlain with contours of bottom Mineral Coal structure (isopach CI:0.10ft; structure CI:25ft).

2.3.9 V-Shale Interval

Description

The interval from the top of the Mineral shale to the top of the V-Shale ranges in thickness from 20 to 70 feet with an average of 40 feet (6.1 to 21.9 m, average of 12.2 m; Figures 2.02 and 2.24). The V-Shale interval consists, in ascending order, of a dark gray shale facies that is locally overlain by approximately 10 feet (3 m) of an interlaminated sandstone and siltstone facies. The upper part of the V-Shale interval consists of thin bedded (3-10 cm), massive, clean sand, which is capped by a blocky mudstone facies and a thin (less than 3 ft; 0.9 m) discontinuous coal facies known as the Fleming coal. Overlying the Fleming coal is another dark gray shale facies or sideritic shale facies. Locally, an additional blocky mudstone facies and coal facies known as the Croweburg coal occurs on top of the sideritic shale facies. The top of the V-Shale interval is defined by a regionally extensive phosphatic black shale facies known as the V-Shale (Figure 2.24). The erosional basal contact of the interlaminated sandstone and siltstone facies below the Fleming coal is interpreted as an unconformity.

Fleming Coal Isopach Map

The V-Shale is the most recognizable radioactive black shale within the Cherokee Group, and is correlatable throughout southeastern Kansas and into adjacent states. The V-Shale is identifiable on logs due to a high gamma ray response (> 225 API units) moderate neutron response (~ 800 neutron counts; Figure 2.24). The high gamma ray response and stratigraphic position of the V-Shale is underlain by a much lower gamma ray response (< 150 API units) and lower neutron response (< 100 neutron counts) due to the underlying Croweburg coal. Approximately 10 feet (3 m) below the V-shale lies another thin radioactive shale (> 150 API units) that although not as laterally continuous is a useful marker for identifying the underlying Fleming coal.

Detailed isopach mapping of the Fleming coal reveals a coal that is laterally discontinuous but has a consistency in thickness over an average of 4 square miles (6.4 km2; Figure 2.26). Thickness of the Fleming coal can be up to 2.6 feet with an average of 1 foot and a distribution skewed to the minimum (0.8 m, average of 0.3 m; Appendix 2). The Fleming coal exhibits a dendritic geometry that is oriented parallel to depositional dip (southwest). In contrast with some of the other Cherokee Group coal deposits in the study area, structure does not appear to have as much control on coal thickness. The Fleming coal is consistently thicker in the southern half of the study area. Thin or zero coal trends of the Fleming coal appear to be the result of non-deposition.

Fleming Coal

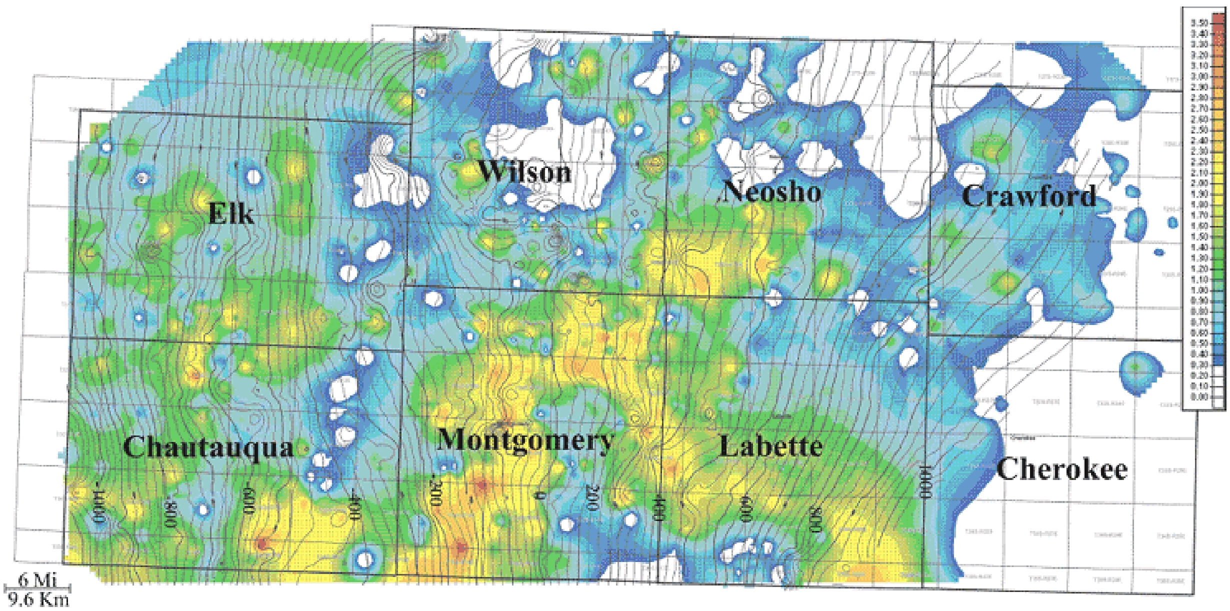


Figure 2.26 - Isopach of Fleming Coal (color) overlain with contours of bottom Fleming Coal structure (isopach CI:0.10ft; structure CI:25ft).

Croweburg Coal Isopach Map

Detailed isopach mapping of the Croweburg coal reveals a laterally continuous coal that has a consistency in thickness over an average of 6 square miles (9.6 km2; Figure 2.27). Thickness of the Croweburg coal can be up to 3 feet with an average of 1 foot and has a normal distribution (0.9 m, average of 0.3 m; Appendix 2). The Croweburg coal exhibits a lenticular geometry that is oriented parallel to both depositional dip (northwest) and strike (southeast). When overlaying structural contours of bottom of the Croweburg coal onto an isopach of Croweburg coal thickness, the coal appears to thicken on structural highs and thin into lows. The Croweburg coal is consistently thicker in Wilson, Montgomery, Neosho, and Labette counties. Localized thin areas and trends within the thicker Croweburg coal may be due to removal by erosion.

Croweburg Coal

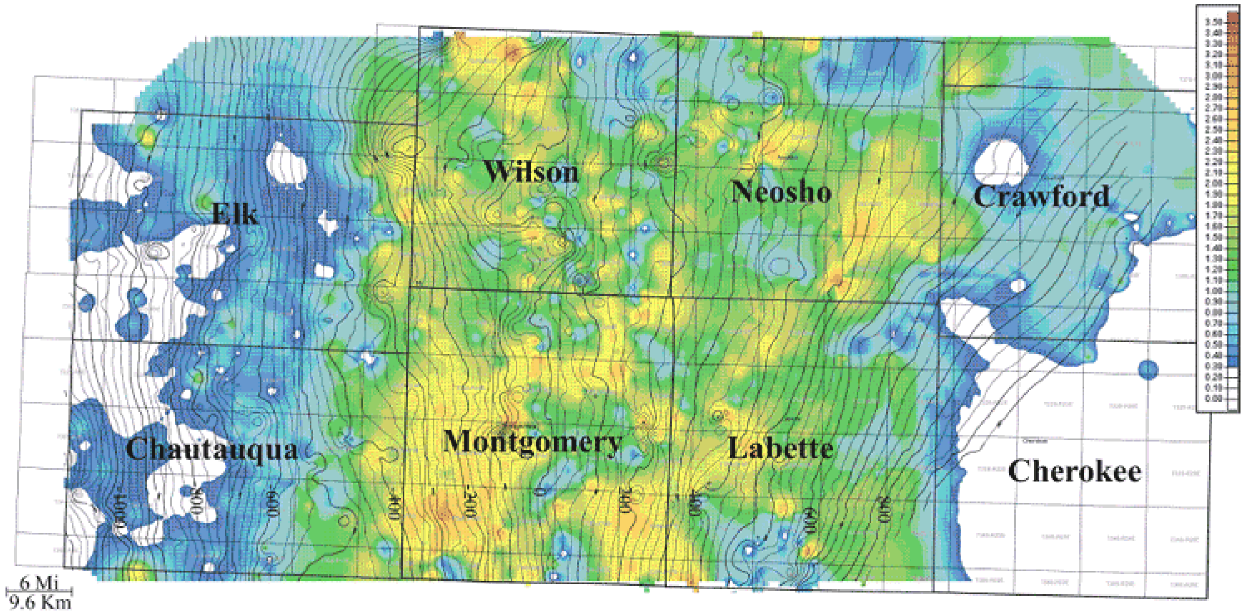


Figure 2.27 - Isopach of Croweburg Coal (color) overlain with contours of bottom Croweburg Coal structure (isopach CI:0.10ft; structure CI:25ft).

2.3.10 Bevier Interval

Description

The interval from the top of the V-Shale shale to the top of the Bevier shale ranges in thickness from 5 to 24 feet with an average of 14 feet (1.5 to 7.3 m, average of 4.3 m; Figures 2.01 and 2.28). In ascending order, the Bevier interval consists of a bioclastic mudstone to wackestone facies passing upward into a dark gray shale facies overlain by a 5 to 10 feet of thick (1.5 to 3 m) interlaminated sandstone and siltstone facies. The Bevier interval is capped by a blocky mudstone facies, coal facies (Bevier coal), and a dark shale facies (Bevier shale marker; Figure 2.28). An unconformity is located at the base of the interlaminated siltstone and sandstone facies below the Bevier coal.

Bevier and Lower Excello Interval

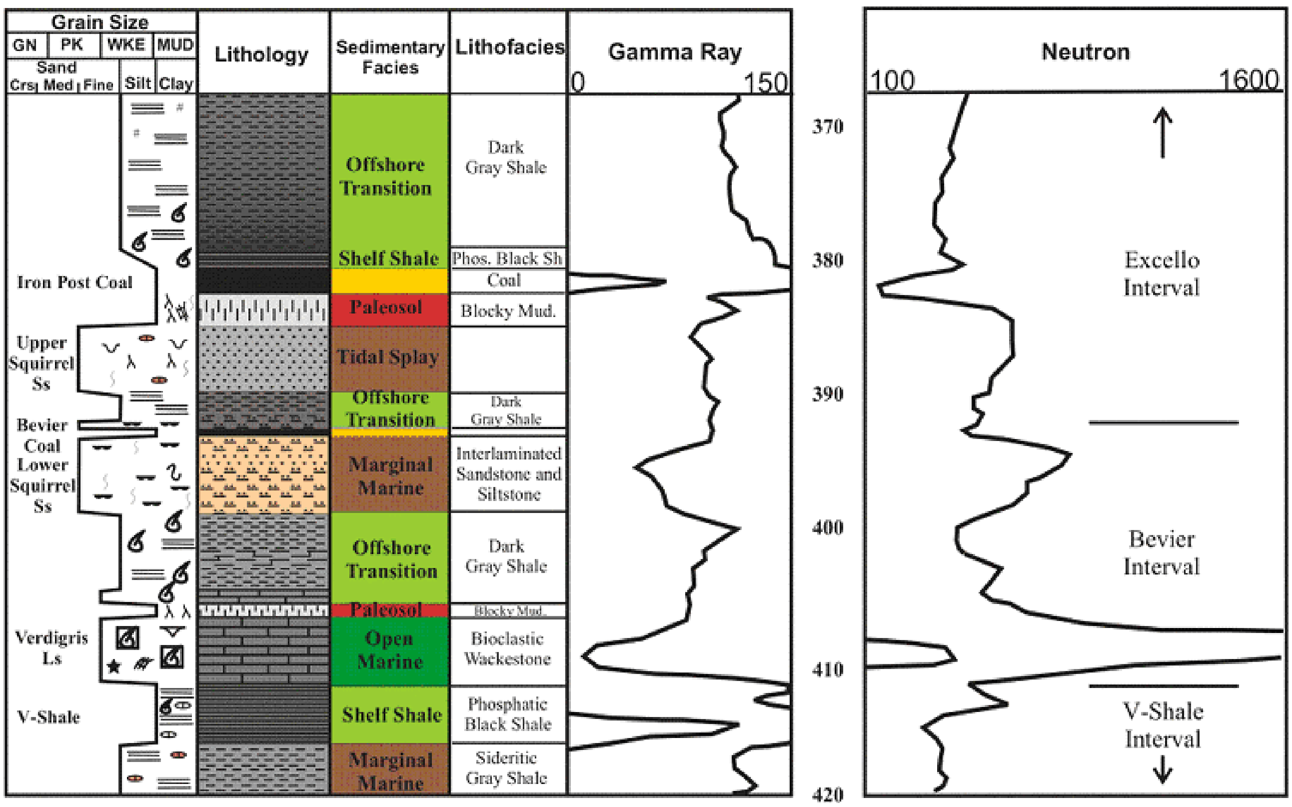


Figure 2.28 - Depositional sequence and log characteristics of the Bevier and Lower Excello interval, based on core and well log from the Cooper CW#1 well 11-T35S-R18E, Labette County, Kansas (scale in feet). See Figure 2.15a for legend.

Bevier Coal Isopach Map

A shale marker is present above the Bevier coal and is recognizable on logs due to a relatively high gamma ray response (> 105 API units) and low neutron response (~ 475 neutron counts) followed down hole by a lower response (< 90 API units) associated with the Bevier coal (Figure 2.28). The Bevier coal marker extends through most the Cherokee basin. If present, the Bevier coal is the next coal stratigraphically below the Iron Post coal.

Detailed isopach mapping of the Bevier coal reveals a coal that is discontinuous in the southern half of the study area and has a consistency in thickness over an average of 6 square miles (9.6 km2) in the northern half of the study area (Figure 2.29). Thickness of the Bevier coal ranges can be up to 4.5 feet with an average of 1.5 feet and has a normal distribution (1.4 m, average of 0.5 m). The Bevier coal exhibits a lenticular geometry that is oriented parallel to depositional dip (southwest). Structure appears to influence coal thickness. The Bevier coal appears to thicken on highs and thin into lows as defined by structure contours of the base of the Bevier coal overlain onto an isopach of Bevier coal thickness (Figure 2.29). The Bevier coal is consistently thicker in the northern half of the study area especially within Wilson, and Neosho counties. Localized thin trends in areas of thicker Bevier coal may be due to erosion.

Bevier Coal

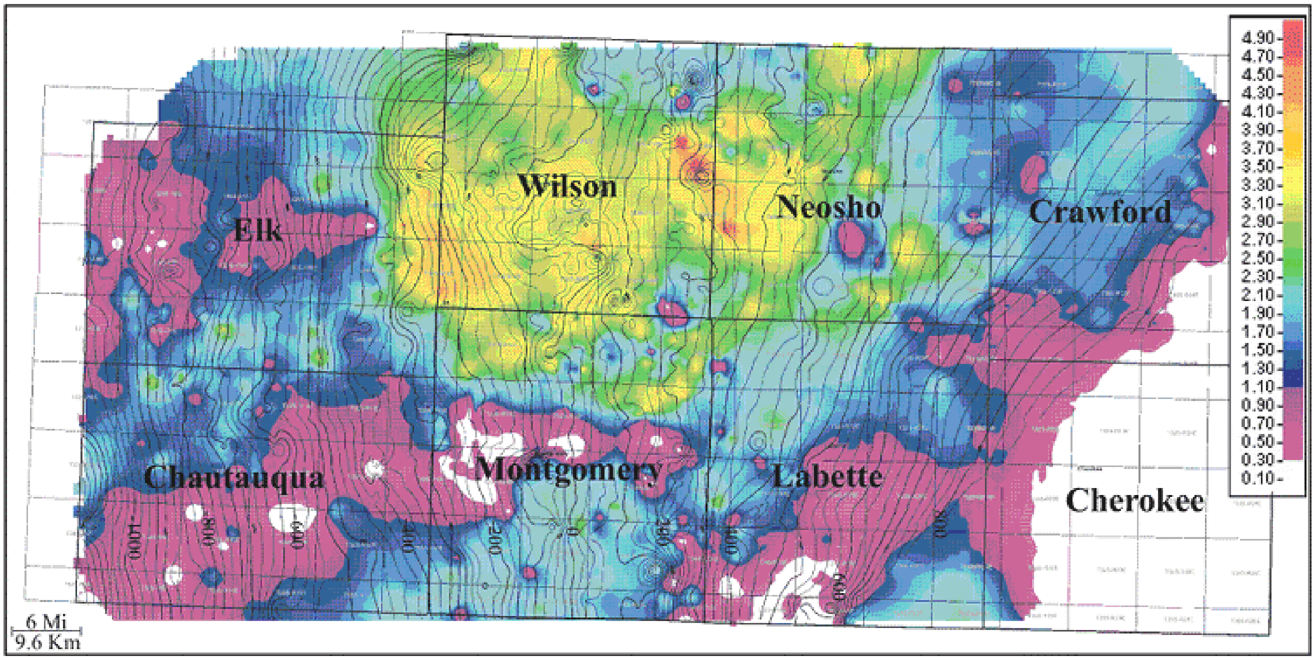


Figure 2.26 - Isopach of Bevier Coal (color) overlain with contours of bottom Bevier Coal structure (isopach CI:0.10ft; structure CI:25ft).

2.3.11 Excello Interval

Description

The interval from the top of the Bevier shale to the top of the Excello Shale ranges in thickness from 25 to 130 feet with an average of 63 feet (7.6 to 40 m, average of 19 m; Figures 2.01 and 2.30). Variability in interval thickness may be due to thick sandstone accumulations within the interval (up to 30 ft, 9m; Staton, 1987). The Excello interval consists of a dark gray shale facies passing upward into a blocky mudstone facies or locally discontinuous sandstone, which is known as the Squirrel Sandstone. The Squirrel Sandstone is overlain by a coal facies known as the Iron Post coal (Figure 2.30). Above the Iron Post coal is a dark gray shale facies that grades into a pyritic shale facies (Figure 2.30). Overlying the pyretic shale facies is a regionally continuous bioclastic wackestone facies that grades into a bioclastic packstone facies. This carbonate facies is known as the Breezy Hill Limestone. Locally, capping the interval is a coal to carbonaceous shale facies (Mulky coal), followed by a phosphatic black shale facies (Figure 2.30). The phosphatic black shale facies is a regionally extensive unit known as the Excello Shale.

The Excello Shale is a highly radioactive phosphatic black shale that extends throughout the Cherokee basin and mid-continent (Wanless et al., 1969). The Excello is the first highly radioactive shale in the Cherokee Group and is recognizable on logs by a high gamma ray response (> 225 API units) and low neutron response (< 325 neutron counts) followed down the hole by a lower gamma ray response (< 150 API units). The lower gamma-ray response is associated with the underlying Mulky coal or carbonaceous shale (Figure 2.30). The Iron Post coal is identifiable as either the next coal stratigraphically below the Breezy Hill Limestone or by the overlying Iron Post shale. The Iron Post shale exhibits a relatively high gamma ray response (> 105 API units) and high neutron response (~ 925 neutron counts) followed down hole by a lower gamma ray response (< 90 API units) and low neutron response (< 100 neutron counts) due to the underlying Iron Post coal. Due the close stratigraphic relationship between the Iron Post and Bevier coals, misidentification can be a problem when only one relatively thick and easily identifiable coal is present in the upper portion of the Cherokee Group. Through mapping and cross section construction, the Bevier coal is identified as the predominate of the two coals in the northern half of the study area, whereas the Iron Post coal tends to be the thicker coal in the southern half of the study area.

Iron Post Coal Isopach Map
Detailed isopach mapping of the Iron Post coal reveals a coal that is laterally continuous and has a consistency in thickness over an average of 6 square miles (9.6 km2; Figure 2.31). Thickness of the Iron Post coal ranges from 0 to 2.6 feet with an average of 1 foot and a distribution that is skewed to the minimum (0 to 0.8 m, average of 0.3 m; Appendix 2). The Iron Post coal exhibits an elongate geometry that is oriented parallel to depositional dip (southwest). Unlike some of the other coals local structure does not appear to influence the local thickness of coal. The Iron Post coal is consistently thicker in the southern half of the study area, especially within Chautauqua, Montgomery, and Labette counties.

Iron Post Coal

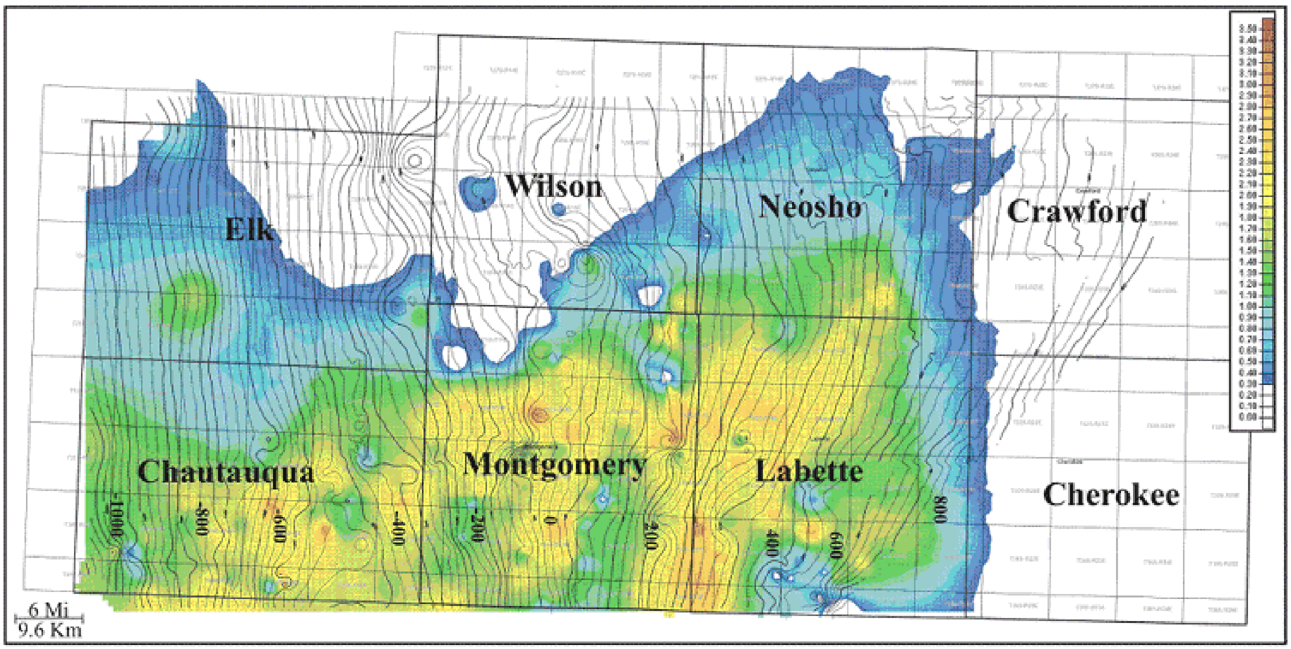


Figure 2.31 - Isopach of Iron Post Coal (color) overlain with contours of top Iron Post coal structure (isopach CI:0.10ft; structure CI:25ft).

Mulky Coal Isopach Map
Detailed isopach mapping of the Mulky coal reveals a coal that has a consistency in thickness over an average of 3 square miles (4.8 km2; Figure 2.32). Thickness of the Mulky coal can be up to 2.5 feet with an average of 0.75 feet and a distribution that is skewed to the minimum (0.8 m, average of 0.2 m, Appendix 2). The Mulky coal exhibits an irregular distribution. Local structure appears to have influenced coal thickness. When overlaying structural contours of top Brezzy Hill Structure onto an isopach of Mulky coal thickness, the coal appears to thicken on highs and thin into lows. The Mulky coal is consistently thicker in areas of Montgomery, Labette, and Neosho counties. Areas and trends of thin Mulky coal thickness may be due to non-deposition or deposition of carbonaceous shale instead of coal.

Mulky Coal

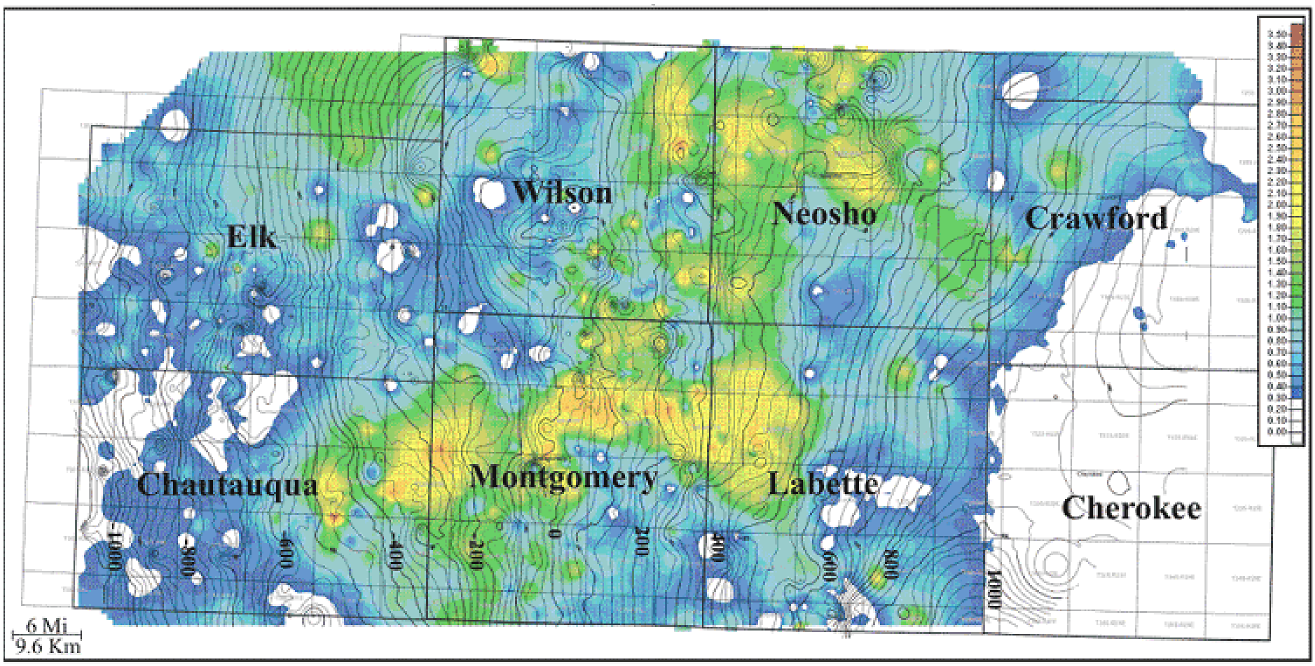


Figure 2.32 - Isopach of Mulky Coal (color) overlain with contours of top Brezzy Hill Limestone structure (isopach CI:0.10ft; structure CI:25ft).

2.3.12 Little Osage Interval

Description

The Little Osage interval extends from the top of the Excello Shale to the top of the Little Osage Shale and ranges in thickness from 10 to 45 feet with a mode of 20 feet (3 to 13.7 m, average of 6 m; Figures 2.01 and 2.30). The Little Osage interval consists of a regionally extensive bioclastic wackestone facies that grades into a bioclastic packstone/grainstone facies known as the Blackjack Creek Limestone. Above the Blackjack Creek Limestone is a coal to carbonaceous shale facies known as the Summit coal that is overlain by regionally extensive phosphatic black shale known as the Little Osage Shale (Figure 2.30).

The Little Osage Shale is a highly radioactive phosphatic black shale in the Fort Scott Limestone Formation that extends throughout the Cherokee basin and into adjacent states. It separates the Higginsville Limestone from the Blackjack Creek Limestone and is recognizable on logs due to a high gamma ray response (> 225 API units) and low neutron response (< 200 neutron counts) followed down the hole by a lower gamma ray response (< 150 API units) and low neutron response (< 100 neutron counts) associated with the underlying coal or carbonaceous shale known as the Summit coal (Figure 2.30).

Little Osage and Upper Excello Interval

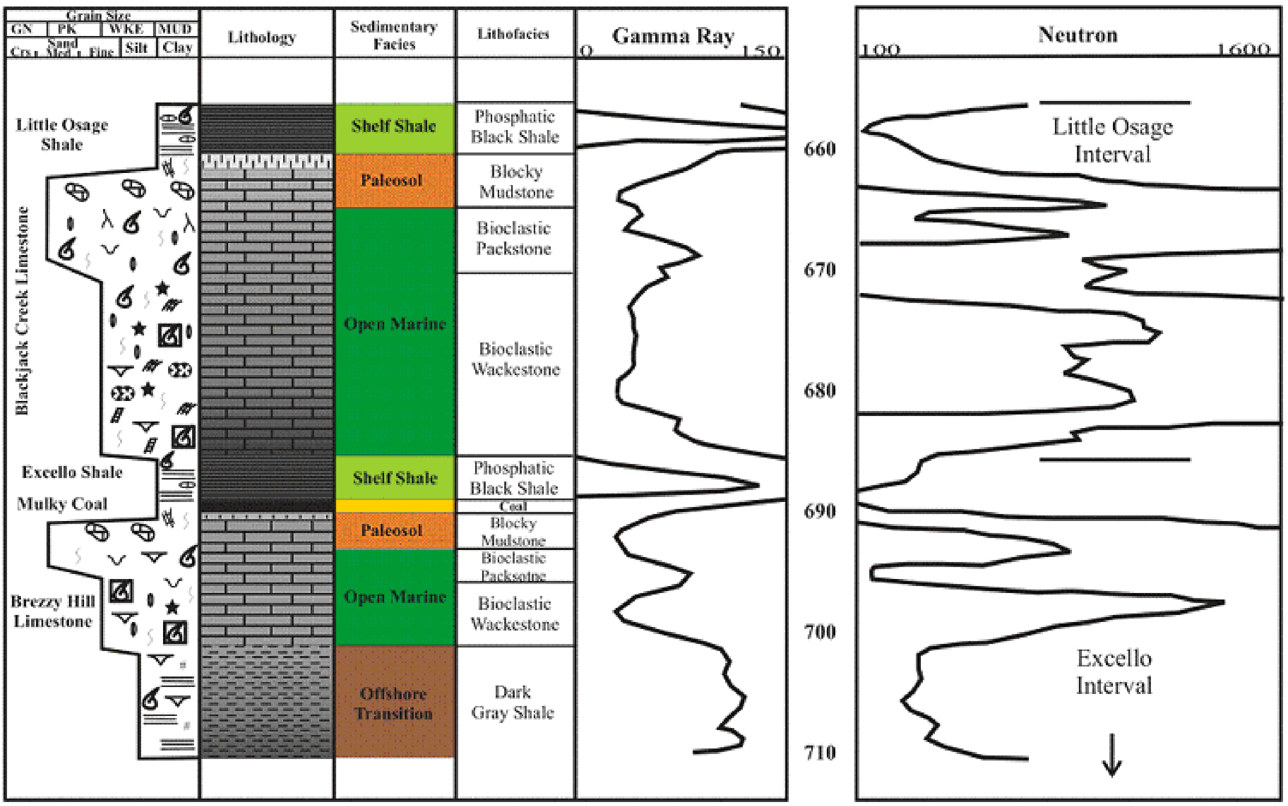


Figure 2.30 - Depositional sequence and log characteristics of the Little Osage and Upper Excello interval, based on core and well log from the Hinthorn CW#1 well, 14-T32S-R16E, Montgomery County, Kansas (scale in feet). See Figure 2.15a for legend.

Summit Coal Isopach Map

Detailed isopach mapping of the Summit coal reveals a coal that has a consistency in thickness over an average of 6 square miles (9.6 km2; Figure 2.33). Thickness of the Summit coal can be up to 2.8 feet with an average of 1 foot and a distribution that is slightly skewed to the minimum (0.9 m, average of 0.3 m; Appendix 2)). The Summit coal exhibits an irregular circular to polygonal geometry. Structure appears to have an influence on coal thickness. When overlying contours of top Blackjack Creek Limestone structure onto an isopach of Summit coal thickness, the coal usually to thickens on the highs and thin into lows. The Summit coal is consistently thicker in Neosho County. Areas and trends of thin Summit coal thickness may be due to non-deposition or deposition of carbonaceous shale instead of coal.

Summit Coal

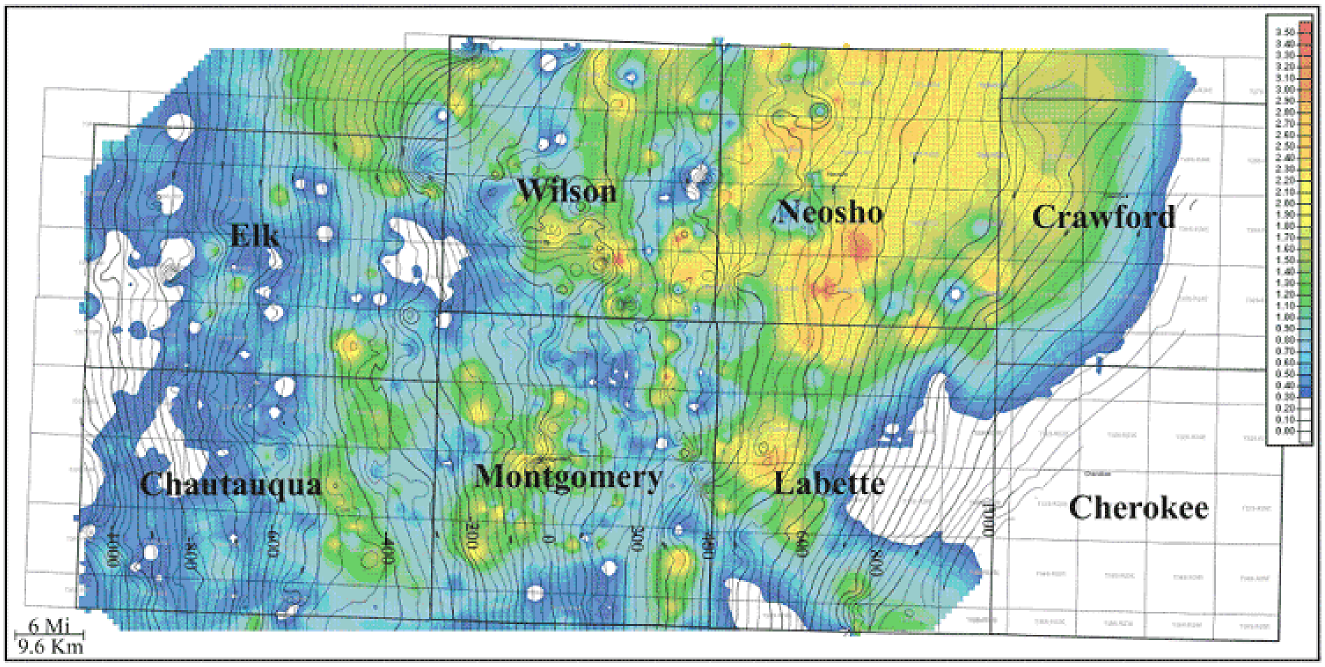


Figure 2.33 - Isopach of Summit Coal (color) overlain with contours of top Blackjack Creek Limestone structure (isopach CI:0.10ft; structure CI:25ft).

Chapter Three: Coalbed Gas in the Cherokee Basin

The first test in Kansas to assess coalbed gas potential in southeastern Kansas was from several wells drilled during the late 1980's in Wilson and Montgomery counties (Stoeckinger, 1989). Desorption analyses were conducted on the Mulky, Weir-Pittsburg, and Riverton coal beds and gas contents were determined to be more than 200, 220, and 190 scf/ton, respectively (Stoeckinger, 1989). Additional testing of coalbed gas potential continues with many independent oil and gas companies operating in eastern Kansas. Detailed desorption data collected by the Kansas Geological Survey from several wells in eastern Kansas will be released during late 2003 and into mid 2004. Currently the KGS Cooper CW #1 (11-T35S-R18E, Labette County, Kansas) is the only well with desorption data available through an open-file report.

3.2 Geochemical Composition

Conventional gas from both oilfields (associated gas) and gasfields (nonassociated gas) in eastern Kansas range in origin from thermogenic, to microbial carbon dioxide reduction, and microbial origins, based on crossplots of the δD, $\delta^{13}C$ and wetness of methane (Jenden et al., 1988; Figure 3.01). In cooperation with operators, two gas samples were recovered from Cherokee Group coal samples during desorption, and sent to an outside laboratory for isotopic analysis (Isotech Laboratories, Champaign, IL). These samples have similar intermediate δD vs. $\delta^{13}C$ composition, suggesting mixed thermogenic and microbial origins (Figure 3.01). The mixed origin of coal gases in eastern Kansas is also supported by the plot of wetness versus methane $\delta^{13}C$, where the coal gas samples plot below the thermogenic arrow and in the region of mixed microbial and thermogenic gases (Figure 3.01).

Pennsylvanian rocks are mature to marginally mature in the eastern part of Kansas where Cherokee Group coals have vitrinite reflectance values of 0.5 - 0.7% (Jenden et al., 1988). Considering degree of maturation and gas geochemistry, conventional and coal natural gases in eastern Kansas are a combination of indigenous dry microbial methane, and either indigenous or migrated early thermogenic methane. An additional source of indigenous thermogenic methane is the black shale that typically overlies each coal. Also, longer distance migration of thermogenic gases into Cherokee Group reservoirs in Kansas may have occured along the regional Mississippian-Pennsylvanian unconformity from the Arkoma basin in northeastern Oklahoma (Jenden et al., 1988).

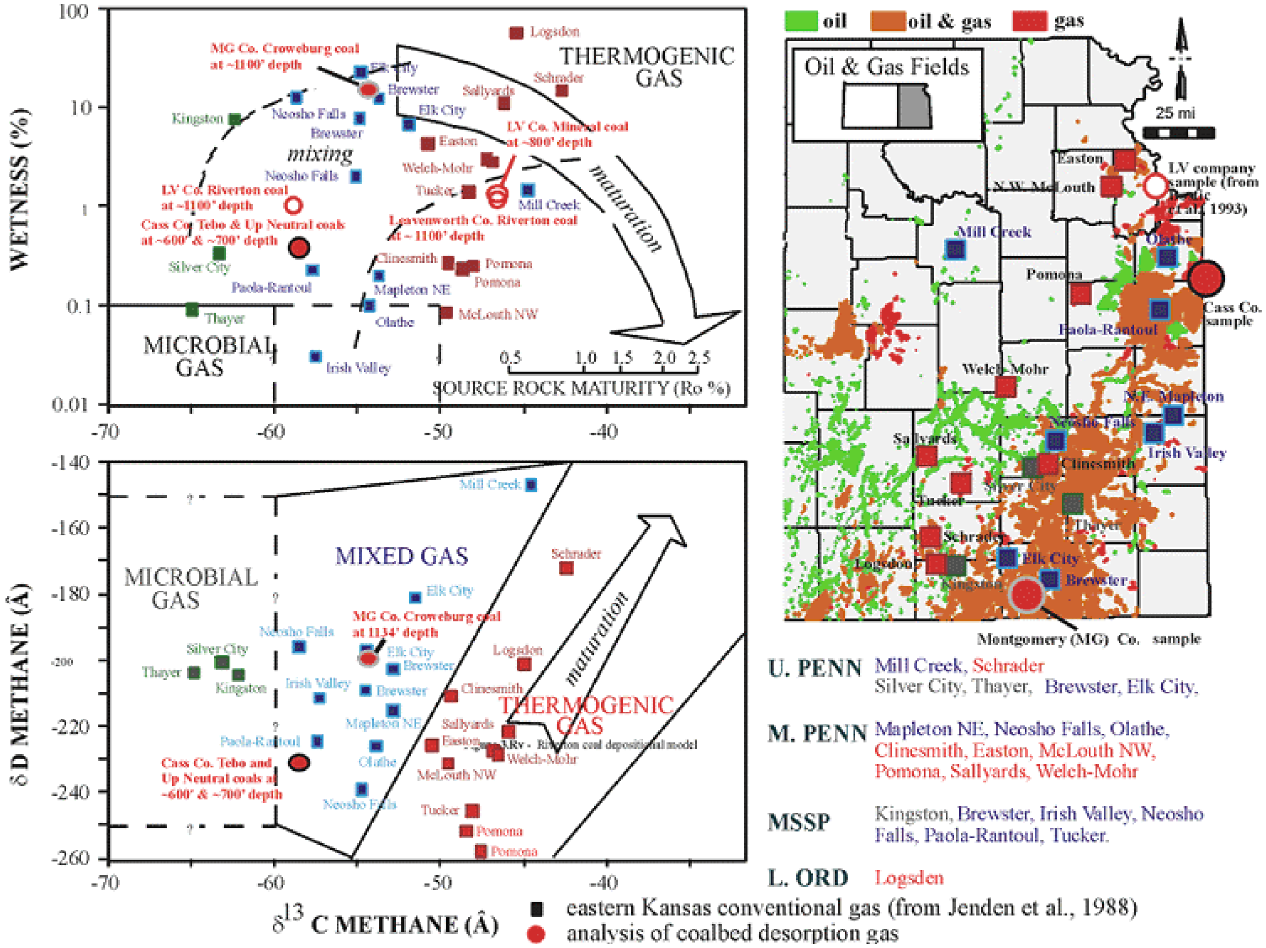


Figure 3.01 - Plots of conventional gases sampled compared to coal bed gases sampled in eastern Kansas (modified from Jenden et al., 1988).

3.3 Gas Content

Evaluation of coalbed gas potential for the Cherokee Group involves estimates of the gas content of coal samples. Gas content is based on desorption measurements of coal samples. Following catchment of cuttings or retrieval of core at the wellsite, desorption is continued under near stable conditions in the laboratory (see Chapter 1 for methodology). In the case of cuttings, lost gas is significantly greater than that of cores because the cuttings sample is pulverized before reaching the surface. However, cuttings reach the surface in a matter of seconds in air-drilled wells, whereas cores can take several minutes to reach the surface. The measured volume of desorbed gas for cuttings is commonly on the order of 25-30% lower than desorbed gas from cores (Nelson, 1999). In this study, a correction of +25% was used when calculating and comparing desorbed gas contents for cuttings samples.

Desorption analysis was conducted on core and cuttings samples from ten wells in the Cherokee basin (Figure 3.02). Desorption measurements for cores were calculated on an as-received basis (gas content calculated on whole dry weight of sample) and averaged for each coal and shale sampled and reported as standard cubic feet per ton (scf/ton; Figure 3.03). In the case of cuttings, the gas content of the coal was calculated assuming that admixed dark shales desorbed 3 scf/ton. This latter measure is consistent with the lower range of gas contents measured in dark shales from the Cherokee Group. Gas contents have a wide range from 3 scf/ton to over 300 scf/ton for coal. Black shale gas contents range from 3 scf/ton to 35 scf/ton. The highest quality coals, based on their gas content, are the Riverton, Weir-Pittsburg and Mulky (Figure 3.03). Putting all desorption values from Cherokee Group coals versus sample depth shows a slight trend of increasing gas content with depth (Figure 3.04).

Figures 3.05 - 3.08 depict the typical desorption characteristics versus time for coals from individual wells in Montgomery, Labette, Wilson and Neosho counties. In general, coals have higher gas contents in Montgomery County. This may be due to the coal deposits in Labette and Neosho counties, being up dip (i.e., shallower), the use of cuttings in Neosho and Wilson counties resulting in lower measured gas contents, or the limited sampling in Neosho, Labette and Wilson counties.

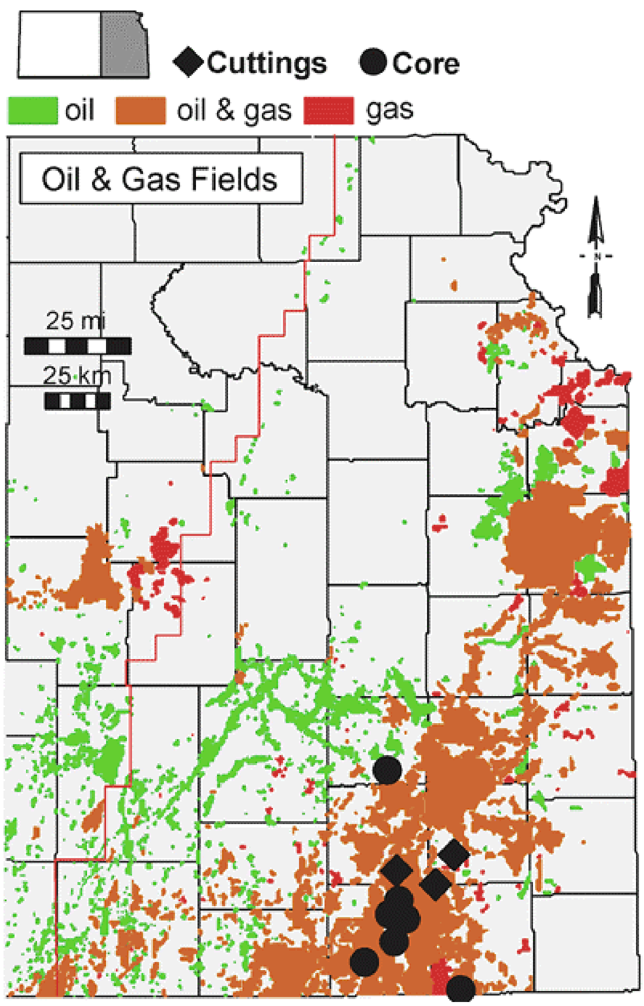


Figure 3.02 - Locations of cores and cuttings of Cherokee Group coal collected for desorption analysis.

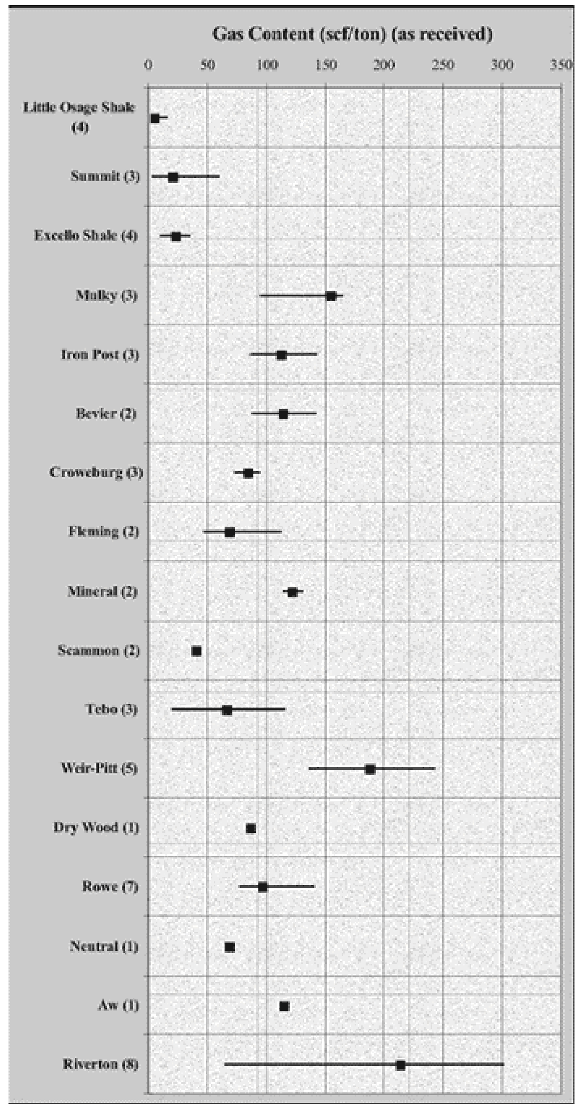


Figure 3.03 - Range and average gas content from the Cherokee basin on as received basis (see Figure 5.02 for sample locations and type). Number of samples in parentheses.

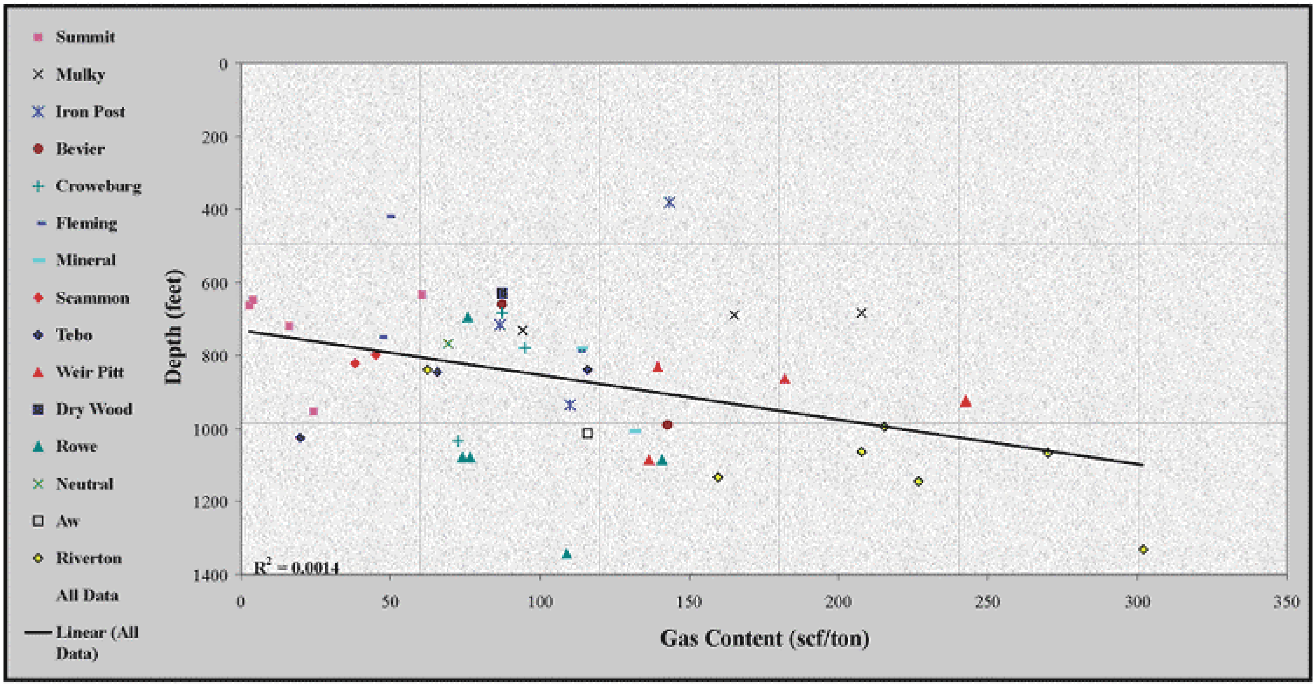


Figure 3.04 - Gas content conducted on an as received basis, plotted as a function of depth for coal samples from the Cherokee basin (see Figure 3.02 for sample location and type). Plot shows a relationship of increasing gas content with depth.

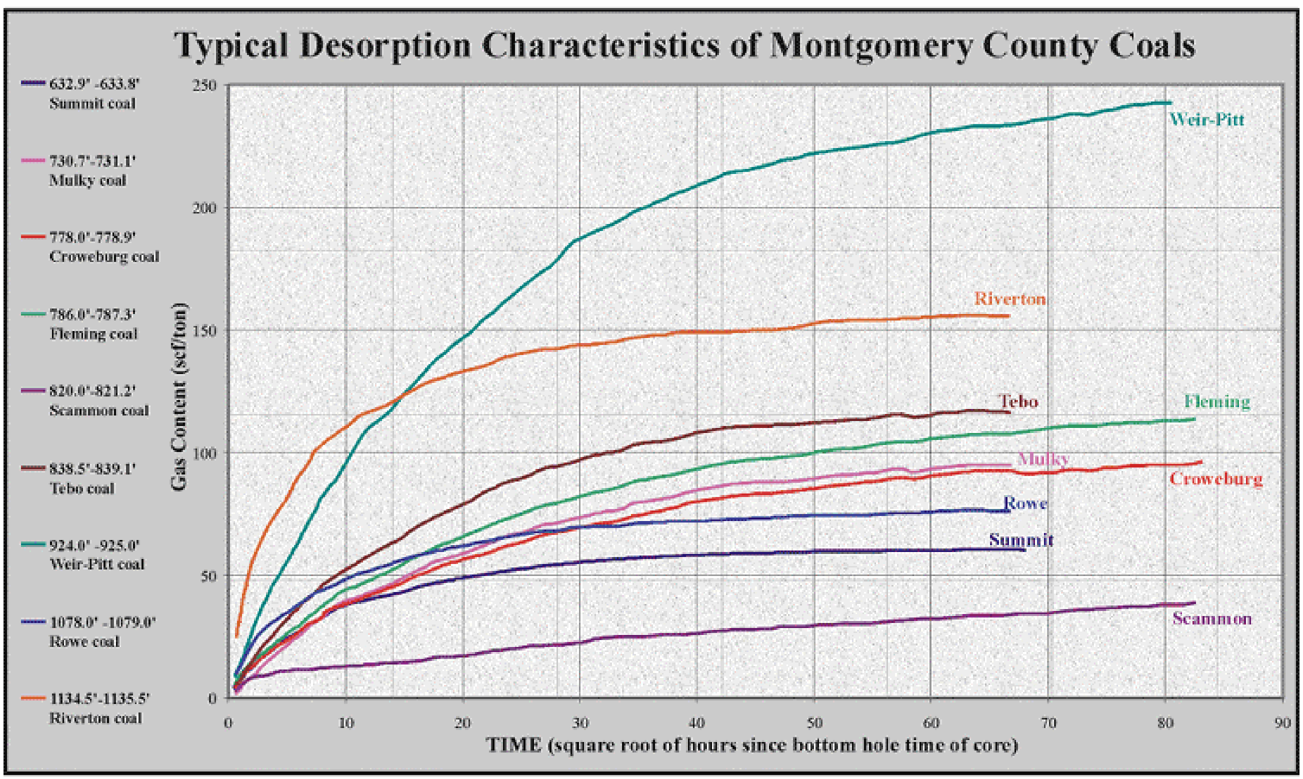


Figure 3.05 - Typical desorption characteristics for coals sampled from a single well in Montgomery County, Kansas

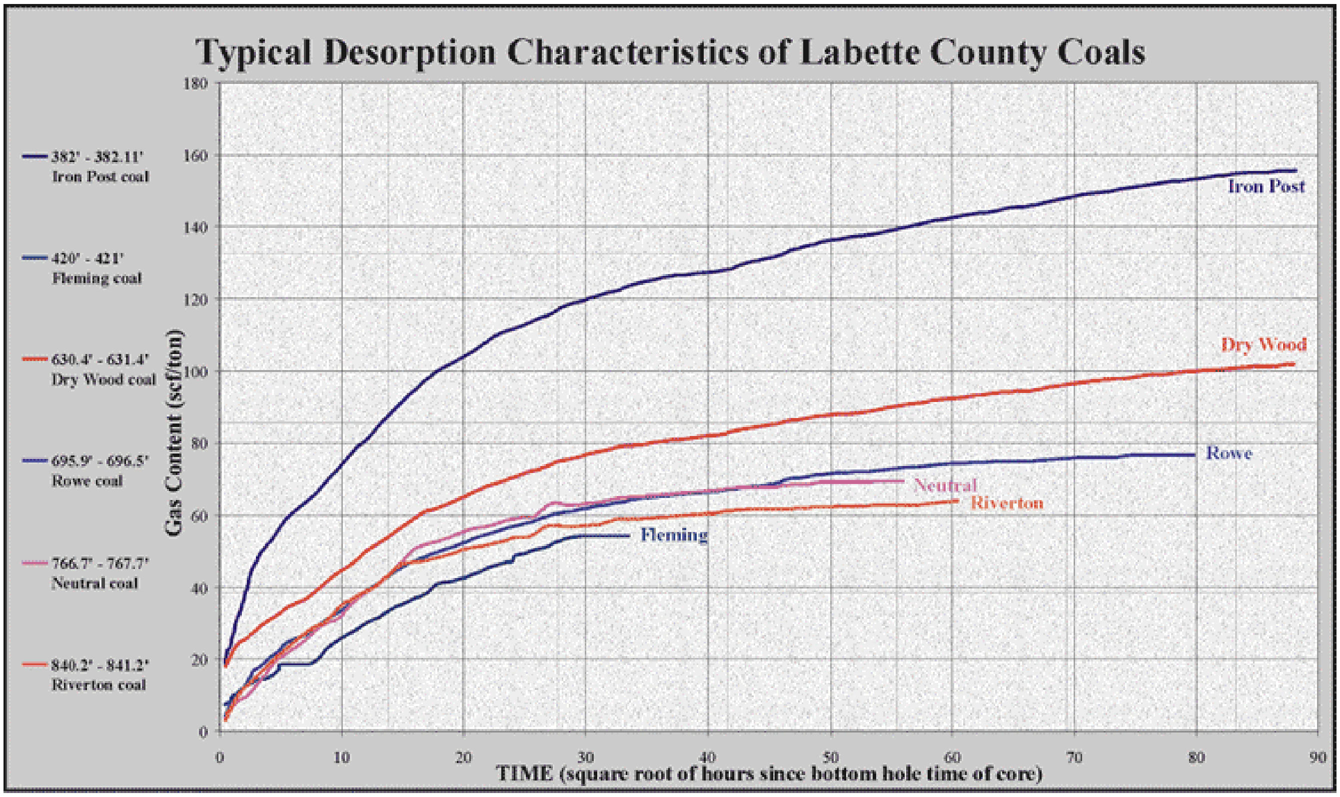


Figure 3.06 - Typical desorption characteristics for coals sampled in the Cooper CW#1 well, 11-T35S-R18E, Labette County, Kansas

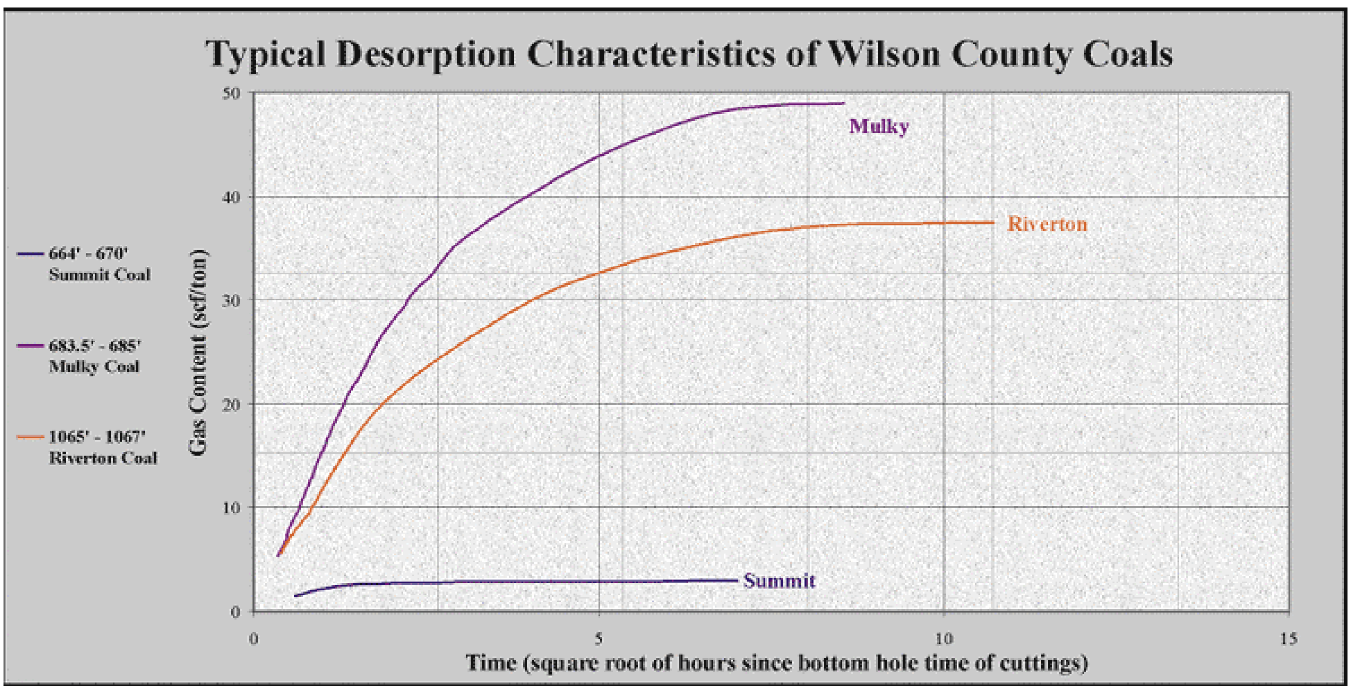


Figure 3.07 - Typical desorption characteristics for coal cuttings from a single well sampled in Wilson County, Kansas. A correction of +25% was used when calculating desorbed gas contents of cutting samples.

