SEQUENCE STRATIGRAPHY OF THE SHAWNEE GROUP (VIRGILIAN, PENNSYLVANIAN) IN SOUTHEASTERN KANSAS

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I.

INTRODUCTION

Purpose

The purpose of this investigation is first to describe lithologies and geometries in sequence stratigraphic terms the Shawnee Group cyclothems (Virgilian Stage, Upper Pennsylvanian Series, Pennsylvanian System; Figure 1) exposed in southernmost Kansas. Secondly, interpret the relative sea-level history of the study area as revealed by the distribution of facies, stacking patterns and geometries of these depositional sequences through time.

Location of Area of Study

The components of this project are located in a relatively north-northeasterly, south-southwesterly trending outcrop belt situated in portions of Chautauqua, Elk, Greenwood and Woodson counties in the southeastern part of Kansas (Figure 2). Outcrop data from 14 various sites were measured, sampled and described. Topographic maps in Appendix A show the aerial location of each of these sites in relation to surface landmarks. From these outcrops, 182 samples were collected and 52 cross-sections were prepared.

Methodology

Surface exposures of the Shawnee Group examined in this study include the Oread Limestone, Kanwaka Shale, Lecompton Limestone, Tecumseh Shale, Deer Creek Limestone, Calhoun Shale and Topeka Limestone, in ascending order. Fourteen localities were selected for the study so that all the units that are

SYSTEM	SERIES	STAGE	GROUP	FORMATION	MEMBER OR BED
PENNSYLVANIAN	UPPER PENNSYLVANIAN	VIRGILIAN	WABAUNSEE	SEVERY SHALE	
			SHAWNEE	TOPEKA LIMESTONE	Coal Creek Limestone Holt Shale Du Bois Limestone Turner Creek Shale Sheldon Limestone Jones Point Limestone Curzon Limestone Iowa Point Limestone Hartford Limestone
				CALHOUN SHALE	
				DEER CREEK LIMESTONE	Ervine Creek Limestone Larsh & Burroak Shale Rock Bluff Limestone Oskaloosa Shale Ozawkie Limestone
				TECUMSEH SHALE	
				LECOMPTON LIMESTONE	Avoca Limestone King Hill Shale Beil Limestone Queen Hill Shale Big Springs Limestone Doniphan Shale Spring Branch Limestone
				KANWAKA SHALE	Stull Shale Clay Creek Limestone Jackson Park Shale Elgin Sandstone
				OREAD LIMESTONE	Kereford Limestone Heumader Shale Plattsmouth Limestone Heebner Shale Leavenworth Limestone Snyderville Shale Toronto Limestone
			DOUGLAS	LAWRENCE FORMATION	

Figure 1.
Stratigraphic nomenclature of the Shawnee Group.

accessible in this part of the state would be represented. The combination of these 14 exposures results in a composite cross-section containing units from the base of the Oread Limestone to the top of the Topeka Limestone.

Lithostratigraphic analysis was the primary method for this study, with each exposure measured and a preliminary description made in the field. Field descriptions include unweathered color based on the Geological Society of America Rock Color Chart, 1984 reprint. Also, bedding and contact characteristics, fossil content, and lithology based on Dunham's carbonate classification were noted. When possible, at least 2 kilograms were collected for each sample location for future lab analysis. Most locations were photographed in their entirety with detailed photographs of individual members also acquired.

Initial analysis of each sample included microscopic examination and description with 52 samples selected for thin-section preparation. A fresh rock surface was removed from each selected specimen and a small billet was cut to the size of a standard microscope slide. The billet was then glued to a slide and ground thin enough for light transmission. Each slide was then photographed and analyzed under a petrographic microscope, noting lithology, matrix constituents and microfaunal content.

After all the available data was compiled, rock units at each location were organized within a specific sequence-stratigraphic framework (systems tract and sea-level curve) composite stratigraphic cross-sections were prepared based on the interpolation of important sequence stratigraphic bounding surfaces and the interpretation of the depositional environment.

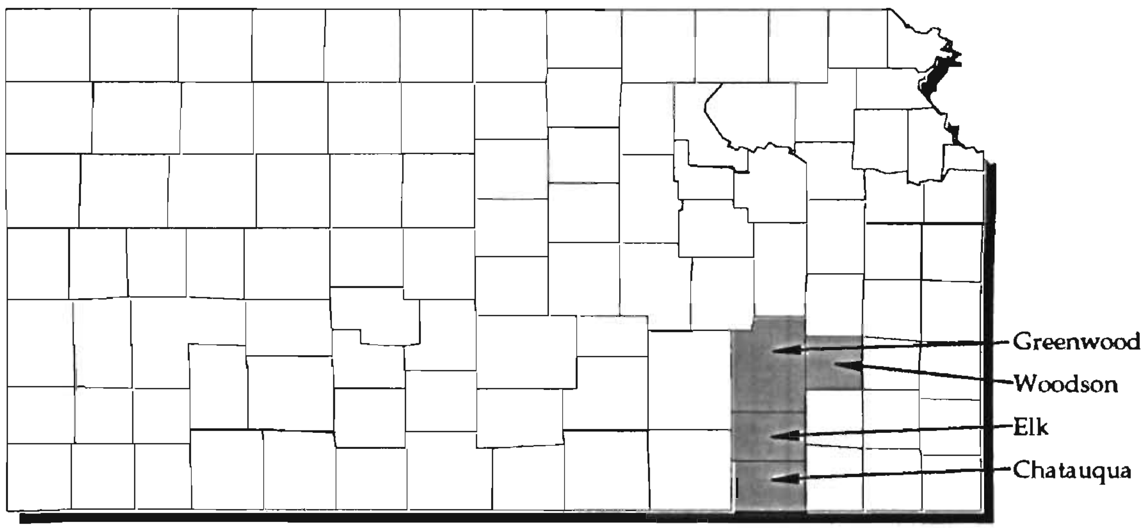


Figure 2.
Location of counties mentioned in study.

Geologic History

The Pennsylvanian is considered a period of increased tectonism in the Mid-continent with most major activity occurring during the early and middle stages of the system. By the time of Late Pennsylvanian the majority of regional tectonic activity had declined significantly. However, substantial alteration of the basement structure of Midcontinent rocks had already formed major uplifts and depressions that were persistent throughout the Late Pennsylvanian effectively controlling the sedimentation rates, duration and patterns during the latter stages of the Paleozoic (Heckel, 1977) (Figure 3.)

One of the predominant structural features affecting the depositional patterns of the Virgilian in the study area was the Ouachita Orogeny. This mountain building episode occurred in the Pennsylvanian (Morrowan through Desmoinesian) as a result of the collision between the North American and South American continental plates as the supercontinent Pangea was being

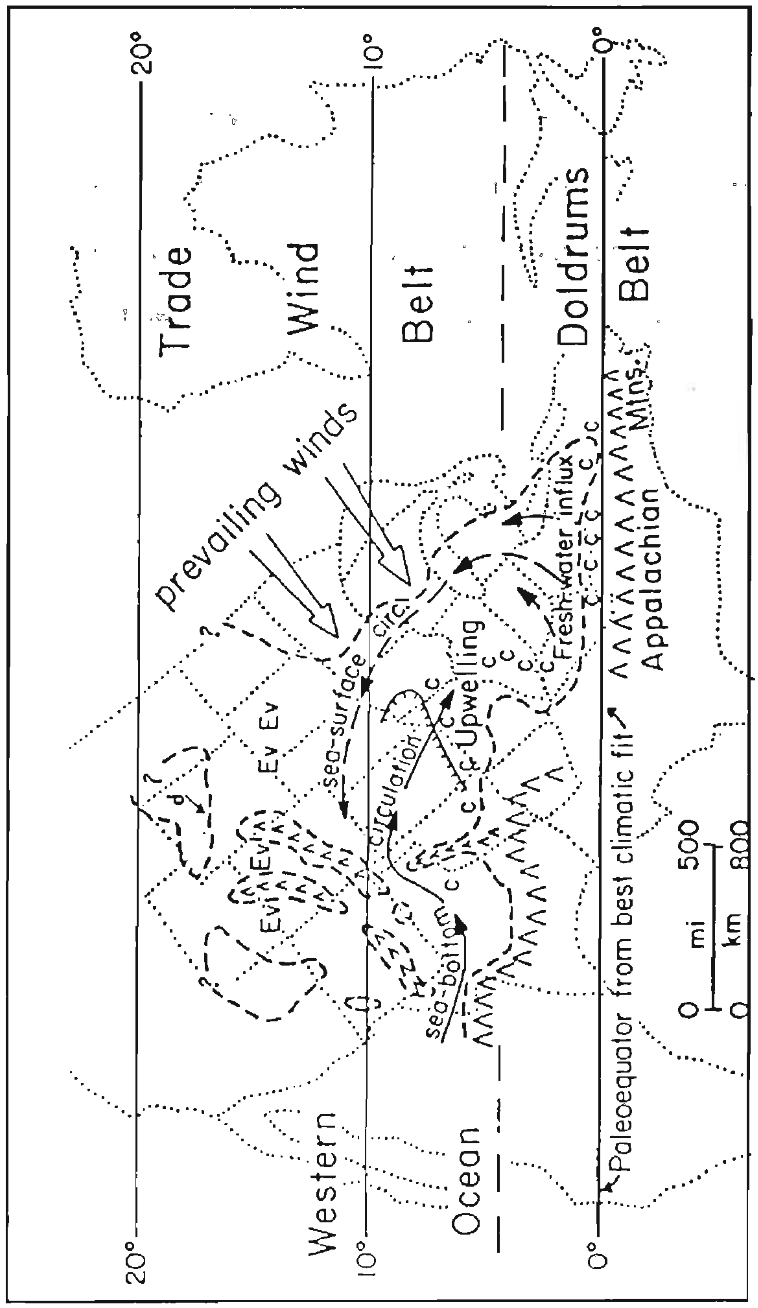


Figure 3.
Paleogeography and orientation of North America in Late Pennsylvanian
(from Heckel, 1977.)

assembled (Rascoe and Adler, 1983). This uplift was likely a major source of siliclastics in Oklahoma and southern Kansas. The ancestral Rocky Mountains, lying to the west of the Midcontinental platform, were probably actively supplying clastic debris along the western margin of the region. On the eastern margin, the Ozark Uplift/Dome, primarily an early Paleozoic positive element, was a relatively low-lying remnant that was covered with older Paleozoic carbonate rocks that contributed little in the way of clastic debris into the depositional area. However, this positive element obviously influenced the sedimentation patterns and platform development limiting eastern migration of sediments. The landmass to the north was part of an ancient stable shield area which was also covered with early Paleozoic carbonate rock, and was no longer supplying significant sediments to the south. Locally, the Bourbon Arch and the Nemaha Uplift (Figure 4) supplied minor amounts of siliclastic material.

