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The Depositional, Stratigraphic and Diagenetic Relationships of the Curzon Limestone Member of the Topeka Limestone (Upper Pennsylvanian) in Eastern Kansas

by

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ABSTRACT

THE DEPOSITIONAL, STRATIGRAPHIC, AND DIAGENETIC RELATIONSHIPS OF THE CURZON LIMESTONE MEMBER OF THE TOPEKA LIMESTONE (UPPER PENNSYLVANIAN) IN EASTERN KANSAS

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The Curzon Limestone Member (Topeka Formation, Shawnee Group, Upper Pennsylvanian Series) overlies the continental-nearshore Iowa Point Shale Member, and lies beneath the marine Jones Point Shale Member, both units of the Topeka Formation. The Curzon consists of an upper and lower iron-stained, calcareous limestone, which usually is separated by a silty, micaceous claystone. The lower limestone was deposited in a transgressive marine environment and the upper unit in a regressive marine environment. The Curzon, therefore, represents a minor marine advance and retreat cycle within the larger cycle of the Topeka Limestone.

The upper limestone portion of the Curzon outcrop may be dolomitic in the northern one-third of the State, has paleosols developed to southern Doniphan County, and shows evidence of subaerial exposure in Osage, Coffey, and Greenwood Counties. It becomes more calcareous in the southern one-third of the outcrop but begins to thin to the south and pinches out near the Oklahoma border where masked or overwhelmed by an increasingly large input of clastic sediments

eroded from the Arbuckle and Ouachita Mountains.

Evidence in Greenwood and Coffey Counties points to local tectonic activity, which interrupted the transgressive cycle and exposed Curzon sediments subaerially. The localized uplift influenced by regional tectonism may have lowered sealevel sufficiently to allow the subaerial exposure in the northern area. The tectonic activity also may have formed the joints which occur in the Curzon Limetone as well as generally subparallel faults and folds which occur in Virgilian strata from Osage County, Oklahoma to Doniphan County, Kansas.

Surface drainage from north, east, and south furnished both clastic sediments and dissolved and colloidal iron compounds to the Curzon Sea where alkalinity quickly precipitated the iron. Alternate drying and wetting conditions oxidized the iron and concentrated it to a noticeable degree in the Curzon Limestone. Quantitative analyses indicate lessening iron concentration in a southward direction although no real trend could be defined.

At the end of Curzon deposition, the transgressive Pennsylvanian sea continued to rise eustatically in response to glacial retreat in Gondwana. Subsequently, renewed glaciation in late Shawnee time initiated marine regression which terminated the Topeka megacycle by depositing the nonmarine to marginal marine Severy Shale.

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Proper acknowledgment of all the persons who have helped me attain a masters degree in geology would require an autobiography. I must thank my wife, Mary, and sons, Harold and John, who have provided constant encouragement. Also my late parents, Harold and Gail Skelton, merit thanks for encouraging this undertaking as well as encouraging and abetting an interest in geology that began 43 years ago. Dr. Daniel Francis Merriam has been a mentor and friend and remains an endless source of inspiration and initiative who deserves more thanks than this mere sentence. Other faculty members at The Wichita State University, particularly Dr. Peter G. Sutterlin, have been of material assistance as has the Department of Geology which graciously provided sample preparation equipment and paid for the preparation of thin sections. The Kansas Geological Survey has provided invaluable aid in time, transportation, chemical analyses, and encouragement. Among others there special thanks to Mr. John Charlton, Dr. John H. Doveton, Mr. Karmie Galle, Dr. Lee Gerhard, Dr. David Grisafe, Dr. Larry Hathaway, Mr. David Newell, and Dr. Lynn Watney. Ms. Jessica Wolf of the Wichita Well Sample Library provided exemplary assistance with typing and the entire Sample Library staff merits thanks for tolerating me during this exercise. Similar to many things of importance in life, this has been a team effort and every-

one deserves a share of any credit. I, however, in the words of the immortal Mark Twain, take full credit for any slanders, errors, calumnies, mistakes, contradictions, maligns, and misrepresentations that may be contained herein.

INTRODUCTION

Subject

The cyclic nature of Pennsylvanian age strata in Mid-continent United States has been recognized since the early 1930's. R. C. Moore had commented on that cyclicity in 1930, and in 1935, noted that he had first clearly recognized cyclothems in the Shawnee Group in Kansas.

The uppermost formation of the Virgilian Stage Shawnee Group is the Topeka Limestone which is comprised of five limestone and four shale members. The Topeka Limestone, which was deposited about 290 mybp, is overlaid by the Severy Shale and underlaid by the Calhoun Shale, both of continental origin although the Calhoun in places contains at least two significant limestone beds (B. M. Allen, per. comm., 1989)

The subject of this study is the Curzon Limestone Member of the Topeka Limestone. The Curzon Limestone was named in 1898 from its type locality at Curzon Station, in Holt County, Missouri. The Curzon Limestone was described in Zeller (1968, p. 68) as ranging from 5 to 12 ft (1.5 to 3.6 m) in thickness consisting of "two or more beds of massive bluish-gray, brown weathering limestone that is mostly hard and resistant" locally, containing chert nodules. The lower part of the Curzon Limestone is thick bedded and contains fusulinids and other shallow-marine fossils; the upper part is thin to wavy-bedded, burrowed, and locally displays evidence of subaerial exposure. The Curzon is characteristically iron-stained on weathered surfaces and displays regular vertical parallel joints which are spaced at intervals of approximately 18 to 24 in (45 to 60 cm). The Curzon is underlaid by the Iowa Point Shale Member and is overlaid by the Jones Point Shale Member. Locally, particularly in the southern portion of the outcrop area, the Iowa Point Shale is absent and the Curzon lies directly upon the Hartford Limestone Member. The Curzon may be divided into upper and lower portions by a yellow to gray mudstone ranging from a few millimeters to about 60 cm in thickness. Stratigraphic relationships are indicated in Figure 1.

Purpose and Scope

The primary purpose of this study is to interpret the depositional environment and subsequent alteration of the Curzon Limestone, determine its stratigraphic relationship with adjacent units, and delineate the extent of jointing. Field and laboratory methods are discussed in detail in the Methods of Study section.

The petrology, mineralogy, and chemical composition of the Curzon Limestone were studied using thin-sections, acetate peels, and atomic-absorption analyses. Some fossils and fossil assemblages were identified in order to better

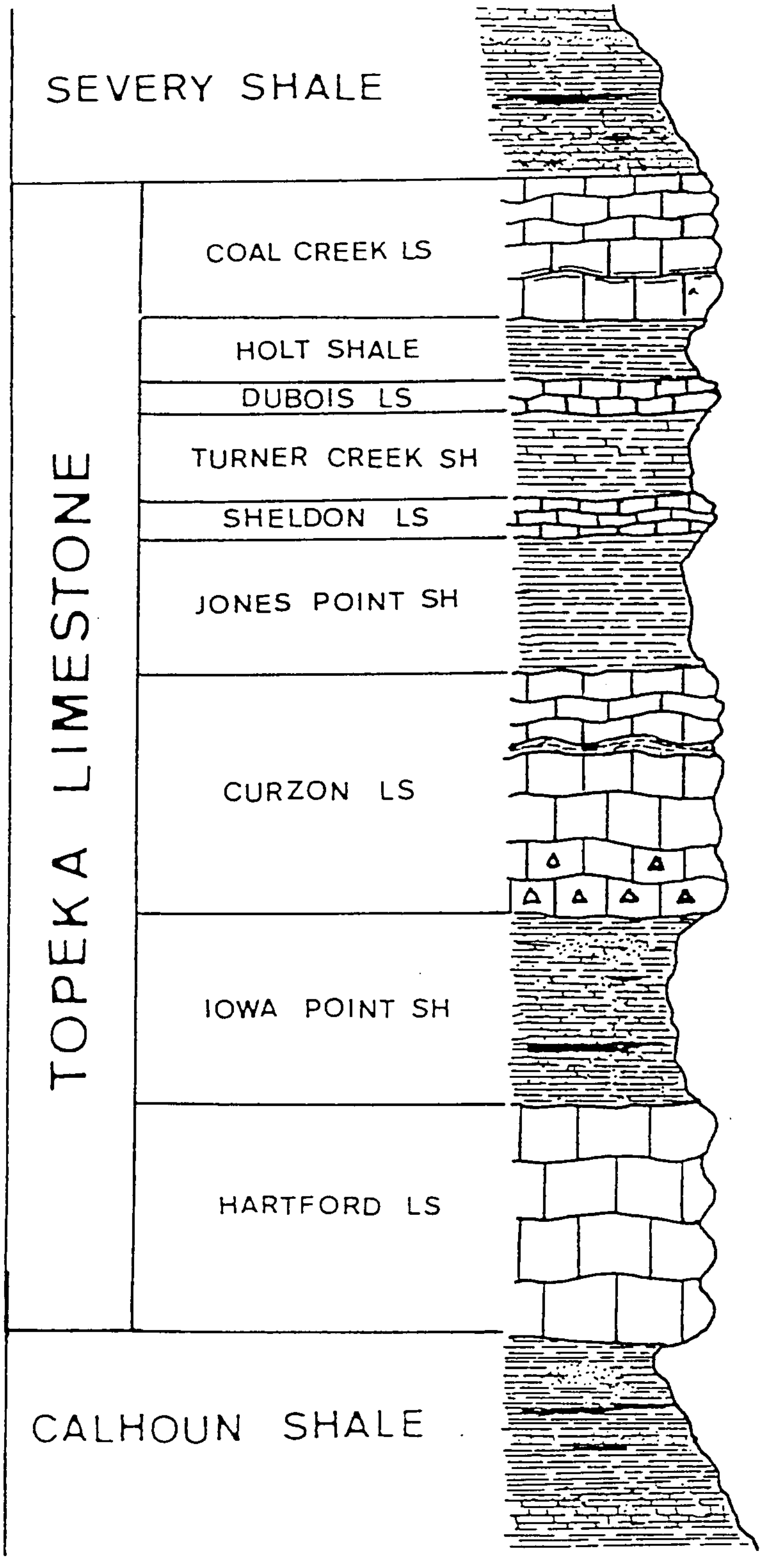


Figure 1. Topeka Limestone.

comprehend ecologic conditions during the time of deposition.

Study Area

The study was conducted along approximately 200 mi (322 km) of outcrop of the Curzon Limestone from Doniphan County to Chautauqua County, Kansas. The southern two-thirds of this area, shown in Figure 2 is part of the Osage Cuesta physiographic province of Kansas, and the northern one-third lies within the glaciated region (Schoewe, 1949). The Osage Cuesta topography is developed on a series of gently dipping shales and limestones which, by weathering, have created a gently rolling topography of shallow valleys alternating with moderate to steep slopes. The glaciated northern one-third presents rolling hills developed on dissected glacial outwash. The climate is moderate with approximately 30 in average annual precipitation and average annual temperatures of approximately 54°F (12.2°C). Surface elevation ranges from about 875 ft to 1300 ft (267 to 396 m) above sealevel.

Previous Work

There is no detailed study of the Curzon Limestone Member of the Topeka Formation. Pabian and Stremple (1974) studied crinoids in the Curzon and Ervine Creek Limestones. Silfer (1986) and Schultz (1985), respectively, studied the Hartford Limestone and Iowa Point Shale. Jeffords (1940)

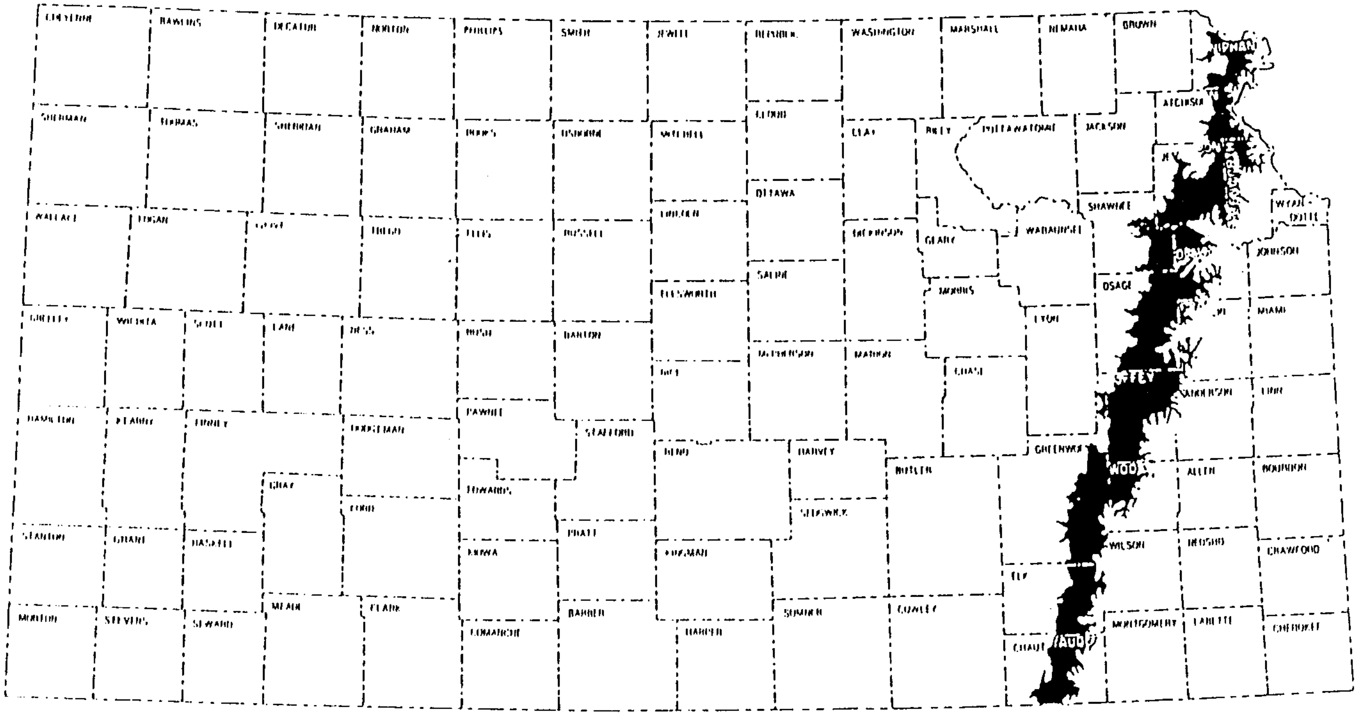
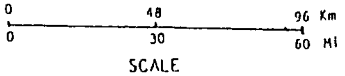


Figure 2. Outcrop area of Shawnee Group with Topeka Formation on western side (after Moore, 1949).



studied the stratigraphic relationship of the Topeka Limestone. Condra and Reed (1937) studied the Shawnee Group in the northern Midcontinent. Shannon (1954) studied strata correlated to the lower Topeka Formation immediately south of the study area in Osage County, Oklahoma.

Pennsylvanian deposits, such as the Topeka, have been studied for more than one-half century by many authors including Moore (1936, 1964), Heckel and others (1978), Merriam (1963), Wagner (1964), and Weller (1958). Chemical analyses of eastern Kansas limestones were made by Runnels and Schleicher (1956) and Cubitt and Merriam (1979).

Moore (1935) considered the Curzon Limestone to be a unit of the Hartford Limestone Member. He included what presently are identified as the three lower limestone members and two lower shale members of the Topeka Limestone as units within the Hartford Member. He noted that the beds in the Hartford "are characterized by their ferruginous content which produces the strong brown color of the weathered rock." A few years later, Moore and others (1944, p. 178) had revised the interpretation to the currently accepted definition of the Topeka Limestone, including the Curzon Limestone as a member separated from the Hartford Limestone Member by the Iowa Point Shale Member. Other contemporary studies questioned the Curzon's position as being stratigraphically part of the Hartford Limestone. Jeffords (1940, p. 12) reported that Condra and Reed reviewed the name Curzon in 1937, because they thought that that portion was not equivalent at all to the Hartford Limestone in its type area. Students engaged in a field study at The University of Kansas in 1940 described the Curzon as part of the Hartford. Jeffords, however, properly identified the Curzon, and so may have reflected or initiated R. C. Moore's thoughts which led Moore to his 1944 revised interpretation of the Topeka Limestone.

METHODS OF STUDY

Field Techniques

The field work undertaken for this study was accomplished during a two-year period from the spring of 1988 to the spring of 1990. Fifteen sections were measured and described (see Appendix I). Samples were taken at the upper, middle, and lower portions of the Curzon Limestone Member at each of the measured sections. Thin sections were prepared for petrographic study and 33 samples were analyzed for iron content using atomic-absorption. Three shale samples from an Osage County location were analyzed by x-ray diffraction. Results are reported in Appendix II.

Laboratory Methods

Fresh unweathered pieces were removed from samples using a nonferrous hammer and were reduced to a powder in a vibrating nonferrous roller mill at The Wichita State University. The milling chamber was cleaned with distilled water and acetone after each crushing operation. A sample size of approximately 0.2 gram was used. The sample was dried at 115°C. The sample then was fused with 1 gram of lithium metaborate. The fused button was dissolved and put into solution in 100 ml of 10% HCl (hydrochloric acid). This solution was used for the analysis of iron using flame atomic absorption.

The analyses were carried out using a Video ZZ model Thermo-Jarrell Ash Atomic Absorption Spectrophotometer. Standard atomic absorption techniques were used, and included the following: the wave length was 248.3 nm (nanometers) and a background correction was used. A standard curve was constructed using five standards in the range of 1.0 to 10 ppm. The concentration of iron in the samples was determined with the use of this standard curve. Three readings for each sample and standard were made using a three-second integration time. The three readings for each sample averaged to give a representative reading for each calibration point and sample.

For quality control, a National Bureau of Standards standard sample was analyzed along with the Curzon Limestone samples. Analysis of the standard sample compared favorably with the known value. For example, the known value of the standard is 4.79% Fe_2O_3. The control sample analyzed 4.75% Fe_2O_3. In addition, several spiked samples were tested to ensure that complete recovery of the iron was being made. These all checked within one percent, well within acceptable limits. Finally, replicate analyses were made on six of the samples. The replicate analyses all checked to within 0.1 percent or less.

GEOLOGIC BACKGROUND

Paleogeographic and Tectonic Setting

During the middle and late Pennsylvanian, Kansas was submerged beneath a shallow sea located 5°-10° north of the Equator (Heckel, 1977, p. 1056). This sea, which opened southwest to the ocean, was bounded by highlands in a manner analogous to present-day Hudson Bay, a modern epeiric sea (Eardley, 1951, p. 12). Heckel (1977, p. 1056) noted that the Pennsylvanian sea was bounded on the east by the Ozarks, on the west by active highlands, the ancestral Rocky Mountains, to the south by the Ouachita and Arbuckle Mountains, and on the north by a gently sloping craton shelf. These features are illustrated by Figure 3.

It seems likely that the Nemaha Ridge would influence Virgilian Stage deposition in eastern Kansas during middle and late Pennsylvanian time. After forming during the interval between the end of Mississippian and the start of middle Pennsylvanian deposition, it continued incremental movements through the remainder of Pennsylvanian time (Lee, 1954). The Nemaha Ridge subparallels the present outcrop of the Topeka Formation some 25 to 35 mi (40 to 56 km) to the west. As a positive feature, the Nemaha would have both furnished sediment and influenced sea currents, and perhaps provided a wave barrier during times of low-sealevel stand. The Bourbon Arch, an east-west trending feature, supposedly

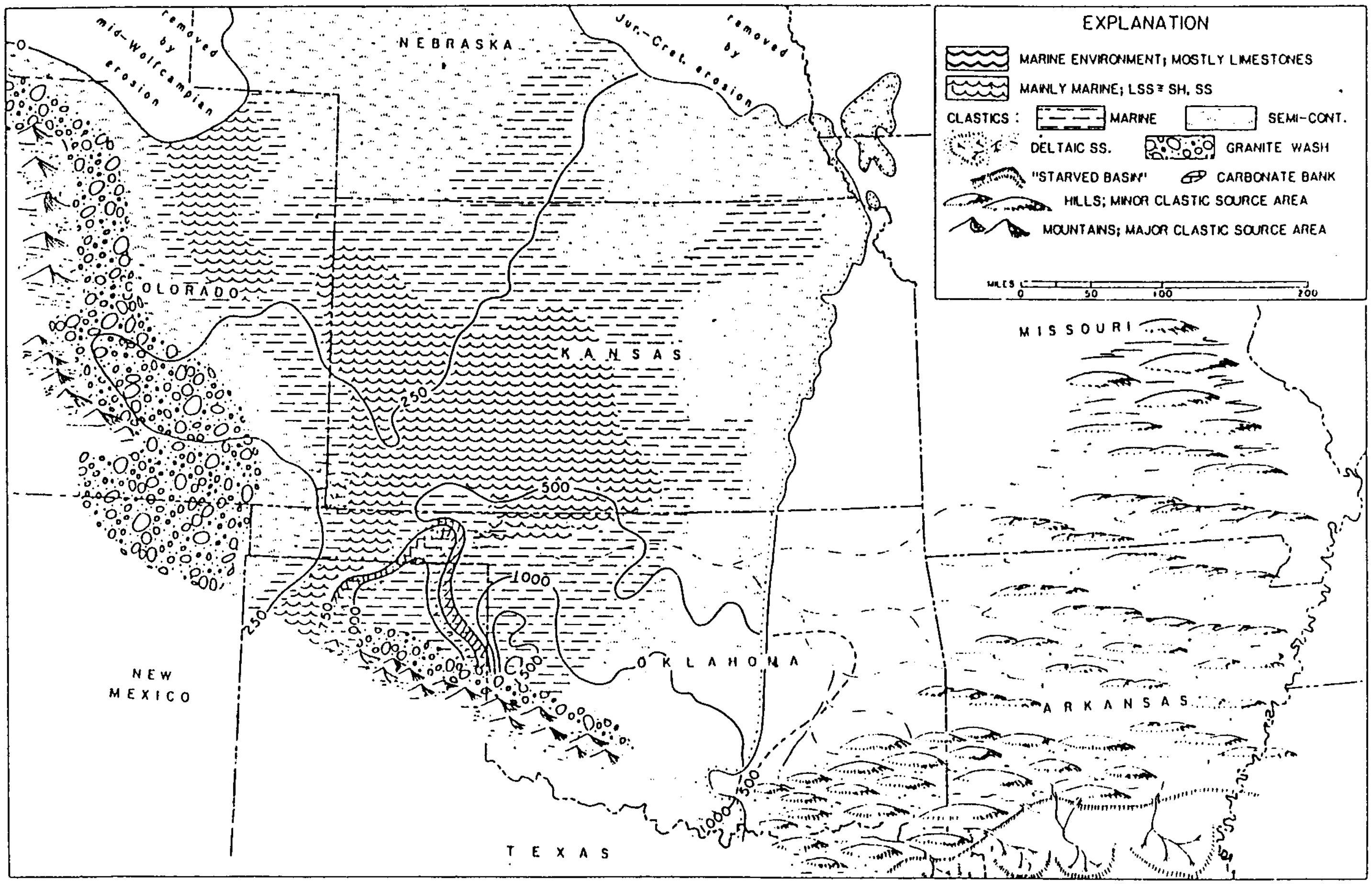


Figure 3. Late Virgilian paleography of Midcontinent (from Rascoe and Adler, 1983).

the same age as the Nemaha Ridge (Merriam, 1963, p. 179) also may have influenced sedimentation. The entire interior platform must have been close to sealevel during the Pennsylvanian so that slight tectonic or eustatic changes caused widespread immersion or exposure (Moore, 1949, p. 211). The Kansas Sea was perhaps an average 100 m in depth, and fluctuated in depth and area through the Pennsylvanian (Harbaugh, 1959, p. 325). Basing his evaluation on Recent fauna, Elias in 1937 presumed that late Paleozoic seas in Kansas were no more than 200 ft deep (Weller, 1956, p. 30).

The source of upper Pennsylvanian clastic sediments in northeastern Kansas was from the low-lying craton area. Limestones dominate the lithologic sequence. Sandstones and shales increase proportionately southward, supplied by sediments eroded from the Ouachita and Arbuckle Mountains in southern Oklahoma which were formed in late Pennsylvanian time (Eardley, 1951, p. 19). Orogeny in a low-latitude tropical area such as that postulated by Heckel would be subject to rapid erosion which may account for the increasing volume of clastic materials toward the southern end of the outcrop area. The Arbuckles and Ouachitas as a source is consistent with Harbaugh's (1959, p. 324) thoughts on the source of clay and silt in the upper Missourian Lansing Group in southeastern Kansas.

The increased volume of clastic materials is particularly apparent in Osage County, Oklahoma, where the Pawhuska Formation is exposed. The Pawhuska Formation, which is equivalent in part to the Topeka Formation, consists principally of limestone and sandstone (Jordan, 1957, p. 153). Shannon (1954, p. 44) reported that the Little Hominy Limestone in its type area (NW sec. 35, T. 25 N., R. 8 E., Osage County, Oklahoma), "contains such a large percentage of algal structures that is appears sandy." He noted that the Little Hominy was overlaid by 4 ft (1.2 m) of sandstone or, in several localities, by conglomerate. Shannon considered the Little Hominy Limestone to be equivalent stratigraphically to the Hartford Limestone Member.

Shannon observed that the unnamed sandstone, which is equivalent to the Iowa Point Shale in stratigraphic position, locally ranged in thickness from less than 5 ft to about 18 ft. About 8¼ mi (13.3 km) north-northeast of the Little Hominy Limestone type area, Shannon measured a section where 4 ft of Little Hominy (i.e., Hartford) Limestone is overlaid by 33.5 ft (10.2 m) of shale and sandstone which lies beneath 1.5 ft (46 cm) of Pearsonia Limestone, a stratigraphic equivalent of the Curzon Limestone. The Pearsonia is described in this locality (SW sec. 11 and CN2, sec. 15, T. 26 N., R. 8 E.) as dark gray, coarse-grained, dense, fossiliferous, topped by a thin layer of fusulinid limestone, weathering gray to orange-brown (Shannon, p. 83-84). He noted that the Pearsonia (i.e., Curzon) Limestone "disappears southward, the southernmost exposure being in sec. 28, T. 26 N., R. 8 E." Figure 4 is a correlation chart comparing Topeka equivalent strata in Oklahoma.

Cyclic sedimentation in the Pawhuska area is not as well defined as it is in equivalent strata to the north in Kansas (Shannon, p. 69). R. O. Fay (verbal comm., 1988) noted that massive conglomerate to the south "swallows up" the cyclic deposits.

General Description and Facies of Cyclothems

Moore (1930, p. 51-52) commented on the cyclical nature of the Pennsylvanian of the Midcontinent noting that studies of these strata "show that well marked rhythms or cycles of sedimentation characterize at least a considerable portion of the section." Weller and Wanless (1932, p. 1003) proposed the term "cyclothem" for the type of repeating or rhythmic strata in the Pennsylvanian System.

Moore (1935, p. 24) described an ideal cyclothem as containing nine units which he numbered from .0 to .9, base to top. Members .0 and .1 at the base and .9 at the top were nonmarine and the members in between were of marine origin. Heckel (1977, p. 1046), generalizing about eastern Kansas cyclothems wrote that there were five limestone and three shale members, with three of the limestone members usually absent. Two of the shale members are nonmarine, and are referred to as "outside" shales. They surround the limestone sequences and represent a period of maximum re-

<table>
<tr><th colspan="4">OKLAHOMA</th><th colspan="5">KANSAS</th></tr>
<tr><td rowspan="9">PENNSYLVANIAN</td><td rowspan="9">VIRGILIAN</td><td colspan="2">SEVERY SHALE</td><td colspan="2">SEVERY SHALE</td><td rowspan="9">VIRGILIAN STAGE</td><td rowspan="9">UPPER PENNSYLVANIAN SERIES</td><td rowspan="9">PENNSYLVANIAN SYSTEM</td></tr>
<tr><td rowspan="8">PAWHUSKA FORMATION</td><td>Turkey Run Limestone</td><td>Coal Creek Limestone Member</td><td rowspan="5">TOPEKA LIMESTONE</td></tr>
<tr><td>Unnamed Shale</td><td>Holt Shale Member
Jones Point Shale Member</td></tr>
<tr><td>Pearsonia Limestone</td><td>Curzon Limestone Member</td></tr>
<tr><td>Unnamed Shale</td><td>Iowa Point Shale Member</td></tr>
<tr><td>Little Hominy Limestone</td><td>Hartford Limestone Member</td></tr>
<tr><td>Unnamed Shale</td><td colspan="2">CALHOUN SHALE</td></tr>
<tr><td>Deer Creek Limestone</td><td>Ervine Creek Limestone Member</td><td rowspan="2">DEER CREEK LIMESTONE</td></tr>
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Figure 4. Correlation chart of upper Virgilian strata in Kansas and Oklahoma (from Schultz, 1985, p. 4).

gression of the sea. The third shale member is a gray-brown to black phosphatic marine shale which represents maximum marine transgression. It is referred to as the "core" shale by Heckel (1977, p. 1048).

The five limestone members which have been referred to are designated by their relative positions as "lower", "middle", "upper", "super", "fifth" by Heckel and Baesemann (1975, p. 486). Heckel (1977, p. 1046) noted that the lower, super, and fifth are absent in all except the most complete cyclothems. The basic sequence usually encountered is from bottom to top: outside shale, middle limestone, core shale, upper limestone, and outside shale. Heckel added that the other limestone units were present in less than one-half of the observed cyclothems and that their presence was regarded as fortuitous. His generalized cyclothem is illustrated by Figure 5.

The depositional environment of upper Pennsylvanian cyclothems in Kansas generally is regarded to be a shallow warm sea. McCrone (1964, p. 280) wrote that evidence in lower Permian strata of Kansas indicated less than 60 ft of water in basin areas. He noted that deposition in most Permian and Pennsylvanian cyclothems in the Midcontinent occurred over wide areas in water of uniform depth.

