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STRATIGRAPHY, PETROLOGY, AND DEPOSITIONAL SEQUENCE
OF THE MARMATON, PLEASANTON, AND LOWERMOST KANSAS
CITY GROUPS (LATE MIDDLE - EARLY UPPER PENNSYLVANIAN)
IN A CORE FROM SOUTH-CENTRAL IOWA

by

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ABSTRACT

The stratigraphy of the Marmaton, Pleasanton and lowermost Kansas City Groups of Iowa has been poorly understood because of a scarcity of outcrops. Investigation of a two-inch-wide core (CP37 of the Iowa Geological Survey) through this sequence has permitted a complete section to be described from Clarke County in south-central Iowa. In the core all 5 limestone formations and intervening shale formations known from Iowa, Missouri and Kansas outcrop were identified. In addition several unnamed members, or undescribed facies of named members, were observed, but lateral relations are uncertain at this time. However, the Exline Limestone and Chariton Conglomerate described from Iowa outcrop are absent from the Pleasanton Group in the core.

Two lithologies that were previously unreported but are environmentally quite significant were discovered: 1) The Anna Shale Member of the Pawnee Formation contains a nearshore carbonaceous, black shale with macrofossils, underlying the well known offshore, phosphatic, black shale which lacks macrofossils; 2) The Cooper Creek Limestone Member of the Lenapah Formation contains near its base a green shale with phosphatic

nodules. Such phosphatic nodules, which have been interpreted to indicate maximum extent of a significant transgression, are present in all other limestone formations studied, but were not previously reported from the Cooper Creek.

The basic five-member cyclothem sequence (nearshore shale, transgressive limestone, offshore shale, regressive limestone, nearshore shale) recognized in the Upper Pennsylvanian of Kansas is applicable to the rocks studied in Iowa. Six cyclothems are recognized nucleating basically around the limestone formations: Lower Fort Scott, Upper Fort Scott, Pawnee, Altamont, Lenapah (all Marmaton cyclothems), and Hertha (lowermost Kansas City cyclothem).

Transgressive deposits typically are very thin in all the cyclothems. Transgressive limestones are present only above nearshore deposits other than coal. Each cycle contains a phosphatic offshore shale marking maximum transgression.

Regressive limestones in the lower half of the Marmaton (below Bandera Formation) are thin and lack phylloid algae, whereas those above are thicker and contain phylloid algae. The lack of thick algal limestone in some cases (Houx, Higginsville) may be explained by early clastic influx.

Nearshore shales are mainly the shale formations that separate the limestone formations. They consist of: 1) laminated gray shales and sandstones, which record nearshore rapid detrital influx, 2) thin limestones, which develop during cessations of clastic influx, 3) coals, which represent reducing vegetation-rich marginal or terrestrial environments, and 4) reddish mudstones, which suggest an oxidizing, subaerial environment. These lithologies acutally may be inserted into all but the most offshore units of a cyclothem. They often give the appearance of a partial cyclothem and are called a clastic wedge by Wanless (1966). Clastic wedges develop in response to local deltaic influx and pinch out laterally. Major transgressions of cyclothem are usually marked by regionally persistent phosphatic black shales, which thus differentiates them from more local cycles of deposition caused by delta processes.

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INTRODUCTION

The Desmoinesian Series of Middle Pennsylvanian age was named in Iowa by Keyes (1893), yet the Iowa section is one of the least known sequences of this age in the United States (Branson, 1962, p. 439). This is largely because of widespread Quaternary cover that results in a lack of much good bedrock exposure. The Iowa Geological Survey coal drilling project has recently put down a long core through Middle Pennsylvanian rocks in south-central Iowa. A complete section has been recovered from the lowermost Kansas City Group and entire Pleasanton Group of the Missourian Series as well as the entire Marmaton and Cherokee Groups of the Desmoinesian Series. This core thus provides an uninterrupted stratigraphic sequence of this interval that cannot be duplicated in outcrop.

The purpose of this project is to study in detail the stratigraphy and petrology, and to interpret the depositional environment of each lithic unit recognized from the uppermost Cherokee Group to lower Kansas City Group (figure 1), in order to gain a better understanding of late Middle Pennsylvanian history in south-central Iowa.

Figure 1. Pennsylvanian stratigraphic nomenclature of Iowa including outcrop thicknesses and notation of interval studied in Core CP37 (modified after Landis, 1965, figure 4; Iowa Geological Survey, 1968).

LOCATION

The core studied is number CP37 of the Iowa Geological Survey coal project. This two-inch diameter core was drilled in 1975 at NE $\frac{1}{4}$, SE $\frac{1}{4}$, NE $\frac{1}{4}$, section 2, T. 72 N., R. 26 W., Clarke County, Iowa. This part of Iowa is on the northeast side of the Forest City Basin where Pennsylvanian strata dip southwestward toward the center of the basin (figure 2). Structural highs of this area that were active during much of the Pennsylvanian are: Wisconsin Arch, Mississippi River Arch, Ozark Uplift, and Nemaha Uplift. Pennsylvanian rocks have been eroded back from the 3 eastern uplifts to form the present outcrop (figure 2), which has been interpreted by Schenk (1967) to approximate the trend of original depositional strike.

PREVIOUS STRATIGRAPHIC STUDY

States with Pennsylvanian outcrop south of Iowa have less Quaternary cover and more actively sought economic deposits, and thus have received more detailed study. The latest stratigraphic summary reports of these states are Howe and Koenig (1961) for Missouri, Willman et. al. (1975) for Illinois, and Zeller (1968) for Kansas.

The only recent stratigraphic summary available for Iowa is that of Landis (1965). Much of this report is based on a long traverse by Cline (1941) and on

Figure 2. Midcontinent Desmoinesian isopachous and outcrop map showing core location, and Pennsylvanian structural features (modified after Branson, 1961, figure 6; Wanless, 1975, figure 15).

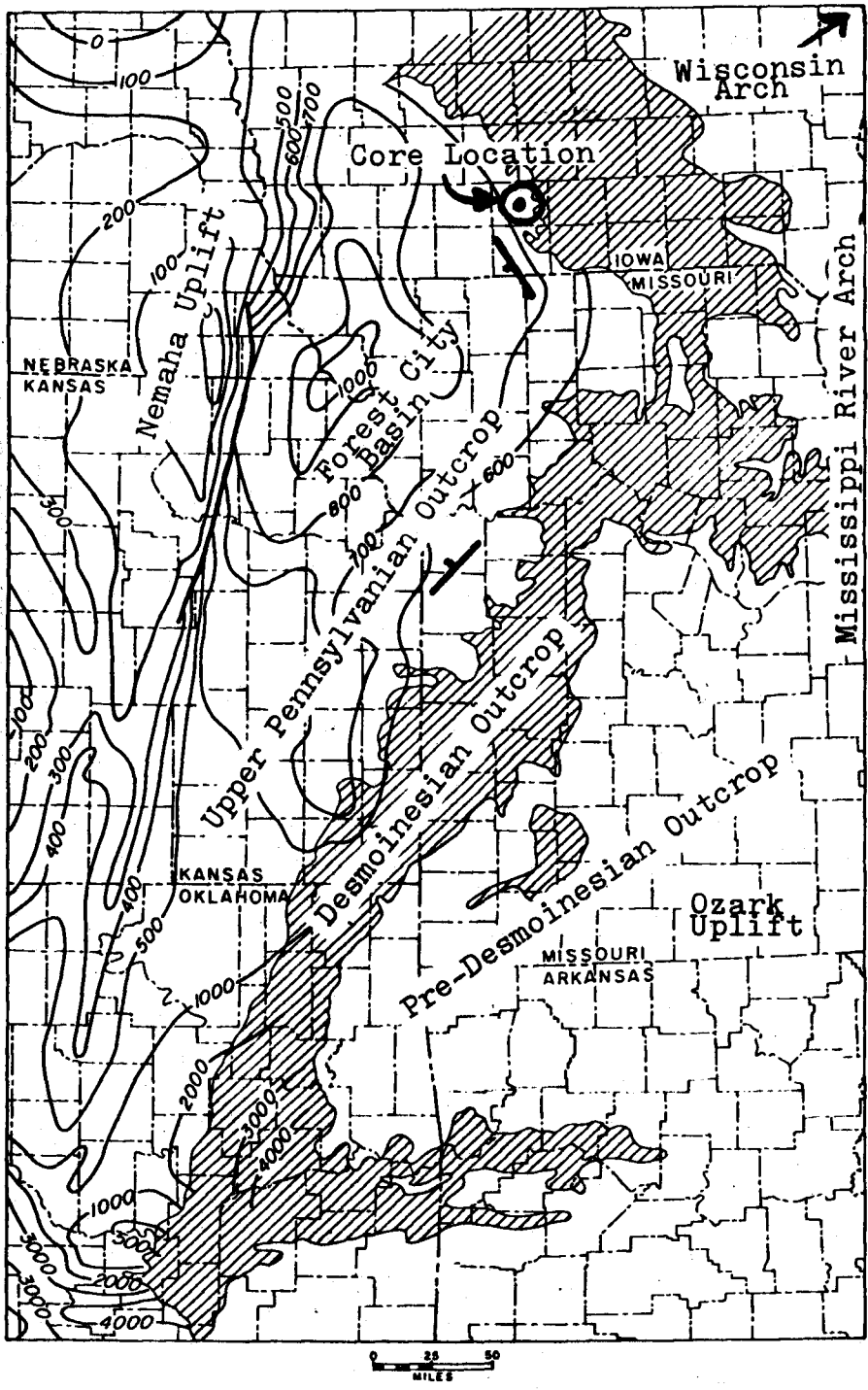


Figure 2.

correlations established by Weller and others (1942). The stratigraphic terminology used by Landis (figure 1) is similar to that used in Missouri. Several generalizations of Landis concerning lithologies, thicknesses and distributions are out of date. Also, some formations contain unnamed units that need to be defined. New information that will help to update Landis is presented in the descriptive section of this report.

GENERAL LITHOLOGY

Seven formations are recognized in the Marmaton Group of Iowa, which has an average total thickness of 145 feet (43.5 m) (Iowa Geological Survey, 1968) (figure 1). The shale formations are almost exclusively gray shale and sandstone, with only occasional limestone and coal beds. The limestone formations have members consisting of limestone, black shale, gray shale, and some thin coals.

The alternating shale and limestone formations of the Marmaton Group display a lithologic pattern that is distinctly different from that of adjacent groups. The underlying Cherokee Group is dominantly siltstone, shale, and mudstone, with some sandstone, coals, and only a few thin limestones (Landis, 1965, p. 23). Overlying the Marmaton is the Pleasanton Group of the Missourian Series, which is mainly undifferentiated clastics

averaging 40 feet in thickness in Iowa. The Kansas City Group, which overlies the Pleasanton, is an alternating sequence of limestone and shale formations, like the Marmaton, but with thicker limestones (Landis, 1965).

METHODS

The wide variety of rock types in this core required different methods of laboratory study. Indurated units were cut vertically by diamond saw, polished with size 600 carborundum grit, and then sprayed with clear enamel. This method was particularly successful in that these polished slabs displayed features, such as sedimentary structures or mottling, not observable in thin section. Sedimentary structures were identified with the aid of Pettijohn and Potter (1964). Another advantage of polished slabs is that hard nodules could be polished and studied in place within softer units, a difficult or impossible procedure when making a thin section.

Indurated units were also suitable for thin sectioning. Approximately 125 thin sections were produced for this study. These were particularly useful in fossil group identification using the criteria of Horowitz and Potter (1971). Terminology of Dunham (1962) was used in lithologic description.

Enlarged photonegative prints were made of all thin sections by using each thin section, as if it were film, in a standard photographic enlarger. These prints were useful in recognizing structures or relationships that were difficult to see in the relatively small field of view of a petrographic microscope.

Mottles in the Cooper Creek Limestone were analyzed using 13 etched thin sections according to the method described by Lees (1958). Basically, the procedure is to remove all acid-soluble material (mostly carbonates) from a standard thin section; insoluble residues remain in relief in original distribution across the slide. The etched sections were made to determine if mottles resulted from differences in limestone solubility or in distribution of insoluble residues.

Soft units could not be polished or thin sectioned. These were split along bedding planes to uncover fossils, trace fossils, or sedimentary structures not shown on the wall of the core.

Six phosphorites were identified with a G.E. XRD-5 X-ray. Sixteen powdered samples were used, each mounted with Vaseline onto a glass slide. To verify that the identification was correct, one sample was re-run and identified by an X-ray research assistant using a Philips XRD-3000. Phosphorite occurs in this core as both visible

nodules and as finely dispersed material in a dark shale matrix. In cases of suspected finely dispersed phosphorite particles, both matrix with and matrix without these particles were X-rayed. Then only the peaks unique to the suspected phosphorite particles were used to identify them. In practice there was almost no interference of the phosphorite peaks by the matrix (figure 3). A peak at 26.6° was sometimes present in both the matrix and the nodules. This peak was ignored for identification purposes. All phosphates identified matched identification number 21-141 of the Joint Committee on Powder Diffraction Standards for Minerals. This is carbonate fluorapatite, also known as francolite.

The vertical range of the 6 phosphates identified by X-ray was determined by a simple chemical test used by the Iowa Geological Survey. Ground ammonium molybdate and ground phosphorite wetted with 10% hydrochloric acid turns yellow in this test, whereas other minerals do not.

Figure 3. X-ray traces of two shale partings from nearly the same level of the core. Sample on right has phosphatic nodules, that on left does not. Only those peaks unique to the sample with nodules were used for identification. The peaks common to both samples were considered to be from the shale (e.g. 26.6°) and were disregarded.

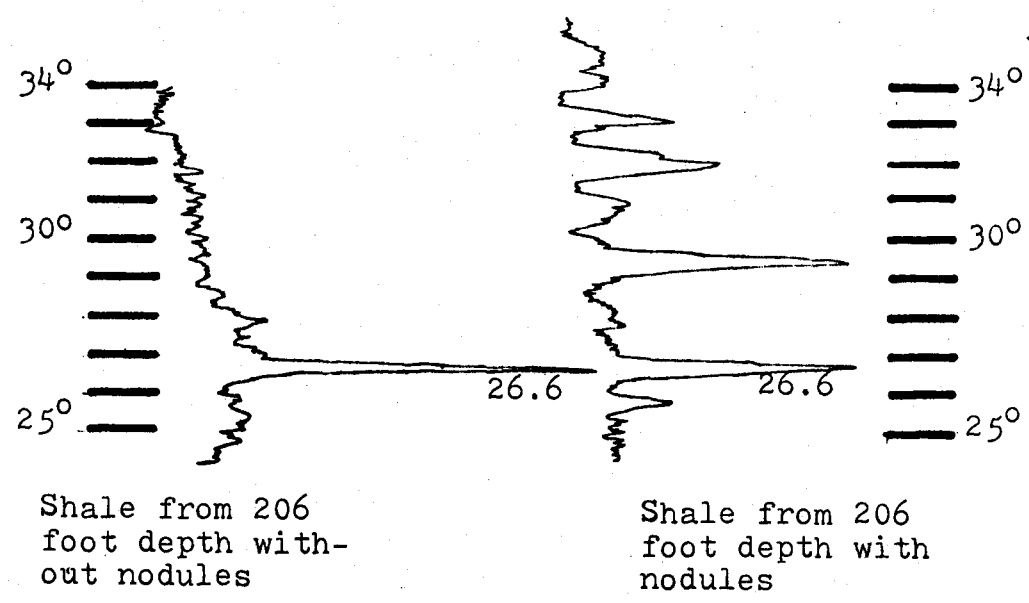


Figure 3.