During Mid-Pennsylvanian time, the previous steady source of clastic sedimentation from northern areas was gradually decreasing and finally ceased near the end of the upper Desmoinesian. This termination of terrigenous influx allowed the development of a broad carbonate shelf along a platform edge in the southern Midcontinent area. This shelf edge divided the actively subsiding and sediment starved Anadarko Basin, situated to the south in western Oklahoma and the Texas Panhandle, from the mildly positive platform extending north into Kansas and Nebraska.

Most of the platform covering Kansas and Nebraska comprised a slowly subsiding open-sea carbonate platform where limestone was prominent, but where shales and sandstones were also deposited. The limestone and part of the shales are marine; some of the shales, the coal beds, and most of the sandstones are nonmarine. Repeated cycles of transgression and regression produced stacks of depositional sequences that are typical of Kansas cyclothems (Heckel, 1977.)

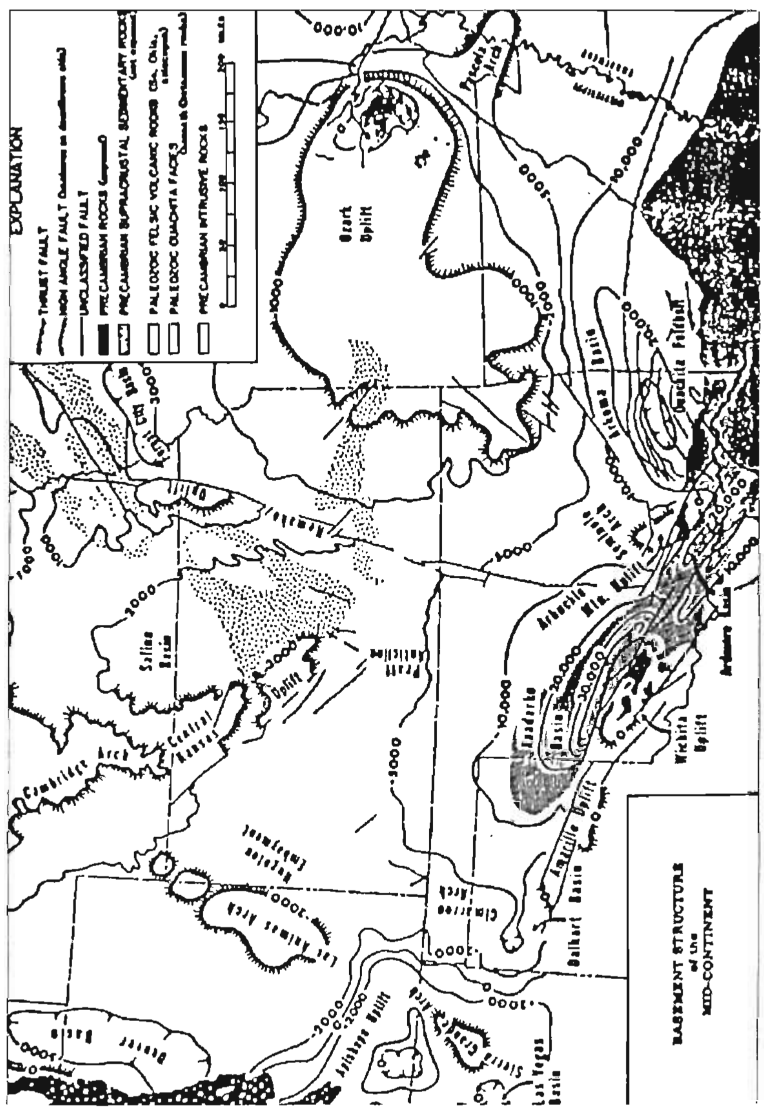


Figure 4.
Basement structure of the Midcontinent (Rascoe et al., 1983.)

These rocks occur in constant sequences which permit recognition of alternating successions, especially the limestones and black shales, many of which are laterally continuous over much of the Midcontinent (Rascoe, 1962; Heckell, 1977.)

Western Kansas evolved into a broad, stable shelf that covered much of the Midcontinent during the Late Pennsylvanian. The cyclic shelf carbonates of western Kansas thicken and merge southward at the northern edge of the Anadarko Basin to form a constructive carbonate shelf edge that abruptly changes southward to dark shales, sandstones and thin limestones. In eastern Kansas and northeastern Oklahoma, the shallow shelf environment allowed thin clastics to prograde laterally over large distances (Wanless and Wright, 1978) on the gentle, westward-sloping ramp (sedimentary platform.)

In contrast, thick, coarser clastics prograded over the region immediately southeast of the study area (Figure 5). This shelf setting, though less stable, continued southward into eastern Oklahoma dominated by clastics derived from the major fluvial-deltaic systems draining the rising Ouachitas (Moore, 1979).

Rock formations of the comparatively even-surfaced platform region are mostly thin but they have remarkable lateral uniformity throughout large areas often traceable along outcrops for 160 to 485 kilometers (100 to 300 miles.) In contrast, southern Oklahoma regions are well developed geosynclinal deposits, distinguished by thickness of formations measured in hundreds and thousands of feet. Individual rock units are typically not traceable for long distances because they have lenticular form or they grade laterally into different types of deposits.

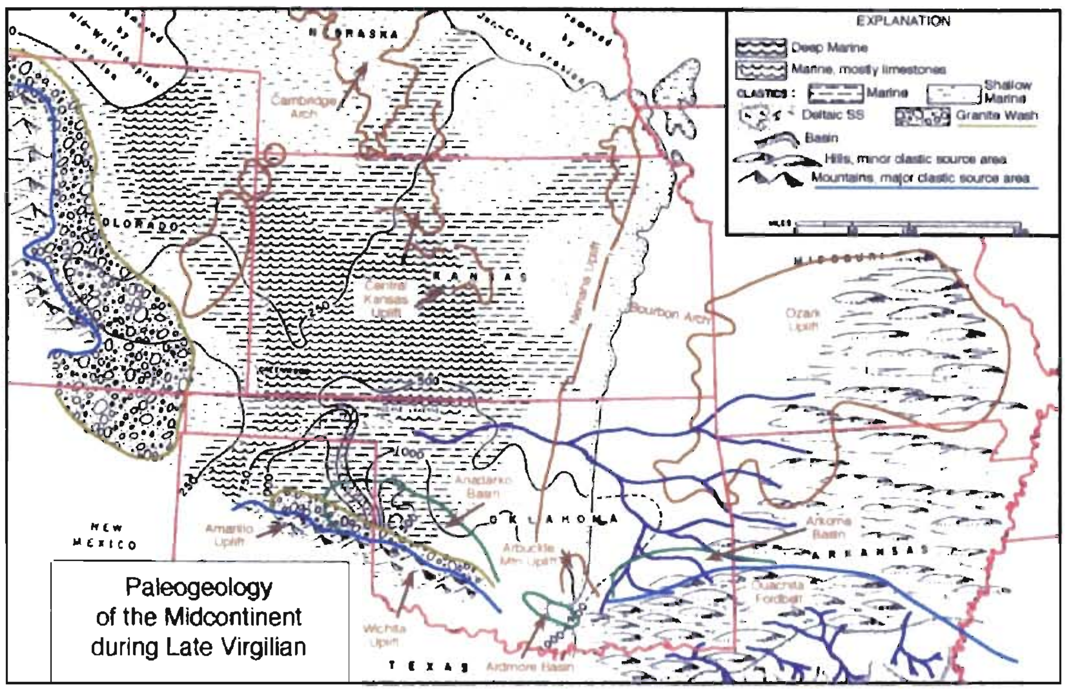


Figure 5.
Paleogeographic map of Midcontinent during Late Virgilian. Connection to deeper basins via Texas Panhandle became shallower as the Anadarko Basin filled with clastics and carbonates (modified from Rascoe and Adler, 1983.)

II.

STRATIGRAPHY

Lithostratigraphic Nomenclature

The term 'Shawnee' was originally defined by E. Haworth in 1898 and was subsequently adopted in Kansas and adjacent states for many years. Initially used as a "formation" name, Haworth included beds between the base of the Kanwaka Shale to the top of the Scranton Shale (base of the Burlingame Limestone) (left column in Figure 6.) In 1921, Fath advanced the Shawnee to group ranking with the upper and lower limits redefined by R.C. Moore in 1932 (Condra and Reed, 1937.) Moore's revision, as now accepted, includes beds from the base of the Oread Limestone to the top of the Topeka Limestone (labeled "New" in Figure 6.)