The outside shales of Virgilian cyclothems represent nearshore environments. Outside shales are sandy and micaceous and sometimes contain fossil plant fragments in local

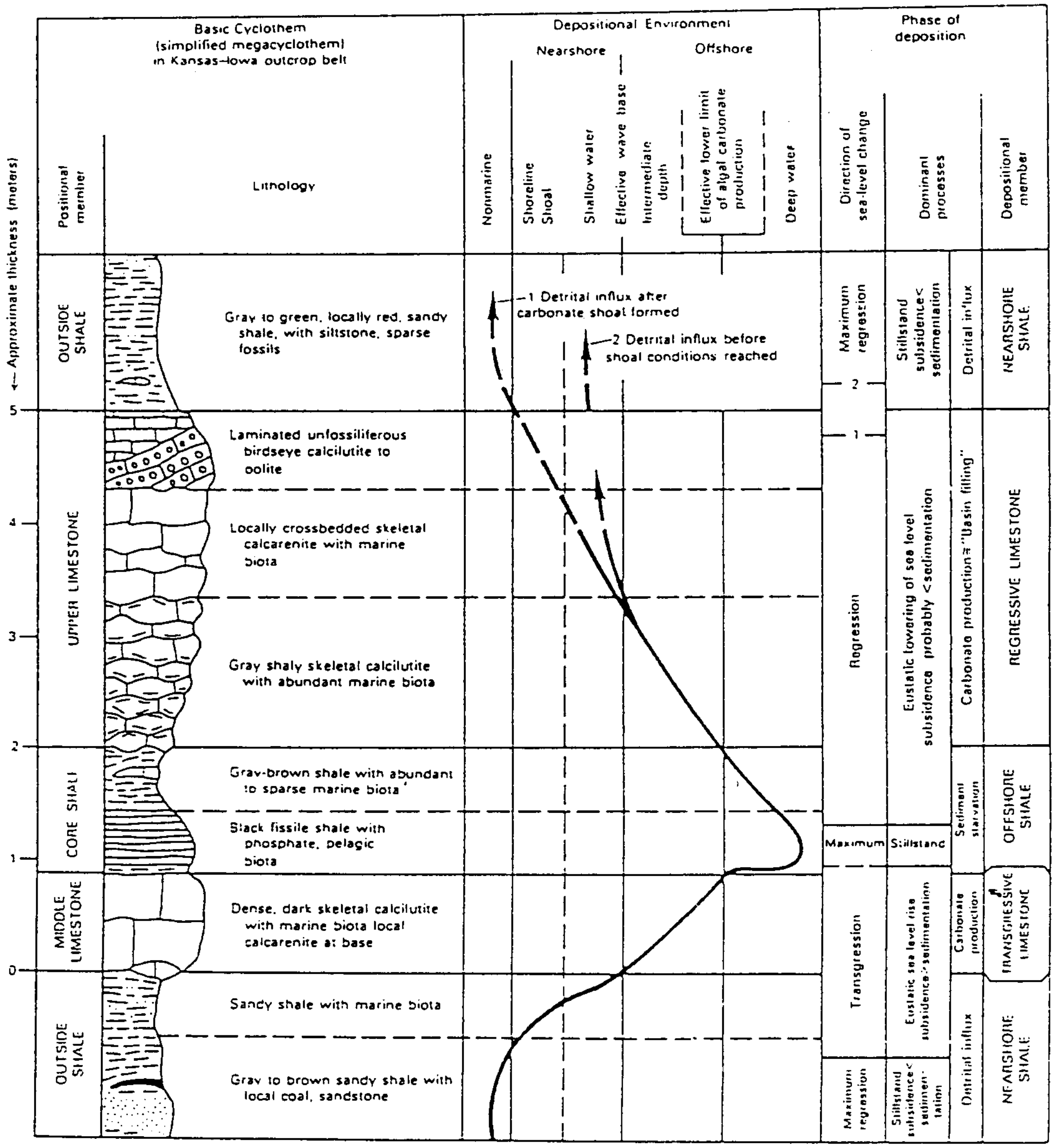

Figure 5. Basic Kansas cyclothem and sealevel curve (from Heckel, 1977).

thin sandstone or siltstone lenses. Heckel (1979, p. 15) reports that nearshore shales are generally thick, usually attaining 15 m and locally 40 m in thickness. Such shales locally contain nonmarine coal, underclay, channel deposits, and redbeds. Heckel (1979, p. 15) stated that the characteristics of outside shales were attributable to a delta supplied with abundant detritus, prograding into a shallow sea. The outside shales thicken southward in Kansas as they approach a closer source of major delta-building detritus from the Oklahoma mountains. In some of the nearshore shales, there is evidence of subaerial exposure.

According to Heckel, strata between the lower outside shale and the core shale which typically contain a middle limestone, represent progressively advancing seas followed by a regressive period which is represented by a middle limestone between the core shale and the upper outside shale. The lower limestone normally is absent in the Missourian but is present in the Virgilian. Heckel (1979, p. 15) reported that the middle limestones, which range from 0.3 to 1.5 m in thickness, are "dense, dark, skeletal calcilutites" which contain diverse and abundant marine fossils. The diversity and abundance indicate greater distance from shore and increasing depth of water below effective wave base but within the photic zone (Bandy and Arnal, 1960, p. 1921). In view of the shallowness of the sea as described, a wide biotope would be available, restricted only by the circulation of nutrients from shore area.

Heckel (1979, p. 17) reported that the transgressive limestones are fairly constant in thickness, except where thickened by local algal banks in southeastern Kansas, and undergo little facies change laterally for hundreds of miles along outcrop.

Core Shale

The core shales are typically thin, gray to dark-gray, marine shales ranging from 0.3 to 2.0 m in thickness, are high in trace-metal content and have a sparse to abundant fossil population. In the lower to middle part, core shales contain a black fissile shale and may contain phosphate nodules (Heckel, 1977, p. 1048).

Heckel (1979, p. 17) reported the lack of pelagic fossils in the black shale facies. He noted the presence only of fish remains, large quantities of conodonts, orbiculoid brachiopods, and other phosphatic fossils. Heckel (1977, p. 1065) attributed the black core shale to a combination of a thermocline and quasiestuarine circulation which together depleted oxygen and supplied necessary phosphate to create an anoxic condition favoring the widespread sedimentation typical of the cyclothemic core shales in the Virgilian of Kansas.

The core shale also contains a gray shale. This facies, which may have been caused by variations in sea floor topography, contains more abundant and diverse fossils than the black shale and indicates areas of less-than-total oxygen depletion.

Upper Limestone

After deposition of the core shale, the typical cyclothem was subjected to a regressive phase of the sea which formed the upper limestone members. The upper limestone members, according to Heckel (1979, p. 10), are generally thicker and contain a greater variety of lithofacies than the transgressive lower limestones. The variation of lithofacies may be caused by the advancing shoreline continuing to furnish clastic material into a carbonate producing environment, increasing the amount of shale or shaly units within the limestone. The limestone members would become thinner because much of their composition was the result of carbonate-secreting algae which, of necessity, would remain in shallow water and follow the retreating sea. Johnson (1961, p. 251) commented that algal limestones are generally indicative of "very shallow water" which leads to the observation of thicker algal-formed limestone banks in the southern portion of the outcrop zone. Merriam and Wolf (1983, p. 5) reported that these banks usually occur at the top of the limestone, replacing the overlying shale units so that the total thickness of the interval remains constant. They noted that they form in the upper or lower but rarely in the middle limestones.

Although the algae seen in the Topeka Formation algal bank have not been identified by the writer, there is some likelihood of them being of the Codiaceae or Dasycladaceae families. Anderson (1982) identified *Epimastopora*, a green alga, in the Howard Limestone algal bank and Merriam (1983) noted both *Epimastopora* and *Eugonophyllum* in the Oread Limestone algal bank. These are members of the Dasycladaceae and Codiaceae families respectively.

Johnson (1961, p. 34-35) discussed ecological distribution of these families, stating that modern representatives are marine and confined to tropical or warm waters. He wrote that modern Dasycladaceae occur at depths ranging from low tide level to 5 or 6 m. The Codiaceae are present in modern seas from slightly below tide to 90 m (Johnson, 1961, p. 35). Johnson reported that in lagoons, certain species were characterized by occurring at shallow depths, from below tide to 10 m.

It seems likely that the representatives of these algal families in the Virgilian would both be shallow-water varieties if they occur together. This could indicate a shallowing sequence during the regressive period when deltas from the southern mountains were extending farther seaward and forming shoals. James (1983) stated that there are two general cycles of reef growth, the first from Early Cambrian through Late Devonian and the second from the Mississippian to present. He noted that during the early phases of these cycles, reef mounds occur on or around shoal-rimmed platforms and that such areas are sites of rapid carbonate fixation.

In northeastern Kansas, the uppermost limestone of a megacyclothem represents a shallowing but an open-marine environment according to Ebanks and others (1979, p. O-15), who added that the water shallowed above effective wave base in places. Evidence of such shallowing includes abraded algal and invertebrate grains, _Osagia_-coated grains, local oolite formation, and local crossbedding.

In southernmost Kansas, south of the algal banks, the regressive limestones grade into shale and sandstone which represents offshore to deltaic environments dominated by terrigenous clastic materials from the mountain ranges farther south in Oklahoma. The deltas formed and, moving northward, deposited the outside shale to begin the next cycle. The typical north to south sequence is shown in Figure 6.

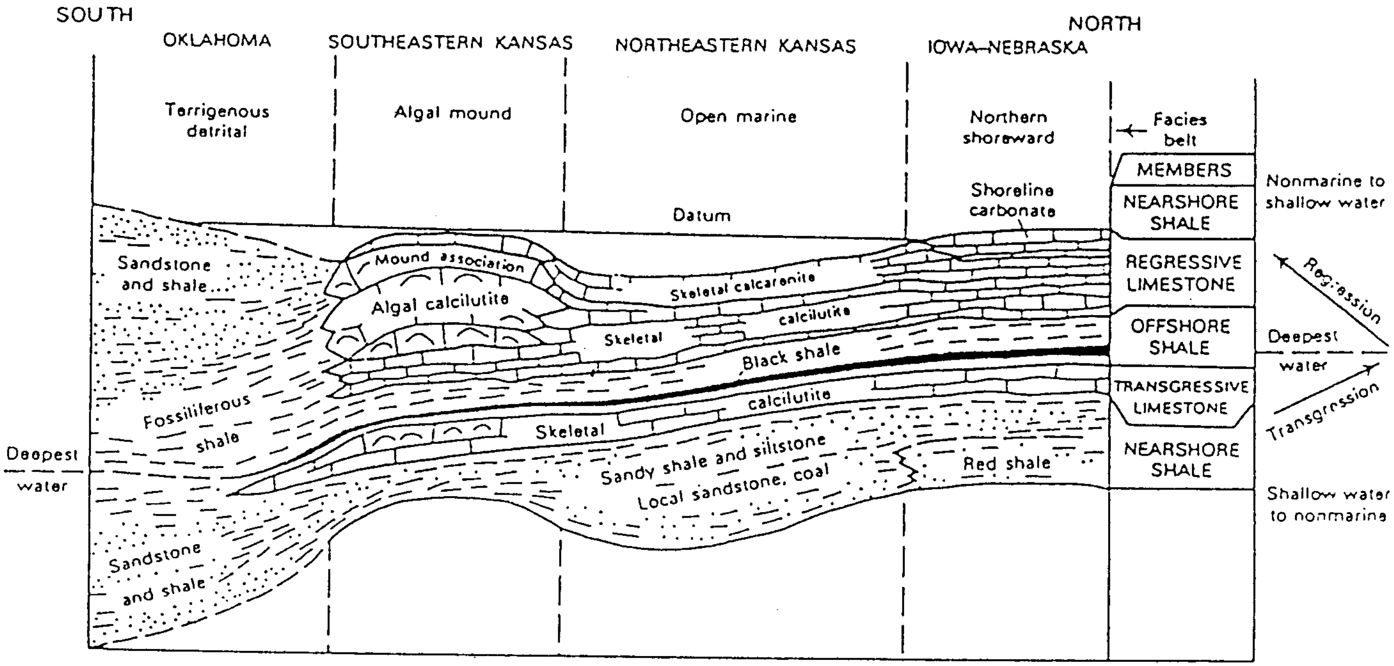

Figure 6. Typical north to south facies changes in Kansas cyclothems (from Heckel, 1977).

GENERAL DESCRIPTION OF THE TOPEKA LIMESTONE FORMATION AND ITS CYCLIC DEPOSITION

Calhoun Shale

The Topeka Limestone is separated from the older Deer Creek Limestone Formation by an outside shale, the Calhoun Shale. The Calhoun Shale consists of predominantly continental clastic materials ranging from clay to sand size and contains one or possibly more limestone beds. The limestone contained within the Calhoun is laterally extensive, ranging in thickness and principally is an osagite. Allen (1990, p. 56) identified this limestone, which he has named the "Tonovay Limestone", to an "at least partially transgressive ...." stratum within the otherwise regressive Calhoun Shale. He noted that the resumption of regressive conditions following deposition of the Tonovay was succeeded by a widespread transgression which resulted in deposition of a marine carbonate, the Hartford Limestone, the basal member of the Topeka Formation.

Hartford Limestone Member

The Hartford Limestone,named by M. Z. Kirk in 1896 (Wilmarth, 1938, p. 917), is the basal member of the Topeka Limestone. The type area is at the north edge of Hartford, Coffey County, Kansas (Moore, 1935, p. 195). The Hartford is described in Zeller (1968, p. 38) as a massive, light, bluish-gray limestone that weathers yellow brown and usually contains numerous fusulinids. Osagia is abundant in the upper portion, and the lower portion is characterized by the presence of the sponge, Amblysiphonella. The Hartford is underlaid by the Calhoun Shale, an outside shale which increases in thickness from approximately 7 ft (2.1 m) near the Nebraska-Kansas border in northeastern Kansas to its maximum of 50 ft (15.2 m) in Shawnee County, Kansas and then progressively thins southward to the point of absence near the Oklahoma-Kansas boundary. The Hartford Member, as with much of the lower Topeka Formation seemingly has been a problem to identify, and its stratigraphic equivalent has been termed the "Wolf River Limestone" and "Dashner Limestone" and seemingly has been confused with the Curzon. Nomenclature changes during this century are shown in Table 1. Silfer (1986) identifed four vertical facies within the Hartford Limestone (in ascending order), skeletal, algal, oncolitic and fusulinid facies. He interpreted these facies as representing a rise in sealevel, that is, marine transgression, from initiation of the basal skeletal limestone facies atop the Calhoun Shale to an offshore environment about one-third through the algal facies. From maximum transgression, at which the distal algal facies was near an offshore-deeper marine margin, a longer period of regression occurred, as represented by the upper portion of the algal facies, the oncolitic facies, and culminated with

Table 1. Nomenclature of Topeka Limestone.

1908	1927		1932		Aug. 1936		Sept. 1936		1937		1940		Present	
Severy Shale	Severy Shale		Severy Shale		Severy Shale		Severy Shale		Severy Shale		Severy Shale		Severy Shale	
Topeka Limestone	Topeka Limestone	Coal Crk Ls Mbr	Topeka Limestone	Coal Crk Ls Mbr	Topeka Limestone	Coal Crk Ls Mbr	Topeka Limestone	Coal Crk Ls Mbr	Topeka Limestone	Coal Crk Ls Mbr	Topeka Limestone	Coal Crk Ls Mbr	Topeka Limestone	Coal Crk Ls Mbr
		Holt Sh Mbr		Holt Sh Mbr		Holt Sh Mbr		Holt Sh Mbr		Holt Sh Mbr		Holt Sh Mbr		Holt Sh Mbr
		Dubois Ls Mbr		Dubois Ls Mbr		Dubois Ls Mbr		Dubois Ls Mbr		Dubois Ls Mbr		Dubois Ls Mbr		Dubois Ls Mbr
		Turner Crk Sh Mbr		Turner Crk Sh Mbr		Turner Crk Sh Mbr		Turner Crk Sh Mbr		Turner Crk Sh Mbr		Turner Crk Sh Mbr		Turner Crk Sh Mbr
		Curzen Ls Mbr		Curzon Ls Mbr		Hartford Ls Mbr		Hartford Ls Mbr		Sheldon Ls Mbr		Sheldon Ls Mbr		Sheldon Ls Mbr
Calhoun Shale	Calhoun Shale	Iowa Pt Sh Mbr	Calhoun Shale	Iowa Pt Sh Mbr	Calhoun Shale	Iowa Pt Sh Mbr		Jones Pt Sh Mbr		Jones Pt Sh Mbr		Jones Pt Sh Mbr		Jones Pt Sh Mbr
		Meadow Ls Mbr		Sheldon Ls Mbr		Sheldon Ls Mbr		Dashner Ls Mbr		Curzen Ls Mbr		Curzen Ls Mbr		Curzon Ls Mbr
		Jones Pt Sh Mbr		Jones Pt Sh Mbr		Jones Pt Sh Mbr	Calhoun Shale	Iowa Pt Sh Mbr		Iowa Pt Sh Mbr		Iowa Pt Sh Mbr		Iowa Pt Sh Mbr
								Sheldon Ls Mbr		Wolf R. Ls Mbr		Wolf R. Ls Mbr		Hartford Ls Mbr
								Shale Mbr	Calhoun Shale		Calhoun Shale		Calhoun Shale	
Haworth (1908)	Condra (1927)		Moore & Condra (1932)		Moore (1936a)		Moore (1936b)		Condra & Reed (1937)		Jeffords (1940)		Zeller (1968)	

the fusulinid facies in a nearshore environment at the surface of the Hartford.

Silfer (1986, p. 54) suggested that phylloid algae, most likely the green codiacean alga Eugonophyllum dominated the fossil assemblage within the algal facies. Johnson (1961) discussed ecological distribution of Codiaceae stating that modern representatives of this family are confined to tropical or warm seas, and occur from slightly below the water surface to 295 ft (90 m) below low tide level. That depth corresponds to the 300 ft (91 m) level identified as the base of the photic zone by Lowman (1949, p. 1959) who noted that in lagoonal environments, however, certain species were characterized by occurring at shallow depths, from below tide level to 33 ft (10 m). Considering the tropical location postulated for the Midcontinent during the Virgilian, it seems likely that representatives of the Codiaceae in the Virgilian would inhabit a similar environment with the representative Eugonophyllum occurring within an equivalent range of depth. Such occurrence would explain the vertical distribution of the Hartford Limestone algal facies during both a marine transgression and regression.

Iowa Point Shale Member

The marine regression as recorded in lithology of the upper Hartford Limestone culminated with renewed deposition of an outside shale, the Iowa Point Shale Member.

The Iowa Point Shale Member is a yellow-gray to bluish-gray clayey to calcareous shale that locally contains sandstone and a thin coal bed (Zeller, 1968, p. 38). It was named by Condra in 1927 for the type area on the Missouri River bluffs southeast of Iowa Point, Doniphan County, Kansas (Jeffords, 1940, p. 13). Jeffords stated that the Iowa Point typically contains a basal, thin, soft, micaceous sand which contains plant fossils. A gray, blocky, marine, fossil-bearing shale lies at the top of the unit. The thickness ranges from a few inches to several feet (Moore, 1935, p. 196) and thins southward to only 2 ft near Topeka "disappearing" south of there (Zeller, 1968, p. 38). However, Schultz (1985) traced the Iowa Point Shale Member southward to the Oklahoma border where it correlates with an unnamed shale in the Pawhuska Formation. Schultz (1985) noted the presence of a varved lacustrine sequence in the Iowa Point Shale in Doniphan County, Kansas. His conclusion was that the Iowa Point was deposited in a nearshore coastal environment with a deltaic complex in the northern part of the State.

Curzon Limestone Member

The Curzon Limestone Member overlies the Iowa Point Shale and represents reinitiation of the marine transgressive sequence displayed in the older Hartford Limestone. The Curzon Limestone Member was named by J. A. Gallaher of the Missouri Bureau of Mines and Geology in 1898 and takes its name from the type locality east of Curzon Station in Holt County, Missouri (Jeffords, 1940, p. 12).

The Curzon Limestone generally consists of a lower bed ranging in thickness from about 4 ft (1.2 m) which is separated from a wavy-bedded upper portion by a thin, silty, micaceous mudstone. The lower portion contains crinoid columnals and occasional plates, articulate brachiopods, ramose and fenestrate bryozoans, fusulinids, and echinoid parts; typical of a moderate depth community associated with a transgressive limestone (Boardman and others, 1984, p. 156-157).

The upper portion of the Curzon Limestone is usually slabby or wavy bedded. At locations from T. 17 S., R. 15 E. to T. 28 S., R. 12 E., evidence of subtidal to subaerial exposure was noted. This evidence includes desiccation cracks, a probable hardground, trails, tracks, and burrows.

Typically, the Curzon Limestone displays many of the characteristics of a transgressive limestone in its lower portion. Apparently, the micaceous, silty claystone which separates the upper from the lower parts in many locations represents the onset of a renewed regressive phase which is represented by the wavy-bedded upper limestone unit with its frequent occurrences of subaerial exposure. Subaerial exposure may account for the concentration of iron oxide which stains the Curzon Limestone; filling fossil interiors and joints. A possible source for this iron oxide will be discussed later. Moore (1935, p. 195-196) considered the Curzon to be a portion of the Hartford Limestone along with the Jones Point Shale and Sheldon Limestone, because he indicated the next lower member of the Topeka Limestone beneath the Turner Creek Shale member and above the Calhoun Shale was the Hartford (which, for a brief time, he termed the "Dashner"). Moore's 1935 description varies from that in Zeller in that Moore wrote that if two or more limestone beds of the Hartford were present, they were separated by a shale bed which varied from "a few inches to several feet in thickness." In Zeller (1968) no mention is made of a shale bed in the Hartford but it is noted that the Iowa Point Shale Member which separates the Hartford and Curzon disappears south of Topeka and from that point southward, the lower Curzon rests on the topmost part of the Hartford Limestone. However, the Curzon Limestone is separated by an "outside" shale from the Hartford along most of the outcrop in Kansas. Fusulinids are sparse to abundant in the lower and middle portions of the Curzon with brachiopods, bryozoans, and echinoid parts plentiful in the upper portion (Zeller, 1968, p. 38). Jeffords (1940, p. 12) noted that fauna were abundant but restricted in numbers of species.

Jones Point Shale Member

The Jones Point Shale, which has its type locality at

Jones Point four miles east of Union, Cass County, Nebraska is a clayey, calcareous, silty, gray shale, containing local platy or nodular limestone layers (Zeller, p. 39). It is not readily distinguishable as a separate member farther south than the southern Osage-northern Coffey County area. The thickness in northern Kansas ranges from a foot to 10 ft (30.5 cm to 3 m). Moore and others (1951, p. 64) noted beds 10 to 15 ft (3.0 to 4.5 m) thick in Elk and Chautauqua Counties are correlatable with Jones Point Shale and included them with other upper Topeka members in the southern outcrop area as "undifferentiated upper Topeka" (D. F. Merriam, pers. comm.). There are numerous brachiopods and mollusks at some outcrops but a sparcity of fossils at many exposures (Zeller, p. 39). Jeffords (p. 11) noted that in the northern or identifiable portion of the outcrop area, the Jones Point consisted of a green-gray clayey shale with calcareous or thin limestone zones near the middle. He observed that the lower portion contained abundant fusulinids and echinoid spines, and that the limestone, where present, contained abundant *Osagia*. Jeffords (p. 11) identified fossils in the lower Jones Point Shale Member:

- Brachiopods
  - *Composita*
  - *Dielasma*
  - *Neospirifer*
  - *Echinoconchus*
  - *Chonetes*
  - *Derbyia*
  - *Juresania*
  - *Marginifera*
- Bryozoa
  - *Polypora*
  - *Rhombopora*
- Others
  - *Osagia*
  - echinoid spines
  - crinoid stems

Moore (1964, p. 308) described a variety of faunal assemblages associated with different marine environments. Of the brachiopod and bryozoan genera identified by Jeffords, six are included in Moore's Speiser-type (Derbyia) assemblage. Additionally, Jefford's Echinoconchus (now Echinaria) and Marginifera both belong to suborders, other members of which are in the Speiser faunal assemblage. Moore also included echinoid spines, crinoid stems and Osagia, noting that Osagia was not common. Moore noted that "Examples of the Speiser-type assemblage invariably belong to initial marine phases of cyclothems, being found above nonmarine deposits..." The Speiser-type environment was interpreted by Hattin (1957) to belong to an offshore environment of nearly normal salinity and mild wave-generated turbulence. Features of the Jones Point Shale meet that description sufficiently to attribute deposition in a similar environment. The description seems to indicate the onset of a transgressive marine period which continued to the deposition of the overlying member, the Sheldon Limestone.

Sheldon Limestone Member

The Sheldon Limestone, named by Condra in 1930, takes its name from the Vilas Sheldon Quarry east of Nehawka, Cass County, Nebraska (Jeffords, 1940, p. 10). The Sheldon is described in Zeller (1968, p. 39) as "a massive, light-gray to nearly white, very fine grained dense limestone that weathers light yellowish-gray." It is characterized by abundant Osagia and according to Jeffords, also contains mollusks. The Sheldon ranges in thickness from 0.7 to 2.0 ft (14.8 to 60.9 cm). Although the Sheldon begins to pinch out in southern Lyon-northern Greenwood County, Moore and others (1951, p. 64) noted the presence of an algal limestone correlative with the Sheldon horizon in southern Kansas. The Sheldon has been identified as a "number two" or middle limestone by D. F. Merriam (pers. comm., 1990). It deviates from the ordinary descriptions of a middle limestone as it is white to light-gray whereas the usual description of a middle limestone is "dense, dark, skeletal calcilutite with marine biota" (Heckel, 1977, p. 1047). The fine grain size of the Sheldon is that of a calcilutite but the color is lighter, perhaps because of decreased organic content or a lesser quantity of iron oxides, both indicative of a distal, oxygenated, shallow-marine depositional environment.

Both, finer grain size and white to light-gray color may have been caused by deposition farther offshore on a slowly subsiding shelf. The present of Osagia indicates shallow water, within the photic zone and the existence of fossil mollusks strengthens that supposition. The small grain size would be expected at greater distance from a limy shore which would supply mud-sized particles of calcium carbonate winnowed seaward by ebbing tides.

The light shade of the Sheldon Member poses a question in identifying it as a transgressive limestone which is indicated by its stratigraphic position, dense character and relative thinness ranging from 0.5 ft (15 cm) to 2 ft (61 cm). Heckel (1983, p. 751) noted that they "have been noted as dense on outcrop" and that "most are relatively thin." In some instances however, middle limestones can be relatively thick (Watney and French, 1988, p. 11). The question raised by the light shade of color of the Sheldon Limestone merits additional study.

Turner Creek Shale Member

The Turner Creek Shale Member, named by Condra in 1927, has the type locality located on Turner Creek southeast of DuBois, Pawnee County, Nebraska (Moore, 1935, p. 137). Moore (1935, p. 197) noted that the Turner Creek is distinguished by its stratigraphic location below the DuBois Limestone more than by its character. He described it as bluish-gray, calcareous, and mostly unfossiliferous shale. Jeffords (1940, p. 9) stated that the upper portion contains thin, nodular limestone layers in some sections. He noted that those in some areas contained <u>Myalina</u>, <u>Aviculopectin</u>, and <u>Juresania</u> with <u>Rhombopora</u> and <u>Batostomella</u> bryozoans obtained from shale near the top in the same locality. Moore (1964, p. 308) identified all these forms as belonging to a Speiser-type faunal assemblage typical of the initial marine phase of a cyclothem. The Turner Creek Shale Member overlies the Sheldon Limestone and possibly represents a temporary lull in the transgression occurring during deposition of the Sheldon.

The Turner Creek is described in Zeller (1968, p. 39) as a "bluish-gray or greenish-gray clayey and calcareous shale that contains few fossils." Schultz (1985, p. 45) noted that it is silty locally, contains yellow-white calcareous concretions, and thins and coarsens southward toward the Kansas Oklahoma border. During the time of deposition of the Turner Creek Shale, it is possible that ongoing eustatic sealevel rise that was occurring during Late Virgilian time was regionally balanced by almost equivalent tectonic movement; either shelf subsidence, rising of the land surface or both.

DuBois Limestone Member

The DuBois Limestone Member which overlies the Turner Creek Shale also was named by Condra in 1927 and has the same type locality as the Turner Creek Shale (Moore, 1935, p. 137). The DuBois is a thin (0.5 to 2.0 ft - 15.2 to 60.9 cm) dark-blue or greenish-blue limestone comprised of one or two beds which display prominent vertical jointing. Jewett, O'Conner, and Zeller (1968, p. 39) reported that the DuBois contained numerous brachiopods and mollusks.

Jeffords (1940, p. 8) noted that pelecypods and gastropods predominate, fusulinids are rare and that Osagia is abundant. Moore and others (1951, p. 64) described it as "one or more dark-blue or greenish-blue fine-grained, somewhat earthy limestone beds with prominent vertical jointing" usually ranging from about 0.5 to 2.0 ft (15 to 61 cm) in thickness. It is not recognized south of Topeka but two thin limestone beds totalling about 1 ft (30 cm) in thickness occur in an equivalent stratigraphic position in northwestern Chautauqua County (Schultz, 1985, p. 45). Jeffords (1940, p. 8) noted that the predominant fauna in the DuBois are gastropods and pelecypods, and that brachiopods and bryozoans infrequently occur. He noted that Osagia is common and that fusulinids are very rare. The fossils identified by Jeffords are typical of the Leavenworth-type faunal assemblage described by Moore (1964, p. 332) as occurring in "dense, brittle, rather dark-bluish" limestones rarely exceeding 2 ft (61 cm) in thickness. These characteristics correspond to those of a middle limestone as described by Heckel (1983) in the discussion of the Sheldon Limestone Member on page 32. The DuBois Limestone therefore is a repeated middle limestone, and indicates resumption of a transgressive marine sequence.

The Holt Shale Member

The Holt Shale Member of the Topeka Limestone was named by Condra in 1927 for an area south of Forest City and west of Oregon, Holt County, Missouri (Moore, 1935, p. 198).