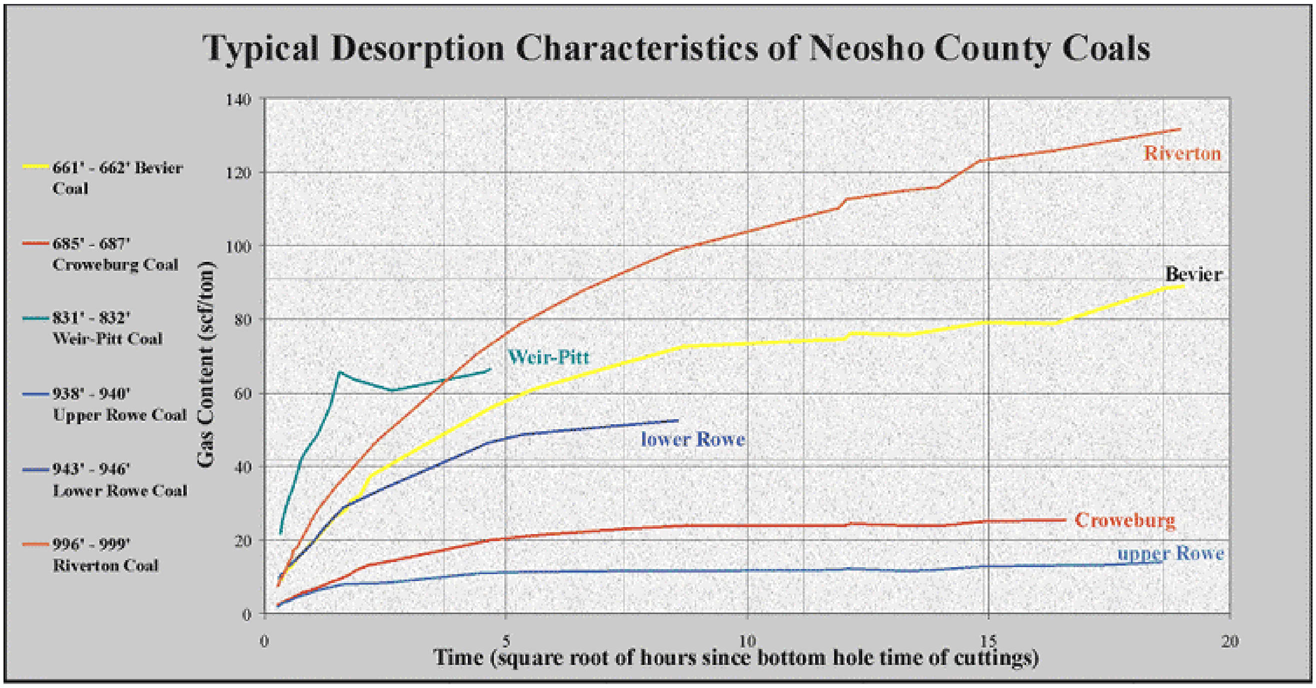


Figure 3.08 - Typical desorption characteristics for coal cuttings from a single well sampled in Neosho County, Kansas. A correction of +25% was used when calculating desorbed gas contents of cutting samples.

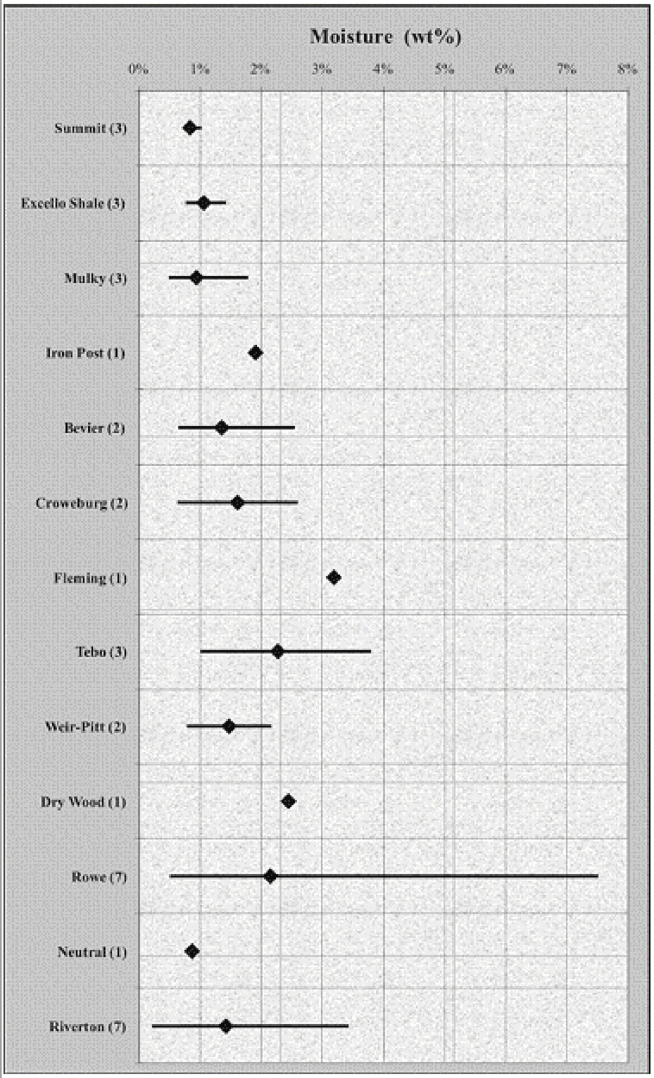
3.4 Proximate Analysis

The ASTM Book of Standards (2002) describes the process of proximal analysis on coals. Proximal analysis of coal samples used in this study was conducted at Luman's Lab (Chetopa, KS). To report analytical results including desorbed gas on a dry (moisture free) basis, moisture content must be determined (Figure 3.09). Testing for moisture entails calculating the weight loss of a sample when heated. Moisture ranges from 0.1 to 7.5 % for Cherokee Group coals (Figure 3.09).
Determining ash content involves burning the sample and weighing the residue. Ash is an important indicator of clastic input, likely derived from marine or fluvial deposition of clay, silt and sand during peat development. The moisture-free weight percentage of ash ranges from 7 to 90 % for Cherokee Group coals and carbonaceous shales (Figure 3.10). The Summit, Tebo, and Rowe coals have ash contents that are significantly higher than other coals. When comparing ash contents of subsurface samples with outcrop samples, ash content on average appears to be lower for outcrop samples (Allen 1925; Schoewe, 1959; Brady and Hatch, 1997; also see Figure 3.10). Lower ash contents of outcrop samples may be due to coal deposits being up dip and further away from a marine influence than samples down-dip.

Calculation of sulfur entails mixing part of the sample with Eschka mixture that dissolves with the sulfur in hot water and precipitates it as barium sulfate. The barium sulfate is then filtered, ashed, and weighed. Sulfur and ash content are traditional indicators of coal quality. Coals with a lower ash and sulfur content are generally regarded as higher quality. Coals with higher sulfur contents (> 2.5%) reflect a marine influence (Brady and Hatch, 1997). For Cherokee Group coals, the moisture-free weight percentage of sulfur ranges from 2 to 12.5 % (Figure 3.11). The Mulky, Iron Post, Dry Wood, Rowe, and Riverton coals have sulfur contents that suggest strong marine influence. When comparing sulfur contents of subsurface samples with outcrop samples, sulfur content on average appears to be slightly higher for the outcrop samples (Allen 1925; Schoewe, 1959; Brady and Hatch, 1997; Figure 3.11).

Once calculations for moisture and ash content are obtained, the calorific value (Btu/lb) can be determined on a moist, ash-free basis. Calculating the calorific value involves burning a sample in an adiabatic oxygen bomb calorimeter. Observation of temperature before and after combustion represents the calorific value. The calorific value provides a basis to determine coal rank. Most Cherokee Group coals on a moist, ash-free basis have calorific values greater or equal to 14,000 Btu/lb and are classified as high-volatile A bituminous (Figure 3.12). Cherokee coals with calorific values ranging between 13,000 and 14,000 are classified as high-volatile B bituminous (Figure 3.12). When comparing the calorific value of subsurface samples with outcrop samples, the calorific values for subsurface and outcrop samples are fairly consistent with each other (Allen 1925; Brady and Hatch, 1997; Schoewe, 1959).

Once moisture and ash content are obtained, desorption measurements can be calculated on a moisture ash-free basis (MAF) and averaged for each coal and shale sampled (Figure 3.13). Gas contents on a MAF basis range widely from 28 scf/ton to over 360 scf/ton for coals, and 64 scf/ton to 115 scf/ton for black shales. Gas content may be a reflection of several factors such as coal quality, rank, depth, association with adjacent source rock, and the amount and type of organic matter. As shown in Figure 3.14, there is an indication that gas contents generally increase with decreasing weight percentages of moisture-free ash. Figure 3.15 supports a relationship between increasing Btu/lb and gas content. Slight evidence for increasing gas content (MAF) with depth can be seen in the combined desorption data as well as in the data for individual wells (Figure. 3.16). Results presented in the previous graphs are from whole samples rather than multiple samples through each sampled coal. Individual coals may significantly vary laterally.



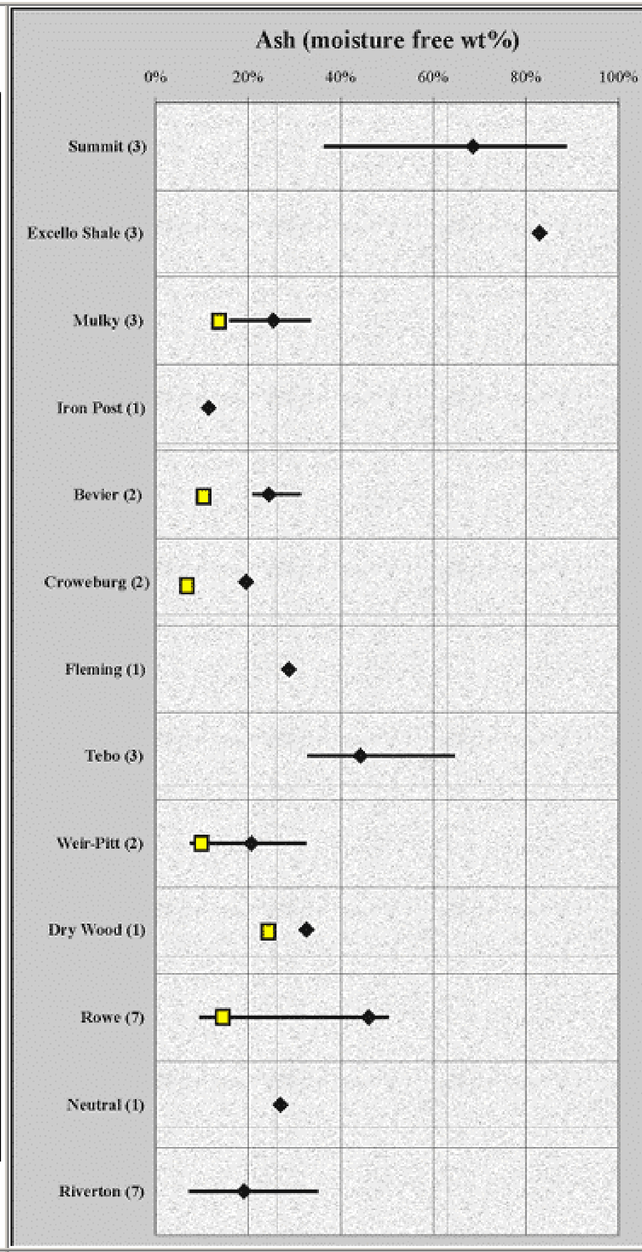


Figure 3.09 - Range and average moisture (weight percentage for coal samples from the Cherokee basin (see Figure 3.02 for sample locations and type). Number of samples indicated in parentheses.

Figure 3.10 - Range and average ash content on a moisture free basis for coal and shale samples from the Cherokee basin (see Figure 5.02 for sample locations and type). Samples are compared against the average ash content of coals along the outcrop belt ( ). Higher ash contents reflect a closer relationship with fluvial or marine processes. Number of samples indicated in parentheses.

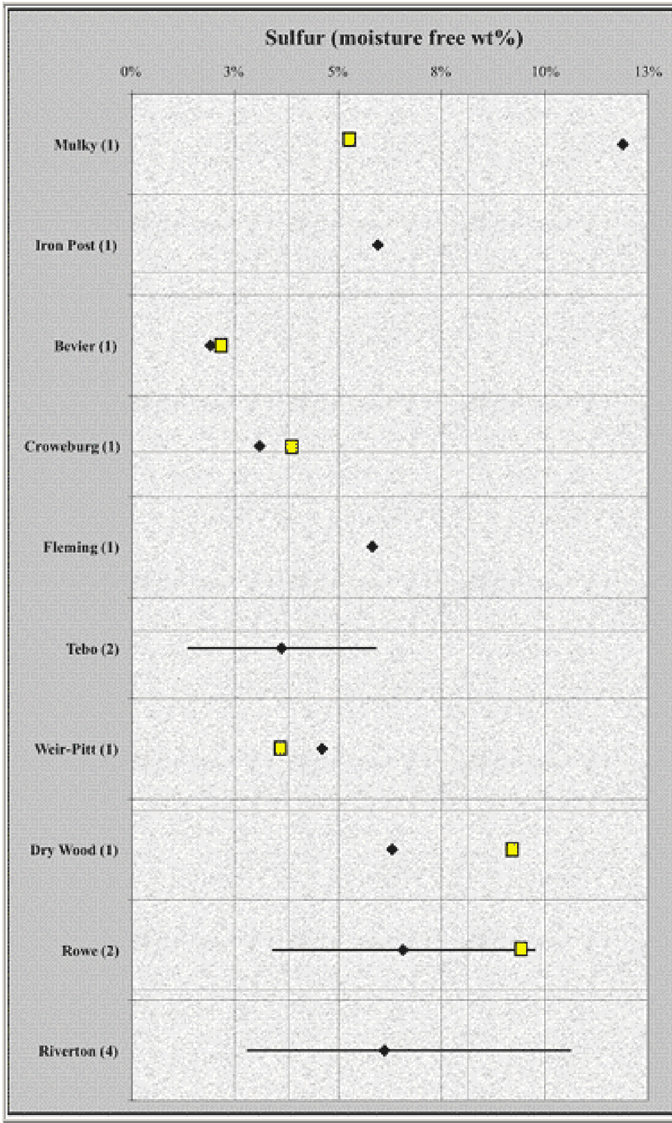


Figure 3.11 - Range and average sulfur content on a moisture free basis for coal and shale samples from the Cherokee basin (see Figure 5.02 for sample locations and type). Samples are compared against the average ash content of coals along the outcrop belt (□). Higher sulfur contents reflect a closer relationship with marine processes. Number of samples indicated in parentheses.

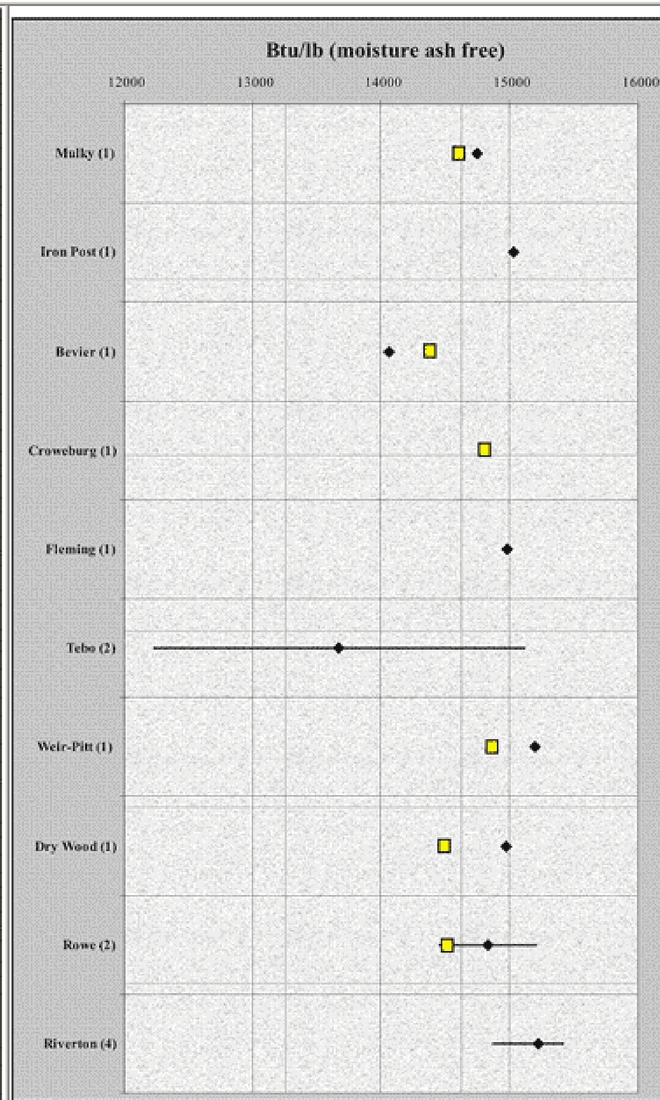


Figure 3.12 - Range and average calorific value (Btu/lb) on a moist, ash free basis. Most Cherokee Group coal have calorific values greater than 14,000 Btu/lb and would be classified as high-volatile A. Samples are compared against the average calorific values of coals along the outcrop belt (□). Number of samples indicated in parentheses.

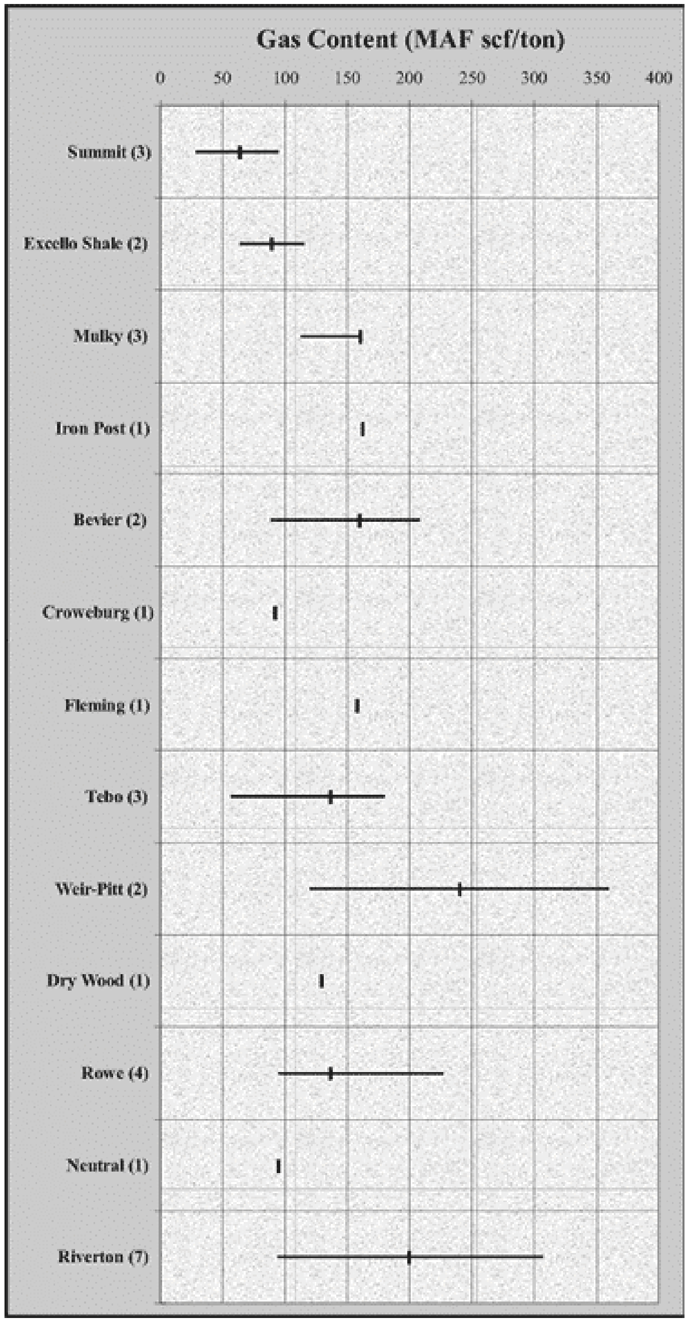


Figure 3.13 - Range and average gas content on a moisture ash free basis for coal and shale samples from the Cherokee basin (see Figure 3.02 for locations and type). Number of samples indicated in parentheses.

3.5 Discussion

Based on averaged desorbed gas content data from ten wells, estimates of original gas in place (OGIP) can be made for a portion of the Cherokee basin. Since the outcrop belt of the Cherokee Group follows a northeast trend throughout Cherokee and Crawford counties, all volumetric calculations include only coal contained within Chautauqua, Elk, Montgomery, Labette, Wilson, and Neosho counties. An estimate of coal mass for each individual coal must first be determined by using equation 1:

$$C_m = C_{A\text{-}F} * T/A\text{-}F \qquad (1)$$

where C_m is coal mass (short tons); $C_{A\text{-}F}$ is the volume of coal (acre-feet); and T/A-F is tons per acre-foot. In this study a value of 1800 tons per acre-foot for coal, and 2850 tons per acre-foot for shale was applied in the equation. Total coal mass (C_m) for an individual coal is estimated by determining the amount of acre-feet for coal greater than 1.5 feet (0.46 m). Estimates of OGIP are derived using equation 2:

$$OGIP = G_c * C_m \qquad (2)$$

where OGIP is original gas in place (scf); G_c is the average gas content (scf/ton), on an as received basis; and C_m (short tons) is the total coal mass. Using the above equation, volumetrics for twelve coals and two black shales found within the Fort Scott Limestone and Cherokee Group were determined (Table 3.1).

Unit	avg. scf/ton	acre-feet	Tons (short)	OGIP (bcf)
Little Osage Shale	6.4	13,097,227	37,327,097,378	239
Summit coal	22	875,520	1,575,935,694	35
Excello Shale	24	12,080,067	34,428,192,005	826
Mulky coal	156	511,071	919,928,556	144
Iron Post coal	113	1,195,535	2,151,963,324	243
Bevier coal	115	3,137,264	5,647,075,056	649
Croweburg coal	85	1,271,683	2,289,029,292	195
Fleming coal	70	878,086	1,580,553,918	111
Mineral coal	123	2,238,127	4,028,628,492	496
Scammon coal	42	1,087,171	1,956,907,044	82
Tebo coal	70	800,868	1,441,561,644	101
Weir-Pittsburg coal	190	3,028,844	5,451,919,740	1,036
Aw coal	116	3,832,218	6,897,992,742	800
Riverton coal	214	4,295,402	7,731,723,078	1,655
			Total OGIP	**6,612**

Table 3.1 – Volumetric calculations for the Fort Scott Limestone shales and Cherokee Group coals (avg. scf/ton is reported on an as received basis).

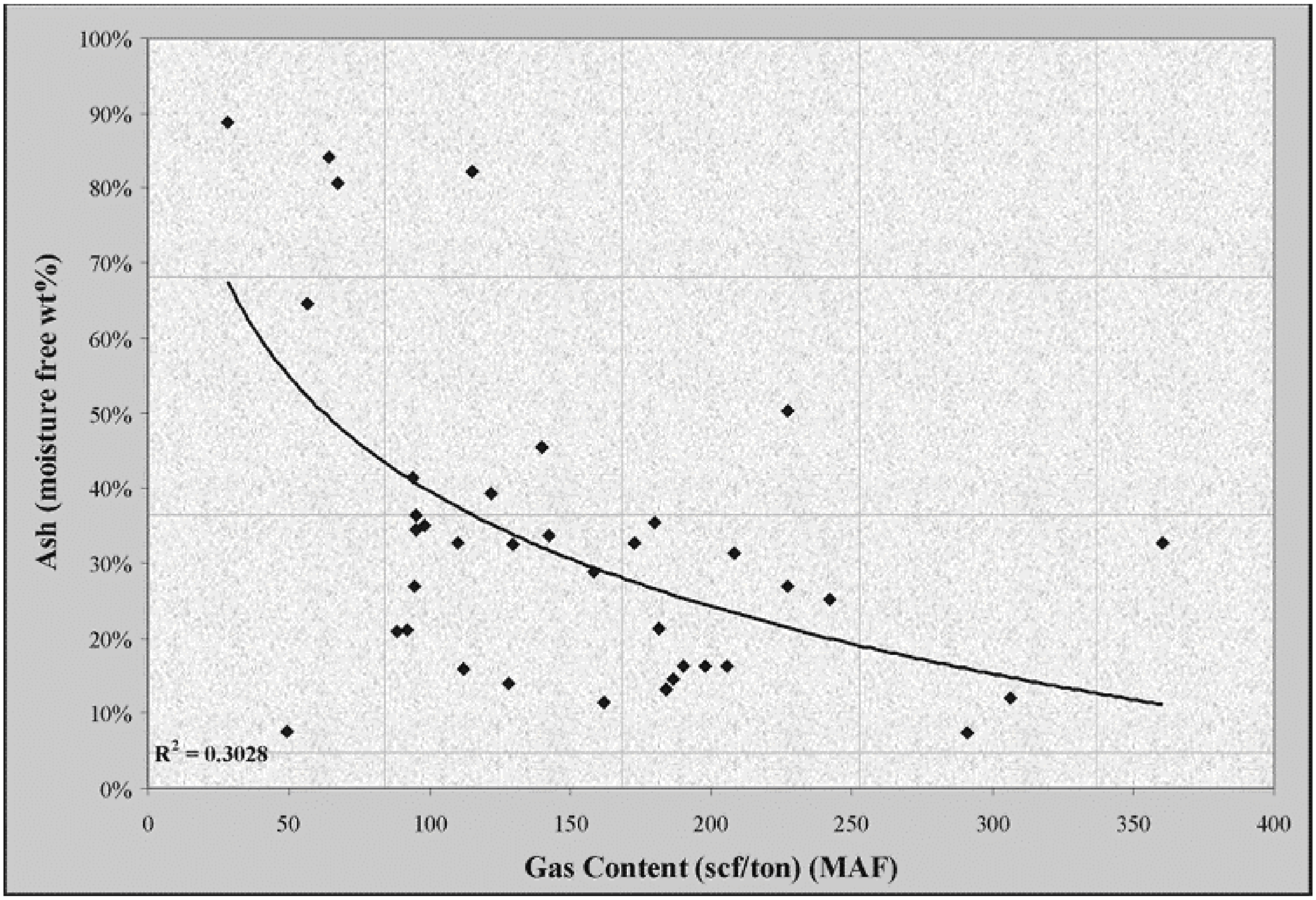


Figure 3.14 - Gas content conducted on an moisture ash free basis (MAF), plotted as a function of moisture free ash content. Plot shows a general relationship of increasing gas content (MAF) with decreasing ash content (MF).

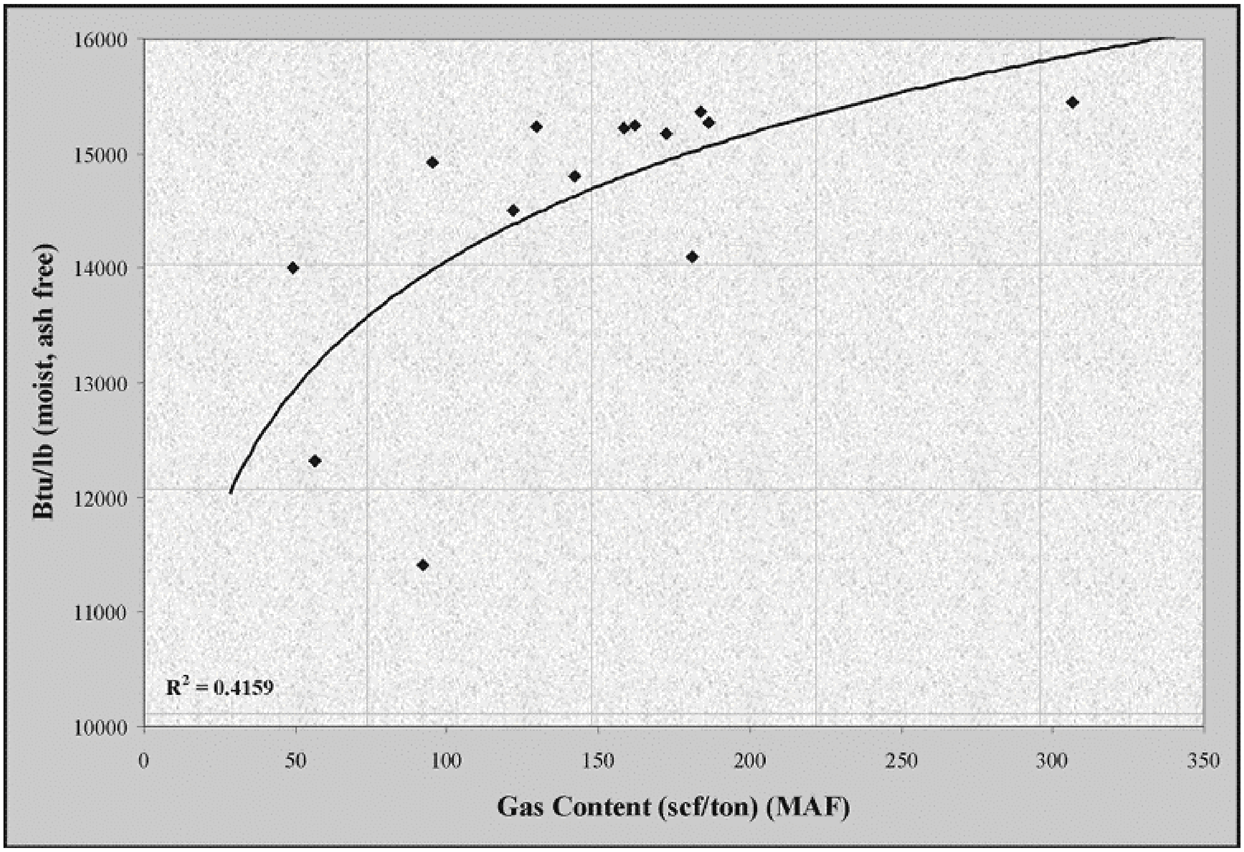


Figure 3.15 - Gas content conducted on an moist, ash free basis, plotted as a function of Btu/lb (moisture as free). Plot shows a general relationship of increasing gas content (MAF) with increasing Btu/lb (MAF).

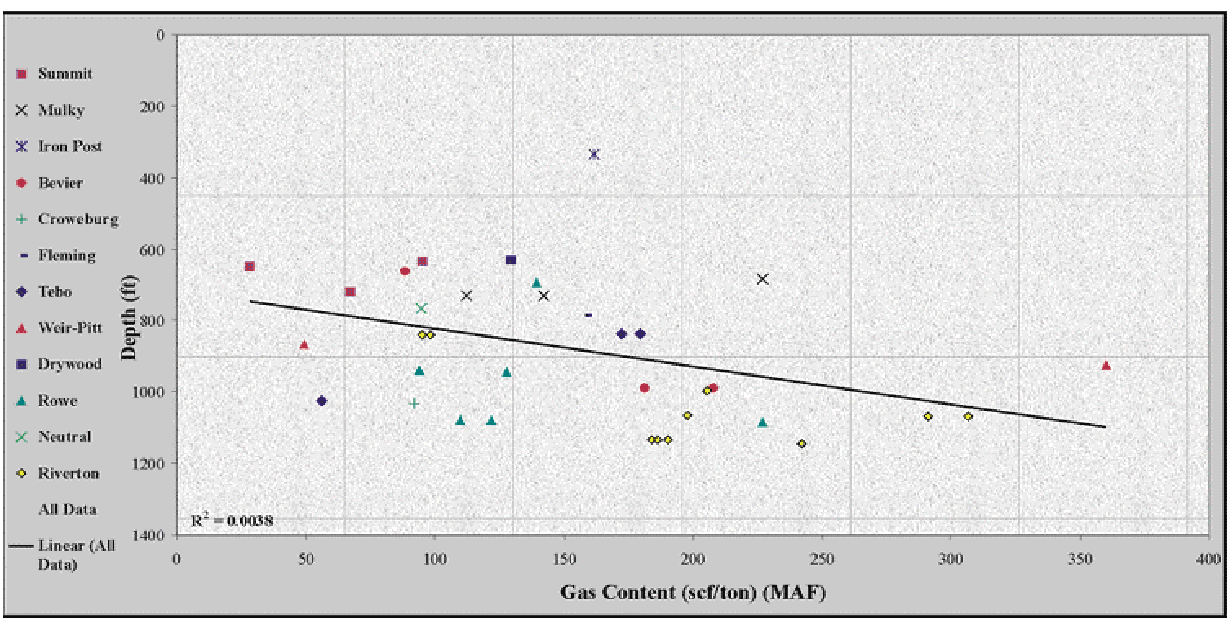


Figure 3.16 - Gas content conducted on a moisture ash free basis, plotted as a function of depth for coal samples from the Cherokee basin (see Figure 3.02 for sample location and type). Plot shows a relationship of increasing gas content with depth.

Values for total gas in place for individual coals range from 35 to 1,655 billion cubic feet (bcf). Exploration cutoffs for individual coal seams based on gas content (MAF) versus depth can be made using Figure 3.16. For example, when considering the Riverton coal as an exploration target, gas saturations less than 100 scf/ton (MAF) are found at depths shallower than 800 feet (244 m). If coal is thin (less than 1.5 ft; 0.5 m) it may have insufficient gas content to be a viable exploration target. Figure 3.17 indicates the ranges in gas in place for each coal over an area of one square mile (one section), assuming a constant thickness. Combined coal gas resource estimates for Chautauqua, Elk, Montgomery, Labette, Wilson, and Neosho counties area are more than 6,600 bcf. Several moderately gas-saturated coals such as the Neutral, Rowe and Dry Wood and miscellaneous informally known coals are not included in the above estimate.

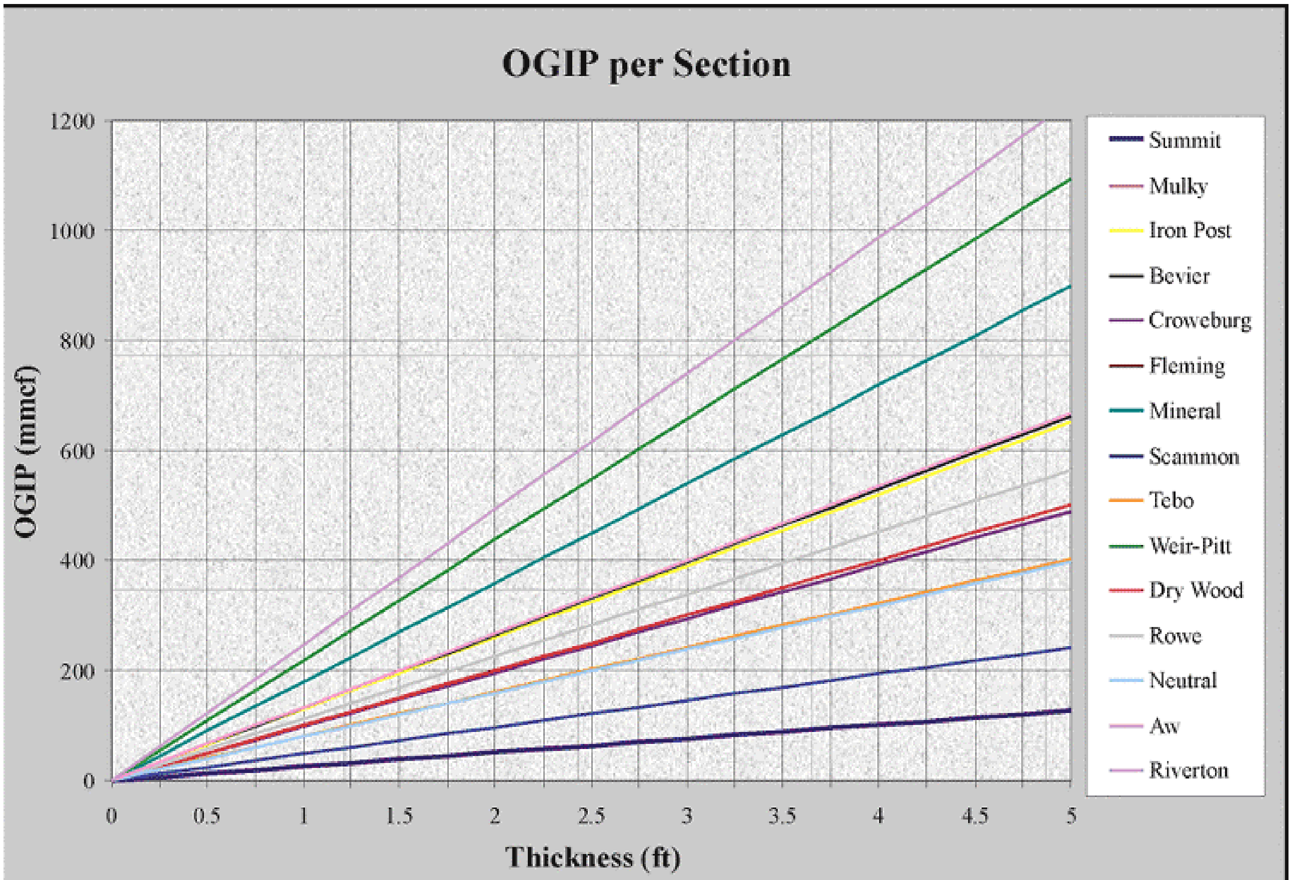


Figure 3.17 - Range of gas in place for each coal per section (one square mile) assuming a constant thickness.

Chapter 4: Sequence Stratigraphy of the Cherokee Group

4.1 Sequence Stratigraphic Nomenclature

Sequence stratigraphic concepts provide a framework to better explain and predict the lateral distribution, relative thickness and ash content of coal beds in the Cherokee Group. Although a complete review of sequence stratigraphy concepts and nomenclature are beyond the scope of this study, a brief summary of basic concepts and terminology is provided.

Sequence stratigraphy is the study of genetically related facies within a framework of chronostratigraphically significant surfaces, where the depositional sequence is considered to be the fundamental unit for sequence-stratigraphic analysis (Van Wagoner et al., 1990). The depositional sequence is defined as a genetically related succession of strata bounded by unconformable surfaces and their correlative conformities (Mitchum et al., 1977). An alternative method to divide the rock record would be the genetic sequence, defined as strata bounded by surfaces that reflect the depositional hiatus occurring during maximum marine flooding (Galloway, 1989). This study applies the Mitchum et al. (1977) and Van Wagoner et al. (1990) approach to the definition of depositional sequences in the Cherokee Group of southeastern Kansas. It is much easier to map intervals of the Cherokee Group separated by “core” shales, which can be interpreted as flooding surfaces. Some of these flooding surfaces are also interpreted as maximum flooding surfaces (sensu Galloway, 1989).

4.1.1 Identification of Parasequences

Parasequences are the stratal building blocks of sequences. The parasequence is a relatively conformable succession of genetically related beds or bedsets bounded by marine-flooding surfaces (FS) or their correlative surfaces (Van Wagoner et al., 1990). A marine flooding surface (parasequence boundary) has a correlative surface in the coastal plain as well as on the shelf. The correlative surface on the coastal plain may be marked by local erosion or evidence of subaerial exposure such as soil or root horizons, whereas the correlative surface on the shelf is marked by thin pelagic of hemipelagic deposits (Van Wagoner et al., 1990). In this study, well-log cross-sections of the Cherokee Group aided in determining flooding surfaces, as well as helping to define the transition of coals or paleosols into deeper marine rocks. Well log data are abundant throughout the study area with over 930 wells incorporated in the study. However, core control is very limited, and was not sufficient to correlate individual beds, so parasequences and parasequence sets were not correlated.

4.2 Identification of Sequences and Systems Tracts

Sequences are separated by sequence boundaries, which form in response to falls in base level (Van Wagoner et al., 1990). Sequence boundaries are laterally continuous, correlatable over at least the basin scale, and appear within the limits of chronostratigraphic resolution to be synchronous in many basins around the world (Vail et al., 1977). One or more of the following must be established over at least a basin scale to define a sequence boundary:

1. subaerial-erosional truncation and laterally equivalent subaerial exposure surfaces and down-dip submarine-erosion;
2. coastal onlap;
3. downward shift in coastal onlap (Van Wagoner et al., 1990).

In this study, the base of incised valleys and laterally equivalent subaerial erosion on interfluves are interpreted as sequence boundaries.
Within the study area, seven sequences were defined within the Cherokee Group (Figures 4.01, 4.02 in packet, 4.03). Utilization of closed loop well-log cross sections aided in determining incised valley geometries. Core analysis tied to the well log response provided criteria to recognize laterally equivalent well developed soil or root horizons (paleosols) interpreted as interfluves (Figures 4.04-4.10). The widespread features of erosion and subaerial exposure recognized and mapped in the Cherokee Group are interpreted as sequence boundaries.

4.2.2 Incised Valleys

An incised valley is a low, elongated, paleotopographic feature that formed as result of a fall in sea level and the erosion of an exposed shelf by fluvial processes (Van Wagoner et al., 1988). Incised valleys are generally characterized by the following;

1. incised valleys commonly are aligned and tend to increase in dimension down-valley;
2. the walls and the bases of the incised valleys are bound by sequence boundaries that may be correlated to subaerially erosional surfaces (paleosol, interfluve);
3. incised valleys are larger and deeper (with a width/thickness ratio of 1/1000) than individual channels (with a width/thickness ratio of 1/100) and have valley-like features;
4. incised valley incisions take the form of terraces;
5. within an incised valley, basinward shifts in facies are present across a sequence boundary;
6. the fill of an incised valley records a trend of increasing accommodation space (sea level rise) and an onlap relationship with the valley walls

(Van Wagoner et al., 1988; Zaitlin et al., 1994).
As the sea level rises, an incised valley is converted into a drowned river-mouth estuary and the valley fill begins to accumulate. The drowned valley receives sediment from two major sources: from the land via a river and from the sea via wave and tidal currents, longshore drifts, and storms. The balance between the rate of the relative rise in sea level and the volume of sediment input from both sides control the type and the geometry of the valley fill (Nichols and Biggs, 1985). Therefore, an incised valley can be filled completely or partially with fluvial sediments or with open marine sediment (Allen and Posamentier, 1993). However, estuarine deposits are the most common fill of drowned valleys (Allen and Posamentier, 1993).

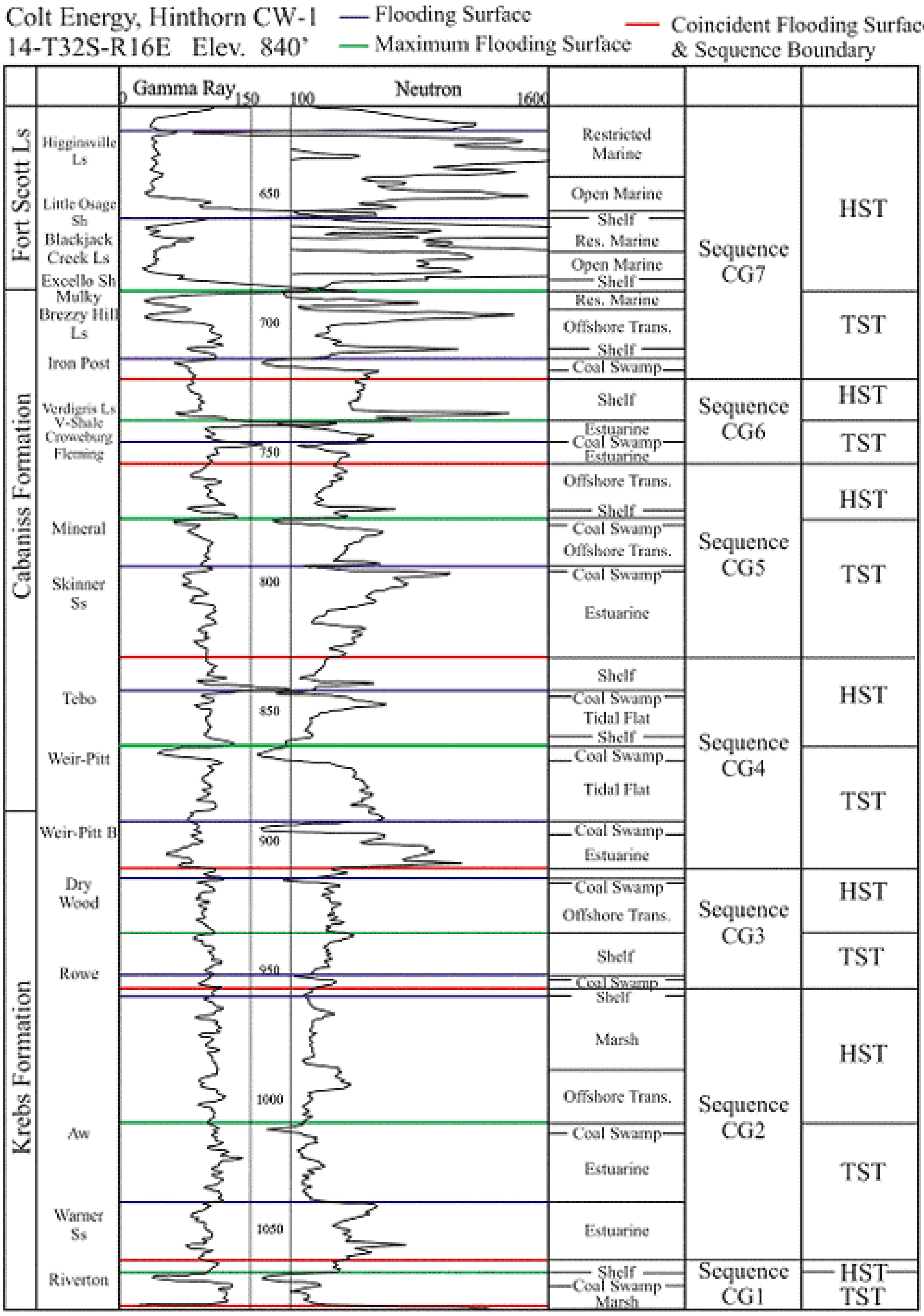


Figure 4.03 - Well log expression of sequence stratigraphy in the Colt CW-1, Montgomery County, Kansas

4.2.3 Estuaries

An estuarine setting can contain any number of the following environments: braided, meandering, tidal flat, back barrier island, tidal channel complex, bay-head delta, and shoreface environments. The degree of preservation and the dominance of both marine and fluvial facies within an estuary environment are mainly controlled by the rate of the rise in sea level, the intensity of wave and tidal currents, and fluvial discharges of sediment (Allen and Posamentier, 1993).

Estuarine environments are characterized by fluctuations in salinity, fluctuations in current energy, increasing accommodation space, and landward transgression of marine facies. Fluctuations in salinity (marine-brackish-fresh water) can be inferred from the following: (1) an increase of ichnofauna size, abundance and diversity seaward; (2) an alternation of pyrite, siderite and glauconite intervals; (3) a seaward increase in bioturbation; (4) the presence of coal and carbonaceous material; and (5) a seaward increase in bioclastic diversity and size (Zaitlin et al., 1994). Fluctuations in current energy can be inferred from a combination of the following: (1) an alternation between high-energy (unidirectional or bi-directional cross-bedding) and low-energy sedimentary structures (characterized by ripple marks and mud drapes); (2) interbedding of highly bioturbated and unbioturbated intervals; and (3) the presence of fining upward intervals (Zaitlin et al., 1994).
The interlaminated sandstone and siltstone facies and sideritic gray shale facies (described in Chapter 2) are interpreted as being part of estuarine incised valley fills. This conclusion is based on core observations in facies transitions, sedimentary structures, abundance and diversity of ichonofauna, and the identification of facies that appear to fill above incision surfaces, which exhibit elongate and linear trends. In this study, the interlaminated sandstone and siltstone facies is interpreted as channel fills of a bay-head delta (upper estuarine) and the overlying sideritic gray shale facies is interpreted as being formed in a central basin (inner estuarine) of an estuary.

4.2.4 Systems Tracts

Sequences can be subdivided into systems tracts based on types of bounding surfaces, position within a sequence, parasequences set-stacking patterns, geometry, and facies associations (Van Wagoner et al, 1988). In this study, lowstand (LST), transgressive (TST) and highstand systems tract (HST) are used to partition sequences. The lowstand systems tract forms during a significant sea-level fall that results in extensive subaerial exposure and/or widespread fluvial incision (thick paleosol and/or incised valley respectively). Lowstand systems tracts are bounded by a sequence boundary and by the first major marine flooding surface (FS). Since fluvial deposits were not observed at the base of incised valleys within the Cherokee Group, a lowstand systems tract was not identified in any of the sequences of this study. Fluvial deposits however, have been interpreted further north and up depositional dip from the Cherokee basin in the Cherokee Group (Cole, 1969; Visher et al., 1971). Transgressive systems tracts are bounded at the base by the first major marine flooding surface, and at the top by the maximum flooding surface (MFS). Maximum flooding surfaces are indicative of regional development of a condensed section consisting of hemipelagic or pelagic sediments (Posamentier and Allen, 1999). In this study, maximum flooding surfaces are picked on the highest gamma-ray values within a sequence (API). The highest gamma-ray values provide for a consistent marker, and appear to be linked to condensed section development during maximum flooding. The phosphatic black shale facies (“core shale”) described from the Cherokee Group are considered to be at or near a maximum flooding surface (Walton, 1995). The highstand systems tract is bounded at the base by the maximum flooding surface and at the top by the overlying sequence boundary (Van Wagoner et al., 1990).

4.2.5 Sequence CG1

Sequence Cherokee Group 1 (CG1) is distributed over the entire study area and contains the Riverton shale and coal, along with many thin underlying local coals (Figures 4.01, 4.02). A surface of subaerial exposure on the top of the Mississippian Warsaw Limestone (Meremecian) is the basal boundary of sequence CG1 (Figures 4.03 and 4.04). The top Mississippian limestones exhibit extensive paleokarst features, which are unconformably overlain by Middle Pennsylvanian siliciclastics (Watney et al., 2001). A marine flooding surface is coincident with the basal sequence boundary, where marginal marine shales and coastal marshes overlie the top Mississippian limestones (Figure 4.04). The widespread presence of marginal marine deposits suggests that sequence CG1 begins in the transgressive systems tract, while the lowstand systems tract was not preserved in the sequence.

A regionally extensive, high gamma-ray black shale overlies the Riverton coal, informally known as the “Riverton shale,” marks the maximum flooding surface (MFS) and transition into the highstand systems tract (Figure 4.04). Progressing up through the transgressive systems tract, coals beds are thin and highly discontinuous until reaching the first thick and laterally continuous coal bed (i.e. Riverton coal; and 4.02). The highstand systems tract of CG1 is characterized by a few thin unnamed local coals, and offshore transitional environments (Figures 4.01 and 4.02). In CG1, only the Riverton coal is of sufficient thickness, continuity, and quality (high organic content, low ash, high Btu/lb) to be a target for coalbed gas development in southeast Kansas.Figures 4.01.

Sequence Cherokee Group 1 and 2

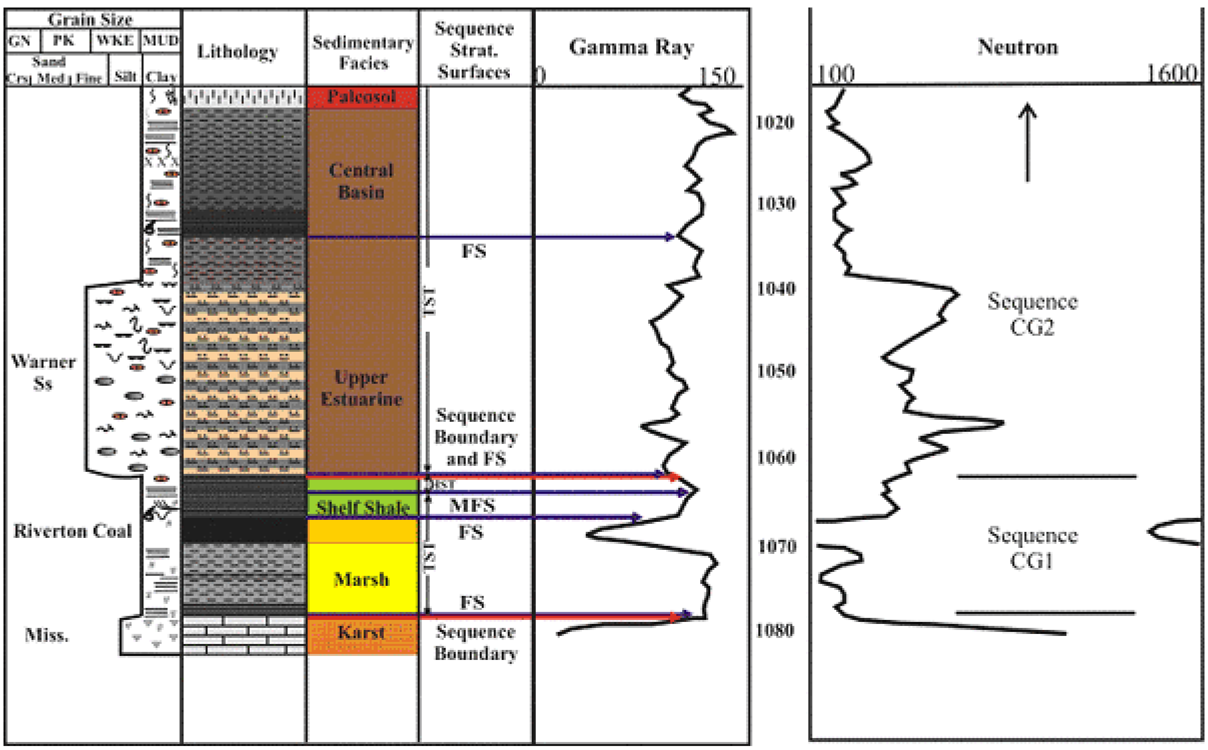


Figure 4.04 - Sequence stratigraphic log characteristics of Cherokee Group sequence 1 and 2, based on core and well log from the Hinthorn CW#1 well, 14-T32S-R16E, Montgomery County, Kansas (scale in feet). See Figure 2.15a for legend.