LITHOLOGIC DESCRIPTION OF CORE

The general lithology of each formation in the studied portion of the core is shown in figure 4. Thicknesses correspond roughly to those determined in outcrop (figure 1) except for the Pleasanton Group which is only 17 feet (5.1 m) thick compared to the average thickness of 40 feet (12.0 m) reported by the Iowa Geological Survey (1968) for Iowa. More detailed lithologic columns of the core are shown in plates 8 through 13. For ease of discussion some formations or members are divided into units (shown on plates 8-13) that are more lithologically homogeneous.

CHEROKEE GROUP

The Cherokee Group, which underlies the Marmaton Group, is dominantly clastic in Iowa (Landis, 1965, p. 27). Only the upper 14 feet (4.2 m) of this 755-foot thick (226.5 m) group was analyzed in this study. Much of the Cherokee is not further subdivided in Iowa, but a few distinctive units are recognized and named such as the Pleasantview Sandstone and Mulky Coal, which are present in the core. Above the Mulky is the Excello Shale, which is a formal unit in Missouri and Illinois, but is not yet recognized in Iowa.

Figure 4. General stratigraphic column of Core CP37.

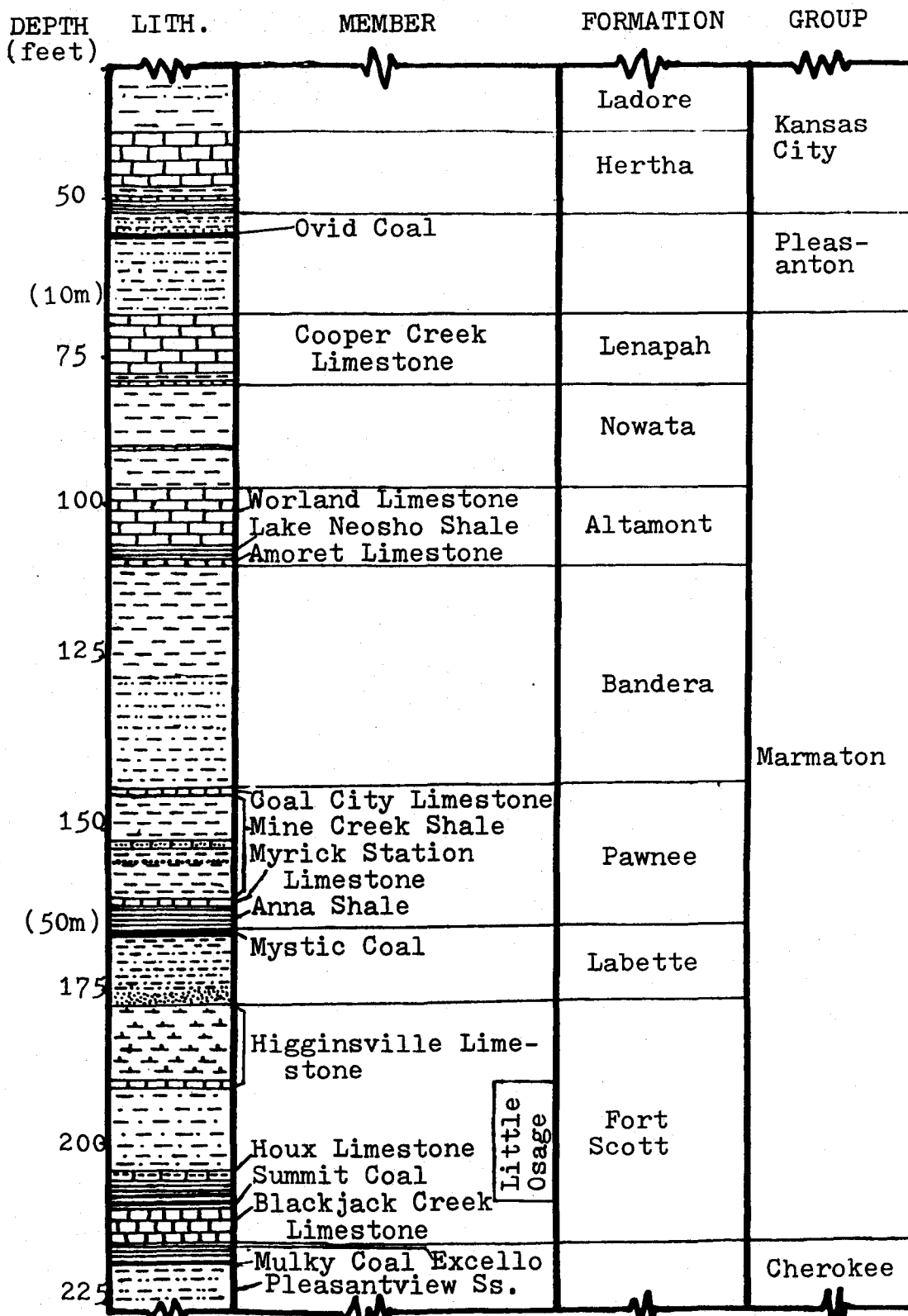


Figure 4.

Pleasantview Sandstone

The Pleasantview Sandstone of the Carbondale Formation of Illinois is recognized in Iowa based on a correlation established by Weller and others (1942, p. 1590). In the core this interval consists of 2 units differing mostly in grain size.

Unit 1 (the lowest unit) is a barren, coarsening upward clastic sequence 13 feet (3.9 m) thick (partially shown on plate 9). Flat to slightly dipping interbeds of mudstone and mica-bearing siltstone predominate in the lower half (plate 1A). The upper half is coarser, consisting of massive and crossbedded, very fine grained, carbonate-cemented quartz sandstone as well as finely interbedded sandstone and siltstone. Distorted convolute bedding is present here but lacking below.

Unit 2 grades over several inches from unit 1 and is 1 foot (0.3 m) of massive, light gray, silty mudstone unlike the sediment below. Carbonaceous fragments are present particularly in the upper portion of unit 2. This portion is brecciated with anastomosing, blocky patches and vertical seams of light gray, quartz-bearing, mudstone (plate 1B). Highly irregular, barren, structureless, quartz-bearing limestone nodules are also present.

Mulky Coal

The Mulky Coal has been correlated with the Sumnum (no. 4) Coal of Illinois by Weller and others (1942, p. 1590). In the core this coal is poorly developed. It consists of a $\frac{1}{2}$ -inch-thick carbonaceous shale overlain by a $1\frac{1}{2}$ -inch-thick bed of brown fossiliferous shale with very fine coal fragments (plate 1C). Only a few fossils are large enough to be identified in this shale; these are brachiopods. The remainder of the fossil material is very fine sand to silt-sized, broken, and concentrated in very thin horizontal layers of "hash."

Excello Shale

The Excello Shale is the uppermost unit of the Cherokee Group. It underlies the Blackjack Creek Limestone and overlies the Mulky Coal (Searight, 1955). This formation is recognized in Missouri, Illinois, and Oklahoma, and is almost universally characterized by abundant phosphatic nodules (Howe, 1956). The Iowa Geological Survey has noted that a lithic unit with the same lithology as the Excello is present at this position in Iowa (Landis, 1965, p. 28) but has not named this unit. This lithic unit is present in the core and is distinctive enough to be identified as the Excello Shale (plate 9).

The Excello in the core is 3 feet (0.9 m) thick and has a sharp contact with the underlying brown shale. The lower 2 feet of the Excello is barren, black, phosphatic shale. The phosphate is in the form of small 1 millimeter particles (plate 1C), large 1 centimeter to 3 centimeter nodules, and lensoid beds.

The upper 1 foot of the Excello grades upward to fossiliferous, green and dark gray mudstone with green, mud-filled burrows. Much of the fauna was very fine grained and found particularly within the green burrows rather than the darker matrix. Only brachiopods were observed but some other fossil material, which is too small to identify, may be of other phyla. This mudstone becomes limey and more fossiliferous as it grades to the overlying Blackjack Creek Limestone.

MARMATON GROUP

The Marmaton Group is easily distinguished from the Cherokee Group by the several limestones the former contains. The first reference to the Marmaton is by Keyes (1897). Jewett (1941) first presented a complete classification of the formations of this group, which was the basis of the classification agreed upon by State geological surveys of the northern midcontinent region (Moore, 1948). The members of these formations recognized in Iowa are shown in figure 1.

FORT SCOTT LIMESTONE

The Fort Scott Limestone is a persistent marker formation at the base of the Marmaton. In Iowa this formation has not been as completely differentiated as in other States (Landis, 1965, p. 26) where additional shale members are named.

Blackjack Creek Limestone Member

The Blackjack Creek Limestone is reportedly one of the thickest and most persistent limestones in the Desmoinesian Series in Iowa (Landis, 1965, p. 27). There may be as many as 6 facies of the Blackjack Creek in the Midcontinent (Neal, 1969). In the core this limestone is only 4 feet (1.2 m) thick and has two lithologic units (plate 9). Unit 1 is 3 feet thick and is fossiliferous whereas unit 2 is unfossiliferous and only 1 foot thick.

Unit 1 is a burrowed, skeletal, lime wackestone grading to skeletal lime packstone in places (plate 1D & E). Burrowing is displayed by a swirled pattern of skeletal fragments. Much of the skeletal material is broken and as small as sand and silt sizes. Some whole brachiopods are present as well as some large, delicate, single brachiopod valves. The fauna consists of echinoderms, bryozoans, brachiopods, molluscs, fusulinids,

and forams. Fossil fragments increase in abundance upwards through unit 1. An exception to this trend is the basal few inches of the Blackjack Creek which are as fossiliferous at the top of the unit.

Irregular dark mottles are present in the upper half of this unit and continue into unit 2. The mottles were not displayed in thin section; the cause and manner of coloring is unknown. Fossil fragments and cracks that cut or are within the mottles have light colored halos, similar to the uncolored matrix of this unit.

Unit 2 is generally barren, lime mudstone. Very rare ostracodes, brachiopods, and forams are present at the base. The basal contact is abrupt. This unit is thoroughly brecciated, especially at the top, by vertical, anastomosing, clay veins and irregular clay blotches (plate 1F). Dark pyritic and carbonate pebbles, some of which are fossiliferous, are present in the upper part of this unit. These same types of pebbles form a clay matrix conglomerate, which is less than 1 inch thick, capping unit 2. This conglomerate has clasts ranging from very fine sand to coarse pebble sizes. Many of the clasts are brecciated in place.

Little Osage Member

The Little Osage Member was named in Kansas for the strata lying above the Blackjack Creek Member and below the Higginsville Member by Jewett (1941). This interval is the Little Osage Formation in Missouri (Howe & Koenig, 1961). The Little Osage is not formally recognized in Iowa where individual beds between the Blackjack Creek and Higginsville are given member status. The named units in Iowa are the Summit Coal and Houx Limestone; three other unnamed beds were recognized in this core.

Summit Coal

In Iowa the Summit Coal is usually a mere smut where present (Landis, 1965, p. 27). In the core studied, the Summit is an 8-inch (20 cm) thick, highly carbonaceous, black shale with thin discontinuous coal stringers interbedded with fossil-bearing shale. No fossils were identifiable. The lower contact with the thin conglomerate of the Blackjack Creek is sharp. The upper contact is gradational to gray shale.

Gray Shale Unit Above Summit

A 3-foot-thick (0.9 m) fossiliferous limestone and shale unit occurs above the Summit Coal (plate 9). The

lower half of this unit is gray silty shale with carbonaceous fragments, as well as broken brachiopods and molluscs.

The upper half of this unit comprises lenticular interbeds of dark gray shale and mostly non-abraded skeletal lime packstone (plate 2A). Most fossils are broken but some whole single valves are present. Fossils concentrated in the limestone layers are dominantly brachiopods, but echinoderms, molluscs, trilobites, fusulinids, and other foraminifers are also present. Some burrow traces are preserved in the limestone beds.

Black Shale Unit Above Summit

Two feet (.7 m) of black shale form the second unnamed unit above the Summit Coal (plate 9). This unit is below the Houx Limestone. The basal few inches are black brachiopod-bearing shale, that grades rapidly from the underlying unit. Above the basal fossiliferous shale, is a generally barren, phosphatic, black shale (plate 2B). Conodonts and a few fish scales are the only fossils present. The phosphate occurs as thin layers of minute nodules as well as lenticular beds a few millimeters thick.

The upper few inches of this black shale unit lacks phosphate and contains distinctive burrows filled with green mud that is similar to the overlying Houx Limestone

bed (plate 2C). Sparse brachiopod fragments are present in the burrows and black matrix. The burrows are largely horizontal and can extend the width of the core but are only several millimeters wide.

Houx Limestone

The Houx Limestone is thin in Iowa, varying in thickness from 4 to 8 inches of light to dark gray shale that is characteristically earthy and very fossiliferous (Hershey et. al., 1960, p. 33).

In the core studied the Houx is 4 inches (10 cm) of burrowed brachiopod-bearing green mudstone (plate 2C, 9). Most fossils are broken and arranged in a swirled pattern due to burrowing. Only brachiopod fragments are identifiable, but other phyla may be present. The upper and lower contacts of the Houx Limestone are gradational.

Gray Shale Unit Above Houx

Fourteen feet (4.2 m) of barren, finely and regularly interbedded, green-gray mudstone, micaceous siltstone, and very fine grained sandstone gradationally overlie the Houx Limestone (plate 2D, 9). Minor crossbed sets $\frac{1}{2}$ -inch-thick are present throughout, as are sparse vertical burrow traces. The only detectable vertical change in lithology is in the upper several feet of this

unit where several highly burrowed beds, each a few inches thick, alternate with the normal lithology. The upper contact with the Higginsville Limestone is sharp.

Higginsville Limestone Member

The Higginsville Limestone is the uppermost member of the Fort Scott Formation. This limestone is recognized from Oklahoma, where it reaches a maximum thickness of 35 feet (Alexander, 1954), to Iowa where in places it is 2 feet thick. At some localities in Iowa the Higginsville is reportedly divided into two layers by a thin green calcareous shale (Landis, 1965).