Moore and others (1951, p. 64) describe the Holt Shale Member as a bluish-gray shale in the upper part and a black shale with "distinctive black slaty beds" in the lower part. The black beds are not recognized with certainty south of Topeka (Moore, 1935, p. 193). However, the writer has observed a thin, dark-gray to black, fissile shale situated in the appropriate stratigraphic position at the Bower Quarry (SW sec. 30, T. 17 S., R. 15 E.) Osage County, Kansas, and D. F. Merriam (pers. comm., 1991) has been told of a thin, black shale within undifferentiated upper Topeka strata in Chautauqua County, Kansas. Ranging from 1 to 3 ft (30 to 91 cm) in thickness, the Holt Shale contains corneous brachiopods and conodonts (Moore and others, 1951) and in the lower black portion, phosphatic nodules (Schultz, 1985). These criteria identify the Holt Member as a core shale following the descriptions of Heckel, Merriam, Watney, and numerous others.

In an attempt to determine the geographic extent of the Holt Shale, subsurface sample cuttings were examined from wells located in Phillips County, Kansas (sec. 22, T. 1 S., R. 18 W.) and in southern Stafford County, Kansas (sec. 12, T. 25 S., R. 13 W.). No black shale was identified in the interval of the Topeka Formation samples examined from the Phillips County well. However, numerous pieces of fissile, black shale, two showing vitrain-appearing smears on bedding plane surfaces, were noted in the upper Topeka portion of the Stafford County well. Subsurface samples from a well in Harper County, Kansas (sec. 26, T. 31 S., R. 7 W.) contained fragments of a hard, black fissile shale in a horizon about 15 to 20 ft (4.5 m to 6.1 m) below the top of the Topeka Formation. One fragment of the shale from the Harper County well contained a small, lustrous, black, orbiculoid brachiopod and a probable conodont fragment.

The observed characteristics of the Holt Shale fit Heckel's (1977) description of the core shale member of a cyclothem: a thin, laterally persistent, black, fissile shale.

Coal Creek Limestone Member

The Coal Creek Limestone Member is the uppermost member of the Topeka Limestone Formation. It was named by Condra in 1927, the name derived from the type locality, on Coal Creek, about ½ mi north of Union, Nebraska (Moore, 1935, p. 199). It is a light bluish-gray with a tendency to form thin wavy beds which are caused by shale partings. In the absence of shale partings, the beds are more even and thicker than normal upper limestones (Moore, 1935, p. 199). The Coal Creek contains abundant fusulinids and a large variety of brachiopods and bryozoans. Jeffords (1940) noted that in northern Kansas, the Coal Creek Limestone Member surpassed the other members of the Topeka Formation in both numbers of species and individual fossils. Jeffords listed 19 genera and 23 species of fossils occurring in the Coal Creek, of which 83 percent are included in the paleobiotope described by Moore (1964, p. 316) as the Beil-type (Pulchratia) assemblage which existed in clear waters, on the average less than 20 m (66 ft) deep at a distance of 50 to 100 mi from the nearest shore. Moore (1964, p. 316) interpreted such an environment as representative of the culminating marine portion of a cyclothem. This seems to be just the situation. The Coal Creek usually is not present south of the Kansas River, but is identified locally in southeastern Kansas as the Turkey Run (Oklahoma term). In some areas, the Coal Creek occurs as limestone lenses in shale. The Coal Creek was observed in the C sec. 15, T. 11 S., R. 11 E., Shawnee County, Kansas, where it is a 12 to 18 in (30.5 to 45.7 cm) thick, osagite containing brachiopods, fusulinids, and gastropods. In Elk County at SE SW sec. 5, T. 30 S., R. 11 E., an exposure of Coal Creek (Turkey Run) Limestone is 8 to 10 ft (2.4 to 3.0 m) thick. The lower portion is massive, with beds 10 to 14 in (25.4 to 35.6 cm) thick and contains large thick-walled fossils. The upper 4 ft is wavy bedded with beds approximately 6 in (15.2 cm) thick, contains many fossils with fusulinids being most prolific, and has an osagite at the top. These three features are regularly associated with regressive upper Paleozoic carbonates in the Midcontinent. Zeller (1968, p. 39) reported that the thickness of the Coal Creek ranges from 2 to 8.5 ft (0.6 to 2.6 m). Shannon (1954, p. 83-84), however, described the Turkey Run Limestone in Osage County, Oklahoma as a 2 ft (61 cm) thick limestone immediately underlying the Severy Shale, and as about 65 ft (19.8 m) above the Little Hominy Limetone which is equivalent to the Hartford Member. The Turkey Run is considered correlative with the Coal Creek.

Severy Shale Member

Overlying the Coal Creek Member is the Severy Shale, a distinctive outside or nonmarine shale which represents the end of the series of marine transgressions and regressions which formed the outcropping portion of the Topeka Formation.

DESCRIPTION AND INTERPRETATION OF THE CURZON LIMESTONE MEMBER

Description

Outcrops of the Curzon Limestone Member were examined and measured at 16 locations along strike. Thin sections were prepared and studied from 27 samples and chemical analyses were performed on 36 specimens.

The Curzon Limestone generally consists principally of one of three components: micrite, biomicrite or pelmicrite which usually occur in two to four layers separated by micaceous, silty shale or mudstone. Total thickness, measured at 16 outcrops, averages 54.7 in (138.9 cm), ranging from 12 in (30.5 cm) to 120 in (304.8 cm). The thickest portions are in the area between R. 7 and 20 S. with thinning to the north and south. The Curzon Limestone is brown to yellow on fresh surfaces weathering to a brownish-gray on the outcrop.

At most sites, the Curzon Limestone is micritic and contains mostly an assortment of fossil brachiopods, echinoderm parts, mollusks, and fusulinids. Microscopic examination reveals a "fossil-hash" of whole or fragmented fusulinids, other foraminifera genera, ostracodes, algal particles principally Osagia, fragmented echinoid and brachiopod spines, occasional trilobite fragments, crinoid stems, fecal pellets, and unidentifiable particles of organic origin. E. Yochelson, cited in Johnson and Adkison (1967, p. 37) reported the following fossils in the Curzon Limestone:

- *Osagia* sp. indet.
- fusulinids, indet.
- crinoid plate and stem fragments
- echinoid spines
- rhomboporoid bryozoans
- ramose bryozoans
- fenestrate bryozoans (several genera)
- *Derbyia* sp indet.
- *Chonetes granulifer*
- *Neospirifer dunbari*
- *Composita subtilita*
- *Composita* sp. indet.
- *Linoproductus* sp. indet.
- high-spired gastropod, indet.

Johnson and Adkison (p. 37) also note the presence of ostracodes. Added to these, Jeffords (p. 12) reported the presence of the brachiopod *Echinoconchus moorei* (now renamed *Echinaria moorei*).

Iron-Oxide Content

The Curzon Limestone usually is distinguishable by its reddish-brown iron-staining on outcrop. Quantitative analyses for iron oxide (Fe_2O_3) were made on 33 samples taken from 12 locations along the outcrop.

Analyses were performed in the laboratory of the Kansas Geological Survey at Lawrence, Kansas, by Karmie Galle, staff geochemist. Sample results are presented in Table 2 and are displayed in graphic form in Figure 7.

Cursory examination of the trend plot in Figure 7 reveals a rough southward decline in Fe_2O_3 content on the linear trend plotted on the means of upper, middle, and lower Curzon Limestone samples taken along the outcrop. Closer examination however, reveals that the two northern-

Table 2. Curzon Limestone Fe_2O_3 Analyses

Stratigraphic position within outcrop

	Site	County	Sec-Twp-Rge	Top	Upper	Middle	Lower	Base	Mean
1.	K-7 west of Iowa Point	Doniphan	36-1S-19E	4.85	0.86	2.50	-	5.24	3.36
2.	Denton Section	Doniphan	11-4S-19E	8.68	-	-	-	6.99	7.84
3.	K-92 Ozawkie Section	Jefferson	27-9S-18E	1.92	-	-	-	2.24	2.08
4.	I-70 East Topeka rest stop	Shawnee	2-11S-16E	3.07	-	1.46	4.26	-	2.93
5.	Bowers Quarry	Osage	30-17S-15E	2.65	4.43	2.23	1.57	-	2.72
6.	Haworth Quarry	Coffee	2-21S-13E	2.35	-	-	1.73	-	2.04
7.	Hilltop Section	Greenwood	13-23S-12E	0.75	0.87	0.91	1.80	1.11	1.09
8.	U.S. 54 East of Tonovay	Greenwood	32-25S-12E	1.47	-	5.68	-	1.99	3.05
9.	Severy Quarry	Greenwood	10-28S-11E	-	3.24	1.61	0.84	-	1.90
10.	Moline Quarry	Elk	12-31S-10E	-	1.02	-	2.89	-	1.96
11.	Fudge Quarry	Chautauqua	5-33S-10E	-	1.95	-	0.83	-	1.39
12.	U.S. 166	Chautauqua	10-34S-10E	-	-	2.19	-	-	2.19

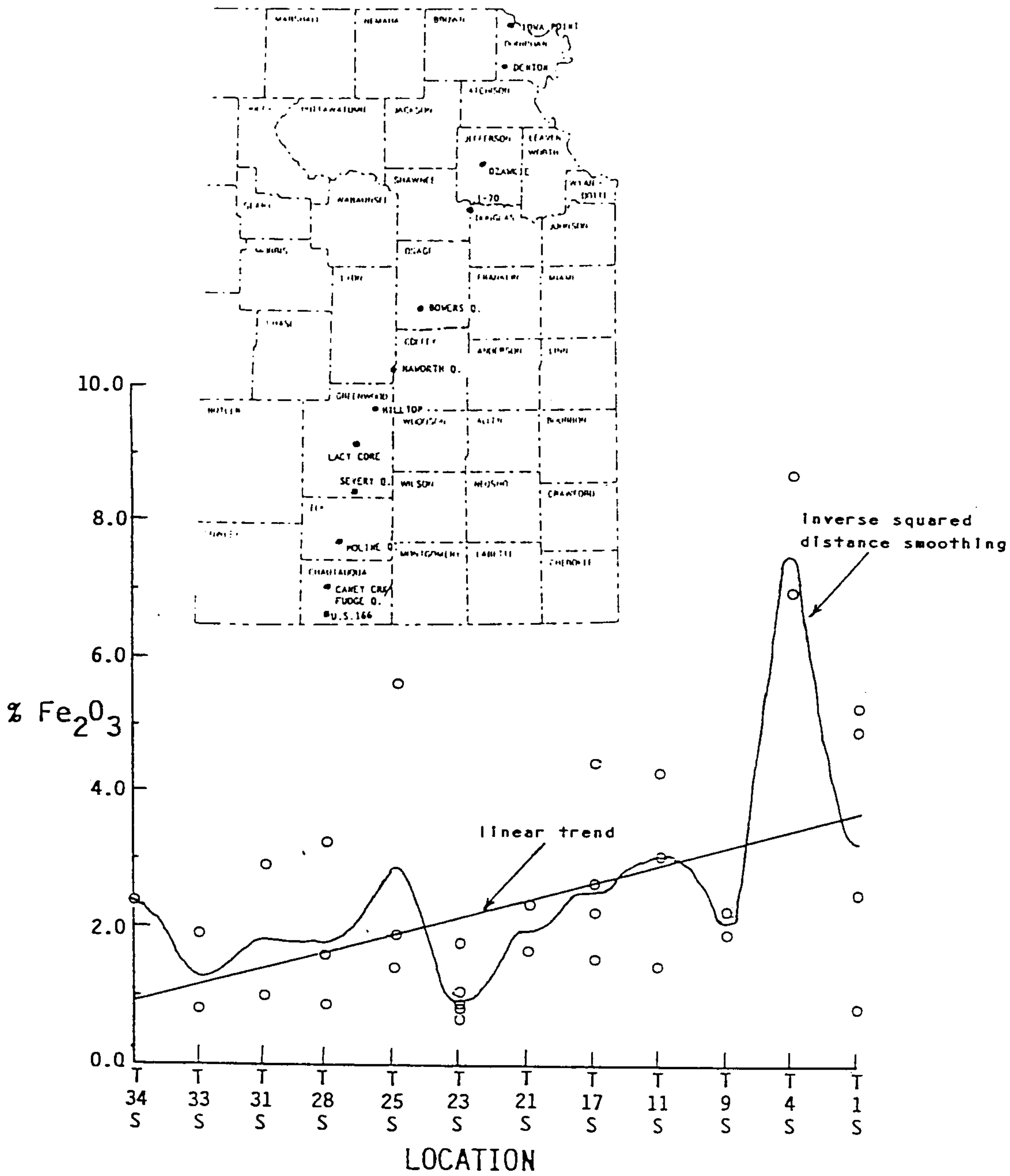

Figure 7. North-south trends of Fe_2O_3 concentration in Curzon Limestone.

most localities, which are the highest in Fe_2O_3 skew the right side of the line upward, and thus account for most of the trend. Point plots of Fe_2O_3 at each site show somewhat of a lowering concentration southward, but the inverse squared line shows that in reality, the trend is more or less even when the northern sites are excluded. The conclusion is that there are insufficient data, (from only 12 sites), to determine if a statistically significant trend indeed exists. Visually, a "geologic" trend seems to be indicated, but as noted, the skewness induced by high concentrations of Fe_2O_3 in the two northern sites may be misleading.

Bowers Quarry Shale Samples

Additional x-ray diffraction qualitative analyses were performed on three shale/mudstone samples collected from the Curzon Limestone Member at the Bowers Quarry, located in the SW sec. 30, T. 17 S., R. 15 E., Osage County. The diffraction patterns obtained for these samples are marked and are included as Appendix II. Sample SK-A represents a 2 to 3 ft (61 to 91.4 cm) thick shaly layer between a thick, massive, cherty limestone and a thin, slabby, laminated limestone, respectively the lower and upper units of the Curzon. Sample SK-B is from an 18 to 20 in (45.7 to 50.8 cm) thick calcareous shale which overlies the laminated limestone and visually resembles the shale immediately below the laminated limestone. The SK-B layer is overlaid by an 18 in (45.7 cm) thick algal limestone which, in turn, lies beneath an upper shale unit which may be the Jones Point Shale Member of the Topeka Formation. The upper shale is represented by sample SK-C. All three samples were dried, then each broken into small pieces in a mullite mortar, and then passed through a splitter to reduce the sample size. The split was ground finer, and the splitting process repeated until a small sample was obtained. The latter was ground into a fine powder using an alumina mortar and pestle. A portion of the powder was slurried with acetone on a glass slide for subsequent x-ray diffraction examination. During the grinding, it was noted that most of samples A and C were relatively soft. By contrast, sample B was harder, and also effervesced when exposed to dilute HCl.

The diffraction patterns indicate that sample B has less clay mineral content relative to A and C. In addition, both calcite and dolomite type structure are present in B. Sample A is primarily quartz and clay, the latter being a mixture of kaolinite, mica-illite, and mixed layer types. Sample C is similar except that it contains some dolomitic type mineral. Both A and C may contain traces of calcite. All three samples may contain traces of feldspar.

Thin-Section Examination

A total of 27 thin sections from 11 sites were prepared and microscopically examined using both a standard binocular and a polarizing microscope. The slides were stained using Alizarin Red dye in order to distinguish dolomite from calcite. Samples for thin sections were taken from outcrop along the strike from T. 1 S. to T. 34 S. Samples at each location were taken on the basis of visual differences in lithology, or on the basis of overall thickness in instances of seemingly homogeneous lithology. Each thin-section is described in Appendix III.

Generally, thin-section examination indicates fine-to-medium grained micritic calcite, deposited in laminae, which cements broken fragments of various fossils and complete foraminifera. Algal remains are prevalent consisting principally of fragments of chlorophycophytes, the green algae, represented by different dasycladacean genera. Infrequent examples are found of rhodophyte or red algae, genus Archeolithophyllum, the cyanobacteria or blue-green algae which are represented by encoating type forms such as Osagia and Ottonosia. Excepting foraminifera, all fossils noted in thin-section are well sorted and finely fragmented, with particles less than 1 mm in diameter. A single exception is a probable worm, possibly some variety of a chaetognathid approximately 1 mm in diameter by 5 mm long (Plate 1).

The most frequently occurring invertebrate fossils in-

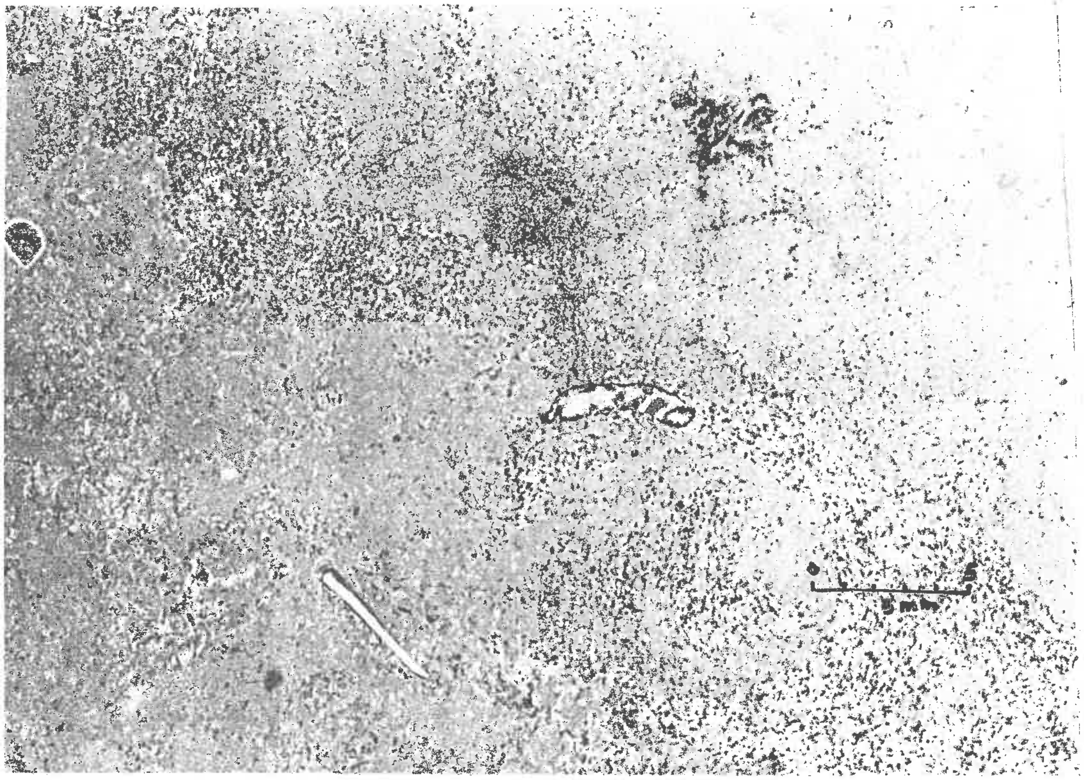

Plate 1. Photograph of probable worm in burrow in lower bed of Curzon Limestone at Moline Quarry, Elk County, Kansas.

clude ostracodes and fusulinids. Occasional uniserial and biserial foraminifera and a probable endothryrid were observed. Chambers of foraminifera observed are generally filled with sparite; micrite-filled examples sometimes occur. Three slides display chambers or void areas of fossils lined with siderite crystals. Algal cells are predominantly filled with sparry calcite. Minute (less than 0.25 mm) particles of angular to subrounded silica were randomly scattered in almost one-half of the thin-sections. Table 3 is a summary of the numbers of the 27 thin-sections which contain features indicated.

Acetate Peel Examination

An acetate peel was prepared of a crust-resembling upperpost portion of the lower unit of the Curzon Limestone outcrop at Bowers Quarry (sec. 30, T. 17 S., R. 15 E). The outcrop is illustrated in Plate 2 where the portion described by the peel, (reproduced in Plate 3), is shown as the light-gray top of the limestone ledge in the foreground. Plate 4 is a closer view of the top portion of the ledge.

The bed represented by the peel is 2.25 in (58 mm) in thickness. The upper and lower portions consist of laminated lime mud crust which is stromatolitic in appearance. Some of the laminae are broken into fragments and, in the upper portion, two spar-filled desiccation cracks are visi-

Table 3. Frequency of occurrence of fossils and other features in 27 thin-sections of Curzon Limestone.

pyrite	10
pellets	9
ostracodes	12
fusulinids	18
burrows	7
osagite or algal wrapped grains	12
other algae	14
echinoderm fragments	10
ooids	2
silica grains	12

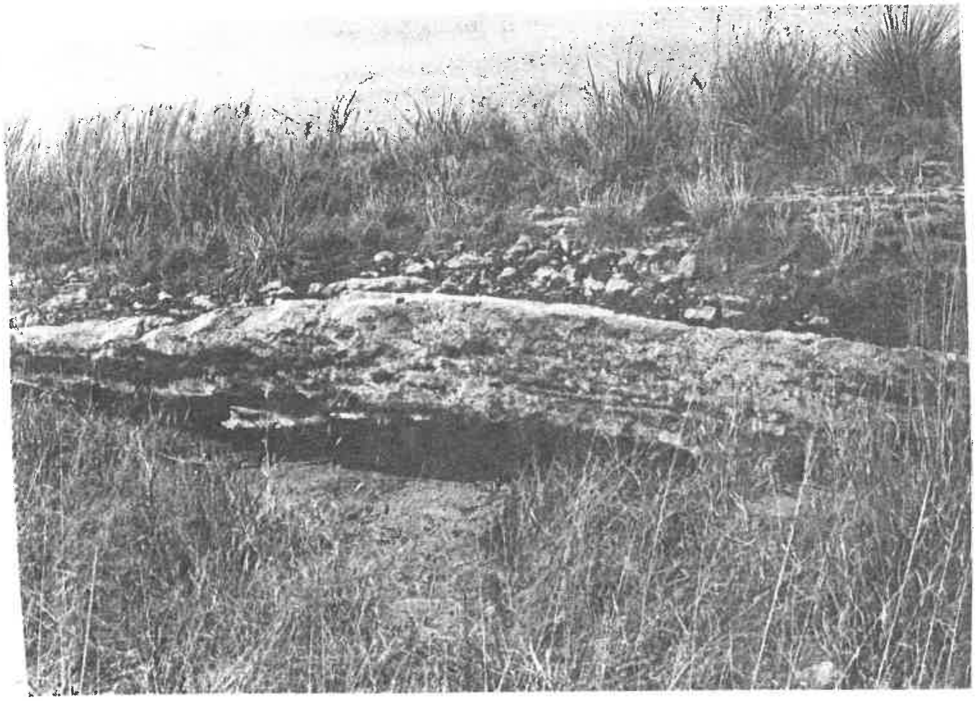

Plate 2. Photograph of uppermost unit, Curzon Limestone outcrop at Bowers Quarry, sec. 30, T. 17 S., R. 15 E.

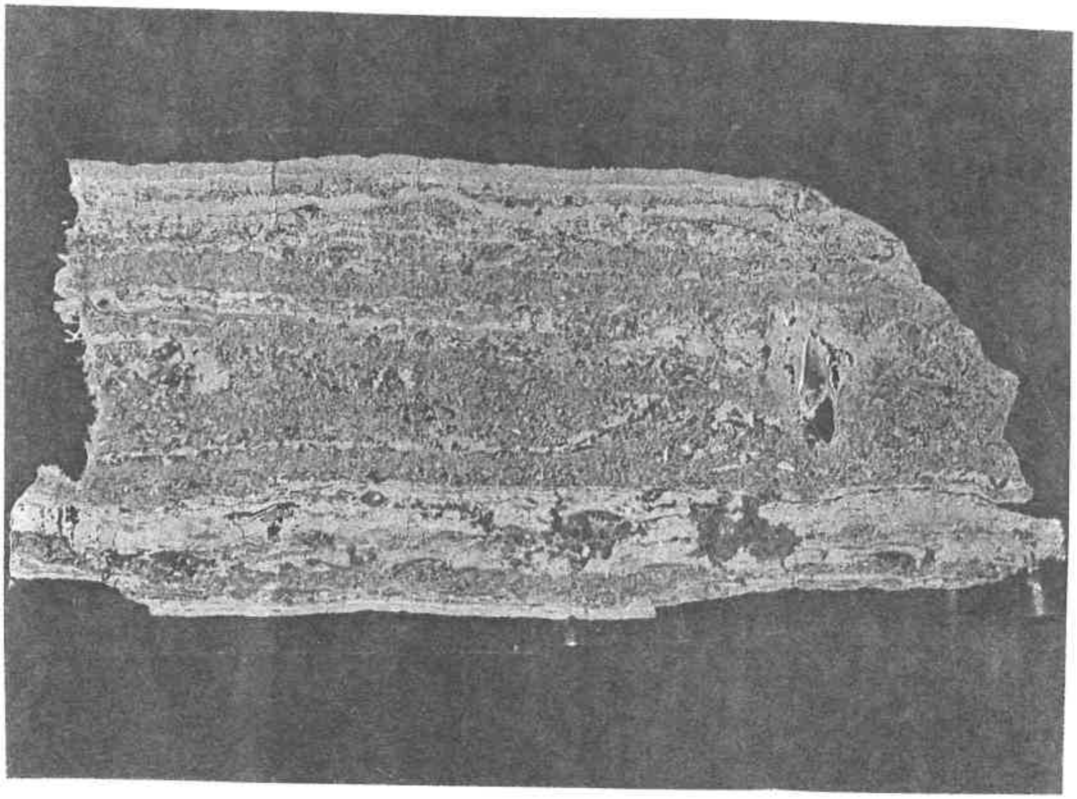

Plate 3. Photograph of acetate peel of uppermost portion of lower Curzon Limestone at Bowers Quarry.

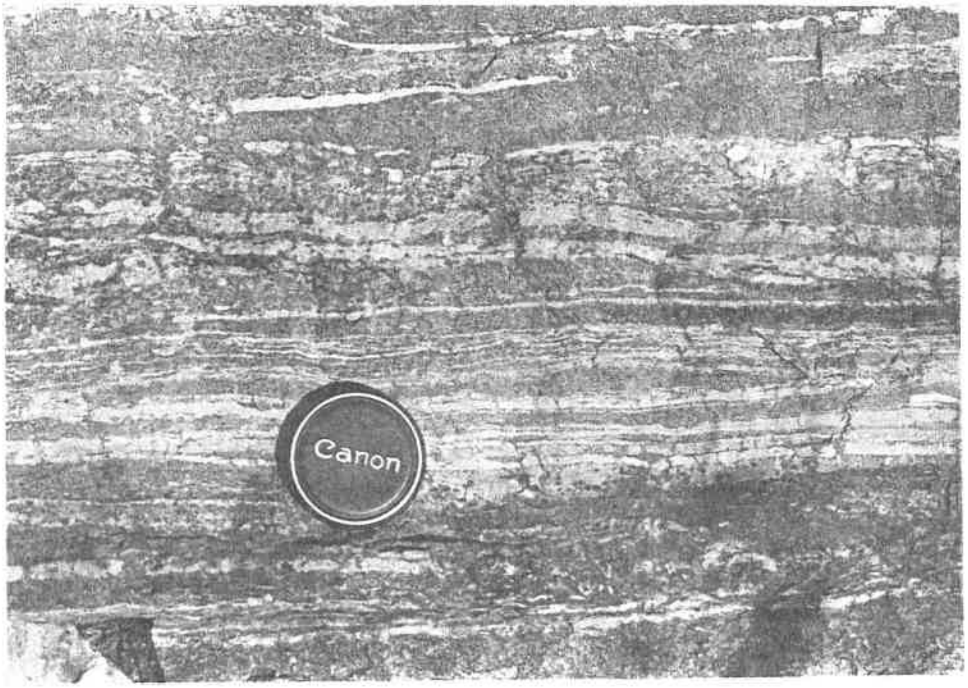

Plate 4. Closeup photography of crust forming top of outcrop pictured in Plate 2.

ble. Clasts are wedged in the lower portion of one of the cracks. The lower laminated portion contains siderite and hematite filled molds of fusulinids.

Some evidence of lamination is visible in the center portion of the peel, however, grains comprising this portion are oriented in various directions and apparently have been bioturbated. This layer, 1 to 1.25 in (25 to 30 mm) in thickness consists of randomly oriented pellets, bryozoan fragments, Osagia particles, ostracode valves, and miscellaneous debris. A remnant lamination, which has been bent upwards on one end, is observable in the middle of the turbated section. Numerous spar-filled voids representative of a fenestral structure are present. The entire bed represented by this peel is colored by iron oxide, which comprises 4.43% of the sample from this location (Table 1, site 5, upper), the greatest concentration of iron oxide from this location.

Interpretation

Deposition of the Topeka Formation began with a marine transgression represented by the Hartford Limestone Member, a nearshore to offshore lower limestone deposited on the alluvial-deltaic plain which had developed on the continental-sourced Calhoun Shale Formation (Silfer, 1986, p. 94).

The Hartford Member should represent the onset of a major transgression which would culminate in the deposition of a "core" shale. The sealevel curve representative of a Kansas cyclothem as described by Heckel (1977) is a more-or-less bell-shaped curve (Figure 5) but is not representative of what occurred during lower Topeka deposition. The Hartford seems to have initiated Topeka deposition in the manner expected during a transgression wherein, as a typical middle limestone, it was deposited in water depths ranging from shallow shoreline to below wave base in deeper water (Watney and French, 1988, p. 11). Silfer (1986, p. 46) describes an argillaceous subfacies which is restricted to the base of the Hartford and which grades into the underlying Calhoun Shale Formation. Such a transitional boundary indicates the slow, steady increase in water depth suggestive of eustatic rise.

A core shale would be expected to follow the Hartford in depositional sequence in normal cyclothemic succession (Heckel, 1977). However, the Hartford Member is succeeded stratigraphically by the Iowa Point Shale Member which, similar to the Calhoun Shale, is a continental-origin shale typical of a regressive marine environment. Such location, surrounded by "outside" shales, classifies the Hartford as a "fifth" limestone. Properly described, the Hartford and Iowa Point Shale are both members of the Calhoun Shale.