4.2.6 Sequence CG2

Sequence Cherokee Group 2 (CG2), is correlated over the entire study area and contains the informally known Aw, Bw, Cw, and Dw coals and the sporadically distributed Warner Sandstone (Figures 4.01, 4.02). A surface of erosion at the base of the Warner Sandstone is the basal boundary for sequence CG2 (Figures 4.03 and 4.04). Erosional indicators are based on cross-sections that illustrate incised valley geometries, and core observations of the transition from sequence CG1 offshore deposits (HST) to estuarine environments or a thick paleosol (Figure 4.01 and 4.02). The widespread presence of marginal marine deposits at the base of sequence CG2 suggests that the sequence begins in the transgressive systems tract, where a marine flooding surface is coincident with the basal boundary of the sequence.

The A-B shale marker just above the Aw coal is interpreted as being the maximum flooding surface (MFS) of sequence CG2 due to its higher gamma-ray value than other shales in the sequence (Figure 4.03). The transgressive systems tract is characterized by an estuarine incised valley fill, including the marginal marine environments of the Warner Sandstone, and thin, highly discontinuous coals beds such as the Cw and Dw (Figures 4.01 and 4.02). The thicker and laterally extensive Aw and Bw coals are part of the upper transgressive systems tract. The highstand systems tract consists of a shoaling-upward sequence manifested by shelf to coastal marsh environments. In this study there are no coal beds observed within the highstand systems tract of sequence CG2. Coals in sequence CG2 in southeast Kansas have not been significant targets for coalbed gas development due to lack of continuity. However, the Aw and Bw coals may have the potential for coal gas development due to relative thickness and higher gas saturations than other coals in sequence CG2.

4.2.7 Sequence CG3

Sequence Cherokee Group 3 (CG3), is distributed over the entire study area, and contains the Dry Wood coal, Rowe coal, Neutral coal, and upper Warner Sandstone (Figures 4.01, 4.02). Although the upper Warner Sandstone was not recognized in sampled cores, it is recognized in numerous well logs. The log response of the upper Warner Sandstone is similar to the log response of the lower Warner Sandstone (Figures 4.03 and 4.04). The base of an incised valley was identified by cross section geometry starting at the base of the upper Warner Sandstone, which is interpreted as the basal boundary for sequence CG2. A marine flooding surface is interpreted to be coincident with the basal boundary of Sequence CG3 due to marginal marine deposits observed in cores (Figure 4.03).
The maximum flooding surface (MFS), approximately 20 feet (6.1 m) above the Rowe coal, was picked on the highest gamma-ray values in sequence CG3 (Figure 4.03). Shelf deposits, and thin, regionally semi-continuous coals such as the Rowe and Neutral are part of the transgressive systems tract (Figures 4.01 and 4.02). Highstand systems tract deposits are characterized by a shoaling-upward sequence of offshore to marginal marine environments. A thin and laterally discontinuous coal (i.e., Dry Wood) is located within the highstand systems tract of sequence CG3. The discontinuous nature of the Dry Wood coal is partially the result of erosion by deep incision of the overlying sequence. The Rowe coal is a major target for coalbed gas development to the south in Oklahoma. Although the Rowe is not as well developed or continuous in the Cherokee basin, it is starting to become a more significant coalbed gas target in southeast Kansas due to relatively high gas contents (Jim Stegeman, Colt Energy, personal communication, 2003).

4.2.8 Sequence CG4

Sequence Cherokee Group 4 (CG4), is distributed over the entire study area and contains the Tebo coal, Weir-Pittsburg coal, Weir-Pittsburg B coal, informally known Tebo B, Abj, Bbj, Cbj, and Dbj coals, along with the Bluejacket Sandstone or informally known Bartlesville sandstone (Figures 4.01, 4.02). Incised valley geometries identified in cross-section are interpreted as the basal boundary for sequence CG4 (Figure 4.05). In addition, cores show an upward transition from offshore deposits of the HST of sequence CG3 to estuarine environments, and an erosional surface or a thick paleosol at the base of CG4 (Figure 4.05). The presence of marginal marine deposits at the base of the sequence indicates that a flooding surface is coincident with the basal boundary of sequence CG4 (Figure 4.03).

Immediately above the Weir-Pittsburg coal, a regionally extensive black “core shale” (informally known as the Weir-Pittsburg shale) marks the maximum flooding surface (MFS) and transition into the highstand systems tract (Figure 4.05). Progressing up through the transgressive systems tract, environments range from marginal marine estuarine incised valley fill to muddy tidal flats. Coals beds, such as the Abj, Bbj, Cbj, and Dbj, are thin and highly discontinuous until the appearance of the Weir-Pittsburg coal. The Weir-Pittsburg coal is just below the maximum flooding surface and is one of the thickest and laterally extensive coals in the Cherokee Group. The highstand systems tract consists of two shoaling-upward successions from shelf to marginal marine environments. Within this HST, the Tebo coal is thin but fairly continuous, and the underlying “Tebo B” coal occurs sporadically (Figure 4.06). In CG4, the Weir-Pittsburg coal is of sufficient thickness, continuity, and quality (high organic content, low ash, low sulfur, high Btu/lb) to be a primary target for coalbed gas development in southeast Kansas.

Sequence Cherokee Group 4

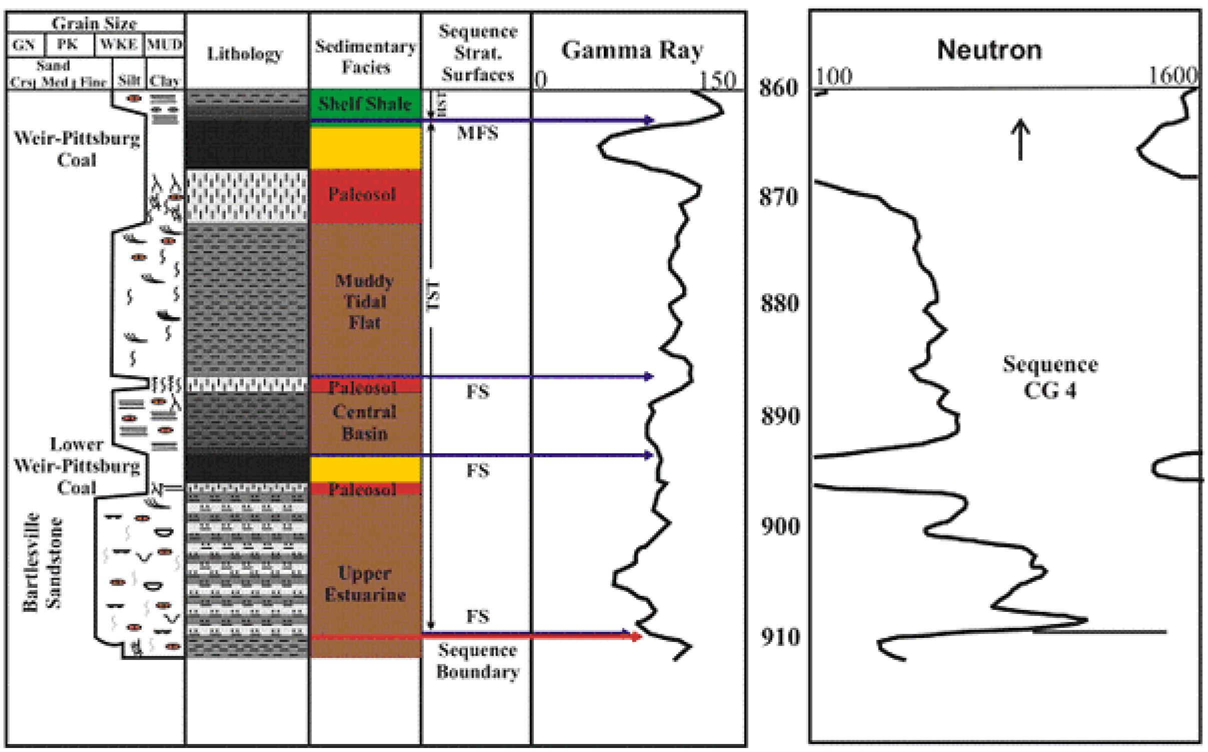


Figure 4.05 - Sequence stratigraphic log characteristics of Cherokee Group sequence 4, based on core and well log from the Hinthorn CW#1 well, 14-T32S-R16E, Montgomery County, Kansas (scale in feet). See Figure 2.15a for legend.

4.2.9 Sequence CG5

Sequence Cherokee Group 5 (CG5), is distributed over the entire study area, and contains the Mineral, Scammon, and “Scammon B” coals along with the Chelsea Sandstone or informally known Skinner sandstone (Figures 4.01, 4.02). A basinward shift in facies at the base of the Chelsea or Skinner observed in cores is interpreted as the basal boundary for sequence CG5 (Figure 4.03 and 4.07). Lithofacies transitions and erosional surfaces are observed in cores throughout the study area that are indicated by the shift from HST offshore deposits in CG4 to estuarine environments or a thick paleosol at the base of sequence CG5 (Figure 4.07). Additionally, incised valley geometries are identified in cross-section (Figure 4.01). Marginal marine deposits observed in cores at the base of sequence CG5 suggest that a marine flooding surface is coincident with the basal boundary of the sequence.

A regionally extensive phosphatic black shale above the Mineral coal, informally known as the Mineral shale has the highest gamma-ray values within the sequence, which marks the maximum flooding surface and transition into the highstand systems tract (Figure 4.08). Moving up through the transgressive systems tract, environments range from shelf to marginal marine with estuarine incised valley fill. Coals beds in the lower TST of CG 5, such as the “Scammon B” and Scammon, are thin and highly discontinuous (Figures 4.01, 4.02 and 4.07). The Mineral coal is relatively thicker than other CG5 coals and is laterally continuous across the study area (Figure 4.01 and 4.02). The highstand systems tract consists of shelf to offshore transition deposits with no identified coals. In CG5, only the Mineral coal is of sufficient thickness, continuity, and quality (high organic content, low ash, low sulfur, high Btu/lb) to be a target for coalbed gas development in southeastern Kansas.

Sequence Cherokee Group 4

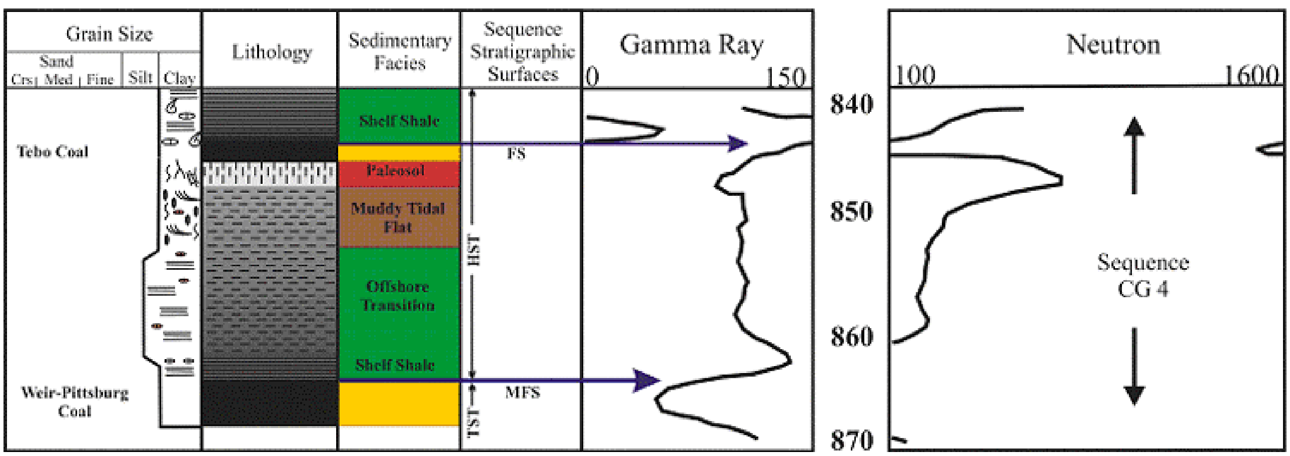


Figure 4.06 - Sequence stratigraphic log characteristics of Cherokee Group 4, based on core and well log from the Hinthorn CW#1 well, 14-T32S-R16E, Montgomery County, Kansas (scale in feet). See Figure 2.15a for legend.

Sequence Cherokee Group 4 and 5

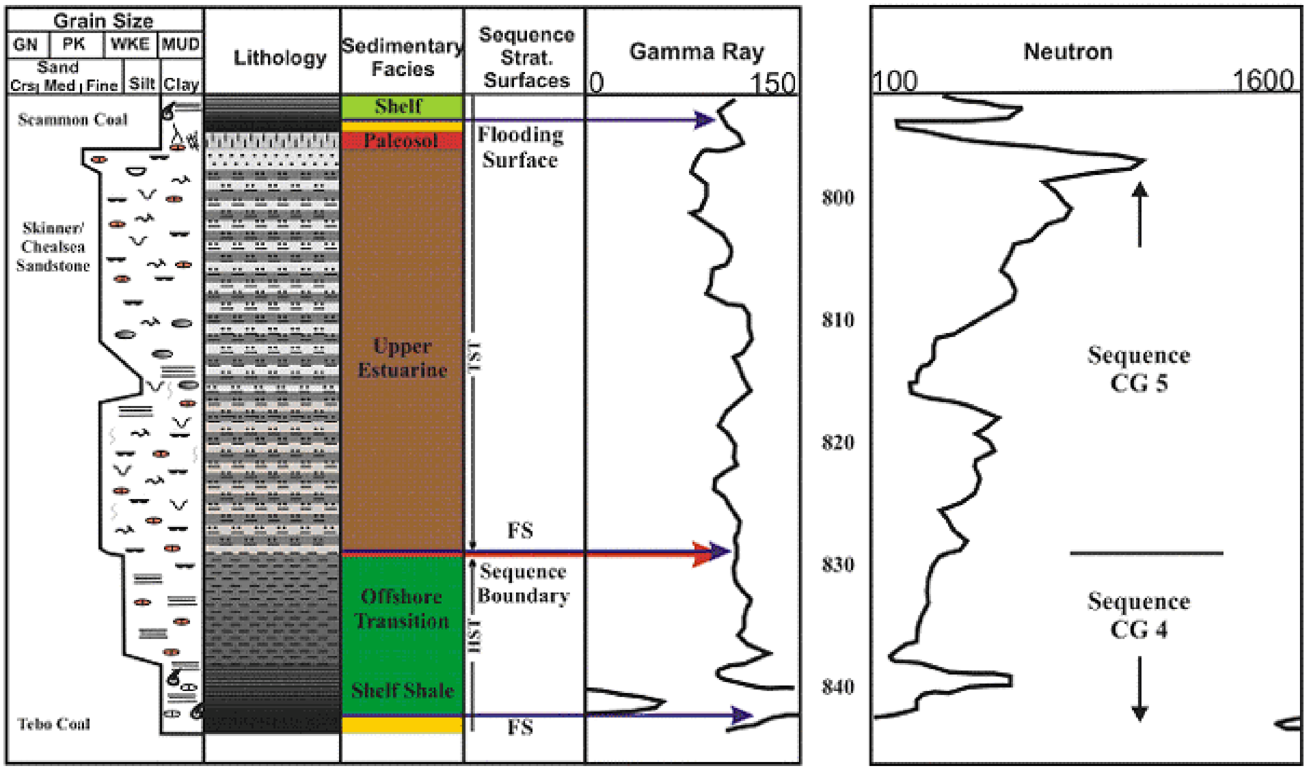


Figure 4.07 - Sequence stratigraphic log characteristics of Cherokee Group 4 and 5, based on core and well log from the Hinthorn CW#1 well, 14-T32S-R16E, Montgomery County, Kansas (scale in feet). See Figure 2.15a for legend.

4.2.10 Sequence CG6

Sequence Cherokee Group 6 (CG6), is distributed over the entire study area and consists of the Bevier coal, Verdigris Limestone, V-shale, Croweburg coal, and Fleming coal (Figures 4.01, 4.02). A surface of subaerial exposure at the base of the Fleming coal or erosion at the base of an unnamed underlying sandstone observed in cores, is interpreted as the basal boundary for sequence CG6 (Figures 4.03 and 4.08). A basinward shift in facies is observed in cores as the transition from offshore deposits in the HST of CG5 to estuarine environments or a thick paleosol in CG6 (Figure 4.08). Additionally, incised valley geometries are identified in cross-section (Figure 4.01). Marginal marine deposits observed at the base of sequence CG6 suggests that a marine flooding surface is coincident with the basal boundary of the sequence.

The lateral extent and high gamma-ray value of the V-Shale indicates a maximum flooding surface (MFS), and transition into the highstand systems tract of sequence CG6. Environments ranging from shelf to estuarine characterize the transgressive systems tract. Coals beds within the lower transgressive systems tract such as the Fleming are thin and highly discontinuous. The laterally extensive Croweburg coal is present at the top of the TST, and near the maximum flooding surface (Figures 4.01, 4.04 and 4.08). Although the Croweburg coal is relatively thinner than most other coals, it is one of the most extensive Pennsylvanian coals as it is correlatable across the mid-continent (Wanless, 1969). The highstand systems tract consists of shelf to offshore transition deposits and the Bevier coal (Figure 4.09). With sufficient thickness, continuity, quality (high organic content, low ash, low sulfur, high Btu/lb), and relatively high gas content, the Bevier coal in sequence CG6 is a secondary target for coalbed gas development in northern portion of the Cherokee basin.

Sequence Cherokee Group 5 and 6

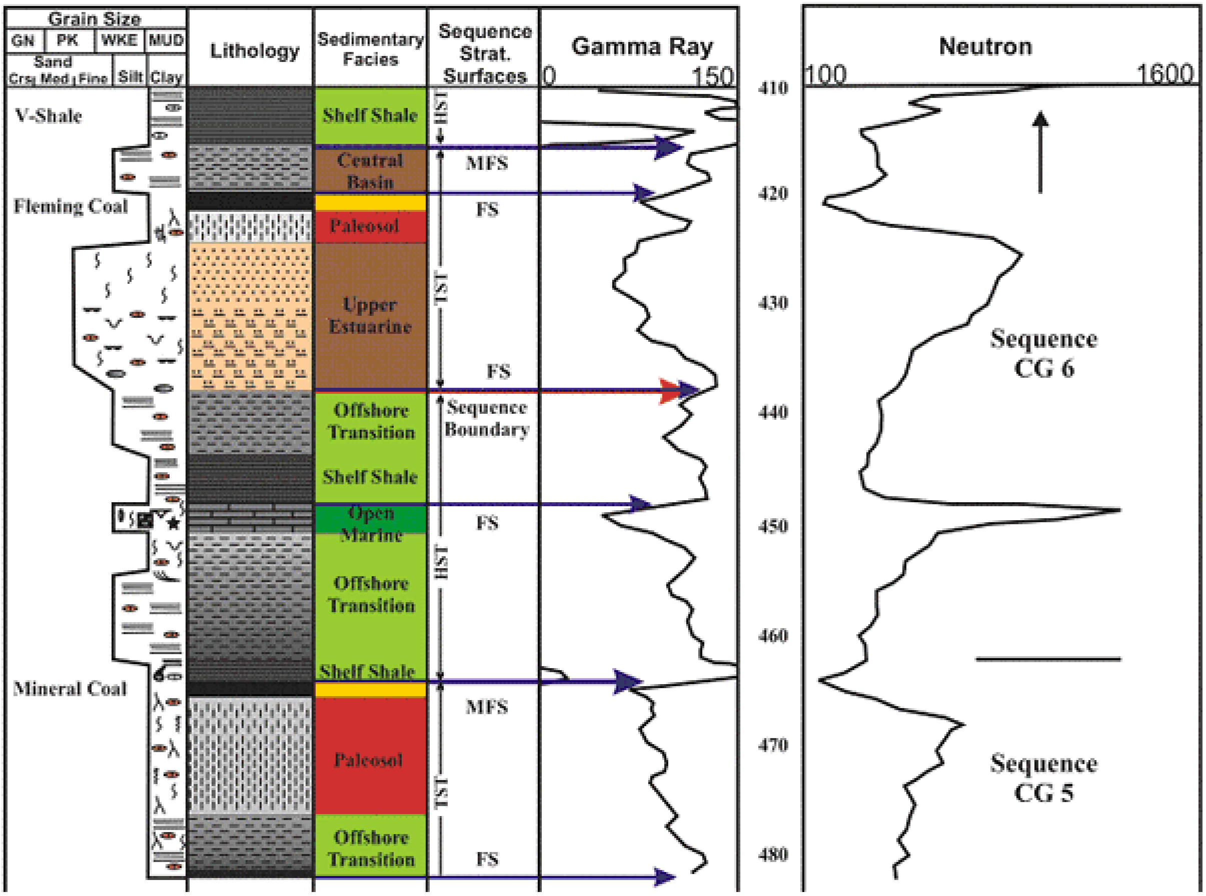


Figure 4.09 - Sequence stratigraphic log characteristics of Cherokee Group 5 and 6, based on core and well log from the Cooper CW#1 well, 11-T35S-R18E, Labette County, Kansas (scale in feet). See Figure 2.15a for legend.

4.2.11 Sequence CG7

Sequence Cherokee Group 7 (CG7), is distributed over the entire study area and contains the Fort Scott Limestone, Mulky coal, Iron Post coal, and Squirrel sandstone (Figures 4.01, 4.02). A surface of erosion at the base of the Squirrel sandstone observed in cores is interpreted as the basal boundary for sequence CG7 (Figure 4.10). A transition from shelf deposits in the HST of CG6 to estuarine and tidal environments or a thick paleosol in sequence CG7 observed in cores provide evidence for a basinward shift in facies (Figures 4.03 and 4.10). The presence of marginal marine deposits at the base of sequence CG7 suggests that a marine flooding surface is coincident with the basal boundary of sequence.

The regionally extensive, high gamma-ray, phosphatic black shale named the Excello Shale marks the maximum flooding surface and transition into the highstand systems tract (Figure 4.10). Moving up through the transgressive systems tract, environments range from shelf to restricted marine (Figure 4.10). Coal beds contained within the transgressive systems tract, such as the Iron Post and Mulky, are relatively thin and discontinuous (Figures 4.01 and 4.02). The highstand systems tract consists of two shoaling-upward cycles from shelf to open marine and restricted marine carbonates separated by a phosphatic black shale (Little Osage Shale) that is interpreted as a flooding surface (FS). With the combination of a highly gas-saturated thin coal (Mulky), and a moderately gas-saturated black shale (Excello), this sequence is a major economic coal and shale gas target.

Sequence Cherokee Group 7

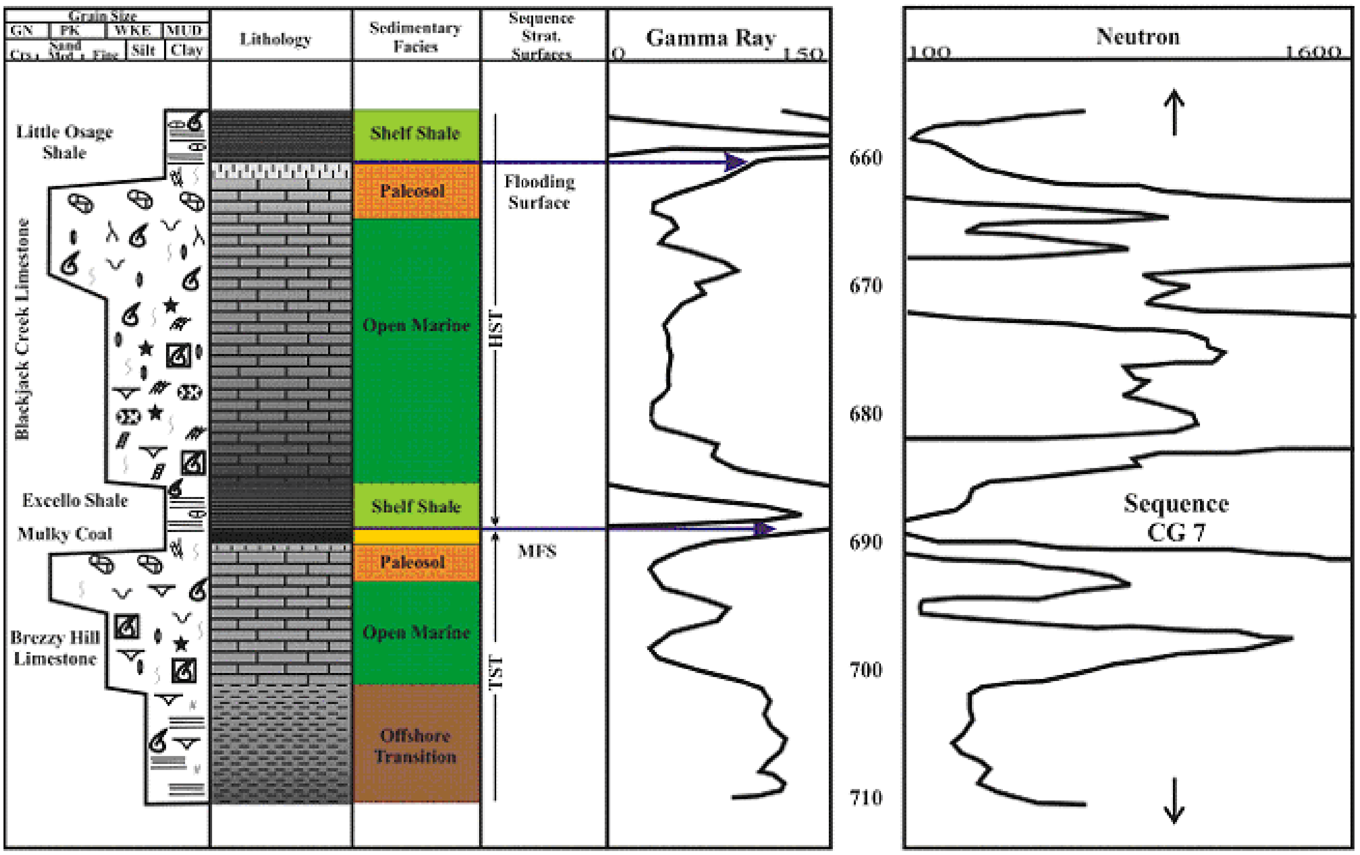


Figure 4.10 - Sequence stratigraphic log characteristics of Cherokee Group 7, based on core and well log from the Hinthorn CW#1 well, 14-T32S-R16E, Montgomery County, Kansas (scale in feet). See Figure 2.15a for legend.

4.3 Discussion

Sequences of the Cherokee Group record abrupt changes from marine to non-marine conditions, followed by periods of rapid relative seal-level rise. Each successive sequence begins with a relative drop in sea level resulting in incision into the lower sequence. Following each incision, relative sea level rises, filling paleovalleys with estuarine deposits as part of the transgressive systems tract. During the early transgressive systems tract interfluves remain subaerially exposed. Since fluvial deposits filling incised valleys were not observed, a lowstand systems tract was not identified in any of the sequences. Within the estuarine deposits of the upper portions of paleovalleys, rooting and development of thin and laterally discontinuous coal were observed.

The preservation and continued growth of peat is dependent on a rising water table and high accommodation achieved by a relative base level rise (McCabe and Shanely, 1992). The movement of destructive fluvial processes landward enhances preservation of peat during the late transgressive systems tract, while peat accumulation attempts to keep up with an accelerating relative rise in sea level (Aitken, 1994). During the late transgressive periods of the Cherokee Group sequences, sea

level rise resulted in flooding of interfluves, increased accommodation, and a rise in water tables. Widespread coastal successions capped by progressively thicker and more regionally extensive coals were developed (i.e. Riverton, Weir-Pittsburg, and Mineral coals). In addition to being thicker and more laterally continuous, late transgressive systems tract coals are of higher quality (i.e., lower ash, and higher gas content). The end of each Cherokee Group transgressive systems tract is characterized by regionally extensive phosphatic black shales interpreted as the maximum flooding surface. This shale also commonly overlies the thickest and most extensive coal of a sequence.
The close association with marine shales and coals resulted in relatively higher sulfur content of Cherokee Group coal. Coal gas content may also be augmented by gas generated from the shales and migrating into the immediately underlying high porosity coals. Following each major transgression, the highstand systems tract is reflected by relatively rapid progradation of offshore transitional environments over marine environments followed by progradation of marginal marine and then non-marine environments.

The most extensive, thickest, and highest quality coals (i.e. low ash) within each Cherokee Group sequence are interpreted to occur at the end of the deposition of the transgressive systems tract near the maximum flooding surface (i.e. Riverton, Weir-Pittsburg, and Mineral coals). Generally, coals tend to thicken and become more laterally extensive up through the transgressive systems tract and thin upward through the highstand systems tract (Aitken, 1994). However, Cherokee Group coals are not restricted to the upper part of the transgressive systems tract and can occur in any systems tract. Coals that form during the LST, HST or lower TST are typically thinner, laterally discontinuous and have higher ash contents.

4.4 Mechanisms for Sequence Development

The highest resolution of changes in relative sea level is on the order of about 240 Ka, although changes in relative sea level may have varied substantially during these periods (Walton, 1995). Mechanisms such as tectonics, and climatic changes are not resolvable on this time scale. The high frequency, and widespread nature of Middle Pennsylvanian sequences over eastern Kansas and into adjacent states suggests an allogenic mechanism such as glacio-eustacy. Previous studies established that the upper Paleozoic was a time of large-scale continental glaciation resulting in glacio-eustasy (Heckel, 1977).

The Cherokee Group sequences are interpreted as the product of high-frequency progradational pulses of sedimentation during a major relative sea level rise throughout the Desmoinesian. Perhaps the best explanation for controls on the observed sequence development in the Cherokee Group of southeastern Kansas is glacio-eustasy. Tectonic changes in elevation and subtle paleotopographic features may however, have locally influenced the nature and development of Cherokee Group sequences.

Chapter Five : Depositional Models

Depositional models are intended as teaching tools, mental concepts, and temporary fixed points in nature (Miall, 1999). The function and utility of a model aids in the distillation of many observations for ease of comparison, and serves as a framework and guide for future investigations (Walker, 1976). In the subsurface, models serve as predictive tools for reconstructing sparsely observed systems or for interpreting preliminary results.

5.1 Previous Models and Work

Previous studies of the development of Pennsylvanian coal beds in the mid-continent have shown that coal accumulation is influenced by several general environmental factors (eg. climate, sea level change, basin subsidence, sediment accumulation, and depositional environment). Depositional environment reflected in the type of mire in which peat developed is believed the most important control on distribution, thickness, and quality of coal (Wanless et al., 1969; McCabe and Shanley, 1992).

According to Wanless et al. (1969) distribution of Pennsylvanian coals are controlled by environmental patterns such as widespread deltas, unfilled channels, estuaries, coastal marshes, barred and non-barred coast lines, cut-off stream meanders, coastal plains exposed after regression, and pre-Pennsylvanian topographic irregularities. Flores (1993) suggested that when studying coals in the ancient, depositional orientation, average thickness, areal extent, and geometry of coal beds are reflective of the environment of deposition, and can be used as a predictive model. Conversely, McCabe and Shanley (1992) stressed equal or greater importance on the concept that the type of mire in which peat accumulated is reflected in the characteristics of coal beds. With the mire concept, low-ash coals are predicted to have formed from raised mires, while high ash coal formed in low-lying mires. Marine influenced mires will have higher sulfur contents while inland mires will tend to be protected from influence of marine water during coalification, and will have reduced sulfur contents (< 2.5 %).

Pennsylvanian coals are widely distributed throughout the mid-continent, and have been correlated for hundreds of miles (Wanless et al., 1969). Transition into or out of coal from other lithologies is relatively sharp. The abruptness in which coal accumulation is initiated and terminated has been attributed to climatic shifts, such as changes in humidity, precipitation and temperature (Wanless et al., 1969). During the Pennsylvanian, the mid-continent is believed to have been a vast level plain near sea level. This plain was subject to frequent extensive marine transgressions, when the sea covered most of the continental interior (Wanless, 1969). The occurrence of frequent marine transgressions likely played an important factor in development and demise of the numerous thin Cherokee Group coals.

Previous work also suggests that most Pennsylvanian coals accumulated in situ (Wanless, 1969). Support for this interpretation is from observed rooting into underlying rock such as underclay or seat earth, shale, sandstone or limestone (Staub and Cohen, 1970). The origin of underclay beneath many of the coals is a subject of debate, in relation to depositional or post depositional weathering, and classification as a soil (Wanless et al., 1969). In general, most Pennsylvanian underclays are accepted as, originally deposited outside the basin of peat accumulation, and as a soil under swampy conditions. The underclay is subsequently altered by leaching during peat accumulation, and not directly related to upland soil development (Wanless et al., 1969).

Many studies conducted in the last decade have been in relation to the understanding of coal deposits within a sequence stratigraphic framework due to the increased interest in the hydrocarbon potential of coals (Aitken, 1994; McCabe and Shanely, 1994; Boyd and Diessel, 1995; Bohacs and Suter, 1997; Diessel, 1998). A widely excepted view is that preservation of peat is dependent on near equal rates of increasing accommodation and peat production (McCabe and Shanely, 1994; Boyd and Diessel, 1995; Bohacs and Suter, 1997). Additionally, for mires, peat will not continue to accumulate with only an increase in accommodation and therefore an increasing water table is needed for sustained peat growth (Aitken, 1994; Bohacs and Suter, 1997). An increasing water table is strongly controlled by sea level rise and the precipitation/evaporation ratio (Aitken, 1994; Bohacs and Suter, 1997).

With an understanding of the delicate balance between peat production, accommodation and sea-level rise, coal seams can be predicted within a sequence stratigraphic framework. Base-level falls, typically occurring during early lowstand and late highstand systems tracts, lead to a loss in accommodation, incision, and valley formation, causing low peat preservation (Boyd and Diessel, 1995; Bohacs and Suter, 1997). When accommodation rates are significantly above peat production rates, mires will become stressed and inundated by clastics or stagnate water, due to base level rises typical of the mid-transgressive systems tract (Bohacs and Suter, 1997). During periods of aggradation, typical of late transgressive and early highstand systems tracts, peat-producing mires may block marine transgressions and stabilize coastlines for longer periods of time, leading to higher preservation of peat (Diessel, 1998; McCabe and Shanely, 1992).

Diessel (1998) has also applied sequence stratigraphy to amalgamated coal seams in Australia, where the coal is interpreted as forming over multiple sequences. Basinward marine splits in the coal seams are interpreted to represent prograding stacking patterns, and a marine split above a ravinement surface and angular unconformity is thought to be a sequence boundary (Diessel, 1998). In the case of the Cherokee basin coals, none of the coals observed appear to be amalgamated.

5.2 Modern Analogs

Comparison of modern peat forming environments to the inferred depositional environments in the Cherokee Group of the Cherokee basin aids in understanding the depositional controls on peatland growth and development in the ancient. Several works on modern environments such as that of the Orinoco Delta of South America (Andel, 1967), a Malaysian tropical delta (Coleman et al., 1970), and the Snuggedy swamp (Staub and Cohen, 1979) are analogs that have resemblance to environments during the Middle Pennsylvanian throughout southeastern Kansas.
The Orinoco Delta is situated off the coast of northeastern South America in Venezuela, Colombia and Brazil, and appears analogous to many of the coastal plain settings of the Cherokee basin. The Orinoco delta has built the entire coastal plain during a rapid coastal accretion that resulted in a wide zone of swamps and marshes with local chenier plains that merge into extensive tidal mud flats (Andel, 1967). Due to the low gradient, streams are not considered as significant transporters of sediment, and the coastal plain is subject to tidal flooding. Marine processes such as long shore drift supply clastic sediments to the coastal plain. The outer delta is described as a featureless marsh plain traversed by many swamp streams, estuaries, and distributary channels (Andel, 1967). Lithologies are similar to that of those described for Cherokee Group coastal plains and consist of sandy clays, mud flats, silty clays and peaty clays.

The Snuggedy swamp of South Carolina is analogous to coals associated with coastal plains and estuaries of the Cherokee basin. Peat development in these settings is described as thick extensive deposits underlain by a kaolonite rich underclay within a back-barrier estuarine depositional environment (Staub and Cohen, 1979). Similar to many of the coals in the Cherokee Group, coals in the Snuggedy swamp are formed above coarsening upward sands and shales described as lagoonal deposits, and thick well developed underclay's interpreted as soils. Peatlands are also dissected by crevasse and fire splays. In the ancient, the presence of fusinite within a coal bed is interpreted as the product of fire (Staub and Cohen, 1979). The presence of fusinite ranging from 0 up to more than 3.5 percent has been noted in many of the Cherokee Group coals of eastern Kansas (Bensley et al., 1990). Many of these peat fires can result in localized thin coals replaced by clastic "fire splay" deposits.

Peat accumulation in the Snuggedy swamp is controlled by sea level rise, rate of sediment influx and or basin subsidence, related to an increase in accommodation (Staub and Cohen, 1979). The preservation of peat in the Snuggedy swamp is related to rapid flooding. A similar condition of rapid transgression occurred with many of the Cherokee Group coals where deep marine deposits directly overly coal. The distribution and thickness of Snuggedy swamp peat is also a function of topographic relief, fresh water versus brackish water, and relation to barrier islands. According to Staub and Cohen (1979) the thickest and most continuous peat forms in fresh water, near barrier islands and in areas with a slightly higher topography. Areas near tidal channels are also higher in sulfur content due to marine influence.

A Malaysian compound delta of the Klang and Langat Rivers located off the west coast of the Malay Peninsula in southeast Asia is also analogous to many of the coastal environments formed during deposition of the Cherokee Group. This compound delta is described as a complex network of tidal passes that function as an open-ended estuary in which large mangroves and freshwater swamps form between channels (Coleman et al., 1970). Seaward, the delta transitions into irregular and extensive tidal mud flats that typically do not have any beach development. Much of the coastal mangrove swamps formed in the above settings are colonized on top of the muddy tidal flats at or just above the neap high water (Coleman et al., 1970). Tides and tidal current processes are considered as the primary control on the delta morphology. The widespread distribution of the Malay swamps parallels the shoreline and is rapidly prograding (Coleman et al., 1970). Cherokee coals such as the Weir-Pittsburg have similar distributions.

5.3 Depositional Models

Cherokee Group coals accumulated in a variety of depositional settings including, marshes, open and back barrier coastlines, estuaries, and fluvial flood basins. Pre-existing topography coupled with relative position within a systems tract, played a major role in the growth, distribution and quality of Pennsylvanian peatlands that eventually develop into coal. Interpretations of depositional environments and controls on peat development are primarily based on isopach map interpretations (Chapter Two), relation to underlying and overlying stratigraphy (Chapter Two) and proximate analysis (Chapter Three). A brief description of depositional orientation, average thickness and geometry of coal beds used for interpretations of depositional environments and controls on peat development are summarized in Table 5.1.

Coal Unit	Orientation	Average Thickness (ft)	Geometry	Depositional Setting or Control
Summit	Dip & Strike	1.0	Thin, circular	Topography
Mulky	Dip & Strike	0.75	Thin, circular	Topography
Iron Post	Dip	1.0	Thin, elongate	Fluvial Floodbasin
Bevier	Strike	1.5	Thin, lenticular	Coast Plain
Croweburg	Strike	1.0	Thin, lenticular	Coast Plain
Fleming	Dip	1.0	Thin, dendritic	Estuarine
Mineral	Strike	1.5	Thin, lenticular	Coast Plain
Scammon	Dip	1.0	Thin, dendritic	Estuarine
Tebo	Dip	0.9	Thin, elongate	Fluvial Floodbasin
Weir-Pitt.	Strike	1.5	Thin, lenticular	Coast Plain
Aw	Dip	1.7	Thin, elongate	Fluvial Floodbasin
Riverton	Dip & Strike	1.8	Thin, lenticular	Pre-Penn. Topography

Table 5.1 – Interpretations for Cherokee Group coal depositional settings and controls according to depositional orientation, average thickness, and geometry (approach is modified from Flores, 1993).

5.3.1 Abrupt Marine Regression

Several times through the Middle Pennsylvanian in southeast Kansas coal beds are found directly above fossiliferous marine limestones or shales with little or no underlying paleosol development. When present, the clay (paleosol) overlying the limestone may have either accumulated during the marine regression or be non-marine in origin. It would appear that these Cherokee Group coals formed after an abrupt regression on extensive low-lying plains (Wanless, 1969). Examples include the Mulky coal situated above the Breezy Hill Limestone of the Cherokee Group, and the Summit coal located above the Blackjack Creek Limestone of the Fort Scott. The limestone formed in a relatively shallow sea with a moderately smooth floor (Wanless, 1969). However, small-scale topographic highs on the sea floor provided areas that submerged earlier than the rest of the sea floor, creating a favorable surface for initiation of peat accumulation.

The Mulky and Summit coals tend to be highly variable in thickness and show thin, circular geometries as the coals thicken onto structural highs (Figures 2.32, 2.33). Variation in thickness appears related to subtle changes in topography. It appears that shallower areas emerge and peat swamps initiate prior to the peat swamps that formed in deeper areas (Figure 5.01). The initial formation of a peat hammock would form a freshwater lens due to the topography followed by enhancement of the lens through enhancement of topographic relief (Spackman et al., 1969). Proximate analysis indicates that the Mulky and Summit coals tend to be carbonaceous shale or high-ash coal rather than a pure coal. The Mulky and Summit coals have ash contents that range from 36.3 to 88.8 percent and sulfur contents that are greater than 11 percent. The close association with marine carbonate sediments and low relief can explain the high-ash, high-sulfur and carbonaceous nature of the coal (Figure 5.01). Continued peat growth in topographic lows subject to periodic invasion by admixed marine mud results in carbonaceous shale, or high-ash, and sulfur-rich coals. It appears that the better quality low-ash and thickest coal develops in mires on topographic highs more protected from the marine influence. The influence of topography and relative marine influence are themes throughout deposition of the Cherokee Group coals.

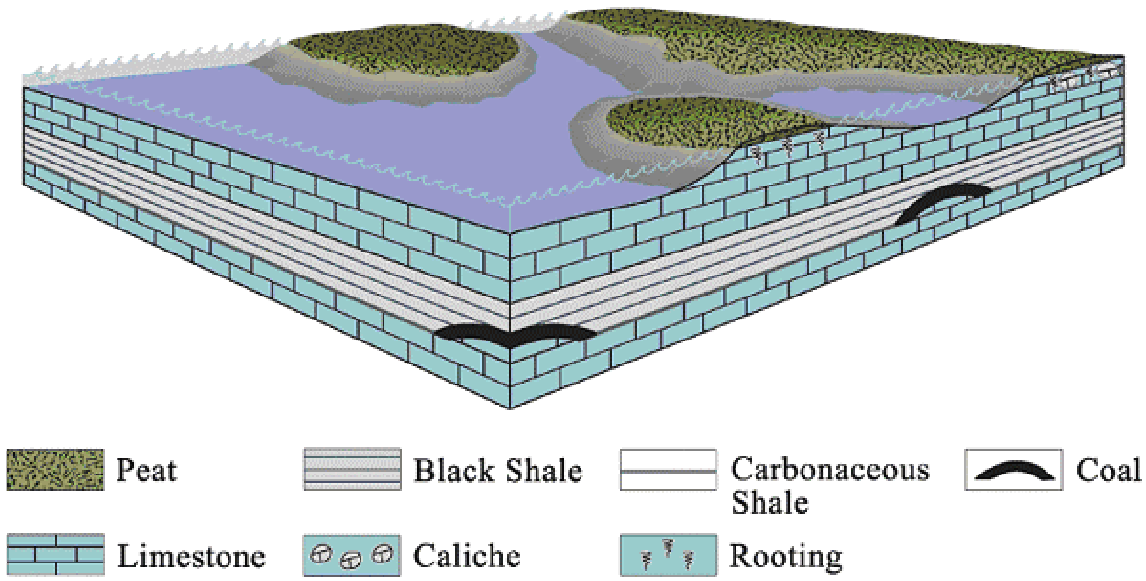


Figure 5.01 - Depositional model for peatland development above regressive marine carbonates. Variation in coal thickness may be due to subtle changes in topography, where shallower areas that submerge before deeper areas are conducive to peat development.

5.3.2 Fluvial Floodbasin

Distribution of peatlands associated with fluvial flood basins increase in thickness and abundance away from fluvial axes. Detritus decreases away from fluvial axes except when detritus is transported by crevasses splays and overbank processes (Flores, 1993; Figure 5.02). Coal beds formed from peatlands in the above setting are commonly interbedded with marine to marginal marine coarsening upward mudstones, siltstones and sandstones, fining-upward fluvial channel sandstones, coarsening-upward crevasse-splay mudstones, siltstones, and sandstones, and thin lacustrine deposits (McCabe, 1991; Flores, 1993). Geometry of coal beds in this setting vary from dendritic, elongate, lens, and lenticular along depositional dip (Flores, 1993). Coal adjacent to channels that are thin and or contain splits, suggests contemporaneous channel and peat development (McCabe, 1991).

Laterally extensive although discontinuous, thin, elongate, and dendritic coals such as the Iron Post, Tebo, and Aw coals are interpreted to have formed in an associated fluvial floodbasin setting. Many other local and informally known coals may have also formed in settings similar to that of the Iron Post, Tebo, and Aw. The ash content of coals in floodbasin sediments can be highly variably depending on the amount of detritus transported into the peatland. In the Cherokee basin, coals interpreted as deposited in floodbasin settings have between 11.4 and 64.7 percent ash. Presumably the range in ash content is also a reflection from the type of mire.

Raised and low-lying mires have been suggested as an explanation of differences between ash contents of coals (McCabe and Shanley, 1992). Sulfur contents are typically less than 4 percent due to the decreased marine influence.

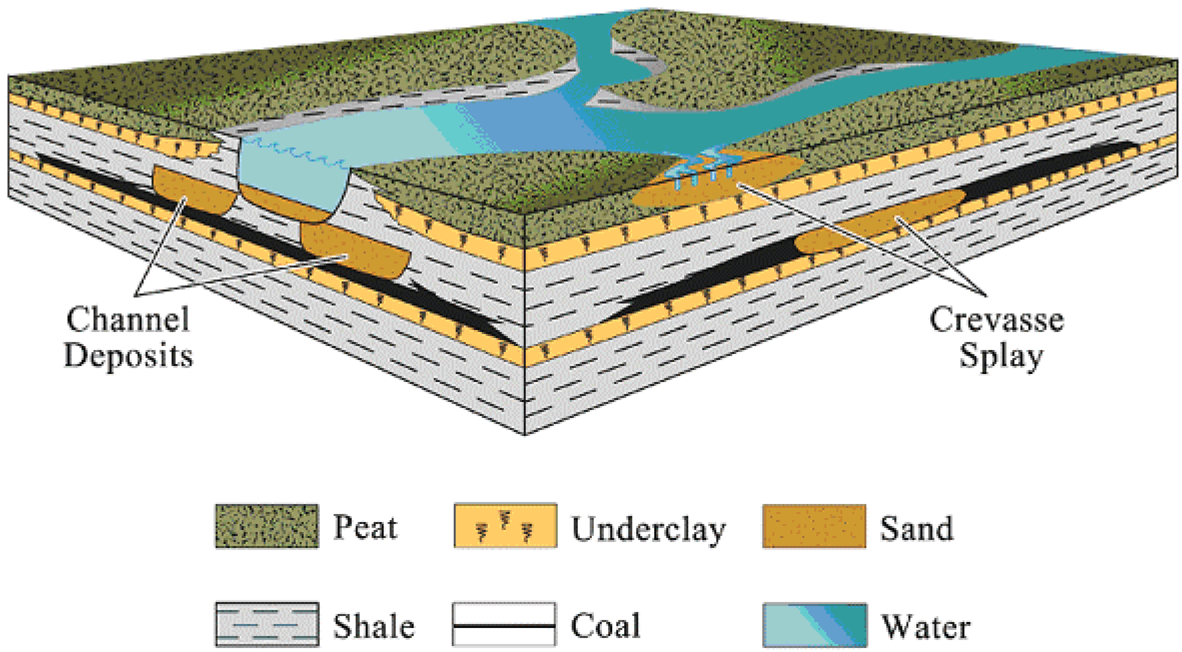


Figure 5.02 - Depositional model for peatland development associated with fluvial systems. Coals that develop from peatlands in fluvial systems tend to thicken away from channels and split toward channels. Areas of peatlands are removed by fire splays, crevasse splays or eroded by fluvial incision.

5.3.3 Estuarine

Several times throughout deposition of the Cherokee Group, relative sea level dropped, resulting in fluvial incision. Remnants of this process are indicated by several mappable, fluvially eroded, elongate topographic lows that are typically larger than any one single channel form. These features are known as incised valleys (Zaitlin et al., 1994). During sea level rise, incised valleys are filled with fluvial sands, estuarine sands, and shelf muds (Zaitlin et al., 1994; Figure 5.03). As for relation to peat accumulation, the inner incised valley where the bay head delta is formed is the most important. With a continued transgression, stream gradient and capacity decreases, and freshwater organic facies increase in abundance on less mature soils of the upper estuary (Zaitlin et al., 1994; Figure 5.03).

In the mid-continent several Middle Pennsylvanian coals have been interpreted as developing in estuaries prior to drowning (Wanless, 1969). Coals associated with estuarine environments are described as occupying linear troughs that range from less than 1.5 miles (2.4 km) up to more than 4 miles (6.4 km) in width and have thin dendritic geometries (Wanless, 1969 and; Flores 1993). Discontinuous, thin and dendritic coals, such as the Fleming coal, Scammon coal, and several informally known coals are interpreted to have formed in association with upper estuarine environments. The previously mentioned coals are also closely associated with lithofacies that are interpreted as bay head delta and central bay sediments (Chapter Two). The ash content of coals in estuarine strata is relatively high (30 percent +/-) due to the input of clastic material brought into the upper estuary by the fluvial system. Sulfur content of 6 percent is also relatively high due to the marine influence up into the estuarine system.

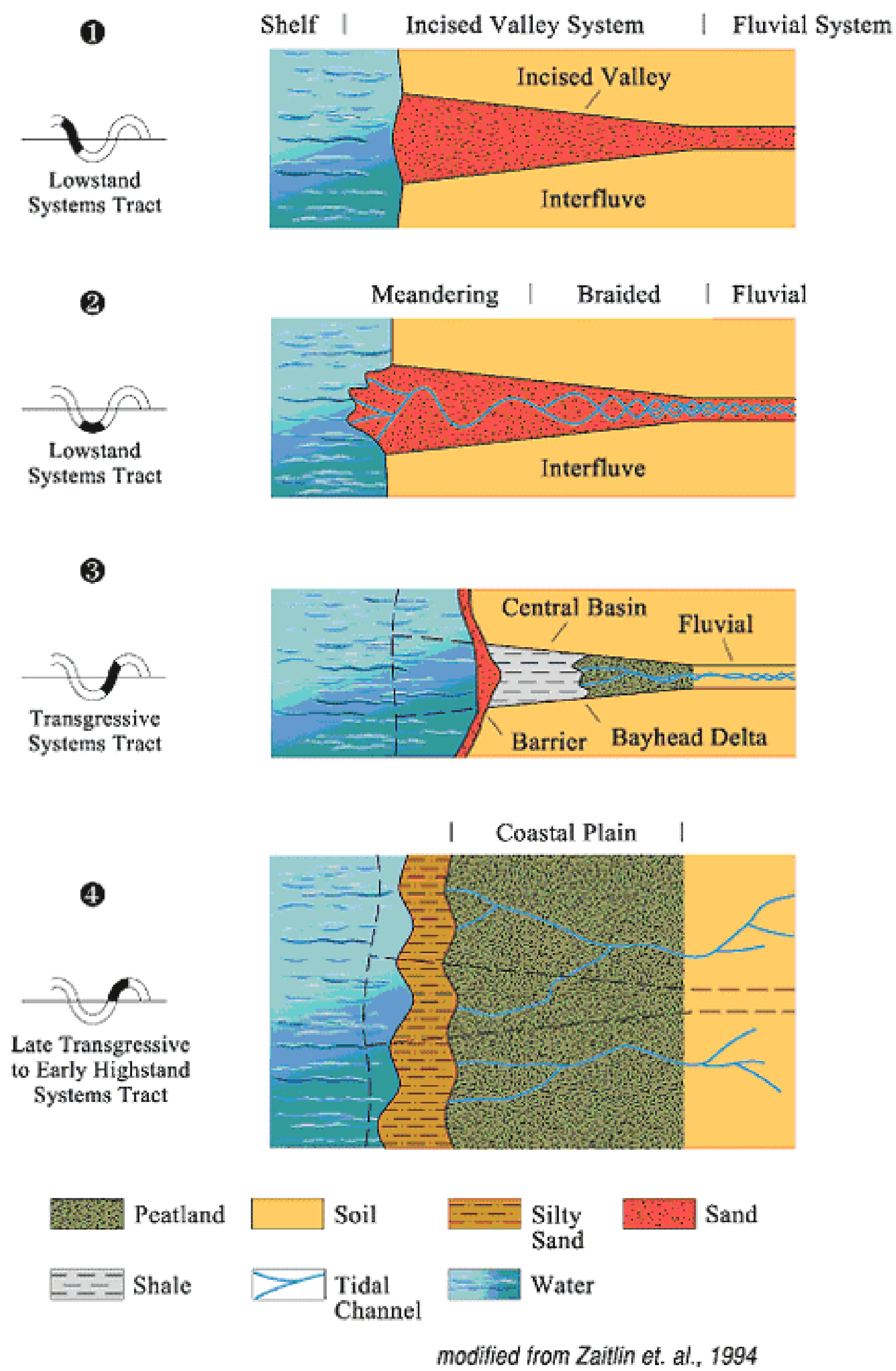


Figure 5.03 - Depositional model for peatland development in estuarine systems. Thin, locally developed coals are interpreted to have formed from peatlands constrained within estuarine valleys (3). After flooding of an estuarine valley, coastal plains and extensive peatlands will develop over top of the valley (4)

5.3.4 Coastal Plain

Peatlands in coastal plains develop above and behind open and back barrier shorelines, on estuaries, above infilled lagoons, and atop interfluves (Flores, 1993; Figures 5.03, 5.04). Back-barrier coals are generally laterally continuous and parallel to depositional strike (Wanless, 1969; Flores, 1993). Sustained growth and preservation of peat requires protection from marine influence. A gradual increase of base level will raise the water table aiding in the growth of mires. Continued transgression will lead to aggradation and eventually marine rocks bury the peatlands. In addition barred or stationary shorelines aid in the protection of peatlands from marine processes.

Coals such as the Bevier, Croweburg, Mineral, and Weir-Pittsburg have lenticular geometries oriented parallel to depositional strike and suggest peatland development on coastal plains. Average thickness of coastal plain coals is approximately 1.5 ft (0.5 m) with a normal distribution in thickness (Appendix 2). The scale of coastal coal development in the Cherokee basin is similar to peatland development described from coastal plains of the Malay Peninsula (Coleman et al., 1970). The ash content of coals interpreted, as coastal plain deposits is relatively low compared to other Cherokee basin coals. Cherokee Group coals associated with the coastal plain have ash contents between 19.5 and 32.7 percent. Sulfur contents are also relatively low, ranging from 1.9 to 3.6 percent, which suggests some protection from marine influence during coalification.

Topographic relief of the mire also plays a significant role in the development of peat. Low-lying peatlands are prone to tidal effects and form brackish mires, while fresh water peatlands form in elevated areas with high precipitation and migrate across the low-lying mires to form protected raised mires (Flores, 1993; McCabe, 1991; Figure 5.04). Tidal channels, estuaries, and short-headed streams, form drainage systems for peatlands peatlands on coastal plains (Coleman et al., 1970).