The term 'megacyclothem', defined as a cycle of cyclothems, was conceived by Moore after his observation that the beds of the Shawnee consisted of an unusually complete series of cyclothems. This orderly recurrence of lithologies within the megacyclothems record the repetition of the various environments of deposition (Moore et al., 1951.) He stated that:

> "The outstanding elements in the Shawnee cyclic sedimentary rhythm are the three or four different types of limestone that appear in the same order in each of the four limestone formations of the group.... The thin shale members that separate the limestones differ from one another in various characters and the order of succession of these is constant in each formation."

Moore later expressed that the Shawnee Group contains the most complete record of these so-called megacyclothems in all of the Upper Pennsylvanian sediments of the Midcontinent (Moore, 1949.)

The Shawnee Group is a very well differentiated assemblage of strata, in which thick limestones and a distinctive type of cyclic sedimentation are prominent features. In southeastern Kansas it is typically composed of an alternating sequence of sedimentary rock members characterized by a diversity of lithologies represented and the relationship of these lithologies to one another. Many of these members are known to have a wide areal distribution, frequently sustaining relatively uniform lithologies throughout the region. This suggests that the depositional environment of each of these members was often fairly uniform throughout its time of deposition (von Bitter, 1972.)

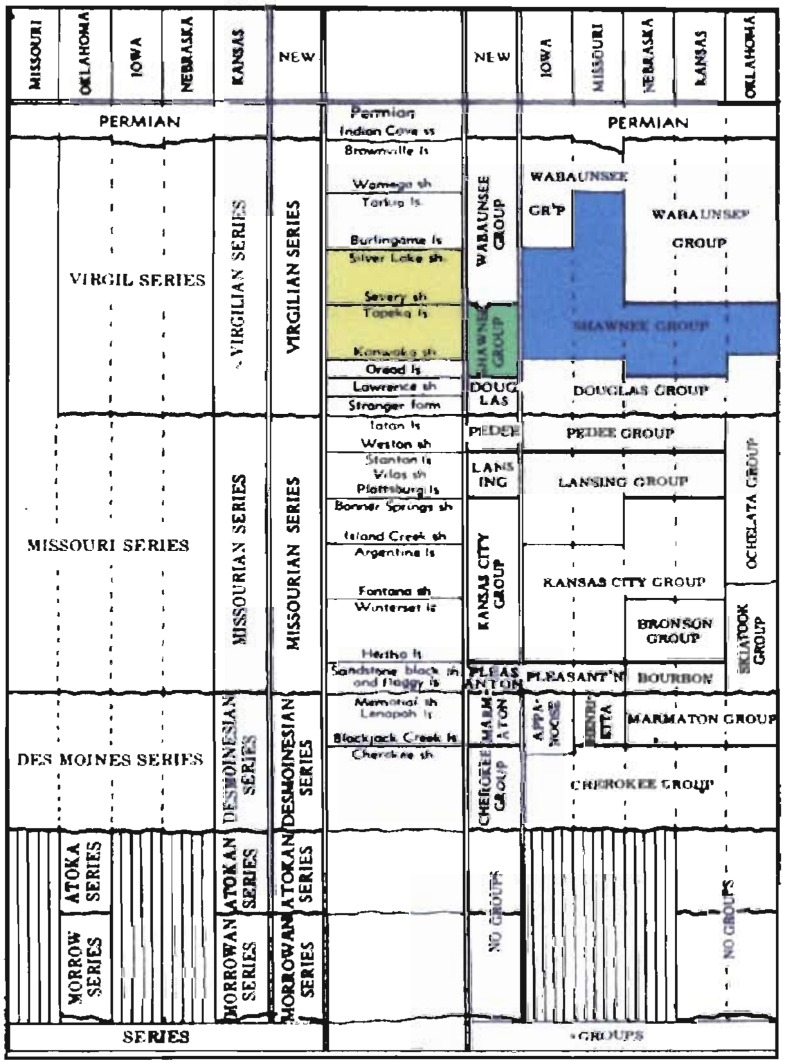


Figure 6. Old and new nomenclature of the Pennsylvanian System (from Moore, 1949.)

Distribution and Thickness

The outcrop belt of the Shawnee Group occupies the middle part of the area of the exposed Virgilian Series in eastern Kansas (Figure 7.) These exposures of Shawnee rocks are markedly persistent in this region and are readily recognized across Kansas from Doniphan County on the north, to Chautauqua County on the south. The width of this outcrop belt averages about 32 kilometers (20 miles) (Condra and Reed, 1937.) Excellent exposures of Shawnee limestones, and less commonly, shale deposits, are found in virtually every county crossed by the belt. Based on surface features, the greater prominence of escarpments and typically more rugged topography distinguish it from the Douglas and Wabaunsee belts.

Thickness of the Shawnee Group along the outcrop belt in Kansas is fairly uniform, amounting to about 99 meters (325 feet) (Moore et al, 1951.) This lack of great variation in total thickness is somewhat remarkable due to the considerable change in thickness of individual Shawnee formations. Evidently, the thickening of some formations along parts of the outcrop belt is compensated by thinning of others.

West of the outcrop belt the Shawnee Group underlies all of Kansas with the exception of small areas along the northern portion of the Nemaha Ridge where Wabaunsee strata directly overlie Pre-Cambrian rocks. In the subsurface, the limestone members of the Shawnee Group are found to converge forming a thick body of nearly solid lime (Figure 8.) This is readily distinguishable from the clastic Douglas beds below and from the shaly strata and thin limestones of the Wabaunsee Group above.

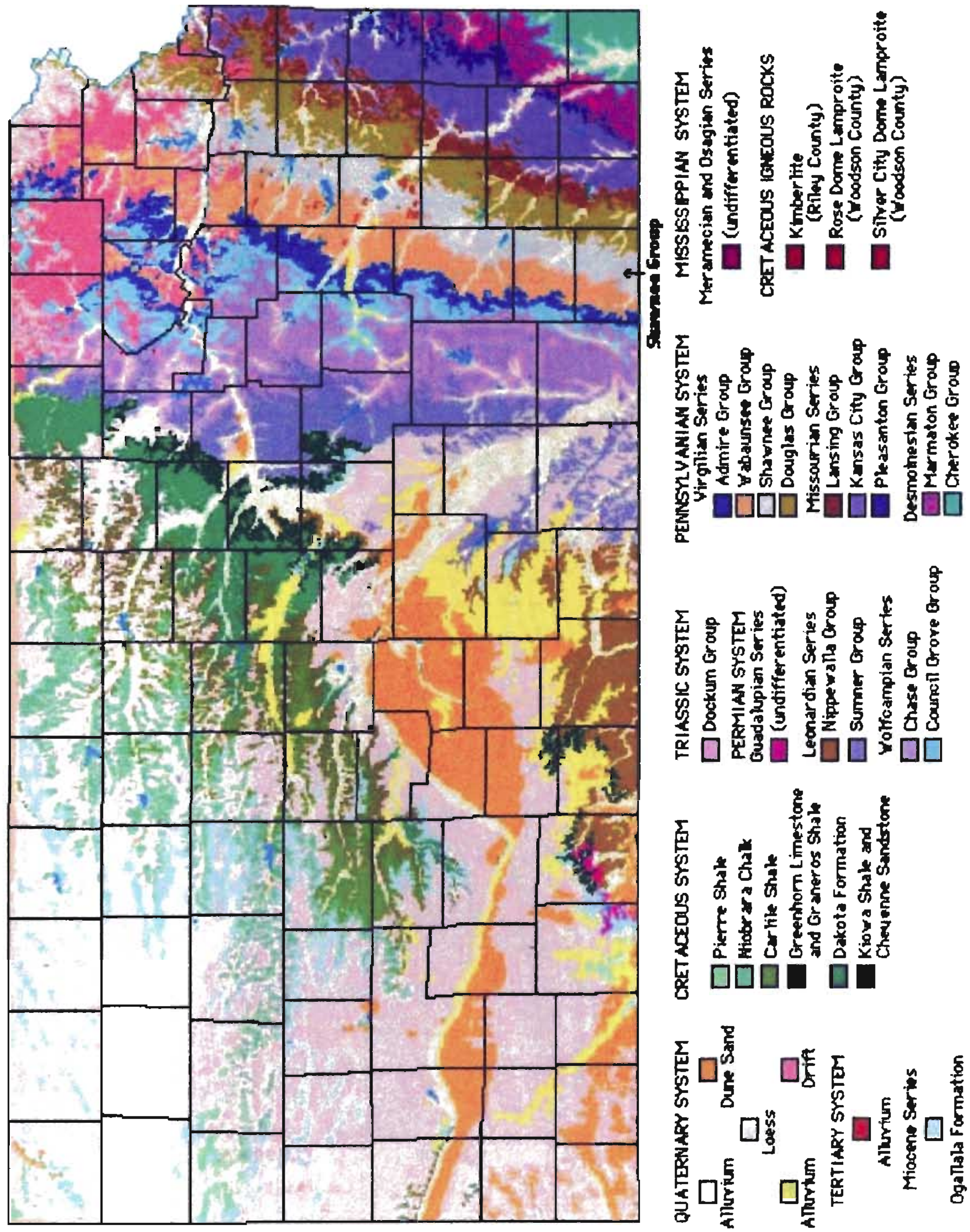


Figure 7.
State map showing outcrop belt of the Virgilian Series and the Shawnee Group.