The lower portion of the Curzon Limestone Member exhibits lithology similar to that of the Hartford Limestone. As the sealevel curve postulated in Figure 8 indicates,

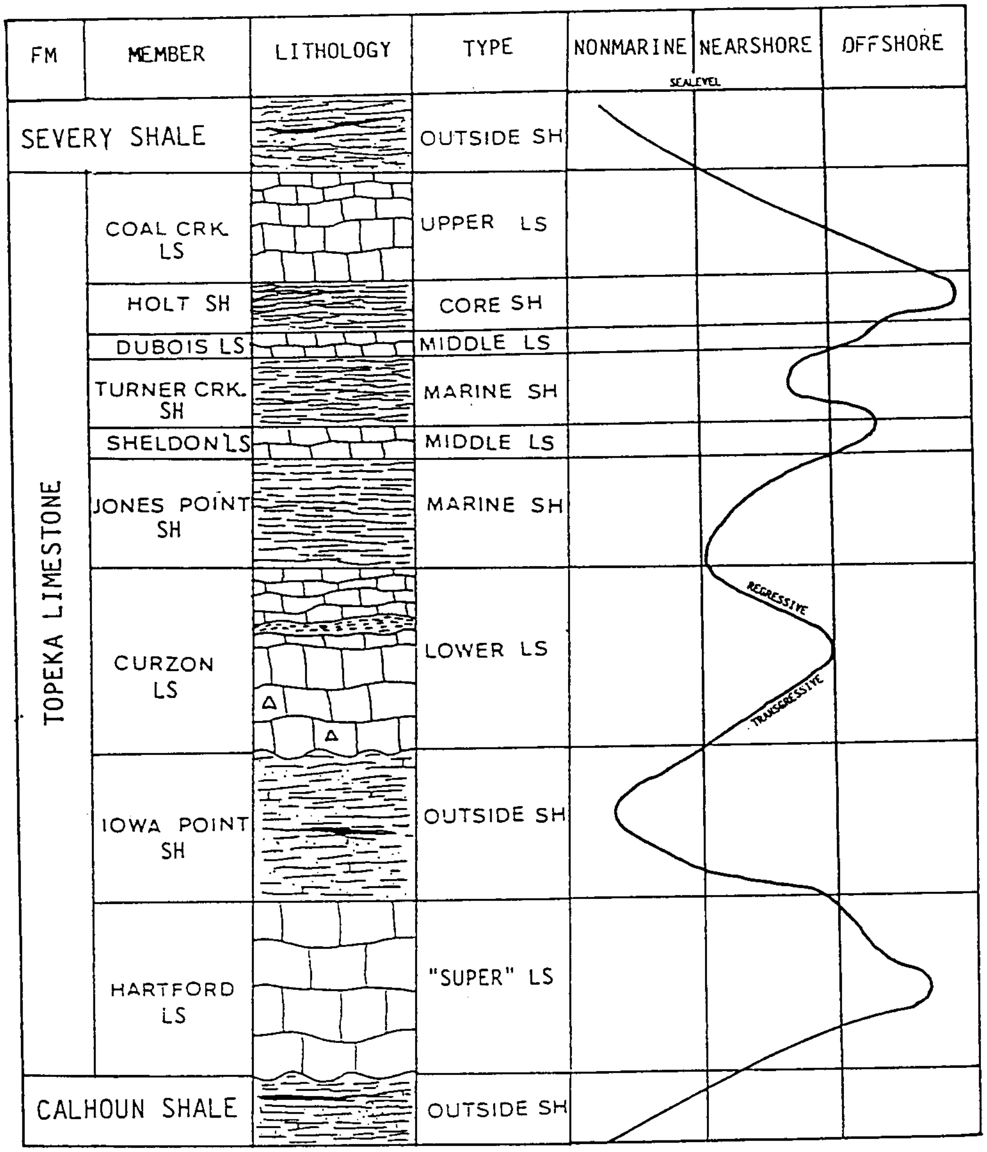

Figure 8. Proposed sealevel variation during deposition of Topeka Limestone.

Curzon deposition began in a nearshore environment during a marine transgression. The lower two-thirds of the Curzon is thick-bedded, fossiliferous and contains chert nodules. To the eye, it resembles the Hartford Member. The upper one-third however, becomes wavy bedded and flaggy or slabby, a characteristic of regressive limestones. At most locations studied along the outcrop, the upper portion of the Curzon Member is separated from the lower by a silty, micaceous mudstone or calcareous shale which ranges in thickness from less than an inch to approximately 2 ft (61 cm). The clay zone represented by the x-ray diffraction pattern in Appendix II-A is such a separating layer between the upper and lower Curzon at Bowers Quarry in Osage County.

Northern Outcrop Area

The Curzon Limestone Member is exposed on outcrop beneath Quaternary loess west of Iowa Point, Doniphan County, in sec. 36, T. 1 S., R. 19 E. It consists of four distinctive beds which are about 22 in (55.9 cm) in total thickness. The upper bed which is 4 in (10 cm) thick is iron-stained and thinly bedded; the layers are separated by clay partings ranging from 0.375 to 1.0 in (0.9 to 2.5 cm) in thickness. There are no discernible fossils. However, in thin section, the upper bed is seen as a biopelmicrite. It is bioturbated and contains algal-coated fragments of unidentified fossils. Some fossils are replaced completely with iron oxide. There are fusulinids, ostracodes, echinoid parts, and pellets discernible.

The two middle beds of the Curzon at Iowa Point are together 11 in (27.9 cm) thick. They weather to a limonitic yellow brown and are wavy bedded and laminated with 2 to 3 in (5.0 to 7.6 cm) thick clay partings between layers. Thin-section examination shows algal-wrapping of grains and pellets, with some pellets in concavo-convex contact, probably indicating compaction during diagenesis. There are some elongate shell fragments, 1.0 mm or less in length that are roughly parallel to and aligned with the bedding. Some pore space and fusulinid chambers are filled with pyrite, probably secondary in origin. The lower bed is 7 in (17.8 cm) thick, thick bedded, weathering gray. It contains angular chert clasts and the only readily visible fossils consist of crinoid columnals, fusulinids, brachiopod fragments, and some pellets. A thin section shows randomly oriented, spar-filled, fusulinid-shaped cavities and an area of tightly packed micritized pellets or ooids, none greater than 0.25 mm in diameter. There are micritized features which may be ghosts of burrows; and circular, sparry features, unstained by Alizarin Red dye, which are dolomitic and some of which resemble fenestral fabric. The Curzon overlies 8 ft (2.4 m) of the Iowa Point Shale Member, which is a dark gray, carbonaceous, calcareous fissile shale weathering light gray.

About 14 mi south of Iowa Point, the Curzon Member is exposed southeast of Denton on the north bank of Independence Creek, Doniphan County, in sec. 11, T. 4 S., R. 19 E. The Curzon and Iowa Point Members are mostly covered. The Curzon is 2 ft (61 cm) thick, thick bedded and fine grained. The upper bed contains the greatest percentage of Fe_2O_3 (8.68%) of any of 12 sites tested. Thin-section examination of the upper bed shows an almost featureless, iron-stained, dolomitic micrite which has been identified as a paleosol horizon (S. J. Mazzullo, pers. comm., 1991). Two fossils can be seen; a poorly preserved strand of a possible algal filiment and an eroded, possibly swash-washed fusulinid. The lower bed of the Curzon is a calcitic micrite which contains algal filaments, fusulinids, and crinoid columnal fragments. Some microfossils have been dissolved and voids filled with dolomite or ankerite. Macrofossils contained in the lower bed include fusulinids, brachiopods, crinoid columnals, and fragments of fenestrate bryozoans.

The Curzon overlies 8 to 9 ft (2.4 to 2.7 m) of silty, micaceous, gray rock ranging from claystone to shale. It is slightly calcareous in the middle. Beneath this claystone/shale is 4 ft (1.2 m) of thick to thin-bedded, gray weathering to dark gray, dense limestone which is wavy bedded at the top. It contains fusulinids, brachiopods, crinoids, and fenestrate bryozoan fragments. Some fractures are filled with chalcopyrite.

The Curzon Limestone Member crops out again about 19 mi south in sec. 24, T. 7 S., R. 19 E., in southern Atchison County. The Curzon at this site consists of approximately 6 ft (1.8 mm) of wavy-bedded, gray limestone which weathers to orange brown. Fractures are filled with Fe_2O_3. Individual beds range from 2 or 3 in (5.0 to 7.6 mm) to 8 or 9 in (20.3 to 22.8 cm) in thickness. They contain fusulinids, crinoids, and brachiopods. Microscopic examination of the upper portion reveals a burrowed micrite with burrows containing assorted fusulinids, ostracode valves, echinoderm fragments, and fragmented crinoid columnals. The area outside the burrows is relatively unfossiliferous. Some areas of the micrite are dolomitic. A thin section of the middle of the upper bed resembles a micrite-bound, silt-sized fossil hash. This portion shows no dolomite and usually contains algal-wrapped fossil fragments along with fragments of red algae, echinoid fragments, fusulinids, and other foraminifera. There are three possible mud clasts surrounded by micrite.

The upper portion of the Curzon lies atop an estimated 12 ft (3.6 m) of covered shale and weathered surface material. Approximately 100 yds (91 m) north, is a single, massive bed of limestone, 23 in (58 cm) in thickness which weathers dark-gray and is iron stained on fresh surfaces.

It contains chert pebbles and nodules and overlays an unknown thickness of gray, plastic claystone. The writer considers the chert-containing limestone bed to be the basal portion of the Curzon Member at this site.

The Ozawkie Section is in Jefferson County in sec. 27, T. 9 S., R. 18 E., about 16 mi (25.7 km) south-southwest from the previously described site. The Curzon here is 7.5 ft (2.3 m) thick. The lower portion consists of seven limestone beds, each approximately 7 in (17.8 cm) thick, which are separated by 2 in (5 cm) thick shale partings. The upper section of the lower part contains chert nodules. Macrofossils include brachiopods, algal filaments, fusulinids, echinoid spines, crinoid columnals, gastropods, fenestrate bryozoans, and trilobite fragments. Microscopic examination reveals burrows and algal-wrapped grains. This portion of the Curzon Member is separated from the upper portion, which is a 1 ft (30.5 cm) thick osagite, by 15 in (45.7 cm) of a silty, limy shale.

The Curzon Limestone Member is next encountered in outcrop 18 mi (30 km) south-southwest where Interstate Highway 70 West crosses the Shawnee-Douglas County line. The Curzon Limestone is approximately 8 ft (2.4 m) thick. The lowermost part is light gray, weathering brown limestone which contains profuse fusulinids, brachiopods, and crinoid columnals. It is overlaid by a 1 ft (30.5 cm) layer of softer, shaly limestone which in turn is overlaid by 2 ft

(61 cm) of thick-bedded, earthy, fractured limestone which contains brachiopods and crinoids. Above the earthy limestone layer is 18 in (46 cm) of brown-weathering, limy shale which has a thin limestone bed in its middle. The shale and limestone both contain brachiopods. The uppermost bed of the Curzon is a rusty-brown, 15 in (38 cm) thick limestone containing Osagia, brachiopods, ramose bryozoans, clams, and crinoids. A thin section of the upper bed indicates some dolomitization where rhombic sparry, nonstained areas are surrounded by Alizarin Red stained micrite.

The next site is a roadcut on U. S. Highway 75 at the south side of the Wakarusa River, 12 mi southwest of the Interstate 70 exposure, in sec. 32, T. 13 S., R. 16 E., southern Shawnee County. The Curzon Limestone at this location closely resembles the exposure described at Ozawkie and is approximately 10 ft (3 m) thick. It consists of an upper and lower limestone section separated by 2 ft (61 cm) of shaly, silty, limestone which contains unidentified spines and brachiopods. The lower portion is 6 ft (1.8 m) of wavy-bedded limestone layers, 6 in (15 cm) in thickness which alternate with 1 in (2.5 cm) thick partings of limy shale. The upper beds of this lower part contain chert nodules. Fossils in the lower part include ramose and fenestrate bryozoans, clams, brachiopods, algae, crinoids, fusulinids, and Osagia.

The upper limestone layer which is similarly bedded and about 2 ft (61 cm) thick contains Osagia, echinoid spines, brachiopods, and crinoid columnals.

The Topeka Limestone exposure at Dragoon Creek in sec. 3 and 4, T. 16 S., R. 15 E. in Osage County is located in a convenient site to tie together the descriptions of the northern and central outcrops of the Curzon Member. This outcrop is no longer accessible. The following description of the Curzon Limestone is taken from a section which was measured by H. Hall and D. Sass of the Kansas Geological Survey on 3 August 1949 and is included in the measured sections filed in the Survey's Open File collection. The Curzon Limestone Member is a weathered, dark-brown, limonitic limestone containing abundant fusulinids and is 2.5 ft (76 cm) thick. It overlies 1.4 ft (42.7 cm) of brown, weathered Iowa Point Shale.

Discussion of Northern Sections

The northern portion of outcrops show strong evidence of shallow-water limestone deposition over a generally thicker Iowa Point Member than is present in the central outcrop area. At least one area, near Denton, was subaerially exposed for sufficient time to develop a soil profile. Development of dolomite at Iowa Point, southern Atchison County and I-70 W locations suggests subaerial exposure or at least exposure to freshwater to create epigenetic dolomite (Gerhard, 1984, p. 10-3). The presence of an osagite limestone at the top of the Curzon at Ozawkie, as well as Osagia in the upper parts of the same at I-70 and Wakarusa, and algal-wrapped fragments at Iowa Point and southern Atchison County, suggest shallow-water deposition. Moore, (1964, p. 343) pointed out that abundant Osagia at the top of marine portions of Pennsylvanian cyclothems indicates "marginal and nearshore deposits laid down by retreating shallow seas". The constancy and frequent profusion of fusulinids in almost all areas described is additional paleontological evidence of shallow-marine conditions. McCrone (1964, p. 273) suggests that fusulinids are deposited in water depths varying from 5 ft (1.5 m) to 50 ft (15 m) and presents evidence from other workers which generally supports the same depth range.

Central Eastern Outcrop Area

The Bowers Quarry exposure of the Curzon Limestone Member is unique among exposures of the Curzon in that it apparently represents a complete cycle within the greater cycle of the Topeka Limestone Formation. Beginning with the Iowa Point Shale Member, which genetically may represent the uppermost part of the Calhoun Shale (a point to be discussed later in this thesis), the lower Curzon contains the thick, even-bedded, fossiliferous characteristics associated with a transgressive limestone. However, it is topped by a sandy, ferruginous crust which may indicate a sudden cessation of transgression with subsequent subaerial exposure. The zone above the crust is primarily a mixture of quartz and clay, the clay portion being a mixture of kaolinite, mica, illite, and mixed-layer types. According to Pettijohn (1957, p. 127), kaolinite is characteristic of an acidic freshwater environment whereas illite is more dominant in the marine environment. He commented that montmorillonite is characteristic of lagoonal sediments. Powers (1967, p. 1245) noted that after burial, montmorillonite alters to illite and mixed-layer clay (p. 1251), but that such alteration occurs at burial depths beginning at about 6,000 ft and continuing to 9,000 to 10,000 ft. Such burial depths could have been achieved beneath now eroded and removed Permian and Mesozoic strata. Pettijohn (p. 137) suggested that illite also may be a transformation product of kaolinite in the marine environment. The presence of potassium in clays after burial also seems necessary for conversion of montmorillonite (Powers, p. 1241). Surface weathering, particularly of granitic rock, would provide a source of potassium in addition to creating kaolinite by the decomposition of orthoclase feldspars.

Appendix II-B shows an x-ray diffraction pattern of a limy shale which lies atop the wavy-bedded, laminated upper Curzon Limestone Member at the Bowers Quarry site. Superficially, it resembles the lower shale which separates the

Curzon but is more indurated and limy. Its diffraction pattern is substantially different, showing strong calcite and dolomitic peaks. It is probably a slightly dolomitized argillaceous limestone formed in supratidal condition as clastic influx increased in response to continuing regression; and is the uppermost portion of the normal Curzon Limestone Member.

At this site, however, a third limestone layer, an 18 in (45.7 cm) thick laminated algal limestone is deposited upon the dolomitic layer. It can be seen as the ledge in the upper-right section of Plate 2. It, in turn, is overlaid by limy shale. It seems that the laminated algal (uppermost) limestone at Bowers Quarry could be a low-energy lagoonal algal facies of the Curzon developed atop a supratidal mud flat. The algal layer showing a crusty top, desiccation cracks, and small fossil fragments, is illustrated in Plate 5. The algal layer is overlaid by a shale which x-ray diffraction (Appendix II-C shows to be similar in composition to the shale separating the lower transgressive portion and indicates the initiation of a new transgressive phase. It probably represents the Jones Point Shale Member but more conservatively should be described as "undifferentiated upper Topeka".

There are other examples of an entire cycle in Curzon Limestone Member outcrops, although none seem to be so complete as at the Bowers Quarry location. At the Peterson

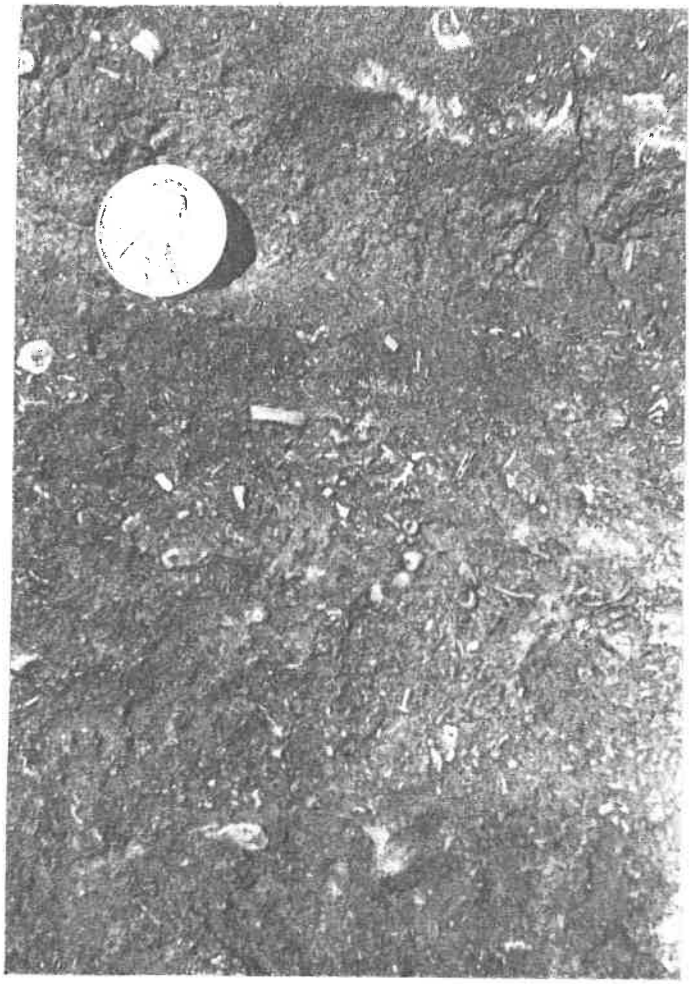

Plate 5. Photograph of top surface of uppermost Curzon Limestone bed seen in upper portion of Plate 2.

Quarry located approximately 21 mi (33.8 km) south-southwest from the Bowers Quarry in sec. 34, T. 20 S., R. 13 E., the lower portion of the Curzon overlies the Iowa Point Shale Member, is about 84 in (213 cm) thick and is divided into beds, each about 12 in (30.5 cm) thick. This thick bedded portion contains algal blades, echinoids, crinoid columnals, clams, ramose and fenestrate bryozoans, and solitary corals. The top of the lower portion contains Ottonosia algae and displays an iron-oxide buildup that forms a pronounced crust similar to that at Bowers Quarry. The middle portion of the Curzon here is a shaly limestone about 36 in (91.5 cm) thick. It contains ramose bryozoans, brachiopods, echinoid parts, and profuse fusulinids. It is capped by a 15 in (38 cm) thick, wavy-bedded limestone which contains 2.35% Fe_2O_3. The upper portion exhibits Osagia, brachiopods, fenestrate bryozoa, crinoid columnals, and clams and is burrowed with individual burrows approximately 0.5 in (1.27 cm) in diameter. Although no fossils were present in the burrows, their size suggests that they were formed by clams. The exposed upper surface of the upper Curzon Member at Peterson Quarry is laminated similarly to the laminated upper layer at Bowers Quarry and shows preserved desiccation cracks.

Marlin Quarry is about 23 mi (37 km) south-southwest of Peterson Quarry, in sec. 17, T. 24 S., R. 12 E., Greenwood County. The Curzon Member at this site overlays the Iowa Point Shale Member which here is a light-gray, limy shale containing carbonized plant remains. The carbonate content increases upward in the bed as evidenced by increased vigor of effervescence with application of 10% hydrochloric acid.

The Curzon Limestone is a thin, wavy-bedded, dense, gray grainstone which weathers yellow on the surface. It is vertically jointed at approximately 18 in (45.7 cm) intervals. Beds are 2 to 5 in (5 to 12.7 cm) thick, the entire unit being 22 to 26 in (56 to 66 cm) in thickness. It is laminated and cross bedded, the cross-bedded portions being oolitic. Ooids are small, 1.0 mm or less in diameter. The most abundant fossils are 0.5 in (1.27 cm) diameter clams which have been replaced with a dark-red ferroan spar. The clams may have been responsible for the burrows which are present at this outcrop. The upper portion of the Curzon contains mud chips. It is of interest to note that the Hartford Limestone Member of the Topeka lies directly upon the Ervine Creek Limestone Member of the Deer Creek Limestone at this site. The Calhoun Shale is missing in the stratigraphic sequence, a condition again which is encountered farther south.

Approximately 7 mi (11 km) to the northwest, in sec. 13, T. 23 S., R. 12 E., a roadcut in the Curzon Limestone exposes approximately 40 in (102 cm) of limestone comprised of 5 distinct beds, each of which vary from 4 to 8 in (10 to 20 cm) in thickness. The top bed is 8 in (20 cm) thick, dense, fossiliferous, gray limestone which weathers to tan on exposed surfaces. Its upper weathered surface is slabby. It overlies a 4 in (10 cm) thick, shaly limestone which contains wavy, algal filaments and lies upon a 2 in (5 cm) thick, yellow-tan, clayey shale.

The clayey shale parting overlies a 5 in (12.7 cm) thick, dense, hard, tan limestone which lies upon 1 to 2 in (2.5 to 5 cm) of thin-bedded shaly limestone. There are no visible fossils in this bed, however, at the top is a rough hardground and truncated clasts. The bed displays a single large cup-shaped burrow which is approximately 6 in (15 cm) in vertical dimension by 4 in (10 cm) horizontally. This burrow, which is illustrated in Plate 6, begins immediately beneath the yellow-tan, clayey shale and penetrates the hardground. It may be a malacostracan burrow.

The remainder of the Curzon Limestone at this site consists of an 11 in (28 cm) thick, tan limestone which is separated from a 7 in (17.8 cm) thick, tan to brown, fine-grained massive limestone by a 0.5 in (1.27 cm) thick layer of mudstone. Neither of the lower limestones contain macrofossils. The clayey shale layer beneath the top bed of the Curzon at this site may represent the parting which is seen elsewhere between the upper and lower Curzon and which represents the intramember change between transgressive and regressive conditions illustrated in Figure 8. The burrow-containing bed is apparently supratidal and was a mudflat. It represents a stalemate in sealevel change. Sealevel had

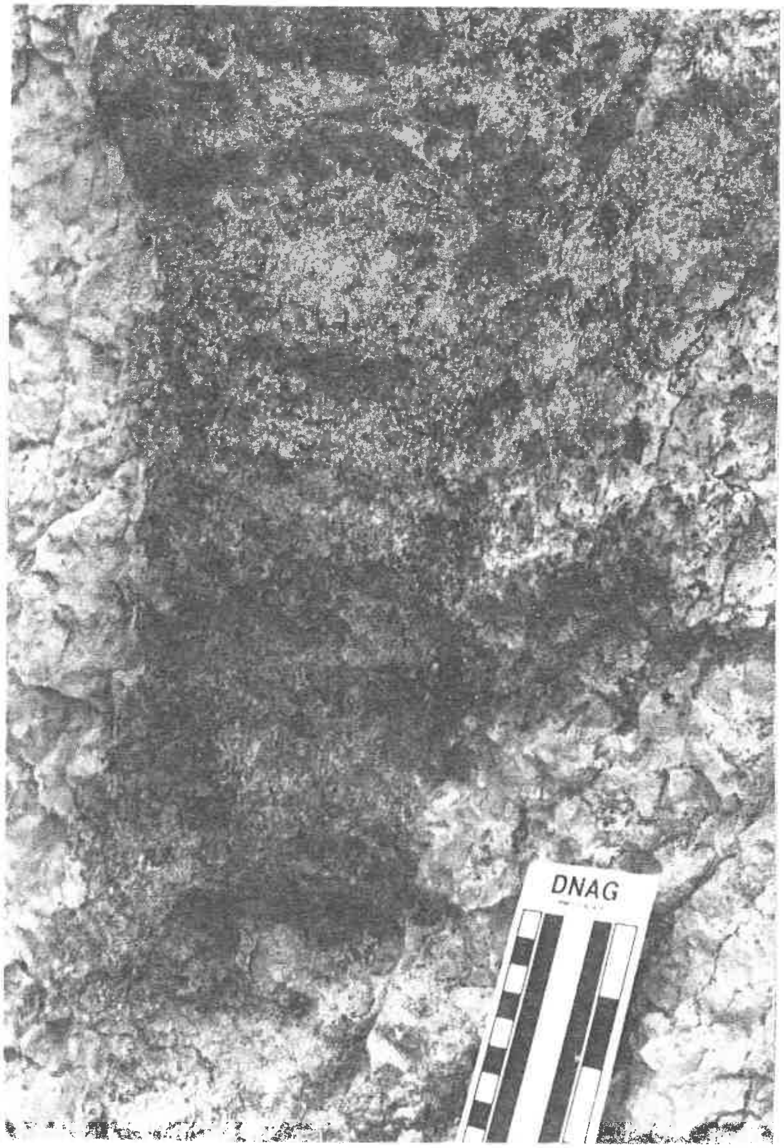

Plate 6. Photograph of probable arthropod burrow which penetrates hardground at top of Curzon Limestone at sec. 13, T. 23 S., R. 12 E.

begun to rise, relative to the land, at the end of the Iowa Point deposition. It stalled and remained at standstill during much of the remainder of Curzon deposition which, at least in this general area, was accomplished in a shallow marine environment where algae proliferated, and which occasionally dried out. Finally, renewed rise in sealevel was sufficient to initiate deposition of the Jones Point Member, a marine shale, atop the then inundated Curzon.

A final example of subaerial exposure of Curzon Member sediments in central-eastern Kansas is the Hilltop Section in Greenwood County, sec. 11, T. 23 S., R. 12 E. The Curzon at this location consists of two limestone units separated by an approximately 10 in (25.4 cm) thick, yellow mudstone. The upper limestone is approximately 24 in (61 cm) thick, yellow-brown, weathering to yellow, and divided into 3 beds, each approximately 8 in (20.3 cm) thick. The surface of the upper bed shows numerous filled desiccation cracks, contains clam fragments, and displays the wavy-bedded, platy, slabby weathering associated with regressive limestones (Merriam, 1989, p. 20). The center bed of the upper portion contains a fusulinid zone. The lower bed of the upper limestone is wavy bedded and densely burrowed. The lower portion of the Curzon, below the mudstone, is about 14 in (35.5 cm) thick and contains fusulinids, clams, fenestrate and ramose bryozoans, echinoid spines and fragments, gastropods, brachiopods, and <u>Osagia</u>. There is a coquina zone near the bottom.

The Iowa Point Shale Member is missing at this locality but is present nearby in section 7 and the northeastern corner of section 19 where it is only about 12 in (30 cm) thick, (Bridge, 1988, p. 28).

The Curzon at the Hilltop section is directly atop the Hartford Member. The Hartford is about 15 ft (4.6 m) thick. The upper 4 ft (1.2 m) consists of dense, thickly bedded, light brown limestone which weathers to yellow-brown. The upper portion is sandy and laminated in 0.5 to 1.0 in (1.3 to 2.5 cm) thick layers. Although unquestionably a sandy carbonate, this interval effervesces less vigorously with 10% hydrochloric acid than other portions of the Hartford at this site. The upper 4 ft (1.2 m) of the Hartford below the sandy zone is fingered with four identifiable beds of calcareous shale, each bed about 10 in (25.4 cm) thick, which contain thin limestone lenses and exhibit soft-sediment deformation or "slurp" structures. The lower 10 ft (3 m) of the Hartford exhibit "tepee" structures which also have been identified as "megaripples" (Bridge, p. 28). These features consist of a core of hard, dense, microcrystalline limestone over which a bed of dense fossiliferous limestone is draped, forming an anticlinal shape about 5 ft (1.5 m) across. The flanks are comprised of a bed of dense, algal limestone which contains fossils of large boring clams and Ottonosia in the lower part, and fusulinids at the top. The base of these folds is not exposed so their height is unknown.

Overlying and underlying strata are horizontal. Silfer (1986) selected the surface between the folded beds and the overlying horizontal beds as the Hartford-Curzon boundary. Price (1925, p. 1010) described similar features in sedimentary strata in the State of Tamualipes, Mexico and attributed them to the formation of caliche in interbedded shale. Bridge (1988, p. 30) considers tepees to have occurred prior to lower Topeka lithification and to have been formed by local seismic activity which mobilized underlying Calhoun or lower Hartford sediment and injected it upward, forming the folds and the soft sediment deformation in the Hartford. Rascoe (1975) described similar deformation in the Bartlesville area. Bechstadt and Dohler-Hirner (1983, p. 55) interpreted Austrian Triassic tepee structures as forming in the intertidal environment. Estaban and Klappa (1983, p. 38-39) identified caliche-formed tepees and noted that generally, tepee structures form in marine and coastal environments.

It was observed that the Iowa Point Shale Member is missing at this site although it is present nearby. Bridge (1988, p. 29) noted that this site is located in a graben which was undergoing tectonic movement contemporaneously with Topeka deposition. It may have been that Iowa Point sediments were never deposited here, they may have been deposited and removed by erosion, or the sandy facies of the upper Hartford and the coquina at the base of the Curzon may be representative of an aborted Iowa Point Member.