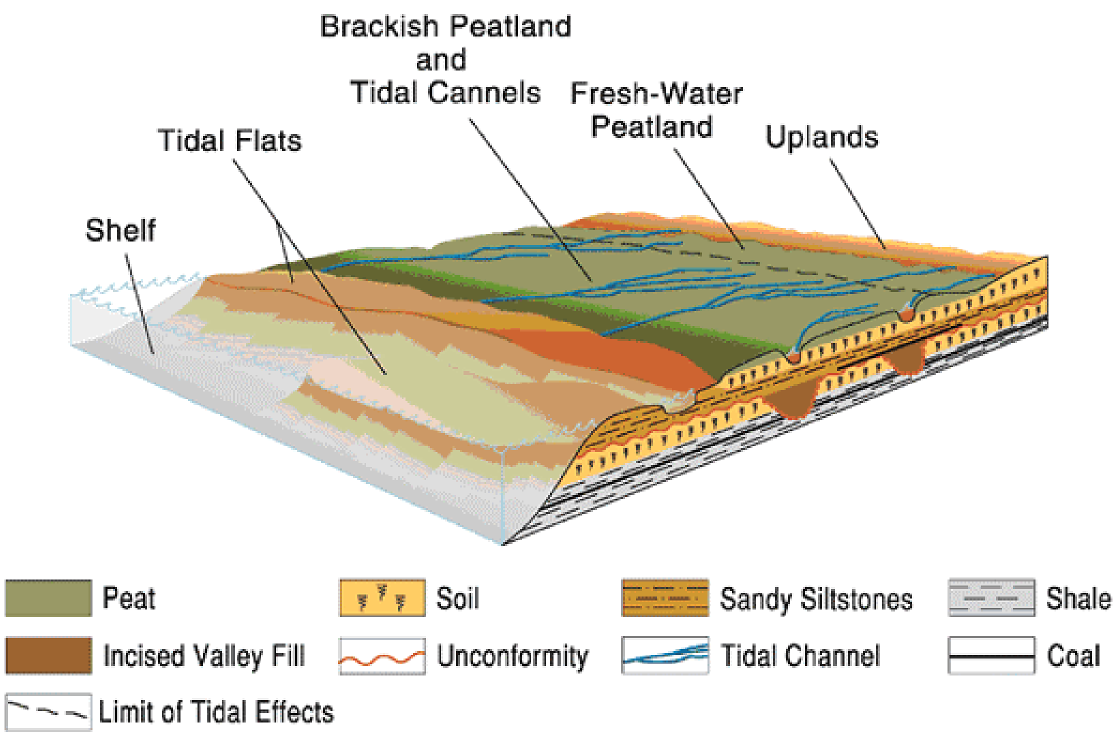


Figure 5.04 - Depositional model for peatland development associated with coastal plains. Low-lying peatlands are prone to tidal effects and from brackish mires, while fresh water peatlands form in elevated areas and migrate across the low-lying mires to form protected raised mires.

5.3.5 Pre-Pennsylvanian Topography

Topographic relief up to 300 feet (91.5 m) existed on the karsted limestone terrain in the central United States prior to deposition of Pennsylvanian sediments (Siever, 1951). As a result, initial Pennsylvanian sedimentation occurred in erosional valleys created by karstification. The karst topography on top of the Mississippian limestones provided many low-lying areas where lakes and marshes developed (Figure 5.05). During the initial Pennsylvanian transgression, low-lying mires formed across topographic lows as the water table rose. Raised mires developed above the low-lying mires (McCabe, 1991). Given sufficient precipitation raised mires can sustain their water table while building upward (McCabe, 1991; Figure 5.05). Margins of raised mires are typically steep and eventually pinch out into clastic sediments of marginal marine environments. The presence of marine deposits directly above the Riverton coal suggests that a transgression eventually drowned and buried the peatlands. Burial, compaction and coal formation can reduce coal thickness to less than 10 percent of original peat thickness and result in coals that appear to pinch out onto paleotopographic highs (Mukhopadhyay and Hatcher, 1993; Figure 5.05).

Coals such as the Riverton and informally known Riverton A-D coals will tend to thicken into Mississippian lows where peat developed from both raised and low-lying mires (Figure 5.05). Evidence of this relationship is indicated in the Riverton coal isopach map of Figure 2.16, and was observed at the outcrop scale of the Riverton coal in a sinkhole at the Sunflower lead-zinc mine in Cherokee County, Kansas (Figure 5.06). Ash contents of coals developed in this setting range from 7.3 to 35 percent, and sulfur contents are also highly variable and range from 2.8 to 10.7 percent. Variability in ash content is likely due to differences in peat development between raised and low-lying mires, and the relative influence of marine waters during coal formation. During coal formation, influx of marine water can result in a significant pyrite formation and relatively high sulfur content (> 5 %). Other early Cherokee Group coals (eg. Krebs Formation) have depositional patterns influenced by the topographic irregularities on top of the Mississippian limestones (Wanless, 1969).

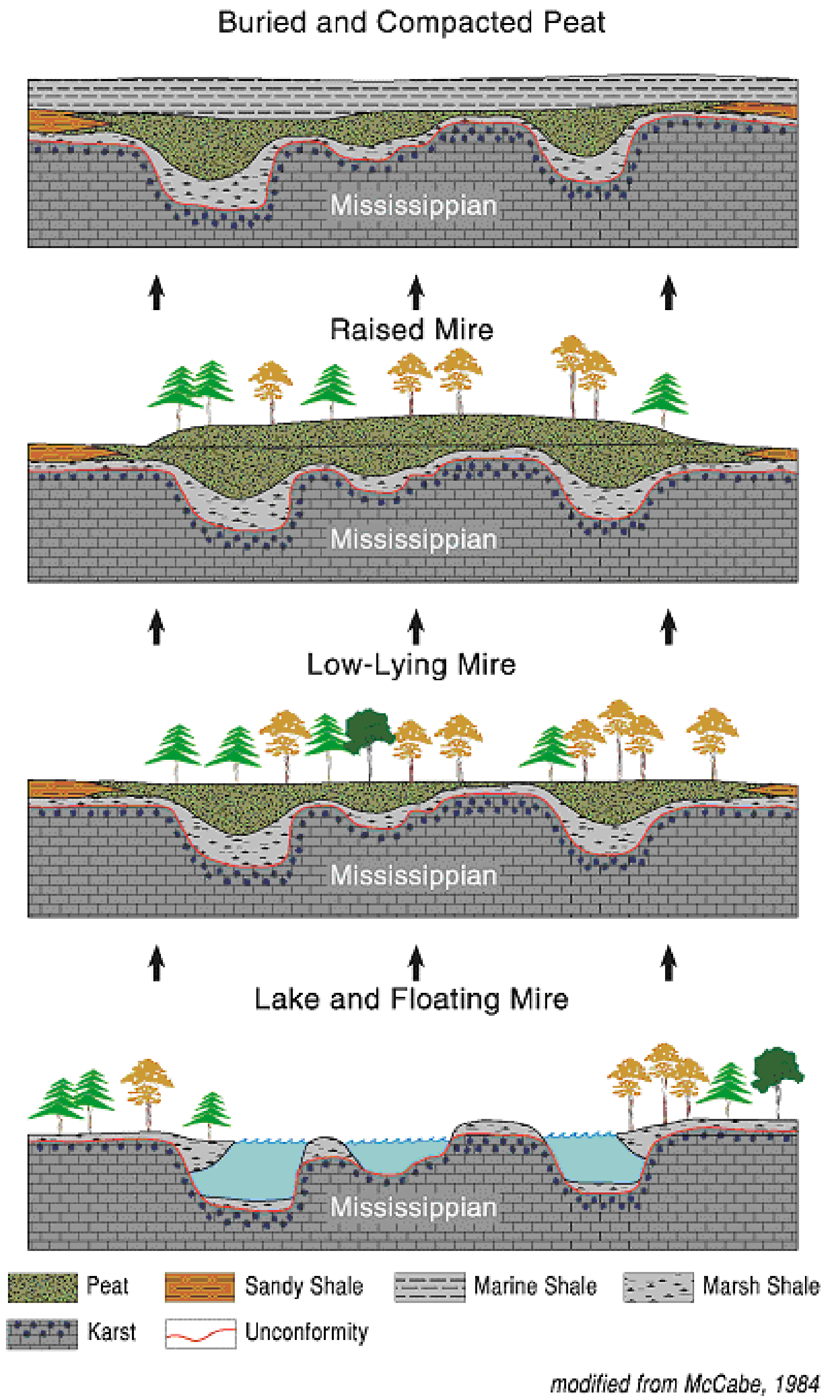


Figure 5.05 - Depositional model for peat development influenced by pre-Pennsylvanian topography. The karst topography on top of the Mississippian limestones provided many low-lying areas where lakes and marshes developed and subsequent peatlands. As a result, Riverton coals tend to thicken into Mississippian lows where peat developed from both raised and low-lying mires.

Figure 5.06 - Sink hole at Sunflower Pb-Zn mine in Cherokee County, Kansas: SW 10-T35S-R24E. Note the Riverton coal thickening into Mississippian lows.

Chapter 6 : Conclusions

The Cherokee basin of southeast Kansas is part of the western region Interior Coal Province, and is a hydrocarbon-bearing foreland province. Abundant resources of deep coal [>30m burial depth] are contained within the Cherokee Group (Desmoinesian Stage, Middle Pennsylvanian Series) of eastern Kansas. The following conclusions can be made regarding the stratigraphic and depositional controls on coal development relating to the coalbed gas potential of the Cherokee basin.

1. The Cherokee Group and Fort Scott Limestone can be divided into ten lithofacies. The phosphatic black shale, dark gray shale, and bioclastic mudstone to wackestone lithofacies were deposited in open marine environments, below fair-weather wave base. The bioclastic packstone to grainstone, and cross-laminated lithofacies were deposited in restricted to open marine, above fair-weather wave base, in a relatively shallow environment. The sideritic gray shale and interlaminated sandstone and siltstone lithofacies were deposited in a marginal marine environment, probably estuarine (central bay and bay head delta, respectively). The blocky mudstone lithofacies is interpreted as a paleosol formed under swampy conditions. The pyritic black shale and coal to carbonaceous shale lithofacies were formed in non-marine environments including swamps, mires, marshes and peatlands.
2. Sequence stratigraphic concepts provide a framework to explain and predict the lateral distribution, relative thickness and quality of coal beds in the Cherokee Group. Within the study area, seven sequences were identified. Each sequence contains multiple coals and portions of the transgressive and highstand systems tract resulting from changes in relative sea level.
3. Thicker and laterally extensive coals developed toward the end of the transgressive systems tract and beginning of the highstand systems tract as a consequence of increasing accommodation, back stepping of a destructive fluvial system, and preservation by an extensive marine flooding surface. Coals formed during the upper transgressive systems tract and lower highstand systems tract are typically of higher quality (low ash, low sulfur, and higher adsorbed gas content).
4. Cherokee Group coals accumulated in a variety of depositional settings, such as marshes, open and back barrier coastlines, estuaries, and fluvial flood basins. Coals formed in mires associated with the coastal plain are commonly thicker and laterally continuous, while coals associated with estuarine and fluvial floodbasin environments are thinner and laterally discontinuous. On average, coals accumulated within the coastal setting have lower ash contents, lower sulfur content, and higher adsorbed gas contents than other coals. Coastal plain mires are best developed during the late transgressive or early highstand systems tract, and under more stable shoreline conditions.
5. The differences in raised and low-lying mires probably had a significant influence on the distribution and quality of coal formation. The type of mire is a significant factor in ash content, where raised mires are typically of lower ash due to protection from marine and fluvial processes. Raised and low-lying mires can form in any of the coal accumulation settings, but raised mires require persistence of coal forming conditions for longer periods of time. Raised mires and coal forming conditions appear to be better maintained during periods of rising base level.
6. Pre-existing topography played a major role in the growth, distribution and quality of peatlands that developed into coal. Variation in thickness appears related to subtle changes in topography, where shallower areas emerge and lead to the development of peat swamps prior to deeper areas. These slight topographic highs provide some protection from the marine

influence, resulting in a lower ash coal rather than a carbonaceous shale or high-ash coal that formed from an admixed marine setting in the lows. Conversely, pre-Pennsylvanian topographic lows provided many areas in which coal is interpreted to have accumulated in raised and low-lying mires above marsh and lake environments associated with the karstic Mississippian limestone lows. Mires influenced by pre-Pennsylvanian lows resulted in coals that thicken into lows and thin on highs.

7. Based on preliminary gas isotopic analysis, Cherokee basin coal gas samples represent a mixed thermogenic and microbial origin. Considering degree of maturation and gas geochemistry, natural conventional and coal gases in eastern Kansas are likely a combination of indigenous dry microbial methane, and either indigenous or migrated early thermogenic methane. An additional source for indigenous thermogenic methane is sourcing from the black shales that typically overlie coal seams.
8. Desorption data indicates that coals of the central part of the study area have higher methane contents than coals in the eastern portion of the basin where coals are shallower. Desorption of coal samples also indicate a general relationship of increasing gas content with depth. There may be a minimum depth for economic coal gas based on this relationship and the relative thickness of Cherokee coals.
9. An estimated 6.6 tcf of original gas in place from twelve coals and two black shales exists in the study area of the Cherokee basin. This resource is contained within the Cherokee Group and Fort Scott Limestone, which have net coal thickness ranging from 2 to more than 25 feet (0.6 to 7.6 m) at depths of less than 2,500 ft (762 m).
10. With moderate gas saturation, high resolution mapping, and an understanding of depositional controls of coals, ease of water disposal, and relatively inexpensive drilling, the Cherokee basin has the potential to provide successful coal gas plays and significant quantities of natural gas for Kansas and the nation.

References

Abernathy, G.E., 1936, The Cherokee Group of Southeastern Kansas: unpublished doctoral dissertation, University of Kansas, 108p.

Aitken, J.F., 1994, Coal in a sequence stratigraphic framework: Geoscientist, Vol. 4, no. 5, p. 9-12.

Allen, H.C., 1925, The chemistry of Kansas coal: Kansas Coal, Bulletin of the University of Kansas, Vol. 26, no. 5, p. 127-202.

Allen, G.P., and Posamentier, H.W., 1993, Sequence stratigraphy and facies model of an incised valley fill: the gironde estuary, France: Journal of Sedimentary Petrology, Vol. 63, p. 378-391.

Andel, TJ.H., 1967, The Orinoco Delta: Journal of Sedimentary Petrology, Vol. 37, p. 297-310.

ASTM Committee D05, 2002, Petroleum Products, lubricants, and fossil fuels, *in* Annual Book of ASTM Standards, p. 197-330.

Barker, C.E., Hatch, J.R., Wojcik, K.M., Goldstein, R.H., and Walton, A.W., 1992, Thermal maturity, organic geochemistry, and burial history of Pennsylvanian Rocks, Cherokee basin, Southeastern Kansas: Oklahoma Geological Survey, Circular 93, p. 299-310.

Bass, N.W., 1934, Origin of the shoestring sands of Greenwood and Butler counties, Kansas: Kansas Geological Survey Bulletin 23, 135p.

Bensley D.F., Crelling, C.C, Finkelman, R.B., Bragg, L.J., and Dulong, F.T., 1990, Petrographic, chemical, and mineralogical analyses of selected samples from the interior coal province, western region: Supplement to the coal geology division Field Trip guidebook, 1990 Annual meeting of GSA, 26 p.

Bohacs, K., and Suter, J., 1997, Sequence stratigraphic distribution of coaly rocks: Fundamental controls and paralic examples: American Association of Petroleum Geologists Bulletin, Vol. 81, No. 10, p 1612-1639.

Boyd, R., and Diessel, C., 1995, The effects of accommodation, base level and rates of peat accumulation on coal measure architecture and composition: Houston, Annual Convention of the American Association of Petroleum Geologists, Abstracts, p. 12A.

Brady, L.L., 1990, Kansas coal resources, production, and potential use in the near future, *in* Coal Geology of the Interior Coal Province-Western Region: Coal Geology Division Fieldtrip and Guide Book-1990 Annual meeting of Geological Society of America, p 122-124.

Brady, L.L., 1997, Kansas coal Resources and their potential for coalbed methane, *in*

Transactions of the 1997 AAPG Mid-Continent Section Meeting, September 14-16, 1997: Oklahoma City geological Society, Oklahoma City, Oklahoma, p. 150-163.

Brady, L.L. and Hatch, J.R., 1997, Chemical analyses of Middle and Upper Pennsylvanian coals from southeastern Kansas: Current Research in Earth Sciences, Kansas Geological Survey, Bulletin 240, p. 43-62.

Brady, L.L., Livingston, N.L., and Adams, D.B., 1976 Strippable coal reserves in Kansas: Kansas Geological Survey Mineral Resources Series 5, 40 p.

Branson, C.C., 1957, Oklahoma facies of Kansas formations: Kansas Geological Society, Annual Field Conference No. 21, P. 92-104.

Buatois, L.A., Mangano, G., Carr, T.C., 1999, Sedimentology and Ichnology of Paleozoic Estuarine and Shoreface Reservoirs, Morrow Sandstone, Lower Pennsylvanian of Southwest Kansas, USA: Current Research in Earth Sciences, Kansas Geological Survey Bulletin 243, part 1.

Charles, H.H., and Page, J.H., 1929, Shale-gas industry of eastern Kansas: American Association of Petroleum Geologists, Vol. 13, no. 4, p. 367-381.

Cole, J.G., 1969, Cherokee Group, east flank of the Nemaha ridge, north-central Oklahoma: Part 1, Shale Shaker, Vol. 19, no. 8, p. 134-146.

Coleman, J.M., Gagliano, S.M., and Smith, W.G., 1970, Sedimentation in a Malaysian high tide tropical delta, *in* Morgan, J.P. ed., Deltaic sedimentation, modern and ancient: Society of Economic Paleontologists and Mineralogists Special Publication, v. 15, p. 185-197.

Dake, L.P., 1978, fundamentals of reservoir engineering, Elsevier Scientific Publishing, New York, NY, 443 p. Gould, C. N., 1927, Stratigraphy and aerial geology, in The Upper Paleozoic rocks of Oklahoma: Oklahoma Geological Survey Bulletin, No. 41, p. 5-17.

Diessel, C.F.K., 1998, Sequence stratigraphy applied to coal seams: two case histories: Society for Sedimentary Geology Special Publication No. 59, p 151-173.

Flores, R.M., 1993, Coal-bed and related depositional environments in methane gas producing sequences, *in* Chapter Two, Hydrocarbons from coal: AAPG Special Publication 38, p. 13-37.

Galloway, W.E., 1989, Genetic stratigraphic sequences in basin analysis 1: Architecture and genesis of flooding-surface bounded depositional units: American Association of Petroleum Geologists Bulletin, v. 73, no. 2, p. 125-142.

Gould, C.N., 1927, Stratigraphy and areal geology, *in* The Upper Paleozoic rocks of Oklahoma: Oklahoma Geological Survey Bulletin No. 41, p. 5-17.

Gustavson, T.C., 1991, Buried vertisols in lacustrine facies of the Pliocene Fort Hancock Formation, Hueco Bolson, West Texas and Chihuahua, Mexico: Geological Society of America Bulletin, Vol. 103, p. 448-460.

Ham, W.E., and Wilson, J.L., 1967, Paleozoic epeirogeny and orogeny in the central United States, *in* Symposium on the chronology of tectonic movements in the United States: American Journal of Science, Vol. 265, no. 5, p. 332-407.

Harris, J.W., 1894, Stratigraphy and depositional environments of the Krebs Formation (Lower Cherokee Group, Middle Pennsylvanian) in southeastern Kansas: unpublished masters thesis, University of Kansas 139 p.

Haworth, E. and Kirk, M.E., 1894, A geologic section along the Neosho River from the Mississippian Formation of the Indian Territory to White City, Kansas, and along the Cottonwood River from Wychoff to Peabody: Kansas University Quarterly, Vol. 2, P. 104-115.

Hayes, M.O., 1963, Petrology of the Krebs Subgroup (Pennsylvanian, Desmoinesian) of western Missouri: American Association of Petroleum Geologists Bulletin, Vol. 47, no. 8, p. 1537-1551.

Heckel, P.H., 1977, Origin of phosphatic black shale facies in Pennsylvanian cyclothems of Mid-Continent North America: American Association of Petroleum Geologists Bulletin, Vol. 61, no. 7, p. 1045-1068.

Ho, C., and Coleman, J.M., 1969, Consolidation and cementation of recent sediments in the Atchafalaya basin: Geological Society Bulletin, Vol. 80, p. 183-192.

Howe, W.B., 1956, Stratigraphy of the pre-Marmaton Desmoinesian (Cherokee) rocks in southeastern Kansas: Kansas Geological Survey Bulletin 123, 132 p.

Jenden, P.D., Newell, K.D., Kaplan, I.R., and Watney, W.L., 1988, Composition and stable isotope geochemistry of natural gases from Kansas, Midcontinent, U.S.A.: Chemical Geology, v. 71, p. 117-147.

Jewett, J.M., 1951, Geologic structures in Kansas: Kansas Geological Survey Bulletin 90, pt. 6, 172 p.

Jewett, J.M., O'Connor, H.G., and Zeller, D.E., 1968, The Pennsylvanian system, *in* Zeller, D. E., ed., The stratigraphic succession in Kansas: Kansas Geological Survey Bulletin 189, P. 21-43.

Kissel, F.N., McCulloch, C.M., and Elder, C.H., 1975, The direct method of determining methane content of coals for ventilation design: U.S. Bureau of Mines, Report of Investigations, RI7767.

McCabe, P.J., 1984, Depositional models of coal and coal-bearing strata. *In*: Rahmani, R.A. & Flores, R.M., (eds) Sedimentology of coal and coal-bearing sequences: International Association of Sedimentologists, Special Publication, 7, p. 13-42.

McCabe, P.J., 1991, Geology of coal; Environments of deposition, *in* Gluskoter, H.J., Rice, D.D., and Taylor, R.B., eds., Economic Geology, U.S.: Boulder, Colorado, Geological Society of America, The Geology of North America, Vol. P-2, p. 469-482.

McCabe, P.J., and Shanley, K.W., 1992, Organic control on Shoreface stacking patterns: Bogged down in the mire: Geology, Vol. 20, p. 741-744.

McCabe, P.J., and Shanley, K.W., 1994, The role of tectonism, eustacy, and climate in determining the location and geometry of coal deposits: Denver, Annual Convention of the American Association of Petroleum Geologists, Abstracts, p. 209.

McLennan, J.D., Schafer, P.S., and Pratt, T.J., 1995, A guide to determining coalbed gas content: Gas Research Institute, Chicago, IL, Reference No. GRI-94/0396, 180 p.

Merriam, D.F., 1963, The Geologic History of Kansas: Kansas Geological Survey Bulletin No. 162, p. 317.

Miall, A.D., 1999, In defense of facies classification and models: Journal of Sedimentary Research, Vol. 69, p. 2-5.

Mithcum, R.M., Vail, P.R., and Thompson, S., 1977, Seismic stratigraphy and global changes in sea level, Part 2: the depositional sequence as a basic unit for stratigraphic analysis, *in* C.E. Payton, ed., Seismic stratigraphy applications to hydrocarbon exploration: AAPG Memoir 26, p. 53-62.

Moore, G.H., 1979, Pennsylvanian paleogeography of the southern mid-continent, *in* Hyne, N.J., ed., Pennsylvanian sandstones of the mid-continent: Tulsa Geological Society Special Publication 1, p. 2-12.

Moore, R.C., 1931, Pennsylvanian cycles in the northern Midcontinent Region: Illinois Geol. Survey Bull., 60, p. 247-258.

Mukhopadhyay, P.K. and Hatcher, P.G., 1993, Composition of coal, *in* Hydrocarbons from Coal: AAPG Special Publication, p. 79-118.

Nelson, C.R., 1999, Advances in coalbed reservoir gas-in-place analysis: Gas Research Institute, Gas Tips, Vol. 5, p. 14-19.

Newell, K.D., Brady, L.L., Lange, J.P., Carr, T.R., 2002, Coalbed gas play emerges in eastern Kansas basins: Oil and Gas Journal Vol. 100.52, p. 36-41.

Nicholas, M.M., and Biggs, R.B., 1985, Estuaries, *in* Davis, R.A., Jr., ed., Coastal Sedimentary environments (2nd ed.): New York, Springer-Verlag, p. 77-142.

Posamentier, H.W., and Allen, G.P., 1999, Siliciclastic sequence stratigraphy – Concepts and applications, *in* Dalrymple, R.W., SEPM Concepts in Sedimentology, No. 7, 210p.

Postma, D., 1982, Pyrite and siderite formation in brackish and freshwater swamp sediments: American Journal of Science, Vol. 282, p. 1151-1183.

Priestman, A., 2003, Mid-continent, Black Warrior and Appalachian basins CBNG statistics: Coalbed Natural Gas Alert, Gas Technology Institute, Denver, Colorado, No. 21, p. 5-9.

Rascoe, B.A., and Adler, F.J., 1983, Permo-Carboniferous hydrocarbon accumulations, mid-continent U.S.A.: American Association of Petroleum Geologists Bulletin, Vol. 67, no. 6, p. 979-1001.

Reineck, H.E., and Singh, I.B., 1980, Depositional Sedimentary Environments, Springer-Verlag, New York, 549p.

Retallack, G.J., 1990, Features of fossils soils, *in* Soils of the Past, An introduction to paleopedology, Cabridge University Press, p. 20-54.

Saueraker, P.R., 1966, Solution features in southeastern Kansas: The Compass, Vol. 43, no 2, p.109-128.

Scholes, P.L., and Johnston, D., 1993, Coalbed methane application of wireline logs, *in* Hydrocarbons from Coal: AAPG Studies in Geology 38, p. 287-302.

Searight, W.V., Howe, W.B., Moore, R.C., Jewett, J.M., Condra, G.E., Oakes, M.C., and Branson, C.C., 1953, Classification of Desmoinesian (Pennsylvanian) of northern mid-continent: American Association of Petroleum Geologists Bulletin, Vol. 37, p. 2747-2749.

Searight, W.V., and Howe, W.B., 1961, Pennsylvanian system, *in* Howe, W.B., and Koenig, J.W. eds., The stratigraphic succession in Missouri: Missouri Geological Survey and Water Resources, Report of Investigations 40, series 2, p. 78-122.

Siever, R., 1951, The Mississippian-Pennsylvanian unconformity in southern Illinois: American Association of Petroleum Geologists Bulletin, Vol. 69, p. 363-402.

Spackman, W., Riegel W.L., and Dolsen, C.P., 1969, Geological and biological interactions in the swamp-marsh complex of southern Florida, *in* Environments of coal deposition: Geological Society of America, Special Paper 114, p. 1-35.

Staton, M.D., 1987, Stratigraphy and depositional environments of the Cherokee Group (Middle Pennsylvanian) central Cherokee basin, southeastern Kansas: unpublished masters thesis, University of Kansas 102 p.

Staub, J.R., and Cohen A.D., 1970, The Snuggedy swamp of South Carolina: A back-barrier estuarine coal-forming environment: Journal of Sedimentary Petrology, Vol. 49, p. 133-144.

Stoeckinger, B.T., 1989, Coalbed methane production in eastern Kansas, Its potential and Restraints, *in* Transactions of the 1989 AAPG Mid-Continent Section Meeting, September 24-26, 1989: Oklahoma City geological Society, Oklahoma City, Oklahoma, p. 4.

Vail, P.R., Mitchum, R.M., and Thompson, S., 1977, Seismic stratigraphy and global changes in sea level, Part 3: relative changes in of sea level from coastal onlap, *in* C. E. Payton, ed., Seismic stratigraphy applications to hydrocarbon exploration: AAPG Memoir 26, p. 63-97.

Van Wagoner, J.C., Posamentier, H.W., Mitchum, R.M., Vail, P.R., Sarg, J.F., Loutit, T.S., and Hardenbol, J., 1988, An overview of sequence stratigraphy and key definitions, *in* C. W. Wilgus et. al., eds., Sea level changes, an integrated approach: Society of Economic Paleontologists and Mineralogists Special Publication 42, p. 39-45.

Van Wagoner, J.C., Mitchum, R.M., Campion, K.M., and Rahmanian, V.D., 1990, Siliciclastic Sequence Stratigraphy in Well Logs, Cores, and Outcrops: AAPG Methods in Exploration Series, No. 7, 55 p.

Visher, G.S., Saitta, B.S., and Phares, R.S., 1971, Pennsylvanian delta patterns and petroleum occurrences in eastern Oklahoma: American Association of Petroleum Geologists Bulletin, Vol. 55, no. 8, P. 1206-1230.

Walker, R.G., 1976, Facies models 1. General introduction: Geoscience Canada, Vol. 3, p. 21-24.

Walton, A.W., 1995, Sequences in the Cherokee Group (Desmoinesion, Middle Pennsylvanian) of southeastern Kansas: unpublished manuscript, University of Kansas, 13p.

Wanless, H.R., 1931, Pennsylvanian cycles in western Illinois: Illinois Geological Survey Bulletin, no. 60, p. 179-193.

Wanless, H.R., 1969, Marine and non-marine facies of the Upper Carboniferous of North America: Compte Rendu 6e Congress International Stratigraphy Carboniferous, Sheffield, Vol. 1, p. 293-336.

Wanless, H.R., Baroffio, J.R., and Trescott, P.C., 1969, Conditions of deposition of Pennsylvanian coal beds: *in* Environments of coal deposition; Geological Society of America, Special Paper 114, p. 105-142.

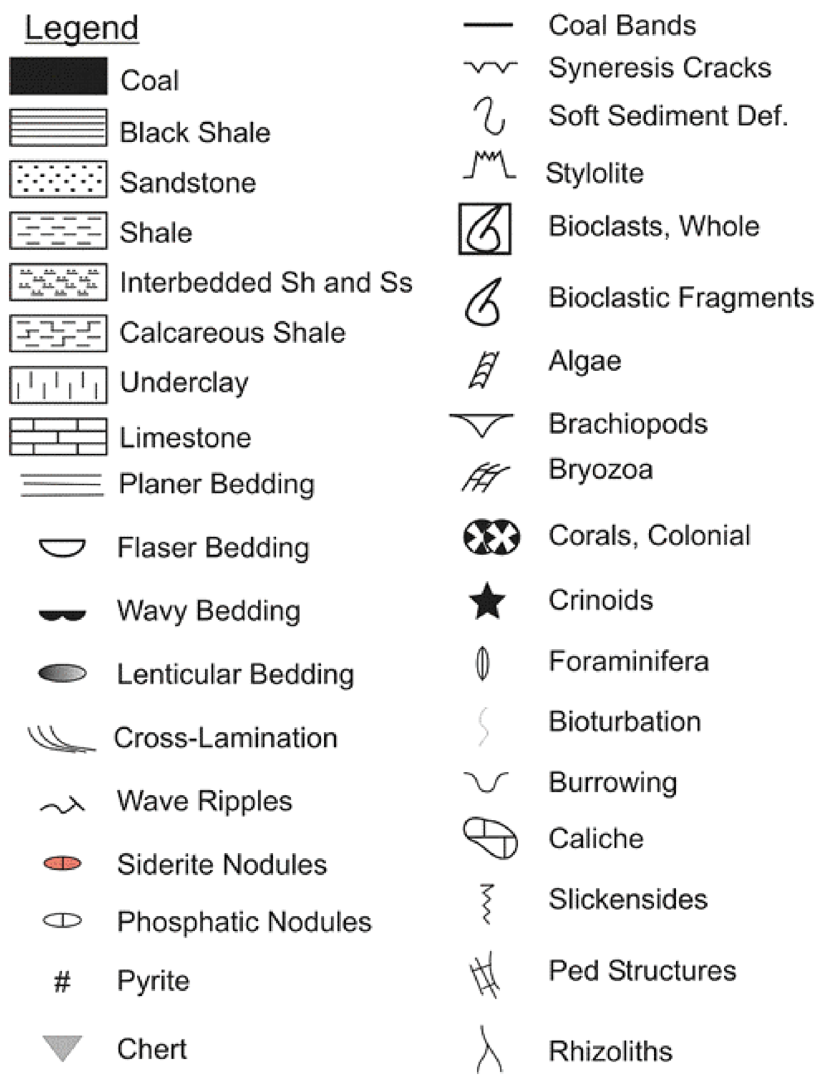
Watney, W.L., Guy, W.J., and Byrnes, A.P., 2001, Characterization of the Mississippian chat in south central Kansas: American Association of Petroleum Geologists Bulletin, Vol. 85, no. 1, p. 85-133.

Zaitlin, B.A., Dalrymple, R.W., and Boyd, R., 1994, The stratigraphic organization of incised-valley systems associated with relative sea-level change, *in* Incised-Valley Systems: Origin and Sedimentary Sequences: SEPM Special Publication 51, p. 45-60.

Zeller, D.E., 1968, The stratigraphic succession in Kansas: State Geological Survey of Kansas, Bulletin 189, 81p.

Appendix 1: Descriptions of Core

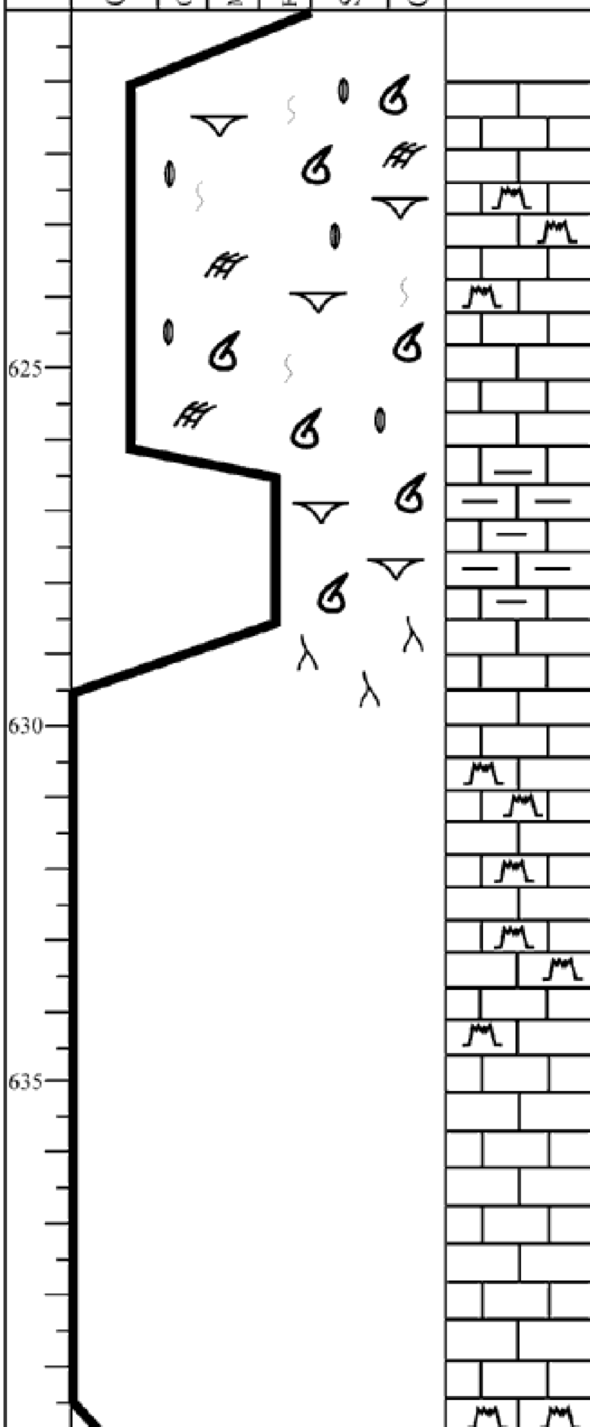
Hinthorn CW#1
Colt Energy and Kansas Geological Survey
SE SE SE 14-T32S-R16E



NAME: HINTHORN CW-1 | STRUCTURAL SETTING: CHEROKEE BASIN

LOCATION: SE SE SE 14-T32S-R16E | DESCRIBED BY: JONATHAN LANGE

DEPTH (FT)	TEXTURE, GRAIN SIZE AND STRUCTURES — CARBONATES: GN, PK, WKE, MUDST, EVAP; CLASTICS: Gravel, Sand (Coarse, Medium, Fine), Silt, Clay	LITHOLOGY	BOX #	DESCRIPTION - Lithology - Color - Comp., Cement, or Matrix - Shape and Sorting - Bedding - Sed. Structures - Upper Contact - Fossils	DATE: JUNE 2002; UNIT: Fort Scott; PAGE 01 OF 24 PAGES; REMARKS, INTERPRETATION



BOX # 41

Limestone
- Light gray to tan
- Calcareous
- Medium Bedded
- Stylolites and horse tail stlyolites
- Rooting and plant fragments
- Calcite veins
- Gradational upper contact
- Bioturbated
- Abundant bioclasts of brachiopods, tabulate corals, fusilinids, and bryozoans
- Slightly oil stained

Top of Fort Scott - Higginsville Limestone
Bioclastic packstone facies
-Shallowing upward, regressive upper limestone

- Above wave base

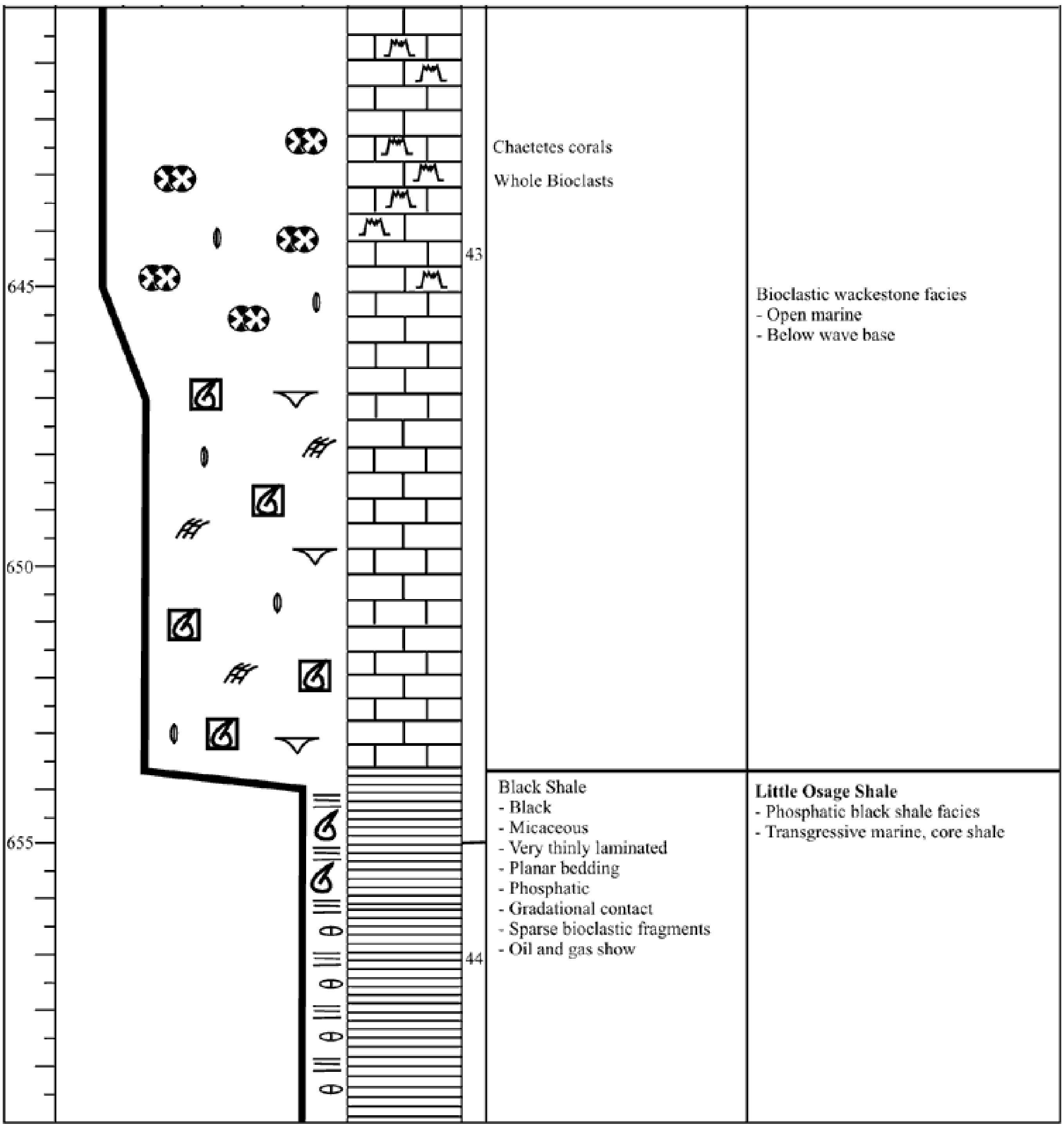
Bioclastic mudstone facies
- Transgressive muddy limestone

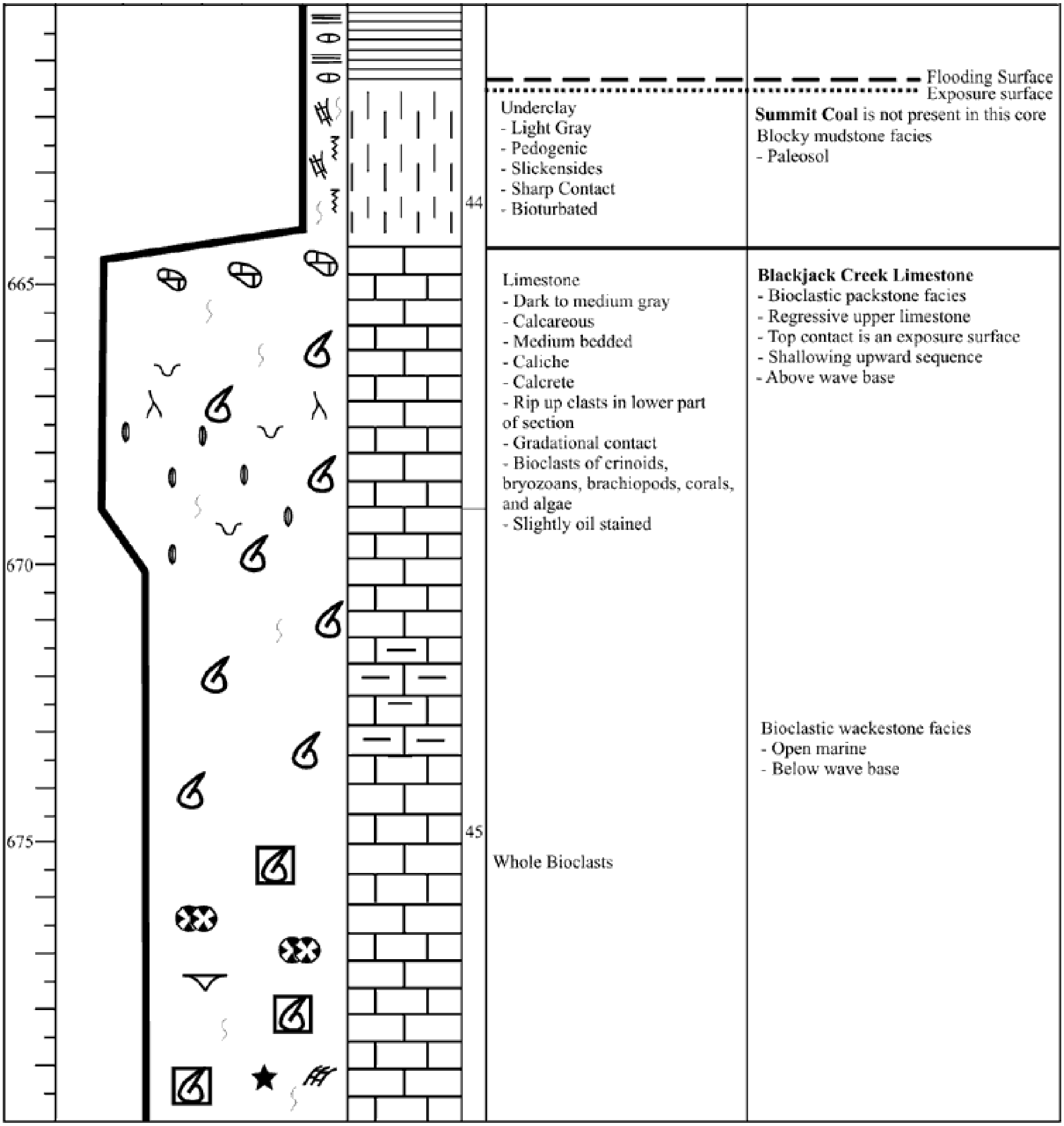
Flooding Surface
Exposure Surface

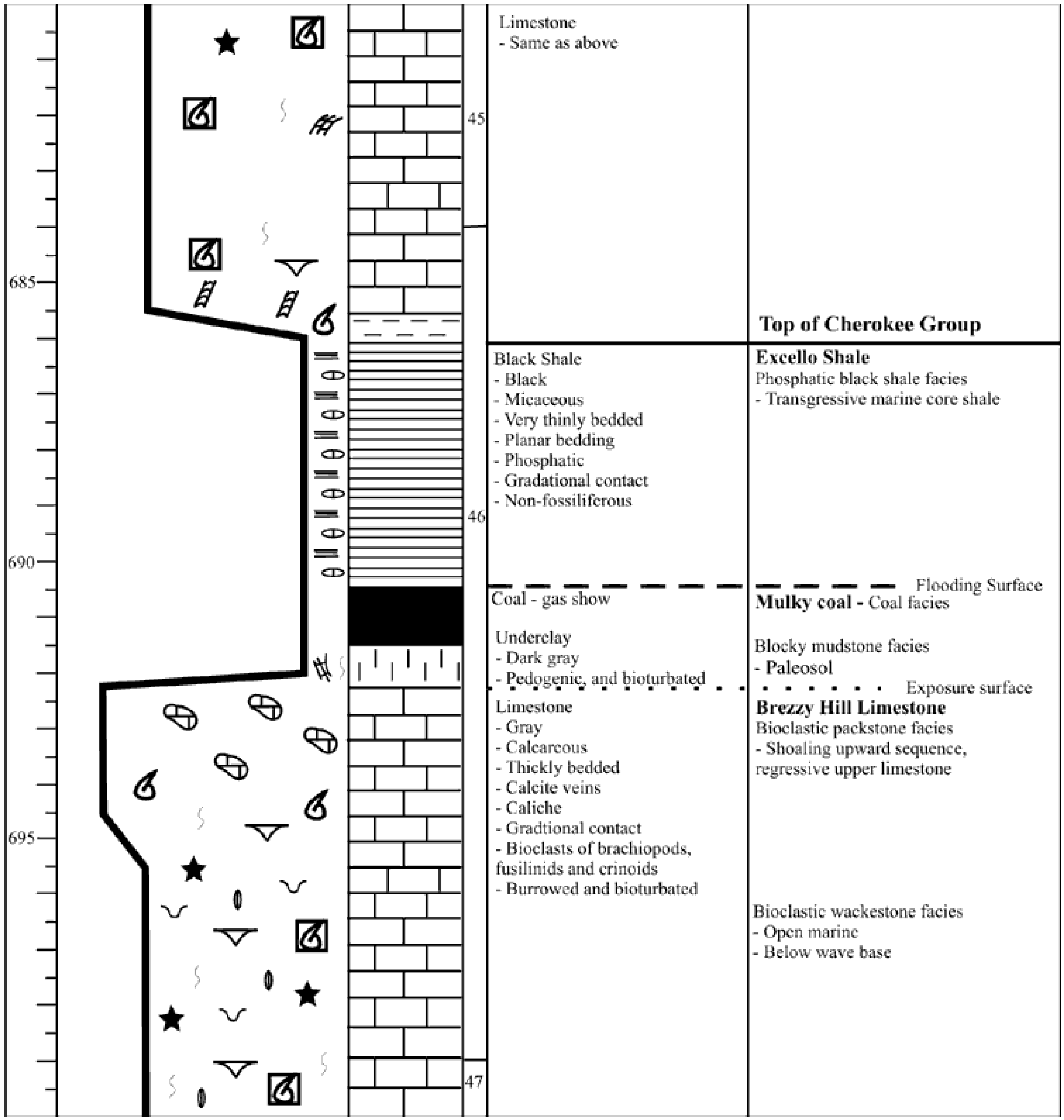
BOX # 42

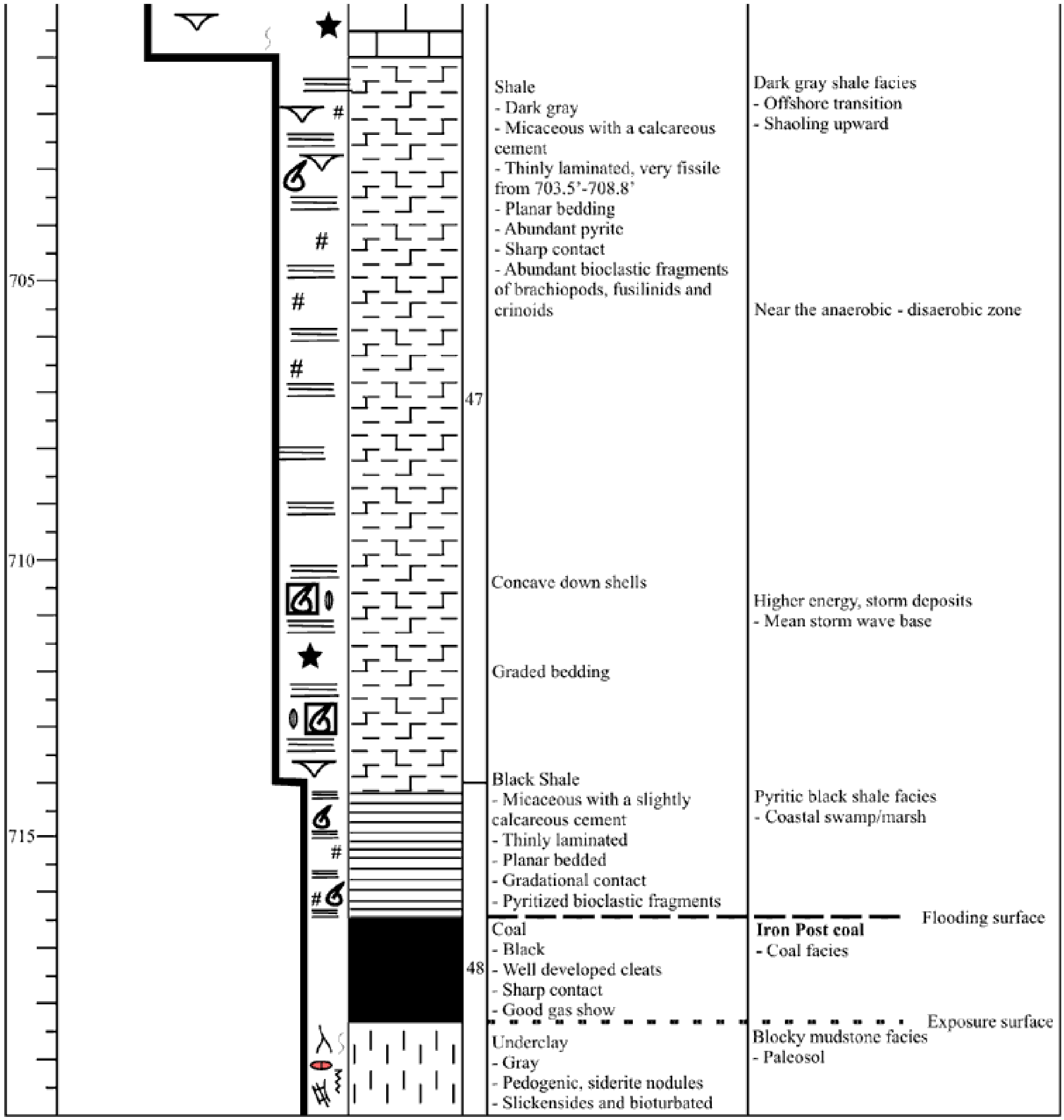
Peloidal and non-fossiliferous from 631' - 640'

Peloidal grainstone facies
- Open marine
- Above wave base

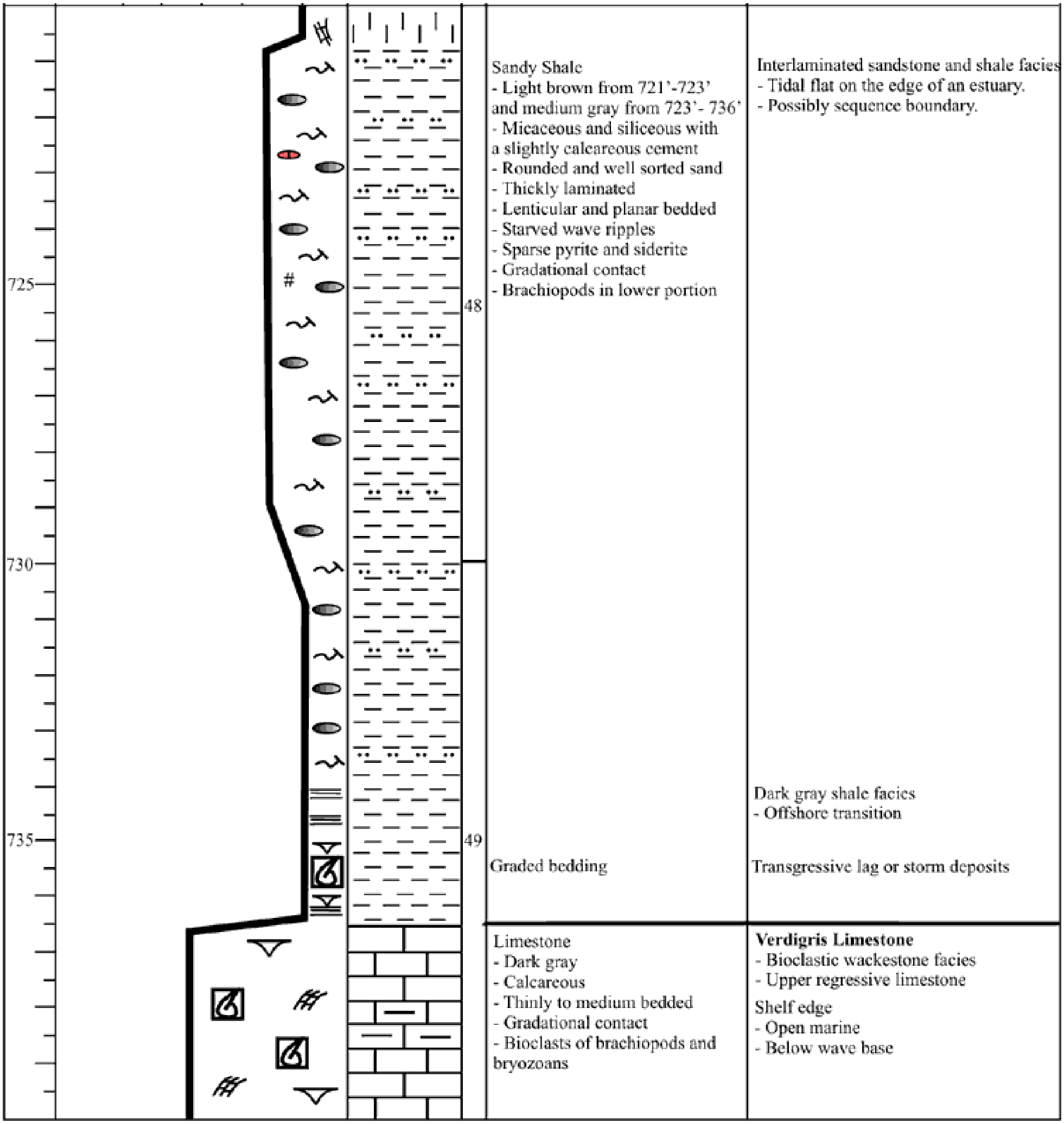

645
650
655
43
44
Chaetetes corals
Whole Bioclasts
Bioclastic wackestone facies
- Open marine
- Below wave base
Black Shale
- Black
- Micaceous
- Very thinly laminated
- Planar bedding
- Phosphatic
- Gradational contact
- Sparse bioclastic fragments
- Oil and gas show
Little Osage Shale
- Phosphatic black shale facies
- Transgressive marine, core shale