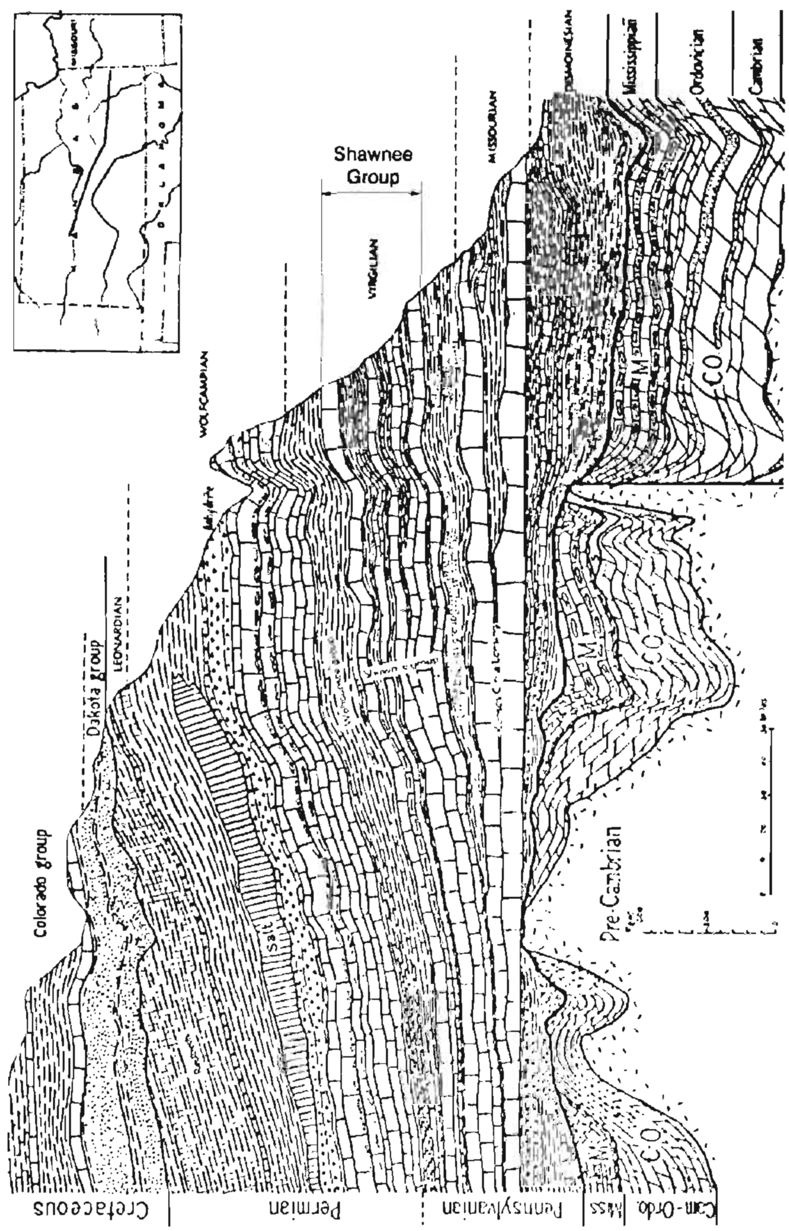


Figure 8.
Diagrammatic east-west section of subsurface Shawnee Group in Kansas (From Moore, 1949.)

Beyond the borders of Kansas, outcrops of Shawnee rocks are mappable across northwestern Missouri into southwestern Iowa and southeastern Nebraska. The persistence of most stratigraphic units and the striking uniformity displayed throughout their known area of distribution in these states permit unusual uniformity in classification and nomenclature.

Although problems are introduced near the Kansas-Oklahoma boundary due to the southward change of facies of certain members some outcrops are traced readily across the central part of Osage County southward. Equivalents of the Shawnee group in northern Oklahoma include the topmost beds of the Nelagoney formation (Oread), Elgin sandstone, Pawhuska formation (Deer Creek), and approximately the lower 15 meters (50 feet) of the Buck Creek formation (Moore, 1949.)

Lithologic Character and Classification

The mid-portion of Virgilian time, predominantly during deposition of the Shawnee Group, was characterized in the Kansas region by maximum accumulation of clear-water, calcareous sediments which seem to be mainly organic in origin. Although the total thickness of clastic deposits exceed the aggregate of all limestone beds, they are much less prominent than the limestones.

Four of the formations assigned to the Shawnee group are largely, if not predominantly, made up of limestone. The three intervening formations consist mainly of shale and sandstone. These alternating calcareous and clastic deposits reflect major cyclic oscillations of sedimentation, which furnish evidence of important lateral shifting of the strand lines of Virgilian seas. Sedimentation associated with retreat of the shallow seas consists of coal beds and nonmarine sandstone and shale, some of which contain well-preserved land plant remains. Marine sedimentation is represented by the limestones and by several types of shaly deposits, most of which, contain a variety of marine invertebrates. The arrangement of terrestrial and marine deposits indicates both a simple progression in cyclic sedimentation, in which as many as a dozen distinct environments are represented, and a repetition of sets of cycles in constant order. The compound cyclic arrangement of Shawnee deposits, expressed in megacyclothems includes four simple cyclothems having individual peculiarities (Moore, 1936.) These distinctive cyclic sedimentation sequences of the four relatively thick limestone formations and three shale formations distinguish rocks of the Shawnee from those of adjacent groups. The formations in ascending order include: the Oread Limestone, Kanwaka Shale, Lecompton Limestone, Tecumseh Shale, Deer Creek Limestone, Calhoun Shale and Topeka Limestone.

Oread Limestone Formation

The Oread Limestone was named by Haworth (1894) from prominent scarp-forming exposures at Mount Oread, University of Kansas campus, Lawrence, Kansas. The total thickness of the type section for the Oread at Lawrence is 14 meters (45 feet) with an average thickness in northern and central Kansas of 16 meters (52 feet.) In southern outcrops the average thickness increases to about 30 meters (100 feet) by virtue of an increased interval between the lower two limestone members (Moore et al, 1951.)

Due to the erosion resistance of the Oread its outcrop is marked by a prominent escarpment that is traceable across the entire state of Kansas. The northern half of the state exhibits thin shale members resulting in the limestone members correspondingly close together. These alternating beds of relatively thin limestone and shale members tend to form minor ledges of a single escarpment. In contrast, the lower shale members in southern Kansas thicken considerably to as much as 23 meters (75 feet,) so that the limestone members form distinct escarpments, which may be separated by a mile or more (Moore, 1936.)

The five limestone of the Oread recognized by Moore are widespread and distinct. The lower three limestones are characterized by lithologic types and faunas thought to be diagnostic of individual cyclothems. Each cyclothem is viewed as being partly to completely developed and differing in composition from associated cyclothems (Troell, 1969.)

Members of the Oread Limestone Formation includes, in order of decreasing depth: Toronto Limestone, Snyderville Shale, Leavenworth Limestone, Heebner Shale, Plattsmouth Limestone, Heumader Shale and Kereford Limestone.

Toronto Limestone Member

The Toronto, the basal member of the Oread, is typically yellowish-brown and tends to weather a distinct deep brown. It is irregularly bedded with an average thickness of 3 meters (10 feet) and locally may be argillaceous to sandy (Troell, 1969.) Fossils are usually numerous with fusulinids, brachiopods and crinoid fragments being abundant in most exposures. Corals and molluscs are also present but in fewer numbers. It was named in 1894 from a town in southwestern Woodson County by E. Haworth and W.H.H. Piatt (Moore, 1936.) This member has been traced from the townsite of Toronto southward into Oklahoma and extending northward to Nebraska (Moore et al., 1951) where some geologists have considered it equivalent to the Weeping Water Limestone (Condra, 1927.)

Snyderville Shale Member

The Snyderville Shale was named by Condra (1927) from exposures at the Snyderville quarry, west of Nehawka, Cass County, Nebraska. The thickness is around 4 meters (12 feet) in Nebraska and western Iowa (Condra and Reed, 1937) increasing to as much as 23 meters (75 feet) in southern Kansas averaging perhaps 8 meters (25 feet) (O'Conner, 1955.)

Typical coloration of this member ranges from gray to bluish-gray, green and may be locally red near the base. In northern outcrops, the lower and middle parts of the Snyderville consists of structureless underclay-like deposit that weathers in irregularly shaped block fragments. The uppermost intervals are often well laminated shale bearing a marine fauna of brachiopods, bryozoans and some pelecypods and underlain by calcareous gray to yellow-tan shale, thin siltstone, and argillaceous limestone (Moore et al., 1951.) Southern Kansas outcrops tend to be more sandy in at least some parts, and includes discontinuous, argillaceous limestone and calcareous shale nodules in the lowermost few centimeters (von Bitter, 1972.) O'Conner noted that some of these thin, impure, limestone beds within the lower Snyderville were partly mudcracked, containing sparse molluscs and an algal limestone less than a meter above the Toronto (O'Conner, 1955.)

Leavenworth Limestone Member

The middle limestone member of the Oread Formation is the Leavenworth named by Condra from a road cut exposure northwest of the federal penitentiary at Leavenworth, Kansas (Condra and Reed, 1937.) It is very distinctive in physical characteristics and has long been regarded for its lateral persistence and homogeneity as it can be traced without break or significant change for more than 480 kilometers (300 miles) from southern Kansas to southwestern Iowa. Almost everywhere across Kansas the thickness is more than .3 meters (1 foot) and less than .6 meters (2 feet) (Moore et al. 1951.)