The Higginsville Limestone identified in this core is 9 feet (2.7 m) thick, but it is largely calcareous mudstone (plate 9). The lower four feet has 3 fossiliferous lithologies and is designated unit 1. Unit 2, the remaining 5 feet, is largely unfossiliferous.

The basal 1 foot of unit 1 consists of fossiliferous, 2-inch-thick green mudstone layers interbedded with $\frac{1}{2}$ -inch-thick skeletal lime wackestone beds. Large, whole brachiopods and clams are found in both mudstone and limestone. Large horizontal burrows are present.

The middle portion of unit 1 has a different assemblage and texture. This is oncolite-bearing lime wackestone and packstone (plate 2E, 2F). The oncolites have

concentric lamellae (type "C" of Logan 1964) and increase in size upward through this portion of unit 1. The blue-green alga Girvanella was identified in several oncolites. The other fossils present are echinoderms, bryozoans, brachiopods, molluscs, fusulinids, and other foraminifers. Much of the fossil material is broken and abraded in this (middle) portion of unit 1.

The top portion of unit 1 is less fossiliferous lime wackestone. Oncolites are not present, and the fossil material is not abraded. The fauna becomes less diverse until only brachiopods are present.

Unit 2 is a generally barren lime mudstone and calcareous shale. Only rare brachiopods (in the base) and horizontal burrows are present. The upper portion of unit 2 has many vertical anastomosing quartz-bearing clay seams (plate 2G). Dark mottles similar to those in the upper Blackjack Creek are present. This grades upward to rubbly limestone fragments in clay matrix (plate 2H). Unconformably overlying the conglomerate is crossbedded conglomeratic sandstone of the Labette Formation.

LABETTE FORMATION

The Labette Formation is a clastic sequence between the Fort Scott and Pawnee Limestones. In Oklahoma this

formation is locally 250 feet thick (Oakes, 1952, p. 26-28), whereas in parts of Iowa it may thin to as little as 6 feet (Hershey et. al., 1960, p. 32-33).

In the core studied the Labette is 15 feet (4.5 m) of fining-upward clastics (plate 10) with the Mystic Coal bed at the top. This coal is correlated with the Herrin (no. 6) Coal of Illinois and the Lexington Coal of Missouri (Weller, Wanless, Cline, & Stookey, 1942, p. 1591).

The basal contact of the Labette Formation with the Fort Scott Formation is sharp and undulatory, with over 1 inch of relief in the 2-inch-wide core (plate 2H). Small shale and limestone clasts of the uppermost Fort Scott are present in the basal Labette.

The lower 2 feet of the Labette is crossbedded, rounded, medium and fine-grained, silica-cemented quartz sandstone with sedimentary lithoclasts (plate 3A) and in places many carbonaceous fragments (plate 3B).

The middle portion of this formation is 11 feet thick and lacks conglomerate. It is even bedded to cross-bedded, very fine grained sandstone with mica and carbonaceous fragments (plate 3C).

The upper 2 feet is still finer grained, barren mudstone with many carbonaceous particles. The Mystic Coal lies above the mudstone and is about 6 inches thick.

PAWNEE FORMATION

The Pawnee Formation has more lithologic variation than any other in this core. The Mine Creek Shale Member is particularly complex.

Anna Shale Member

The Anna Shale is a widespread thin unit extending along outcrop from Oklahoma to Iowa. In this core the Anna is 2 feet (0.6 m) thick and is divided into 2 units, the lower one conspicuously fossiliferous and the upper one conspicuously phosphatic (plate 10).

Unit 1 is $1\frac{1}{2}$ feet of fossiliferous black shale with many minute carbonaceous particles (plate 3D, 3E). Fossils increase in size and abundance upward in this unit. Only bivalves are present in the basal few inches but echinoderms and brachiopods are found above. A thin whole-shell, gastropod packstone, overlain by a millimeter thick coal stringer, is present in the middle of the unit.

Unit 2 is $\frac{1}{2}$ foot of black shale that lacks macrofossils but contains conspicuous phosphate as thin beds or nodules or thin lenses of small particles (plate 3F, 3G). The upper and lower contacts of this unit are sharp.

Myrick Station Limestone Member

The Myrick Station Limestone is a thin member that also is traceable along outcrop from Iowa to Oklahoma. At the type area in Missouri, the Myrick Station is $5\frac{1}{2}$ feet thick. In the core this limestone is 1 foot (.3 m) thick.

The Myrick Station in the core (plate 10) is burrowed skeletal lime packstone (plate 3H) grading up to wackestone (plate 3I). Echinoderms, bryozoans, brachiopods, molluscs, trilobites, ostracodes, fusulinids, and other foraminifers are present. Many fossils are broken, but these are not abraded. Large, delicate, single and paired brachiopod valves are present. The upper and lower contacts of this limestone are sharp.

Mine Creek Shale Member

The Mine Creek Shale crops out from Oklahoma to Iowa. In Iowa thickness variations of 6.5 to 37 feet are reported. Thicker sections are due to presence of a sandstone in the Mine Creek (Landis, 1965, p. 25).

In the core the Mine Creek is 19 feet (5.7 m) thick and contains a sandy unit (plate 10). There is more lithologic variation in this member than in most others. Three units of about the same thickness are present; shale, then sandy lime wackestone, then shale again.

Unit 1 is 7 feet of sparsely fossiliferous, massive, variegated green mudstone. Only rare whole brachiopods and bivalves are present. Barren lime nodules occur in the upper portion of this unit. The top foot of unit 1 consists of several intraclast and sedimentary lithoclast conglomerates alternating with mudstones (plate 3J). The basal contact of this conglomeratic zone is abrupt and undulatory. Clasts of the underlying mudstone lithology are present. A coal stringer is present above one of the thin conglomerates.

Unit 2 is fossiliferous and has a basal gray mudstone containing clams and brachiopods. The remaining $3\frac{1}{2}$ feet of unit 2 is a burrowed, sandy, skeletal lime wackestone to calcareous sandstone (plate 4A, 4B). Some fossils are broken but many delicate fossils such as some bryozoans are not. Echinoderms, bryozoans, brachiopods, molluscs, forams, and ostracodes are present. The sand grains are angular, very fine sand and silt size quartz.

Unit 3 is 6 feet of mostly barren mudstone. Brachiopods and bivalves are present only in the basal foot. Unlike unit 2, this unit has no detectable silt or sand. The coloring of this mudstone is very irregular. Green and gray colors blend and alternate with each other in a horizontal pattern similar to bedding. In plan view

the colors interfinger as linear and rounded mottles. The linear pattern is often around a zone of small pyrite nodules or an apparent fracture. Irregularity of this coloring seems secondary after an expression of bedding of burrowing. Red and gold colors in feathers, bands, and mottles truncate the green and grays. This too appears to be secondary.

Coal City Limestone Member

The Coal City Limestone is recognized in Iowa and Missouri. The Labertie Limestone forms the uppermost limestone member of the Pawnee in Kansas (Zeller, 1968). In the Iowa outcrop thickness of the Coal City varies from 1 to $4\frac{1}{2}$ feet, whereas in this core it is less than 8 inches (20 cm) thick (plate 10).

The Coal City is a burrowed skeletal lime wackestone and packstone (plate 4C, 4D). Many fossils are broken but some whole brachiopods are present. Echinoderms, bryozoans, brachiopods, molluscs, fusulinids, and other foraminifers are present. Upper and lower contacts are gradational.

BANDERA FORMATION

At 34 feet (10.2 m) the Bandera is a rather thick formation in this core (plate 11). Near its type area

in Kansas, the Bandera is up to 50 feet thick (Zeller, 1968). Two distinct clastic units are present; the lower green and coarse, the upper reddish and finer grained.

Unit 1 is a 14-foot-thick coarsening upward green-gray micaceous siltstone interbedded with very fine grained sandstone (plate 4E). As the grain size changes upward, so do the sedimentary structures. The upward sequence of sedimentary structures is massive bedding, fine laminations, incipient flasers, then massive and crossbedded layers. No fossils and very little bioturbation was observed.

Unit 2 is 20 feet of barren, crumbly, brownish-red, massive mudstone with occasional, slightly pebbly zones (plate 4F). Parts of this unit are fragmented due to in-place brecciation. Sparse, barren, carbonate nodules are present near the bottom of this unit. The top of this unit grades to barren, massive, gray shale with sparse carbonaceous particles and possible root markings. The contact with the overlying Altamont Formation is gradational and burrowed.

ALTAMONT FORMATION

The Altamont is the only formation in the core on which any detailed study in Iowa has been published.

Schenk (1967), in a study of outcrop from Iowa to Oklahoma, reported on lateral and vertical variations in lithology and depositional environment of this formation. The Altamont has 3 members, in ascending order: Amoret Limestone, Lake Neosho Shale, and Worland Limestone. All are developed throughout the outcrop belt except for occasional pinchouts of Amoret Limestone. Lateral variation in petrology is greatest in the two limestone members, which are particularly affected by several minor tectonic elements (Schenk, 1967).

Amoret Limestone Member

In Iowa the Amoret was reportedly restricted to one county (Landis, 1965, p. 24); however, Schenk's (1967) fieldwork demonstrated that the Amoret is widely developed, though several pinchouts do occur. Maximum thickness in Iowa is about 2 feet (Landis, 1965, p. 24).

In the core studied, the Amoret consists of 6 inches (15 cm) of burrowed, oncolite-bearing lime packstone and wackestone with gradational boundaries (plate 5A, 5B, 11). The oncolitic coatings occur on skeletal fragments. The coatings are uneven, not greater than 2 millimeters thick, consisting of Girvanella and encrusting ~~form~~inifers. Many skeletal fragments, whether an oncolite nucleus or not, are abraded and slightly rounded.

Many skeletal fragments are too small to identify. Echinoderms, bryozoans, brachiopods, molluscs, fusulinids, other foraminifers, and ostracodes are present.

Lake Neosho Shale Member

The Lake Neosho Shale has the least lateral lithologic change of any Altamont member (Schenk, 1967). Thickness does vary, however. For example, in Iowa the thickness varies from about 1 to 12 feet (Schenk, 1967, plate 1), though thickness of individual shale types within the Lake Neosho is not available.

In this core the Lake Neosho is only 1 foot (.3 m) thick (plate 11). Several inches of green shale, with echinoderms, occur at the base. This grades up to black shale that is barren and phosphatic (plate 5C). The phosphate occurs as thin lenses and thin beds of minute nodules. The top of the Lake Neosho is again a fossiliferous green shale. This shale has many crushed shells, some large and whole. The fossils include echinoderms, bivalves, and brachiopods, but others may be present that are too small to identify.

Worland Limestone Member

The Worland is petrologically quite similar from Iowa to Oklahoma, more so than the Amoret Limestone,

however biofacies do change abruptly both laterally and vertically. In outcrop, thickness varies from 2 to 12 feet throughout the midcontinent except for an abrupt thickening to about 24 feet in Oklahoma (Schenk, 1967, plate 1).

In the core the Worland is 10 feet (3.0 m) thick and consists of 2 units (plate 11). Unit 1 is 5 feet of fossiliferous lime wackestone and packstone. Unit 2 is mostly barren lime mudstone. Throughout the entire Worland, limestone layers are interbedded with layers of shaly limestone and calcareous shale, which apparently causes the Worland to weather to thin, wavy beds (Landis, 1965, p. 24).

Unit 1 contains a biota consisting of echinoderms, bryozoans, brachiopods, bivalves, forams, and algae. Three forms of algae are present, each dominating in one of 3 zones denoted as lower, middle, and upper.

The lower zone (2 feet thick) of unit 1 is the only zone in which (possible) algal mats dominate (plate 5D). This is also the only zone with fusulinids. The portions of this zone without algal mats are burrowed. Most skeletal grains are broken but unabraded.

The middle zone ($1\frac{1}{2}$ feet thick) grades from the lower and contains blades of phylloid algae (plate 5E, 5F). These algae occur as plates $\frac{1}{2}$ inch long or, where

burrowed, as small fragments several millimeters long. The other fossils occur as broken fragments as below. However, many whole brachiopods with preserved brachidia are present in this zone.

The upper zone of unit 1 (less than 1 foot thick) contains oncolites with Girvanella as its algal constituent, sometimes in a grainstone (plate 5G. 5H). The oncolites are not concentrically laminated. Echinoderms, bryozoans, brachiopods, and molluscs are also present as they are throughout this unit. These fossils are mostly abraded and rounded in this zone, unlike those below. Many more echinoderms occur here than in the other zones.

Unit 2 (5 feet thick) is a limestone marked by a scarcity of fossils, and more clastics than below. Sparse, angular, very fine sand and silt-size quartz is present, increasing in abundance upwards. Echinoderms, bryozoans, brachiopods, and bivalves are sparsely present only in the lower third of this unit. The upper portion of unit 2 is essentially barren.

The barren portion of unit 2 has several distinctive sedimentary features. Well developed sedimentary boudinage is present. The boudins are lime mudstone and have small tension fractures due to compression, as described by McCrossan (1958), whereas the matrix is

calcareous green mudstone. In the top, above the boudinage, the more silty portion of the Worland contains abundant lime pellets in crossbeds (plate 5I). At the upper contact the Worland becomes rubbly and argillaceous.

NOWATA FORMATION

The Nowata Formation is a sandstone and shale sequence between the Altamont and overlying Lenapah Formation. Maximum thickness of the Nowata in Iowa is 80 feet. In this core the Nowata is only 18 feet (5.4 m) thick (plate 12).

Unit 1 is 4 feet of barren mudstone. The basal few inches are green and grade rapidly from the underlying Worland Limestone. The remaining lower half of this unit is barren, brick-red, crumbly mudstone with abundant calcareous nodules (plate 5J). The nodules are brecciated in place and have little internal structure. The upper half of this unit is gray with some maroon mottles and only a few nodules.

Unit 2 has a sharp undulatory burrowed contact with unit 1 (plate 6A). This unit consists of 4 feet of sparsely fossiliferous laminated gray shale with several thin, slightly nodular limestone beds. Bivalves and brachiopods, some crushed, are present in the shale. Some of the limestone beds have sparse, small fossils;

only brachiopods were identifiable but other phyla may be present. One limestone that is almost 2 inches thick is more highly fossiliferous packstone that contains echinoderms, bryozoans, brachiopods, molluscs, forams, and possible blue-green algae (plate 6B).

Unit 3 (9 feet thick) is very similar to unit 1 in lithologic sequence. The base of unit 3 grades upward from the laminated fossiliferous shales of unit 2, to barren, massive, gray and maroon mudstone. Grading upward from this is barren, brick-red, crumbly mudstone with carbonate nodules. The nodules are barren mostly structureless, and are brecciated in place (plate 6C). The upper 7 feet of unit 3 is a similar red mudstone, but without nodules.