The desiccation cracks, fossil content, and sedimentary structures noted in the top of the Curzon Limestone Member in the foregoing descriptions of sites in central-east Kansas establish the shallow shelf and littoral environment of deposition in that portion of the state.

It becomes apparent that the portion of the Curzon outcrop thus far discussed, from T. 1 S. to T. 24 S., was deposited close to shore on a shallow, almost flat shelf that pervaded the Midcontinent (Bennison, 1984, p. 93). Evidence which has been presented shows subaerial exposure along a Virgilian shoreline from T. 17 S., to T. 24 S., and in a local area in T. 4 S. The presence of dolomite at exposures in T. 1 S., and T. 10 S. suggests possible subaerial exposure or exposure to fresh water.

Southern Kansas Outcrop Area

The Kansas Geological Survey drilled a stratigraphic core well, #1 Lacy, located approximately 1 mi (1.6 km) north of the intersection of Kansas Highway 99 and U. S. Highway 54 in Greenwood County in sec. 26, T. 26 S., R. 11 E. A detailed description of the top 21 ft (6.4 m) of the bedrock is given in Appendix I. The Curzon Limestone in this well is 12.8 ft (3.9 m) thick and consists of an upper limestone layer 6.8 ft (2.1 m) thick which is separated from a 3.2 ft (1.0 m) thick lower limestone by a

2.8 ft (85 cm) thick claystone interval. The lower bed becomes clayey toward the bottom and shows sign of compaction and soft-sediment deformation. It overlays and grades into the Iowa Point Shale which ranges in lithology from claystone to limestone and contains a 2.25 in (5.7 cm) thick coal bed 4.5 ft (1.3 m) below the Curzon contact.

The upper portion of the Curzon in the Lacy well is wavy bedded and contains concentrations of fusulinids. There are fragmented brachiopods, clams, and what may be corals. The claystone parting between the upper and lower Curzon Limestone layers is limy with limestone forming an estimated 20% to 30% of the total volume. The clay layers range between 10 mm and 15 mm in thickness. This portion contains ramose and fenestrate bryozoans, brachiopods, and clams. The bottom 4 in (10 cm) looks as though it had been stirred. Clam shells are deposited concave side upwards and also are oriented across the bedding. Had this been their natural orientation in mud during life, both valves should be present but that is not the condition found. This layer grades into limestone which in the lower unit of the Curzon comprises approximately 80% of the rock mass. The lower portion is principally a calcareous grainstone and contains fusulinids and fragmented crinoid columnals, brachiopods, and bryozoans.

The Severy Quarry is located in southern Greenwood County, about 17 mi (5.5 km) south of the Lacy well in sec. 10, T. 28 S., R. 11 E. The Severy Quarry site poses problems in interpretation. The writer has made four different descriptions based on as many visits to the site. Schultz (1985) and Allen (1990) have each proposed different descriptions. All are similar but contain sufficient interpretative differences to indicate that more study is needed at this site. The description furnished here is the writer's current favorite.

The Curzon Limestone Member is approximately 50 in (1.3 m) thick and may be divided into three or four units. The claystone layer separating the upper and lower limestone portions in exposures to the north is absent here. The upper one-half is 22 to 24 in (56 to 61 cm) thick. The uppermost 10 in (25 cm) is a gray, crystalline, slabby limestone which weathers tan. The somewhat wavy slabs range in thickness from 4 to 6 in (10 to 15 cm) and contain fossil brachiopods, crinoid and echinoid parts, and fenestrate bryozoans. It overlays a thin, heavily fractured zone which probably has been fractured by blasting during quarry operations. The lower 14 in (36 cm) (including the fractured zone) of the upper bed contains ramose and fenestrate bryozoan fragments, crinoid columnals, and brachiopods. The lower portion contains large spirifer-type brachiopods, echinoderm spines, and scattered iron-oxide nodules to 0.75 in (1.9 cm) in diameter. Whether the nodules represent a centering of iron oxide around a grain nucleus or the oxidation of pyrite nodules is unknown.

The lower 26 in (66 cm) of the Curzon Limestone is comprised of two beds of dense, gray crystalline limestone, each 13 in (33 cm) thick. Both weather to a rusty yellow brown on the surface. The upper bed contains crinoids and brachiopods as does the lower bed which also contains large burrows probably made by the clam Aviculopinna. The Curzon overlays 4.5 ft (1.3 m) of a gray, weathering to tan, silty, micaceous claystone which becomes carbonaceous in the lower part and contains iron oxide streaks and nodules ranging from 0.06 to 0.125 in (1.5 to 3.1 mm) in diameter. The Hartford Limestone is wavy bedded, the beds being 4 to 6 in (10 to 15 cm) thick, and contains profuse fusulinids. The entire Hartford Member is about 1 ft (30 cm) or slightly more in thickness and may directly overlay the "Tonovay Limestone Member" of the Calhoun Shale.

Approximately 12 mi south, in sec. 6, T. 30 S., R. 11 E., Elk County, the Topeka Formation is exposed alongside the road to Polk Daniels State Lake. The upper Topeka is capped by an 8 to 10 ft (2.4 to 3 m) thick massive to wavy bedded, gray limestone which is identified as the Coal Creek Limestone Member (also known as Turkey Run Limestone). The lower 5 ft (1.5 m) of the Coal Creek is massive-bedded, displaying beds 10 to 14 in (25 to 35 cm) in thickness. It contains large-size brachiopods and near its base, a fossil coquina.

Beneath the Coal Creek Member is an 8 to 10 ft (2.4 to 3.0 m) thick section of dark-gray shale which weathers light gray. The upper portion of the shale contains 0.5 to 0.75 in (1.3 to 1.9 cm) thick limetone beds alternating with shale. The limestone weathers rusty brown and contains fusulinids, brachiopods, crinoid columnals, and echinoid parts.

The Curzon Limestone Member is beneath an undifferentiated upper Topeka Shale. The Curzon is gray, weathering brown and consists of two limestone beds, each 8 to 10 in (20 to 25 cm) thick which are separated by a 6 in (15 cm) thick claystone bed. The limestone beds contain fossil algae, brachiopods, crinoid parts, solitary corals, and fusulinids.

The Iowa Point Shale Member here consists of 3 ft (90 cm) of sandy, yellow claystone which overlays an equal thickness of sandy, micaceous, thin-bedded limestone which is probably the Hartford. Schultz (1985) reported that the Calhoun Shale was absent near this location. Allen (1990) identified 5.5 ft (1.7 m) of Calhoun Formation of which 3.5 ft (1.1 m) was a thick-bedded limestone, the "Tonovay Member."

The Moline Quarry is in Elk County, sec. 1, T. 31 S., R. 10 E., about 6 mi (9.6 km) south-southwest of the previously described section. At the top, it contains about

5 ft (1.5 m) of Coal Creek/Turkey Run Limestone and undifferentiated upper Topeka strata. Below it is the Curzon Member, which consists of two layers of gray, weathering brown limestone, each 6 to 10 in (15 to 25 cm) thick, which are separated by approximately 2 ft (61 cm) of red-brown shale. The upper limestone contains brachiopods, gastropods, clams, algae, and Osagia. The lower limestone contains crinoid columnals, algae, brachiopods, and a dense fusulinid population.

The Curzon overlays approximately 9 ft (2.7 m) of Iowa Point Shale, the center section of which contains an approximately 2 ft (61 cm) thick limestone comprised of three equally thick beds. Above the limestone is 4 ft (1.2 m) of brown-weathering shale which contains two thin layers of limestone, each about 1 to 2 in (2.5 to 5 cm) thick. The bottom one-third of the Iowa Point consists of about 3 ft (91 cm) of gray-brown shale. The Hartford Member consists of 6 to 8 ft (1.8 to 2.4 m) of 4 to 6 in (10 to 15 cm) dense limestone which has thin shale partings between the beds. The Hartford contains crinoids, brachiopods, algae, and the sponge, Amblysiphonella.

The Fudge Quarry-Middle Caney Creek section in Chautauqua County is located about 12 mi (3.6 km) south-southwest of the Moline Quarry. This is a composite section comprised of the Fudge Quarry in the northeastern corner of sec. 5, T. 33 S., R. 10 E., and an outcrop at the Middle

Caney Creek in the southeastern quarter of sec. 33, T. 32 S., R. 10 E. These two locations are about 0.375 mi (0.6 km) apart.

The Curzon Limestone Member is 2 to 5 ft (0.6 to 1.5 m) thick and is dark-gray, dense, crystalline limestone which weathers to rusty yellow. It is wavy bedded in the upper portion with bedding thickening and becoming more even in the lower part. At places, the upper and lower parts are separated by a 6 in (15 cm) thick yellow, silty, micaceous mudstone. The upper surface contains pellets and an abundance of fusulinids along with brachiopods, gastropods, echinoids, and fenestrate bryozoans. The basal Curzon contains algal blades, fusulinids, and brachiopods. Fusulinids occur at all intervals although not with the density encountered in the top bed.

Below the Curzon is a 7 ft (2.1 m) covered area at the base of which is a 2 ft (60 cm) thick limestone below which is 11 ft (3.3 m) of additional cover which ends at a 7 in (18 cm) thick exposure of gray shale which contains no visible fossils. The limestone in the middle of this covered section contains fusulinids, crinoids, brachiopods, and ramose bryozoans. The slope of the upper portion of the covered section indicates it may be alternating limestone and shale. This portion is considered to be the Iowa Point Shale Member displaying the same mid-portion limestone seen at the Moline Quarry and perhaps thicker limestones in the upper part.

The Hartford Limestone is about 4 ft (1.2 m) thick with moderately thick beds. It is brown on fresh surfaces weathering yellowish. It contains an osagite at the top and is burrowed probably by large pinna-type clams. It also contains Amblysiphonella, brachiopods, crinoids, fusulinids, and echinoids.

The Hartford is separated from the Ervine Creek Limestone by 8 in (20 cm) to 2 ft (61 cm) of limy shale which may represent the Calhoun Shale or more likely, is shaly facies of the Ervine Creek such as observed at the Moline Quarry.

The Fudge Quarry-Middle Caney Creek section is the last certain Curzon location the writer has identified in southern Kansas. An Ervine Creek exposure at Hewins, sec. 1, T. 35 S., R. 9 E., in Chautauqua County may be overlaid by Hartford and Curzon Limestones. However, this exposure lacks any shale separations to assist distinguishing the limestones, the lower portion of which contains both the sponge, Amblysiphonella and a heavy concentration of algal filaments of the type frequently encountered in the Ervine Creek. Amblysiphonella occurs in both Ervine Creek and Hartford. At Hewins, the absence of Amblysiphonella in the upper portion of the limestone is the only potential indication of Curzon Limestone. The zone above the limestone consists of sandstones, shales and sandy limestone and could represent either the Severy Shale or an arenaceous facies in the upper Topeka in which clastic sediment from the Ouachita-Arbuckle Mountains overwhelmed carbonate production in a near-shore area during the late Topeka time.

Shannon (1954), in describing the geology of the Pawhuska area, Osage County, Oklahoma, identified the Pearsonia Limestone as a "massive bed, 2.75 ft (84 cm) thick of dark, blue-gray, fine grained, dense, brittle limestone which weathers brownish-gray...topped by 0.8 ft (24 cm) of fusulinid bearing limestone weathering thin bedded." He noted that "the Pearsonia Limestone disappears southward, the southernmost exposure being in Section 28, T. 26 N., R. 8 E.," which is about 23 to 24 mi (37 to 39 km) south-southwest of the Hewins, Kansas site. Shannon noted that the Pearsonia is 30 to 45 ft (9 to 14 m) below the Turkey Run and that the Little Hominy Limestone is 20 to 35 ft (9 to 10 m) below the top of the Pearsonia. He identified the Little Hominy (p. 83-84) as the first limestone above a 21 ft (6 m) thick shale that overlays the Deer Creek Limestone. Shannon's composite section which is included in Appendix I makes it apparent that the Pearsonia is correlative with the Curzon as has been indicated in Figure 4. It represents the thinning and disappearance of the Curzon Limestone as it approaches the southern shore area where an influx of clastic materials overwhelmed the production of limestone. In the measured section shown in Appendix I, clastic sediments comprise 68.11% of the interval between the base of the Little Hominy (Hartford) Limestone and the top of the Turkey Run Limestone. Carbonates comprise 6.25% and 25.64% is covered and composition is unknown.

The Iron Oxide Question

It has been noted that the Curzon Limestone weathers to some shade of red-brown-yellow at all exposures and is brown colored on unweathered surfaces. The coloring is attributed to the presence of iron oxide in the sediment by Weller (1960, p. 132) who noted that "tiny amounts of iron will color sediments and rocks brilliantly." The presence of iron oxide (Fe_2O_3) in the Curzon Limestone has been described and quantitative analyses have been presented in Table 2. The calculated arithmetic mean Fe_2O_3 content of the 33 samples is 2.61%. Runnels and Schleicher (1956) analyzed 325 limestone samples from eastern Kansas and obtained an arithmetic mean of 1.32% Fe_2O_3. Using a weighted mean to allow for differences in thickness of beds sampled resulted in a value of 1.14%. Their samples, excepting three of Mississippian age, were all from Pennsylvanian and Permian strata. The only trend found was a generalization that "any ledge of rock was generally greater in both calcium carbonate and trace element content and of lower content in other major constituents (including Fe_2O_3) towards its southern end as compared to the northernmost exposures". The only samples taken by Runnels and Schleicher along as lengthy an outcrop strike as that of the Curzon were on the Permian Fort Riley Limestone and Pennsylvanian Plattsmouth Limestone. Fe_2O_3 analyses for those beds are shown in Table 4. Other than the generalization noted, Runnels and Schleicher discovered little or no correlation between chemical constituents and stratigraphic or geographic position of the samples analyzed. It becomes apparent that the Curzon Limestone is significantly higher in iron-oxide content than other Pennsylvanian-Permian limestones in eastern Kansas and that the red-brown in the Curzon is the result of its iron oxide content.

Merriam and Pena Daza (1978, p. 58) used Runnels and Schleicher's data to test for recurring chemical contaminants in a cyclic sequence and determined no systematic relationship between the type of limestone that occurs in a cyclothem and its chemical composition. Cubitt and Merriam (1979, p. 638-639) noted, however, that sampling and analytical techniques used by Runnels and Schleicher are suspect and that definitive results require resampling; especially because other workers have reported recognizable relationships.

In their study of carbonate chemical relationships, Merriam and Pena Daza (1978, p. 54) did recognize strong, directly proportional correlations between Fe_2O_3 and MgO,

Table 4. Fe_2O_3 content in other upper Pennsylvanian and lower Permian limestones in eastern Kansas (after Runnels and Schleicher, 1956).

Location Sec-Twp-Rge East	Plattsmouth % Fe_2O_3	Location Sec-Twp-Rge East	Fort Riley % Fe_2O_3
24-2-21	0.14	34-5-6	0.41
26-4-21	0.86	17-9-4	0.34
13-5-21	1.78	15-9-4	0.89
7-6-21	1.28	10-12-5	1.34
14-9-21	0.84	12-12-5	1.03
6-11-21	1.53	3-13-8	0.38
21-11-17	1.57	32-14-7	0.94
1-12-19	1.83	29-16-7	0.91
25-12-19	1.01	20-17-6	0.89
32-12-18	1.07	36-22-7	0.62
4-13-19	1.01	6-22-6	0.65
22-14-18	0.44	2-24-6	1.03
3-18-16	1.32	5-26-6	0.84
14-21-15	1.29	26-27-4	0.56
2-22-15	2.77	9-28-4	0.46
23-27-13	1.21	2-28-4	0.99
3-28-12	1.30	26-32-4	0.69
11-28-12	1.38	22-32-4	0.50
21-29-13	0.62	28-34-5	0.86
3-20-12	0.67		
3-33-11	1.55		
Mean	1.26	Mean	0.75

SiO_2 and Al_2O_3. The study by Cubitt and Merriam (1979) had a similar aim, to search for geographic and geologic correlations to chemical constituents, but examined Upper Pennsylvanian clastic sediments rather than carbonates. Using principal components analysis, they determined a moderate positive relationship between clay-mineral composition in the shales and both total iron oxides and chlorite. Likewise, a moderate positive correlation was shown to exist between samples deposited in a shallow-water versus deep-water environment and both total iron oxides and zirconium which they note is usually a detrital mineral deposited in outside shales (Cubitt and Merriam, 1979, p. 634-638).

Weller (1960, p. 134-135) suggested several reasons for the presence of iron oxide in sediments. They include:

> (1) The color may drive from erosion of older red-beds. During fluvial transport, the red colors became brown because of hydration of hematite to limonite.
> (2) Alternate wetting-drying conditions at the site of deposition.
> (3) Color is inherited from residual soils. The development of tropical laterites leaves a residue high in iron and aluminum oxides which may erode and be added to ongoing sedimentation. Similarly, the development of terra rossa in karst areas leaves an iron oxide containing residue on the surface and in fractures, joints, ect., of dissolving limestones (Thornbury, p. 319)
> (4) Post-burial increases in temperature and pressure and some or all ferric oxide could dehydrate and form "red beds"
> (5) Color developed after erosion and exposure to surface elements. Oxidation of such exposures alters ferrous iron to limonite.

The fifth option may be applicable to the Curzon Limestone. The only truly unweathered sample of Curzon examined was from the Lacy core. The surface of the Curzon and the overlying strata were iron stained but the bulk of the Curzon was a gray limestone. The writer has not been able definitely to identify the Curzon Member in subsurface cuttings from the lower Topeka since the entire limestone section is generally gray. The color phenomenon then seems to be restricted to the outcrop area and sections which at some time, pre-burial or post-burial, have been near to, or exposed to, atmospheric or oxidizing conditions.

The source of the iron oxide which colors the Curzon could be in any or all of several sources. Analyzing sedimentary rocks, Mason (1958, p. 147) showed that the average shale contains 7.44 times the quantity of Fe_2O_3 as occurs in the average limestone (4.02% vs 0.54%). The average shale was found to contain 2.45% FeO whereas none was reported in the average limestone. Mason (p. 159) reported the average content of iron in sea water is about 0.008 ppm whereas the average content in river waters is about 1 ppm...125 times greater. Iron, in both valence states, is far more soluble in acidic than in basic solution. Because sea water is slightly alkaline, it follows that any iron dissolved in streams would be precipitated quickly when the streams emptied into a marine or lagoonal environment (Mason, p. 159). The range of pH in tropical areas is wide. Kerr (1955, p. 537) noted that a pH range from below 3.0 to more than 9.0 has been reported in tropical soils. It therefore seems likely that sufficient iron could have been mobilized under acidic continental conditions during Virgilian time to have been transported and accumulated in strata then being deposited. Iron oxides could have thus been deposited on and in the Curzon Limestone mud as it was accumulating and also could have been deposited in the Jones Point Shale and leached downward. A. W. Walton (pers. comm., 1989) pointed out that growth of ferroan calcite and ferroan dolomite in limestone is a continuous process and would cause iron content to increase with time. Leaching from overlying beds as well as movement of groundwater would contribute iron to this process.

The source of iron may have been from weathering of granitic rocks. Runnels and Schleicher (1956) failed to analyze for zirconium, an accessory mineral in granite, but Cubitt and Merriam (1979, p. 635) noted the presence of zirconium, germanium, and gallium; all with a moderate positive correlation with iron oxides in Upper Pennsylvanian shales. Mason (p. 174) noted that bauxites (laterites) often contain a concentration of gallium and Day (1963, p. 240) pointed out that the germanium in soils and sediments may have been coprecipitated with ferric hydroxide. Day also commented that germanium may be "concealed" in silicate minerals and that granitic rocks seem to be richer in germanium than alkaline ones. Day (p. 236) noted that zirconium minerals seem to form in the last stages of magmatic crystallization, as does quartz. This would indicate that both zircon and germanium would be among the later minerals released during the weathering of granite to a laterite.

The Precambrian granites of the Ozark Uplift and Ouachita/Arbuckle mountain ranges are suggested as a source of the iron which is concentrated in the Curzon Limestone. The iron content in ferromagnesian minerals associated with granitic rocks would be freed during weathering under tropical conditions. Weathering, leading to formation of a laterite, would free all the elements mentioned. Figure 9 is a map of Midcontinent geography near the close of Virgilian time and shows the proximity of granitic highlands to the Virgilian sea in Kansas.

A possible auxiliary source for the iron may be granitic rocks of the Canadian Shield or the Sioux Quartzite to the north (Bunker and others, 1988). Weathering of either, granite or the Sioux Quartzite, could account for both the iron and silica in the Curzon. Figure 9 is Prather's (1985) tectonic map of the Late Pennsylvanian and graphically displays areas where granites or Sioux Quartzite were available and which geographically close enough to eastern Kansas to serve as a sediment source.

Another possible auxiliary source of iron could be the proliferate algae and fusulinid populations which flourished in the Curzon shallow waters. Iron removed from solution is

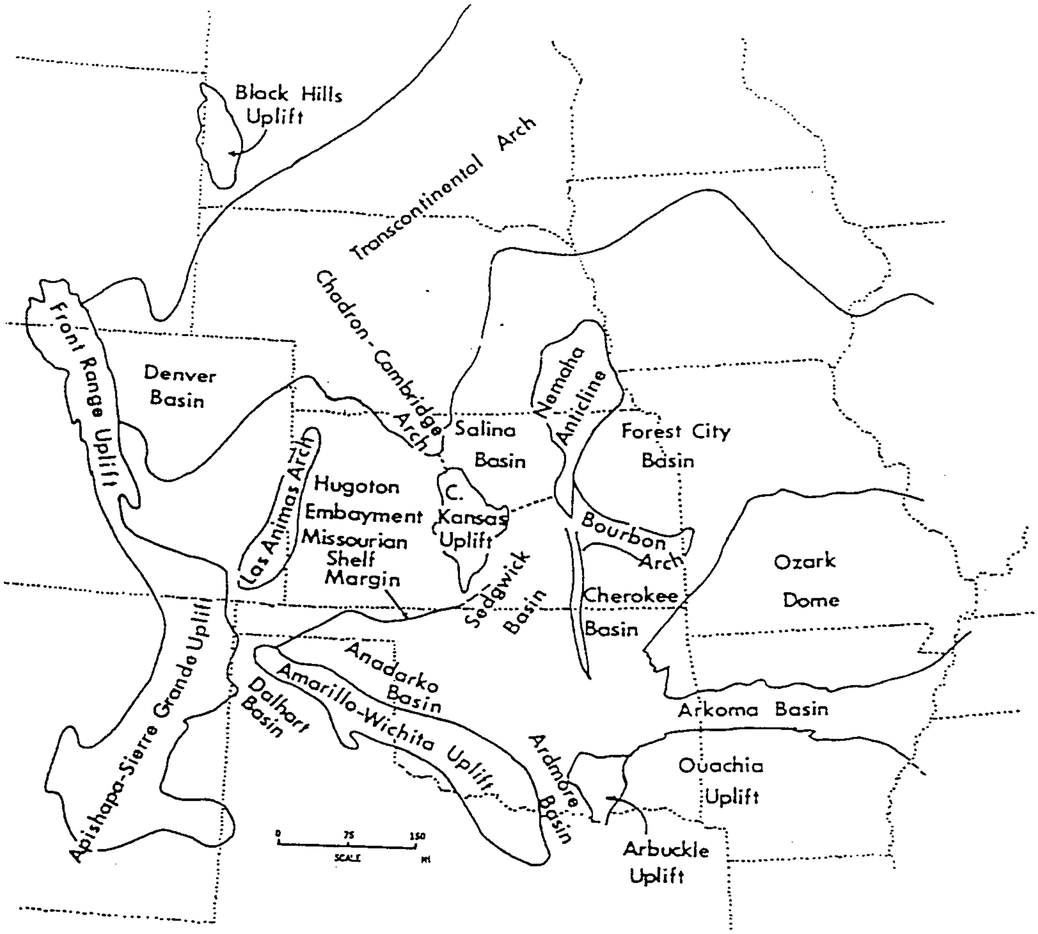

Figure 9. Late Pennsylvanian tectonic elements in Midcontinent (from Prather, 1985).

necessary for both plants and animals in manufacturing porphyrin complexes which are involved in the creation of both chlorophyll and hemoglobin (Day, p. 332). The volume of fossil biota contained in the Curzon Limestone could account for the accumulation of porphyrin compounds which are stable in the geologic environment and identifiable in crude oil. Chemical alteration of porphyrins could contribute to a small but measureable increase in iron in the sediment.

That subaerial exposure occurred at several sites along the Curzon shoreline has been shown by the presence of a paleosol and by desiccation cracks. It is suggested, therefore, that the iron concentration in the Curzon was caused by frequent wetting and drying in a tropical coastal, tidal-flat environment and that the iron was furnished from streams having their sources in granitic or metamorphic rock areas to the south, east, and possibly to the north. Such iron present was precipitated as the stream water encountered the higher pH salt water. Later, iron similarly collected in the Jones Point Shale leached downward and contributed to the total iron content of the Curzon. The precipitation of iron from all freshwater sources as they spread along the coast would explain the visual paucity of iron content in the lower Topeka farther to the west in the subsurface.

Tectonic and Eustatic Aspects

The lower Topeka Limestone Formation is unusual in its apparent start-stop sequence of deposition. Heckel's (1979, p. 1047) well-known sealevel curve (Figure 4) a roughly symmetrical cissoid, can be used to explain a simplified megacyclothem by a single marine transgression-regression which results in changing deposition environments from non-marine to deep water-offshore to nonmarine. Topeka Formation cyclicity, whereas being part of a general late Paleozoic shallowing trend, does not follow Heckel's idealized curve.

The Topeka Formation is separated from the underlying Deer Creek Formation by a well-defined outside shale, the Calhoun. Renewed marine transgression initiated deposition of the Hartford which was interrupted by an out-of-cycle regression which resulted in deposition of the Iowa Point Shale Member, another outside shale. The Hartford then is a complete cycle within itself, lying between two outside shales. An earlier similar reversal may be seen within the Calhoun Shale. Allen (1990, p. 79) identified a thin but laterally extensive shallow-water marine limestone within the Calhoun Shale. That limestone, informally named the "Tonovay", represents a temporary transgression within the overall regression that resulted in the Calhoun. An apparently rapid transgressive period stopped deposition of the Calhoun and allowed formation of the Hartford Member.

Similar conditions occurred during the time of Curzon

Limestone deposition and it too, formed a complete cycle, although not as complete as the Hartford because the Curzon regression failed to reach a level which would initiate deposition of an inside shale. The clay parting frequently encountered in the Curzon Limestone seems to mark the change from a transgressive to a regressive phase. Curzon deposition was followed by a double sequence of inside shale-middle limestone before maximum transgression created conditions appropriate for deposition of the Holt Shale, a core shale. Interestingly, a similar repetition of two middle limestones recurs in the overlaying Howard Formation (D. F. Merriam, pers. comm., 1989). After Holt deposition, normal end-of-cyclothem regression commenced to complete the Topeka at the next major outside shale.

Heckel's sealevel curve represents an idealized situation controlled by eustacy influenced by continental glaciation. The Topeka Formation differs from that ideal because of local tectonic activity which seemingly resulted in relative changes of local sealevel during the lower two-thirds of Topeka time.

Bennison (1984) notes that the primary controls of sea-level changes throughout much of Pennsylvanian time in the Midcontinent are an interplay of short-term glacial eustatic and long-term tectonic events. Watney (1983) has suggested that the Precambrian Central North American Rift System was a major influence on later Paleozoic structures in eastern Kansas such as the Nemaha Uplift and associated folds. Lee

(1954) noted that although principle development of the Nemaha occurred between end of Mississippian time and deposition of earliest Pennsylvanian strata in eastern Kansas, that deformation continued by differential increments through the remainder of Pennsylvanian time into the early Permian. Berendsen and others (1988, p. 15) suggested that an ancestral Nemaha structure existed as early as Middle Ordovician.

Carboniferous continental plate collision between Gondwanaland and Euramerica as shown (Figure 10), began in Kinderhook and continued to Osagean (Ross and Ross, 1987) and through mid-Wolfcampian time (Ball, 1985). The collision resulted in the formation of the Ouachita and Arbuckle Mountains in now southern Oklahoma and in doing so created one of the clastic sediment source areas for eastern Kansas (Bunker and others, 1988). Two major periods of tectonic folding/uplift in the Arbuckle region occurred during Virgilian time, one during the middle and one at the end of the Virgilian (Ham, 1973, p. 14). The depositional basin north of the Ouachita Mountains including southeastern Kansas had been filled by clastic sediments eroded from the Ouachitas during Morrowan time when deltaic sandstones and marine clastics were deposited on the carbonate platform in southeastern Kansas (Watney and French, 1988). East-central and northern Kansas were marine with some clastics and marine limestones. Algal carbonate banks formed in eastern Kansas

Figure 10. Middle and Late Pennsylvanian plate configuration showing position of U.S. Midcontinent (from Ross and Ross, 1987).

at that time (Rascoe and Adler, 1983, p. 995).

Arbuckle orogeny during the Virgilian changed the geography and the environment. Near the close of Virgilian time, most of eastern Kansas was semicontinental and forming coals, deltaic structures, and tidal flat deposition as illustrated in Figure 9. Widespread carbonates were deposited during high stands of sealevel (Rasco and Adler, p. 996). These high stands were caused by glacial eustacy. During this local eustatic and tectonic activity, much of Kansas and Nebraska was an open-sea carbonate platform which was slowly subsiding in a generally southwestern direction toward the Anadarko Basin (Toomey, 1966).

Bridge (1988) has identified a series of folds, faults trending N. 40° E., and an uplift which occurred in the area of northeastern Greenwood-southwestern Coffey Counties. He presented evidence for the tectonic stimulation of mud intrusions into consolidated but not lithified lime mud of the Hartford Limestone to create the previously referred to tepee structures. By analyzing time of paleochannel formation, T. E. Bridge (pers. comm., 1991) presented evidence that about one-half-way through Topeka Formation deposition, local tectonic activity occurred and the area was uplifted. He noted that local tectonic movement continued through Topeka deposition and that there is evidence of 30 ft (9 m) of movement during the remainder of Paleozoic time as locally preserved.