This dark bluish-gray, dense, massive limestone generally occurs in a single bed, with prominent, closely spaced, vertical joints. On weathering a thin surface film is altered to a light gray or slightly creamy color and the substance of the rock is slowly removed by solution. This tends to round the edges of the joint blocks, eventually resulting in bouldery remnants of the bed along some long weathered outcrops. Fusulinids are the most common fossils with brachiopods and other small molluscs also numerous (O'Conner, 1955.)

Heebner Shale Member

The type locality of the Heebner Shale, identified by Condra in 1927, is found along Heebner Creek and farm west of Nehawka, Nebraska, in Cass County (Condra and Reed, 1937.) Thickness of this member varies little from 1.5 meters (5 feet) throughout much of Kansas and Nebraska. In many outcrops, the Heebner consists of four distinct shale units which are, in ascending order: a thin bed of gray or yellow clay shale, black fissile shale, dark bluish-gray shale, and blue-gray to olive-gray calcareous clay shale. The black fissile shale is typically the thickest section of the Heebner, commonly 1 meter (3 feet) thick or less. Small brachiopods occur in the calcareous clay shale, the black shale is found to be conodont bearing, and locally there are numerous gastropods and chonetid brachiopods in the thin clay shale at the base of the member. It is also a widely distributed subsurface marker identified in radioactivity logs by its intense gamma ray emission. (Zeller, 1968, Moore et al., 1951.) Small grayish-brown phosphatic nodules occur sparingly in the black shale (O'Conner.) There is no other occurrence of a black "slaty" shale in the Oread Formation and the deposition between the very distinctive "middle" and "upper" limestones make recognition of the Heebner member easy and certain (Moore, 1936.)

Plattsmouth Limestone Member

Condra and Bengston (1915) used the term Plattsmouth to describe the rocks found at the type locality in the Missouri River bluffs southeast of Plattsmouth, Nebraska. Typical of these northern outcrops the Kanwaka shale is relatively thin and the Spring Branch, Kereford, and Plattsmouth limestones occur so closely together they were all labeled erroneously as "Plattsmouth." In 1927, Condra restricted the name to the interval classified as Spring Branch-Plattsmouth and correlated it with the Plattsmouth interval of Kansas. The member name is now in general use to include the limestone between the Heumader Shale above, and the Heebner Shale below (Condra, 1927.) This is the topmost limestone along the Oread escarpment in most places, for the overlying Kereford limestone, when present, is mostly found at some distance back from the front of the escarpment (Moore, 1936.)

The Plattsmouth Limestone Member, commonly termed "upper Oread," is the thickest unit in the formation, averaging about 5 meters (15 feet) but locally may attain an overall thickness of 9 meters (30 feet) (O'Conner, 1955.) It consists of a thick zone of massive bedded and thin irregularly-bedded, fossiliferous limestones with interbedded, wavy shale partings, some of which may be featheredge and fossiliferous. It is distinguished by the bluish-gray color of the rock which weathers light creamy yellow to light grayish-brown. The texture is predominantly very fine to sub-lithographic but commonly contains thin to coarse streaks and patches of clear crystalline calcite. Scattered nodules of blue-gray chert occurs in parts of the member, generally more prominent in the northern localities (Moore, 1949.)

Fossils, many of which have been replaced with crystalline calcite, are prolific and include fusulinids, brachiopods, bryozoans, crinoid fragments, corals, and molluscs. Algal remains occur locally with *Osagia* found within the upper 1 foot of the member which is immediately underlain by abundant fusulinids in a massive limestone bed. This interval may be traceable throughout all of the Plattsmouth exposures. Below this zone, in Nebraskan exposures, is a thin, dark gray, fossiliferous shale underlain by a 3 foot bed of oölitic limestone, which, in northeastern Kansas is represented by limestone with a molluscan fauna (Condra, 1927.)

<u>Heumader Shale Member</u>

The characteristically thin interval of shale which lies between the base of the Kereford Limestone (where present) and top of the Plattsmouth Limestone was named as the Heumader Shale by Moore (1932) based on exposures in the

Heumader quarry, north of St. Joseph, Missouri. This member of the Oread Formation is mostly gray or greenish colored, clayey to silty shale which becomes arenaceous in southeastern Kansas. A very thin brownish-red zone has also been associated with the Heumader in certain localities (O'Conner, 1955.) Some exposures show the presence of fairly numerous well preserved molluscs and a few other fossils such as bryozoans and brachiopods. However, the shale has also been described as being unfossiliferous at many locations (Moore, 1936, 1949.)

The Heumader Shale Member averages 1 to 1.5 meters (4 to 5 feet) in thickness but varies considerably from almost nothing to over 3 meters (10 feet.) In outcrops where the overlying Kereford Limestone Member is absent, the Heumader and beds which may be shaly equivalents of the Kereford, are not differentiated. Although stratigraphic continuity with units classified as parts of the Oread Formation is recognized, the shale above the Plattsmouth may not consist of the Heumader alone, but may be Heumader combined with Kanwaka (Kanwaka Formation,) and it may be designated as the Heumader-Kanwaka Shale, or more specifically, the Heumader-Jackson Park Shale (Moore, 1936.)

Kereford Limestone Member

The Kereford Limestone, the uppermost division of the Oread Formation, was named by Condra from the exposures at the Kereford quarry just south of Atchison, Kansas. He initially included it as a unit in the Kanwaka Shale (Condra, Reed, 1937) but later agreed with other stratigraphers that the member was definitely associated with the cycle of limestone and marine shale deposits in the Oread Formation (Moore, 1936.)

The Kereford can be characterized by the overwhelming variation of lithologic features, richness of fossil content and its very local development. Contrary to other limestone which are, in general remarkably constant in thickness and physical nature, the Kereford varies considerably in thickness from a featheredge to 3 or 4 meters (10 or 12 feet) within only a few kilometers. There are many outcrops covering distances of many kilometers in which no development of this limestone member is indicated (Moore, 1936.)

Locally, some exposures consist almost entirely of slabby and cross-bedded oölitic rock. In other areas the Kereford is a single massive bedded, dark bluish limestone, apparently somewhat siliceous. In still other outcrops it is a bluish-gray flagstone, consisting of several feet of alternating even-bedded dense blue limestone layers and approximately equal thickness of shale.

Almost all of these type deposits contain numerous very well preserved fossils in which molluscs are strongly predominant and fusulinids and other marine invertebrates also present. In northern Kansas oölitic layers are generally associated with thin, *Osagia*-bearing limestone with local plant remains evident at some localities. As the Kereford thickens, this upper *Osagia*-bearing interval typically overlies the more slabby, irregularly-bedded fossiliferous limestone (Moore et al., 1951.)

Kanwaka Shale Formation

The name for the Kanwaka Shale Formation was originated by Adams in 1903 from exposures east of Stull, Kanwaka Township, Douglas County, Kansas. This nomenclature is used to describe the beds between the top of the Kereford Limestone or, where the Kereford is absent, the top of the Plattsmouth Limestone

Member of the Oread Formation and the base of the Lecompton Limestone Formation (Condra and Reed, 1937.) Overall thickness ranges from about 2 meters to 44 meters (7 feet to 145 feet) averaging around 21 meters to 24 meters (70 to 80 feet) in thickness (O'Conner, 1955.)

In northeastern Kansas and northwestern Missouri, where it is relatively thick, the Kanwaka consists of two shale members separated by a limestone member. The limestone, generally situated in the upper mid-section of the formation, is found in central and northern Kansas, and probably equivalent beds of sandstone and shale with marine fossils occurs in southern Kansas and northern Oklahoma. The limestone contains a varied fauna of brachiopods, bryozoans, and some mollusca, and in places abundant fusulinids. Within the southernmost outcrops much of the interval between the Lecompton and Oread formations is occupied by sandstone, sandy shale and red shale, collectively called Elgin Sandstone (Moore, 1936.)

Where differentiated, the three members of the Kanwaka Shale Formation in ascending order are the Jackson Park Shale, the Clay Creek Limestone followed by the Stull Shale (Moore, 1936.)

Jackson Park Shale Member

R.C. Moore named the Jackson Park Shale in 1932 from outcrops in the south part of Atchinson, Kansas, at a local park called Jackson Park. This member is bounded at the base by the Kereford Limestone, or localities in which that member is absent, by the top of the Plattsmouth Limestone Member. The base of the Clay Creek Limestone defines the upper limit, which at the type locality near Atchison occurs about 7 meters (24 feet) above the top of the Kereford. Bluish-gray and yellowish-brown sandy shale compose most of this unit with some carbonized land plant remains occurring in the shale and locally containing a thin coaly streak (Moore, 1936, O'Conner, 1955.)

Localities where the Jackson Park Shale is clearly defined, the member averages 12 to 15 meters (40 to 50 feet) in thickness. Areas in which the upper limit is not clearly determined because the Clay Creek Limestone cannot be definitively traced the Jackson Park Shale Member is included in the undifferentiated Kanwaka Shale (Condra, 1927.)

Clay Creek Limestone Member

The Clay Creek Limestone Member, named by Moore from exposures on Clay Creek about one mile west of Atchison, Kansas, is bluish-gray in color, medium fine-grained to granular, and moderately hard attaining maximum thickness of 1 meter (3 to 4 feet.) Beginning in northern Kansas, the limestone is persistent at least as far southward as Osage County and only tentatively identified in Greenwood and Elk counties. It is included in the undifferentiated Kanwaka Shale in localities in which it is absent or too thin to trace definitively (Moore et al., 1951.)