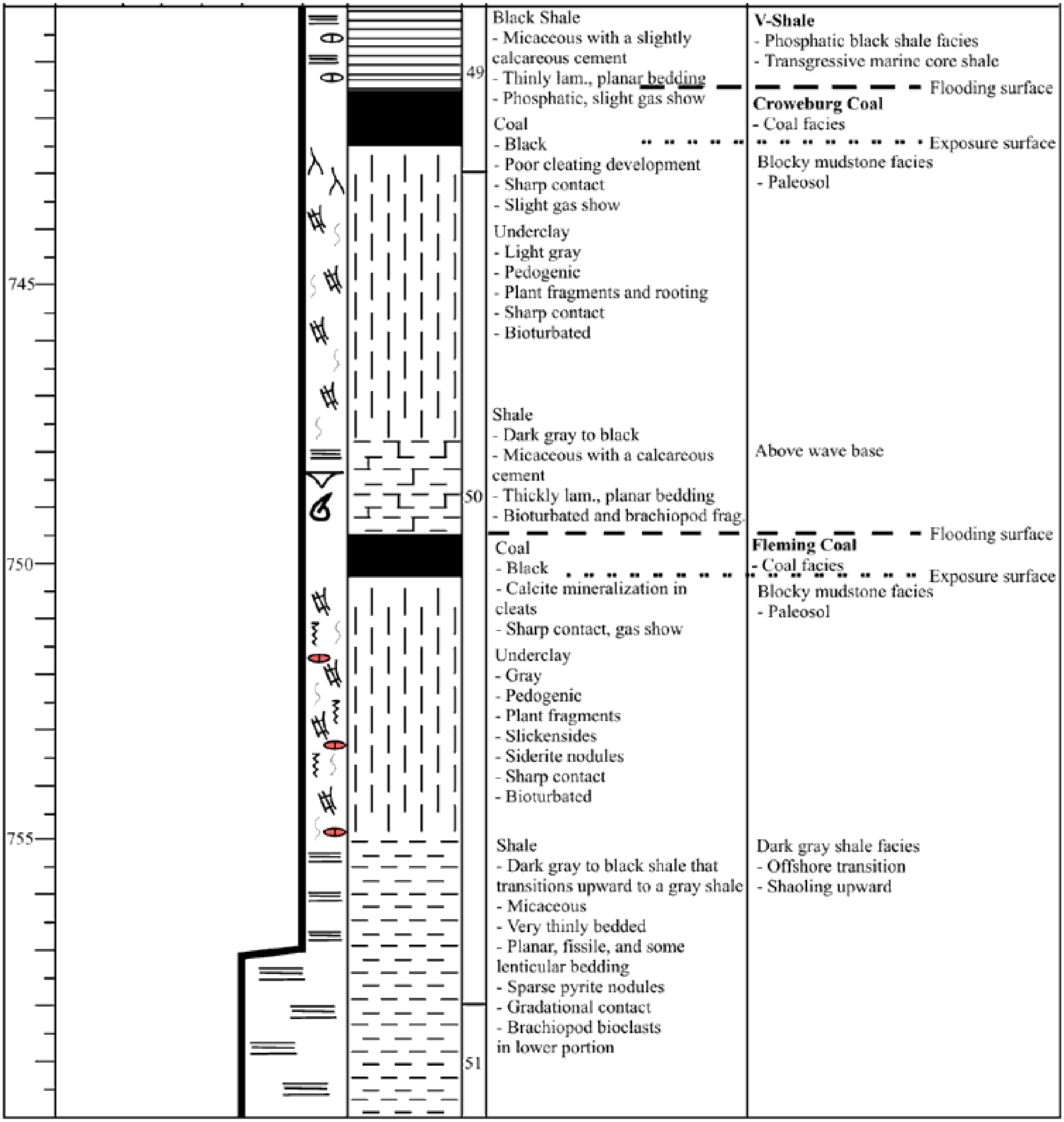

665
670
675
44
45
Flooding Surface
Exposure surface
Underclay
- Light Gray
- Pedogenic
- Slickensides
- Sharp Contact
- Bioturbated
Summit Coal is not present in this core
Blocky mudstone facies
- Paleosol
Limestone
- Dark to medium gray
- Calcareous
- Medium bedded
- Caliche
- Calcrete
- Rip up clasts in lower part of section
- Gradational contact
- Bioclasts of crinoids, bryozoans, brachiopods, corals, and algae
- Slightly oil stained
Blackjack Creek Limestone
- Bioclastic packstone facies
- Regressive upper limestone
- Top contact is an exposure surface
- Shallowing upward sequence
- Above wave base
Bioclastic wackestone facies
- Open marine
- Below wave base
Whole Bioclasts


685
690
695
45
46
47
Limestone
- Same as above
Top of Cherokee Group
Black Shale
- Black
- Micaceous
- Very thinly bedded
- Planar bedding
- Phosphatic
- Gradational contact
- Non-fossiliferous
Excello Shale
Phosphatic black shale facies
- Transgressive marine core shale
Flooding Surface
Coal - gas show
Mulky coal - Coal facies
Underclay
- Dark gray
- Pedogenic, and bioturbated
Blocky mudstone facies
- Paleosol
Exposure surface
Limestone
- Gray
- Calcareous
- Thickly bedded
- Calcite veins
- Caliche
- Gradtional contact
- Bioclasts of brachiopods, fusilinids and crinoids
- Burrowed and bioturbated
Brezzy Hill Limestone
Bioclastic packstone facies
- Shoaling upward sequence, regressive upper limestone
Bioclastic wackestone facies
- Open marine
- Below wave base

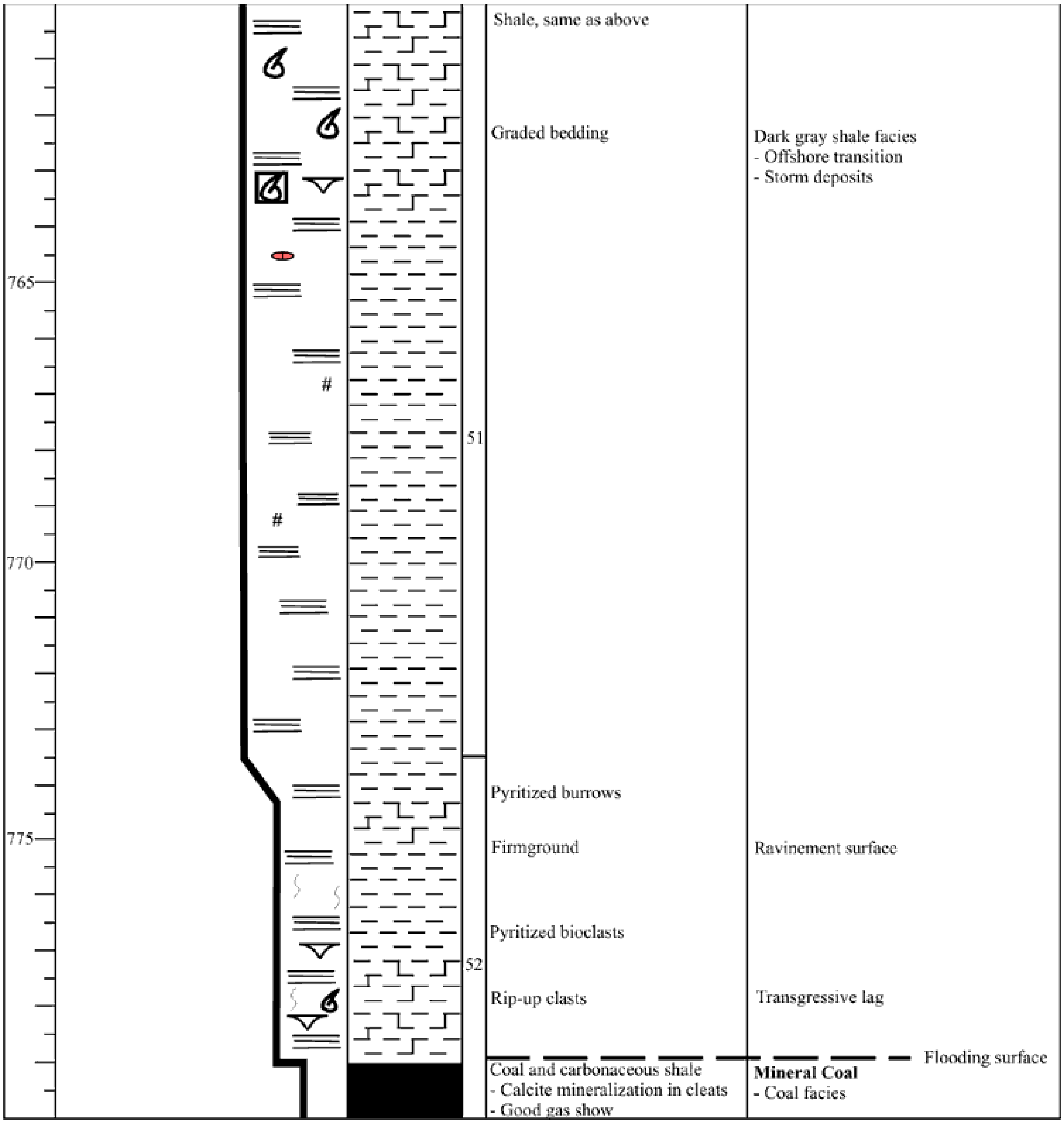


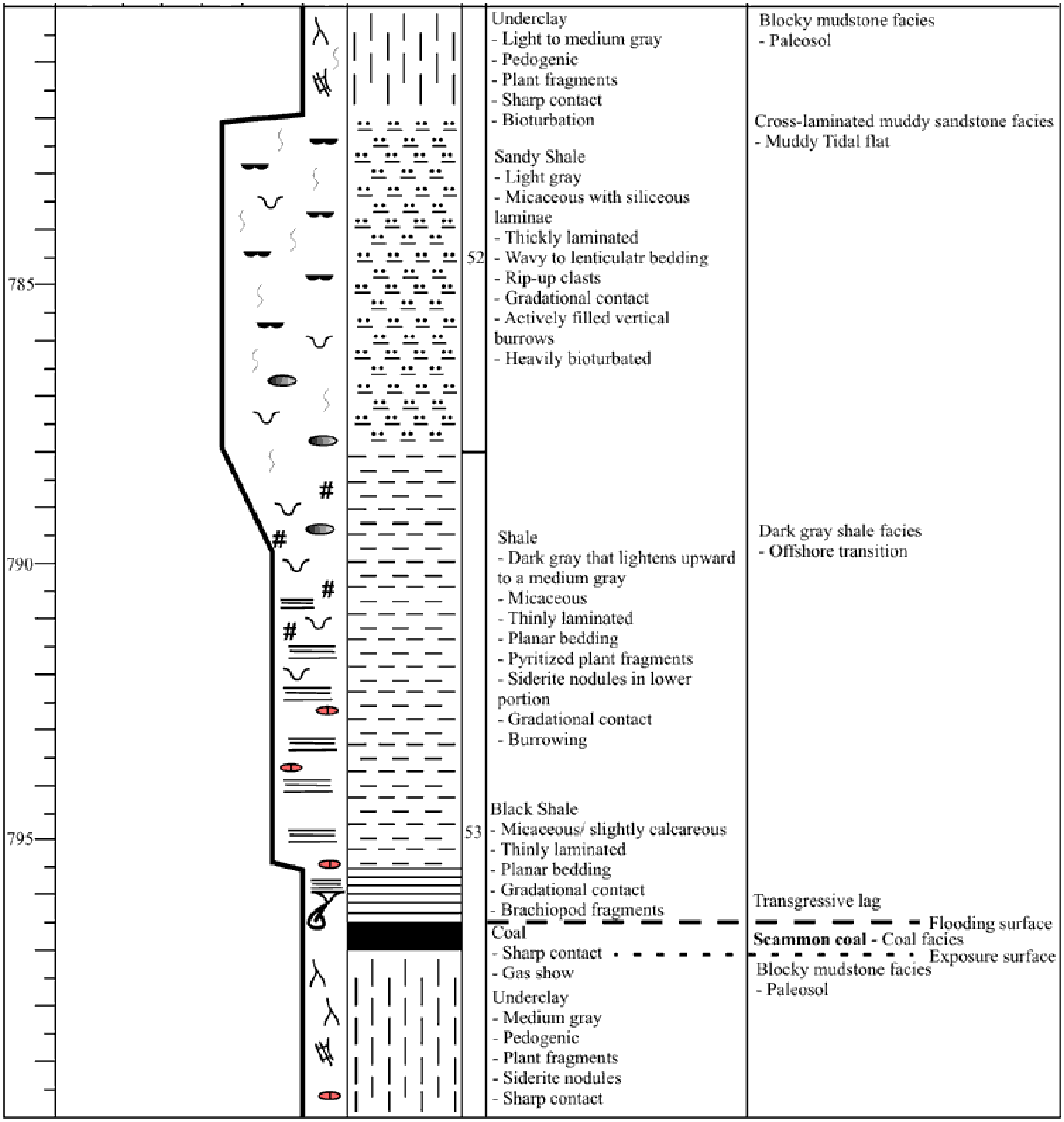
705
710
715
47
48
Shale
- Dark gray
- Micaceous with a calcareous cement
- Thinly laminated, very fissile from 703.5'-708.8'
- Planar bedding
- Abundant pyrite
- Sharp contact
- Abundant bioclastic fragments of brachiopods, fusilinids and crinoids
Dark gray shale facies
- Offshore transition
- Shoaling upward
Near the anaerobic - disaerobic zone
Concave down shells
Higher energy, storm deposits
- Mean storm wave base
Graded bedding
Black Shale
- Micaceous with a slightly calcareous cement
- Thinly laminated
- Planar bedded
- Gradational contact
- Pyritized bioclastic fragments
Pyritic black shale facies
- Coastal swamp/marsh
Flooding surface
Coal
- Black
- Well developed cleats
- Sharp contact
- Good gas show
Iron Post coal
- Coal facies
Exposure surface
Underclay
- Gray
- Pedogenic, siderite nodules
- Slickensides and bioturbated
Blocky mudstone facies
- Paleosol


725
730
735
48
49
Sandy Shale
- Light brown from 721'-723' and medium gray from 723'- 736'
- Micaceous and siliceous with a slightly calcareous cement
- Rounded and well sorted sand
- Thickly laminated
- Lenticular and planar bedded
- Starved wave ripples
- Sparse pyrite and siderite
- Gradational contact
- Brachiopods in lower portion
Interlaminated sandstone and shale facies
- Tidal flat on the edge of an estuary.
- Possibly sequence boundary.
Dark gray shale facies
- Offshore transition
Graded bedding
Transgressive lag or storm deposits
Limestone
- Dark gray
- Calcareous
- Thinly to medium bedded
- Gradational contact
- Bioclasts of brachiopods and bryozoans
Verdigris Limestone
- Bioclastic wackestone facies
- Upper regressive limestone
Shelf edge
- Open marine
- Below wave base

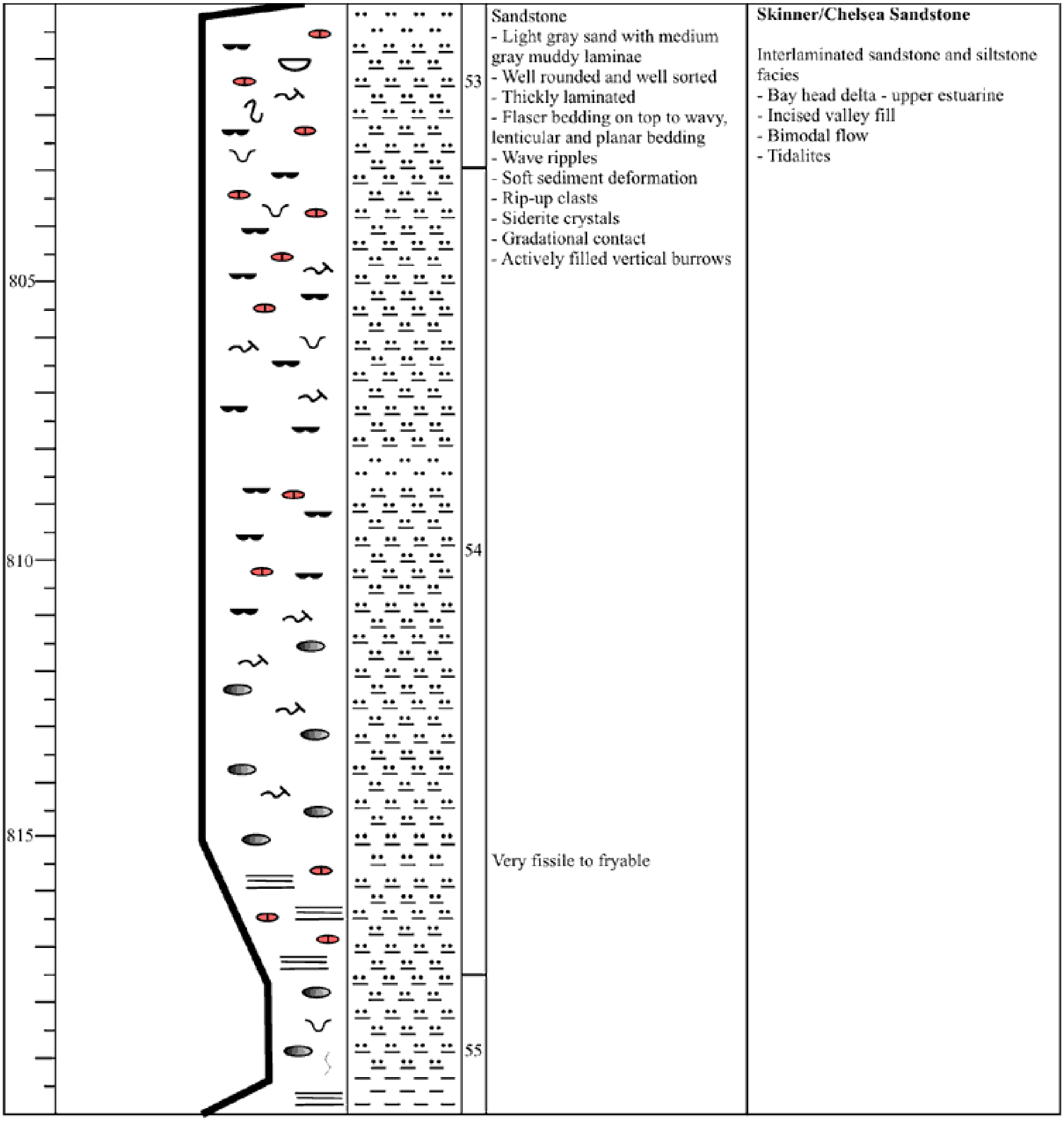


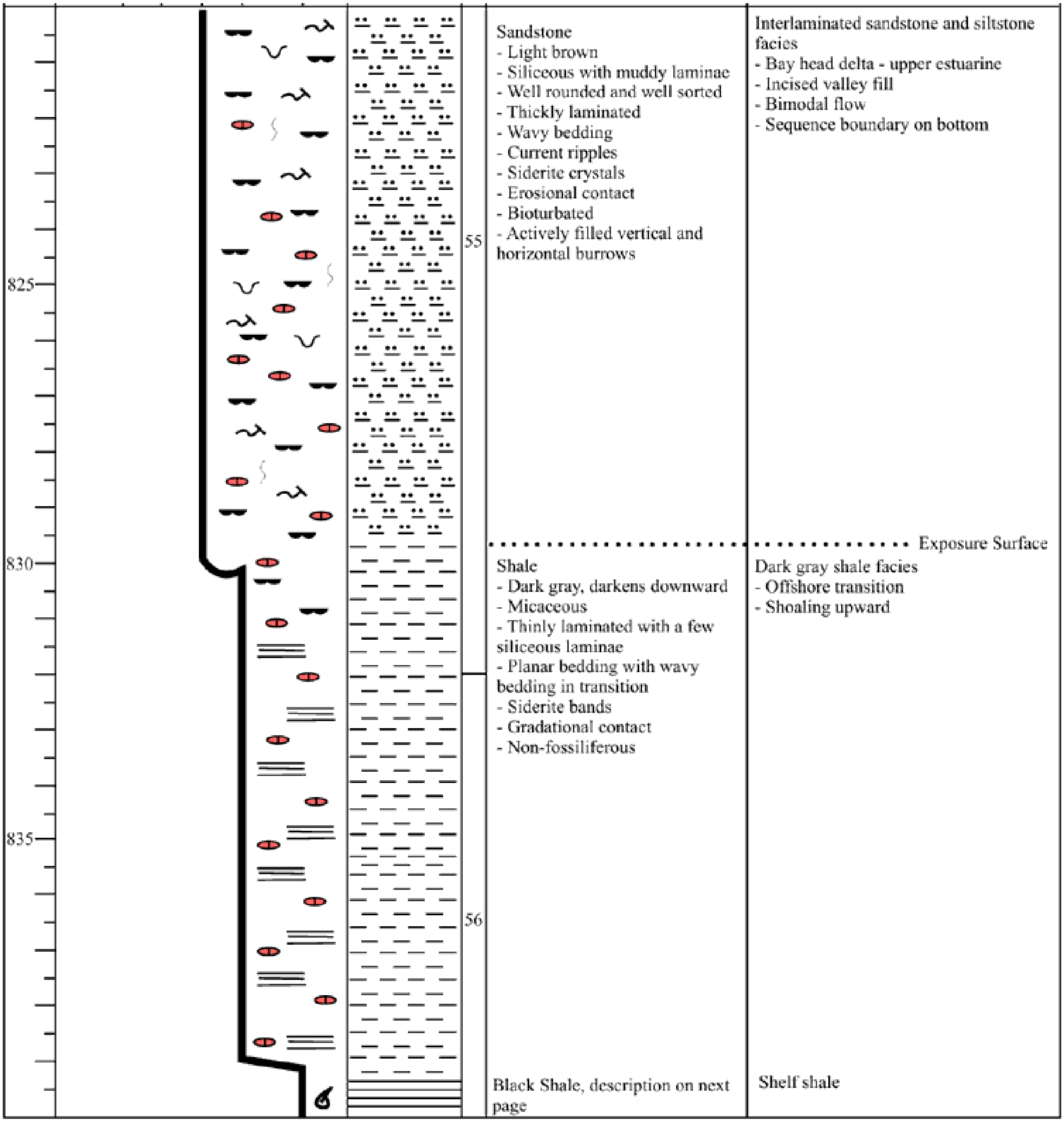
745
750
755
49
50
51
Black Shale
- Micaceous with a slightly calcareous cement
- Thinly lam., planar bedding
- Phosphatic, slight gas show
Coal
- Black
- Poor cleating development
- Sharp contact
- Slight gas show
Underclay
- Light gray
- Pedogenic
- Plant fragments and rooting
- Sharp contact
- Bioturbated
Shale
- Dark gray to black
- Micaceous with a calcareous cement
- Thickly lam., planar bedding
- Bioturbated and brachiopod frag.
Coal
- Black
- Calcite mineralization in cleats
- Sharp contact, gas show
Underclay
- Gray
- Pedogenic
- Plant fragments
- Slickensides
- Siderite nodules
- Sharp contact
- Bioturbated
Shale
- Dark gray to black shale that transitions upward to a gray shale
- Micaceous
- Very thinly bedded
- Planar, fissile, and some lenticular bedding
- Sparse pyrite nodules
- Gradational contact
- Brachiopod bioclasts in lower portion
V-Shale
- Phosphatic black shale facies
- Transgressive marine core shale
Flooding surface
Croweburg Coal
- Coal facies
Exposure surface
Blocky mudstone facies
- Paleosol
Above wave base
Flooding surface
Fleming Coal
- Coal facies
Exposure surface
Blocky mudstone facies
- Paleosol
Dark gray shale facies
- Offshore transition
- Shoaling upward

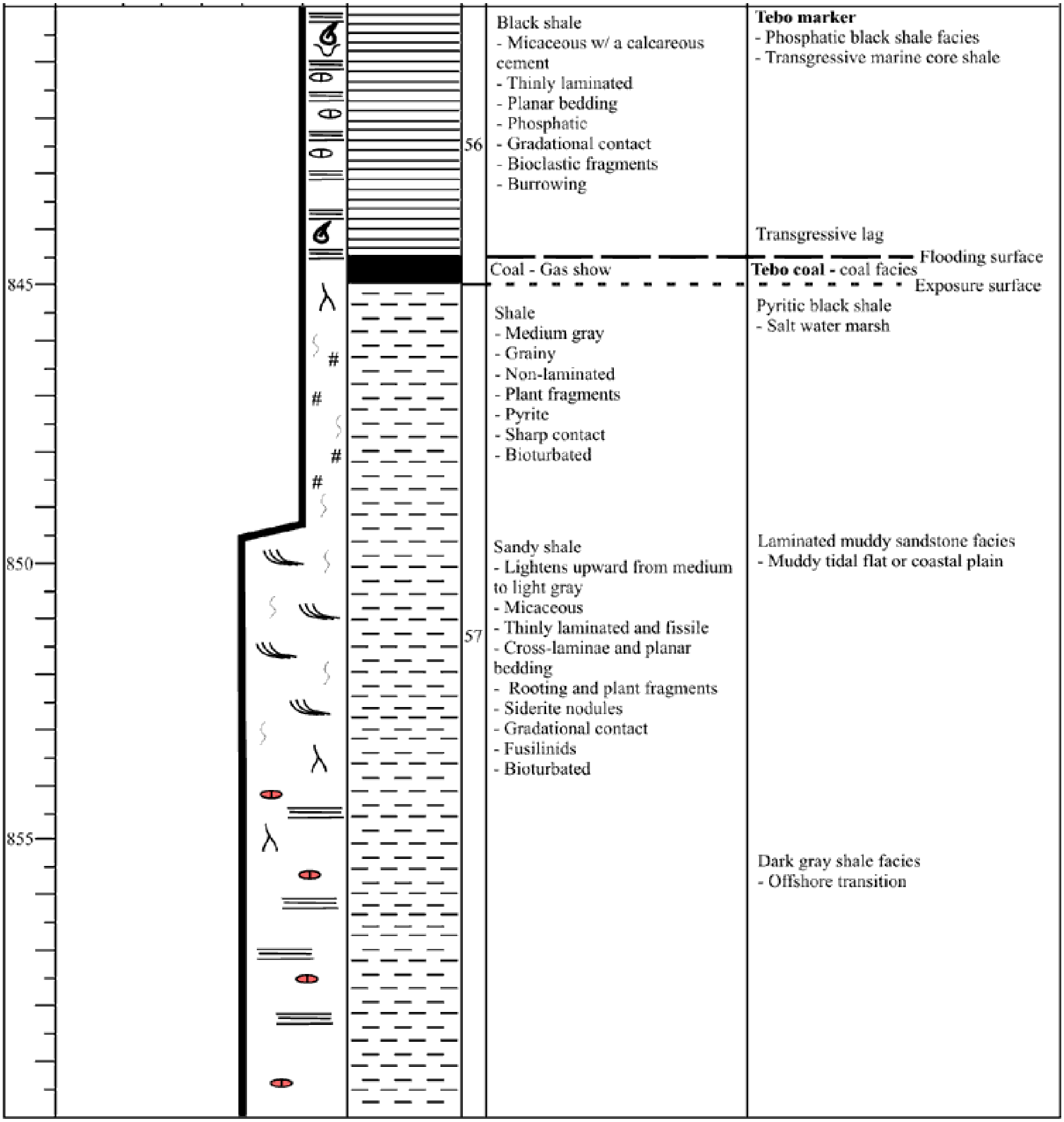

765
770
775
51
52
Shale, same as above
Graded bedding
Dark gray shale facies
- Offshore transition
- Storm deposits
Pyritized burrows
Firmground
Ravinement surface
Pyritized bioclasts
Rip-up clasts
Transgressive lag
Flooding surface
Coal and carbonaceous shale
- Calcite mineralization in cleats
- Good gas show
Mineral Coal
- Coal facies



785
790
795
52
53
Underclay
- Light to medium gray
- Pedogenic
- Plant fragments
- Sharp contact
- Bioturbation
Sandy Shale
- Light gray
- Micaceous with siliceous laminae
- Thickly laminated
- Wavy to lenticulatr bedding
- Rip-up clasts
- Gradational contact
- Actively filled vertical burrows
- Heavily bioturbated
Shale
- Dark gray that lightens upward to a medium gray
- Micaceous
- Thinly laminated
- Planar bedding
- Pyritized plant fragments
- Siderite nodules in lower portion
- Gradational contact
- Burrowing
Black Shale
- Micaceous/ slightly calcareous
- Thinly laminated
- Planar bedding
- Gradational contact
- Brachiopod fragments
Coal
- Sharp contact
- Gas show
Underclay
- Medium gray
- Pedogenic
- Plant fragments
- Siderite nodules
- Sharp contact
Blocky mudstone facies
- Paleosol
Cross-laminated muddy sandstone facies
- Muddy Tidal flat
Dark gray shale facies
- Offshore transition
Transgressive lag
Flooding surface
Scammon coal - Coal facies
Exposure surface
Blocky mudstone facies
- Paleosol


805
810
815
53
54
55
Sandstone
- Light gray sand with medium gray muddy laminae
- Well rounded and well sorted
- Thickly laminated
- Flaser bedding on top to wavy, lenticular and planar bedding
- Wave ripples
- Soft sediment deformation
- Rip-up clasts
- Siderite crystals
- Gradational contact
- Actively filled vertical burrows
Very fissile to fryable
Skinner/Chelsea Sandstone
Interlaminated sandstone and siltstone facies
- Bay head delta - upper estuarine
- Incised valley fill
- Bimodal flow
- Tidalites


825
830
835
55
56
Sandstone
- Light brown
- Siliceous with muddy laminae
- Well rounded and well sorted
- Thickly laminated
- Wavy bedding
- Current ripples
- Siderite crystals
- Erosional contact
- Bioturbated
- Actively filled vertical and horizontal burrows
Interlaminated sandstone and siltstone facies
- Bay head delta - upper estuarine
- Incised valley fill
- Bimodal flow
- Sequence boundary on bottom
Exposure Surface
Shale
- Dark gray, darkens downward
- Micaceous
- Thinly laminated with a few siliceous laminae
- Planar bedding with wavy bedding in transition
- Siderite bands
- Gradational contact
- Non-fossiliferous
Dark gray shale facies
- Offshore transition
- Shoaling upward
Black Shale, description on next page
Shelf shale

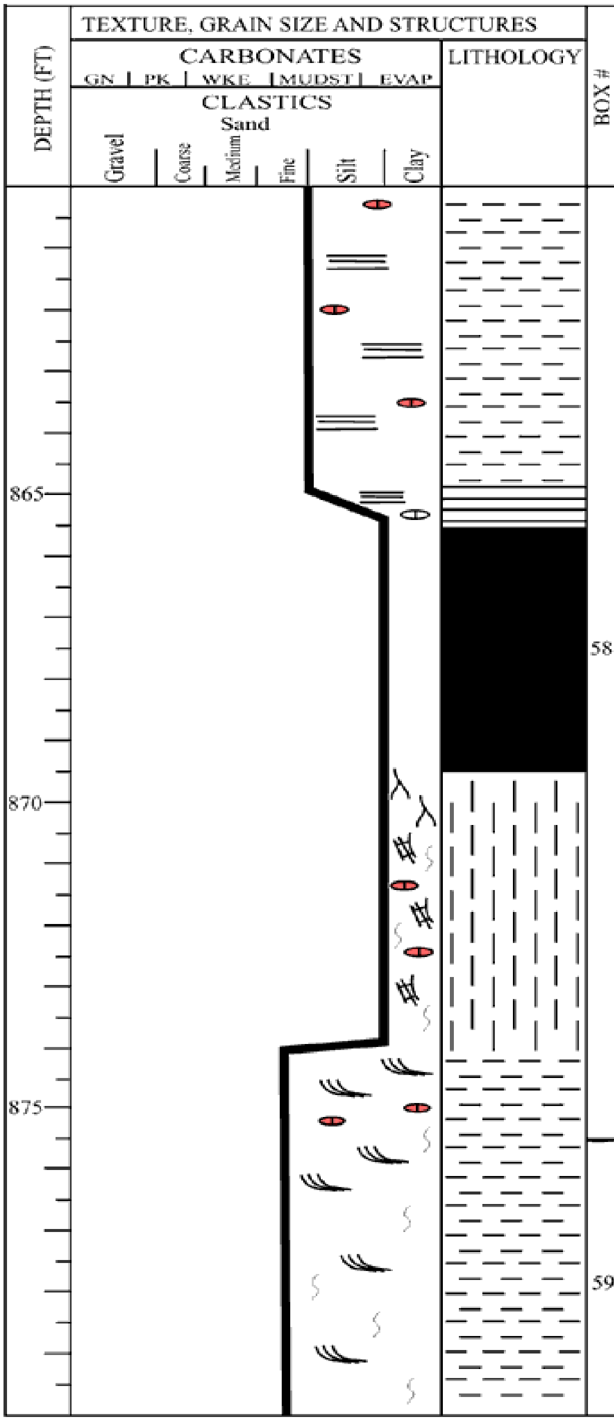


Black shale
- Micaceous w/ a calcareous cement
- Thinly laminated
- Planar bedding
- Phosphatic
- Gradational contact
- Bioclastic fragments
- Burrowing
56
Tebo marker
- Phosphatic black shale facies
- Transgressive marine core shale
Transgressive lag
Flooding surface
Coal - Gas show
Tebo coal - coal facies
Exposure surface
845
Shale
- Medium gray
- Grainy
- Non-laminated
- Plant fragments
- Pyrite
- Sharp contact
- Bioturbated
Pyritic black shale
- Salt water marsh
850
Sandy shale
- Lightens upward from medium to light gray
- Micaceous
- Thinly laminated and fissile
- Cross-laminae and planar bedding
- Rooting and plant fragments
- Siderite nodules
- Gradational contact
- Fusilinids
- Bioturbated
57
Laminated muddy sandstone facies
- Muddy tidal flat or coastal plain
855
Dark gray shale facies
- Offshore transition

DATE JUNE 2002

UNIT: Cherokee Group

PAGE 13 OF 24 PAGES



DESCRIPTION
- Lithology
- Color
- Comp., Cement, or Matrix
- Shape and Sorting
- Bedding
- Sed. Structures
- Upper Contact
- Fossils

REMARKS, INTERPRETATION

Shale, same as above

Black Shale
- Micaceous
- Diagonally laminated
- Planar bedding
- Phosphatic
- Gradational contact
- Gas show

Phosphatic black shale facies
- Shelf shale

Flooding Surface

Coal
- Black
- Well developed cleating
- Sharp contact
- Gas show

Weir-Pittsburg coal
- Coal facies
- Coastal coal

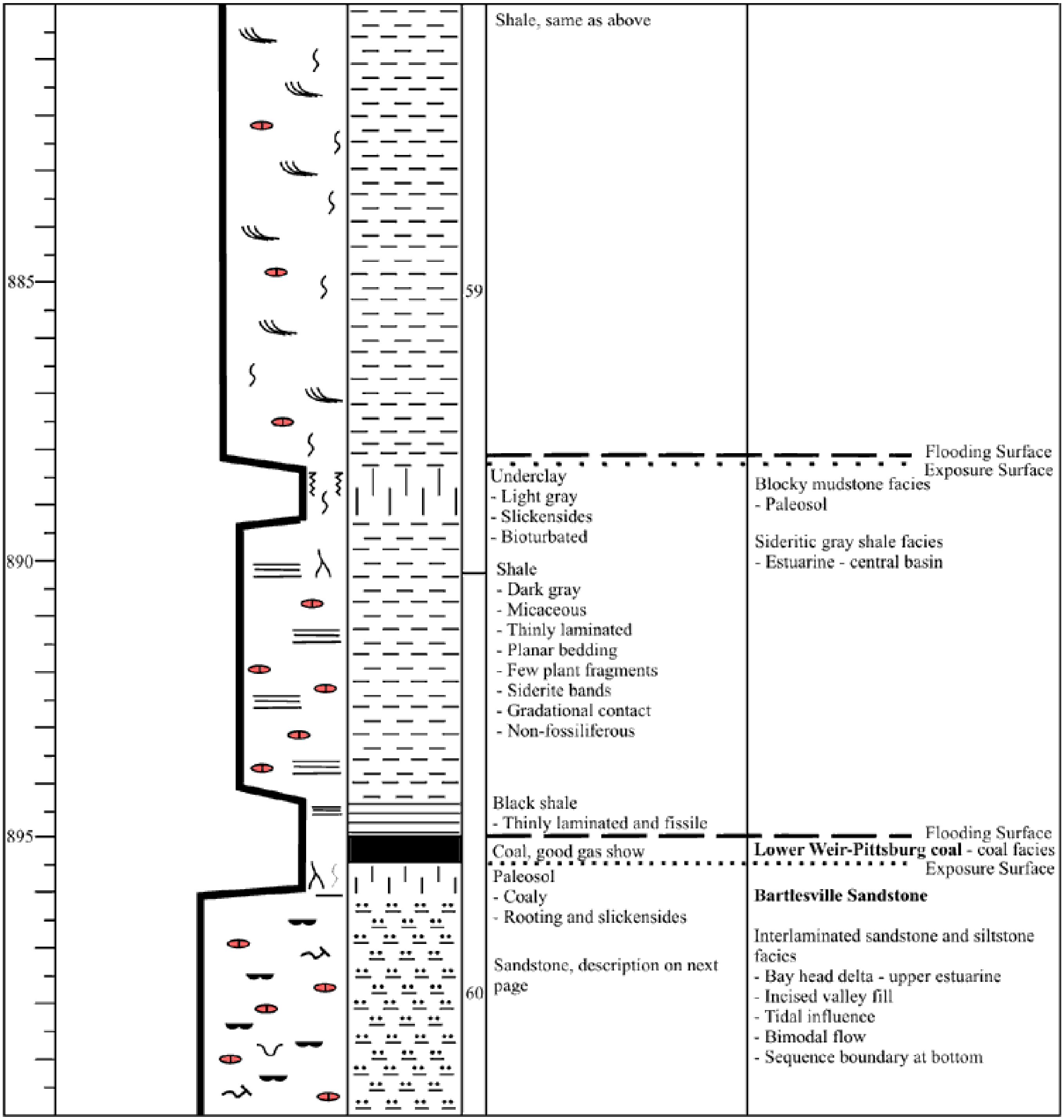
Exposure surface

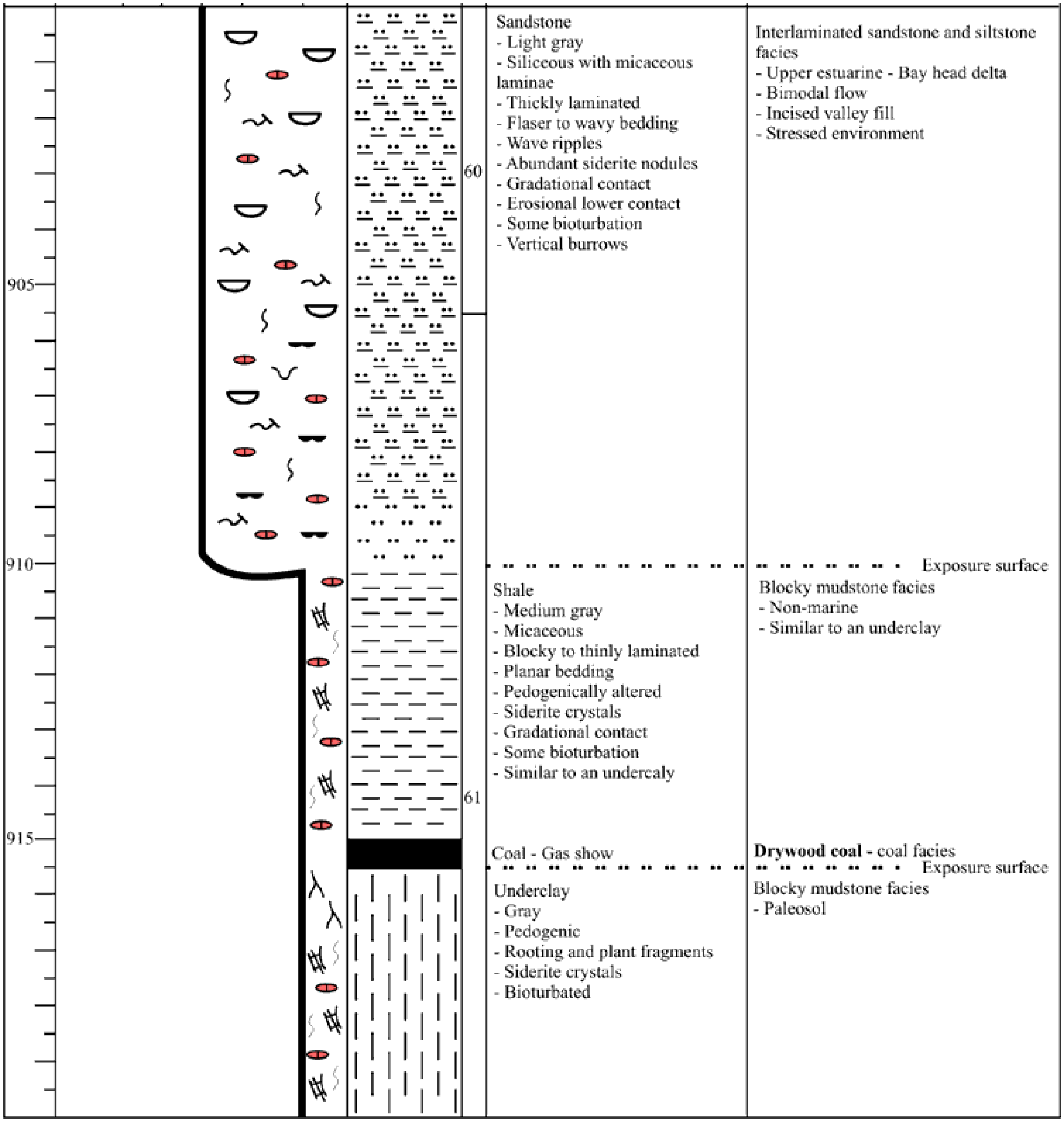
Underclay
- Brown to gray
- Fissile
- Pedogenic
- Rooting and plant fragments
- Siderite nodules
- Sharp contact
- Bioturbated

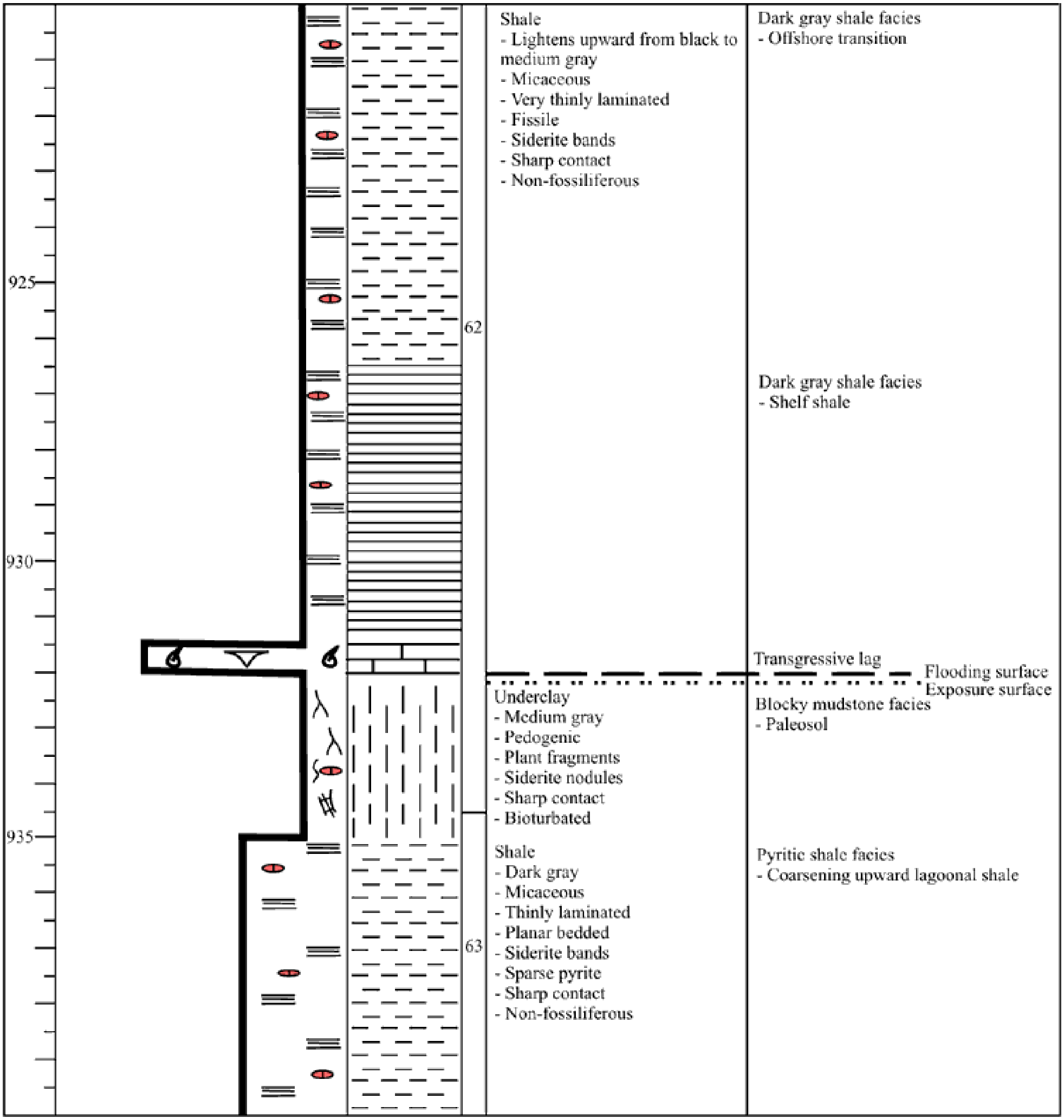
Blocky mudstone facies
- Paleosol

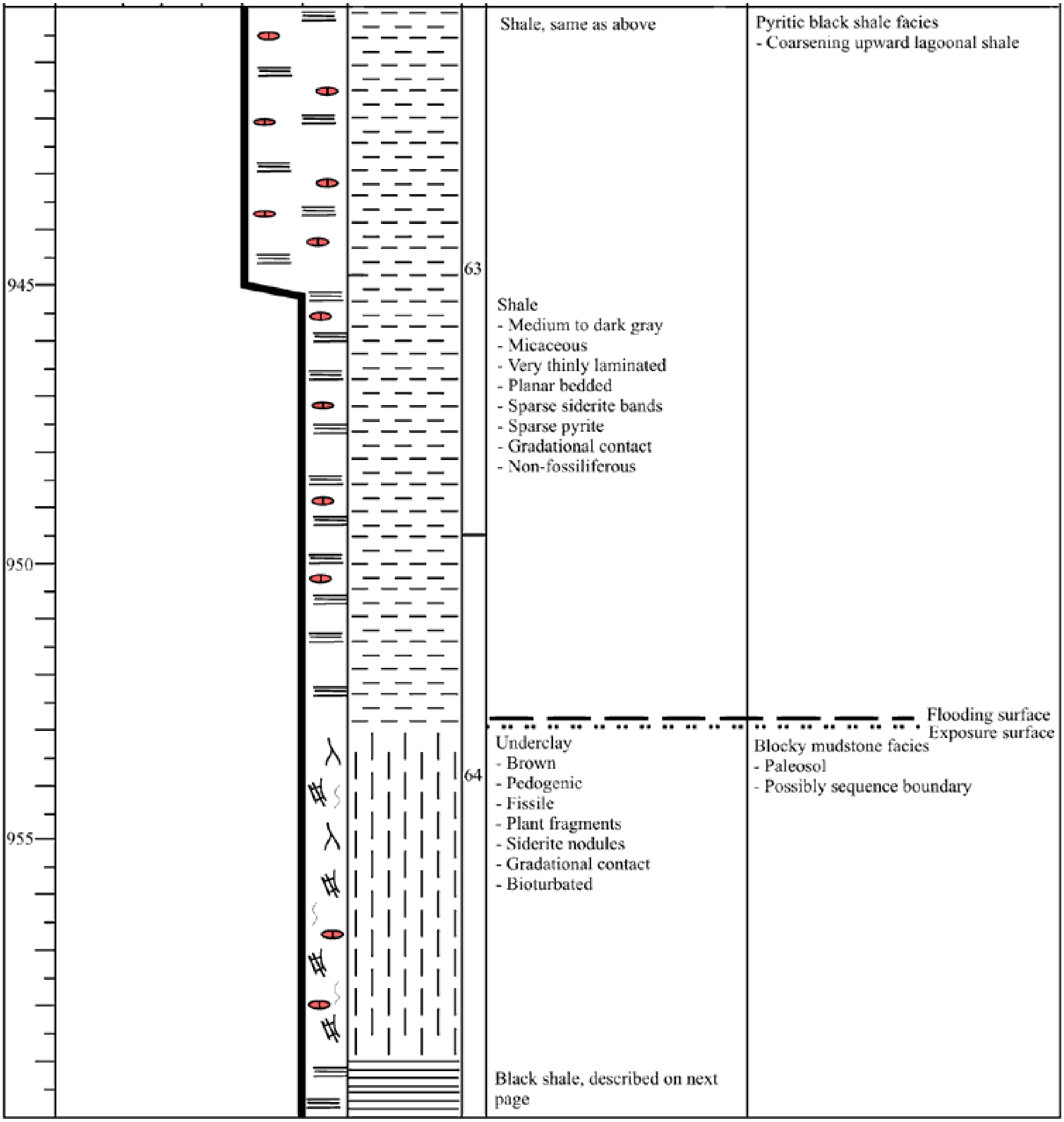
Sandy shale
- Dark gray
- Micaceous
- Thinly laminated
- Cross laminae
- Few plant fragments
- Siderite nodules
- Gradational contact
- Bioturbated

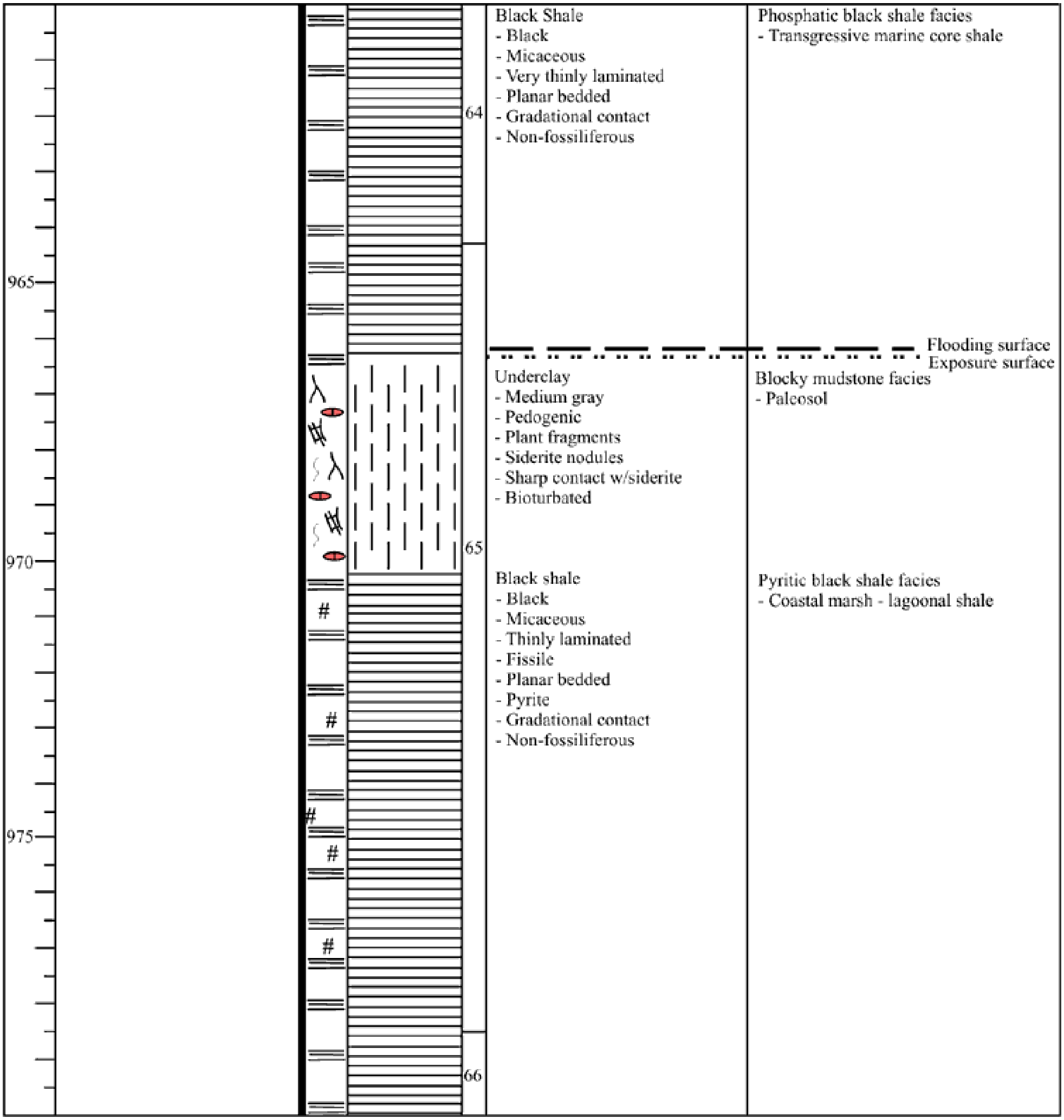
Laminated muddy sandstone facies
- Muddy tidal flat or coastal plain

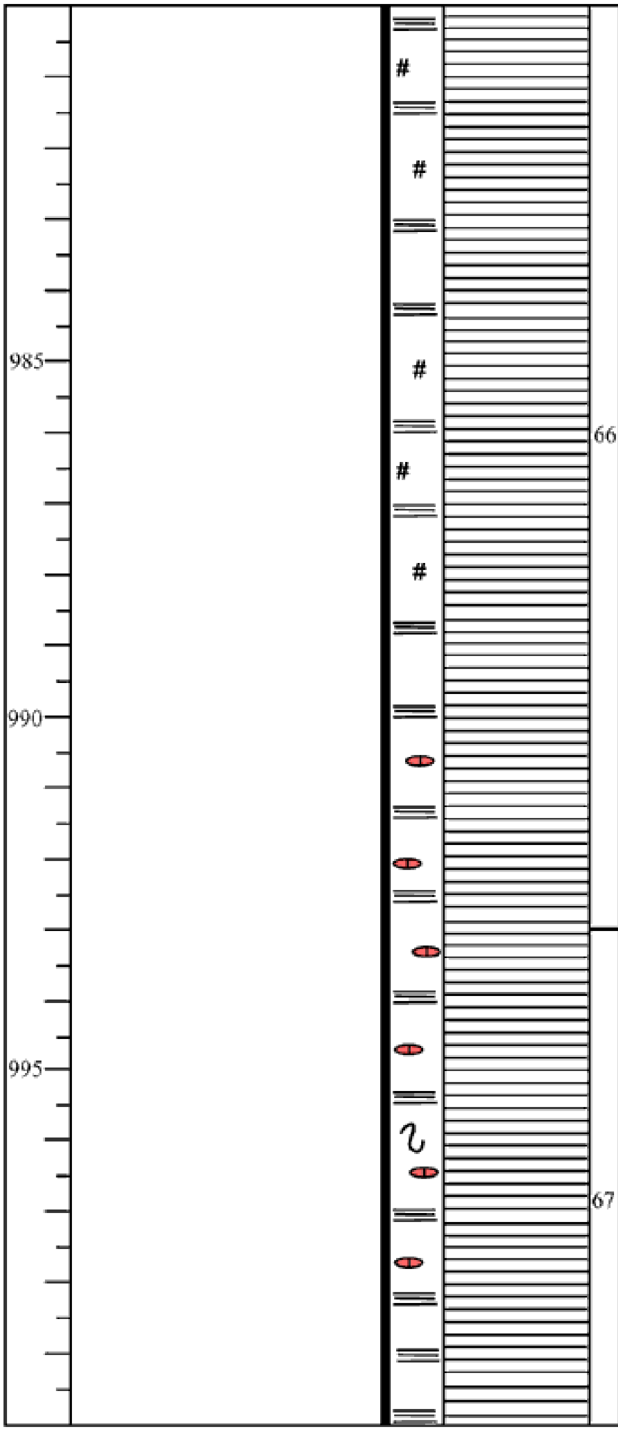

885
890
895
59
60
Shale, same as above
Flooding Surface
Exposure Surface
Underclay
- Light gray
- Slickensides
- Bioturbated
Blocky mudstone facies
- Paleosol
Shale
- Dark gray
- Micaceous
- Thinly laminated
- Planar bedding
- Few plant fragments
- Siderite bands
- Gradational contact
- Non-fossiliferous
Sideritic gray shale facies
- Estuarine - central basin
Black shale
- Thinly laminated and fissile
Flooding Surface
Coal, good gas show
Lower Weir-Pittsburg coal - coal facies
Exposure Surface
Paleosol
- Coaly
- Rooting and slickensides
Bartlesville Sandstone
Sandstone, description on next page
Interlaminated sandstone and siltstone facies
- Bay head delta - upper estuarine
- Incised valley fill
- Tidal influence
- Bimodal flow
- Sequence boundary at bottom


905
910
915
60
61
Sandstone
- Light gray
- Siliceous with micaceous laminae
- Thickly laminated
- Flaser to wavy bedding
- Wave ripples
- Abundant siderite nodules
- Gradational contact
- Erosional lower contact
- Some bioturbation
- Vertical burrows
Interlaminated sandstone and siltstone facies
- Upper estuarine - Bay head delta
- Bimodal flow
- Incised valley fill
- Stressed environment
Exposure surface
Shale
- Medium gray
- Micaceous
- Blocky to thinly laminated
- Planar bedding
- Pedogenically altered
- Siderite crystals
- Gradational contact
- Some bioturbation
- Similar to an undercaly
Blocky mudstone facies
- Non-marine
- Similar to an underclay
Coal - Gas show
Drywood coal - coal facies
Exposure surface
Underclay
- Gray
- Pedogenic
- Rooting and plant fragments
- Siderite crystals
- Bioturbated
Blocky mudstone facies
- Paleosol


925
930
935
62
63
Shale
- Lightens upward from black to medium gray
- Micaceous
- Very thinly laminated
- Fissile
- Siderite bands
- Sharp contact
- Non-fossiliferous
Dark gray shale facies
- Offshore transition
Dark gray shale facies
- Shelf shale
Transgressive lag
Flooding surface
Exposure surface
Underclay
- Medium gray
- Pedogenic
- Plant fragments
- Siderite nodules
- Sharp contact
- Bioturbated
Blocky mudstone facies
- Paleosol
Shale
- Dark gray
- Micaceous
- Thinly laminated
- Planar bedded
- Siderite bands
- Sparse pyrite
- Sharp contact
- Non-fossiliferous
Pyritic shale facies
- Coarsening upward lagoonal shale