Barrs (1989, p. 13) noted that the CNARS rift zone was offset by younger faults along the Central Kansas-Bourbon Arch complex and that both trends are interpreted as continental scale conjugate wrench-fault zones that were periodically reactivated prior to Middle Pennsylvanian time. The Virgilian tectonic collision which produced the Arbuckles probably reactivated these then dormant structures in eastern Kansas. The folding and faulting described by Bridge was a result. The uplift that Bridge ascribed to Virgilian local tectonism explains the evidence of subaerial exposure which has been described in the Curzon Limestone in northeastern Greenwood County and possibly explains the presence of the paleosol in the Curzon Limestone in Doniphan County. It also provides an adequate explanation for the repeated failure of an uninterrupted glacially induced eustatic megacyclothem which would correspond to Heckel's ideal sealevel curve. Although southern glacial retreat was producing a eustatic sealevel rise during the deposition of the lower Topeka Formation, periodic tectonic activity in eastern Kansas locally caused fluctuating shorelines and proximal ramp areas to remain above sealevel. This concept is supported by the evidence of subaerial erosion described and the shallow-water, intertidal zone facies identified in outcrop and thin-section descriptions.

The influence of plate collision-induced Arbuckle tectonism is also evident in joint and fault strike. Bridge

(1988, p. 30) reported that dominant joint sets in northeastern Greenwood County strike N. 40° E. and are parallel to subsurface faults. He noted also that a second joint set trends east-west and that series of discontinuous folds parallel both joint sets. Other faults mapped by Bridge trend N. 30° E. and N. 69° E. The writer measured joint directions in eight locations between T. 12 S., and T. 25 S. Joints at five locations trended between N. 30° E., one site showed a trend of N. 30° W., and two measured N. 70° E. Melton (1930) described joint systems from the Kansas border to the Arbuckle Mountains as having a median strike of N. 35° W. and en echelon faults in Osage County, Oklahoma as having mean strike of N. 20° W. Complementing joints on Melton's map measure N. 68° E. None of these measurements are at such odds as to require an explanation other than the periodic wrench-faulting proposed by Barrs (1989) to have occurred in eastern Kansas. Differences in direction of strike are explainable by tectonism at different times under different amounts of sedimentary loading.

CONCLUSIONS

The Curzon Limestone Member of the Topeka Formation was deposited in an initially transgressive marine environment caused by glacial melting in the southern hemisphere. Another minor transgression had occurred with the beginning of Hartford Limestone deposition, but was interrupted by possibly regional tectonism associated with the plate-induced orogeny to the south. The Iowa Point Shale Member, an outside shale, was deposited during the interval needed for rising sealevel to catch up with the newly uplifted shoreline.

As sealevel rose, Curzon Limestone deposition was initiated and transgressed eastward. About two-thirds through Curzon time, local tectonism, responding to regional compression, uplifted the surface sufficiently to halt limestone formation in most areas along the shoreline and cause deposition of a mudstone which had its source in continental sediments furnished from the Ouachita Mountains, Ozark Dome, and possibly from Siouxia. These stream-borne sediments brought in dissolved iron compounds, iron-oxide particles, and clays formed by decomposition of granitic and older sedimentary rock.

Sealevel continued to rise at a slower rate in response to continued regional uplift and water remained sufficiently deep to form a wavy-bedded regressive type limestone influenced by proximity to shore. Local renewed uplift subaerially exposed the uppermost Curzon Limestone for a long enough period to form and preserve local soil horizons, desiccation features, and intertidal zone biotic hash preserved in swash zones and strand lines. The shallow lagoonal to dry land environment continued to collect iron oxide from continental sources to darken the lime mud surface. Bioturbation, shoreline washing, and normal infiltration of surface water assisted in moving the iron deeper into the mud. Local tectonic adjustment in northeastern Greenwood County at or near this time caused local faulting and folding and permitted the rapid cutting of new stream channels.

Sealevel continued rising, perhaps relatively accelerated by regional downwarping toward the Anadarko Basin or actually accelerated by increased glacial melting or by a combination of both.

Water deepened quickly enough to allow deposition of the Jones Point Shale and Sheldon Limestone, a middle limestone. Renewed regional tectonism seems to have interrupted the sequence temporarily and resulted in the deposition of a second set of inside shale (Turner Creek) and middle limestone (DuBois) after which maximum eustatic inundation was attained and the Holt Shale, a "core" shale, was deposited. A renewed glacial advance in the south then initiated shallowing and completed the remainder of the Topeka cyclothem. The proposed curve which summarizes the local sealevel fluctuations during deposition of the shoreward facies of the Topeka Limestone is shown in Figure 8.

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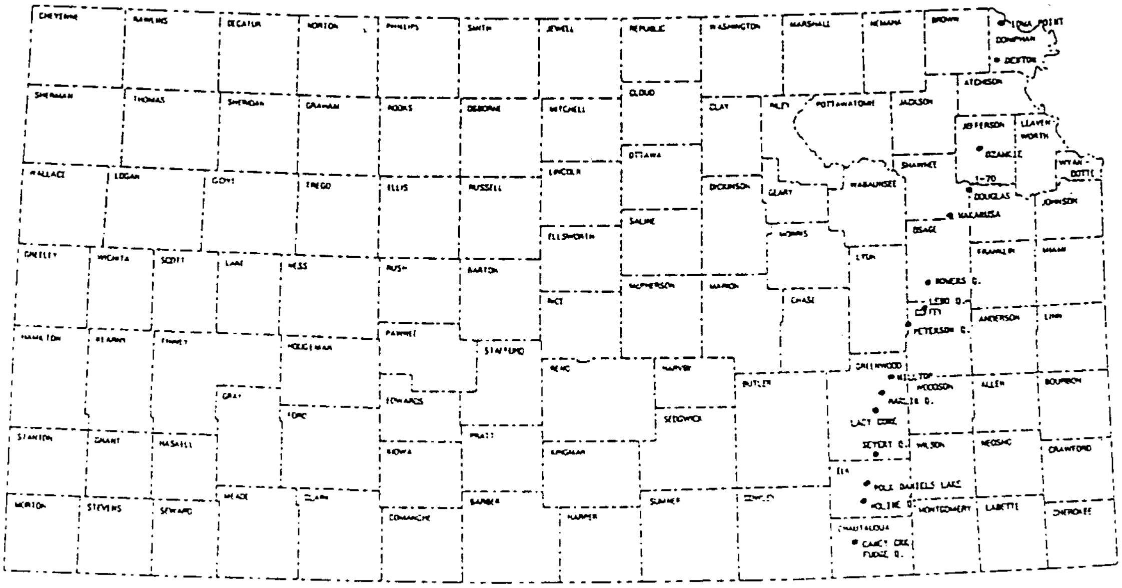
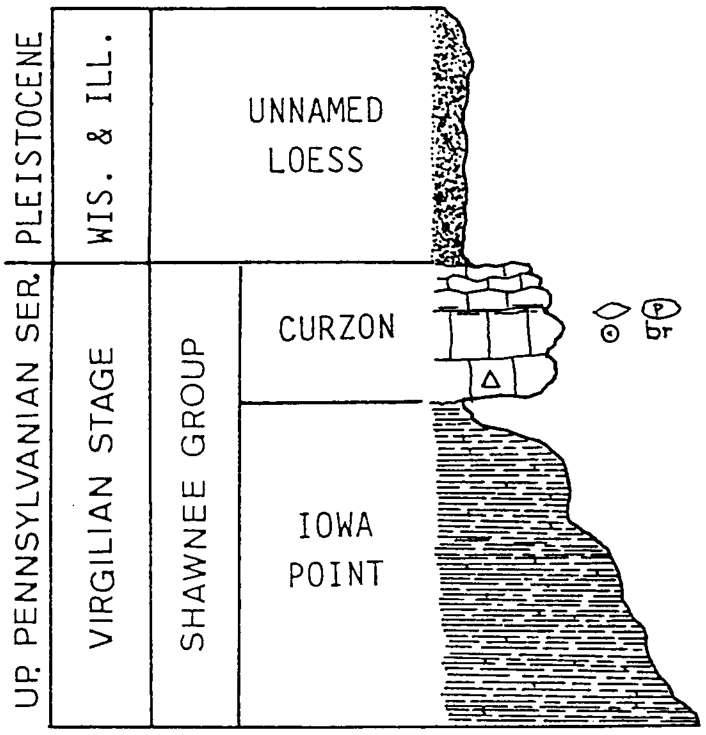
APPENDIX I

Selected diagrammatic outcrop descriptions

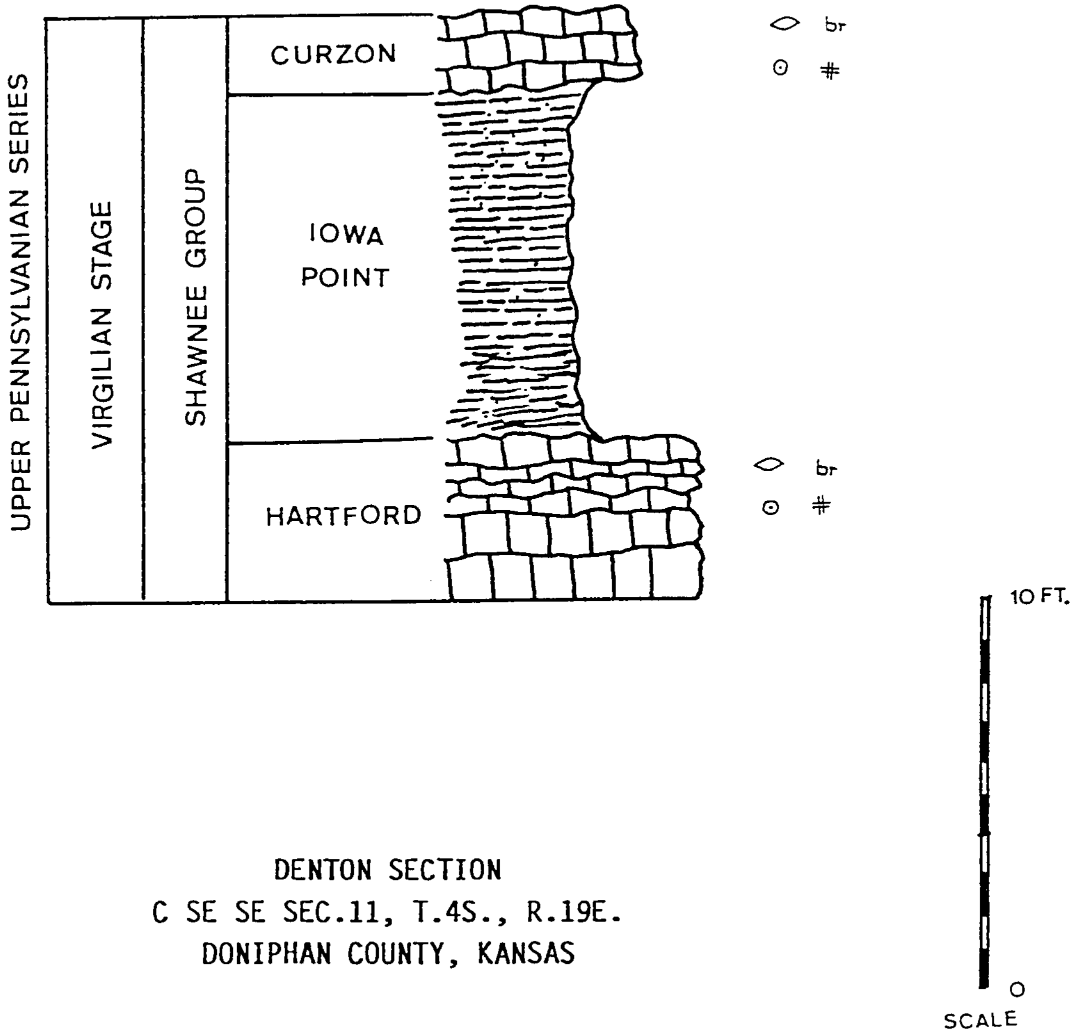
Explanation

Osagia	⬭	Colonial coral	✿
Clams	◡	Pellets	Ⓟ
Fenestrate bryozoans	#	Ichnofossils (trails, tracks, & burrows)	TTB
Ramose bryozoans	Y		
Fusulinids	⬭	Chert	△
Brachiopods	br	Soft-sediment deformation	▧
Algae	✳	Fractures	▥
Echinoids	☼	Crossbedding	▨
Gastropods	@	Coal	▭
Crinoids	⊙	Limestone	▦
Ottonosia	⬬	Algal limestone	▦
Amblysiphonella sponge	$	Dolomite	▨
Terrestrial plants	✿	Sandstone	▒
Solitary coral	♁	Shale	▤
Trilobite	⌓		





IOWA POINT SECTION
C SE SW SEC.25, T.1S., R.19E.
DONIPHAN COUNTY, KANSAS



DENTON SECTION
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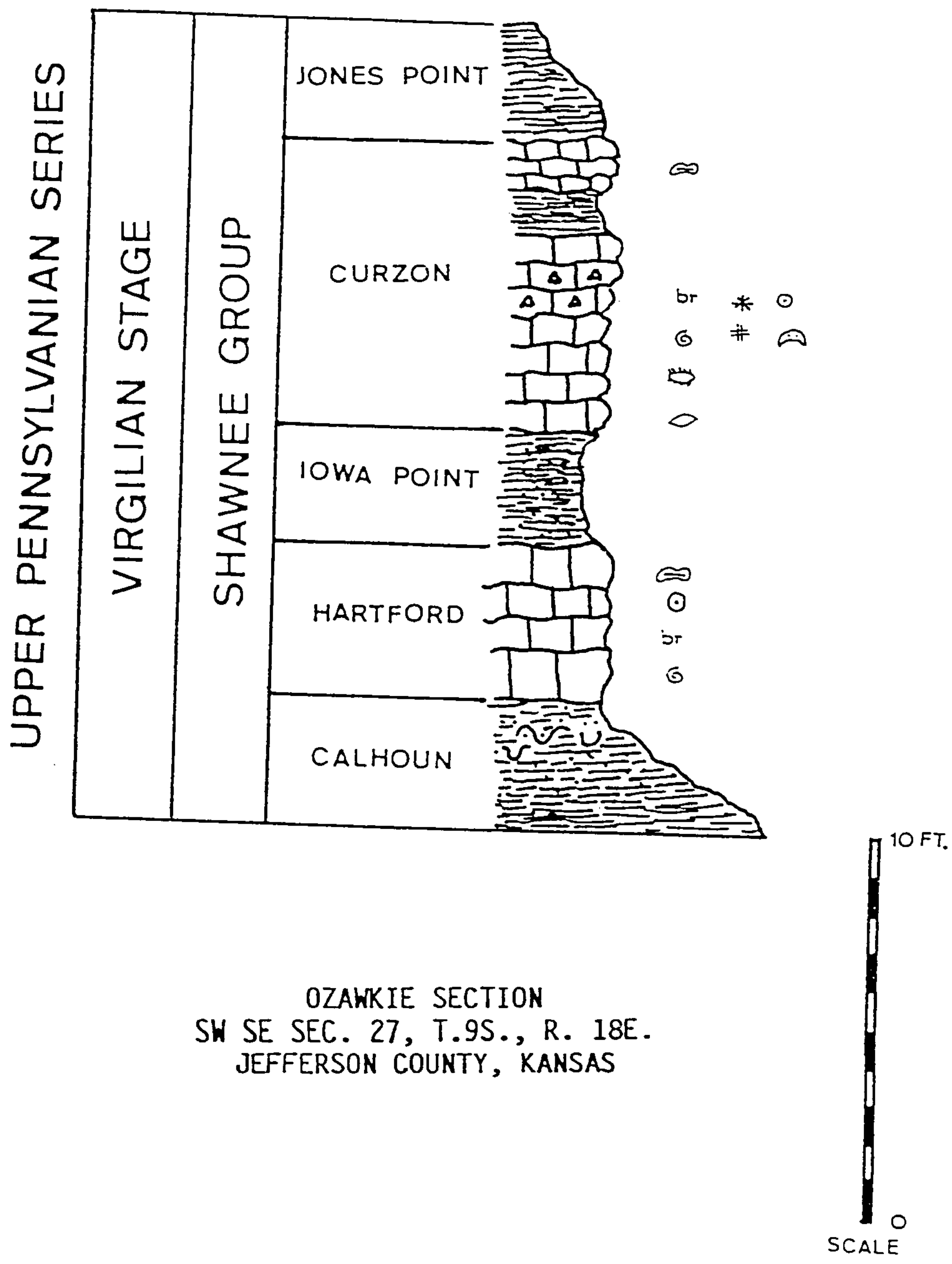
DONIPHAN COUNTY, KANSAS



OZAWKIE SECTION
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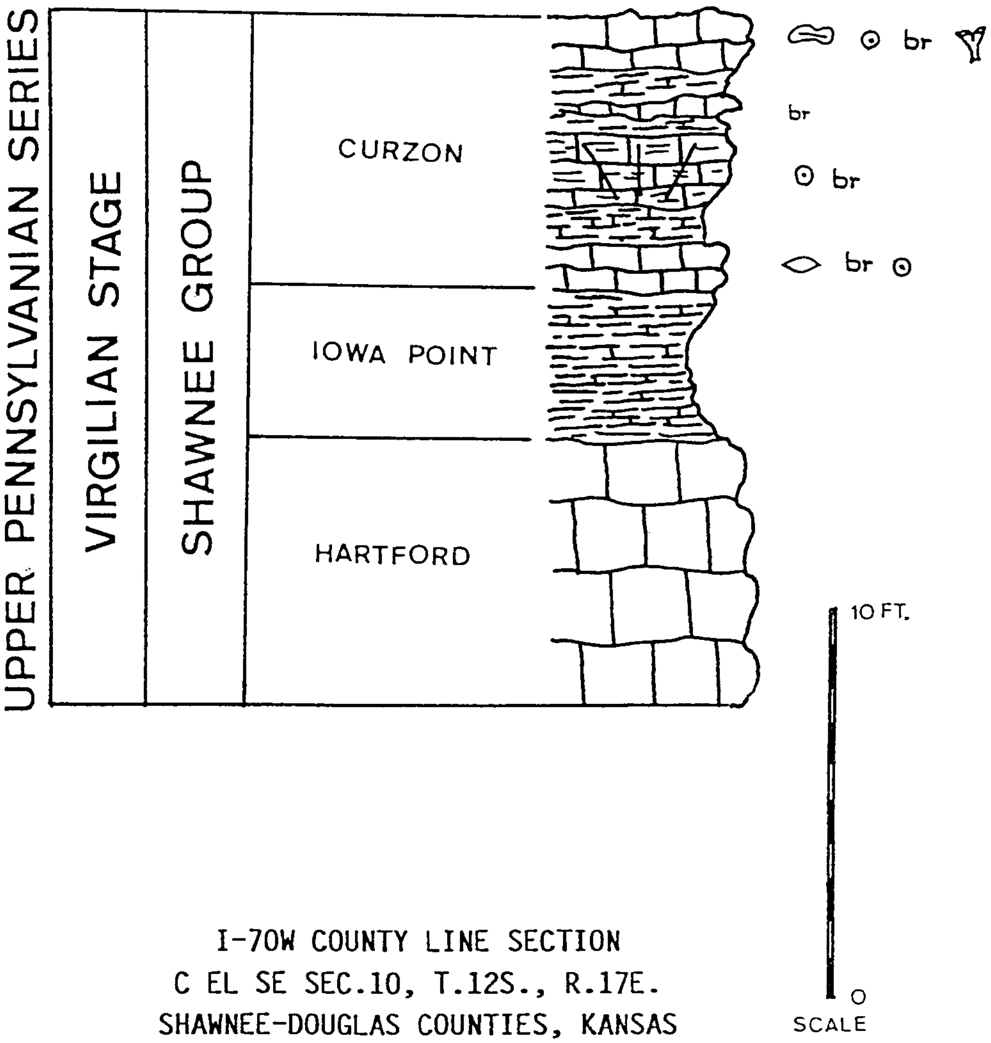
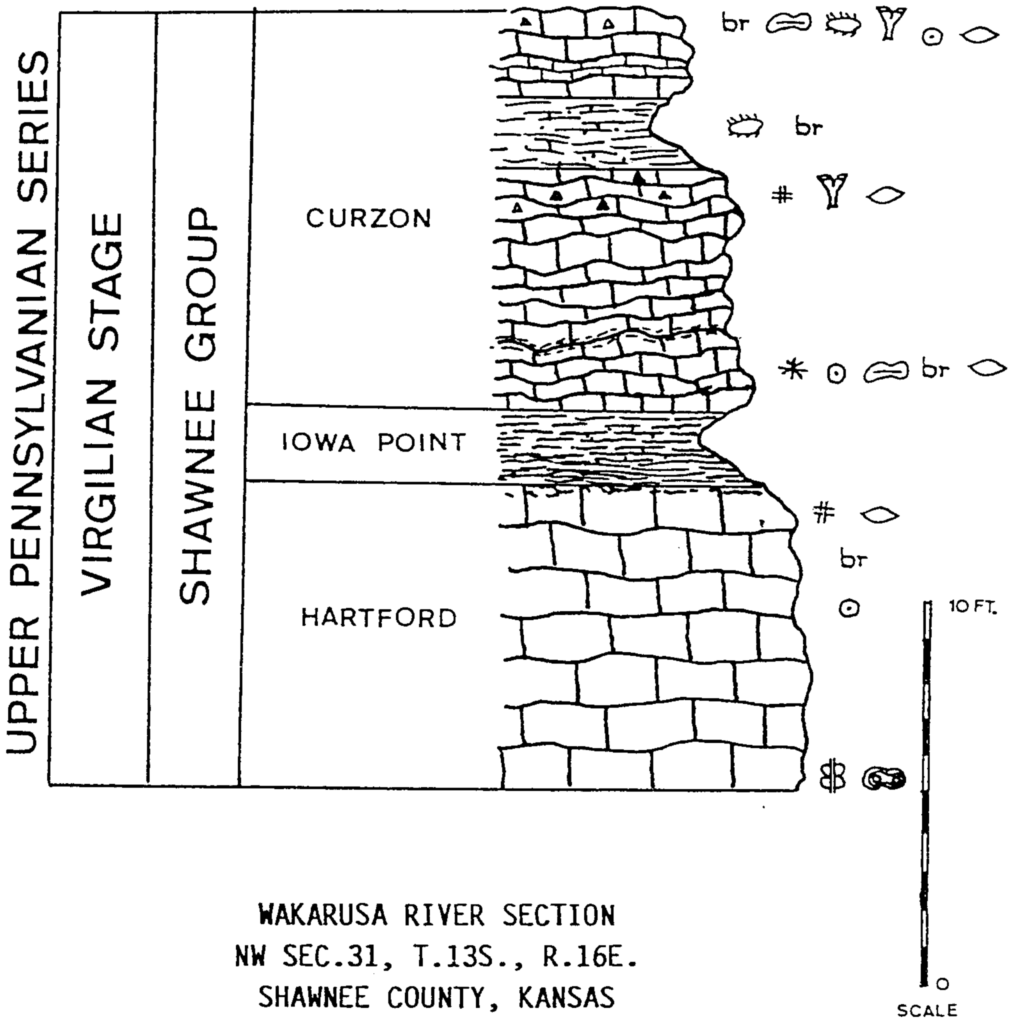
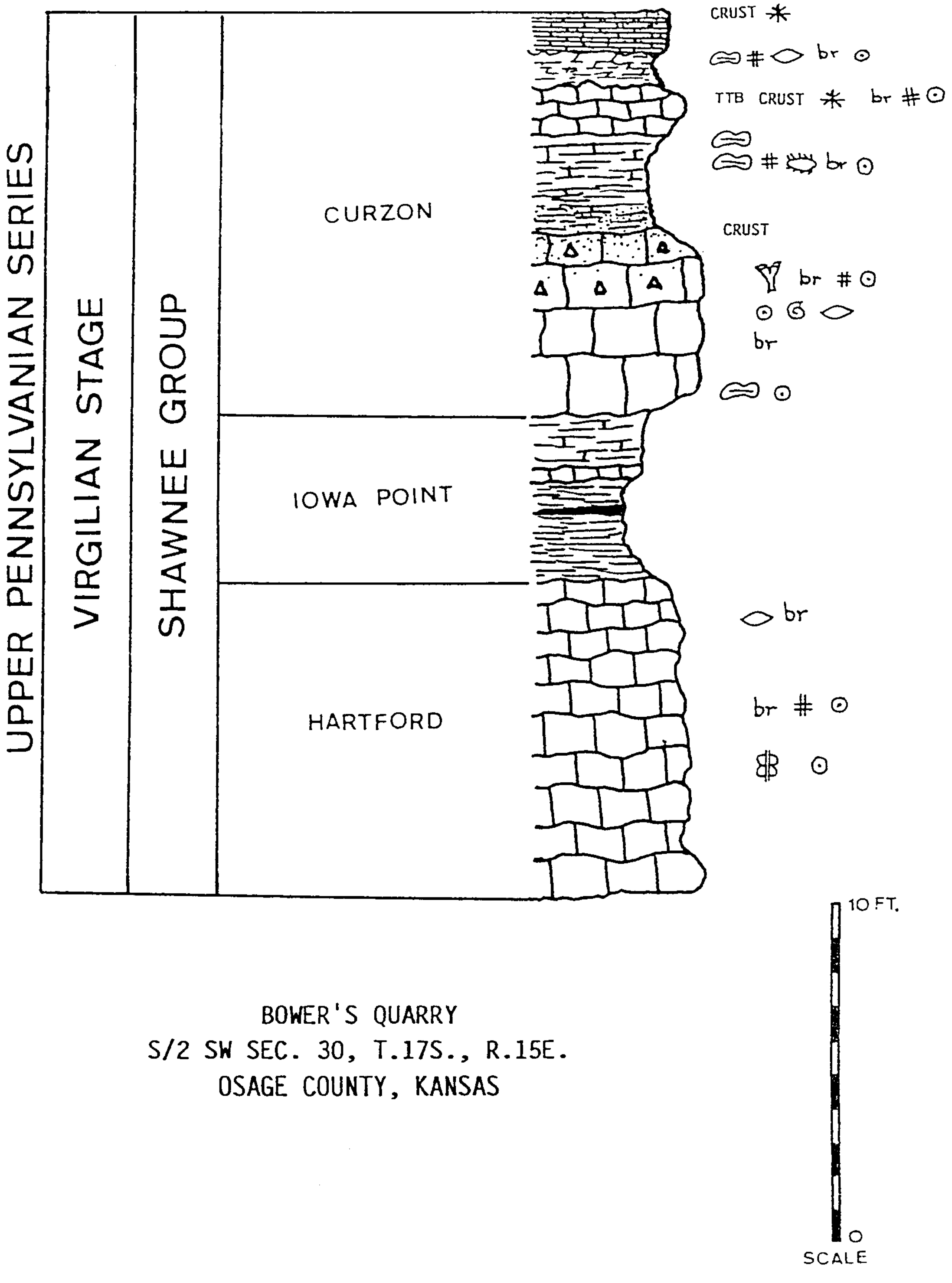
JEFFERSON COUNTY, KANSAS



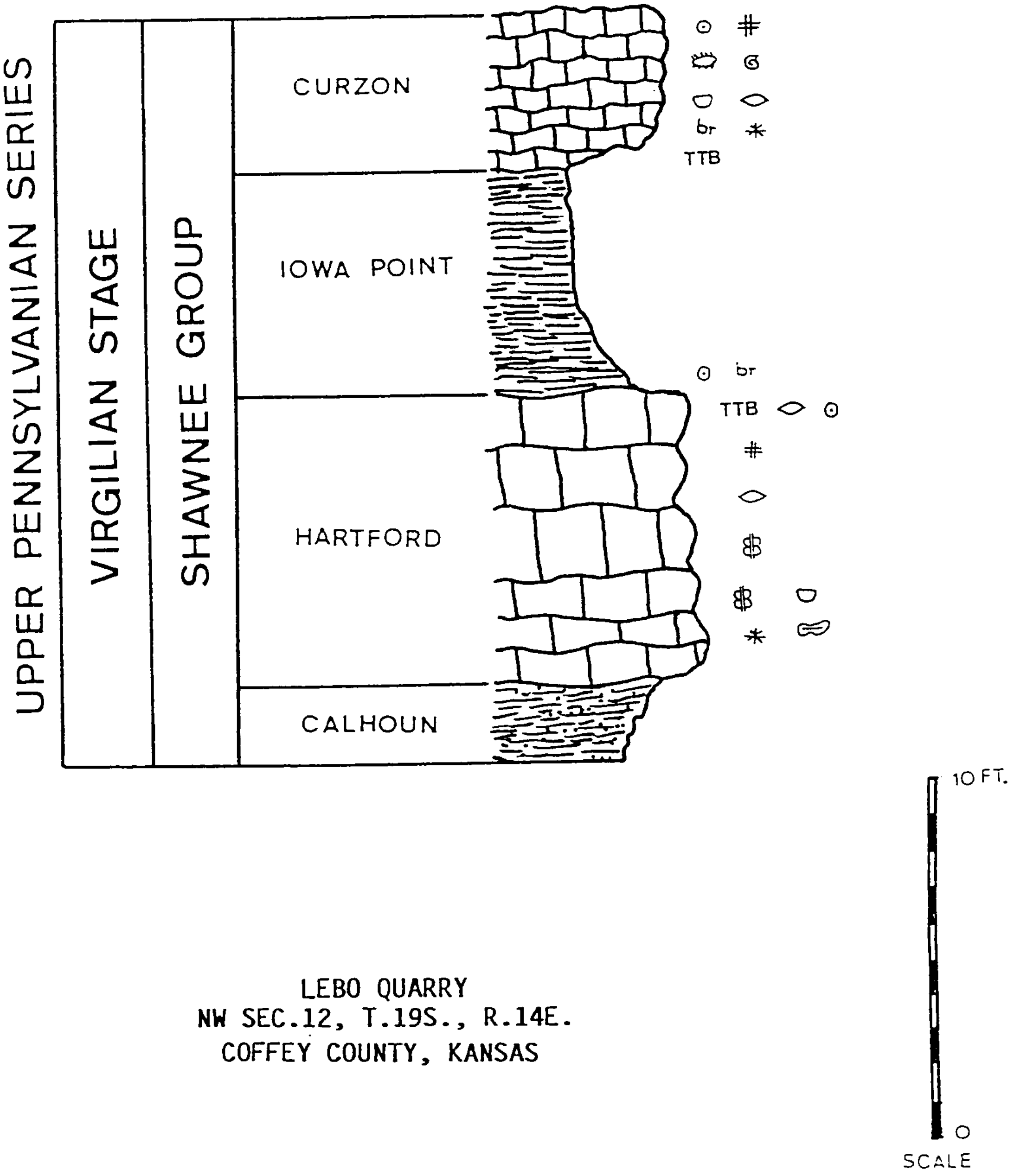
I-70W COUNTY LINE SECTION
C EL SE SEC.10, T.12S., R.17E.
SHAWNEE-DOUGLAS COUNTIES, KANSAS