LENAPAH FORMATION

The Lenapah comprises only the Cooper Creek Limestone Member in Iowa. This is correlated with the Sni Mills Limestone Member of Missouri (Howe, 1953, p. 9), which is underlain by the Perry Farm Shale and Norfleet Limestone, both of which are also members of the Lenapah. Where the Norfleet is not recognized, such as in Iowa, the Perry Farm has been thought to be included in the top of the Nowata Shale (Hershey et. al., 1960). Study of this core shows another alternative. The marine portions

of both lower Lenapah members may be condensed into two thin basal beds (units 1 and 2) of the Cooper Creek Limestone in this core.

Cooper Creek Limestone Member

Although previous reports place a maximum thickness of only 7 feet in Iowa outcrop, the Cooper Creek in this core is 11 feet (3.3 m) thick and consists of 4 units (plate 12). Units 1 and 2 are thin but distinctive basal beds, unit 3 is a skeletal lime wackestone that is strongly mottled, and unit 4 is mostly a packstone that is unmottled.

Unit 1 is a highly fossiliferous lime packstone and grainstone (plate 6D, 6E). Many fossils are abraded and rounded. Echinoderms, bryozoans, brachiopods, molluscs, fusulinids, other foraminifers, ostracodes, and green algae are present. This bed varies in thickness within the core from 1 to 2 inches. The base is nodular with shale partings and grades rapidly from the underlying Nowata Shale.

Unit 2 is a shale bed less than 1 inch thick, containing echinoderms, bryozoans, brachiopods, and molluscs (plate 6E). In the middle is a layer of very small, barren irregular, phosphate nodules, each about 1 millimeter across. At this layer the fauna is limited to

brachiopods and molluscs. This shale has not been previously reported and may not be recognized in outcrop; it was not found during two hours' reconnaissance at an exposure in the type area. However, it may be that more detailed field work is required to locate either the shale or phosphate.

Unit 3 of the Cooper Creek consists of 8 feet of skeletal lime wackestone (plate 6E, 6F) characterized by strong color mottling that is characteristic of the Cooper Creek on outcrop. The mottles are dark limestone, whereas the matrix is lighter colored, more argillaceous limestone as observed in thin sections etched in acid according to the procedure of Lees (1958). This may account for the greater resistance to weathering of the dark mottles observed in outcrop. Other than color, there is little consistent microscopic or macroscopic difference between mottles and matrix.

The fossils present throughout unit 3 are echinoderms, bryozoans, brachiopods, molluscs, forams, and red and green phylloid algae. Broken fossils arranged in swirled patterns indicates some burrowing has occurred. However, burrowing has not completely disturbed the sediment since many whole brachiopods and some bivalves are preserved in living position, and phylloid algal blades up to 1 inch long are present at some horizons. Burrowing appears to be independent of mottling.

Unit 4 is 3 feet thick. It has the same fauna as unit 3, but few whole fossils are present. Another conspicuous difference is the lack of mottling in unit 4. The lithology consists of layers of burrowed skeletal lime wackestone and packstone alternating with rounded, abraded-grain, skeletal lime grainstone (plate 6G, 6H). Gray barren shale partings lithologically similar to the overlying Pleasanton Group also occur in unit 4.

PLEASANTON GROUP

The base of the Pleasanton Group marks the upper boundary of the Desmoinesian Series and the base of the Missourian Series throughout the Midcontinent. The Desmoinesian Series is designated paleontologically as the zone of Fusulina, whereas the Missourian corresponds to the lower part of the zone of Triticites (Moore, 1948). This boundary is defined by a disconformity recognized by Moore (1944) which is inconspicuous in most places but, on the basis of paleontological changes, is judged by him to be a division line of first-rank intrasystemic magnitude (Moore, 1948). In Iowa this boundary is cited as an erosional unconformity (Hershey and others, 1960). However, in Core CP37 the Desmoinesian-Missourian contact is sharp but is not distinctly erosional. Several shale partings that are similar to the Pleasanton lithology

are present in the top of the Cooper Creek Limestone, suggesting several abrupt changes in sedimentation preceded the change from limestone to clastics marking the base of the Pleasanton.

The Pleasanton Group consists mostly of clastic rocks, and is as thick as 262 feet (80 m) in Missouri (Clair, 1943). It is only 17 feet (5.1 ,) thick in Core CP37. Several different formations, members, and beds are recognized in different states, but these have not been proven to be correlatable on a regional basis. In Iowa the Exline Limestone, Chariton Conglomerate, and Ovid Coal are recognized at least locally. Other unnamed units are also present.

Exline Limestone

The Exline Limestone is reported to be a persistent unit low in the Pleasanton Group (Singler, 1964). The units below the Exline are reportedly underclay, coal, and shale in Iowa (Cline, 1941). A study of this 1-foot (.3 m) thick unit by Cline and Burma (1949) covered 270 miles of outcrop in Iowa and Missouri. The fauna ranges from echinoderms, bryozoans, and brachiopods in pure limestone facies to mainly molluscs in more argillaceous facies. Cline and Burma reported that the Exline grades laterally in places, to fossiliferous, dark gray, calcareous shale.

Core CP37, taken about fifty miles from known Exline outcrop, however, has no trace of this limestone. Nor is there any fossiliferous or calcareous zone, which could be considered equivalent to the Exline. The sequence just above the Lenapah Formation (described later) also lacks coal, underclay, and limestone, that are sometimes present below the Exline in Iowa, and it further lacks black phosphatic shale reported by Howe and Koenig (1961) above the Lenapah in Missouri.

Chariton Conglomerate

The Chariton Conglomerate is locally present only in Iowa and is poorly understood. This conglomerate is shown by Cline (1941) locally to cut down to as far as the Pawnee Formation. Singler (1964) described the Chariton as brecciated limestone fragments with water-worn quartzite pebbles in a red sandstone matrix. The Chariton Conglomerate is not present in Core CP37.

Unnamed Pleasanton Units in Core

Three distinctly different clastic units make up the Pleasanton Group in Core CP37 (plate 12, 13).

Unit 1 is 10 feet (3 m) of green-gray laminated, silty mudstone coarsening upward to green-gray sandstone with crossbeds (plate 6I, 6J). The upper contact is

gradational. The basal contact, with the Cooper Creek Limestone, is sharp and irregular. Coal fragments and broken orbiculoid brachiopods are present at this contact. There are no other fossils found in unit 1.

This basal contact presumably separates the Desmoinesian and Missourian Series and elsewhere is interpreted as erosional, as has been mentioned. There is no diagnostic evidence of erosion at this location; rather an abrupt change in sedimentation seems to be indicated.

The lower half of unit 1 is very finely laminated with minor scouring and crossbedding. Occasionally laminations are distorted by burrowing. Laminations dip up to 6 degrees and seem to have a unimodal orientation. Fine grained, sometimes crossbedded, micaceous sandstone interbeds are present in the lower part of unit 1 and increase in abundance upward.

In the upper half of the unit where fine grained, crossbedded sandstone becomes dominant (plate 6I, 6J), crossbeds are up to 1 inch thick with apparent dips up to 25 degrees. Some of these sandstones are disturbed by burrows.

Small limestone nodules (plate 6I) are present in the upper half of this unit. They grade upward to incipient nodules, mottles and stringers (plate 6J).

Some nodules have bedding traces within them but lack fossil or caliche structures. The bedding of the clastic rocks containing the limestone nodules may deform about them, suggesting differential compaction. Septarian cracks are present in some nodules.

Unit 2 consists of a four-foot thick (1.2 m) sequence of barren, carbonaceous, massive mudstone, overlain by a 3-inch-thick coal and a laminated, carbonaceous mudstone with orbiculoid brachiopods. This coal is identified as the Ovid from its position in the Pleasanton.

Unit 3 is a 3 foot (0.9 m) thick sequence of very thin interbeds of dark gray, noncalcareous shale and light colored, very fine sandstone, in the form of pods, lenses, stringers, and possible incipient flasers (plate 7A). The sandstone is almost entirely angular quartz with carbonate cement. Both the upper and lower contacts of this unit are gradational. Fossils are sparse and consist only of whole to broken, but unabraded, brachiopods and bivalves. Carbonaceous fragments are also present.

KANSAS CITY GROUP

The Kansas City Group has a greater thickness of limestones than the Marmaton and Cherokee Groups. Only

the Hertha Limestone and base of overlying Ladore Shale, the lowest formations of this group, are described in this study.

HERTHA FORMATION

The Hertha Formation, which is the basal member of the Kansas City Group, is developed throughout the northern Midcontinent region. This limestone is not divided into members in Iowa, as it is in other states, but several beds are recognized. In Madison County, Iowa, the Hertha is 4 feet thick and is composed of a basal argillaceous and lenticular limestone bed, a thin shale bed, a fossiliferous limestone, and an argillaceous lenticular limestone (Hershey et. al., 1960). Similar beds are recognized as units 3 through 6 in this core (plate 13) where the Hertha is 11 feet (3.3 m) thick.

Unit 1, which is 4 inches thick, is highly fossiliferous, non-sandy, gray shale, grading from the underlying interbedded sand and shale. Fossils increase in abundance upward to a maximum of 34% of the rock and then decrease as this unit grades abruptly to the overlying black shale of unit 2. These fossils are broken and flat-lying, consisting of echinoderms, bryozoans, brachiopods, and molluscs.

Unit 2, which is 1 foot thick, is barren, black shale, with several phosphatic horizons (plate 7B, 7C),

grading upward to burrowed gray mudstone. The burrows contain very fine-grained echinoderm, bryozoan, and brachiopod fragments; however, the mudstone matrix is barren. Several of these burrows extend into the black portion of this unit and truncate a phosphatic layer.

Unit 3 of the Hertha is a dark gray, slightly argillaceous, skeletal lime wackestone about 1 foot thick (plate 7D). The upper and lower contacts are gradational. Burrows are present throughout, displayed as both a swirled texture and as distinct sinuous traces. These sinuous burrows are very similar to those in the top of the underlying shale. The fossils of this unit are echinoderms, bryozoans, brachiopods, molluscs, trilobites, forams, and ostracodes. Most fossils are broken but none seem abraded or rounded.

Unit 4 is 2 feet of massive to slightly laminated fossiliferous gray shale with gradational upper and lower contacts. The fossils are evenly distributed and many are whole, consisting of echinoderms, bryozoans, brachiopods, and molluscs. As opposed to lower units, individual burrow traces were not observed.

Unit 5 is 6 feet of buff-colored skeletal lime wackestone and packstone (plate 7E, 7F) that grades into the underlying and overlying units. Blades of phylloid algae are common in this unit. Encrusting

algae are also present as a more minor component of the biota, as are echinoderms, bryozoans, brachiopods, molluscs, and aulopodid corals. These fossils are frequently broken but are not rounded or abraded.

Dark shale partings are present every foot or less in this unit. The shale occurs as thin laminae in cross section that may merge to a thicker more dense shale parting (plate 7E). Fossils are present in the shale or in tiny lenses of limestone between thin shale laminae.

Unit 6 of the Hertha is a dark gray, slightly argillaceous, burrowed, skeletal lime wackestone 2 feet thick (plate 7G), which is similar to unit 3. Fossils are less abundant in unit 6, consisting of echinoderms, bryozoans, brachiopods, and molluscs.

LADORE SHALE

The Hertha has an upper gradational boundary to the Ladore Shale. Although the Ladore was not analyzed in detail, the basal 6 feet (1.8 ,) are dark gray, laminated shale with bivalves and brachiopods grading upward to at least 3 feet (0.9 ,) of burrowed, sandy mudstone (plate 7H).

INTERPRETATION OF DEPOSITIONAL ENVIRONMENT

INTRODUCTION

Pennsylvanian sedimentary rocks of the Midcontinent are unusual in that they are conspicuously cyclic (e.g. Weller, 1930; Moore, 1936), and involve a great diversity of rock types. These strata have inspired many geologists to devise unusual explanatory mechanisms of tectonism and deposition. Some of these theories have been described as "...suggestive of the rhythmical operation of a modern machine..." or to "...involve a prolonged and almost inconceivable see-saw oscillation..." (Wanless and Shepard, 1936). If we interpret lithology and fossils in each bed of a cyclic sequence by means of actualistic sedimentation models, we may avoid over-emphasis of the unusual appearance of the sequence. Then by integrating the interpretations over a succession of beds, an interpretation of the whole sequence may be developed.

IRWIN MODEL

A basic sedimentation model for applying environmental criteria in depositional interpretation, is Irwin's

(1965) theoretical model for clear-water epeiric seas. Heckel (1972, p. 253 & 258) has shown that several modern carbonate and clastic environments fit the pattern predicted by Irwin's model, and that two different scales of ancient carbonate sequences are readily interpreted by the Irwin model. In this model three regimes of deposition are recognized, that are controlled primarily by depth-related water agitation: 1) below wave base, 2) above wave base, and 3) beyond wave reach.

In the zone below wave base there is little water turbulence, thus mud-size sediment may accumulate. Other environmental conditions, such as salinity, are stable allowing a diverse fauna to develop.

The zone above wave base is the relatively narrow area where waves impinge upon the bottom. The water turbulence abrades skeletal grains and removes mud allowing sandstones or calcarenites to accumulate. The fauna may be diverse here also as the water is oxygenated, well lit, and of normal salinity. This zone will be absent or unrecognizable if wave action is slight, tidal range is low, rate of mud supply by longshore drift is high (Walker and Harms, 1971), or if sea-level changes are rapid (Irwin, 1965).

The zone beyond wave reach consists of extremely shallow areas such as lagoons, in which there is little

consistent water agitation other than that due to storms. The long periods of quiet water allow mud to be deposited. Unstable environmental conditions, especially fluctuating salinity, cause the fauna to be more restricted than that of other zones.

BLACK SHALES

A number of distinctive black shales are found in the Midcontinent Pennsylvanian. Black color in shales is due to a high content of either unoxidized organic matter or finely divided iron sulphide, and indicates a reducing (anoxic) bottom environment (Dunbar & Rodgers, 1957, p. 26, 209; Heckel, 1972, p. 261). Although anoxic conditions have generally been attributed to stagnant water, they require only higher consumption of oxygen by organic decay, than replenishment of oxygen by water circulation. Anoxic conditions can develop under dynamic conditions of quasi-estuarine circulation and upwelling (Brongersma-Sanders, 1971). Water agitation above wave base inhibits development of low oxygen conditions, thus only the sediment zones below wave base or beyond wave reach are likely to develop black shales. Heckel and Swade (1977) have recognized these two occurrences among Pennsylvanian black shales in the Midcontinent.

One type of black shale was deposited nearshore beyond wave reach perhaps in stagnant water.