Fresh rock exposures indicate the rock is massive and dense, with distinct vertical joints and both the upper and lower surfaces fairly even. Upon weathering, the weakened Clay Creek generally breaks into shelly chips, a characteristic not typical of limestones in the Shawnee (Moore, 1936.) This member is usually very fossiliferous with fusulinids in the middle part overlain by algal material (Condra, 1927.) In some places the fusulinids may be very abundant along with copious crinoid stem plates and lesser occurrences of molluscs, bryozoans, and brachiopods (Moore et al., 1951.) O'Conner noted a thin crust of broken brachiopod, crinoid and bryozoan fragments, 2 or 3 inches in thickness, is common at the top of the member. A thin shale parting that apparently expands southward is also evident in the upper middle portion of the member (O'Conner, 1955.)

Stull Shale Member

Moore named the type section of the Stull Shale from exposures found near the town of Stull, Douglas County, Kansas. This member is identified northward from Elk County and tentatively in parts of southeastern Kansas. The average thickness has been estimated by Moore to be 7 meters (23 feet.) Lithologic characteristics include a primarily yellowish-brown and bluish-gray colored, clayey, silty, and sandy shale containing limonite nodules (O'Conner, 1955.) In northern Kansas, sandstone containing somewhat plentiful carbonized land plant remains and partially filled channels occur in the upper part of the member. Much or all of the Elgin sandstone in the southern part of the state may belong in this division (Moore et al., 1951.) Many of the better exposed outcrops may contain a soft friable sandstone which is interpreted by some, to be the initial deposit of the Lecompton cyclothem. Immediately above this sandstone a thin coal bed may be present locally (Moore, 1936.)

Lecompton Limestone Formation

The Lecompton Limestone Formation was named by Bennett from exposures in the upland south of Lecompton, Douglas County, Kansas. It consists of four closely associated limestones and three intervening shale members with a total thickness varying from 9 to 20 meters (30 to 66 feet,) the average being about 13 meters (43 feet) (Condra and Reed, 1937.) It is underlain by the Kanwaka Shale and overlain by the Tecumseh Shale. Persistence of lithologic and paleontologic characteristics of the Lecompton permit definite identification of this formation and of various members at many exposures from Nebraska to Oklahoma. In southernmost Kansas and northern Oklahoma, however, some of the limestones disappear, and further southward, all the limestone members eventually disappear. Stratigraphic equivalents of the Lecompton limestone in northern Oklahoma are included in the lower part of the Pawhuska formation (Moore et al., 1951.)

Due to the thickness and resistance of the Lecompton limestone beds and because the shale formations above and below may reach 18 meters (60 feet) or more in thickness, the Lecompton Formation forms a well defined escarpment in the Kansas River region and throughout the much of northern Kansas. The thinning of the limestone members and thickening of the shales in the Lecompton, accompanied by thinning of the Tecumseh Shale in central and southern Kansas, results in a reduction in the prominence and distinctiveness of this escarpment (Moore, 1949.)

The seven members of the Lecompton Limestone Formation, in upward order, include the Spring Branch Limestone, Doniphan Shale, Big Springs Limestone, Queen Hill Shale, Beil Limestone, King Hill Shale and Avoca Limestone (Moore, 1949.)

Spring Branch Limestone Member

The Spring Branch Limestone, the basal member of the Lecompton Formation, was named by Condra from exposures near Lecompton, on Spring Branch, northeast of Big Springs, Douglas, Kansas (Condra and Reed, 1937.) This member is characterized by massive, grayish rock that weathers to a strong yellowish-brown to brown, ferruginous, slightly wavy bedded limestone and in the majority of outcrops, by an extreme abundance of fusulinids. The fusulinids are most apparent in the middle and lower intervals, often separated from the upper portion by a thin shale parting. In addition to the disseminated iron oxide, which is responsible for the brown coloration, there is frequently an appreciable content of silty or sandy impurities (Moore, 1936.)

A notable bed that occurs in both southern and northern localities is a very dense, light gray, algal limestone about a foot in thickness found at the top of this member. Some exposures in southwestern Douglas and southeastern Shawnee counties, exhibit .3 to .6 meters (1 to 2 feet) of a coquinoid, somewhat conglomeratic limestone with these abundant discoid algal growths, classed as *Osagia*. (Moore, 1936.) Overall total thickness of this member averages about 1.5 meters (5 feet) (O'Conner, 1955.)

Doniphan Shale Member

The Doniphan Shale which overlies the Spring Branch Limestone ranges from 2 to 10 meters (5 to 34 feet) in thickness and consists of shale, sandstone and thin limestone beds. This member was named by Condra from exposures in northern Doniphan County, Kansas (Condra and Reed, 1937.) It is typically bluish and yellowish-brown and clayey but does contain some prominent sandstone beds and red shale in the southeastern part of the state (Moore et al., 1951.) The upper part is thin-bedded or blocky, in places much like an underclay. Locally it contains a few molluscs and may contain marine invertebrates (Moore, 1949.) Beds below the underclay-like shale in limited northern and central areas develop a thin zone of carbonized plant material with abundant ostracods underlain by 1 to 1.5 meters (3 to 4 feet) of gray shale and unfossiliferous siltstone. Middle beds, primarily in the southern outcrops, contain a thin sand or conglomeratic molluscan limestone, 1 to 1.5 meters (3 to 4 feet) of silty shale and siltstone, and another thin molluscan limestone. The lower beds of southern exposures are gray or greenish, blocky to thin-bedded shale with central and northern exposures consisting of interbedded calcareous shale and shaly limestone containing abundant fusulinids (O'Conner, 1955.)

Big Springs Limestone Member

The Big Springs Limestone was named by Condra from exposures near Leavenworth, north of Big Springs in Douglas County, Kansas. It is very persistent, having been recognized from Iowa and Nebraska southward to Oklahoma. Generally about .3 meters (1 foot) thick it has been found locally to be as thick as 1 meter (3 feet) with a thin shale parting often found in these thicker sections. The Big Springs Member is a dark bluish-gray, dense limestone which typically occurs as a single bed and characterized by prominent closely spaced, vertical joints (Condra and Reed, 1937.) Northern outcrops are sometimes argillaceous with exposures in southern Kansas found to be locally very sandy and impure limestone (Moore et al., 1955.) On weathering, a thin section of the surface is altered in color to light yellowish-brown and fusulinids, which are very abundant, stand weathered in slight relief. In addition to fusulinids, other invertebrates present in the Big Springs Limestone include algae, bryozoans, brachiopods, echinoderm fragments and molluscs (O'Conner, 1955.)

After exposure, this limestone member does not typically break down into small fragments, but is slowly removed by solution following the well defined vertical joint planes to produce bouldery blocks with rounding of the originally rectangular masses (Moore, 1949.)

Queen Hill Shale Member

The Queen Hill Shale Member, named by Condra from Queen Hill, 8 kilometers (5 miles) south of Plattsmouth, Cass County, Nebraska, ranges in thickness from 1 to 2 meters (3 to 6 feet.) It is generally divisible into two parts, an upper yellowish-tan or bluish-gray, blocky to thin-bedded, unfossiliferous clay shale underlain by a hard, black carbonaceous, very fissile shale containing conodonts (O'Conner, 1955.)

This member of the Lecompton Limestone Formation is recognized along the outcrop entirely across Kansas, but in southern exposures the black shale is not as commonly found (Moore, 1949.)

Beil Limestone Member

Named by Condra from exposures on the Beil farm south of Rock Bluff, Cass County, Nebraska, the Beil Limestone Member consists of thin to medium-bedded, abundantly fossiliferous, bluish-gray limestone (Condra and Reed, 1937.) Upon weathering a prominent yellowish to yellowish-brown coloration is apparent. Thickness ranges from 1 to 5 meters (3 to 15 feet) with an overall average of 3 meters (10 feet.) Fossils, especially horn corals and fusulinids are abundant in the Beil with lesser quantities of brachiopods, bryozoans and molluscs also present. This characteristic assemblage of fauna evident in most exposures from Nebraska to Oklahoma and the stratigraphic association with the underlying black fissile shale member permit easy differentiation of the Beil from other members of the Shawnee Group (Moore, 1949.)

In northern outcrops, including the type locality and extending into Nebraska and Iowa, the upper part contains alternating layers of thin limestones and calcareous shale overlain by an algal–bearing (*Osagia*) limestone. This top bed is typically .3 to .5 meters (1 to 1.5 feet) thick and appears coarsely granular or oölitic. The lower part is a more massive, irregular to wavy bedded, fossiliferous limestone (Moore et al., 1951.)

In central and southern outcrops, the Beil Limestone is usually more massive, containing fewer and thinner shaly beds with some exposures exhibiting somewhat wavy bedding and other peculiarities characteristic of the Plattsmouth Member of the Oread Formation (O'Conner, 1955.)

King Hill Shale Member

The uppermost shale division of the Lecompton was named by Condra from exposures at King Hill, southeast of Rock Bluff, Cass County, Nebraska (Condra and Reed, 1937.) The King Hill Shale Member is a bluish-green to greenish-gray and reddish colored, typically blocky, clayey or sandy shale ranging in thickness from about 1.2 to 6 meters (4 to 20 feet) (Moore, 1949.) Average thickness of the member appears to be approximately 5 meters (17 feet) (O'Conner, 1955.) Except for numerous brachiopods sometimes encountered near the top of the shale, fossil content in the King Hill is generally sparse or lacking (Moore et al., 1937.)

Exposures of the King Hill shale in northern Kansas commonly include one or two persistent, impure yellowish, irregular, nodular, limestones which weather yellowish-brown. Locally, another impure calcareous siltstone occurs in the lower part (O'Conner, 1955.)