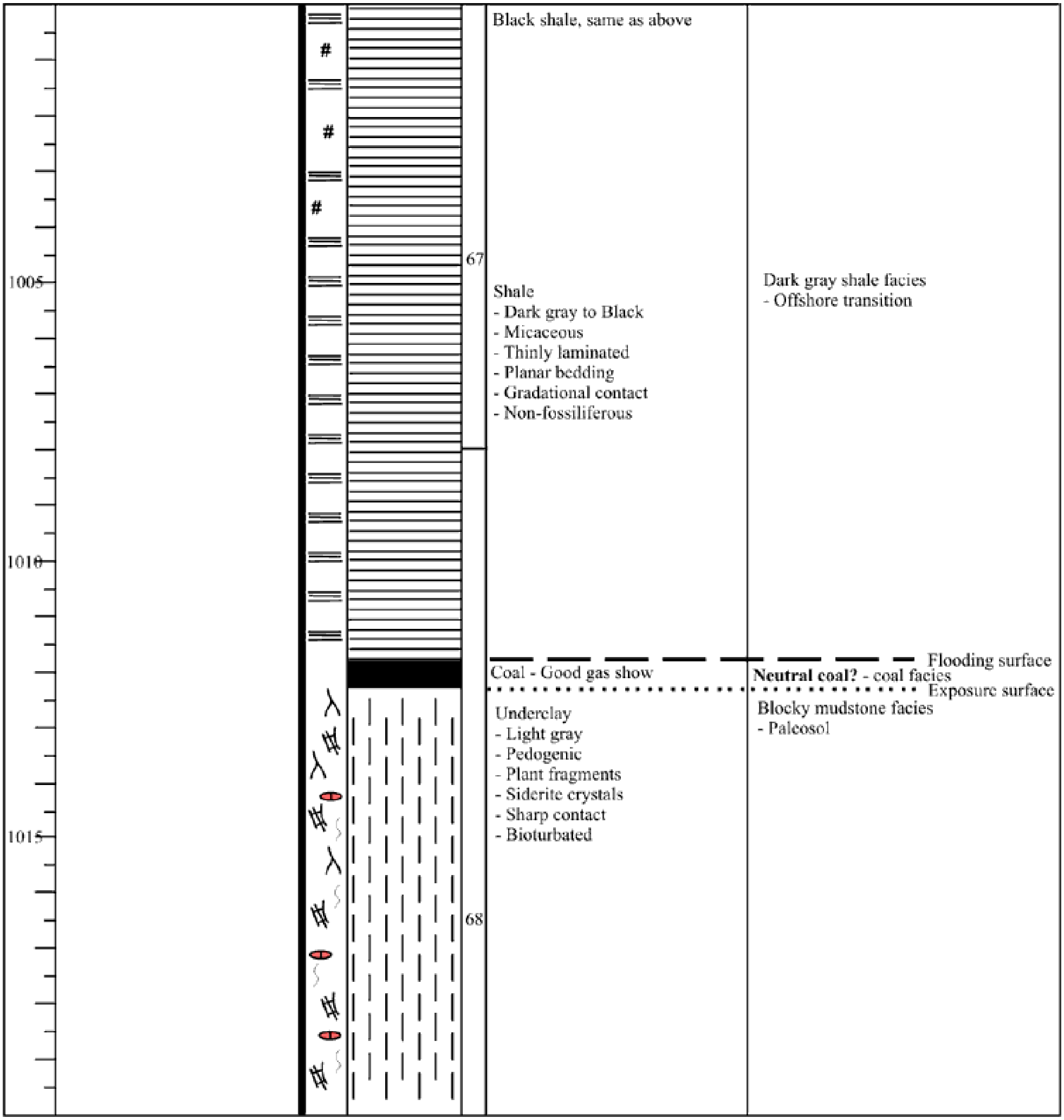

945
950
955
63
64
Shale, same as above
Shale
- Medium to dark gray
- Micaceous
- Very thinly laminated
- Planar bedded
- Sparse siderite bands
- Sparse pyrite
- Gradational contact
- Non-fossiliferous
Underclay
- Brown
- Pedogenic
- Fissile
- Plant fragments
- Siderite nodules
- Gradational contact
- Bioturbated
Black shale, described on next page
Pyritic black shale facies
- Coarsening upward lagoonal shale
Flooding surface
Exposure surface
Blocky mudstone facies
- Paleosol
- Possibly sequence boundary

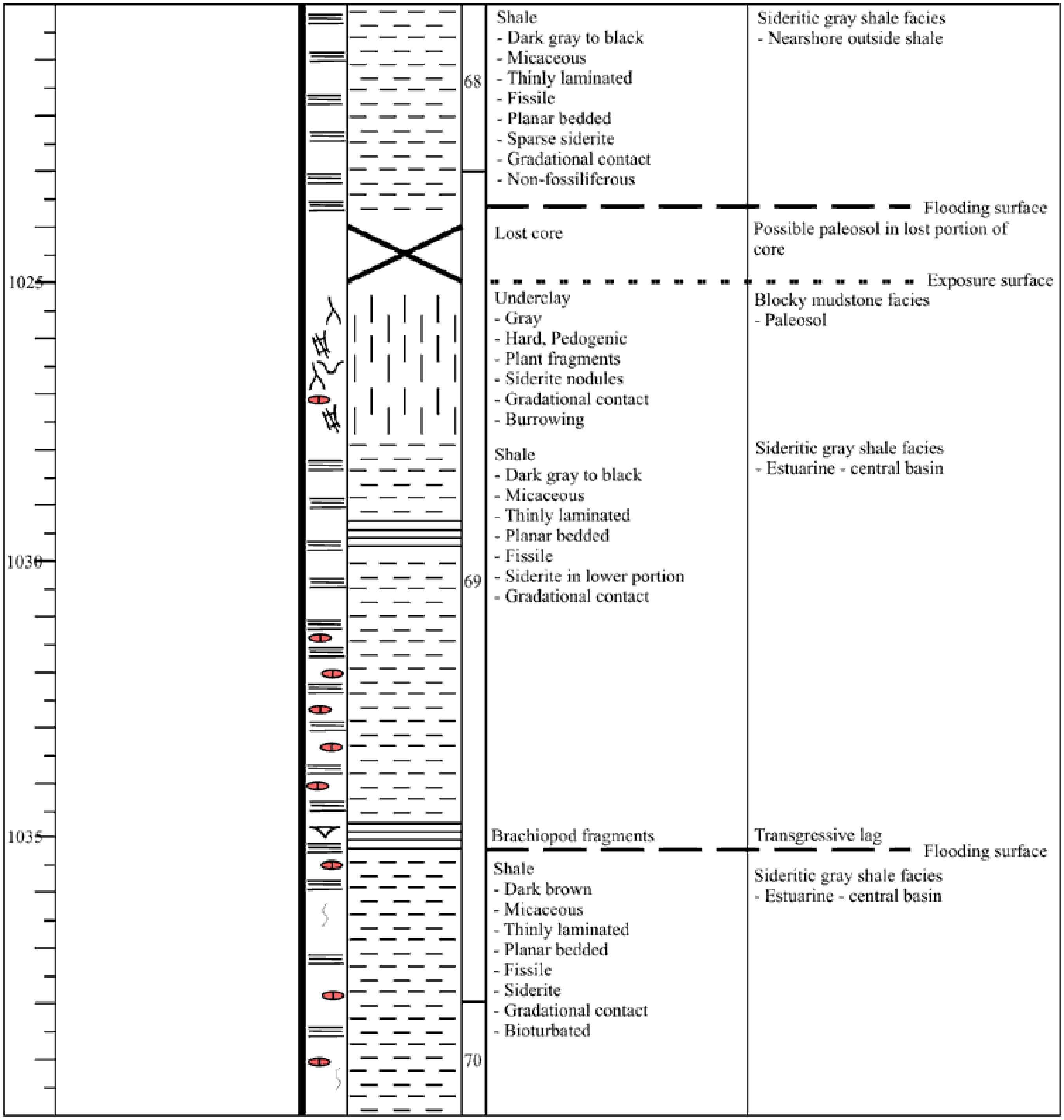

965
970
975
64
65
66
Black Shale
- Black
- Micaceous
- Very thinly laminated
- Planar bedded
- Gradational contact
- Non-fossiliferous
Phosphatic black shale facies
- Transgressive marine core shale
Flooding surface
Exposure surface
Underclay
- Medium gray
- Pedogenic
- Plant fragments
- Siderite nodules
- Sharp contact w/siderite
- Bioturbated
Blocky mudstone facies
- Paleosol
Black shale
- Black
- Micaceous
- Thinly laminated
- Fissile
- Planar bedded
- Pyrite
- Gradational contact
- Non-fossiliferous
Pyritic black shale facies
- Coastal marsh - lagoonal shale



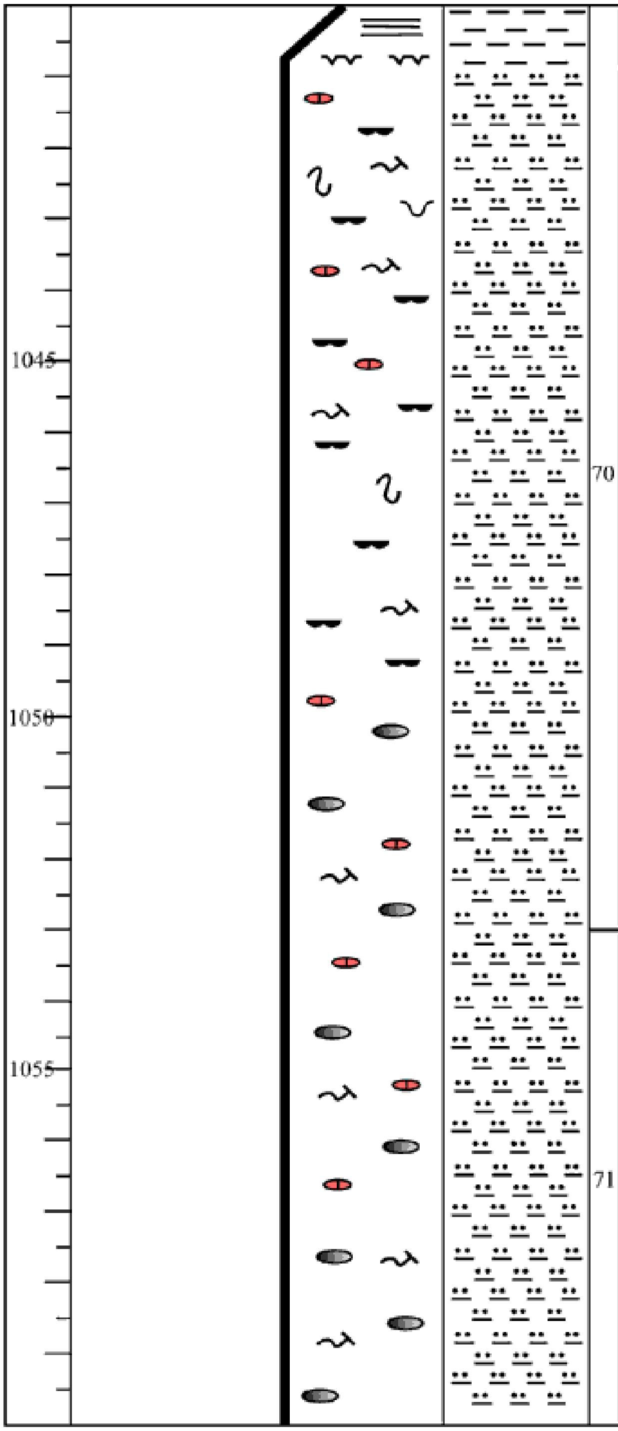
Black Shale
- Black
- Micaceous
- Thinly laminated
- Planar bedding
- Fissile from 985'-990'
- Pyrite and Siderite bands
- Soft sediment deformation
- Gradational contact
- Non-fossiliferous

Pyritic black shale facies
- Costal marsh - brackish water marsh

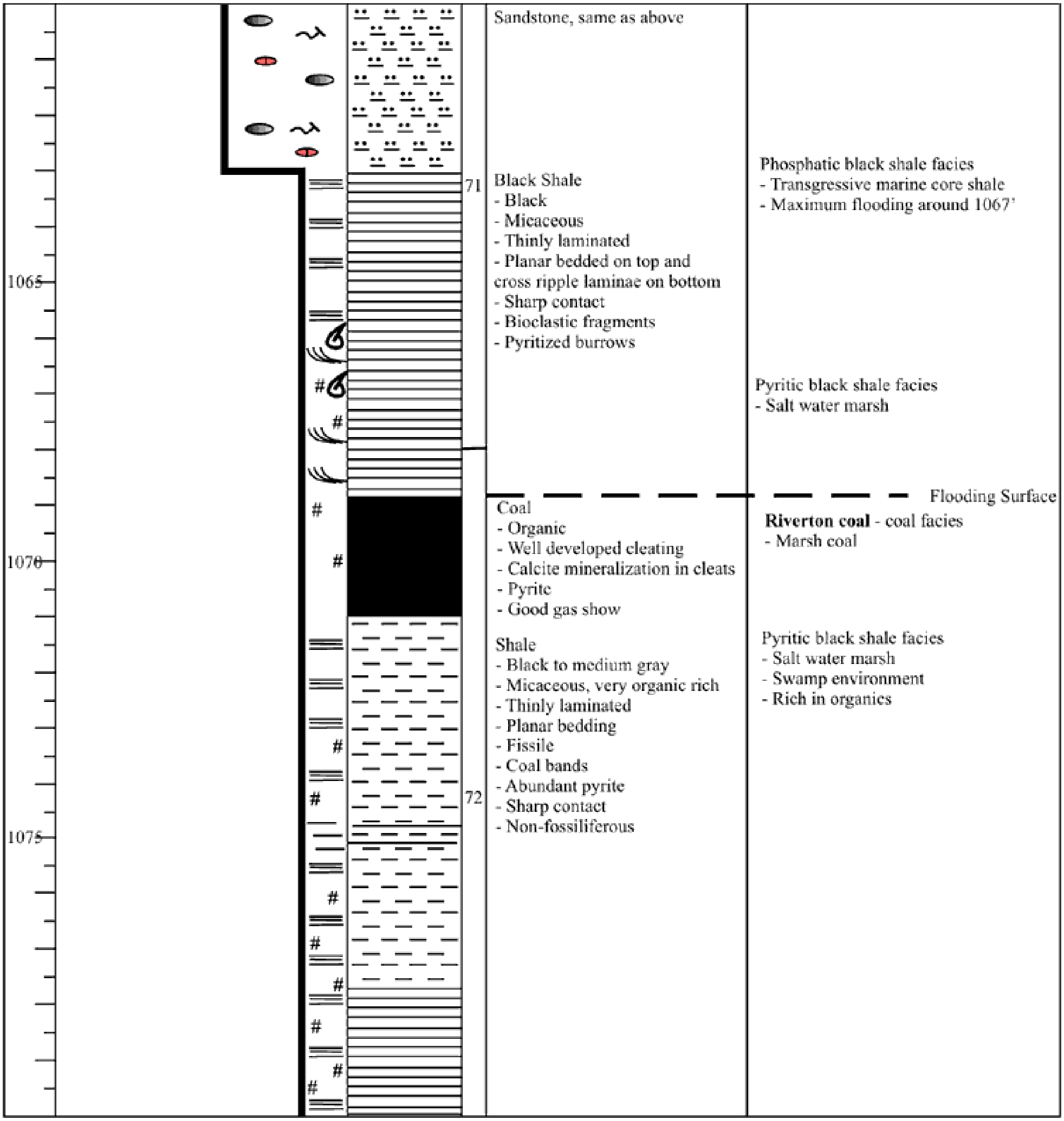

1005
1010
1015
67
68
Black shale, same as above
Shale
- Dark gray to Black
- Micaceous
- Thinly laminated
- Planar bedding
- Gradational contact
- Non-fossiliferous
Dark gray shale facies
- Offshore transition
Flooding surface
Coal - Good gas show
Neutral coal? - coal facies
Exposure surface
Underclay
- Light gray
- Pedogenic
- Plant fragments
- Siderite crystals
- Sharp contact
- Bioturbated
Blocky mudstone facies
- Paleosol



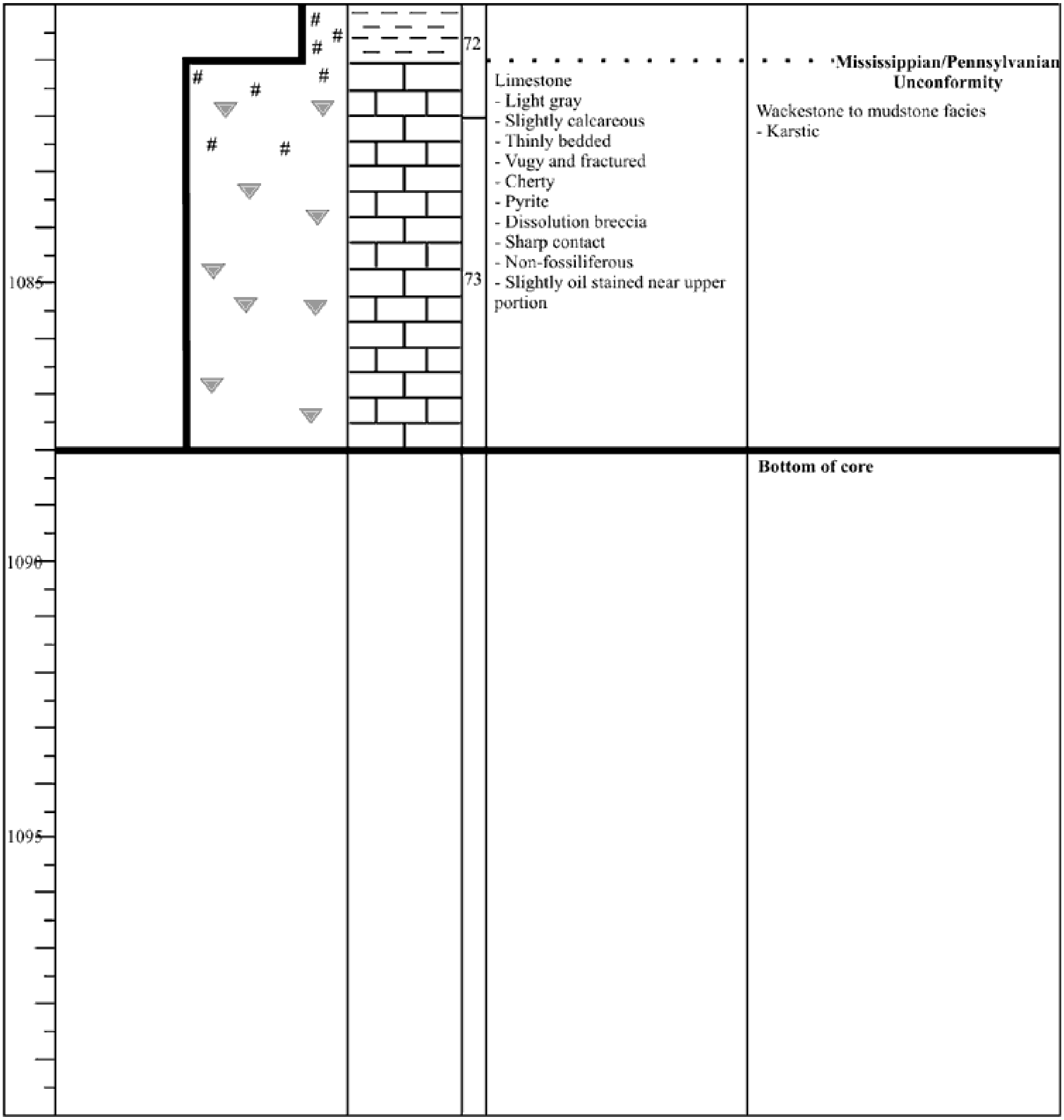
1025
1030
1035
68
69
70
Shale
- Dark gray to black
- Micaceous
- Thinly laminated
- Fissile
- Planar bedded
- Sparse siderite
- Gradational contact
- Non-fossiliferous
Sideritic gray shale facies
- Nearshore outside shale
Flooding surface
Lost core
Possible paleosol in lost portion of core
Exposure surface
Underclay
- Gray
- Hard, Pedogenic
- Plant fragments
- Siderite nodules
- Gradational contact
- Burrowing
Blocky mudstone facies
- Paleosol
Shale
- Dark gray to black
- Micaceous
- Thinly laminated
- Planar bedded
- Fissile
- Siderite in lower portion
- Gradational contact
Sideritic gray shale facies
- Estuarine - central basin
Brachiopod fragments
Transgressive lag
Flooding surface
Shale
- Dark brown
- Micaceous
- Thinly laminated
- Planar bedded
- Fissile
- Siderite
- Gradational contact
- Bioturbated
Sideritic gray shale facies
- Estuarine - central basin



Sandstone - Siliceous with micaceous laminae - Very fine-grained, well sorted and well rounded - Thickly laminated - Wavy bedded in upper half and lenticular bedded on bottom half - Starved wave ripples - Siderite bands - Syneresis cracks - Slumping - Gradational contact - Arenicolites and Diplocraterion burrows	**Warner Sandstone** Interlaminated sandstone and siltstone facies - Bay head delta - upper estuarine - Incised valley fill - Bimodal flow - There are several 1-5cm silting upward packages representing tidal cycles - Low trace fossil diversity indicates a stressed environment

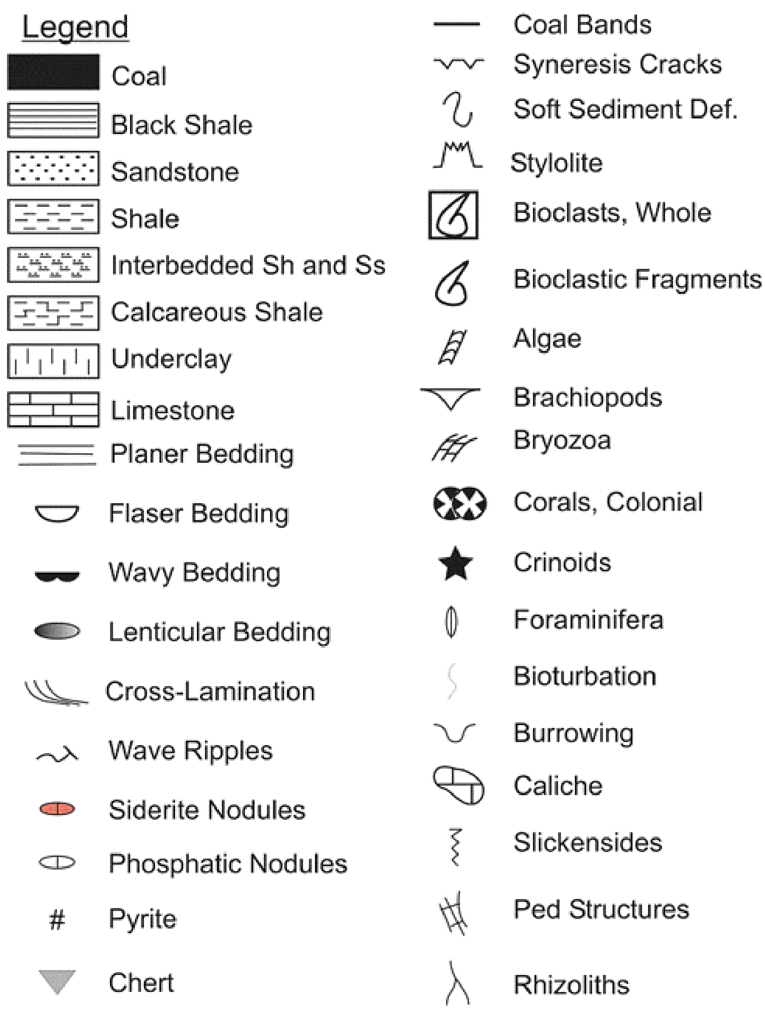


1065
1070
1075
71
72
Sandstone, same as above
Black Shale
- Black
- Micaceous
- Thinly laminated
- Planar bedded on top and
cross ripple laminae on bottom
- Sharp contact
- Bioclastic fragments
- Pyritized burrows
Coal
- Organic
- Well developed cleating
- Calcite mineralization in cleats
- Pyrite
- Good gas show
Shale
- Black to medium gray
- Micaceous, very organic rich
- Thinly laminated
- Planar bedding
- Fissile
- Coal bands
- Abundant pyrite
- Sharp contact
- Non-fossiliferous
Phosphatic black shale facies
- Transgressive marine core shale
- Maximum flooding around 1067'
Pyritic black shale facies
- Salt water marsh
Flooding Surface
Riverton coal - coal facies
- Marsh coal
Pyritic black shale facies
- Salt water marsh
- Swamp environment
- Rich in organics


72
73
1085
1090
1095
Mississippian/Pennsylvanian Unconformity
Limestone
- Light gray
- Slightly calcareous
- Thinly bedded
- Vugy and fractured
- Cherty
- Pyrite
- Dissolution breccia
- Sharp contact
- Non-fossiliferous
- Slightly oil stained near upper portion
Wackestone to mudstone facies
- Karstic
Bottom of core

Appendix 1: Descriptions of Core

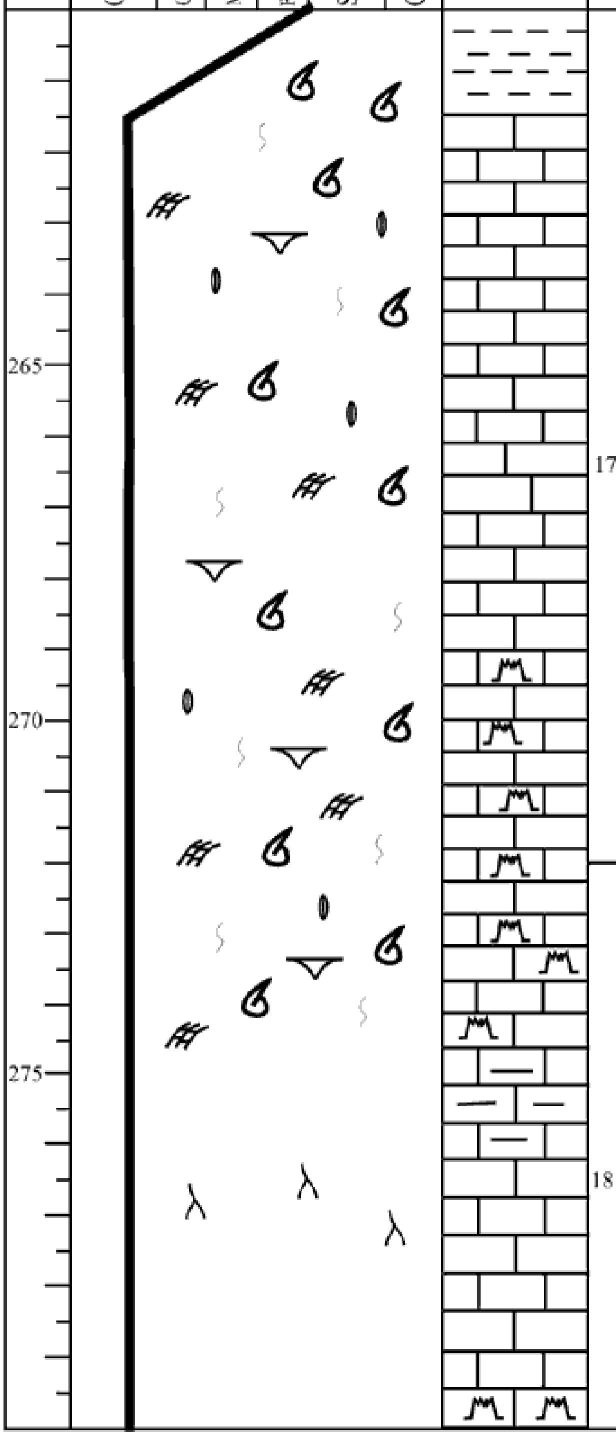
Cooper CW#1
Kansas Geological Survey
SE SW SW 11-T35S-R18E



NAME COOPER CW-1 STRUCTURAL SETTING CHEROKEE BASIN

LOCATION SE SW SW 11-T35S-R18E DESCRIBED BY: JONATHAN LANGE

DEPTH (FT)	TEXTURE, GRAIN SIZE AND STRUCTURES CARBONATES: GN | PK | WKE | MUDST | EVAP CLASTICS: Gravel | Sand (Coarse | Medium | Fine) | Silt | Clay	LITHOLOGY	BOX #	DESCRIPTION - Lithology - Color - Comp., Cement, or Matrix - Shape and Sorting - Bedding - Sed. Structures - Upper Contact - Fossils	DATE JANUARY 2003 UNIT: Fort Scott PAGE 01 OF 30 PAGES REMARKS, INTERPRETATION



Description:

Limestone
- Light gray to tan
- Calcareous
- Medium bedded
- Stylolites, and horse tail stylolites
- Calcite veins
- Rooting
- Gradational upper contact
- Bioclasts of brachiopods, crinoids, fusilinids, and bryozoa
- Bioturbated

Heavily fractured with calcite crystals

Shale parting

Rip-up clasts and rooting

Peloidal and nonfossiliferous

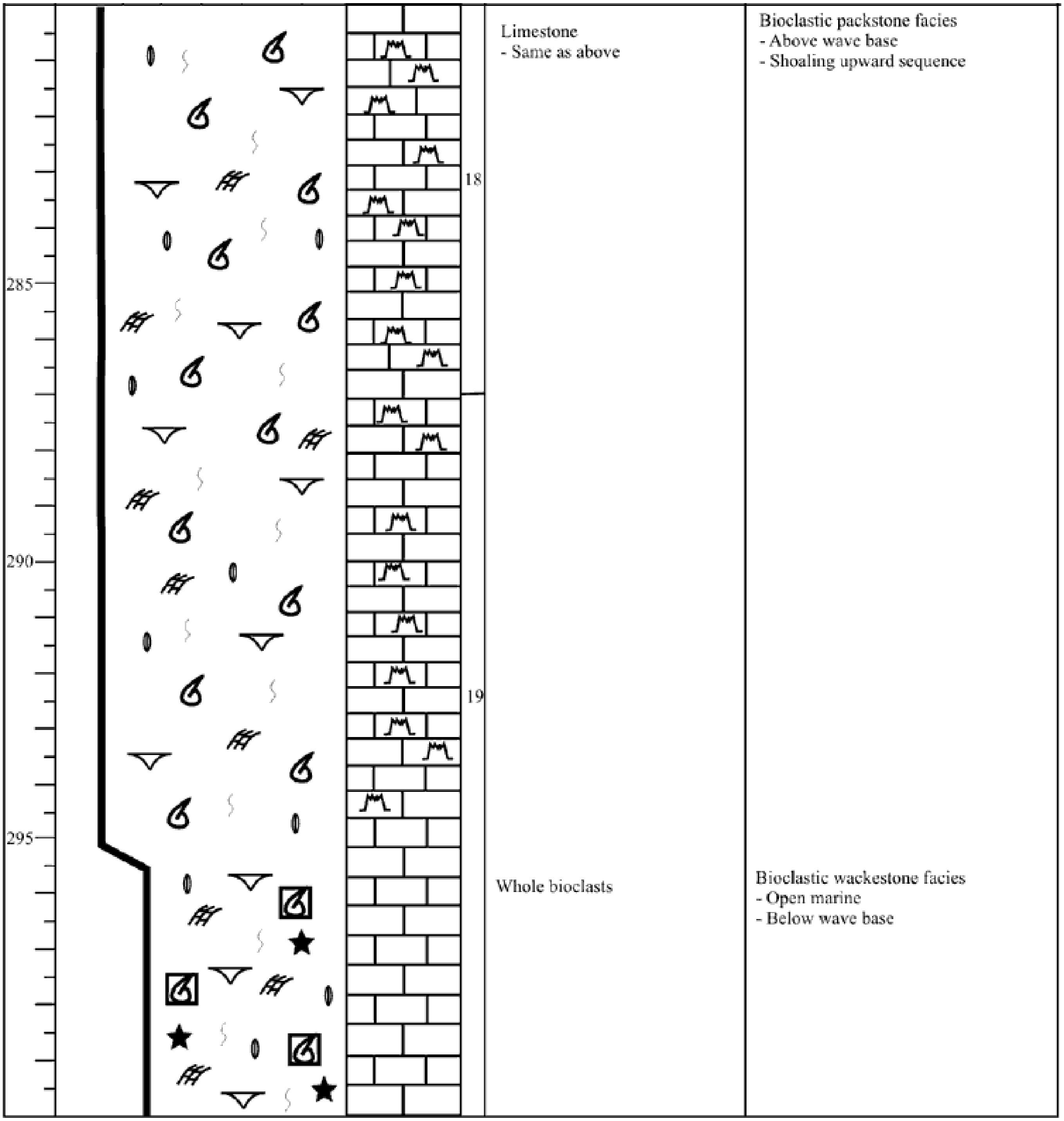
Remarks, Interpretation:

Top of Fort Scott - Higginsville Limestone

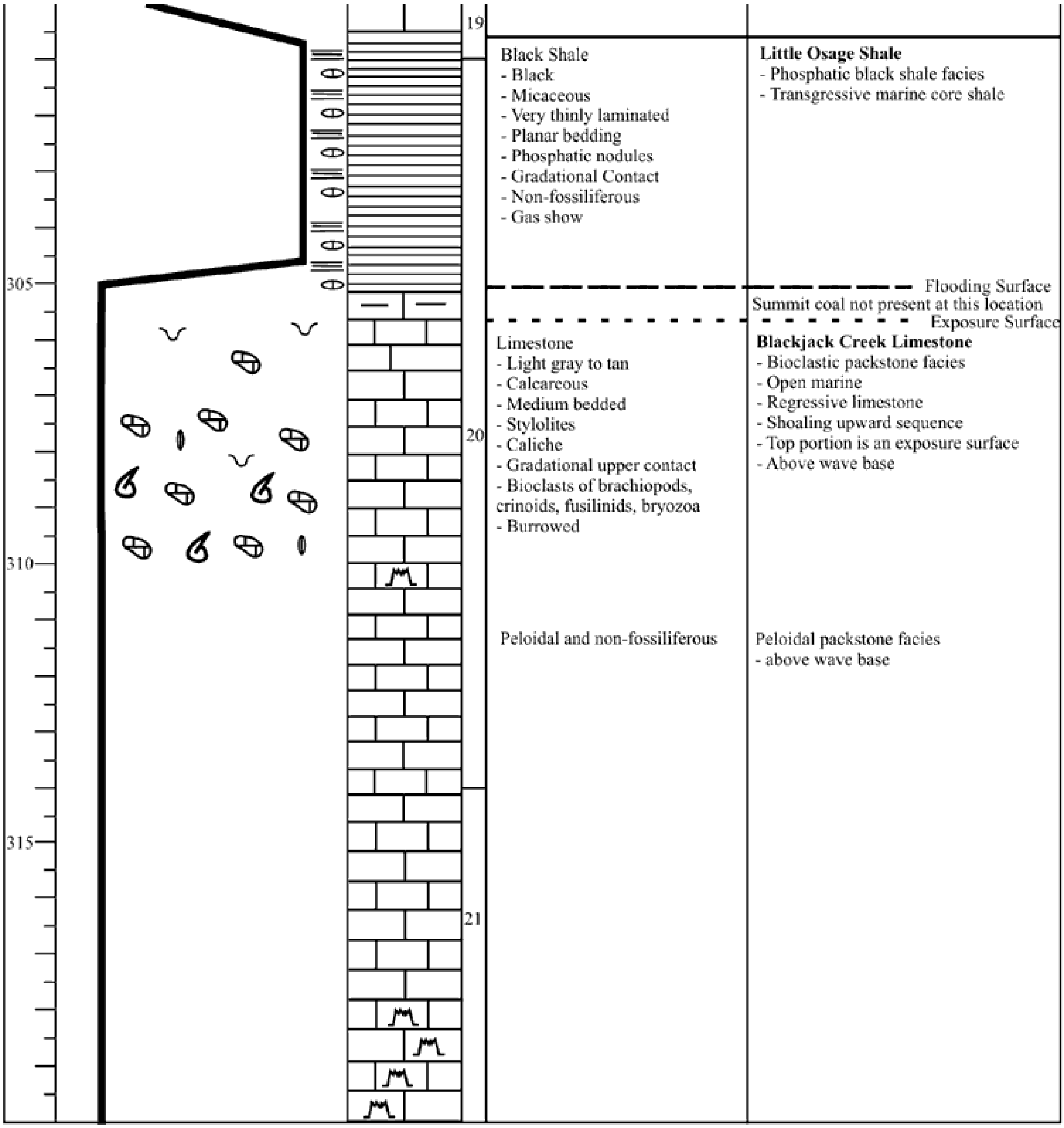
Bioclastic packstone facies
- Open marine
- Above wave base
- Shoaling upward sequence

Flooding surface
Exposure surface

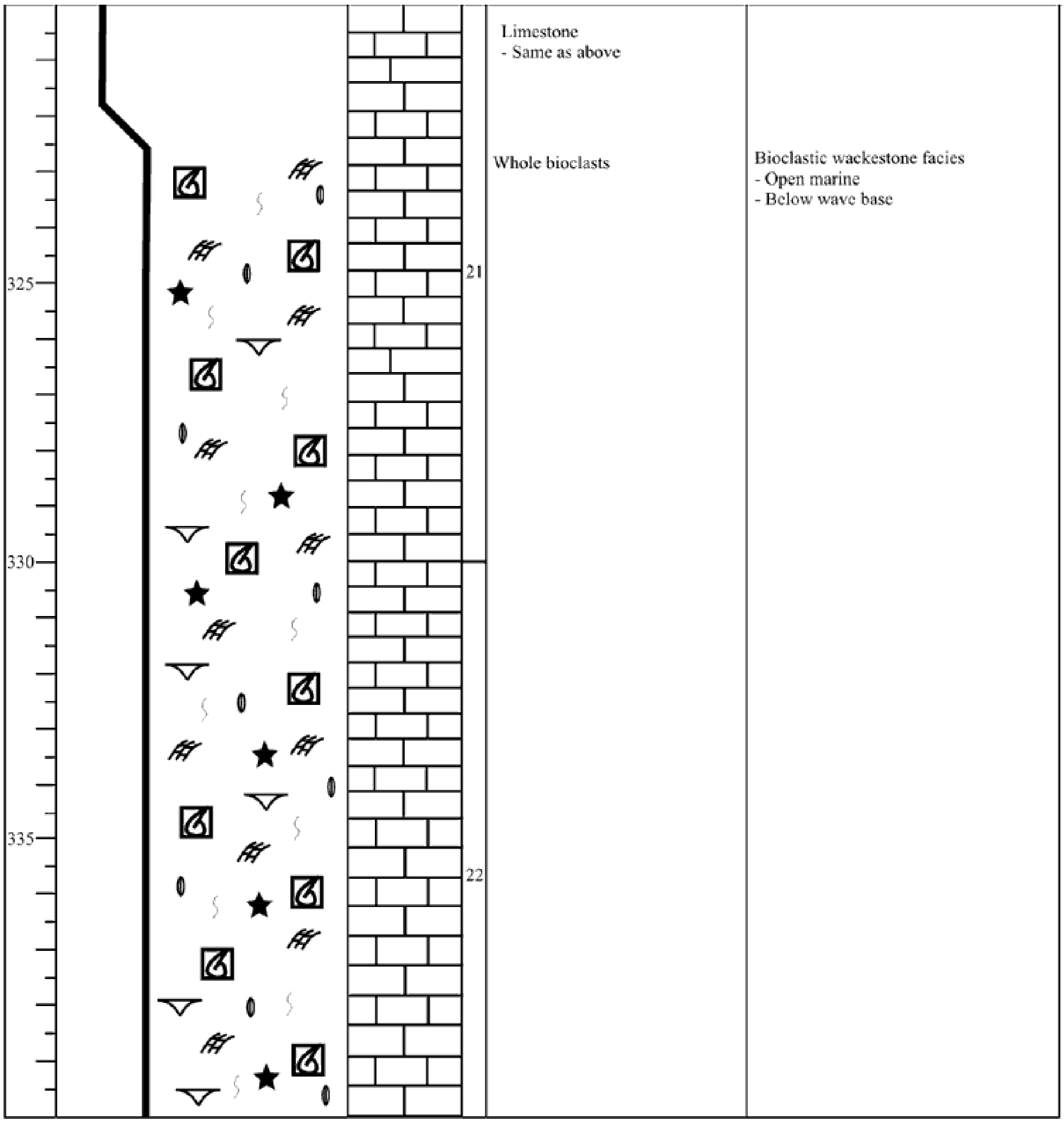
Peloidal packstone facies
- Open marine
- Above wave base



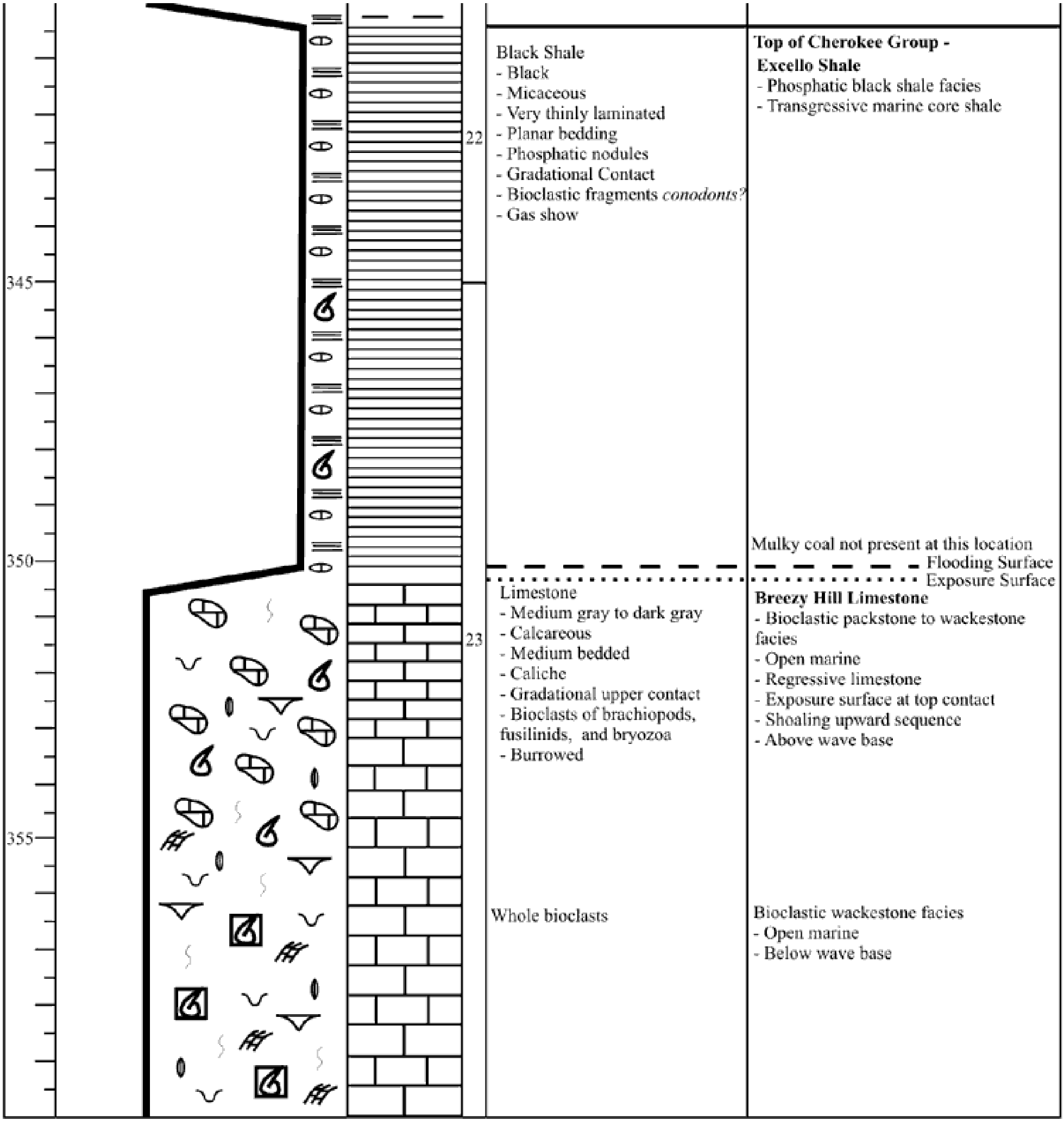
285
290
295
18
19
Limestone
- Same as above
Whole bioclasts
Bioclastic packstone facies
- Above wave base
- Shoaling upward sequence
Bioclastic wackestone facies
- Open marine
- Below wave base



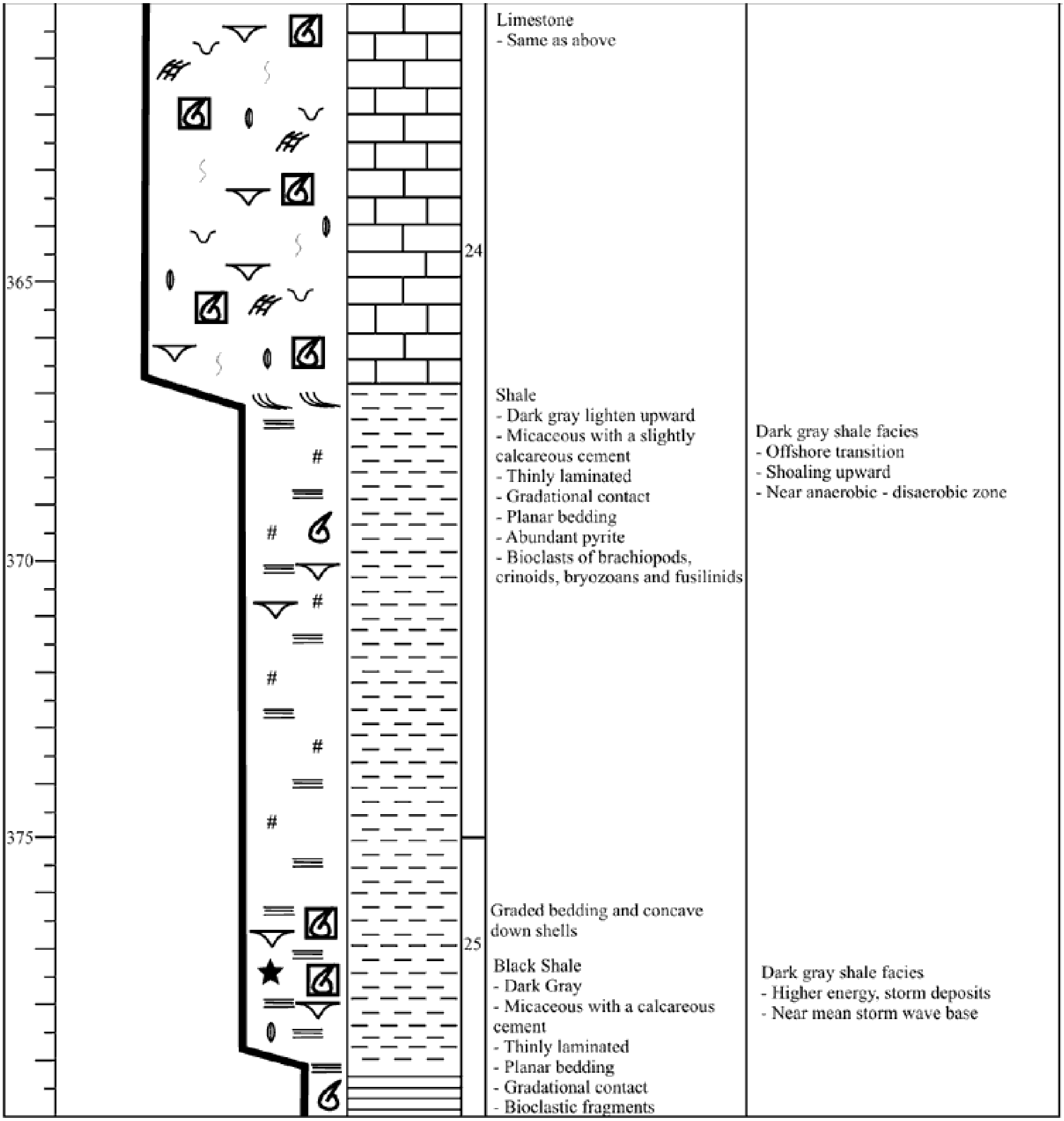
19
20
21
305
310
315
Black Shale
- Black
- Micaceous
- Very thinly laminated
- Planar bedding
- Phosphatic nodules
- Gradational Contact
- Non-fossiliferous
- Gas show
Little Osage Shale
- Phosphatic black shale facies
- Transgressive marine core shale
Flooding Surface
Summit coal not present at this location
Exposure Surface
Limestone
- Light gray to tan
- Calcareous
- Medium bedded
- Stylolites
- Caliche
- Gradational upper contact
- Bioclasts of brachiopods, crinoids, fusilinids, bryozoa
- Burrowed
Blackjack Creek Limestone
- Bioclastic packstone facies
- Open marine
- Regressive limestone
- Shoaling upward sequence
- Top portion is an exposure surface
- Above wave base
Peloidal and non-fossiliferous
Peloidal packstone facies
- above wave base



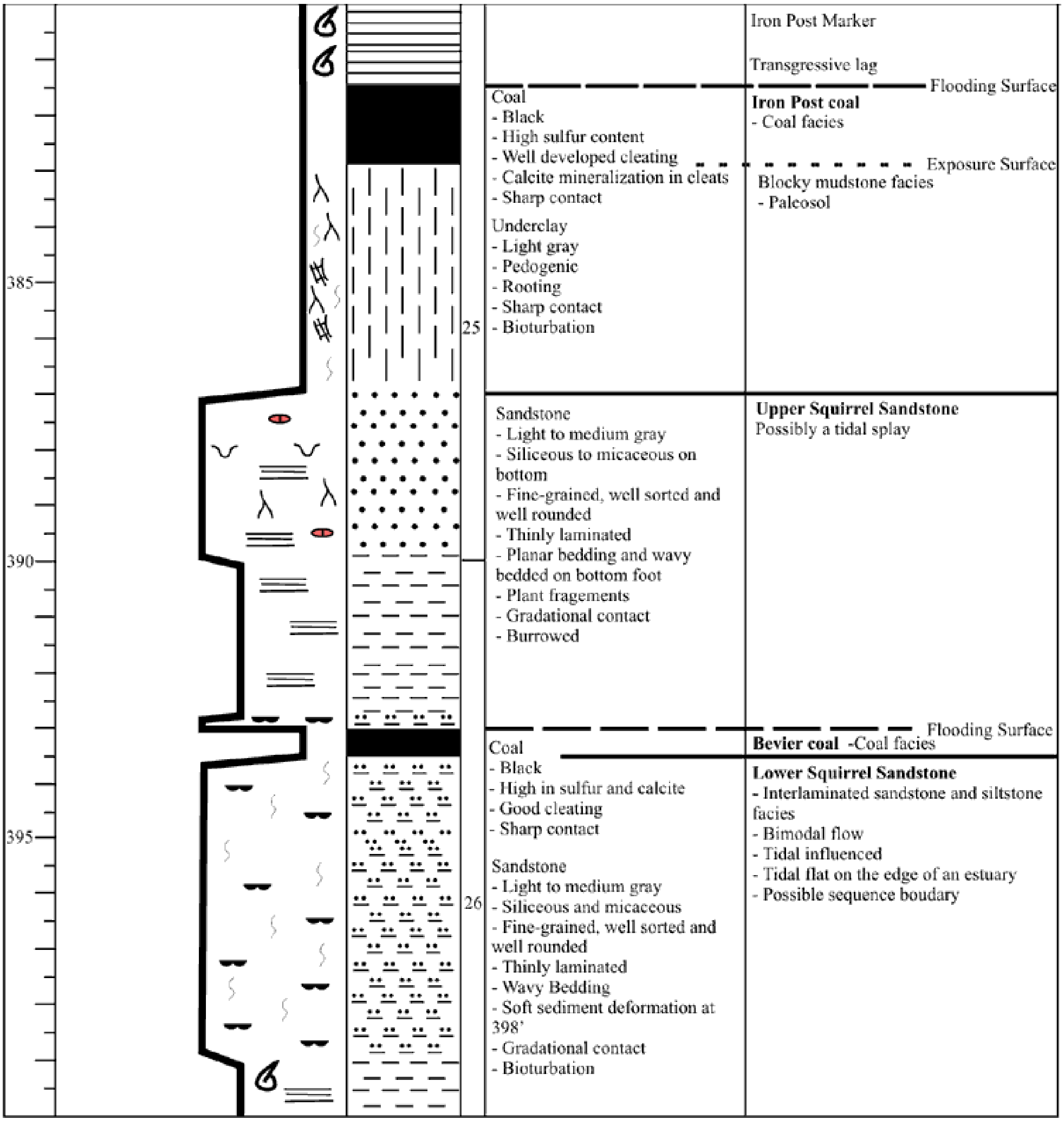
325
330
335
21
22
Limestone
- Same as above
Whole bioclasts
Bioclastic wackestone facies
- Open marine
- Below wave base