"This type of Midcontinent Pennsylvanian black shale occurs within the least marine portions of the cyclic sequence. These black shales typically are interbedded with unfossiliferous gray shales and sandstones, and some lie directly above coals. Most contain much quartz sand, all lack significant phosphorite, and none are known to be laterally traceable. Shales of this type were deposited in local areas of phosphate-poor anoxic water in non-marine to shoreline features, such as lagoons and barely inundated coal swamps." (Heckel & Swade, 1977)

Another type of black shale was deposited offshore below wave base:

"This type of Midcontinent Pennsylvanian black shale occurs within the most marine portions of the cyclic sequence. These black shales are characterized by stratigraphic position between two marine limestones, lateral persistence along the Kansas-Iowa outcrop, and presence of abundant nonskeletal phosphorite laminae and nodules along with near absence of quartz sand. Shales of this type were deposited offshore in phosphate-rich anoxic water, probably derived by quasi-estuarine circulation from intermediate depths of the ocean during maximum marine transgression." (Heckel & Swade, 1977)

A dynamic mechanism to explain offshore development of both black shale and phosphate has been presented by Heckel (1977, p. 1045).

"...The widespread phosphatic black shale facies that commonly accompanies maximum transgression in the core shale is explained by water becoming deep enough to develop a thermocline strong enough to prevent bottom oxygenation by wind-driven vertical circulation. Pennsylvanian position of Midcontinent North America, in the trade-wind belt north of the paleoequator along the

Appalachians, allowed establishment of large-scale quasi-estuarine circulation in the Mid-Continent epicontinental sea. Cold, deep, oxygen-poor, phosphate-rich water from the western ocean was drawn in along the bottom through the basins of West Texas eventually to upwell in the eastern Mid-Continent and replace the surface water moved westward out of the sea by the prevailing winds. Upwelling greatly increased surface-water production of organic matter, which continually settled (while being carried westward) into the deeper incoming current, where it decayed and depleted the remaining oxygen while continually enriching the already high phosphate in a circulatory trap. In this way substantial organic matter and phosphorite were deposited on the anoxic sea bottom to produce the phosphatic black shale facies."

DELTAIC MODEL

Rapidly deposited wedge-shaped deltaic sequences (or clastic wedges) are also common in the Pennsylvanian of the Midcontinent (Wanless, 1966; Wanless et. al., 1970) and Appalachians (Ferm, 1970). In many deltas three basic environments of deposition are recognizable (figure 5), which may be roughly analogized to the 3 basic zones of deposition of Irwin (1965), applied to clastic sediments. The high rate of deltaic deposition and fresher water influx, however, do not permit great faunal diversity. The prodelta consists of fine-grained clastics deposited offshore below the effective depth of wave erosion. The delta front is a narrow zone above

wave base, which consists of linear and sheet sands associated with distributaries and beaches. The delta plain has a number of local and temporary, shallow to subaerial environments beyond wave reach such as embayments, lagoons, tidal flats, river channels, and swamps. These may produce a number of lithologies including barren to sparsely fossiliferous mudstone, interbedded mudstone and sandstone, crossbedded sandstone, or coal.

The vertical sequence that develops from a prograding delta lobe is (in ascending order) muddy prodelta, sandy delta front, and muddy delta plain complex with local fluvial sandstones. Delta lobes may build out at one location, then become abandoned as distributary channels breach, and form elsewhere. This internal sedimentary mechanism allows clastic wedges consisting of all (or at least part) of the delta-lobe sequence to be inserted into relatively nearshore parts of marine sequences (Wanless, 1966).

CHEROKEE GROUP

Pleasantview Sandstone

Unit 1 of the Pleasantview (plate 9) is the top of a regressive, probably deltaic, sequence. Evidence includes coarsening upward grain size, well developed

Figure 5. Idealized model of deltaic clastic wedge showing delta plain, delta front, and prodelta. Note that a former area of sedimentation has been abandoned and a new wedge has developed enveloping its flank (modified after Ferm, 1970, figure 3).

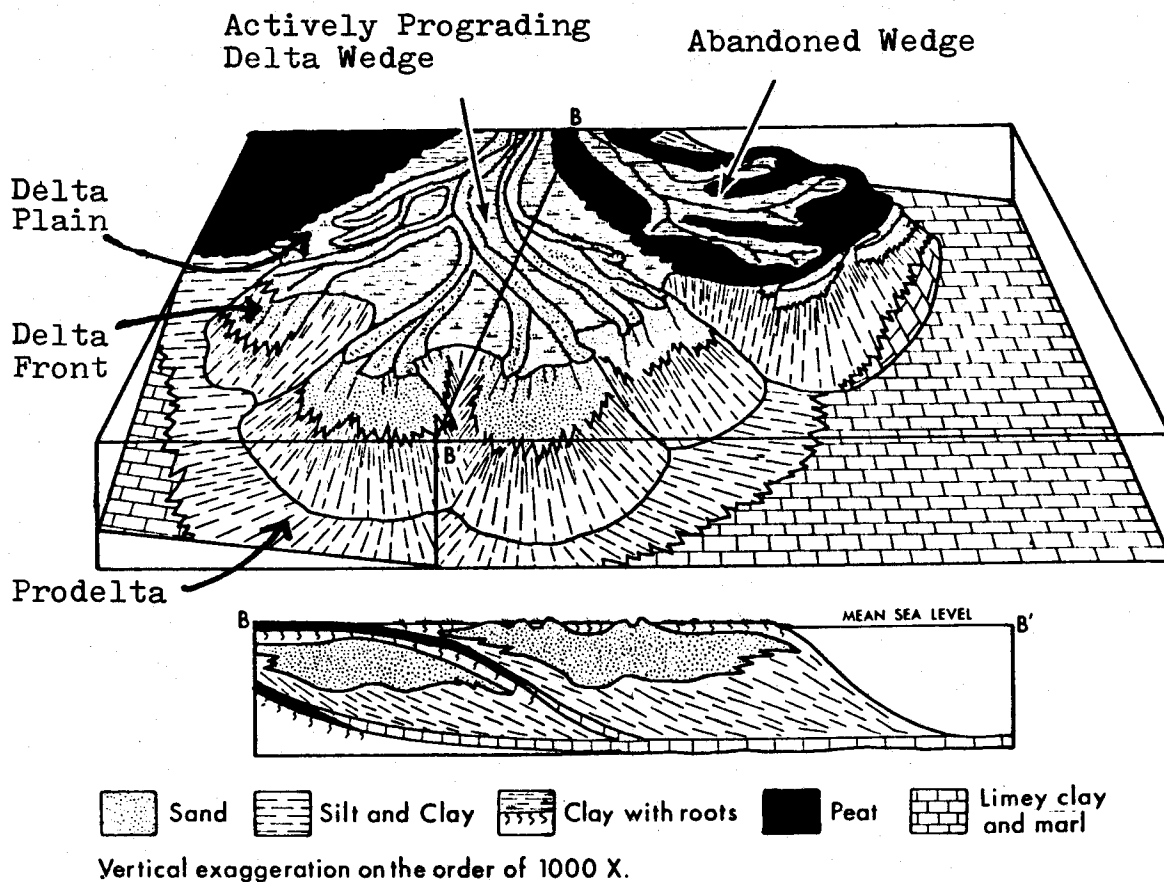


Figure 5.

laminations, lack of fossils, and position below a coal. The coarsening indicates a shallowing of water. The lack of fossils is due to rapid sedimentation and perhaps fluctuating salinities, which many organisms can not tolerate. Those few types that can tolerate this are sparse because they are so diluted by the sediment. Since the sediment is not churned by organisms, it retains its primary laminations.

The barren carbonate nodules in barren clay of unit 2 are interpreted to be possible caliche nodules in a weathering zone because of their position above a regressive marine deposit and below coal. The surrounding sediment is brecciated by vertical clay seams as may occur about calcretes (Read, 1976) (plate 1B). The irregular boundaries and included matrix suggest in-place growth.

Mulky Coal

The Mulky Coal (plate 9) and immediately underlying massive, barren, carbonaceous mudstone represents a plant-rich swamp probably formed on a delta plain. Some of the carbonaceous particles are vertical filaments that could be root traces.

The brachiopod-bearing, carbonaceous shale above this coal marks the beginning of a marine transgression.

The carbonaceous fragments may be reworked from an inundated peat swamp. The restricted fauna of brachiopods probably were forms tolerant of rapid environmental change in shallow nearshore environments.

Excello Shale

The phosphate, lack of benthic fossils, black color, and thin laminations of the Excello indicate deposition offshore when anoxic bottom conditions developed during maximum transgression, according to the interpretation of Heckel (1977) (plate 9). None of the features of a nearshore black shale such as carbonaceous fragments, sand grains, or benthic fossils are present.

The abrupt change across a bedding plane from nearshore carbonaceous shale above the Mulky Coal to offshore carbonaceous shale of the typical Excello records a period of non-deposition. Nearly all sediment apparently was trapped at the increasingly distant shoreline during this time.

The top of the Excello, as it grades into the Blackjack Creek, loses phosphate, becomes greenish in color, is burrowed and has a sparse restricted fauna of only brachiopods. This records *a period of regression* as shallowing of water destroyed the thermocline, and oxygen again became available to the bottom.

MARMATON GROUP

FORT SCOTT LIMESTONE

Blackjack Creek Limestone Member

Unit 1 of the Blackjack Creek Limestone grades upward from the Excello Formation indicating continuous preservation of this portion of the regression (plate 9). The fauna becomes more diverse, as echinoderms and bryozoans appear, indicating reestablishment of a high degree of oxygenation in clear water of normal salinity. The lack of abrasion and presence of mud indicates quiet conditions below wave base.

No algae are present. The ecologic conditions most affecting algae are light, character of bottom, salinity, and water circulation, clarity and temperature (Johnson, 1961; Wray, 1977). Most of these requirements are shown to be acceptable by the presence of the other fossils. However the one factor which affects algae and none of the other organisms is light. Due to the requirement of light for photosynthesis, most living algae are restricted to depths of 100 meters or less (Wray, 1977, figure 142). Thus in view of the presence of algae in similar limestones of the core, a lack of algae here might suggest water depths greater than the effective photic limit for these types of algae.

*from v. deep to
exposed (?)
within B.J. ck.?
(see p. 59)*

Unit 2 of the Blackjack Creek is barren lime mudstone and lies with a sharp contact upon the highly fossiliferous top of unit 1. The presence of mud and lack of fossils indicates deposition in a quiet, highly restrictive environment that was beyond wave reach and perhaps not even marine. This mud is brecciated in place by vertical clay seams indicating probable in-place weathering (plate 1F). The small dark angular pebbles concentrated at the upper contact of this unit may be a weathering residue that was brecciated in place. The lack of any preserved shoal water environment between units 1 and 2 may be due to a lack of wave action, rapidity of regression, erosion, or absence of a clastic source.

Little Osage Member

Summit Coal

The Summit Coal is fossiliferous, carbonaceous, black shale in this core. The calcareous fossils are unidentifiable and of unknown origin. Presence of only coal stringers and abundant carbonaceous particles suggests either a poorly developed coal swamp, or debris washed out of a nearby coal swamp, provided the calcareous fossils are marine. The Summit Coal and the weathered top of the Blackjack Creek represent maximum regression (plate 9).

Gray Shale Unit Above Summit

The lower portion of the gray shale above the Summit is a carbonaceous mudstone, which grades from the underlying more coaly sediment. It has a restricted fauna of only bivalves and brachiopods, indicating a transgressive deposit beyond wave reach (plate 9). In the upper portion of this unit skeletal lime packstone, with a non-diverse fauna including echinoderms, indicates water of normal salinity below wave base. Absence of bryozoans and algae suggests somewhat turbid conditions. The shale interbeds indicate periodic clastic influx with more rapid deposition while the limestone represents times of slower deposition when organisms could better survive.

Black Shale Unit Above Summit

Black color, thin laminations and lack of benthic fossils indicates deposition under anoxic bottom conditions (plate 9). Presence of non-skeletal phosphate suggests these conditions became established under quasi-estuarine circulation that developed during maximum transgression (Heckel, 1977).

The lighter-colored, burrowed, non-phosphatic top of this member indicates that there was enough regression to break up the quasi-estuarine circulation and allow

reoxidation of the sea floor, which again became suitable for benthic life.

Houx Limestone

Although essentially a fossiliferous mudstone, the concentration of fossils in the Houx suggests a more oxygenated sea floor as regression continued (plate 9). Lack of abrasion suggests deposition below wave base. The Houx is thin and was quickly overcome by the overlying unit.

Gray Shale Unit Above Houx

The barren laminated mudstone and siltstone of this unit seem to represent prodelta sediments deposited below wave base (plate 9). The rate of sedimentation was high enough to limit the fauna and prevent burrowers from destroying the primary laminations.

No shallower deltaic environment is recognized above this deposit. It seems to be the prodeltaic part of a clastic wedge inserted during a regression, that then shifted elsewhere to allow deposition here of the Higginsville Limestone.

Higginsville Limestone Member

In contrast with the underlying prodelta sequence, the fossiliferous and burrowed limestone and shale at the base of the Higginsville indicate that deposition slowed enough to allow a larger number of benthic organisms to survive and rework the sediment. The fossils are whole, indicating quiet water which, like the underlying prodelta deposits, was probably below wave base (plate 9).

Rounded, abraded grains and concentrically layered oncolites (Logan, 1964) in limestone of the middle portion of unit 1 indicate almost continually agitated water above wave base (plate 2E, 9). The diverse fauna with bryozoans and echinoderms indicates oxygenated, clear water of normal salinity.

Disappearance of oncolites and abrasion of fossils in the top of unit 1 indicates a return of quiet water (plate 9). Decreasing diversity of the fauna upward suggests that this is a trend toward deposition in more restricted waters beyond wave reach, which is strongly supported by the disappearance of all fossils in the similar lithology of overlying unit 2.

Unit 2 also has vertical anastomosing clay seams, similar to those at the top of the Blackjack Creek Limestone, which are interpreted to be due to ancient

weathering (plate 2G). The top of unit 2 is more intensely weathered with only a rubbly, clay-rich limestone remaining. This seems to be the surface of maximum regression.

LABETTE FORMATION

The Labette Shale (plate 10) is a relatively thick, fining-upward clastic sequence, which is unique in this core. In contrast to the other thick clastics that coarsen upward and generally represent prograding deltaic sequences, the Labette is believed to represent channel and floodplain deposits of an alluvial plain.

The abrupt basal contact is erosional. The coarse basal sediments represent a lag of sedimentary lithoclasts and coal fragments indicating a terrestrial source.

The overlying, barren, finer-grained, crossbedded sandstone represents the main part of the channel fill in which few organisms lived or are preserved. Burrowed sediment overlying these deposits may represent floodplain migration to this spot as the channel shifted. This grades up to massive mudstone with carbonaceous filaments, which could be root traces in a soil. This underclay is overlain by the Mystic Coal, which represents a terrestrial swamp.

PAWNEE FORMATION

Anna Shale Member

Above the Mystic Coal, two distinct environments are represented in the black Anna Shale (plate 3, 10). These correspond to the different types of black shale described by Heckel and Swade (1977).