Avoca Limestone Member

The uppermost member of the Lecompton Limestone formation is the Avoca Limestone named by Condra from exposures on the south fork of Weeping Water Creek, 5 kilometers (3 miles) east of Avoca, Otoe County, Nebraska (Condra and Reed, 1937.) The thickness of this member may reach up to 6 meters (20 feet) but generally ranges between .3 and 1 meter (1 and 3.5 feet,) averaging around .6 meters (2 feet) total thickness (O'Conner, 1955.) It is typically comprised of two or three thin, fossiliferous, dark bluish-gray, somewhat earthy limestone beds separated by thin, fossiliferous shale. Relatively large fusulinids are the most common fossil found in almost all exposed rock with algal-molluscan beds occurring locally near the top of the Avoca. These robust fusulinids are one of the identifying characteristics utilized in recognizing the Avoca Limestone Member in many outcrops from Nebraska and Missouri southwestward to southern Kansas (Moore, 1949.) Other fossils, including algae, brachiopods, crinoids and molluscs occur in parts of the member but are not everywhere abundant (O'Conner, 1955.)

Tecumseh Shale Formation

Generally, gray to bluish-gray in color, the Tecumseh Shale is clayey to sandy and mostly unfossiliferous, locally having a discontinuous limestone in the upper part. In southern Nebraska, this limestone becomes persistent and is formally a member of the Tecumseh Shale Formation called the Ost Limestone. The other members of the Tecumseh recognized in Nebraska are the Kenosha Shale at the base and the Rakes Creek Shale at the top. However, the increasing lack of continuity of the Ost Limestone bed in more southern exposures preclude subdivision of this formation in Kansas (Moore, 1949.)

Including strata between the top of the Avoca Limestone Member of the Lecompton Formation and the basal member of the Deer Creek Formation the thickness of the Tecumseh ranges from an observed minimum of 3.5 meters (12 feet) in southeastern Kansas to a maximum of about 20 meters (65 feet) near the Kansas River (Moore et al., 1951.) The type locality is a few kilometers east of Topeka in the Kansas River Valley. It was named by Beede in 1898 from the townsite of Tecumseh in Shawnee County, Kansas, where it is comprised of sandy shale and some sandstone (Condra and Reed, 1937.)

Deer Creek Limestone Formation

The Deer Creek Limestone is one of the most important, widely persistent, formations of the Shawnee Group. It was named by Bennett from the type locality in eastern Shawnee County, between Lawrence and Topeka on Deer Creek (Condra and Reed, 1937.) It consists of three or four limestone members separated by two or three shale members. Development of the lower limestone does not continue into the northern exposures of the formation. In southern outcrops, the second limestone from the top merges with the upper limestone member with intervening shales either absent or very thin. In ascending order, members of the Deer Creek Formation in Kansas exposures include the Ozawkie Limestone, Oskaloosa Shale, Rock Bluff Limestone, Larsh-Burroak Shale and the Ervine Creek Limestone (Moore, 1949.) The thickness ranges from about 20 to a maximum of 24 meters (80 feet), averaging 15 meters (50 feet) (O'Conner, 1955.)

Most of the formation across Kansas is easily mappable, marked by a very prominent escarpment and common lithologic characteristics. Based on this appearance and fossil content, it is readily differentiated from the adjacent Lecompton Limestone below and the Topeka Limestone above. However, without determination of stratigraphic position, the Deer Creek is easily confused with the Oread Limestone as the members of each formation are very similar in appearance and lithologic content (Moore, 1949.)

Ozawkie Limestone Member

The basal member of the Deer Creek Formation is the Ozawkie Limestone named from the town of Ozawkie, Jefferson County, Kansas by Moore. He defined the type locality in a road cut in the NE/4 of section 31, township 9 south, range 18 east (Condra and Reed, 1937.) It is typically a brownish-gray, massive or thick-bedded, limestone which resembles the lowermost limestone members of the Oread, Lecompton and Topeka formations. In contrast to the upper limestone members of the Deer Creek, the Ozawkie appears somewhat sandy and impure in many outcrops, as indicated by the obvious brown color of weathered outcrops caused by the oxidation of iron. Fossils are not very common in most places but locally, the Ozawkie may contain numerous crinoid stems, brachiopods, bryozoans, fusulinids and corals. It is generally around 1.5 meters (5 feet) in thickness but ranges from .3 to 6 meters (1 to 20 feet) (Moore et al., 1951.)

Oskaloosa Shale Member

This member was named by Moore from exposures in the vicinity of Oskaloosa, Jefferson County, Kansas. It is a bluish-gray or yellowish-gray colored, blocky shale in northeastern Kansas grading to a sandy, micaceous shale containing some red shale and locally nodular, impure limestone beds in the southeastern part of the state. Fossils are rare or absent in most exposures (Moore, 1949.) The thickness of the Oskaloosa Shale ranges from a minimum of 1 meter (3 feet) to a maximum of about 15 meters (50 feet) with most outcrops about 1.5 or 2 meters (5 or 6 feet) thick. In areas in which the Oskaloosa varies much from the average, the underlying Ozawkie limestone thickens correspondingly (Condra and Reed, 1937.)

Rock Bluff Limestone Member

The Rock Bluff Limestone is one of the most persistent, uniform and distinctive members of the Deer Creek Formation in the northern Mid-Continent region. Named by Condra in 1927 from exposures found at Rock Bluff, south of Plattsmouth, Nebraska, it is a dense, massive bed, of dark-blue limestone that weathers a bluish-gray or creamy color. A few inches from the surface may be altered to a purplish or brownish-blue, but because of the denseness of the rock, the interior of the rock remains a dark blue. Similar to the Leavenworth of the Oread Formation and the Big Springs of the Lecompton formation, the Rock

Bluff is typically .3 to .6 meters (1 to 2 feet) in thickness and characterized by abundant closely spaced, nearly vertical joints. This system of well developed joints tends to intersect at approximately right angles resulting in the bed separating into rectangular blocks on outcrop. The sharp edges of these blocks are gradually rounded by solution producing bouldery shapes. Although not abundant, fusulinids are the most common fossil found in this member with brachiopods, crinoid fragments, bryozoans and small molluscs also present (Moore, 1949.)

The lateral persistence, nearly uniform thickness, color purity, sharply fractured edges and the presence of a black slaty shale overlying the Rock Bluff make this member a striking sedimentary unit and stratigraphic marker. These distinctive physical characteristics are persistent from the type locality in southeastern Nebraska eastward into Iowa and Missouri, and southward across Kansas into north-central Oklahoma.

Larsh-Burroak Shale Member

This shale member, formally called the Larsh-Burroak, consists of two persistent, approximately equal, subdivisions, with gray or yellowish-gray, clayey shale in the upper part and black, fissile shale in the lower half. Fossils are rare with the exception of conodonts occurring in the black, fissile portion. The member is equivalent to the Larsh Shale, Haynies Limestone and the Burroak Shale members as described and named by Condra from exposures in Nebraska. Because the intervening Haynies Limestone Member is missing in outcrops in Kansas and the Larsh and Burroak members are indistinguishable, they are treated as one unit. There is very little observed variance in this member from Doniphan County in the far northeastern corner of the state to the point in southern Chautauqua County where the formation passes out of Kansas. Thickness remains relatively consistent ranging from .6 to 2 meters (2 to 6 feet) with an average of around 1.2 meters (4 feet) (Moore, 1949.)

The Larsh Shale, named in 1927 by Condra from exposures on the Larsh farm along Ervine Creek, northeast of Union, Nebraska, occurs throughout the entire area. He named the Burroak Shale for rocks found in road cuts and ravines near the Burr Oak School, Mills County, about 10 kilometers (6 miles) south of Pacific Junction, Iowa (Condra and Reed, 1937.)

Ervine Creek Limestone Member

The upper limestone member of the Deer Creek Formation, which is the thickest subdivision in most exposures, is named the Ervine Creek Limestone by Condra, from outcrops on Ervine Creek, northeast of Union, Cass County, Nebraska (Condra and Reed, 1937.) As redefined by Moore (1936), it is divisible into two parts. The lower unit, typically between 1 to 9 meters (3 to 30 feet) in thickness, is the most persistent and prominent, comprising the majority of the member in most places, at about 80 to 90%. The rock is light-gray to nearly white in most localities but has been found bluish in a few places. Weathered exposures are usually mottled gray or yellowish-brown in color. The texture of the Ervine Creek is finely crystalline, dense and relatively uniform with the exception of irregularly distributed masses of clear calcite and occasional chert nodules. Thin, wavy-bedding with clay and shale partings between the layers is typical. It contains a large assemblage of fossils including fusulinids, calcareous brachiopods, corals, crinoid and echinoid fragments, bryozoans and less commonly molluscs, sponges and trilobites. Ostracods and small foraminifers may be apparent in the shaly partings between the limestone beds. This section is typical of other upper limestone members of the Shawnee Formation, such as the Plattsmouth and Beil limestones, and possesses all the lithologic and faunal characters that distinguish these (Moore, 1949.)

Above the basal wavy-bedded limestone is a less persistent limestone consisting mainly of limestone of algal-molluscan character. The lithologic and faunal content of this upper division are clearly distinct from those of the lower. A single, massive bed of moderately to finely granular, uniform texture, containing numerous small *Osagia* but few other organic remains may represent this unit. Locally it is oölitic, nodular, or sandy. Some outcrops are coquinoidal consisting of a mass of shell fragments pressed together resulting in an irregular platy texture with pelecypods and brachiopods as the chief constituents. This upper bed ranges from 0 to 2 meters (0 to 6 feet) and may rest directly on the underlying limestone or it may be separated by .3 to .6 meters of shale that is commonly yellowish-gray, clayey to sandy shale (Moore et al., 1951.)