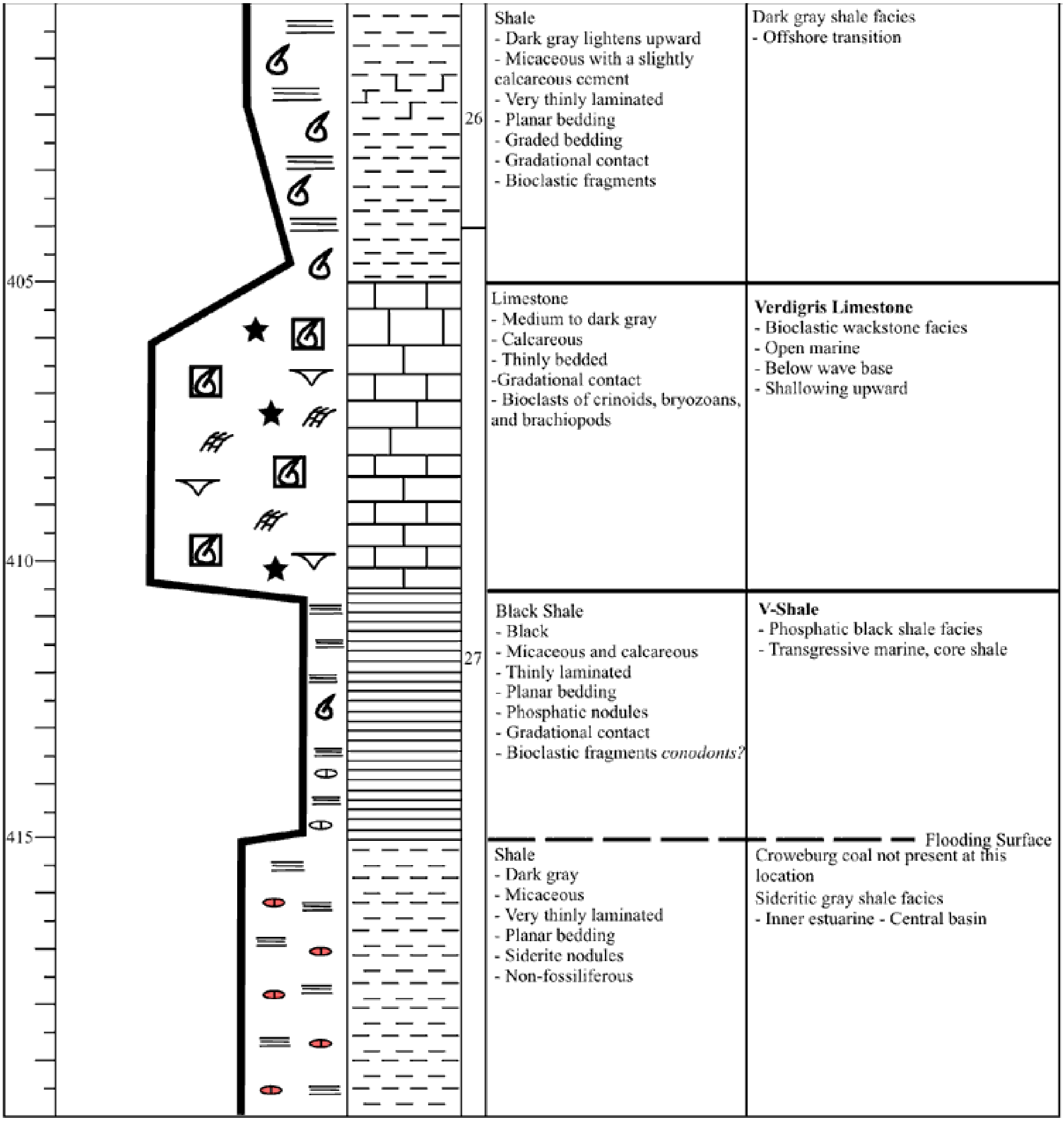


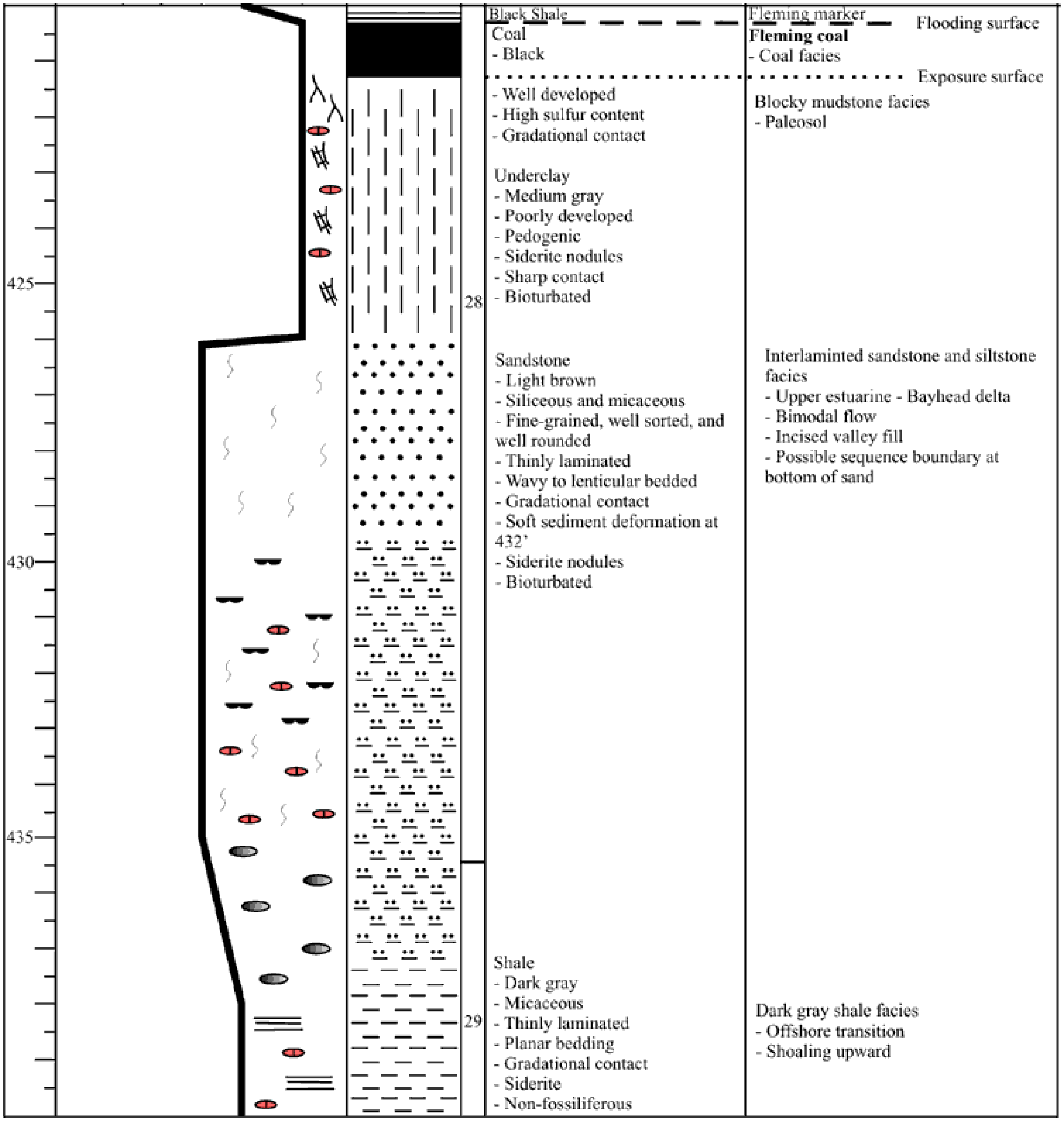
345
350
355
22
23
Black Shale
- Black
- Micaceous
- Very thinly laminated
- Planar bedding
- Phosphatic nodules
- Gradational Contact
- Bioclastic fragments *conodonts?*
- Gas show
Top of Cherokee Group - Excello Shale
- Phosphatic black shale facies
- Transgressive marine core shale
Mulky coal not present at this location
Flooding Surface
Exposure Surface
Limestone
- Medium gray to dark gray
- Calcareous
- Medium bedded
- Caliche
- Gradational upper contact
- Bioclasts of brachiopods, fusilinids, and bryozoa
- Burrowed
Breezy Hill Limestone
- Bioclastic packstone to wackestone facies
- Open marine
- Regressive limestone
- Exposure surface at top contact
- Shoaling upward sequence
- Above wave base
Whole bioclasts
Bioclastic wackestone facies
- Open marine
- Below wave base

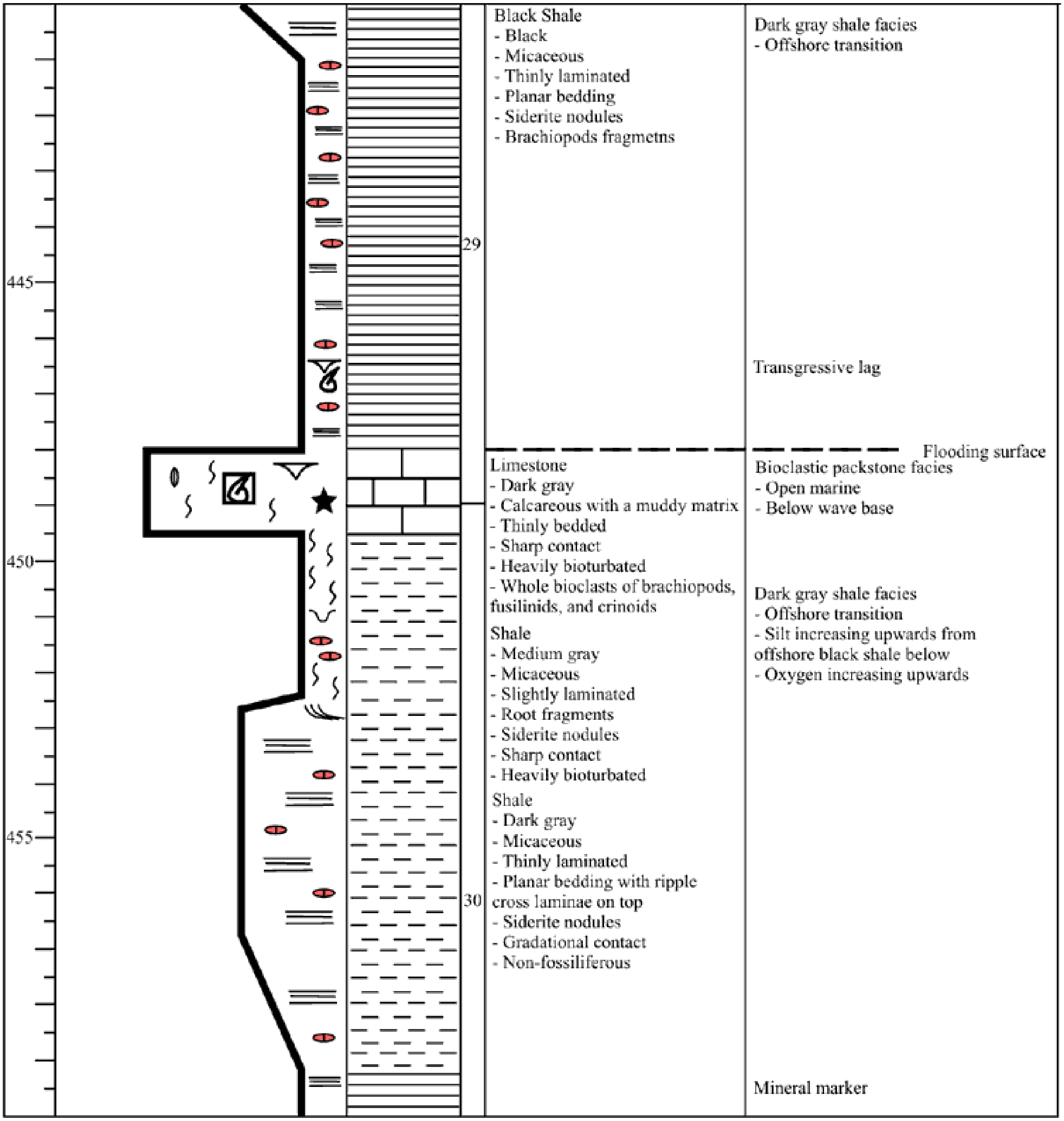


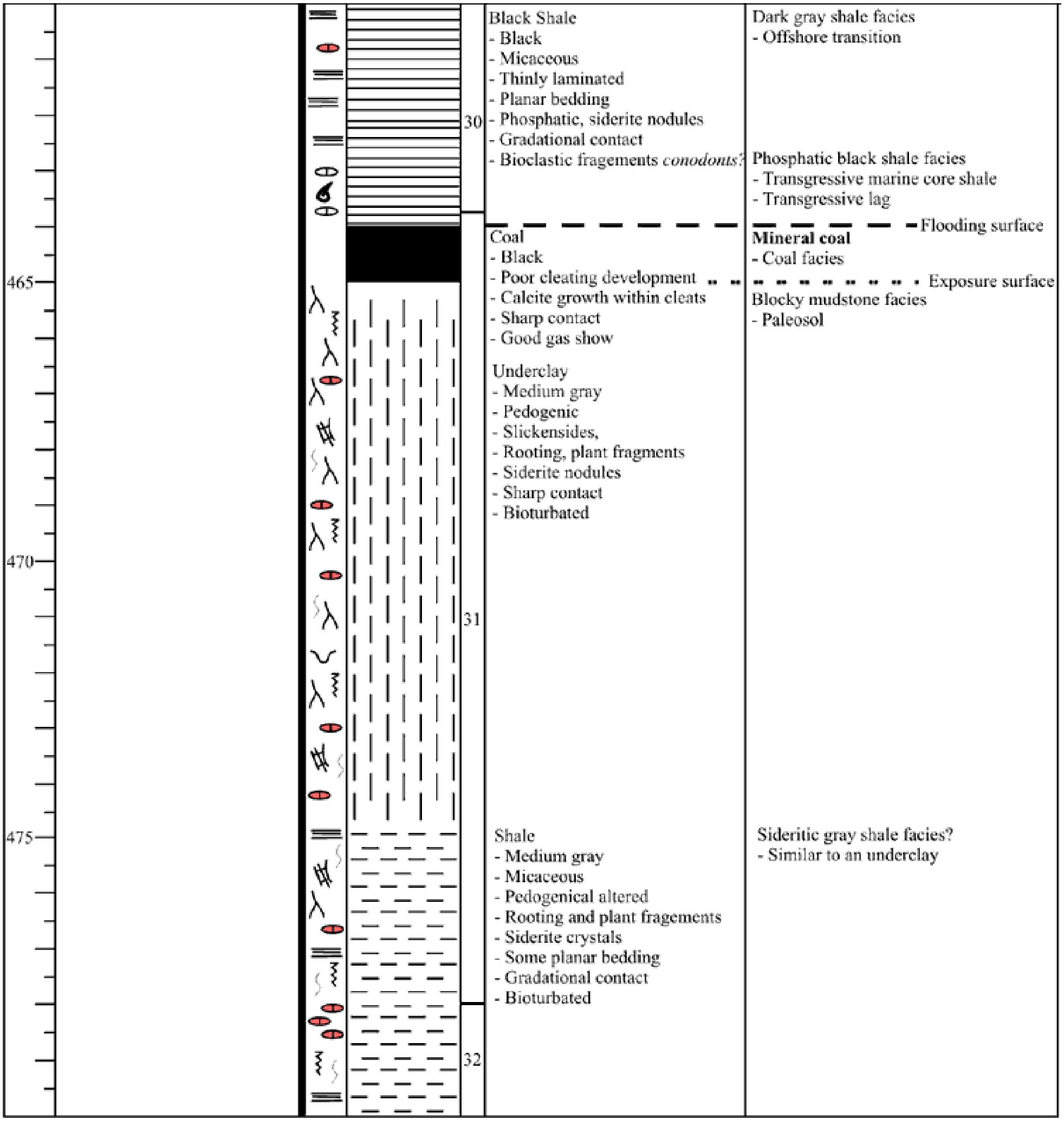
365
370
375
24
25
Limestone
- Same as above
Shale
- Dark gray lighten upward
- Micaceous with a slightly calcareous cement
- Thinly laminated
- Gradational contact
- Planar bedding
- Abundant pyrite
- Bioclasts of brachiopods, crinoids, bryozoans and fusilinids
Dark gray shale facies
- Offshore transition
- Shoaling upward
- Near anaerobic - disaerobic zone
Graded bedding and concave down shells
Black Shale
- Dark Gray
- Micaceous with a calcareous cement
- Thinly laminated
- Planar bedding
- Gradational contact
- Bioclastic fragments
Dark gray shale facies
- Higher energy, storm deposits
- Near mean storm wave base

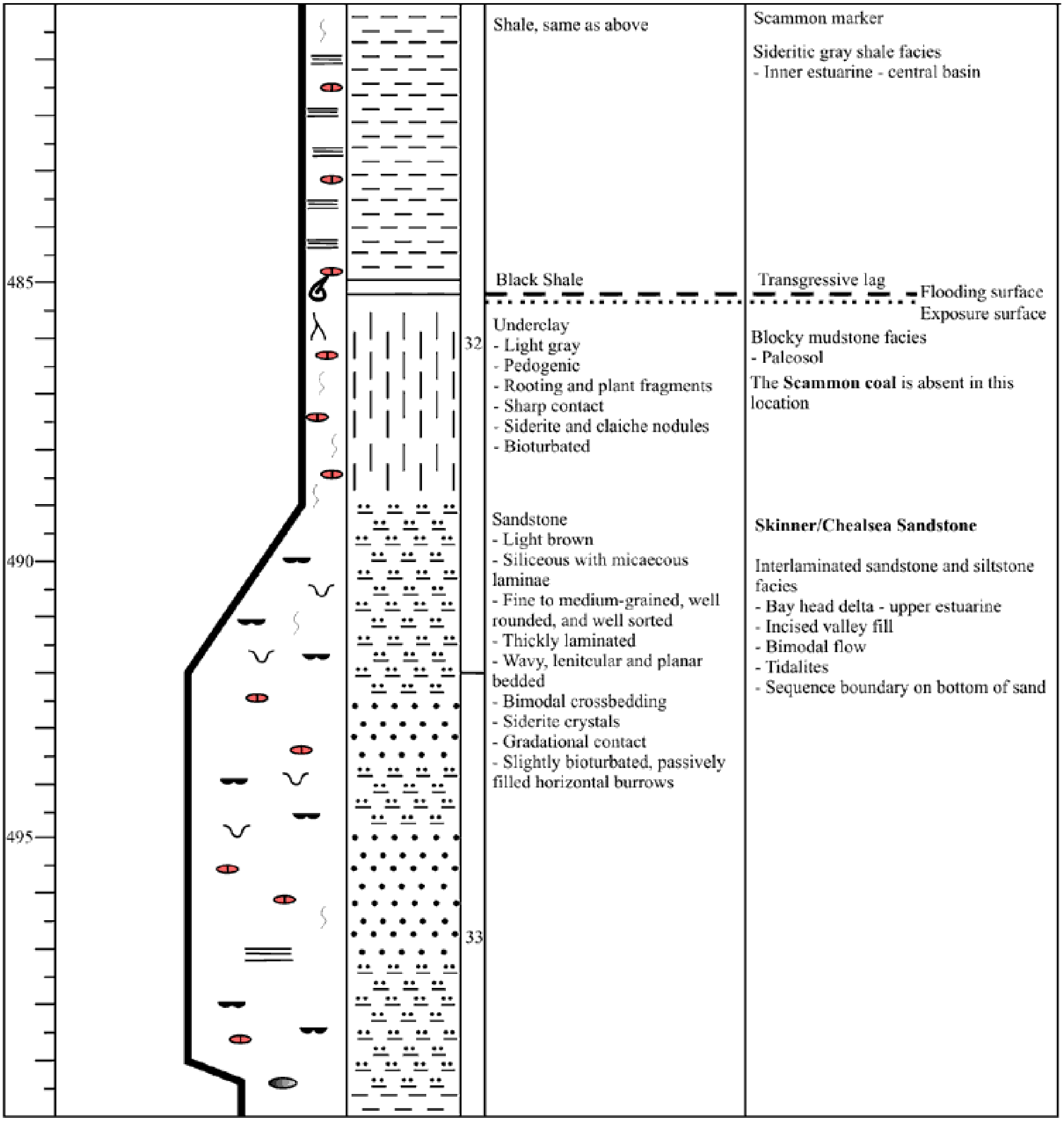

385
390
395
25
26
Iron Post Marker
Transgressive lag
Flooding Surface
Coal
- Black
- High sulfur content
- Well developed cleating
- Calcite mineralization in cleats
- Sharp contact
Iron Post coal
- Coal facies
Exposure Surface
Blocky mudstone facies
- Paleosol
Underclay
- Light gray
- Pedogenic
- Rooting
- Sharp contact
- Bioturbation
Sandstone
- Light to medium gray
- Siliceous to micaceous on bottom
- Fine-grained, well sorted and well rounded
- Thinly laminated
- Planar bedding and wavy bedded on bottom foot
- Plant fragements
- Gradational contact
- Burrowed
Upper Squirrel Sandstone
Possibly a tidal splay
Flooding Surface
Bevier coal -Coal facies
Coal
- Black
- High in sulfur and calcite
- Good cleating
- Sharp contact
Sandstone
- Light to medium gray
- Siliceous and micaceous
- Fine-grained, well sorted and well rounded
- Thinly laminated
- Wavy Bedding
- Soft sediment deformation at 398'
- Gradational contact
- Bioturbation
Lower Squirrel Sandstone
- Interlaminated sandstone and siltstone facies
- Bimodal flow
- Tidal influenced
- Tidal flat on the edge of an estuary
- Possible sequence boudary


405
410
415
26
27
Shale
- Dark gray lightens upward
- Micaceous with a slightly calcareous cement
- Very thinly laminated
- Planar bedding
- Graded bedding
- Gradational contact
- Bioclastic fragments
Dark gray shale facies
- Offshore transition
Limestone
- Medium to dark gray
- Calcareous
- Thinly bedded
-Gradational contact
- Bioclasts of crinoids, bryozoans, and brachiopods
Verdigris Limestone
- Bioclastic wackstone facies
- Open marine
- Below wave base
- Shallowing upward
Black Shale
- Black
- Micaceous and calcareous
- Thinly laminated
- Planar bedding
- Phosphatic nodules
- Gradational contact
- Bioclastic fragments conodonts?
V-Shale
- Phosphatic black shale facies
- Transgressive marine, core shale
Flooding Surface
Shale
- Dark gray
- Micaceous
- Very thinly laminated
- Planar bedding
- Siderite nodules
- Non-fossiliferous
Croweburg coal not present at this location
Sideritic gray shale facies
- Inner estuarine - Central basin

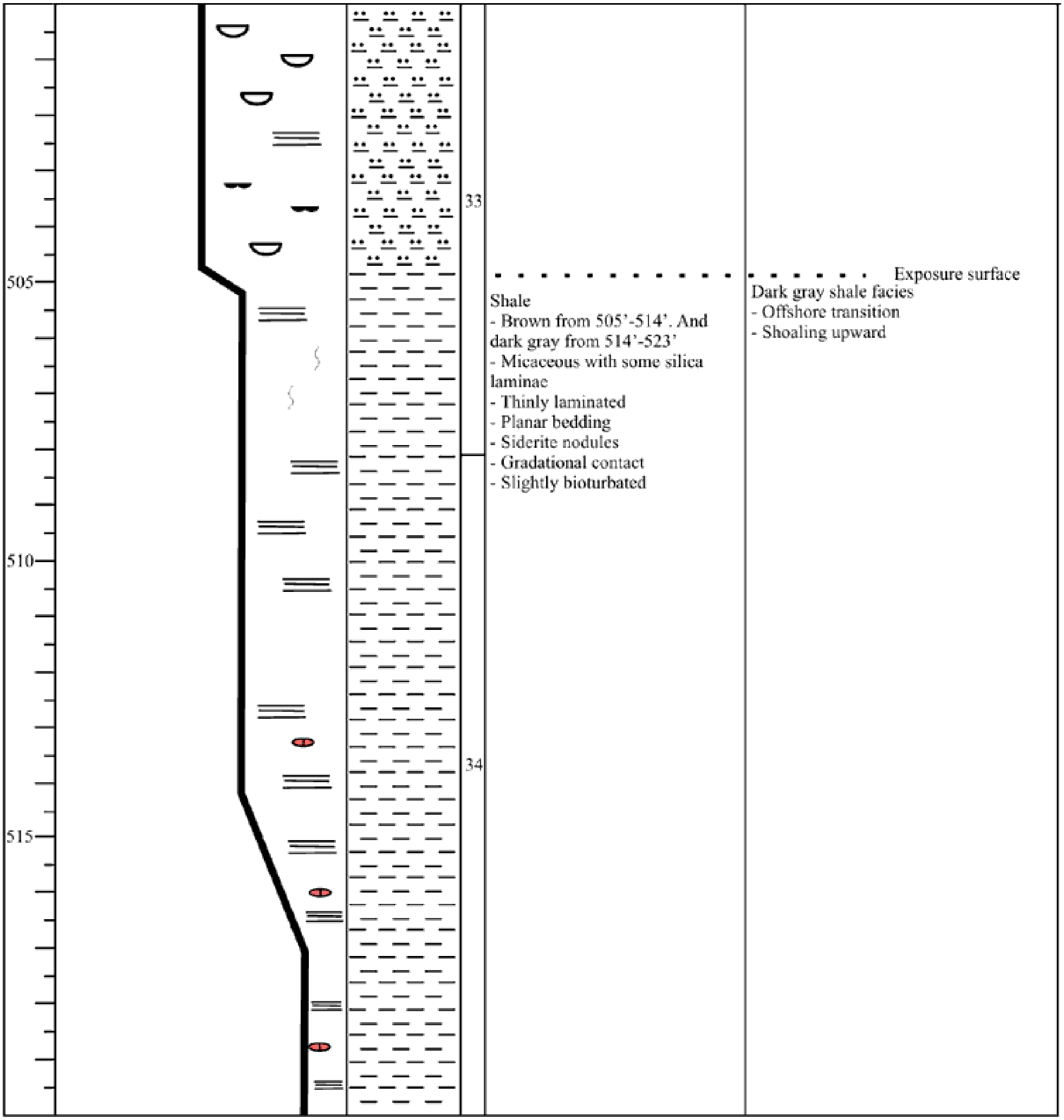

425
430
435
28
29
Black Shale
Coal
- Black
- Well developed
- High sulfur content
- Gradational contact
Underclay
- Medium gray
- Poorly developed
- Pedogenic
- Siderite nodules
- Sharp contact
- Bioturbated
Sandstone
- Light brown
- Siliceous and micaceous
- Fine-grained, well sorted, and well rounded
- Thinly laminated
- Wavy to lenticular bedded
- Gradational contact
- Soft sediment deformation at 432'
- Siderite nodules
- Bioturbated
Shale
- Dark gray
- Micaceous
- Thinly laminated
- Planar bedding
- Gradational contact
- Siderite
- Non-fossiliferous
Fleming marker
Flooding surface
Fleming coal
- Coal facies
Exposure surface
Blocky mudstone facies
- Paleosol
Interlaminted sandstone and siltstone facies
- Upper estuarine - Bayhead delta
- Bimodal flow
- Incised valley fill
- Possible sequence boundary at bottom of sand
Dark gray shale facies
- Offshore transition
- Shoaling upward

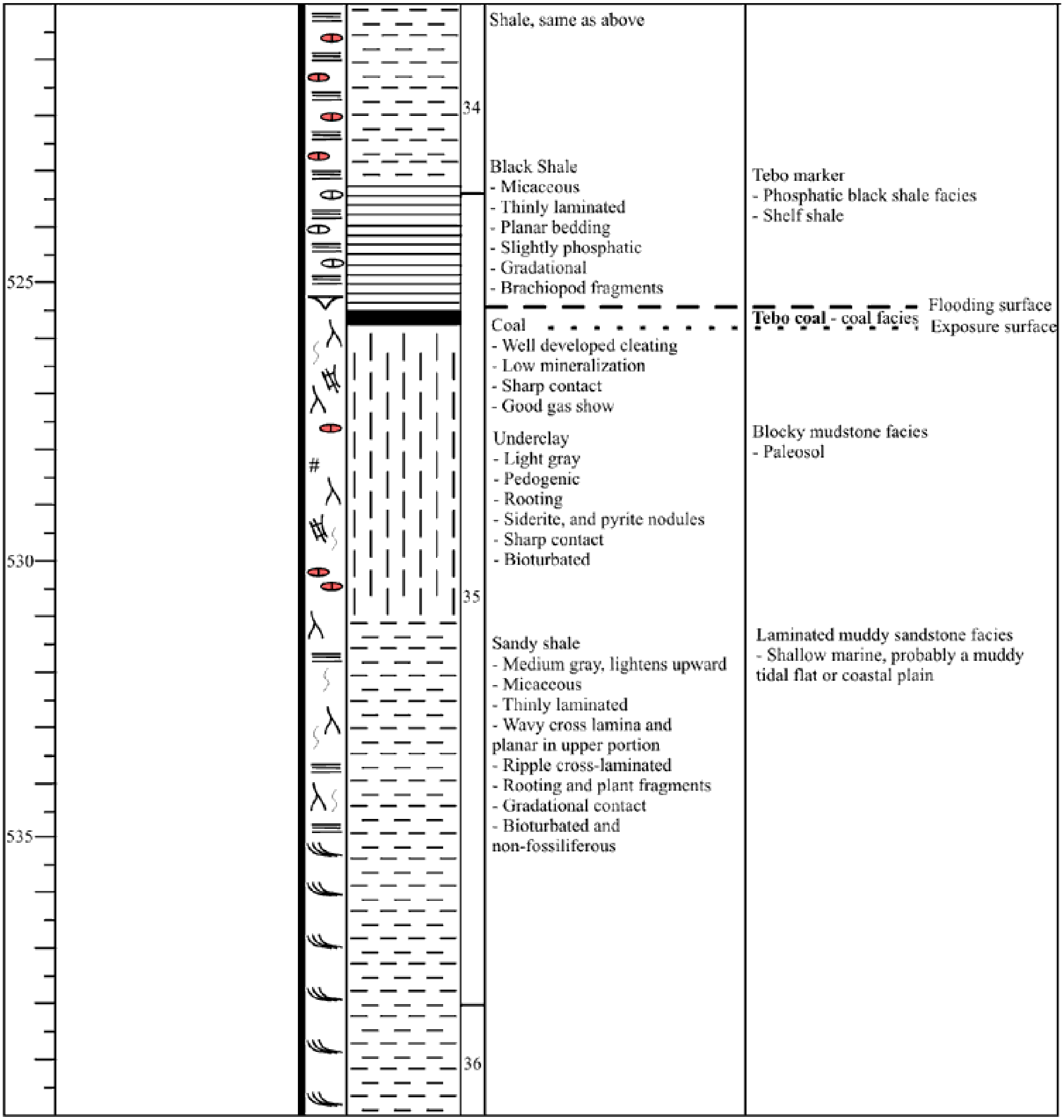

445
450
455
29
30
Black Shale
- Black
- Micaceous
- Thinly laminated
- Planar bedding
- Siderite nodules
- Brachiopods fragmetns
Limestone
- Dark gray
- Calcareous with a muddy matrix
- Thinly bedded
- Sharp contact
- Heavily bioturbated
- Whole bioclasts of brachiopods, fusilinids, and crinoids
Shale
- Medium gray
- Micaceous
- Slightly laminated
- Root fragments
- Siderite nodules
- Sharp contact
- Heavily bioturbated
Shale
- Dark gray
- Micaceous
- Thinly laminated
- Planar bedding with ripple cross laminae on top
- Siderite nodules
- Gradational contact
- Non-fossiliferous
Dark gray shale facies
- Offshore transition
Transgressive lag
Flooding surface
Bioclastic packstone facies
- Open marine
- Below wave base
Dark gray shale facies
- Offshore transition
- Silt increasing upwards from offshore black shale below
- Oxygen increasing upwards
Mineral marker

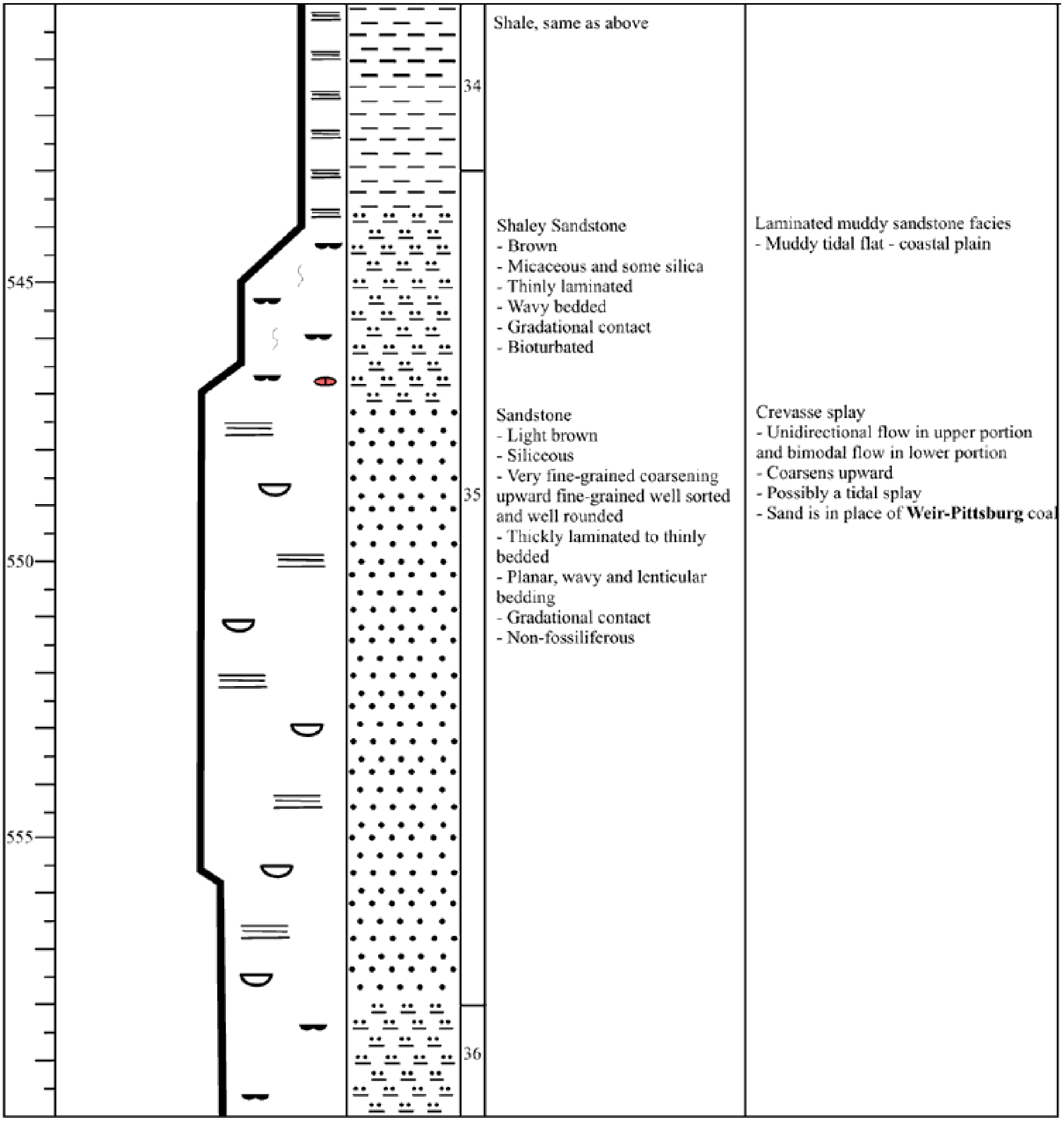

465
470
475
30
31
32
Black Shale
- Black
- Micaceous
- Thinly laminated
- Planar bedding
- Phosphatic, siderite nodules
- Gradational contact
- Bioclastic fragements *conodonts?*
Coal
- Black
- Poor cleating development
- Calcite growth within cleats
- Sharp contact
- Good gas show
Underclay
- Medium gray
- Pedogenic
- Slickensides,
- Rooting, plant fragments
- Siderite nodules
- Sharp contact
- Bioturbated
Shale
- Medium gray
- Micaceous
- Pedogenical altered
- Rooting and plant fragements
- Siderite crystals
- Some planar bedding
- Gradational contact
- Bioturbated
Dark gray shale facies
- Offshore transition
Phosphatic black shale facies
- Transgressive marine core shale
- Transgressive lag
Flooding surface
Mineral coal
- Coal facies
Exposure surface
Blocky mudstone facies
- Paleosol
Sideritic gray shale facies?
- Similar to an underclay

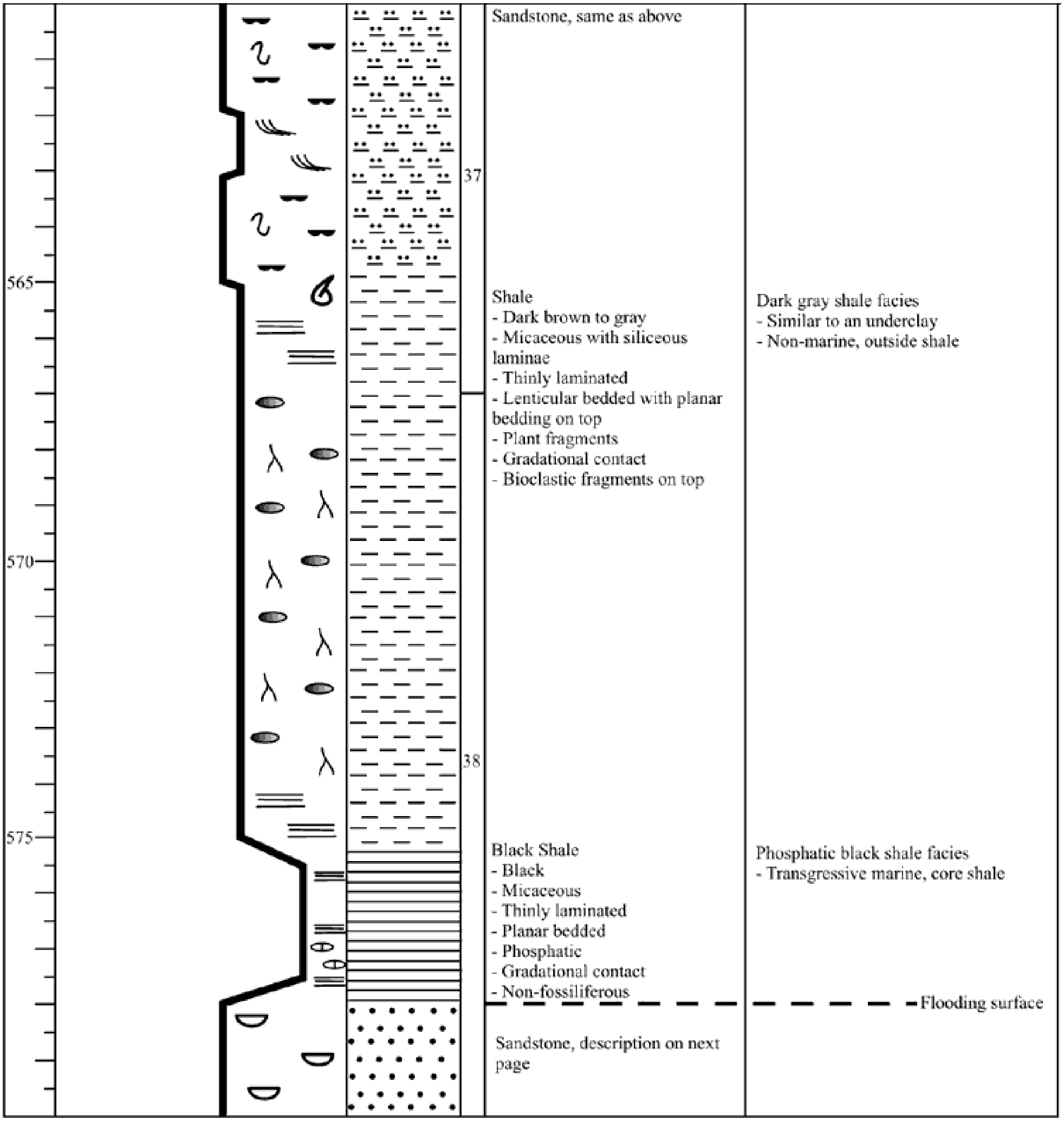


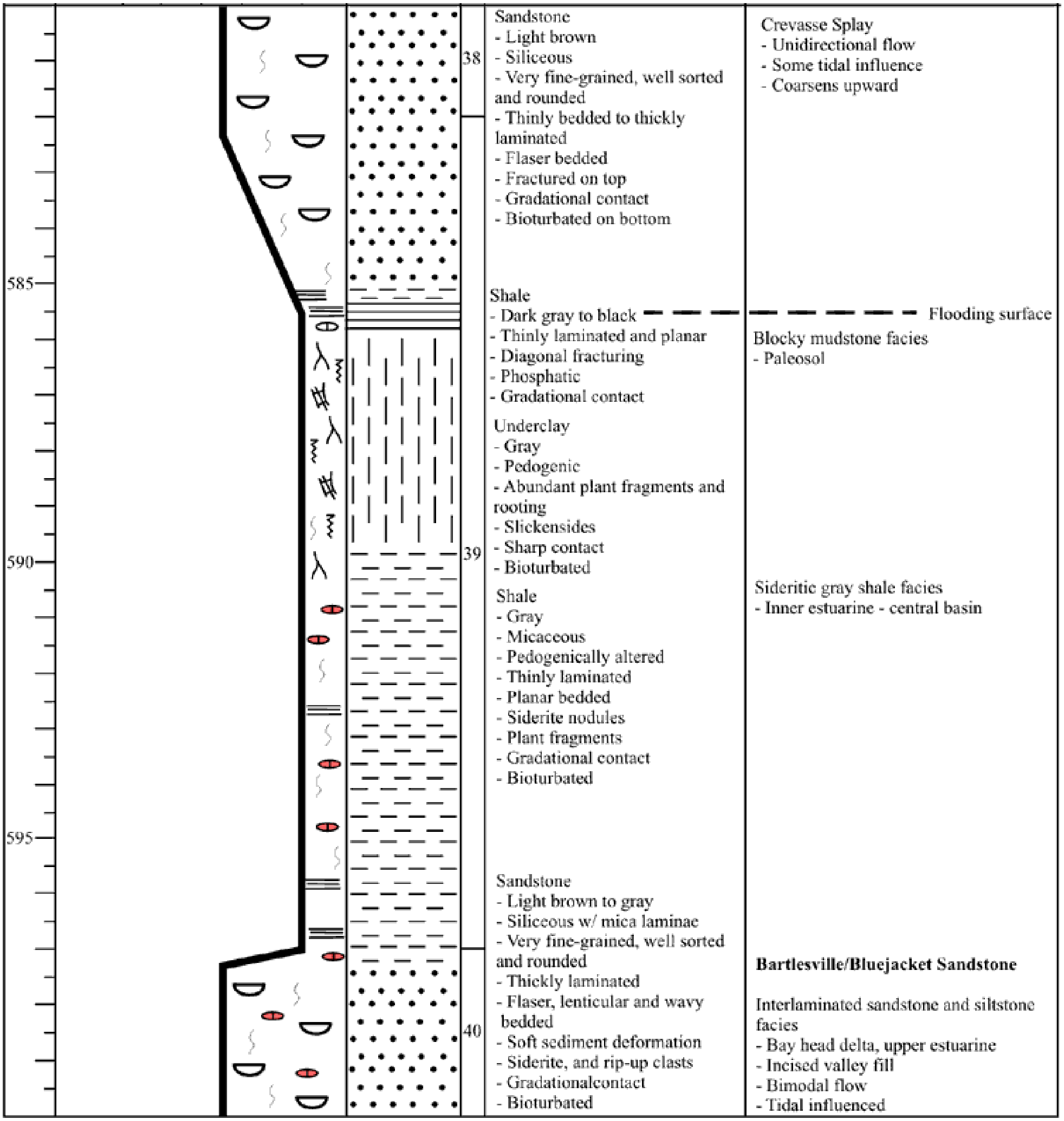
485
490
495
32
33
Shale, same as above
Black Shale
Underclay
- Light gray
- Pedogenic
- Rooting and plant fragments
- Sharp contact
- Siderite and claiche nodules
- Bioturbated
Sandstone
- Light brown
- Siliceous with micaeous laminae
- Fine to medium-grained, well rounded, and well sorted
- Thickly laminated
- Wavy, lenitcular and planar bedded
- Bimodal crossbedding
- Siderite crystals
- Gradational contact
- Slightly bioturbated, passively filled horizontal burrows
Scammon marker
Sideritic gray shale facies
- Inner estuarine - central basin
Transgressive lag
Flooding surface
Exposure surface
Blocky mudstone facies
- Paleosol
The **Scammon coal** is absent in this location
Skinner/Chealsea Sandstone
Interlaminated sandstone and siltstone facies
- Bay head delta - upper estuarine
- Incised valley fill
- Bimodal flow
- Tidalites
- Sequence boundary on bottom of sand

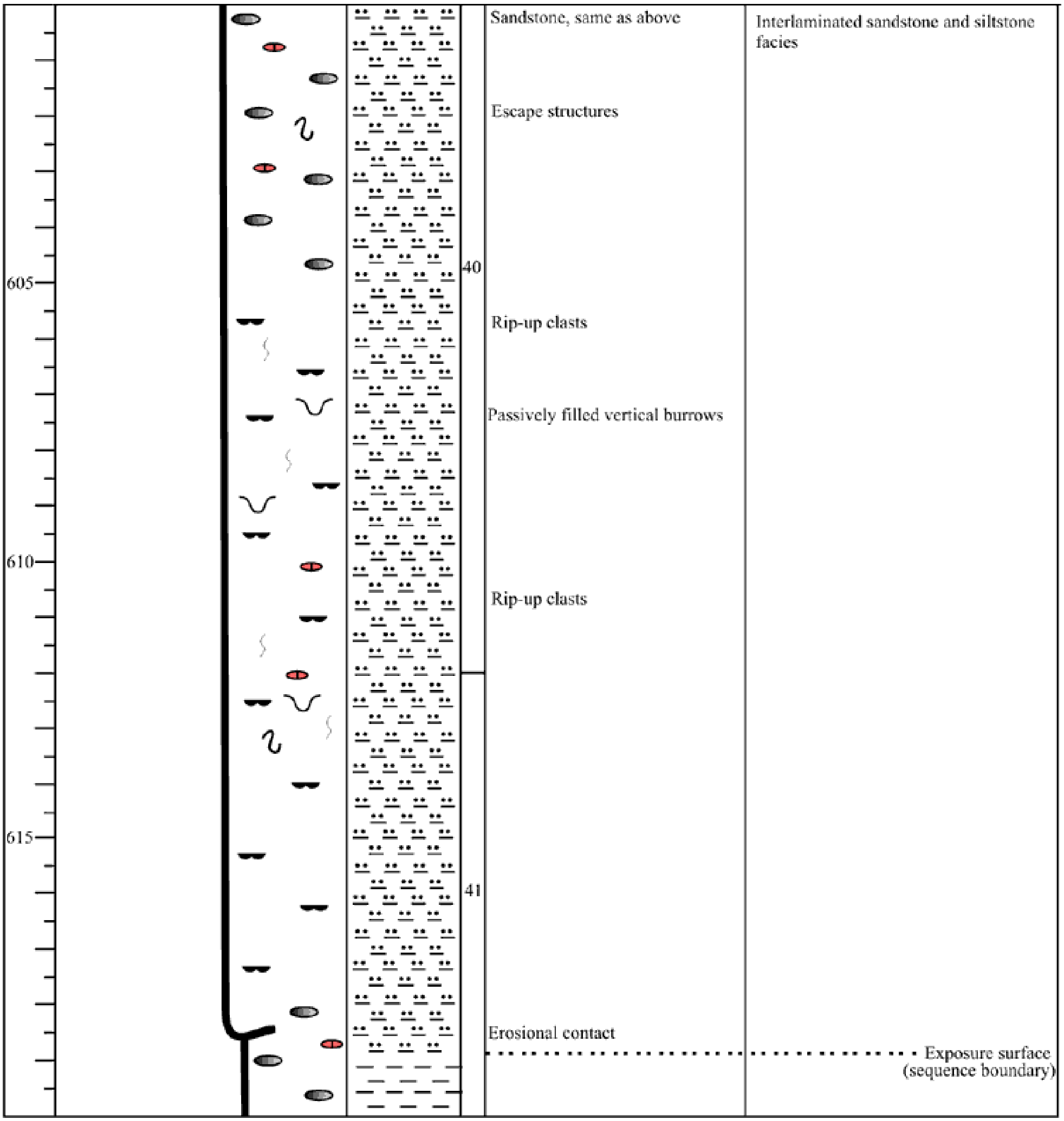

505
510
515
33
34
Exposure surface
Shale
- Brown from 505'-514'. And dark gray from 514'-523'
- Micaceous with some silica laminae
- Thinly laminated
- Planar bedding
- Siderite nodules
- Gradational contact
- Slightly bioturbated
Dark gray shale facies
- Offshore transition
- Shoaling upward

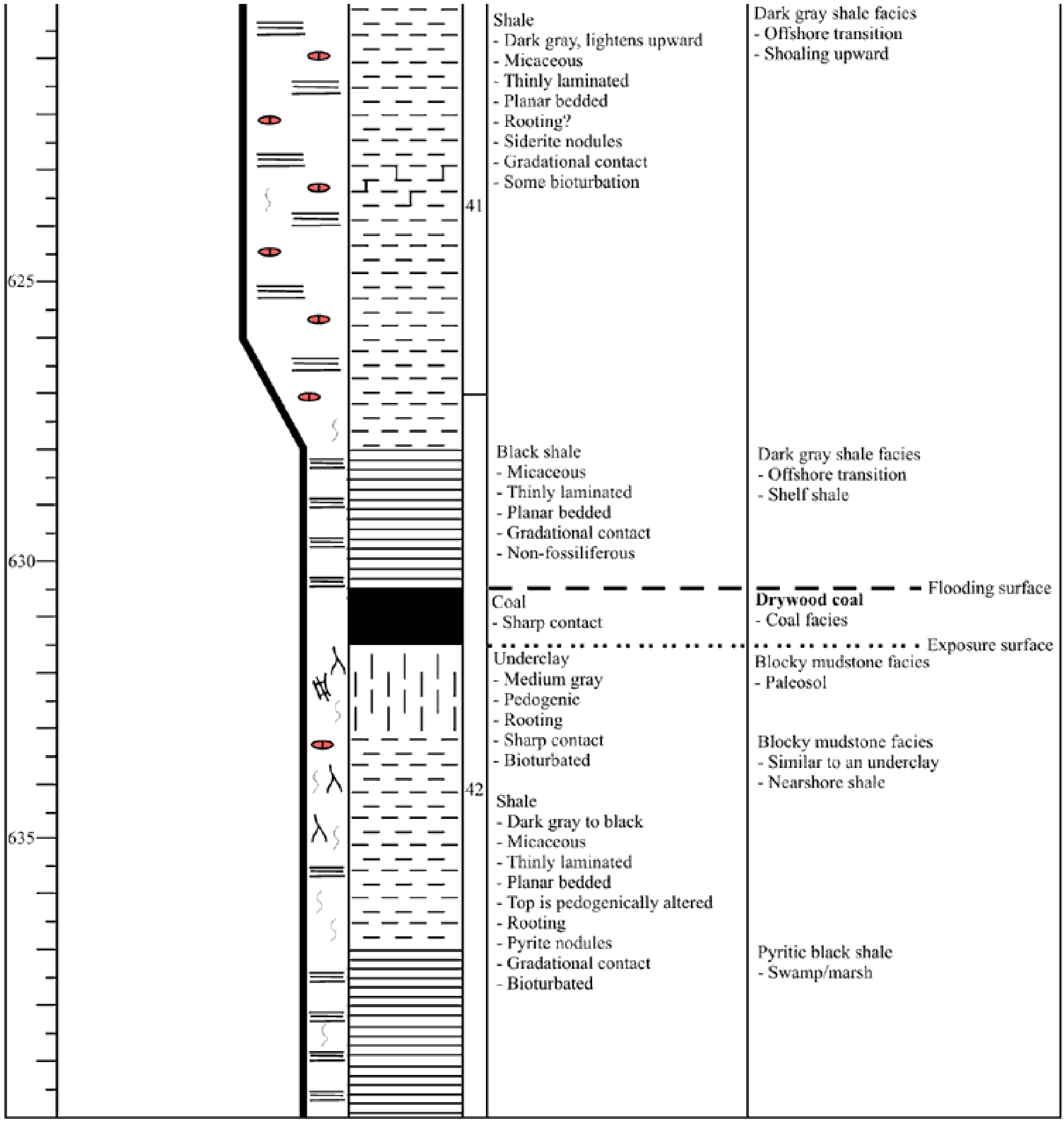

525
530
535
34
35
36
Shale, same as above
Black Shale
- Micaceous
- Thinly laminated
- Planar bedding
- Slightly phosphatic
- Gradational
- Brachiopod fragments
Coal
- Well developed cleating
- Low mineralization
- Sharp contact
- Good gas show
Underclay
- Light gray
- Pedogenic
- Rooting
- Siderite, and pyrite nodules
- Sharp contact
- Bioturbated
Sandy shale
- Medium gray, lightens upward
- Micaceous
- Thinly laminated
- Wavy cross lamina and planar in upper portion
- Ripple cross-laminated
- Rooting and plant fragments
- Gradational contact
- Bioturbated and non-fossiliferous
Tebo marker
- Phosphatic black shale facies
- Shelf shale
Flooding surface
Tebo coal - coal facies
Exposure surface
Blocky mudstone facies
- Paleosol
Laminated muddy sandstone facies
- Shallow marine, probably a muddy tidal flat or coastal plain

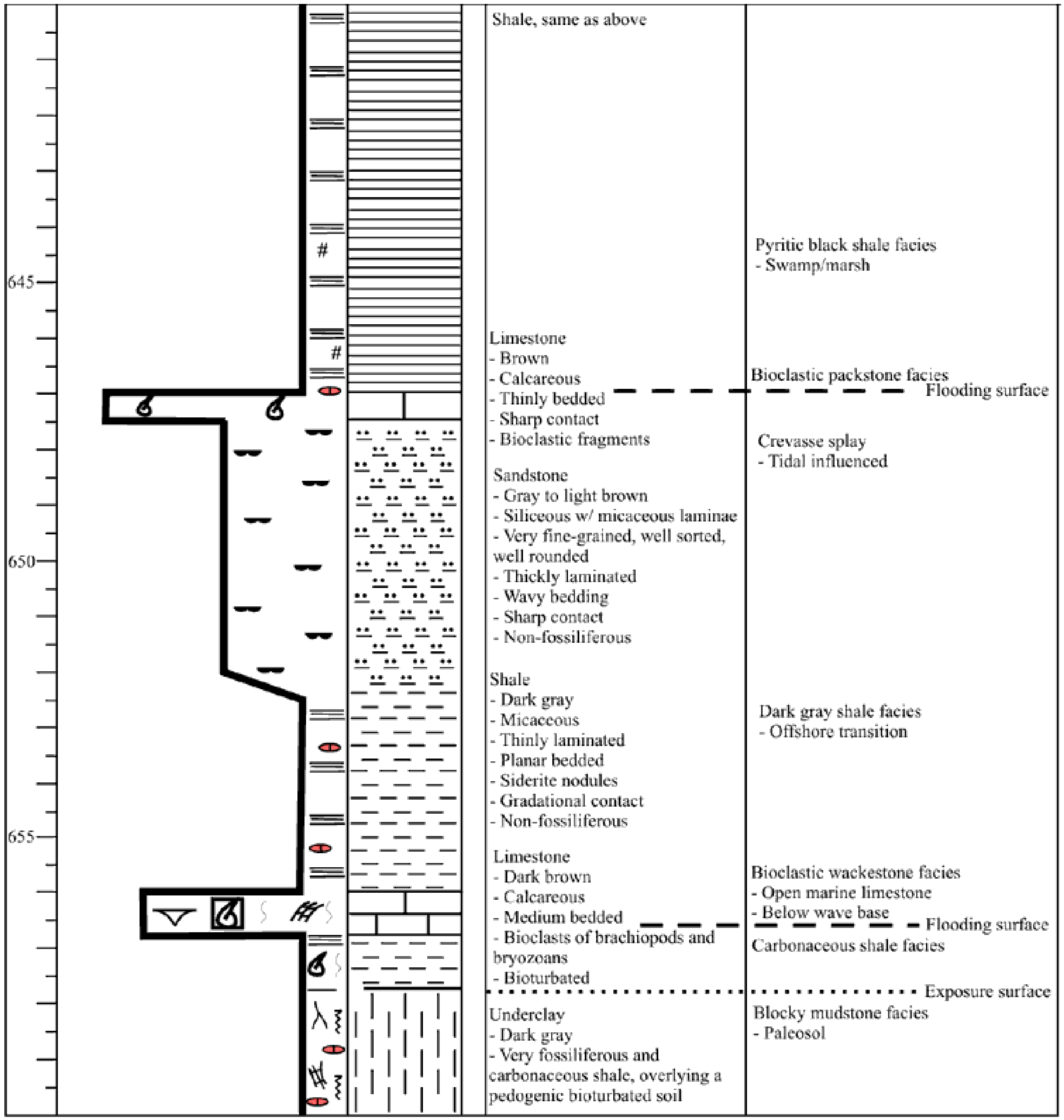

545
550
555
34
35
36
Shale, same as above
Shaley Sandstone
- Brown
- Micaceous and some silica
- Thinly laminated
- Wavy bedded
- Gradational contact
- Bioturbated
Laminated muddy sandstone facies
- Muddy tidal flat - coastal plain
Sandstone
- Light brown
- Siliceous
- Very fine-grained coarsening upward fine-grained well sorted and well rounded
- Thickly laminated to thinly bedded
- Planar, wavy and lenticular bedding
- Gradational contact
- Non-fossiliferous
Crevasse splay
- Unidirectional flow in upper portion and bimodal flow in lower portion
- Coarsens upward
- Possibly a tidal splay
- Sand is in place of Weir-Pittsburg coal


565
570
575
37
38
Sandstone, same as above
Shale
- Dark brown to gray
- Micaceous with siliceous laminae
- Thinly laminated
- Lenticular bedded with planar bedding on top
- Plant fragments
- Gradational contact
- Bioclastic fragments on top
Dark gray shale facies
- Similar to an underclay
- Non-marine, outside shale
Black Shale
- Black
- Micaceous
- Thinly laminated
- Planar bedded
- Phosphatic
- Gradational contact
- Non-fossiliferous
Phosphatic black shale facies
- Transgressive marine, core shale
Flooding surface
Sandstone, description on next page