Unit 1 of the Anna, which overlies the Mystic Coal, has characteristics of a nearshore black shale. The sparse benthic marine fauna indicates that at least some oxygen was available on the bottom. Carbonaceous particles are dispersed through this unit, probably derived from a nearby swamp. The coal stringer, which overlies a thin limestone in the middle of this unit, may be from a single sunken log. This limestone is a gastropod packstone and suggests a period of greater bottom oxygenation perhaps due to establishment of a weak zone of wave activity as predicted by the Irwin model. It certainly indicates that black shale conditions were not continuous during transgression.

Unit 2 of the Anna is barren phosphatic black shale with no macrofossils, carbonaceous particles, or variation in lithology, in contrast with unit 1. The upper Anna was deposited in anoxic marine water below wave base under quasi-estuarine circulation established during maximum transgression.

Myrick Station Limestone Member

The fossiliferous Myrick Station Limestone indicates a regression to the point that the bottom again became oxygenated (plate 10). The fauna is diverse and non-abraded, indicating relatively clear water of normal salinity below wave base. The lack of algae in the Myrick Station might suggest that water was still too deep for calcareous algae, although preservational factors could be involved as well.

Mine Creek Shale Member

Unit 1 of the Mine Creek Shale (plate 10) is a massive mottled green and gray mudstone that is different in appearance from underlying muddy strata. It lacks the laminated sands of older deposits interpreted as prodeltaic. Its restricted fauna of brachiopods and bivalves suggests a restricted environment that could be either; 1) beyond wave reach and restricted by salinity fluctuations or, 2) below wave base and restricted by turbid water accompanying rapid deposition of a prodelta. Lack of sand laminae could reflect either little or no incoming sand or thorough reworking by burrowing, which could also be responsible for some of the mottling.

Because the top of unit 1 is a conglomerate containing clasts of the underlying rocks and coal

fragments and is overlain by a coal stringer, thus indicating regression to subaerial exposure, part of the previous record is missing. In case 1, sediment of the zone of shallow agitated water was eroded or never deposited; in case 2, the delta that provided the far end of the wedge was cut off and regression continued to subaerial exposure without accumulation of any more carbonate material.

The marine fauna in unit 2 of the Mine Creek Shale indicates a transgression from the conglomerate and coal environment at the top of unit 1. The abundance of sand, relative to argillaceous material, throughout this unit suggests detrital influx with a fair amount of winnowing, but the presence of carbonate mud and non-abraded shells suggests a final environment at, or just below effective wave base.

The non-sandy mudstone of unit 3, which has brachiopods and bivalves only near its base, apparently records a rapid influx of mud perhaps from another prodelta in which sand was not transported this far. Rapid sedimentation could be the environmental factor that limited the fauna.

Coal City Limestone Member

The Coal City Limestone is a wackestone with a non-abraded, diverse fauna, marking a cessation of clastic influx in a quiet marine environment below wave base (plate 10). Apparently the delta lobe of the underlying unit became abandoned. Coal City Limestone was terminated by shifting of a new delta into this area.

BANDERA FORMATION

The lower half of unit 1 of the Bandera (plate 11) is laminated, barren mudstone, very similar to the unnamed unit above the Houx, and was deposited below wave base as a prodelta. The rate of sedimentation was high enough so that burrowers were unable to destroy the primary laminations. Unlike the older deltaic deposit the upper half of this unit coarsens upward to barren, crossbedded sandstone, indicating that deltaic deposition continued above wave base.

Unit 2 of the Bandera is barren, red, crumbly mudstone, the color of which is unlike any seen lower in the core. Red color in general (Walker, 1967) and specifically in the Desmoinesian of the U.S. western interior (Walker, 1975) is due to authigenic alteration of iron-bearing detrital grains under oxidizing, mainly subaerial, conditions. This interpretation is supported

by the rubbly appearance, caused by in-place brecciation, that suggests possible weathering.

ALTAMONT FORMATION

Amoret Limestone Member

The diverse fauna, including bryozoans and echinoderms, of the Amoret Limestone indicates transgression from the underlying terrestrial environment to oxygenated, clear water of normal salinity (plate 11). Rounding of some skeletal grains and presence of oncolites, some with incomplete coatings indicate at least periodic water agitation above wave base, although the mud matrix indicates final deposition was below effective wave base.

Lake Neosho Shale Member

Barren phosphatic black shale at the center of the Lake Neosho Shale indicates deposition at maximum transgression in anoxic water (plate 11). Laminated green shales with sparse faunas above and below the phosphatic shale represent slightly oxygenated environments transitional to the anoxic environment.

Worland Limestone Member

The Worland Limestone (plate 11) is part of the best documented regressive sequence in this core. The gray

upper portion of the Lake Neosho recored the start of regression. Unit 1 of the Worland has a diverse biota with algae, bryozoans, and echinoderms, indicating oxygenated, clear, well lit waters of normal salinity. The lowest 2 of 3 zones recognized in unit 1 have non-abraded fossils in mud matrix indicating deposition below wave base. ~~Algae~~ appear just above the base in encrustations indicating deposition above the base of the effective photic zone. Blades of phylloid algae replace the encrustations in the middle zone. Appearance of algal oncolites and abraded fossils in the top zone of unit 1 indicate agitated water above wave base.

Dominance of a muddy matrix and the lack of fossil abrasion in the base of unit 2 indicates a return to quiet water conditions. Disappearance of the fossils upward in this unit indicates continuation of regression into the zone beyond wave reach. The rubbly upper contact suggests subaerial exposure, which is corroborated by the nature of the overlying unit.

NOWATA FORMATION

Units 1 and 3 of the Nowata (plate 12) are similar in appearance and are interpreted to be of the same environment. Both units are barren, rubbly, red mudstone, a color which Walker (1967, 1975) has shown is

due to deposition and diagenesis in an oxidizing environment. In both units, irregular nodules, which are brecciated in place and encompass small dark clasts like those scattered in the matrix, suggest in-place weathering and growth of the nodules as a calcrete. All these subaerial features indicate that unit 1 is the point of maximum regression after deposition of Worland Limestone.

A marine fauna and loss of red color in unit 2 of the Nowata indicates a brief transgression interrupting the terrestrial environment of units 1 and 3. A limestone near the base of unit 2 indicates subsidence with little clastic influx thus suggesting delta abandonment in this area at that time. A diagrammatic illustration of this type of limestone occurrence is shown in the cross section of figure 5.

LENAPAH FORMATION

Cooper Creek Limestone Member

Unit 1 of the Cooper Creek (plate 12) is a grainstone with an abraded, diverse fauna including algae, echinoderms, and bryozoans, indicating deposition in oxygenated, well lit, clear water of normal salinity, above wave base. This environment indicates the beginning of a transgression that terminated Nowata detrital deposition.

The very thin phosphatic shale of unit 2 marks this as more than a minor transgression. Although this shale is green and diversely fossiliferous, unlike all other phosphatic shales in this core. Schenk (1967) indicated that previous studies have shown that non-skeletal phosphate is difficult to form in shallow environments. The large volumes of phosphate-rich water required to form non-skeletal phosphate are most easily explained by upwelling, which occurs only at a high stand of sea level (Heckel, 1977). Lack of a black shale facies means that bottom oxygen was not sufficiently depleted in this area at this time. This situation is apparent in other offshore shales elsewhere in which phosphatic nodules occur marginal to the black facies (Heckel, 1977, p. 1048, 1057).

Unit 3 contains a diverse, non-abraded fauna, including algae, echinoderms, bryozoans, and brachiopods (some in living position), indicating deposition in quiet, oxygenated, well lit water of normal salinity below wave base.

Unit 4 of the Cooper Creek has the same biota as unit 3 indicating a similar marine environment. However the abraded skeletal grainstone in unit 4 indicates turbulent conditions above wave base, therefore demonstrating continuation of the regression beginning above the Cooper Creek phosphate nodules.

PLEASANTON GROUP

The Pleasanton Group (plate 12, 13) represents a prograding deltaic sequence that overwhelmed the underlying carbonates as regression continued. Unit 1 is a coarsening-upward sequence consisting of unfossiliferous, laminated mudstone grading upward to unfossiliferous, crossbedded sandstone, indicating shallowing of the water with increasing water turbulence. The high rate of sedimentation of the delta limited the fauna and did not permit burrowers to destroy the primary laminations. Unit 2 is barren, massive mudstone with carbonaceous particles and a coal, representing establishment of delta plain environments. Reappearance of marine fossils in upper unit 2, and particularly in unit 3, indicates a return to marine conditions. Low diversity of marine fauna, presence of carbonaceous fragments, and dominance of shale lithology suggests nearshore deposition in a sheltered environment beyond wave reach. The fine alternation of mud and sand laminae suggest rapid alternation of high and low turbulence which is best explained by deposition on a tidal flat.

KANSAS CITY GROUP

HERTHA FORMATION

Unit 1 of the Hertha (plate 13) is homogeneous, very fossiliferous, gray shale, with echinoderms, bryozoans,

brachiopods, and molluscs indicating non-turbulent, oxygenated, clear water of normal salinity below wave base. Loss of sand and increasing diversity of fauna indicates transgression from the underlying nearshore environment. The lack of significant sediment recording deposition above wave base may be due to a lack of deposition during a rapid transgression, or a lack of wave energy sufficient to prevent mud deposition (Walker and Harms, 1971).

Unit 2 of the Hertha is a barren, black shale with phosphatic nodules, a diagnostic lithology also seen lower in the sequence. This shale formed during anoxic conditions developed during quasi-estuarine circulation at maximum transgression. The fossil filled burrows from the overlying gray shale that cut a layer of phosphate nodules (plate 7C) developed after the bottom was reoxygenated. Burrowers today are capable of affecting sediment tens of centimeters below the surface (Clifton and Hunter, 1973).

Unit 3 of the Hertha is wackestone with a diverse, non-abraded fauna, including bryozoans and echinoderms, indicating clear, oxygenated water of normal salinity below wave base. Absence of algae suggests that this regressive unit could have formed below the effective photic zone.

The more highly argillaceous unit 4 of the Hertha has a non-abraded fauna of echinoderms, bryozoans, and molluscs, like that of unit 3. This lithology and biota suggest slow deposition in relatively nonturbid water of normal marine salinity, but in a situation in which algal production of lime mud was inhibited, possibly due to depth below the effective photic zone.

In contrast, appearance of phylloid algae and carbonate mud in unit 5, indicate deposition within the photic zone. The lack of fossil abrasion in the remainder of the diverse fauna demonstrates that deposition was still below wave base.

Unit 6 is wackestone with a non-abraded, diverse fauna suggesting deposition was still below wave base. The apparent lack of algae here may be related to the increased argillaceous content of this unit, which could be the earliest stage of the clastic influx evident in the overlying unit.

LADORE SHALE

The basal Ladore Shale (plate 13) is entirely clastics with a limited fauna of brachiopods and bivalves. This coarsening upward sequence strongly suggests that prodeltaic influx overwhelmed Hertha carbonate production.

INTERPRETATION OF CYCLICITY

PREVIOUS STUDY OF CYCLOTHEMS

Pennsylvanian cycles of sedimentation have been long recognized in the Midcontinent region (Moore, 1936, 1950; Weller, 1958). Early studies established that variation exists in Pennsylvanian cyclic sequences of different ages and places. In both Kansas and Illinois several different types of cyclothem sequences were proposed, apparently because these workers strived to discover the most complete and complex cycle for a given group of strata in a certain area.

Each different type of cyclothem was recognized as resulting from fluctuations of sea level. Shales generally were believed to be of shallow water origin with limestones believed to be of deeper water origin (e.g. Moore, 1936). Complex cycles of limestone and shale alternations were thus believed to be caused by several transgressions, while simpler cycles apparently represented fewer sea level fluctuations. The relationship and correlation of these different types of cyclothem was enigmatic (Weller, 1958, 1966).

Over the years new interpretations of lithofacies have been developed. It is now recognized that not all shales are shallow-water deposits and not all limestones are deeper-water deposits. With this knowledge it is possible to explain the differences in the various cyclic sequences. Facies variations are recognized, particularly in shallow-water deposits. It is now seen that cycles with a shallow-water limestone in place of a shallow-water shale need not be genetically different. Clastics may overwhelm limestones in one area while elsewhere, lack of clastics may permit limestone to develop.

A key new interpretation of lithology is that of black shale containing phosphatic nodules and a limited fauna, which is often traceable for hundreds of miles. This distinctive type of shale occurs in most groups of Desmoinesian, Missourian, and lower Virgilian rocks of the Midcontinent. The phosphatic black shale is now interpreted to form offshore at the highest stand of sea level (Heckel, 1977). This interpretation facilitates the naming of new, genetically meaningful members of a basic cyclothem, as well as enabling regional correlation of cyclothem to progress.

The typical Upper Pennsylvanian cyclothem recognized by Heckel (1977) in Kansas is shown diagrammatically

in figure 6. This cyclothem represents a single transgressive-regressive sequence consisting of 5 basic members: nearshore shale, transgressive limestone, offshore shale (maximum transgression), regressive limestone, and nearshore shale again (figure 6, column 1). There is a certain amount of variation in thickness and lithology of each member. The nearshore shales may be hundreds of feet thick if a clastic source is nearby. Transgressive phases tend to be very thin because of progressive stranding of detritus farther away near the increasingly distant shoreline. The limestones developed only when permitted to by a lack of clastics. The relationship of a dominantly clastic cyclothem to a more dominantly limestone cyclothem is shown in figure 7.

Local variations in sea level can occur due to delta progradation and abandonment. The deltaic sequences are not necessarily caused by regional sea level changes and do not produce major cyclothem. A local deltaic clastic wedge can interrupt a cyclothem in any of the shallower phases of deposition (Wanless, 1966; Heckel, 1977). Local coals or underclays may develop on any deltaic clastic wedge, and a marine limestone may develop where a delta has been abandoned while subsidence continued. These situations give the appearance of an additional cyclothem during a phase of lower sea level

Figure 6. Basic Upper Pennsylvanian individual Kansas cyclothem sequence (modified after Heckel, 1977, figure 2).