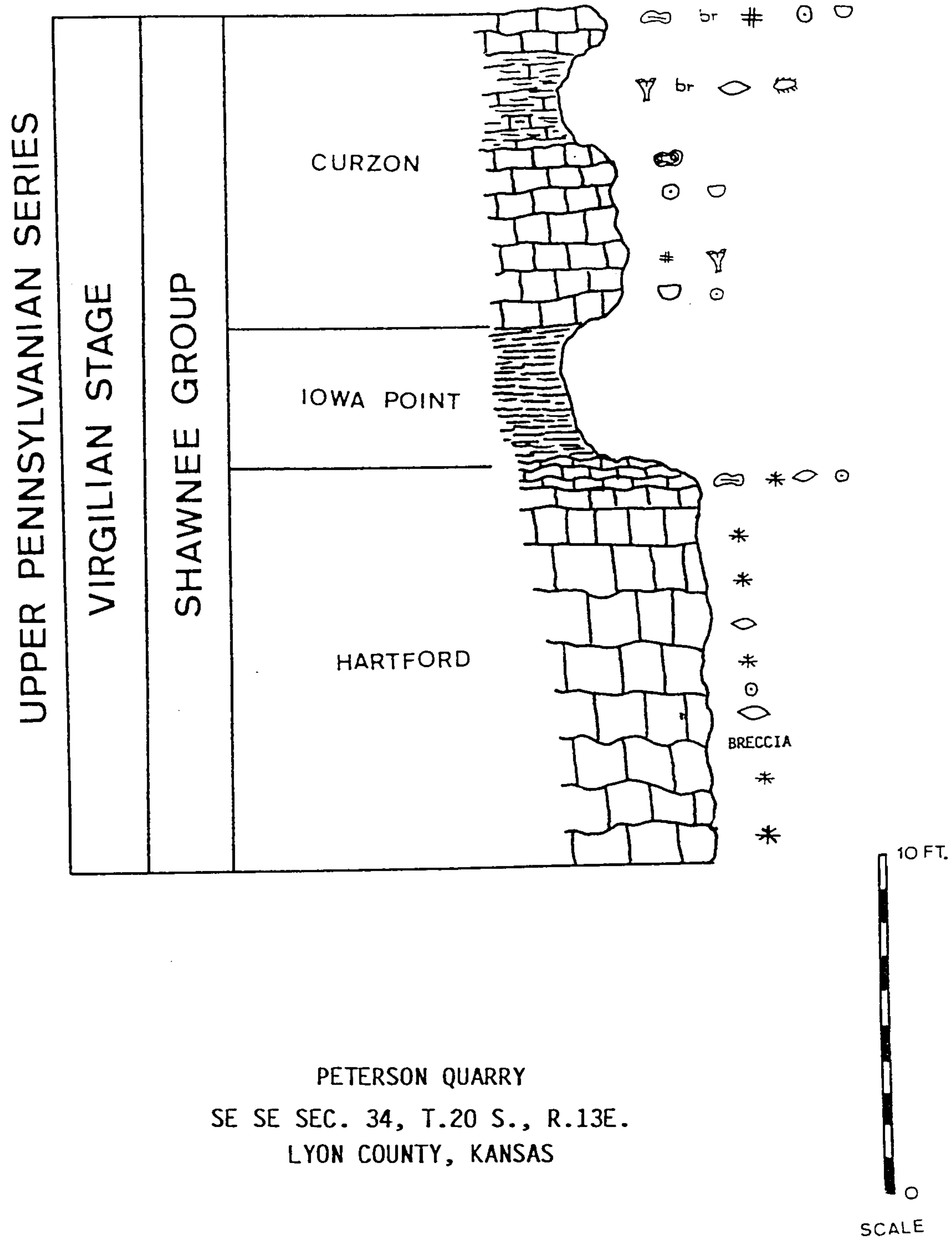
WAKARUSA RIVER SECTION
NW SEC.31, T.13S., R.16E.
SHAWNEE COUNTY, KANSAS



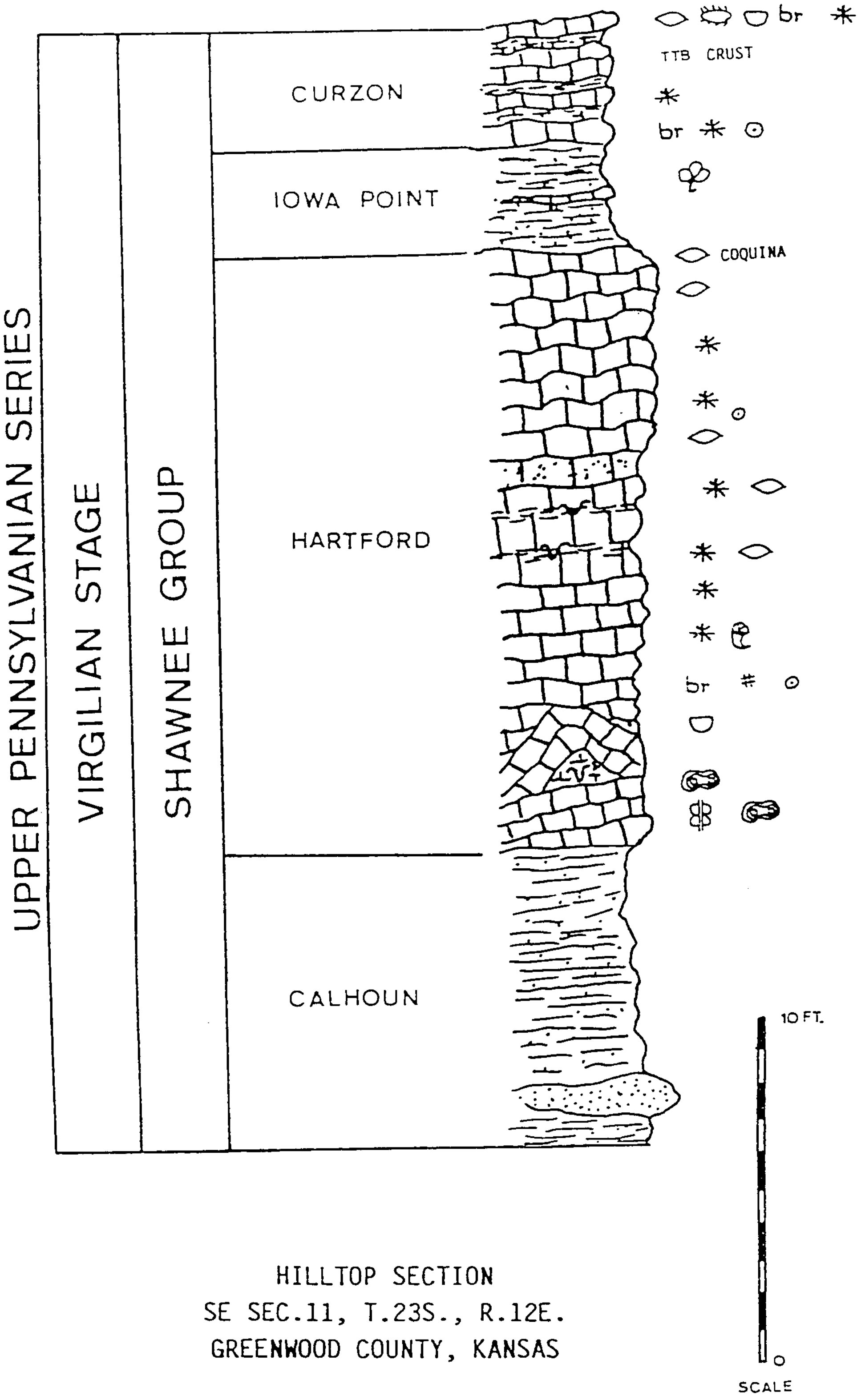
BOWER'S QUARRY
S/2 SW SEC. 30, T.17S., R.15E.
OSAGE COUNTY, KANSAS



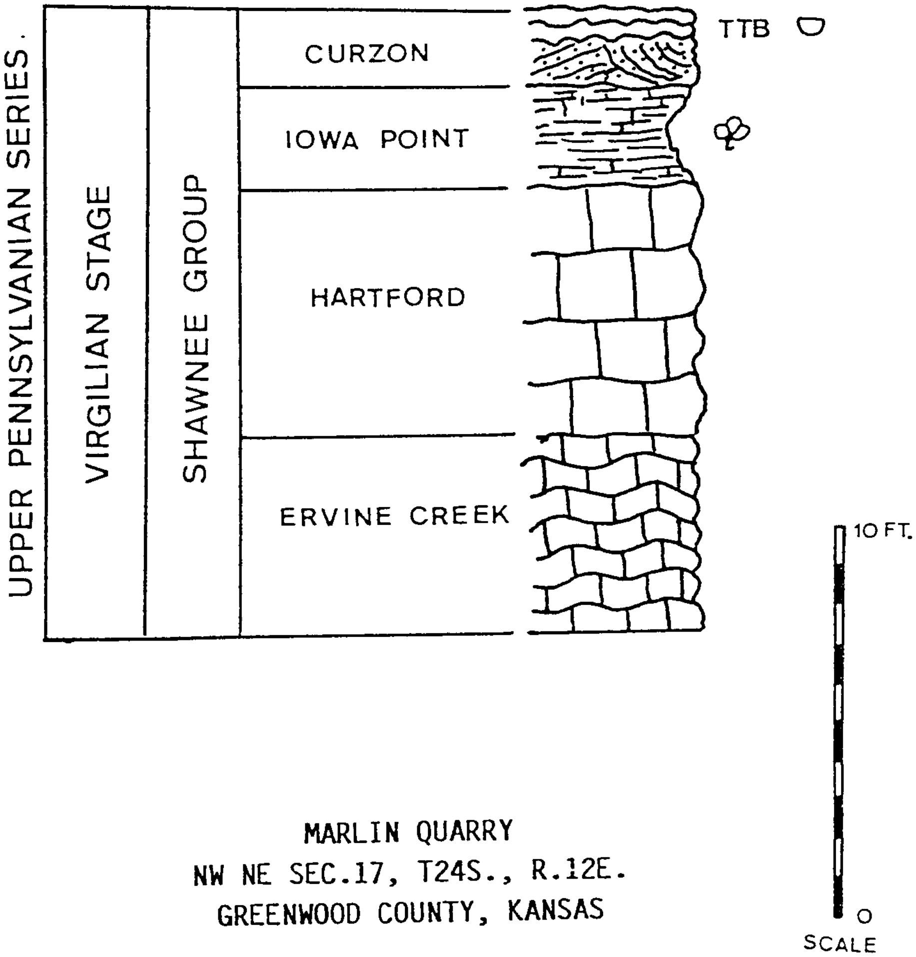
LEBO QUARRY
NW SEC.12, T.19S., R.14E.
COFFEY COUNTY, KANSAS



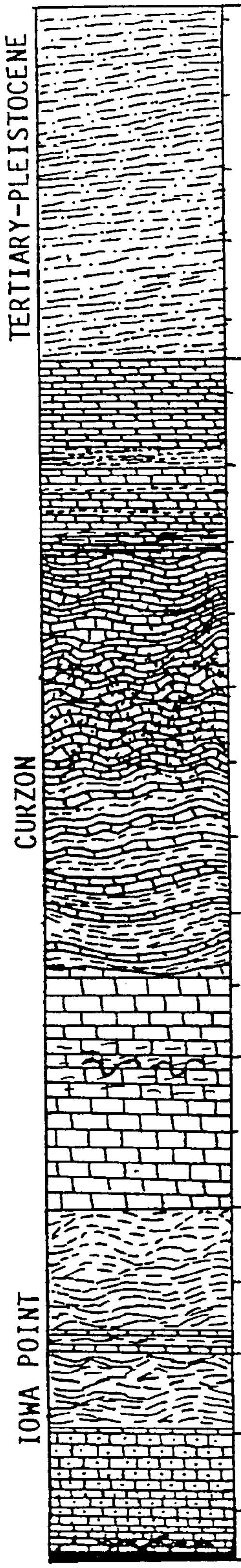
PETERSON QUARRY
SE SE SEC. 34, T.20 S., R.13E.
LYON COUNTY, KANSAS



HILLTOP SECTION
SE SEC.11, T.23S., R.12E.
GREENWOOD COUNTY, KANSAS



MARLIN QUARRY
NW NE SEC.17, T24S., R.12E.
GREENWOOD COUNTY, KANSAS



From top of core at 11.7 ft (357cm) to 16.7 ft (509cm), a predominantly yellow, non-fossiliferous , slightly silty, micaceous, calcareous claystone which contains sub-mm size specks of pyrite. Lamination develops at about 12.5 ft (381cm) and becomes more pronounced as depth increases. Becomes more silty with depth and assumes varved appearence at 14.6 ft (445cm). Indivld. bands are 1 to 2mm, thickening to 2mm to 5.5mm at 16 ft (488cm). The lower foot, to 16.6 ft (506cm) is increasingly silty and weakly indurated, forming a poorly lithified calcareous siltstone.

Contact is weathered, Fe-stained ls with osagite grains & fossil frags at 16.6 ft (505.4cm) overlying 3.75 in. (95.2mm) fine-gr, yel-gry, calc ls which has minutely frag fossils. One poss brach frag & one recog fusulinid at 16.89 ft (514.7cm). At 16.92 ft (515.6cm) is a 4 to 5 cm thk porous coquina zone comp of shell & spine frags & fusulinids. Vuggy to 17.5 ft (533cm), some vugs & fossil cavities spar filled. A few poss ooids. Ls is gry. From 17.4 to 17.7 ft (531 to 538cm), porosity lessens & vugs disappear. A fine gr, yel stained ls with a few fusulinids at 17.7 ft. From 17.7 to 17.9 ft (538 to 545cm) is gry to drk-gry, mica, siltstone to claystone which has a 2mm thk weathered surface atop 0.625 in (15.9mm) gry, mica, lamin claystone which has a 1cm thk near-black zone 0.5cm above underlying weathered ls which is 1.5in (3.8cm) thk & contains numerous fusulinids. From 18 to 18.9 ft (549 to 577cm), a light-gry, yel weathering, grainy ls containing numerous & broken fusilinids. At 18.2 ft (555cm) is a 0.5 in (12.7mm) wavy, weathered zone with a conc of fusulinids. At 18.27 ft (557cm), a clay covered parting zone about 4.5cm thk atop another fusulinid rich, thin, Fe-stained ls zone. This sequence repeats at 4 to 4.5cm intervals to 18.9 ft (577cm). At 18.9 ft is top of lamin, gry to drk-gry, muddy ls which may be weathering surface. At 19.25 ft (587cm) are crushed brach shells. Fusulinids throughout. Laminae bent, wrapped over top of underlying fusulinid rich ls which is light-gry, fine gr, lamin & resembling an erosion surface. At 19.4 ft (592cm) is a 2cm thk weathered-looking ls, containing many fusulinids & a few shell frags, which is separated top & bottom by a sl micaceous clay layer. Below this is a sl wavy-bedded, gry to wht ls loaded with fusulinids. Are a few frag brach shells & spines. This ls becomes siltier & more yel at 20.66 ft (630cm) where it is wavy, lamin, 4 in (10cm) thk, fusulinid rich zone resembling that a foot higher. From 21 to 21.25 ft (640 to 647cm), hte ls is wavier & more weathered. From 21.25 to 21.9 ft (646 to 667cm) is a silty to gritty, poorly indurated, wavy-bedded ls; bed-planes from 5 to 20mm apart, gry to yel-gry, with a few frag poss holoporoid coral tubes, brach frags & poss clam frag. Numerous fusilinids, 2 types: fat with lengthwise striae and "cigar-wrap". From 21.9 to 24.66 ft (667 to 752cm), ls alternates with up to 10mm thk clay layers, clay comprising perhaps 70% of volume. Var of fossils increases at 22.4 ft (683 cm): fenestrate & ramose bryozoa, brachs & clams which are more conc in limy beds. Clay layers are 15mm thk here. Below 23 ft (701cm), clay increases to perhaps 80%; fossils mostly fusulinids & a few brach frags. Near 24 ft (731cm), clay becomes drk to v.drk gry. A small amnt of fine pyrite at 24.33 ft (742cm) where also are some bivalve shells dep concave side upwards or at angles inclined to bedding. Looks stirred. At 24.8 ft (756cm), clay decreases & ls increases in volume.

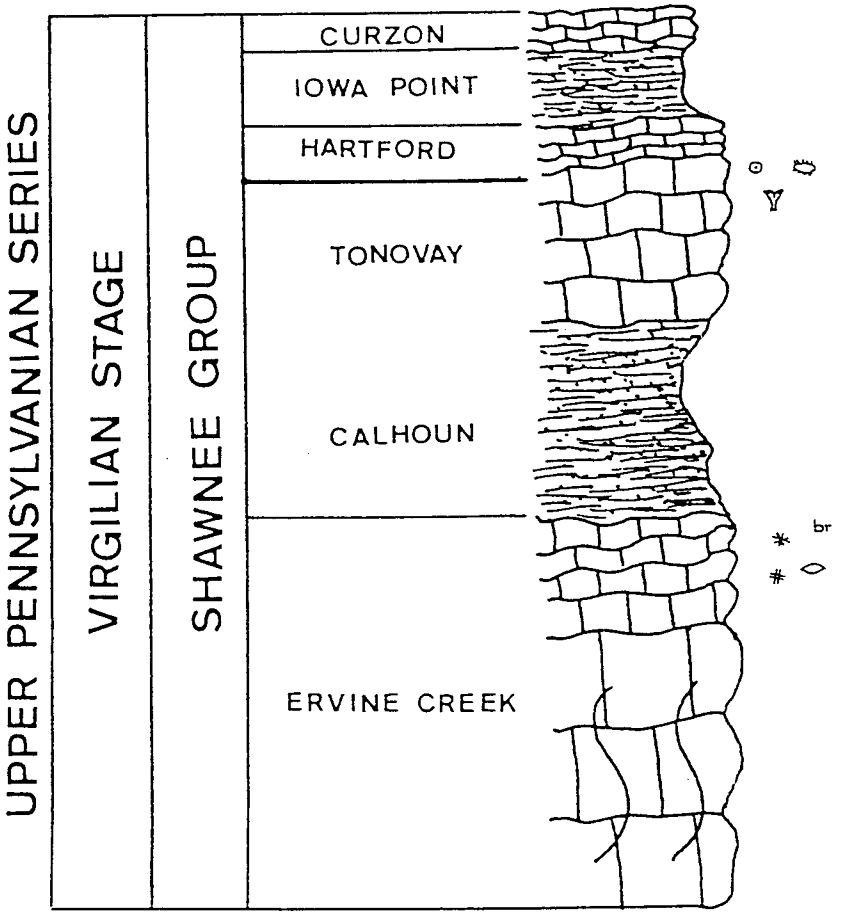
Ls. comprising est. 80% of mass; a grainstone comp. of frag. fossils & unident. carbonate grains. At 25.25 (769.6cm) is a slightly less than 7.0mm diam. crinoid columnal, the largest noted, which is parallel to bedding. This zone is 25-30mm thick and less limy. From 25.5 to 26.0 ft. (777 to 792cm) is dense, calcareous grainstone, individual grains varying from 0.25 or less to 0.50mm diameter, white, incl. a few poorly preserved fusulinids and poss. ooids. At about 26 ft. (792cm), fusulinids increase and whole and fragmented brachiopods and bryozoan fragments are found. The finer grained areas are more clayey & show settling/compaction-soft sediment deformation.

Dark-gry, clayey sh, wavy-bedded, contains soft sed. compaction features. Contains a band, to 5cm thick of crinoid columnals, brachs., fusulinids & frag. bryozoa. At 28.75 ft (876cm), color darkens to blk. wavy-bedded layers 2 to 4mm thk anastomosing in 0.75 to 3 in. (19 to 76mm) thk light-gry ls which contains a 2.3cm x 5.0mm pellet-filled burrow with algal coating on sides. Microstylolites at 29.0 ft (884cm). At 30.25 ft (922cm), gr size & fossil content increase. Fusulinid tests darken & are randomly oriented. Other fossil frags incl brachs, bryozoans & crinoids. Waviness incr in freq toward 30.9 ft (942cm) where there is a thin fusulinid coquina. Below coquina, texture chgs to light-gry, calc grainstone with numerous fossil frags, 0.25 to 1.0mm, comp of broken spines, shell frags & small or broken fusulinids. Friable to 31.4 ft (958cm) where becomes lamin, mica, gry, silty ls with fossil frags less than 0.25mm. Wispy clay separations. Infreq coal clasts from 32.2 to 32.48 ft (980 to 990cm) where ls becomes intercalated with 1mm thk coal layers. Bottom is 2.25 inch (57mm) coal layer, shiny, platy, fine pyrites, carbonized fibers.

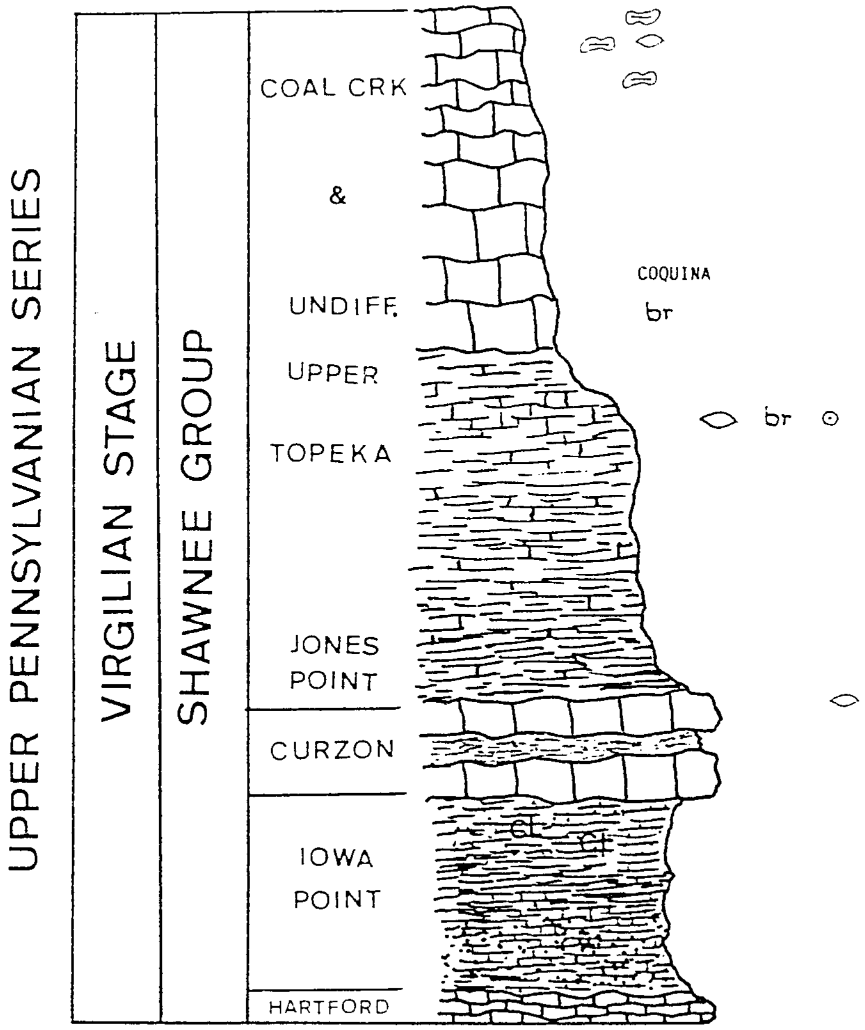
Vertical scale: 0.4 inch = 1 foot

KANSAS GEOL. SURVEY LACY NO.1 CORE

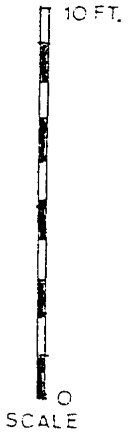
NWcSW SEC.26, T.25S., R.11E. GREENWOOD CO., KANSAS