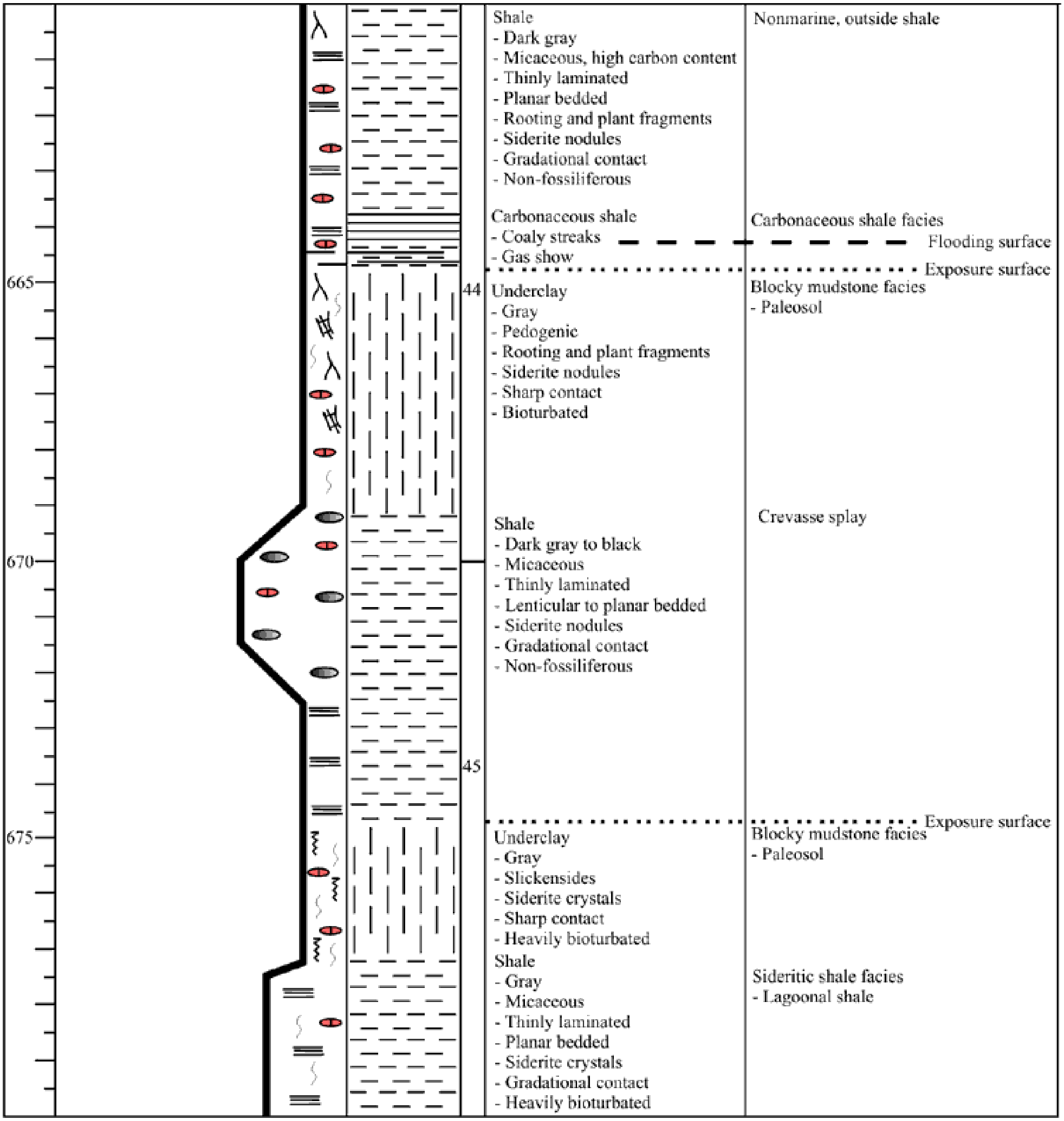

585
590
595
38
39
40
Sandstone
- Light brown
- Siliceous
- Very fine-grained, well sorted and rounded
- Thinly bedded to thickly laminated
- Flaser bedded
- Fractured on top
- Gradational contact
- Bioturbated on bottom
Crevasse Splay
- Unidirectional flow
- Some tidal influence
- Coarsens upward
Shale
- Dark gray to black
- Thinly laminated and planar
- Diagonal fracturing
- Phosphatic
- Gradational contact
Flooding surface
Blocky mudstone facies
- Paleosol
Underclay
- Gray
- Pedogenic
- Abundant plant fragments and rooting
- Slickensides
- Sharp contact
- Bioturbated
Shale
- Gray
- Micaceous
- Pedogenically altered
- Thinly laminated
- Planar bedded
- Siderite nodules
- Plant fragments
- Gradational contact
- Bioturbated
Sideritic gray shale facies
- Inner estuarine - central basin
Sandstone
- Light brown to gray
- Siliceous w/ mica laminae
- Very fine-grained, well sorted and rounded
- Thickly laminated
- Flaser, lenticular and wavy bedded
- Soft sediment deformation
- Siderite, and rip-up clasts
- Gradationalcontact
- Bioturbated
Bartlesville/Bluejacket Sandstone
Interlaminated sandstone and siltstone facies
- Bay head delta, upper estuarine
- Incised valley fill
- Bimodal flow
- Tidal influenced


605
610
615
40
41
Sandstone, same as above
Escape structures
Rip-up clasts
Passively filled vertical burrows
Rip-up clasts
Erosional contact
Interlaminated sandstone and siltstone facies
Exposure surface (sequence boundary)

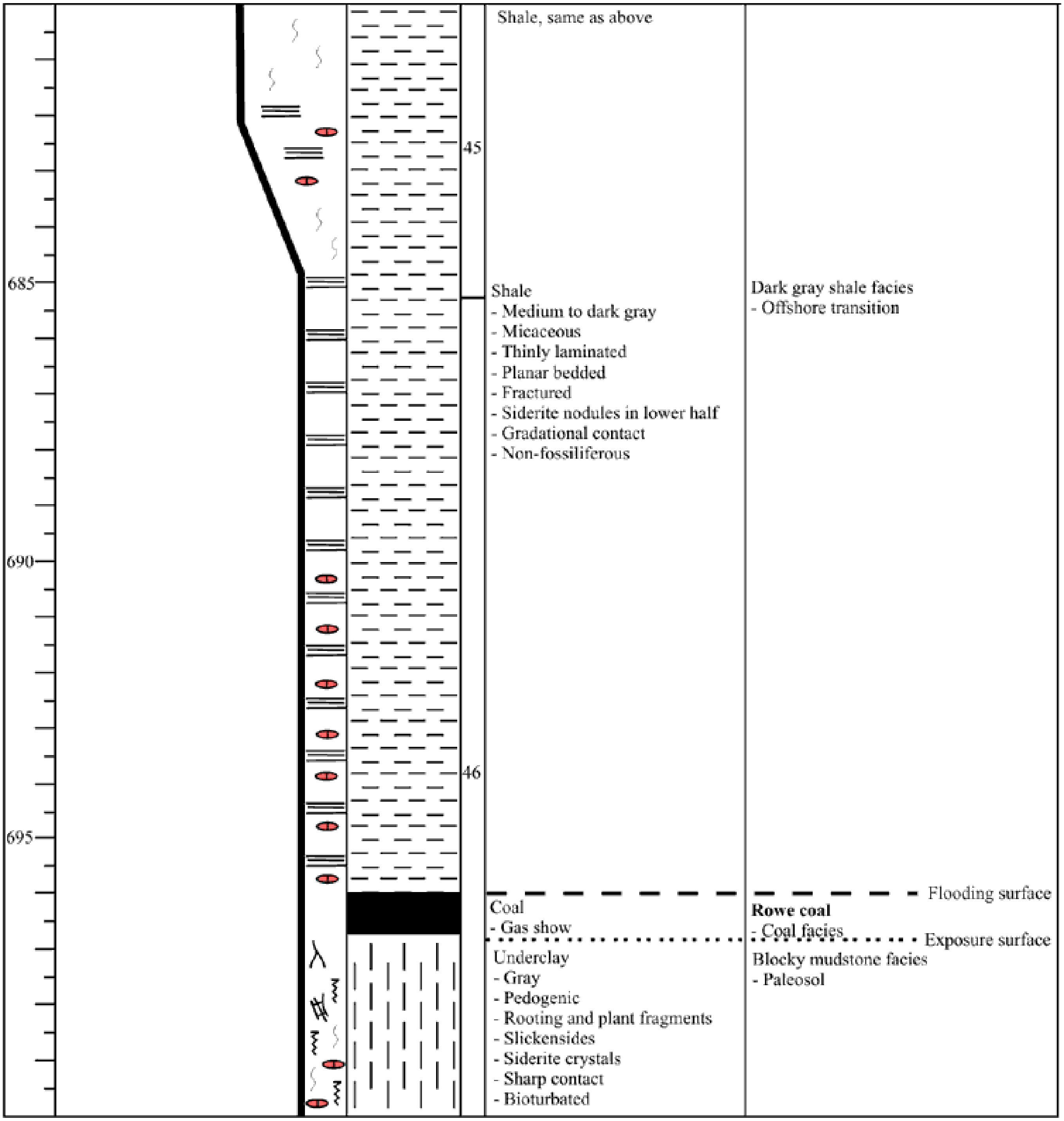

625
630
635
41
42
Shale
- Dark gray, lightens upward
- Micaceous
- Thinly laminated
- Planar bedded
- Rooting?
- Siderite nodules
- Gradational contact
- Some bioturbation
Dark gray shale facies
- Offshore transition
- Shoaling upward
Black shale
- Micaceous
- Thinly laminated
- Planar bedded
- Gradational contact
- Non-fossiliferous
Dark gray shale facies
- Offshore transition
- Shelf shale
Flooding surface
Coal
- Sharp contact
Drywood coal
- Coal facies
Exposure surface
Underclay
- Medium gray
- Pedogenic
- Rooting
- Sharp contact
- Bioturbated
Blocky mudstone facies
- Paleosol
Blocky mudstone facies
- Similar to an underclay
- Nearshore shale
Shale
- Dark gray to black
- Micaceous
- Thinly laminated
- Planar bedded
- Top is pedogenically altered
- Rooting
- Pyrite nodules
- Gradational contact
- Bioturbated
Pyritic black shale
- Swamp/marsh



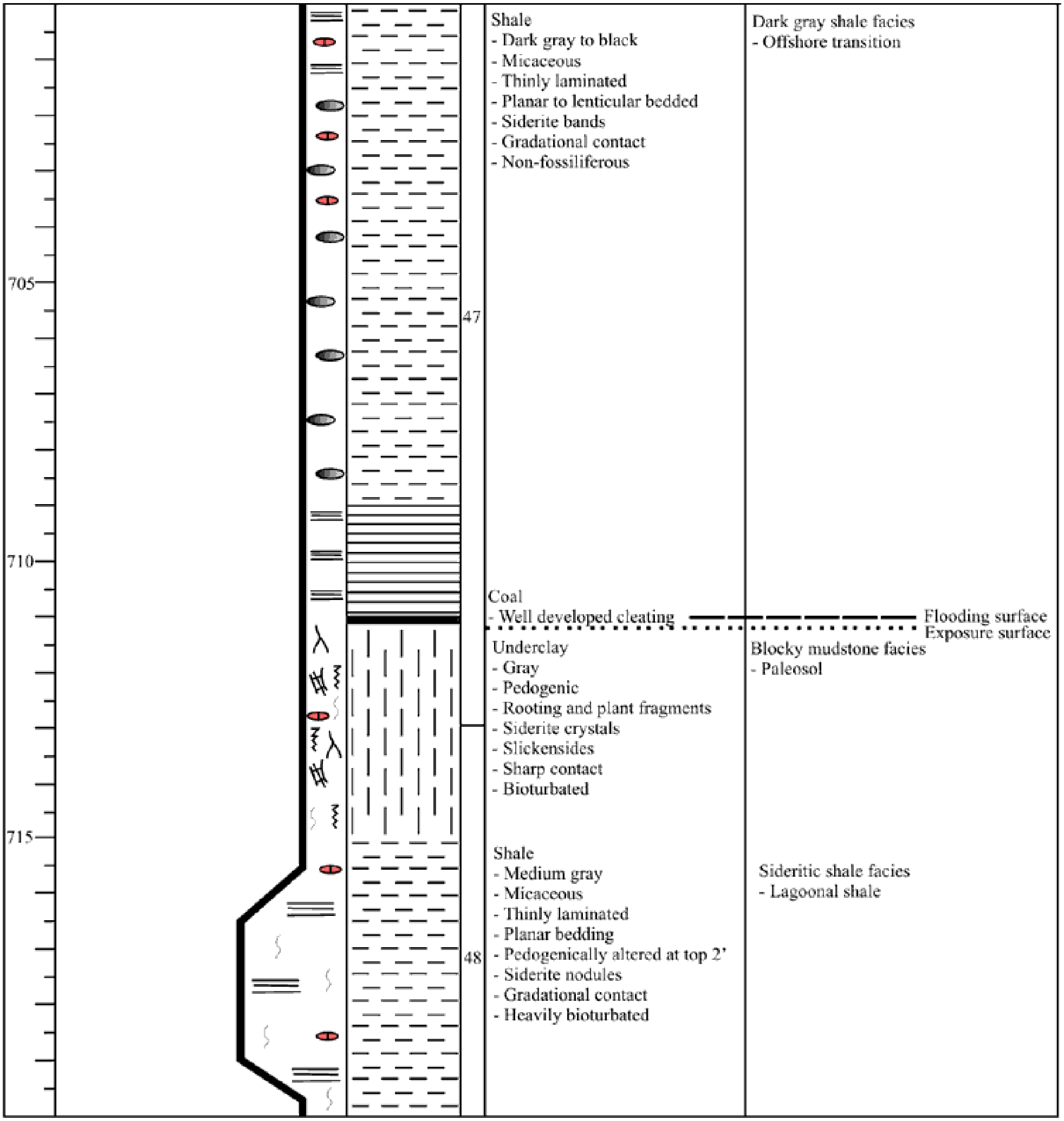
645
650
655
Shale, same as above
Pyritic black shale facies
- Swamp/marsh
Limestone
- Brown
- Calcareous
- Thinly bedded
- Sharp contact
- Bioclastic fragments
Bioclastic packstone facies
Flooding surface
Crevasse splay
- Tidal influenced
Sandstone
- Gray to light brown
- Siliceous w/ micaceous laminae
- Very fine-grained, well sorted, well rounded
- Thickly laminated
- Wavy bedding
- Sharp contact
- Non-fossiliferous
Shale
- Dark gray
- Micaceous
- Thinly laminated
- Planar bedded
- Siderite nodules
- Gradational contact
- Non-fossiliferous
Dark gray shale facies
- Offshore transition
Limestone
- Dark brown
- Calcareous
- Medium bedded
- Bioclasts of brachiopods and bryozoans
- Bioturbated
Bioclastic wackestone facies
- Open marine limestone
- Below wave base
Flooding surface
Carbonaceous shale facies
Exposure surface
Underclay
- Dark gray
- Very fossiliferous and carbonaceous shale, overlying a pedogenic bioturbated soil
Blocky mudstone facies
- Paleosol



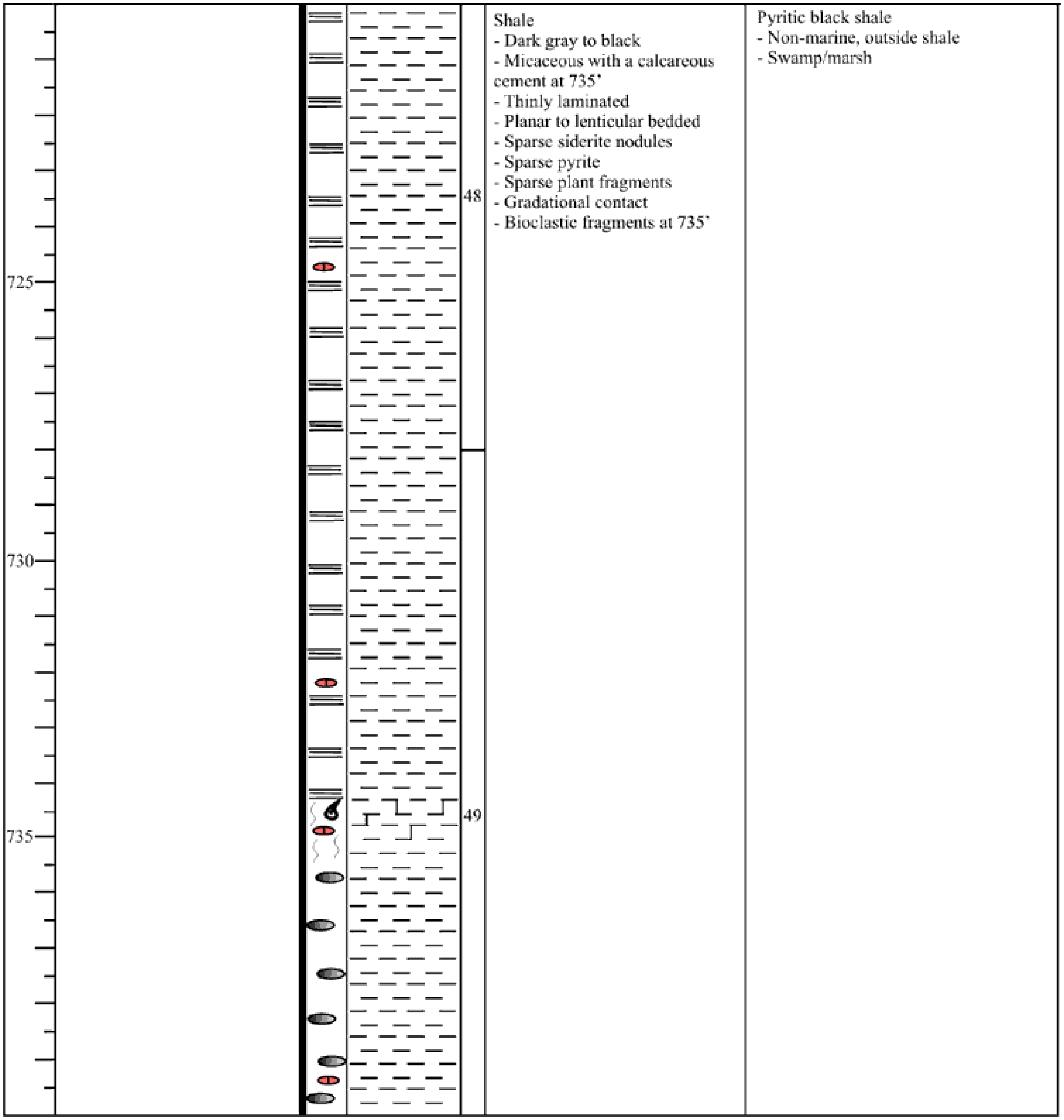
665
670
675
44
45
Shale
- Dark gray
- Micaceous, high carbon content
- Thinly laminated
- Planar bedded
- Rooting and plant fragments
- Siderite nodules
- Gradational contact
- Non-fossiliferous
Nonmarine, outside shale
Carbonaceous shale
- Coaly streaks
- Gas show
Carbonaceous shale facies
Flooding surface
Exposure surface
Underclay
- Gray
- Pedogenic
- Rooting and plant fragments
- Siderite nodules
- Sharp contact
- Bioturbated
Blocky mudstone facies
- Paleosol
Shale
- Dark gray to black
- Micaceous
- Thinly laminated
- Lenticular to planar bedded
- Siderite nodules
- Gradational contact
- Non-fossiliferous
Crevasse splay
Exposure surface
Underclay
- Gray
- Slickensides
- Siderite crystals
- Sharp contact
- Heavily bioturbated
Blocky mudstone facies
- Paleosol
Shale
- Gray
- Micaceous
- Thinly laminated
- Planar bedded
- Siderite crystals
- Gradational contact
- Heavily bioturbated
Sideritic shale facies
- Lagoonal shale

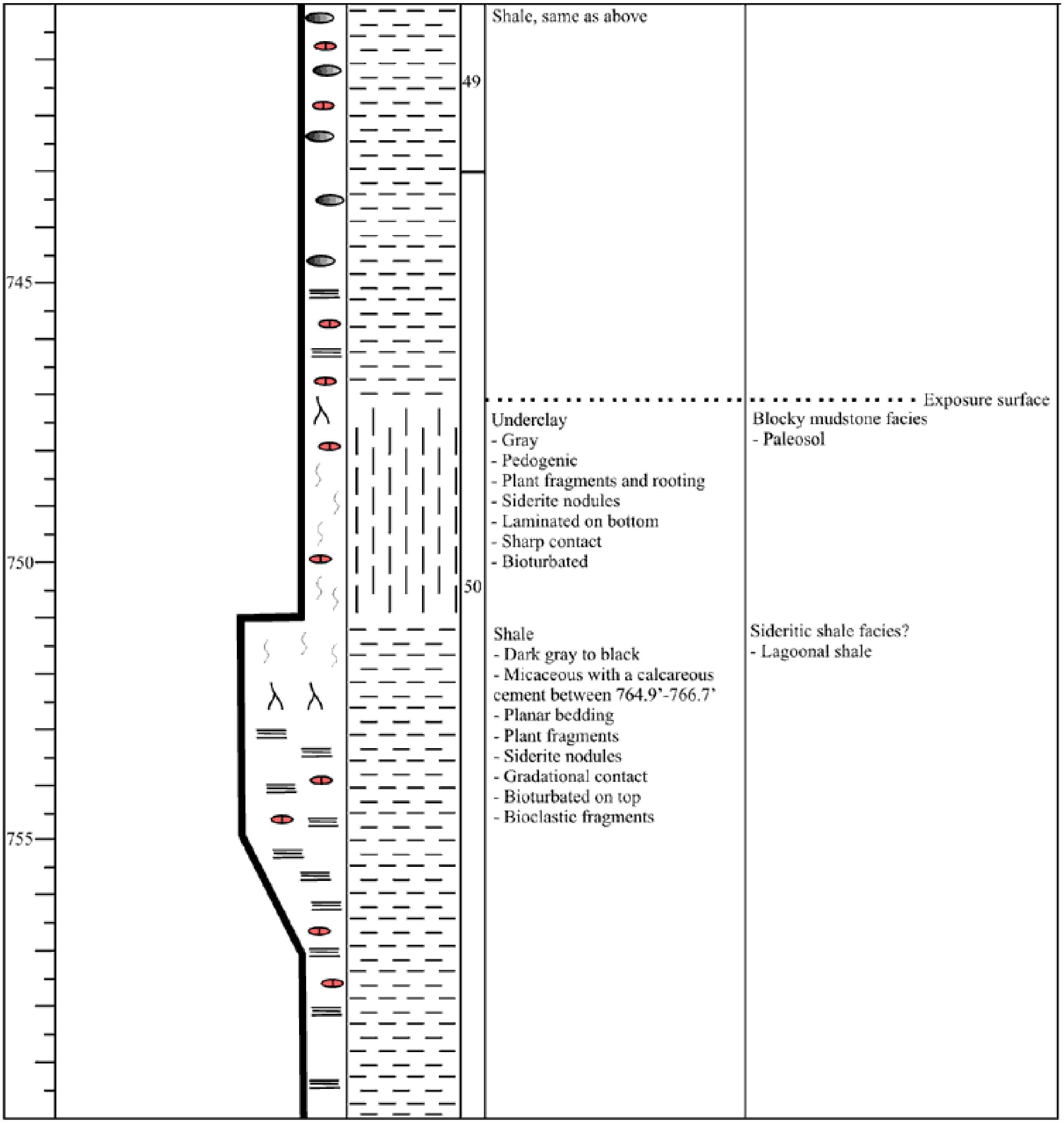


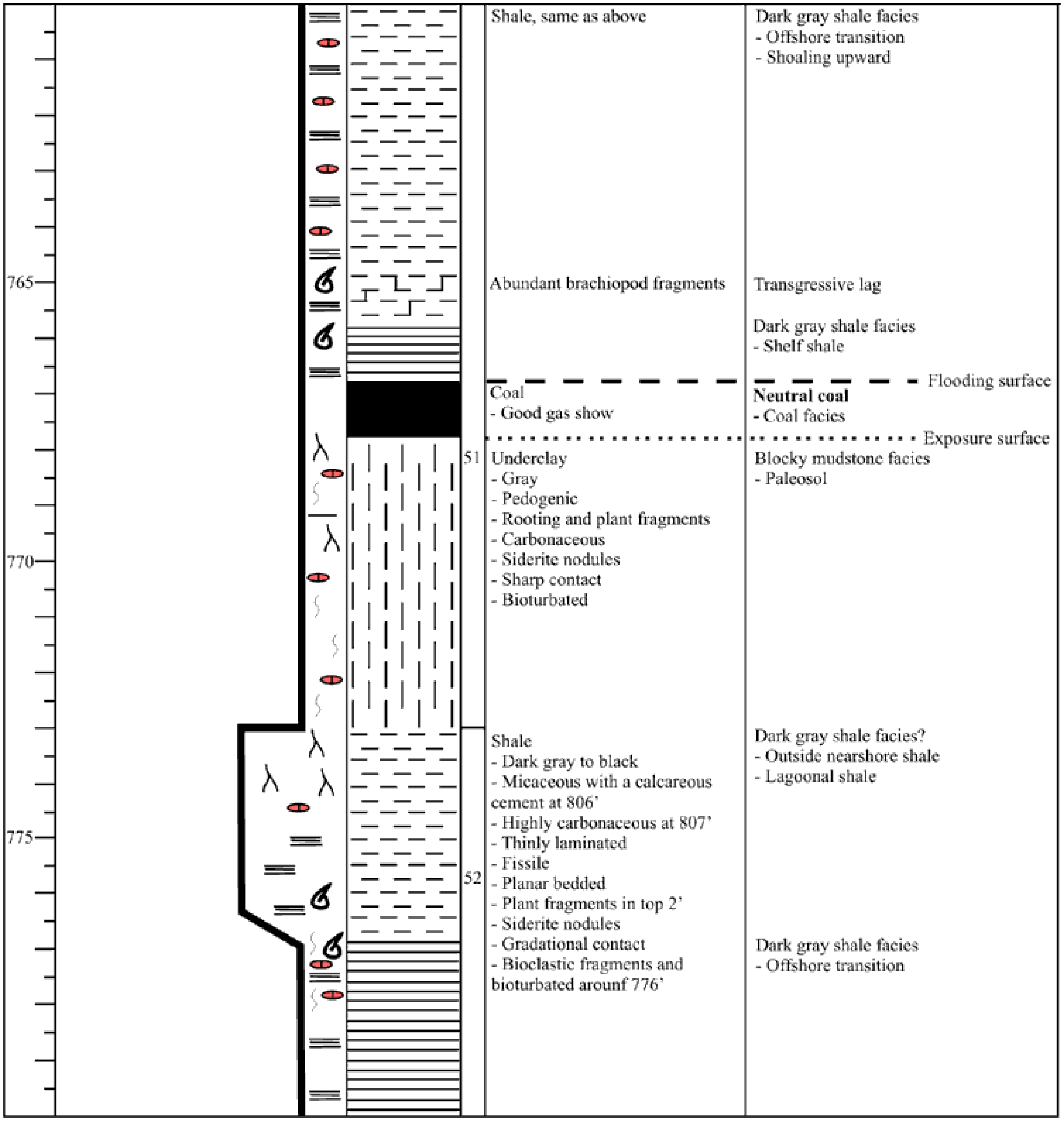
Shale, same as above
45
685
Shale
- Medium to dark gray
- Micaceous
- Thinly laminated
- Planar bedded
- Fractured
- Siderite nodules in lower half
- Gradational contact
- Non-fossiliferous
Dark gray shale facies
- Offshore transition
690
46
695
Flooding surface
Coal
- Gas show
Rowe coal
- Coal facies
Exposure surface
Underclay
- Gray
- Pedogenic
- Rooting and plant fragments
- Slickensides
- Siderite crystals
- Sharp contact
- Bioturbated
Blocky mudstone facies
- Paleosol

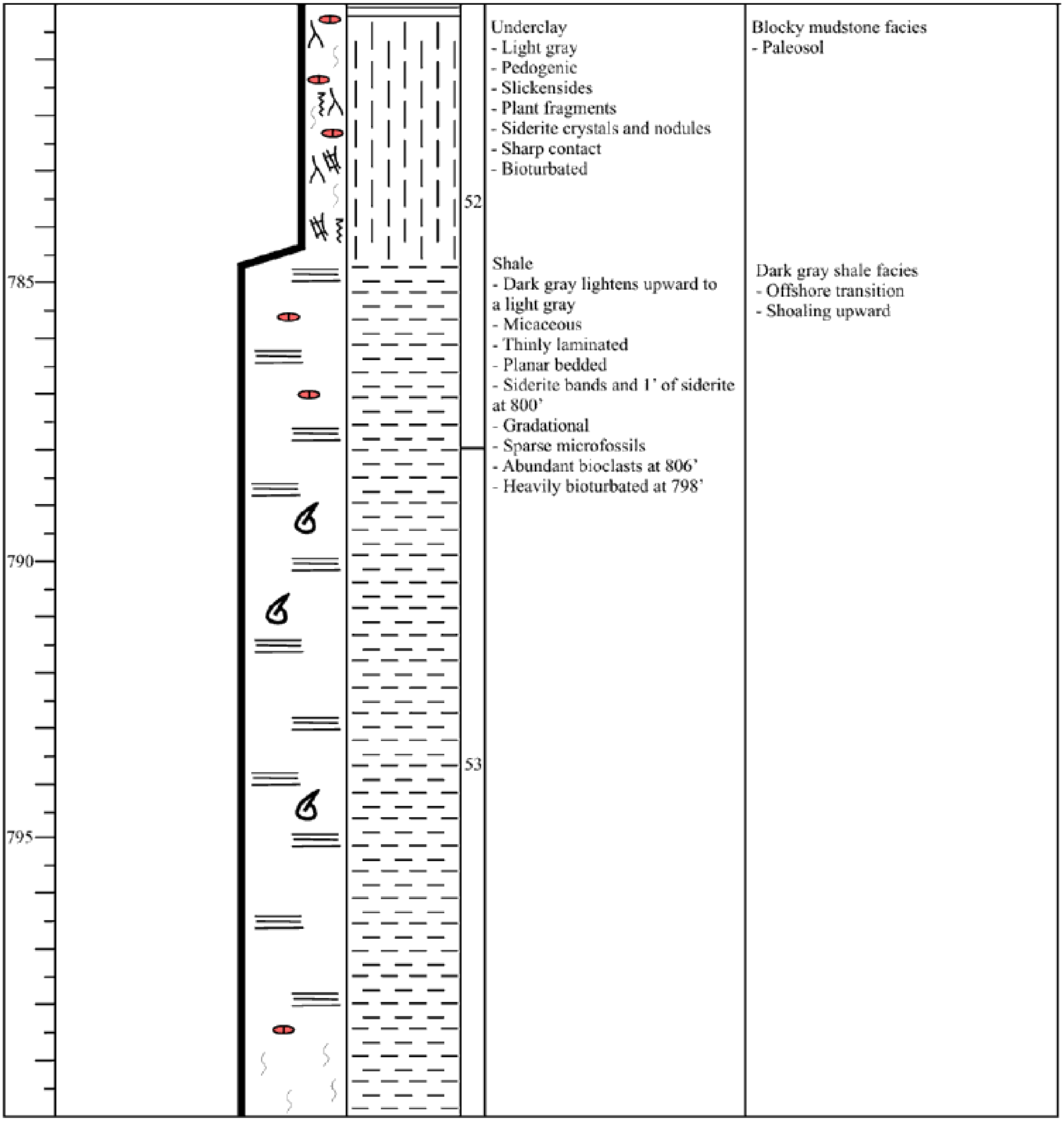


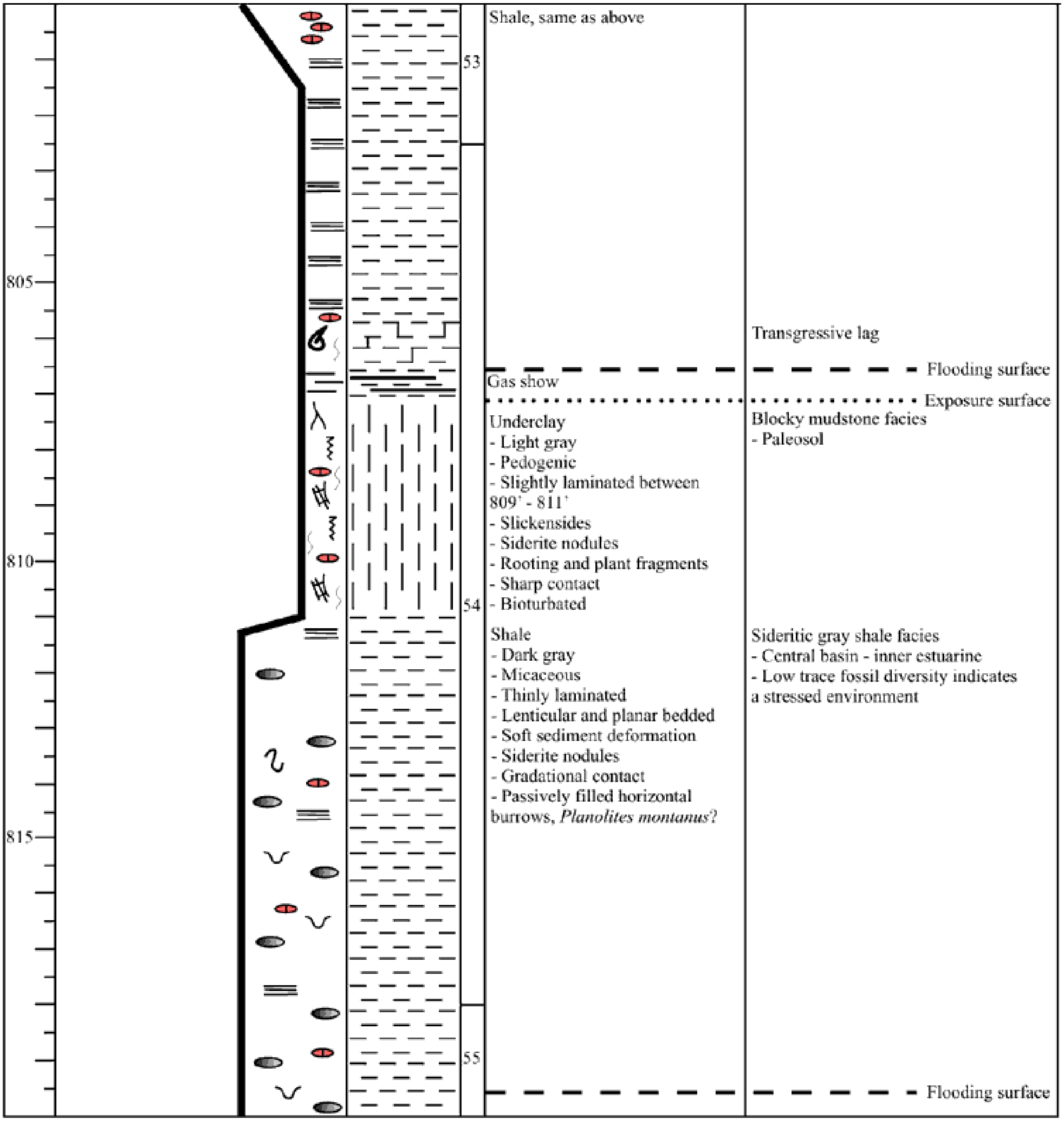
705
710
715
47
48
Shale
- Dark gray to black
- Micaceous
- Thinly laminated
- Planar to lenticular bedded
- Siderite bands
- Gradational contact
- Non-fossiliferous
Dark gray shale facies
- Offshore transition
Coal
- Well developed cleating
Flooding surface
Exposure surface
Underclay
- Gray
- Pedogenic
- Rooting and plant fragments
- Siderite crystals
- Slickensides
- Sharp contact
- Bioturbated
Blocky mudstone facies
- Paleosol
Shale
- Medium gray
- Micaceous
- Thinly laminated
- Planar bedding
- Pedogenically altered at top 2'
- Siderite nodules
- Gradational contact
- Heavily bioturbated
Sideritic shale facies
- Lagoonal shale

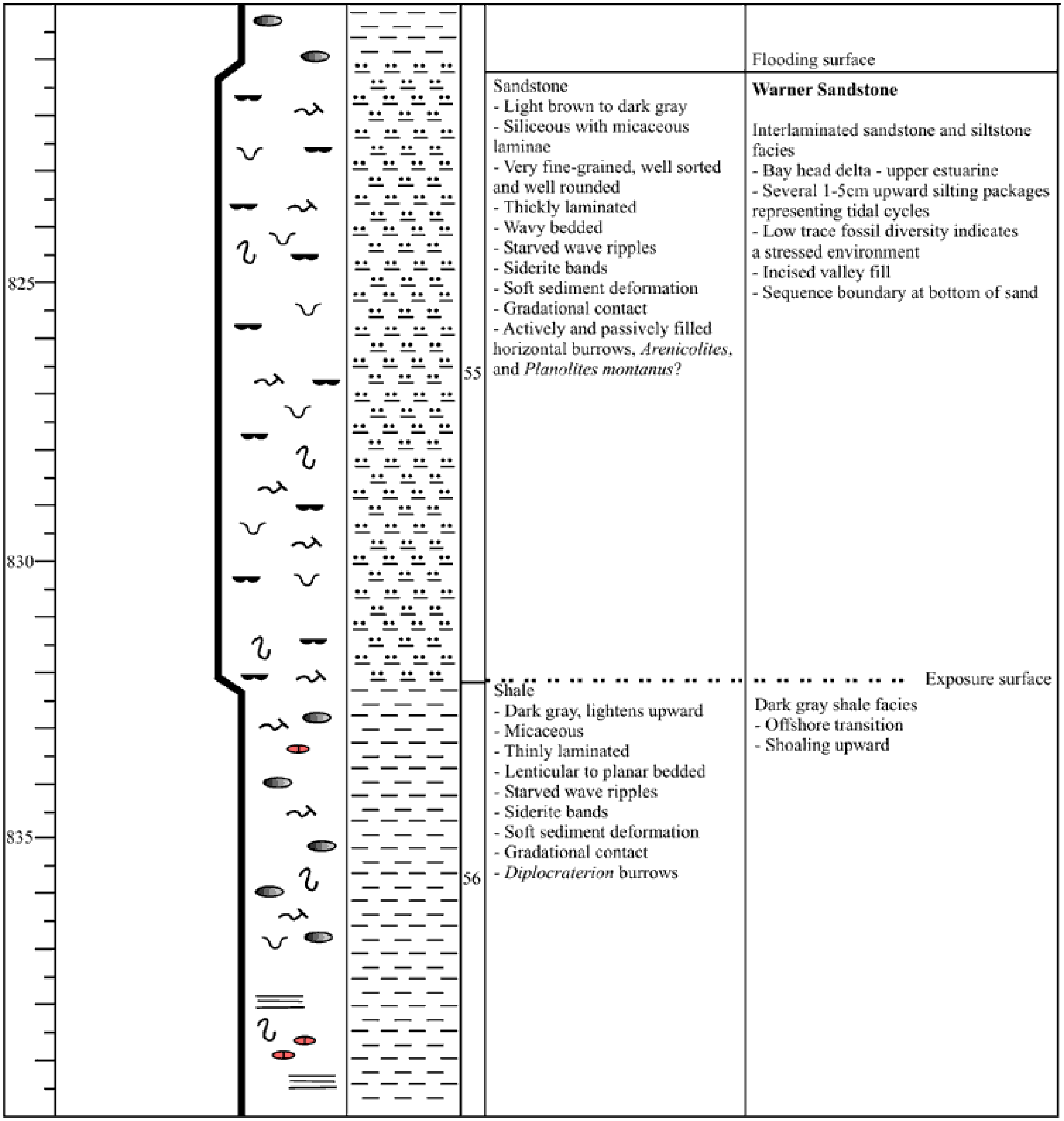

725
730
735
48
49
Shale
- Dark gray to black
- Micaceous with a calcareous cement at 735'
- Thinly laminated
- Planar to lenticular bedded
- Sparse siderite nodules
- Sparse pyrite
- Sparse plant fragments
- Gradational contact
- Bioclastic fragments at 735'
Pyritic black shale
- Non-marine, outside shale
- Swamp/marsh

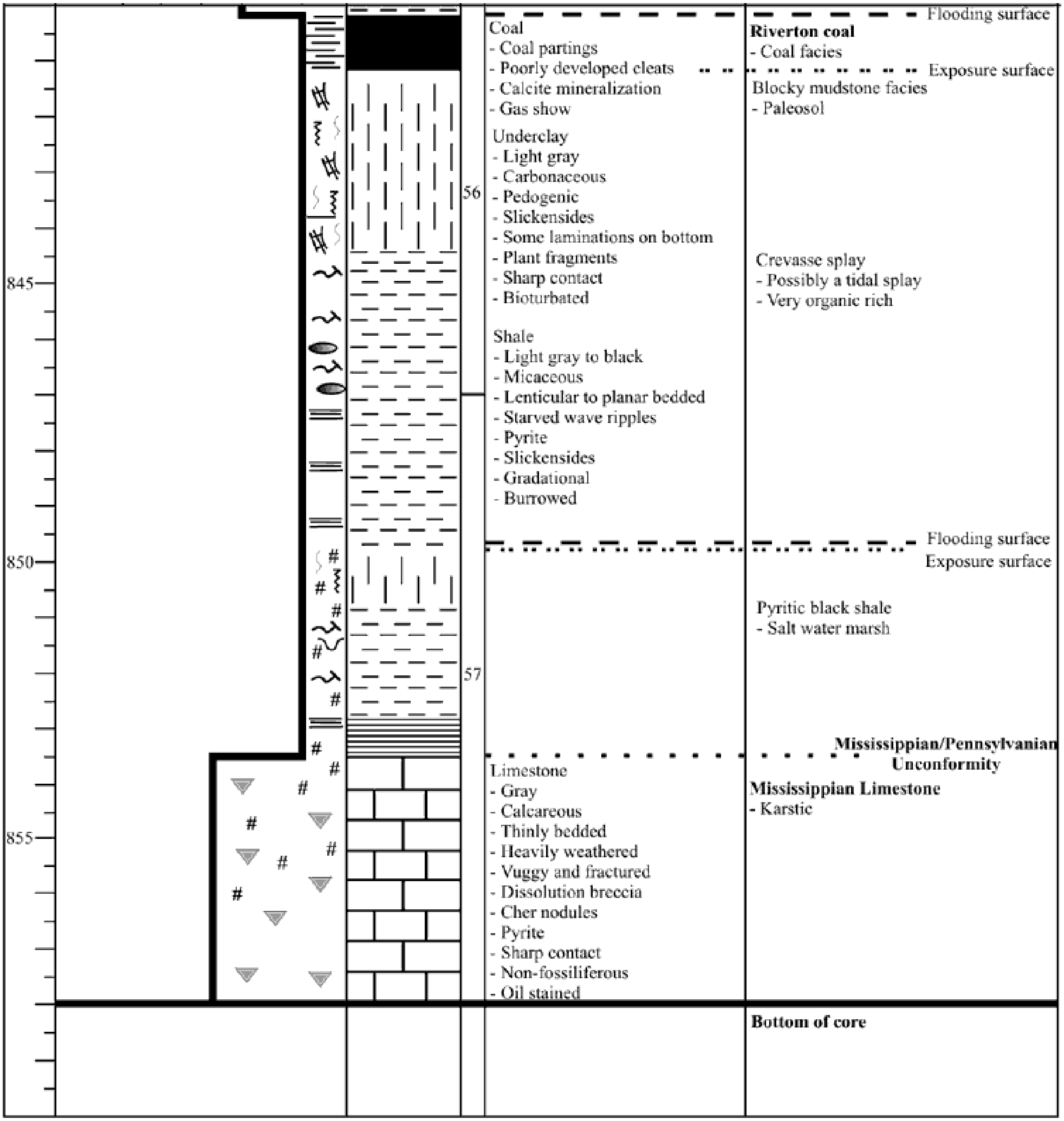

745
750
755
49
50
Shale, same as above
Exposure surface
Underclay
- Gray
- Pedogenic
- Plant fragments and rooting
- Siderite nodules
- Laminated on bottom
- Sharp contact
- Bioturbated
Blocky mudstone facies
- Paleosol
Shale
- Dark gray to black
- Micaceous with a calcareous cement between 764.9'-766.7'
- Planar bedding
- Plant fragments
- Siderite nodules
- Gradational contact
- Bioturbated on top
- Bioclastic fragments
Sideritic shale facies?
- Lagoonal shale


765
770
775
51
52
Shale, same as above
Abundant brachiopod fragments
Coal
- Good gas show
Underclay
- Gray
- Pedogenic
- Rooting and plant fragments
- Carbonaceous
- Siderite nodules
- Sharp contact
- Bioturbated
Shale
- Dark gray to black
- Micaceous with a calcareous cement at 806'
- Highly carbonaceous at 807'
- Thinly laminated
- Fissile
- Planar bedded
- Plant fragments in top 2'
- Siderite nodules
- Gradational contact
- Bioclastic fragments and bioturbated arounf 776'
Dark gray shale facies
- Offshore transition
- Shoaling upward
Transgressive lag
Dark gray shale facies
- Shelf shale
Flooding surface
Neutral coal
- Coal facies
Exposure surface
Blocky mudstone facies
- Paleosol
Dark gray shale facies?
- Outside nearshore shale
- Lagoonal shale
Dark gray shale facies
- Offshore transition


785
790
795
52
53
Underclay
- Light gray
- Pedogenic
- Slickensides
- Plant fragments
- Siderite crystals and nodules
- Sharp contact
- Bioturbated
Shale
- Dark gray lightens upward to a light gray
- Micaceous
- Thinly laminated
- Planar bedded
- Siderite bands and 1' of siderite at 800'
- Gradational
- Sparse microfossils
- Abundant bioclasts at 806'
- Heavily bioturbated at 798'
Blocky mudstone facies
- Paleosol
Dark gray shale facies
- Offshore transition
- Shoaling upward

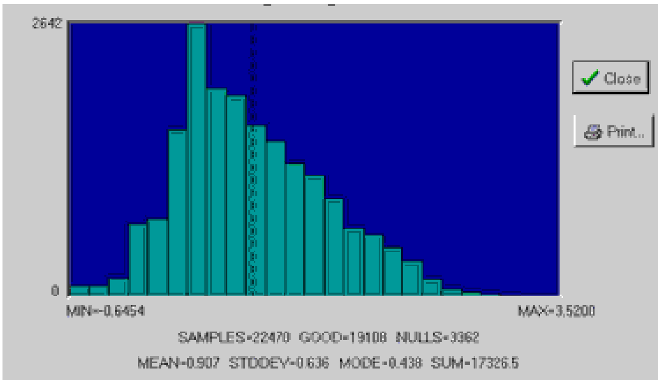

805
810
815
53
54
55
Shale, same as above
Transgressive lag
Flooding surface
Gas show
Exposure surface
Underclay
- Light gray
- Pedogenic
- Slightly laminated between 809' - 811'
- Slickensides
- Siderite nodules
- Rooting and plant fragments
- Sharp contact
- Bioturbated
Blocky mudstone facies
- Paleosol
Shale
- Dark gray
- Micaceous
- Thinly laminated
- Lenticular and planar bedded
- Soft sediment deformation
- Siderite nodules
- Gradational contact
- Passively filled horizontal burrows, *Planolites montanus*?
Sideritic gray shale facies
- Central basin - inner estuarine
- Low trace fossil diversity indicates a stressed environment
Flooding surface

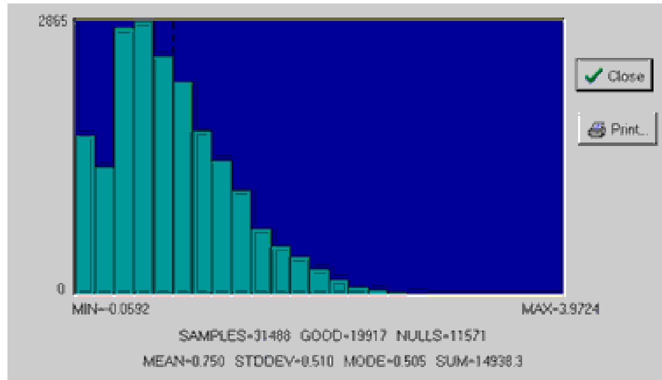

825
830
835
55
56
Flooding surface
Sandstone
- Light brown to dark gray
- Siliceous with micaceous laminae
- Very fine-grained, well sorted and well rounded
- Thickly laminated
- Wavy bedded
- Starved wave ripples
- Siderite bands
- Soft sediment deformation
- Gradational contact
- Actively and passively filled horizontal burrows, *Arenicolites*, and *Planolites montanus*?
Warner Sandstone
Interlaminated sandstone and siltstone facies
- Bay head delta - upper estuarine
- Several 1-5cm upward silting packages representing tidal cycles
- Low trace fossil diversity indicates a stressed environment
- Incised valley fill
- Sequence boundary at bottom of sand
Exposure surface
Shale
- Dark gray, lightens upward
- Micaceous
- Thinly laminated
- Lenticular to planar bedded
- Starved wave ripples
- Siderite bands
- Soft sediment deformation
- Gradational contact
- *Diplocraterion* burrows
Dark gray shale facies
- Offshore transition
- Shoaling upward


845
850
855
56
57
Flooding surface
Coal
- Coal partings
- Poorly developed cleats
- Calcite mineralization
- Gas show
Riverton coal
- Coal facies
Exposure surface
Blocky mudstone facies
- Paleosol
Underclay
- Light gray
- Carbonaceous
- Pedogenic
- Slickensides
- Some laminations on bottom
- Plant fragments
- Sharp contact
- Bioturbated
Crevasse splay
- Possibly a tidal splay
- Very organic rich
Shale
- Light gray to black
- Micaceous
- Lenticular to planar bedded
- Starved wave ripples
- Pyrite
- Slickensides
- Gradational
- Burrowed
Flooding surface
Exposure surface
Pyritic black shale
- Salt water marsh
Mississippian/Pennsylvanian
Unconformity
Limestone
- Gray
- Calcareous
- Thinly bedded
- Heavily weathered
- Vuggy and fractured
- Dissolution breccia
- Cher nodules
- Pyrite
- Sharp contact
- Non-fossiliferous
- Oil stained
Mississippian Limestone
- Karstic
Bottom of core

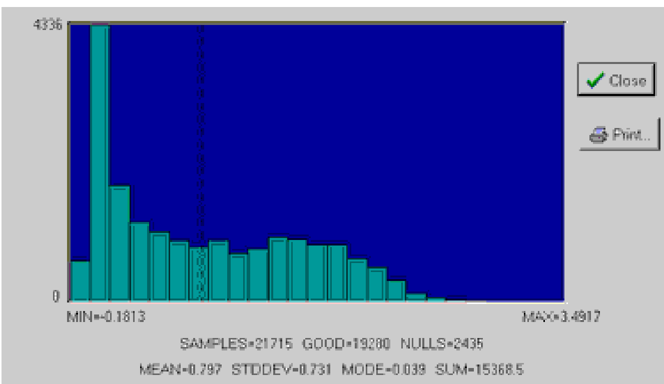
Appendix 2: Statistical distribution of coal thickness

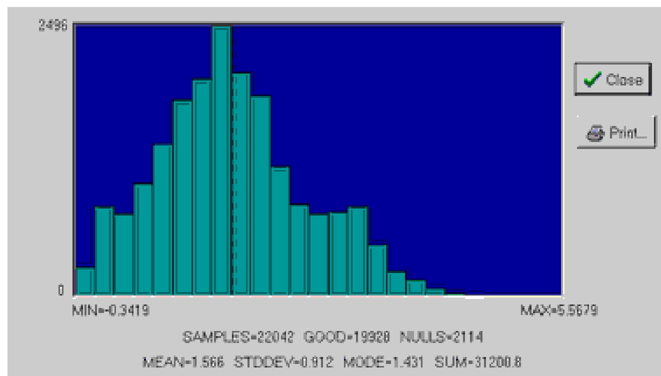
Summit coal | **Mulky coal**



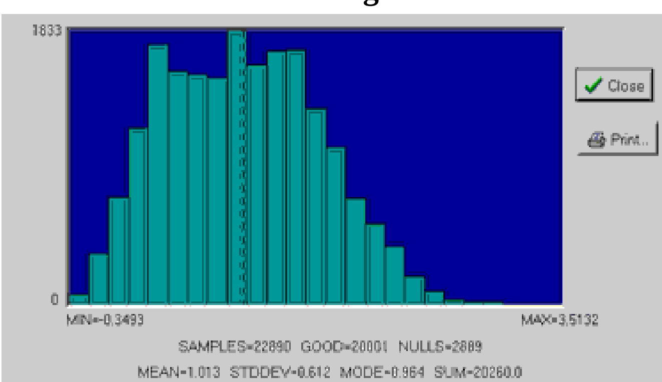


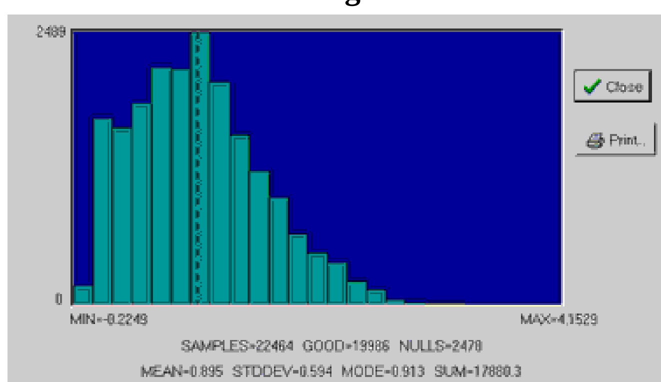
Iron Post coal | **Bevier coal**



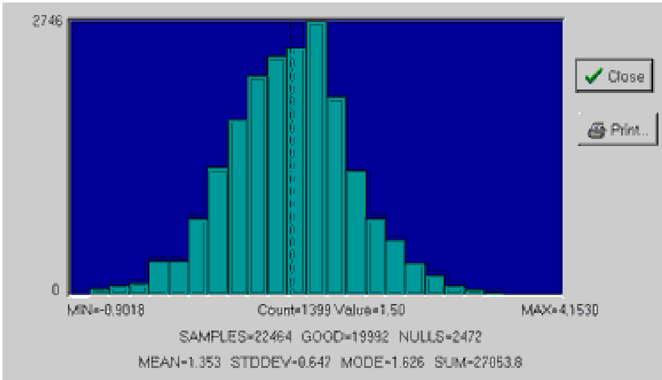


Croweburg coal | **Fleming coal**

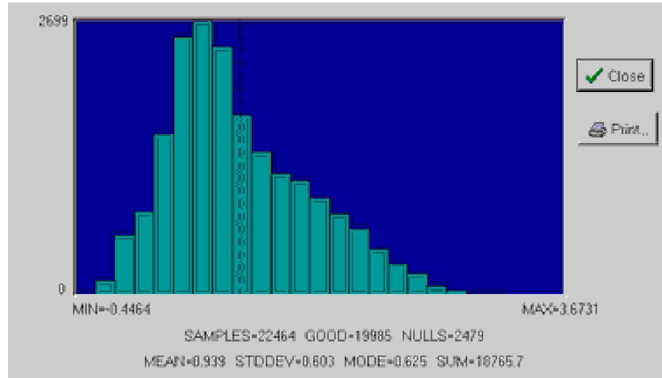




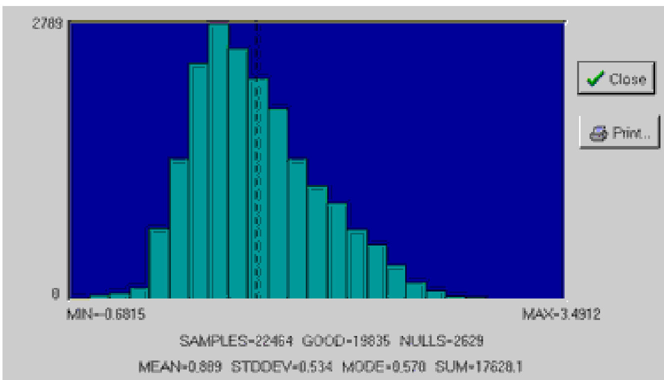
Mineral coal | **Scammon coal**



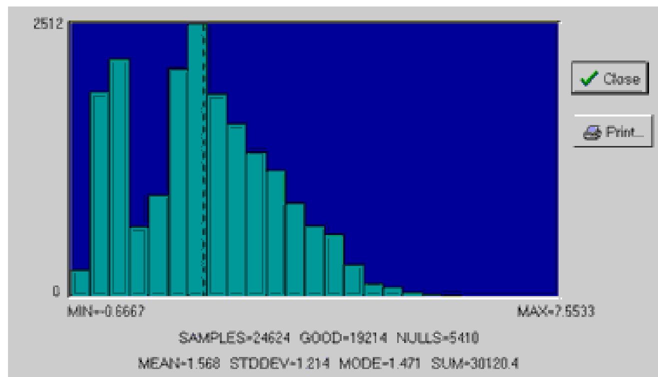
Tebo coal



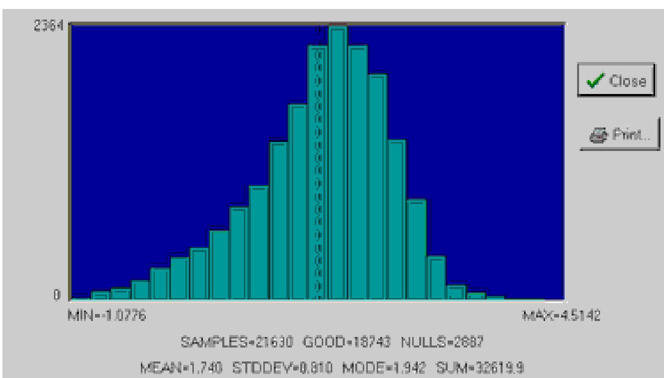
Weir-Pittsburg coal

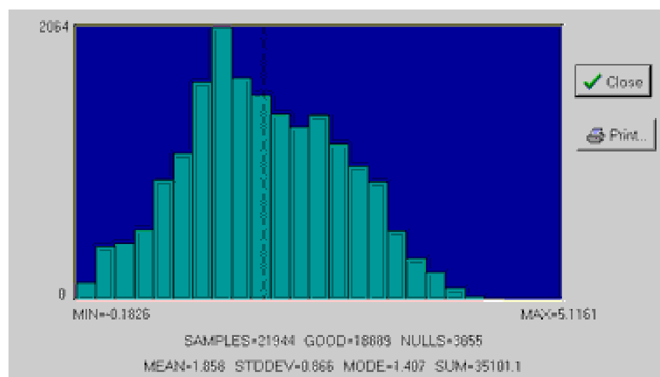


Aw coal



Riverton coal





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