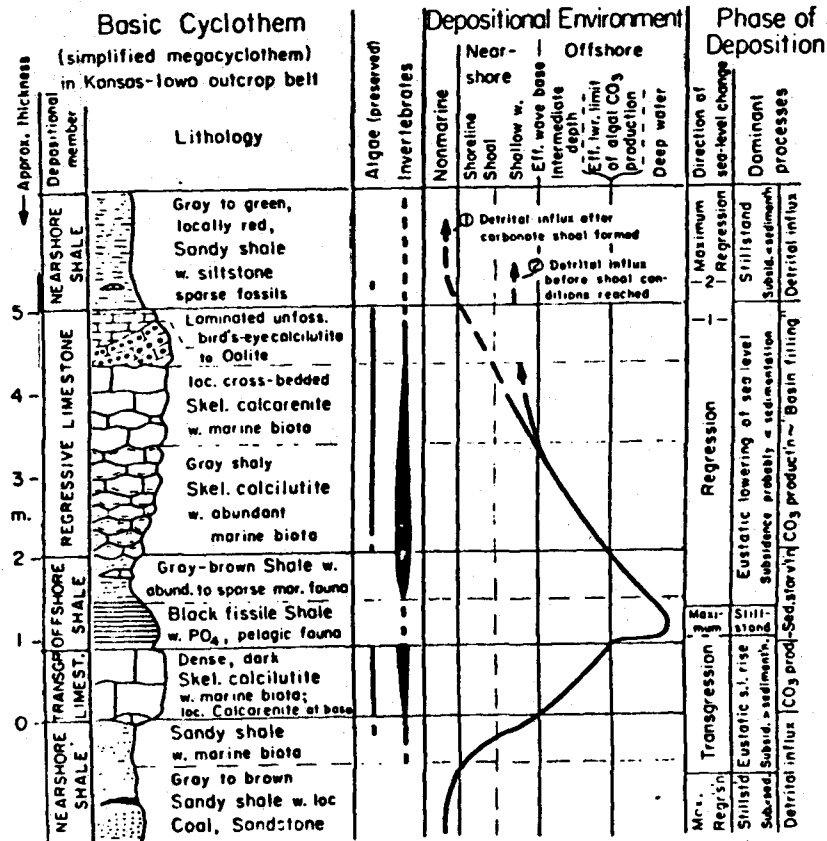


Figure 6.

stand. This additional cyclothem can be considered "partial" because it will lack the deposit of the maximum transgressive phase, the phosphatic black shale.

For example, in figure 8 at "A" the sequence is underclay, coal, limestone, shale, sandstone, and then another coal, whereas only coal and underclay precede the remainder of the cyclothem at "B". This same cyclothem becomes even more complicated laterally (figure 9). At some locations there are 4 limestones, at others 3 coals and 6 clastic units. However, throughout this region there is only one black phosphatic shale (Anna), which is laterally the most extensive member and marks the major transgression of the cyclothem whereas the clastic wedges are local and pinch out laterally above or below the Anna.

CYCLOTHEMS RECOGNIZED IN CORE CP37

Six phosphatic shales are present in Core CP37, each indicating a major transgression. The beds lying between the most nearshore or nonmarine units on either side of a phosphatic shale constitute a cyclothem (plates 9-13). The boundary between two cyclothem may be represented by various nearshore or nonmarine deposits at different locations. However, the phosphatic core shale of a cyclothem should be regionally persistent, allowing

Figure 7. Proposed relationship of dominantly clastic cyclothem to more dominantly limestone cyclothem (modified after Heckel, 1977, figure 7).

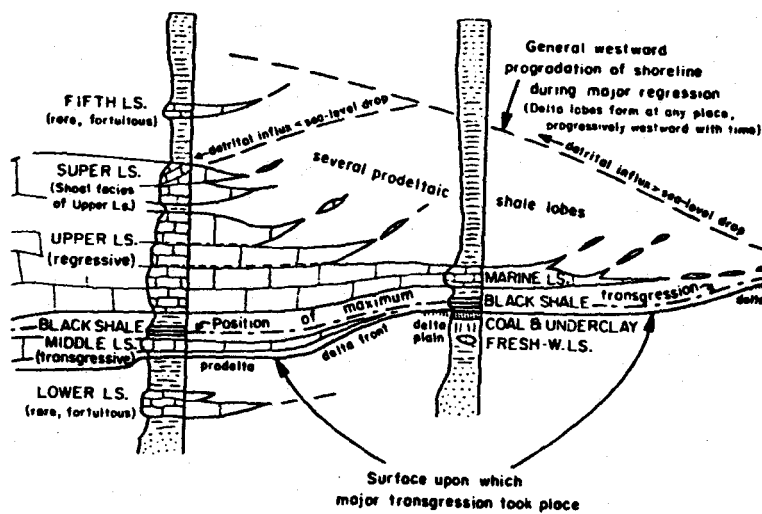


Figure 7

identification of cyclothems that represent major transgressions throughout those parts of the Midcontinent in which phosphate was deposited. Weller (1958) previously named four Marmaton cyclothems in Kansas after the four limestone formations recognized there. These cyclothem names apply to Iowa with the modification that two cyclothems are now recognized in the Fort Scott Limestone.

LOWER FORT SCOTT CYCLOTHEM

The lower Fort Scott cyclothem (plate 1 & 9) extends from the top of the underlying regressive deltaic deposit, which is capped by the Mulky Coal, to the unconformity at the base of the Summit Coal. It thus includes the top most units of the Cherokee Group as well as the lowest units of the Marmaton.

This cyclothem, which is made up almost entirely of the Excello Shale and Blackjack Creek Limestone, is the thinnest in the core. As in most other cyclothems of this core, transgression is poorly preserved. In this case the black phosphatic Excello Shale marking maximum transgression lies on coaly shale.

The regressive limestone (Blackjack Creek) lacks preserved algae and is thinner than those at the top of the Marmaton Group. In addition, there are no thick

Figure 8. Clastic wedge of Englevale Sandstone and associated strata dividing Lexington coal in western Missouri (after Wanless, 1966, figure 3).

Figure 9. Idealized cross section showing clastic wedges within a cyclothem (not to scale) (after Wanless, 1966).

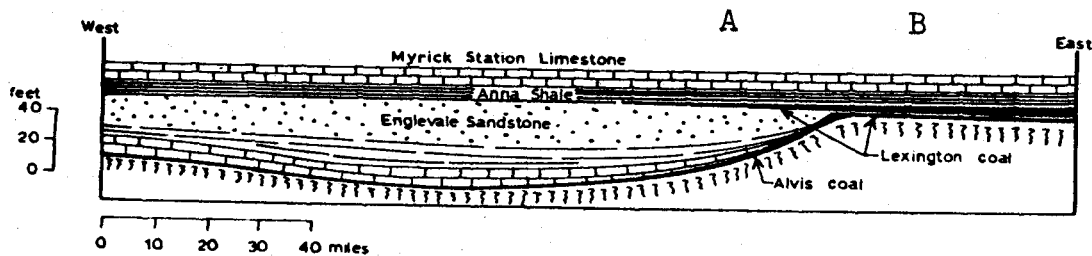


Figure 8 .

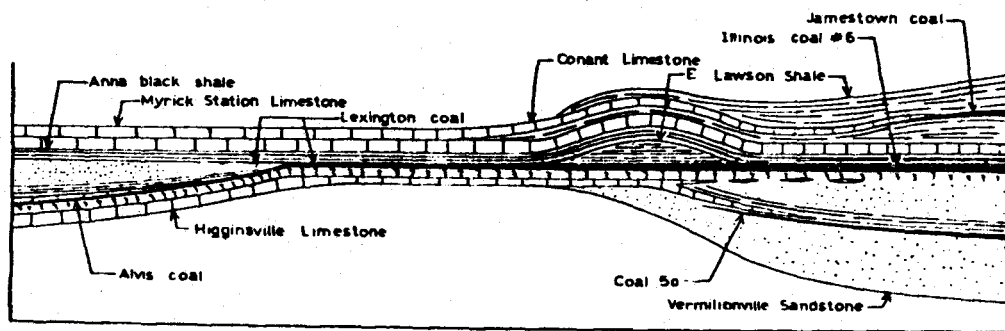


Figure 9 .

clastic wedges as are found in the regressive phase of most other cyclothem, indicating no clastic source was nearby at this time. Lack of thicker limestone development is hard to explain. It does not appear that the limestone was inhibited by turbid water, because there are no clastics. A rapid regression of some other environmental factor may have inhibited carbonate production.

UPPER FORT SCOTT CYCLOTHEM

The black phosphatic shale in the Little Osage Shale beneath the Houx Limestone marks the maximum transgression that identifies the Upper Fort Scott (plate 2 & 9). This cyclothem extends from the Summit Coal to the weathered and eroded contact at the top of the Higginville Limestone.

The transgressive phase of deposition is thin but fairly well represented by the gray shale above the Summit. Maximum transgression is well represented, as is common. Formation of the regressive limestone was interrupted by the prodeltaic portion of a clastic wedge soon after deposition of the Houx Limestone began. A shift in clastic influx eventually allowed the nearshore shaly Higginville Limestone to develop.

PAWNEE CYCLOTHEM

The upper phosphatic half of the black Anna Shale marks the maximum transgression of the Pawnee cyclothem (plate 3 & 10; figure 8 & 9).

The Labette Shale, which at this location is a channel deposit, is included in the Pawnee cycle because it overlies a distinct unconformity. Other locations may not have this same sequence. Elsewhere, an under-clay beneath the Mystic Coal, for example, could be the best division between cyclothem.

The transgression above the Mystic Coal is represented by the fossiliferous, nonphosphatic lower half of the Anna Shale at this location.

The regressive limestone (Myrick Station) above the Anna Shale is thin and without algae. Because this limestone grades upward to shale, it is likely that clastics terminated carbonate production. If these clastics were prodeltaic, the bulk of the sedimentation was soon shifted elsewhere because the shale is quite thin. Conglomerate and thin coal at the top of this shale completes the regressive phase of this cycle, which is almost as thin as that of the lower Fort Scott cyclothem.

MINE CREEK/BANDERA CLASTIC WEDGE

The remainder of the Mine Creek Shale (above the conglomerate and coal stringer) and the overlying Coal

City Limestone and lower Bandera Shale contain marine deposits that do not seem to be part of a major cyclothem. These units are interpreted to be the result of continuing subsidence with marine carbonate sedimentation alternating with minor clastic wedges as described by Wanless (1966) during a time of general regression (plates 4, 10, 11).

The middle of the Mine Creek Shale records slow, coarse clastic influx into a carbonate environment developed during subsidence, followed by more rapid fine clastic influx forming the upper Mine Creek. The Coal City indicates a time when clastic influx shifted elsewhere. The Bandera is a major clastic wedge consisting of a relatively complete regressive deltaic sequence that terminates with subaerially formed red beds.

ALTAMONT CYCLOTHEM

The Altamont cyclothem (plates 5, 11, 12) is the lowest of the 3 cyclothem having thicker limestone development than those below. The Altamont cyclothem is unusual in that it is almost entirely limestone, suggesting that shoreline and the accompanying delta wedges were much farther away from south-central Iowa than in previous cycles. Transgression is recorded by

the Amoret Limestone, which is the lowest well-developed transgressive limestone in the core. Maximum transgression is marked by the black, phosphatic Lake Neosho Shale. The Worland Limestone records the entire regression up to the subaerial red beds of the lower Nowata. Although clastic wedges did not interrupt limestone deposition here, it is conceivable that at other locations clastic influx could have prevented nearshore Worland environments from developing.

NOWATA CLASTIC WEDGE

Clastic influx did not return to south-central Iowa until well into the phase of general regression. The abrupt reappearance of marine fossils in unit 2 of the Nowata above, the soil developed on the Worland, reflects continuation of subsidence but without sediment infilling after Worland carbonate deposition ended. Only later during Nowata deposition did the fine clastics return, possibly as a prodelta grading rapidly up to a delta plain as suggested by the red color of unit 3.

LENAPAH CYCLOTHEM

The lower Cooper Creek phosphatic nodules, even though in a thin green shale, mark the major transgression of the Lenapah cyclothem (plates 6, 12, 13). The

transgressive limestone, which preceded the phosphate, is also thin.

The entire regressive phase of deposition is thick and well represented. The Cooper Creek (above the phosphate) is a complete regressive limestone with phylloid algae grading upward from quiet to agitated water facies. It is overlain by the regressive deltaic sequence of the lower Pleasanton, which is capped by a coal.

HERTHA CYCLOTHEM

A sparsely fossiliferous marine shale, which could represent a tidal lagoon, marks an early stage of transgression of the Hertha cyclothem (plate 7, 13). Only a thin, more shelly mudstone represents the transgressive limestone preceding deposition of the black phosphatic shale that represents maximum transgression of this cyclothem. Although the regressive limestone is split by a shale, this shale is thin and quite diversely fossiliferous with clear water organisms (bryozoan) and thus probably does not represent a clastic wedge, but rather a lack of carbonate (probably algal) mud production. Hertha regressive carbonate production was interrupted before developing into shoal water by a thick deltaic clastic wedge of the overlying Ladore Shale.

SUMMARY AND CONCLUSIONS

Some generalizations and trends of Landis (1965) concerning thickness and distribution of members, which are based on information from sparse outcrops, need to be updated from data becoming available from cores. Several members in the Cherokee, Marmaton, and Pleasanton Groups have remained unnamed, and should be given attention as new (lateral) information is available. The stratigraphic column of Iowa could then be more fully delineated for comparison with those of adjacent states.

The Excello Shale is persistent and easily identified by its position below the Blackjack Creek Limestone.

It is suggested here that Little Osage Shale is readily recognizable between the upper and lower-most limestone members of the Fort Scott Formation. Within the Little Osage there is an unnamed gray shale above the Summit Coal which represents a marine stage of transgression. An unnamed black shale, which is laterally persistent into southeast Kansas, is present above the gray shale, marking maximum transgression of the Upper Fort Scott cyclothem. Also unnamed is a gray shale and siltstone above the Houx Limestone which is a regressive shale of this same cyclothem.

A previously unreported marine limestone is present in the Nowata Formation. If lateral study by cores determined that this unit is laterally traceable, it might be named as a bed.

The Exline Limestone and Chariton Conglomerate of the Pleasanton Group of Iowa are not present in Core CP37.

The black phosphatic shale of the Hertha Formation is an environmentally distinct unit marking a major transgression and is likely to be regionally persistent, but has not been separately named in Iowa.

Two unreported occurrences of important lithologies were also discovered. The lower half of the Anna Shale is a nearshore, fossiliferous, carbonaceous black shale like that described by Heckel and Swade (1977). This is a distinctly different type of black shale from the upper half of the Anna, which is the more common type containing phosphate nodules.

The second previously unreported occurrence is that of phosphatic nodules in a thin fossiliferous green shale near the base of the Cooper Creek Limestone. These phosphate nodules indicate a major transgression and allow definite recognition of the Lenapah cyclothem in Iowa.

The basic five-member cyclothem recognized by Heckel (1977) for the Upper Pennsylvanian of Kansas applies with

minor modification to the sequence studied in Core CP37. Transgressive limestones are not present in cyclothem that lie directly above coals; transgressive limestones are present, although thinner than in Kansas, in those cyclothem where they overlie nearshore deposits other than coals. This is consistent with the proposal of Heckel (1977, p. 1061), that formation of transgressive limestones was inhibited on a substrate of peat.

Six cyclothem were recognized in this core: the uppermost (Hertha) is in the Kansas City Group; the next four are in the Marmaton Group (Lenapah, Altamont, Pawnee, and Upper Fort Scott) and the lowest is half in the Marmaton and half in the underlying Cherokee Group (Lower Fort Scott cyclothem). There are no erosional unconformities between the groups. In fact, the Cherokee-Marmaton boundary is in the offshore marine part of a cyclothem.