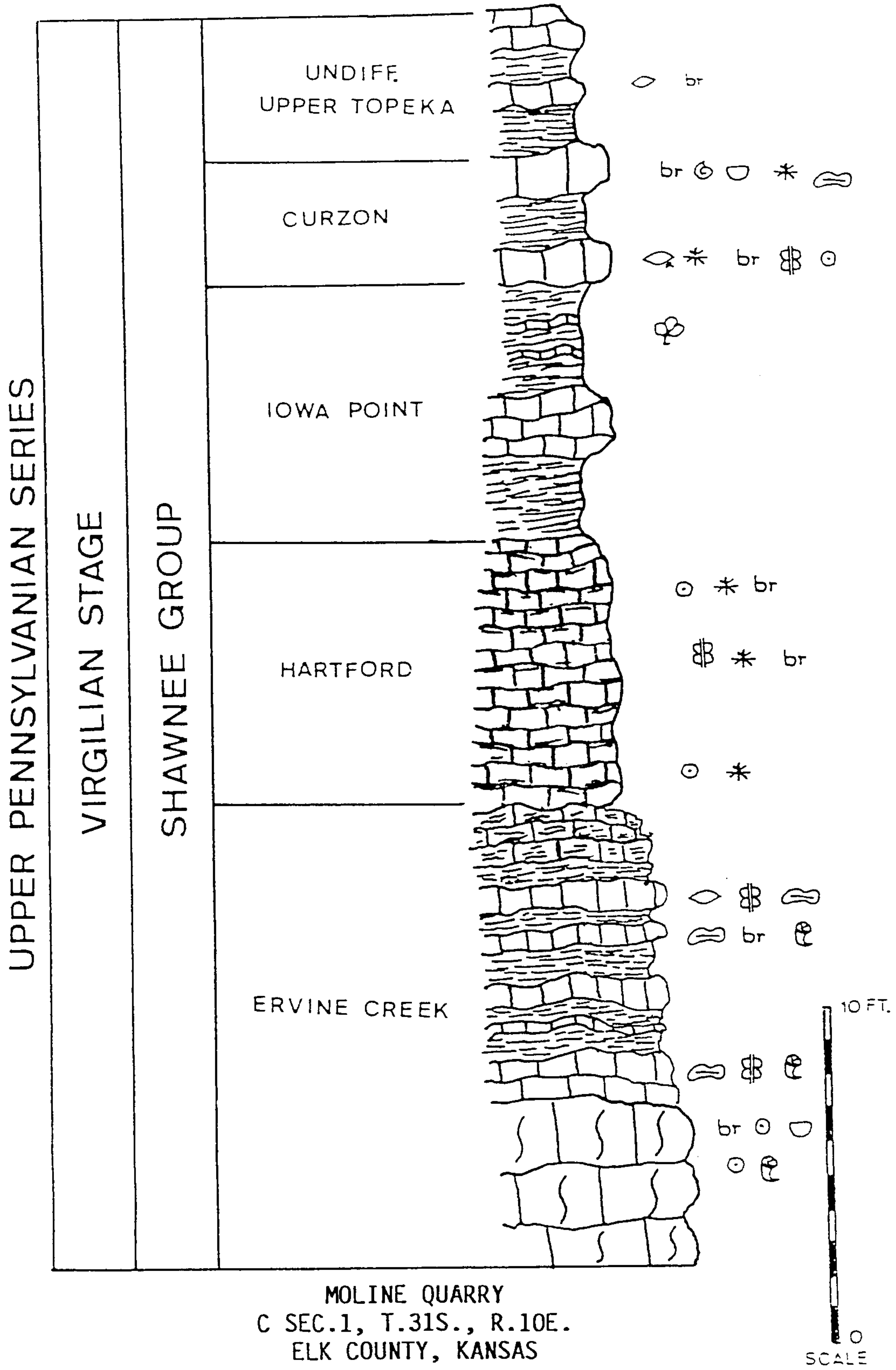


COMPOSITE SECTION OF
SEVERY QUARRY
C NE SW SEC 11, T.28S, R.11E
GREENWOOD COUNTY, KANSAS

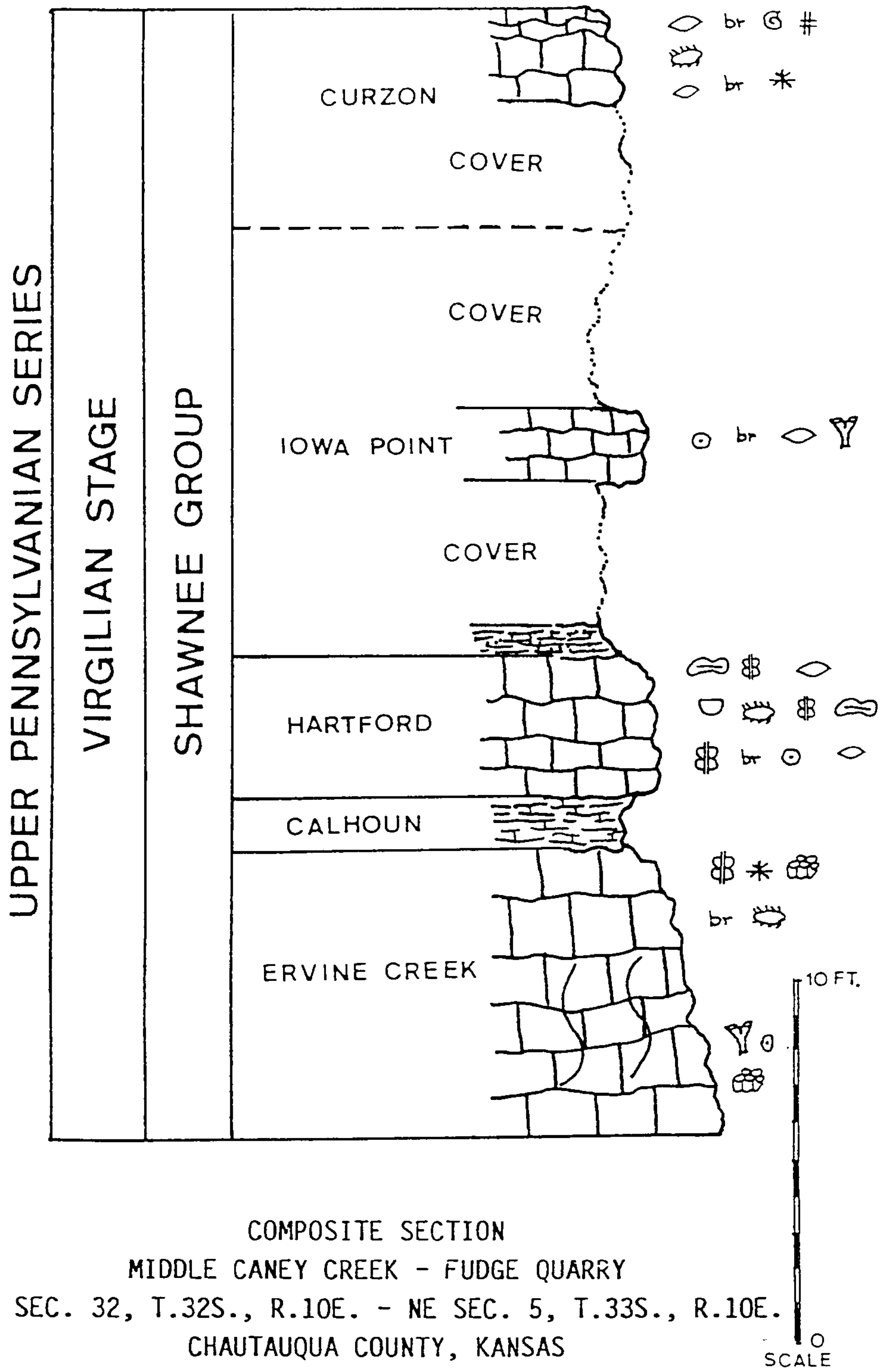


POLK DANIELS' LAKE ROAD SECTION
SE SW SEC.6, T.30S., R11E.
ELK COUNTY, KANSAS





MOLINE QUARRY
C SEC.1, T.31S., R.10E.
ELK COUNTY, KANSAS



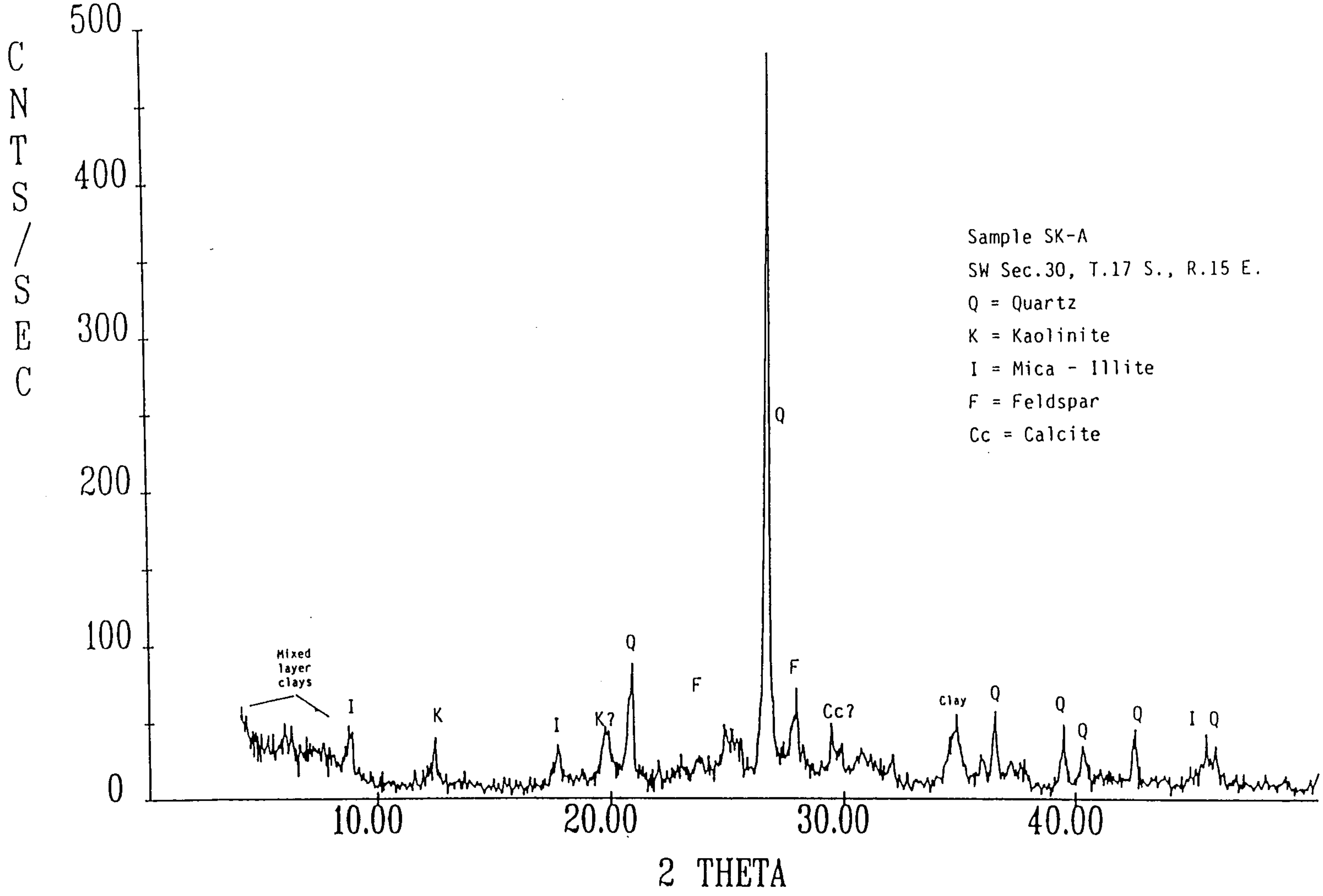
COMPOSITE SECTION
MIDDLE CANEY CREEK - FUDGE QUARRY
NW SEC. 32, T.32S., R.10E. - NE SEC. 5, T.33S., R.10E.
CHAUTAUQUA COUNTY, KANSAS

Severy Shale	19.0 ft.
Turkey Run Limestone: Limestone, dark-gray, fine grained, dense, brittle, subconchoidal fracture, massive, weathers to orange-brown, large rectangular slabs with limonite spots on surface.	2.0
Covered	10.0
Sandstone terrace	2.0+
Shale: Buff to light, silty fissile containing numerous sandstone beds.	13.0
Pearsonia Limestone: Limestone, dark-gray, coarse-grained, dense, fossiliferous, topped by a thin layer of fusulinid limestone. Weathers gray to orange-brown.	1.5
Shale: Buff, silty alternating with thin sandstone beds.	15.5
Sandstone terrace:	2.0+
Covered: Probably shale with thin fusulinid limestone layer.	6.0
Shale: Alternating maroon and gray.	7.5
Sandstone: Poorly exposed	2.5+
Little Hominy Limestone: Limestone, light-gray, algal fusulinids in thin layers at top. Weathers a dirty white with numerous solution cavities. Consists of three massive beds interspersed with thin beds.	4.0
Shale: Buff, nodular, fossiliferous.	21.0
Deer Creek Limestone	-
	106.0 ft.
Less Severy Shale	19.0
Total thickness of Pawhuska Formation	87.0 ft

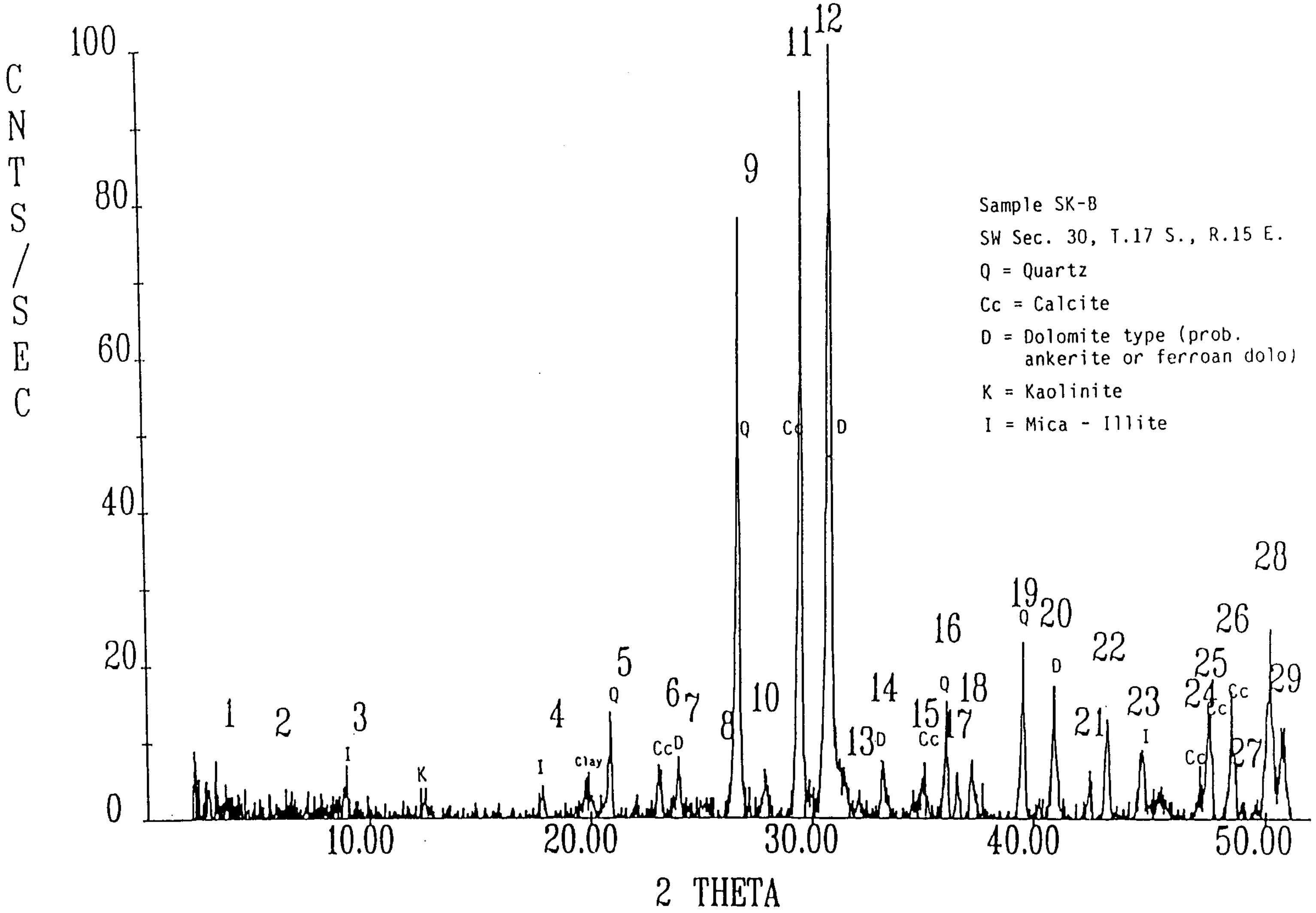
Measured section of Pawhuska Formation. SE Sec. 11, T. 26 N., R. 8 E., Osage County, Oklahoma. From Shannon (1954, p. 83-84).

APPENDIX II

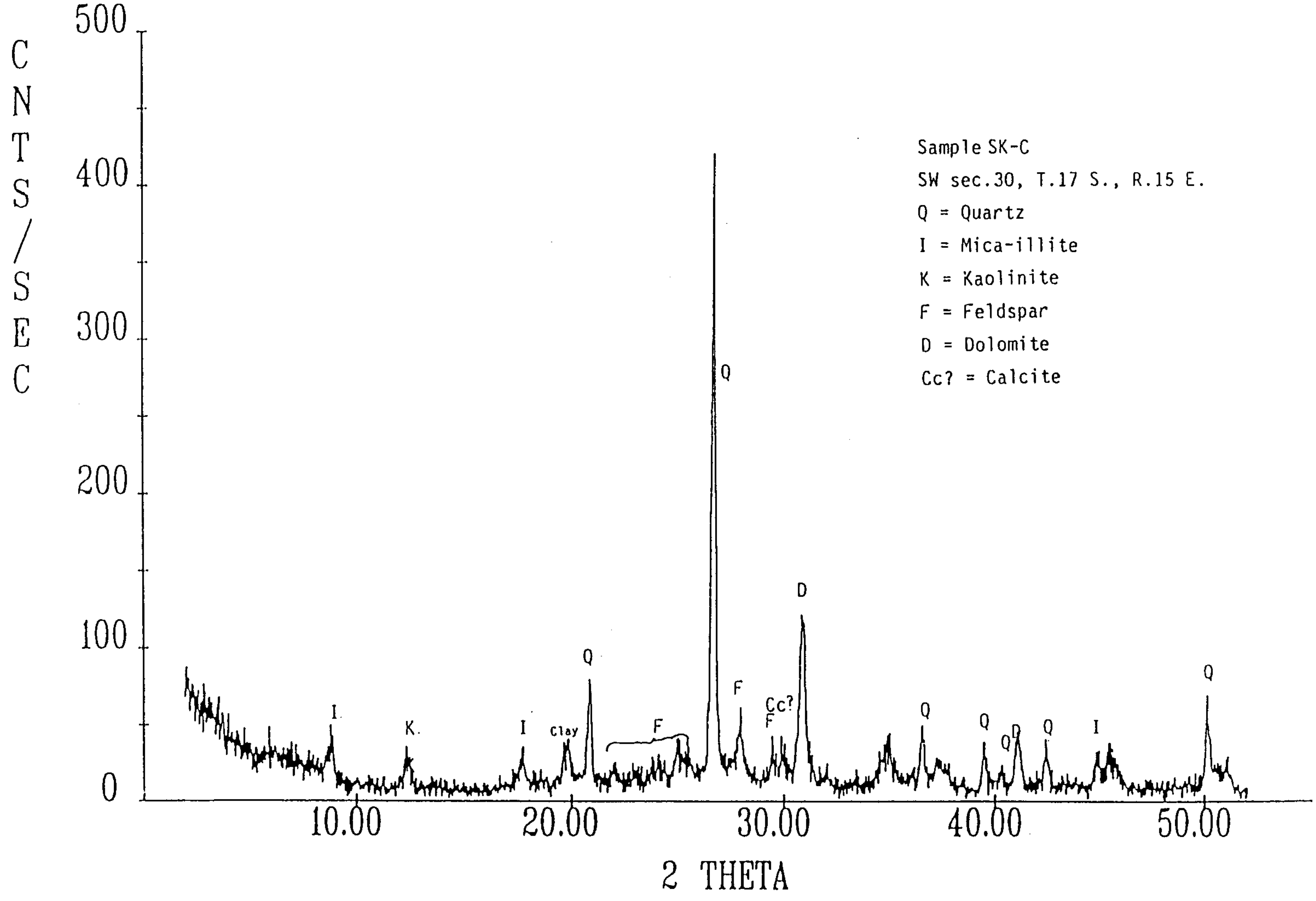
X-ray diffraction patterns of intra-Curzon shales/mudstones Bowers Quarry, SW sec. 30, T. 17 S., R. 15 E.



Appendix 11-A. Shale separating upper and lower limestone units.



Appendix 11-B. Calcareous shale overlaying upper limestone unit.



Appendix 11-C. Uppermost shale overlaying laminated algal limestone unit.

APPENDIX III

Description of Thin Sections of the Curzon Limestone

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Description of Thin Sections of the Curzon Limestone

Iowa Point Section - approximately C SE SW, sec. 25, T. 1 S., R. 19 E., Doniphan County. Top of bed. A calcitic biopelmicrite. Bioturbated; contains rounded algal-coated fragments of unidentified fossils. Void areas filled with euhedral pyrite crystals. Some pores filled with Fe_2O_3 which also has replaced some fragments. Contains fusulinids, ostracode valves, echinoid parts, and one 3.5 mm diameter, rounded pelletoid clast surrounded by pellets.

Iowa Point Section - approximately C SE SW, sec. 25, T. 1 S., R. 19 E., Doniphan County. Center of upper portion of bed. A fine, even-grained, calcitic micrite. Contains ostracode valves, a few slightly micritized fusulinids, and micritized ghosts of unidentified fossils. Some individual pellets are approximately 0.3 mm in diameter.

Iowa Point Section - approximately C SE SW, sec. 25, T. 1 S., R. 19 E., Doniphan County. Middle of outcrop. A biopelmicrite, calcitic, consisting oa a mass of algal-wrapped fossil fragments and pellets. Contacts between some pellets are concavo-convex. Some fusulinids exhibit spar-filled chambers and other fossil fragments replaced by spar. Contains some elongate shell fragments, the long axes of which are roughly parallel and aligned with bedding. Some pore space and fusulinid chambers are filled with pyrite. Contains less than 1% (A.G.I. data sheet 15.2) very fine, angular, quartz grains.

Iowa Point Section - approximately C SE SW, sec. 25., T. 1 S., R. 19 E., Doniphan County. Base of outcrop. Micrite containing only a few small fossil fragments less than 1.0 mm diameter and a few fusulinids. Some spar-filled oval cavities are oriented in various directions and probably are filled cavities of dissolved fusulinids or other foraminiferids. Contains areas of tightly-packed ghost pellets or ooids which are less than 0.25 mm diameter and show no discernible structure. Contains ghosts of probable burrows. Iron oxide (Fe_2O_3) fills cracks and forms a halo around one fragment. Contains sparry patches, some circular, unstained to very light pink stain, which are dolomitic, some of which resemble fenestral of birdseye fabric.

Denton Section - CSL SE, sec. 11, T. 4 S., R. 19 E., Doniphan County. Upper part. Almost featureless, iron-stained, dolomitic micrite. One iron-stain surrounds a poorly preserved strand of probable algal material. Iron-stains are confined to streaks but follow no regular pattern of fractures, grains, roots, etc. Only other fossil found is an eroded, probably water-tossed, fusulinid. Some of the slide area displays distinct rhombic spar areas. Alizarin Red stain does not "take".

Denton Section - CSL SE, sec. 11, T. 4 S., R. 19 E., Doniphan County. Lower part. Calcitic micrite containing algal filaments, fusulinids, fragments of crinoid columnals. Some fossils have been dissolved and voids filled with dolomite or ankerite.

Crooked Creek Section - SEC NE, sec. 24, T. 7 S., R. 19 E., Atchison County. Upper part. Burrowed micrite, area outside of burrows is relatively unfossiliferous. Burrows contain assorted fusulinids, fragments of echinoderm spines and plates, fragmented crinoid columnals, and ostracode valves. There are two euhedral pyrite crystals. Some areas of micrite are not stained red but are very light pink, indicative of dolomite.

Crooked Creek Section - SEC NE, sec. 24, T. 7 S., R. 19 E., Atchison County. Middle part. Fossiliferous, calcitic micrite containing spar-filled fragments of red algae, echinoid spines and fragments, ostracode valves, fusulinids and other foraminiferids including biserial forms. Some fossil fragments are framed with inward-pointing siderite crystals; some of the frames having oxidized into Fe_2O_3 and are blurred around their outer edges. There are numerous algal-coated grains of unidentified fossil fragments and pellets, although not plentiful, are scattered throughout. There are three probable, minute mud clasts surrounded by micrite. No silica observed. Specimen resembles a micrite-bound, silt-size, fossil hash.

Ozawkie Section - SW SW, sec. 27, T. 9 S., 18 E., Jefferson County. Sparsely fossiliferous, calcitic micrite. Burrows are filled with fragments of ostracodes, brachiopod shells, echinoid spines, unidentified organic remnants, and algal-wrapped grains. One burrow is 1 to 2 mm in diameter and is filled with pyritized to partly pyritized fossil hash and lies beneath a convex upward, small, probable pelecypod shell, the underside of which is packed with smaller fragments of fossils. The unburrowed portion contains micritized fusulinids, micrite-filled ostracodes, and a single tapering spine, 6 mm in length; which has a notched node on the basal end. No silica or dolomite areas observed.

I-70/County Line Section - CEL SE, sec. 10, T. 12 S., R. 22 E. Upperpart. Biomicrite which contains algal-wrapped shell fragments, some to 1.5 mm in length, spar-filled fragments of brachiopod and pelecypod shells, and echinoid spines. There are sparse, scattered, silt-size, angular quartz fragments. There are scattered pyrite particles. Although predominantly calcitic, some dolomitization is indicated by the presence of unstained, rhombic zones surrounded by red-stained micrite.

I-70 County Line Section - CEL SE, sec. 10, T. 12 S., R. 22 E. Lower part. Biomicrite containing a dense fusulinid population, three or four tests per 5 mm field-of-view. Individual tests vary in size by a factor of 10. Chamber-fill ranges from void to micrite or spar-filled. Some chambers are filled with Fe_2O_3 or siderite. There are large echinoderm plate fragments and sections of spines. No quartz or dolomitic areas evident.

Bowers Quarry - S/2 SW, sec. 30, T. 17 S., R. 19 E., Osage County. Top of upper part. Fine-grained, sparry, micrite which contains randomly oriented fragments of ostracodes and echinoderm spines, micrite-filled fusulinids, brachiopod fragments, algal-wrapped fossil fragments and algal filaments. One fragment consists of piece of the red coral, Archeolithophyllum. None of the fossil fragments exceed 2 mm in maximum dimension. There is a pellet-filled burrow which ranges from 0.75 to 1.00 mm in diameter. There are no visible quartz grains. There is a micritized, rhomboid ghost which may be dolomitic. (It is difficult to distinguish because the staining on this slide is of poor quality).

Bowers Quarry - S/2 SW, sec. 30, T. 17 S., R. 15 E., Osage County. Lower middle part of upper bed. Iron-stained biomicrite. Iron-stained fossils include fragmented echinoderm spines, fusulinids, ostracodes, and unidentifiable pieces. Ostracode tests are approximately 1.0 mm in cross-section normal to the hinge margin. An estimated 5.0% of the slide is pyrite, much of which is oxidized to Fe_2O_3 and which forms centers in the overall iron-stained area.

Bowers Quarry - S/2 SW, sec. 30, T. 17 S., R. 15 E., Osage County. Upper part of lower bed. Bioturbated micrite containing sparry patches. Fossils are replaced with sparite, several being rimmed with pyrite or Fe_2O_3 where pyrite has oxidized. Fossils include fusulinids, echinoderm spines, ostracodes, molluscan or brachiopod shell fragments, algal filaments, and algal-covered fragments. Fragments are concentrated in poorly defined burrows. There are scattered silt-size quartz particles.

Bowers Quarry - S/2 SW, sec. 30, T. 17 S., R. 15 E., Osage County. Lower bed. Micrite containing sparry fossils, crinoid columnals and plate fragments, ostracode valves, brachiopod or molluscan shell fragments, and algal-coated grains. All are 1.0 mm or less in maximum dimension. Fusulinid chambers are spar-filled. Spar and micrite is all calcitic. A calcite rhombohedron which may be part of an echinoderm plate displays sudden extinction with crossed Nicols. One area consists of a mass of minute pellets approximately 0.1 mm diameter. There are scattered particles of pyrite.

Bowers Quarry - S/2 SW, sec. 30, T. 17 S., R. 15 E., Osage County. Laminated "extra" bed. Parallel, stromatolitic, micrite layers which are 1 to 2 mm thick, irregularly interspersed with layers of fragmented fusulinids, ostracodes, echinoderm spines, algal-coated grains, and unidentified fragments, all of which are 1 mm or less in maximum dimension. Some fragments of red algae and phylloid algae are calcite-filled and several areas of less-than 1 mm diameter are filled with pyrite. The thickest (2 mm) stromatolitic layer is penetrated with a pellet-packed burrow. These layers which have a texture analogous to claystone are mottled and display vague features which resemble algal tubes.

Haworth Quarry - SW NW sec. 2, T. 21 S., R. 13 E., Coffee County. Top of bed. Calcitic micrite, finely laminated with grain-size fining upward until it reaches an algal filament above which there are larger grains. Larger grains are accumulated atop the algal filament and are small, round, and oolitic, some of them eroded or broken. Below the filament are prismatic to blocky clasts, most of which have the long axis parallel to the lamination, the remaining clasts having the long axis inclined or normal to the lamination. The uppermost portion of the slide is fine-grained micrite lacking allochems. One unidentified fossil fragment contains pyrite crystals and a pyrite bleb is visible in another area of the slide. There are scattered pinpoint specks of silica.

Haworth Quarry - SW NW sec. 2, T. 21 S., R. 13 E., Coffee County, Upper one-third of outcrop. Biomicrite. Contains fusulinids and biserial foraminiferids, both with spar-filled tests, algal filaments, and echinoderm spines. Some of the algal matter is tubular with outward-radiating wall structure similar to that of a Dasycladacean algae. There is a single clam valve approximately 6 mm in diameter. Algal-coated grains are angular or round and there are some micritized rhombs, generally larger than the grains. All are calcitic. There are some micritic, pelloidal clasts which are outlined by Fe_2O_3.

Haworth Quarry - SW NW sec. 2, T. 21 S., R. 13 E., Coffee County. Lower one-fourth of outcrop. Calcitic micrite which contains spar-filled fossils and fossil fragments, some of which are algal-wrapped and some sparry. There are micritized ghost fossils. Contains fragments of mollusc shells, ostracodes, vari-sized fusulinids, other foraminiferids, including uniserial and helicoid types, echinoid spine fragments, algal filaments and fragments of red algae. Contains infrequent silt to very-fine-sand sized silica particles.

Hilltop Quarry - NE SW sec. 7, T. 23 S., R. 13 E., Greenwood County. Upper one-half of outcrop. Calcitic micrite containing a few fragmented echinoderm spines, ostracode valves and clusters of fecal pellets. Stained by Fe_2O_3. There are scattered, angular, silt to sand-sized, silica particles.

Hilltop Quarry - NE SW sec. 7, T. 23 S., R. 13 E., Greenwood County. Lower one-half of outcrop. A calcitic biomicrite containing fusulinids, ostracode valves, algal filaments, echinoid spines, and algal-wrapped grains and rods. Some of the fossils are micritized. There are scattered, angular, silica particles in silt to fine-sand size range. Entire specimen is finely laminated.

Marlin Quarry - NW NE sec. 17, T. 24 S., R. 12 E., Greenwood County. Upper part. Calcitic biomicrite containing phylloid algae, encrusting algae, unidentified foraminiferids, ostracode valves, some punctate. There are numerous fusulinids of varied size. There are mud clasts. Micrite is packed around and in-between offset parts of broken clasts and ostracode valves.

Marlin Quarry - NW NE sec. 17, T. 24 S., R. 12 E., Greenwood County. Lower part. Heavily burrowed biomicrite. Burrows are packed with processed mud, fecal pellets, algal blades (some spar-filled), silt-size and smaller silica grains, and ostracode valves. Slide displays three parallel burrows. Fe_2O_3 is concentrated within burrows.

Moline Quarry - NE sec. 12, T. 31 S., R. 10 E., Elk County. Upper portion of top bed. Bioturbated algal micrite which contains laminated algal strands, some broken and tilted across grain. Algal strands are replaced with either calcitic spar or micrite. Micrite layers lie between algal layers. The only non-algal fossils recognized are a single ostracode and a single brachiopod spine. More than half of the slide displays small, algal fragments and segments of algal laminae which are interspersed through fecal pelmicrite. There are scattered particles of silt-size silica throughout slide.

Moline Quarry - NE sec. 12, T. 31 S., R. 10 E., Elk County. Middle "fractured" bed. Even-grained calcitic micrite. Only fossils seen are two micritized probable echinoid spines. There are numerous fine cracks oriented more-or-less parallel. Lesser cracks are inclined at approximately 40° to main ones. All cracks are filled with Fe_2O_3 except where it was removed apparently during slide preparation.

Moline Quarry - NE sec. 12, T. 31 S., R. 10 E., Elk County. Lower bed. Burrowed calcitic micrite. Burrows are packed with rounded, rod-shaped pellets which are predominantly uniform in size and shape. At the end of one burrow are the fossil remains of a probable segmented worm, approximately 5 mm in length by 1 mm in diameter. Its exterior is out-lined by a concentration of Fe_2O_3 and its interior contains a cellular pattern similar to that of a red alga. The burrow wanders becoming bell shaped where it makes a right angle turn. Pellets from the burrow blend into the surrounding micrite. Other burrows contain numerous fecal pellets in micrite. There are scattered fragmented fusulinids and ostracodes. Silt-size silica fragments are scattered throughout the micrite and are more concentrated in the pellet-filled burrows.

U. S. Highway 166 Section - NW NW sec. 10, T. 34 S., R. 10 E., Chautauqua County. Center of bed. Micritized jumble of fragmented shells, spines of unidentified origin, and fuslinids, all thickly-coated with algae. There are concentrated phylloid algal strands, all of which are randomly oriented and display no lamination. One micritized algal filament is approximately 2 cm in length. Algal coating regularly accounts for 55% to 60% of the diameter of coated grains. Interiors of phylloid strands are spar-filled. Approximately 20% of the spar is rhombohedral in outline and the remainder is comprised of angular fragments packed wall to wall. The entire mass is calcite. There are infrequent, scattered, angular, anhedral, silt-sized, silica grains.