Limestones in the lower half of the Marmaton (below Bandera Formation) are rather thin compared to those above. All of these thin limestones, unlike the thicker ones are without preserved blades of phylloid (red or green) algae. It may be that some environmental factor limiting red and green algae prevented these cyclothem from attaining significant limestone thicknesses. This environmental stress need not have been consistent through

time. Clastics appear to have overwhelmed both the Houx and Myrick Station Limestones. However, the Blackjack Creek is not overwhelmed by clastics and yet is rather thin.

Clastic wedges (Wanless, 1966), some containing several units and giving the appearance of a partial cyclothem, are recognized in Core CP37. These wedges develop in response to local clastic influx and may include limestones when clastics are temporarily cut off. Major transgressions of complete cyclothem are usually marked by regionally persistent phosphatic black shales, which thus differentiates them from more local cycles of deposition caused by delta processes.

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Plate 1.

Selected lithologies of Plate 9 (Lower Fort Scott Cyclothem). Photographs are arranged by their location in core (which are shown by dots in depth column of Plate 9); up is to top of page.

- 1A. Pleasantview Sandstone, unit 1; Barren, laminated to cross-laminated, interbedded mudstone and siltstone. Round core .75X (222.5 foot).
- 1B. Pleasantview Sandstone, unit 2; Mudstone brecciated with light colored, anastomosing, blocky patches of quartz-bearing mudstone. Irregular, barren structureless, quartz-bearing lime nodules shown by arrow. Slab .75X (218 foot).
- 1C. Mulky Coal and Excello Shale; Thin, black carbonaceous shale (M) and brown, fossiliferous shale overlying plate 1B and beneath highly phosphatic, Excello black shale (E). Triangle in phosphate is carbonate cone-in-cone structure. Slab .75X (216.8 foot).
- 1D. Blackjack Creek Limestone, unit 1; Burrowed, skeletal lime wackestone. Slab .75X (213.2 foot).
- 1E. Blackjack Creek Limestone, unit 1; Burrowed, nonabraded skeletal lime wackestone. Thin section photomicrograph; 1 mm — , (214 foot).
- 1F. Blackjack Creek Limestone, unit 2; Barren, lime mudstone brecciated by vertical, anastomosing clay veins and overlain by thin conglomerate, which has been brecciated in place. Contact with overlying carbonaceous shale (Summit Coal (S) is sharp. Slab .75X (210 foot).

Plate 2.

Selected lithologies of Plate 9 (Upper Fort Scott Cyclothem). Photographs are arranged by their location in core (which are shown by dots in depth column of Plate 9); up is to top of page.

2A. Little Osage Shale Member, gray shale unit above Summit; Skeletal lime packstone with broken, mostly nonabraded fauna. Thin section photomicrograph; $\frac{1}{2}$ mm —, (207.5 foot).

2B. Little Osage Shale Member, black shale unit above Summit; Barren black phosphatic shale. Phosphate is in beds of very fine nodules and larger nodular beds. Slab .75X (205.4 foot).

2C. Little Osage Shale Member, black shale unit grading up to Houx Limestone bed; Black phosphatic shale (plate 2B) becomes lighter, loses phosphate, and gains thin horizontal burrows containing Houx "Limestone" (the overlying green shale) lithology. At this location Houx is only this fossiliferous shale shown in photo. Slab .75X (204.8 foot).

2D. Little Osage Shale Member, gray shale unit above Houx Limestone bed; Barren, finely laminated mudstone and cross-laminated siltstone. Slab .75X (198 foot).

2E. Higginsville Limestone, unit 1; Oncolite-bearing skeletal lime packstone and wackestone. Slab .75X (189.5 foot).

2F. Higginsville Limestone, unit 1; Well developed oncolite. Thin section photomicrograph; 1mm —, (189.4 foot).

2G. Higginsville Limestone, unit 2; Barren lime mudstone with vertical anastomosing clay seams. Slab .75X (182 foot).

2H. Basal contact of Labette Shale with Higginsville Limestone; Barren rubbly limestone in clay matrix (overlies 2G) below crossbedded sandstone. Round core .75X (181.7 foot).

Plate 3.

Selected lithologies of Plate 10 (Pawnee Cyclothem). Photographs are arranged by their location in core (which are shown by dots in depth column of Plate 10); up is to top of page.

3A. Labette Shale; Sedimentary lithoclasts in quartz sandstone. Slab .75X (180.8 foot)

3B. Labette Shale; Large carbonaceous fragments (black) in crossbedded quartz sandstone. Slab .75X (180.4 foot).

3C. Labette Shale; Crossbedded, very fine grained sandstone with mica and fine carbonaceous fragments. Slab .75X (173.8 foot).

3D. Anna Shale, unit 1; Fossiliferous black shale (echinoderm fragment visible) overlain by gastropod lime packstone and coal stringer. Slab .75X (165.8 foot).

3E. Anna Shale, unit 1; Black shale with fossil and carbonaceous fragments. Thin section photomicrograph; $\frac{1}{2}$ mm —, (165.2 foot).

3F. Anna Shale, unit 2; Barren phosphatic black shale. Thin section photomicrograph; $\frac{1}{2}$ mm — (165.1 foot).

3G. Anna Shale, unit 2; Barren phosphatic black shale with zones of phosphatic particles. Slab .75X (165 foot).

3H. Myrick Station Limestone; Skeletal lime packstone at lower contact. Fossils are broken but not abraded. Thin section photomicrograph, crossed polarizers, $\frac{1}{2}$ mm , (163.3 foot).

3I. Myrick Station Limestone; Skeletal lime wackestone with whole brachiopods. Slab .75X (163.1 foot).

3J. Mine Creek Shale, unit 1 top; Carbonate pebbles in mudstone. Round core .75X (156.2 foot).

Plate 4.

Selected lithologies of Plates 10 & 11 (Mine creek / Bandera Clastic Wedge). Photographs are arranged by their location in core (which are shown by dots in depth column of plates); up is to top of page.

4A. Mine Creek Shale, unit 2; Sandy, skeletal lime wackestone and packstone. Slab .75X (153 foot).

4B. Mine Creek Shale, unit 2; Echinoderms, brachiopods and bryozoans in sandy limestone. Though not apparent in this photo, sand grains are not in depositional contact. Thin section photomicrograph; $\frac{1}{2}$ mm —, (153 foot).

4C. Coal City Limestone; Skeletal lime wackestone with whole and broken fossils. Thin section photomicrograph; $\frac{1}{2}$ mm —, (144.4 foot).

4D. Coal City Limestone; Entire member is shown. Distorted bedding at upper contact is due to burrowing. Slab .75X (144.5 foot).

4E. Bandera Formation, unit 1; Finely laminated barren, green-gray, micaceous mudstone and siltstone. Round core .75X (137.5 foot).

4F. Bandera Formation, unit 2; Barren, massive mudstone with sparse pebbles. Round core .75X (118.6 foot).

Plate 5.

Selected lithologies of Plate 11 (Alamont Cyclothem). Photographs are arranged by their location in core (which are shown by dots in depth column of Plate 11); up is to top of page.

5A. Amoret Limestone; Burrowed oncolite-bearing (arrow) lime wackestone. Oncolites are better developed above (plate 5B). Slab .75X (110.2 foot).

5B. Amoret Limestone; Skeletal lime packstone with oncolitic coatings on some fossils. Thin section photomicrograph; 1mm --, (110 foot).

5C. Lake Neosho Shale; Barren black shale with lenticular phosphate layers (arrows). Slab .75X (109.5 foot).

5D. Worland Limestone, unit 1, lower zone; Lenses of algal boundstone in skeletal lime wackestone. Slab .75X (107 foot).

5E. Worland Limestone, unit 1, middle zone; Burrowed skeletal lime wackestone with phylloid algae (arrow) and whole brachiopods. See plate 5F. Slab .75X (106.1 foot).

5F. Worland Limestone, unit 1, middle zone; Phylloid algae (arrow). Thin section photomicrograph; 1 mm , (106.2 foot).

5G. Worland Limestone, unit 1, upper zone; Oncolite-bearing skeletal lime packstone. Slab .75X (104.1 foot).

5H. Worland Limestone, unit 1, upper zone; Oncolite-bearing skeletal lime packstone. Thin section photomicrograph; $\frac{1}{2}$ mm (104.5 foot).

5I. Worland Limestone, Unit 2; Micro-crossbedded lime pellets and quartz silt with pellet-packed burrows (arrow). Thin section photomicrograph; $\frac{1}{2}$ mm , (100.2 foot).

5J. Nowata Formation, unit 1; Calcareous nodules, brecciated in place and containing smaller pebbles. Round core .75X (98.1 foot).

Plate 6.

Selected lithologies of Plate 12 (Lenapah Cyclothem). Photographs are arranged by their location in core (which are shown by dots in the depth column of Plate 12); up is to top of page.

- 6A. Nowata Formation, base of unit 2; Burrowed basal contact. Round core .75X (95.5 foot).
- 6B. Nowata Formation, unit 2; Skeletal lime packstone. Slab .75X (94.8 foot).
- 6C. Nowata Formation, unit 3; Calcareous nodules brecciated in place, similar to plate 5J. Round core .75X (88.4 foot).
- 6D. Cooper Creek Limestone, unit 1; Skeletal lime packstone of basal bed. Thin section photomicrograph; $\frac{1}{2}$ mm , (80.7 foot).
- 6E. Cooper Creek Limestone, unit 1, 2, base unit 3; Basal skeletal lime packstone (1), overlain by fossiliferous shale with medial very fine grained phosphatic nodules (2), overlain by mottled skeletal lime wackestone (3). Slab .75X (80.6 foot).
- 6F. Cooper Creek Limestone, unit 3; Skeletal lime wackestone of mottled facies. Thin section photomicrograph; $\frac{1}{2}$ mm , (79.7 foot).
- 6G. Cooper Creek Limestone, unit 4; Skeletal lime grainstone (see base of 6H). Thin section photomicrograph; $\frac{1}{2}$ mm - , (71.8 foot).
- 6H. Cooper Creek Limestone, unit 4; Skeletal lime grainstone (of 6G) overlain by burrowed skeletal lime wackestone and packstone. Slab .75X (71.8 foot).
- 6I. Pleasanton Group, unit 1; Laminated barren mudstone with lime nodules (arrow). Slab .75X (65.5 foot).
- 6J. Pleasanton Group, unit 1; Crossbedded sandstone with some mudstone interbeds and irregular lime stringers (arrow). Slab .75X (64.5 foot).

Plate 7.

Selected lithologies of Plate 13 (Hertha Cyclothem). Photographs are arranged by their location in core (which are shown by dots in depth column of Plate 13); up is to top of page.

Pleasanton Group, unit 3; Finely interbedded dark colored mudstone and light colored siltstone. Slab .75X (53.9 foot).

7B. Hertha Limestone, unit 2; Phosphate nodules in barren black shale. Thin section photomicrograph; $\frac{1}{2}$ mm —, (52.6 foot).

7C. Hertha Limestone, unit 2; Zone of small phosphate nodules in barren black shale, which is disturbed by fossiliferous light colored mud-filled burrows. Slab .75X (52.6 foot).

7D. Hertha Formation, unit 3; Dark gray skeletal lime wackestone. Slab .75X (51.5 foot).

7E. Hertha Formation, unit 5; Buff-colored skeletal lime wackestone with phylloid algae, aulopoid corals and dark wispy shale partings (lower left). Slab .75X (44.5 foot).

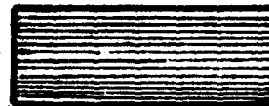
7F. Hertha Formation, unit 5; Burrowed, skeletal lime wackestone with phylloid algae (arrow). Thin section photomicrograph; 1 mm —, (44.6 foot).

7G. Hertha Formation, unit 6; Dark gray sparsely fossiliferous lime wackestone. Slab .75X (42.4 foot).

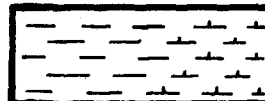
7H. Ladore Shale; Burrowed sandy mudstone. Round core .75X (28 foot).

Plate 8.
Abbreviations and symbols of Plates 9 - 13.

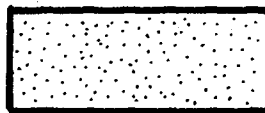
aband.	abandonment
blk.	black
brecc.	brecciated
burrow.	burrowed
calc. nod.	calcareous nodule
carb.	carbonaceous
complt.	complete
foss.	fossiliferous
grad.	grading
grn.	green
gry.	gray
interbed.	interbedded
lagoon.	lagoonal
lam.	laminated
mass.	massive
max.	maximum
mdst.	mudstone
nonabrad.	nonabraded
offsh.	offshore
part.	particles
phos.	phosphatic
poss.	possible
prob.	probable
regr.	regressive
sh.	shale
skel.	skeletal
sltst.	siltstone
ss.	sandstone
subsi.	subsidence
trans.	transgression
up.	upward
vert.	vertically
w/	with
wx.	weathered
xbed.	crossbedded



Shale

Mudstone / Calcareous
Mudstone

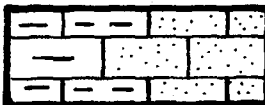
Siltstone



Sandstone

Coal / Conglomerate /
Calcareous Nodules

Limestone

Argillaceous- / Arenaceous-
Limestone

FORMATION	MEMBER	UNIT	LITHOLOGY	DEPTH/PHOTO(°)	LITHOLOGIC DESCRIPTION	COLOR				KEY INDICAT.		BIOTA				SEA LEVEL TREND				PHASE OF DEPOSITION	CYCLOTHEM NAME
						BUFF	RED	GREEN	BLACK.	CARB.PART. PO ₄	ECHINO. BRYO. BRACH.	MOLLUSC	FUSULINID	PHYLOID	OMCOLITE	MARINE					
																NONMARINE	BEYOND WAVE REACH	ABOVE WAVE BASE	BELOW WAVE BASE		
Ladore				30	foss. lam. mdst. overlain by inter-laminated barren sltst. & ss.														Prob. Delta Wedge	Near Shore Shale	
				40																	
Hertha		6		0	dark nonabrad. skel. lime wackestone														Regressive Limestone	Near Shore Shale	
		5		0	nonabraded skel. lime wackestone w/ phyloid algae																
		4		50	fossilif. mdst.																
		3		0	dark nonabrad. skel. lime wackestone																
		2		0	fossilif. calc. mdst. below phos. blk. sh.																
PLEASANTON GROUP		3		0	light colored v. fine grn. ss. flasers in blk. mdst., fossilif.														Lagoon Shale	Near Shore Shale	
		2		60	fossilif. carb. mdst. w/ coal																
		1		0	see Plate 12																

Plate 13. Stratigraphic Column

HERTHA

LENEPAH

Drain??