Calhoun Shale Formation

The Calhoun Shale, named by Beede in 1898 from exposures at the Calhoun Bluffs, 5 kilometers (3 miles) northeast of Topeka, (Condra and Reed, 1937) includes strata consisting primarily of shale between the top of the Deer Creek Limestone and the base of the Topeka Limestone formations. The Calhoun ranges from 11 to 17 meters (35 to 55 feet) in thickness, averaging around 14 meters (45 feet) (O'Conner, 1955.) In southern Kansas, the thickness diminishes until it is locally absent near the Oklahoma boundary. The formation also thins rapidly northward with some exposures in which the Topeka and Deer Creek formations are not clearly separated (Condra and Reed, 1937.)

Upper intervals are primarily gray to olive, sandy and silty shale, with thin sandstone lenses and/or thin beds of coal developed locally. Carbonized land plant fragments may be abundant, particularly in the sandy parts. Near the middle a thin algal and molluscan limestone is observed in a few outcrops. Sandstone, some of which may be micaceous, and sandy shales are also found in the middle intervals underlain by dark-gray fossiliferous shale containing abundant bryozoans and brachiopods and locally flaggy limestone beds. Some of these sandstone lenses are deposited on erosional surface cuts in the Ervine Creek Limestone (Moore, 1949.)

Topeka Limestone Formation

The Topeka Limestone, containing the uppermost members of the Shawnee Group, of formation rank named by Bennett in 1896 from outcrops in the vicinity of Topeka, Kansas. Subsequent studies by others resulted in a redefinition of the Topeka Limestone Formation to include members that are not present at the type locality. As now recognized, the upper beds of this formation are rare or absent in exposures between northern Shawnee County to Greenwood County due to post-Topekan erosion. Following research in northwestern Missouri, Hinds and Greene continued the use of the term Topeka Formation but included higher beds from the Turner Creek Shale Member up to the Coal Creek Limestone Member. In 1927, Condra validated this reclassification followed a few years later by Moore (Condra and Reed, 1937.)

In parts of north-central Kansas, the Topeka forms a distinct escarpment that rises 18 meters (60 feet) or more above the Deer Creek dip slope. Southward, however, the Deer Creek is the prominent scarp forming formation with the Topeka not sharply differentiated. Thickness ranges from less than 3 meters (10 feet) in Nebraska to more than 15 meters (50 feet) in parts of southern Kansas averaging about 6 meters (20 feet) (O'Conner, 1955.) The Topeka is recognized from southern to northern Kansas, in Nebraska and in Missouri. It is equivalent to the uppermost part of the Pawhuska Formation in Oklahoma and forms the top of the Bradyville Formation in Iowa (Moore, 1936.)

It is typically very fossiliferous and where completely developed, consists of nine distinct members, of which the two lowermost limestone members are generally the thickest and most prominent outcrops. The Topeka Limestone Formation is divided into five limestone and four shale members named in upward order the Hartford Limestone, Iowa Point Shale, Curzon Limestone, Jones Point Shale, Sheldon Limestone, Turner Creek Shale, Du Bois Limestone, Holt Shale and the Coal Creek Limestone (Moore, 1936.)

Hartford Limestone Member

The Hartford Limestone, at one time considered as part of the Curzon Limestone Member, was named from a well exposed outcrop below a highway bridge crossing the Neosha River on the north edge of Hartford, Coffey County, Kansas (O'Conner, 1955.) Early workers also referred to it as the Wolf River or the Dashner limestone based on similar appearance of outcrops in adjoining states. This member is generally bluish-gray, massive-bedded, consisting of 1 to 3 beds of limestone separated by shale a few centimeters to several meters in thickness. The texture of the Hartford member is typically fine and dense, but locally the rocks may be medium-grained crystalline limestones or impure and very silty or sandy. Weathered exposures are characterized by their strong brown color caused by ferruginous content but some outcrops exhibit pure limestones that weathers nearly white (Moore, 1936.)

The distribution and character of fossils in the Hartford tend to be irregular. Fusulinids are commonly very numerous at many localities but may be entirely absent. *Osagia* is often found in the upper part with lower beds sometimes containing the chambered sponge, *Amylsiphonella*. Some beds are profuse in invertebrates of many kinds, but others are lacking in identifiable organic remains. Despite the notable differences of physical and biological characteristics at various outcrops, the Hartford is still considered easily distinguishable from other members of the Topeka, in part, due to the very distinctive attributes of these higher members (Moore et al., 1951.)

Thickness of the limestone beds is quite variable, ranging from less than .3 meters to more than 6 meters (1 to 20 feet,) with the overall thickness of the entire member between .3 meter and nearly 13 meters (1 foot to 40 feet.) This variation along the strike, both in thickness and in number of limestone and shale subdivisions, distinguish the Hartford from other lower limestone members of the Shawnee Group (Moore, 1936.)

Iowa Point Shale Member

Named by Condra in 1927, the Iowa Point was initially classified to be part of the Calhoun Formation. Subsequent work by Moore substantiated Condra's classification resulting in miscorrelation in it's northern extension. In 1937, Condra and Reed published a report indicating that the Iowa Point Shale was traceable into the lower part of the Topeka Formation at exposures near Topeka, Kansas, and therefore was not a member of the Calhoun Formation. As now recognized, the type locality is found in the Missouri River bluffs, immediately southeast of the abandoned Iowa Point railroad station, Doniphan County, Kansas. This site was found to contain about 3 meters (10 feet) of bluish-gray, argillaceous to sandy shale with some interbedded sandstone and two thin coal seams. Further northeast, the Iowa Point thins to less than 1 meter (2.5 feet) and consists of similar lithology and locally containing sandstone layers and common carbonized plant remains (Condra and Reed, 1937.)

Curzon Limestone Member

The Curzon Limestone was named by Gallaher in 1900 from exposures at "Curzens Station" southeast of the Missouri River Valley near Forest City, Holt County, Missouri (Moore, 1949.) Originally, misspelled by Gallaher in his original research, the term "Curzen" is common in early literature (O'Conner, 1955.)

Throughout northern Kansas, this member is a persistent, very prominent, scarp forming subdivision of the Topeka Limestone Formation that is easily and positively identifiable. In southeastern Kansas, the Curzon is not differentiated and considered doubtfully identified in early studies (Moore et al., 1951.)

It is variable in texture and often occurs as two limestones separated by a thin shale. Coloration of this massive bedded rock is typically bluish-gray, weathering yellow-brown to tan. Fusulinids may be sparse to abundant in the lower and middle parts of the member with chert nodules common and a fauna of bryozoans, crinoids and brachiopods in the upper layers (Moore, 1949.) A thin, *Osagia*-bearing zone has been found in some of the outcrops in which the Curzon appears to be thickening. Overall thickness of this member ranges from 1.5 to 4 meters (5 to 12 feet) (Condra and Reed, 1937.)

Jones Point Shale Member

The Jones Point was named by Condra in 1927 from exposures on the Missouri River at Jones Point, 6 kilometers (4 miles) east of Union, Cass County, Nebraska (Condra and Reed, 1937.)

This member is comprised of clayey, calcareous and silty bluish-gray and gray-green shale, locally containing platy or nodular limestone beds. Fairly numerous brachiopods and molluscs are evident at some outcrops but sparsely fossiliferous at other exposures. Thickness in northeastern Kansas ranges from .3 to 3 meters (1 to 10 feet) with beds in the southeastern counties of Elk and Chautauqua typically 3 to 4.5 meters (10 to 15 feet.) Average for the state of Kansas is about 2 meters (6 feet) (Moore et al., 1951.)

Sheldon Limestone Member

The Sheldon Limestone, generally thin at .2 to .6 meters (.7 to 2 feet) in thickness, is a massive, light gray to nearly white, very fine-grained, dense limestone that commonly contains numerous algal growths of the type known as *Osagia* (Moore et al., 1951.) In northern areas, this member weathers a brownish-gray color, whereas it is more light gray to white colored in exposures to the south. The name for this member was derived by Condra from a locality in southeastern Nebraska at the Vilas Sheldon quarry, east of Nehawka in Cass County (Condra and Reed, 1937.)

Turner Creek Shale Member

The Turner Creek Shale is about 1 to 2 meters (3.5 to 7) feet thick throughout this region generally averaging 1.5 meters (5 feet.) In 1927, Condra identified the type locality on Turner Creek, southeast of Du Bois, Pawnee County, Nebraska (Condra and Reed, 1937.) The member is a bluish-gray or greenish-gray, clayey and calcareous shale bearing few invertebrate fossils. Locally, thin interbedded mudstones up to 6 inches thick, are developed (Moore, 1936.)

Du Bois Limestone Member

The Du Bois, typically .5 to 1 foot thick, is composed of one or more, dark-blue or greenish-blue, fine-grained to finely crystalline, hard limestone with prominent, closely spaced, vertical joints. Upon weathering, a thin surface film of the rock is altered in color to a light bluish or greenish-blue color. The rock does not disintegrate readily but is gradually decomposed by solution particularly along the joint planes with the edges of fossils often weathered in relief (Moore, 1949.) Molluscs, especially pelecypods, and brachiopods are numerous, with fusulinids present locally. Crinoid fragments, echinoids and bryozoans may also be present (O'Conner, 1955.) Condra is credited with naming this formation from exposures on Turner Creek southeast of the townsite of Du Bois, Pawnee County, Nebraska (Condra and Reed, 1937.)

Holt Shale Member

The highest shale subdivision of the Topeka Limestone Formation is the Holt Shale named by Condra from outcrops near Forest City, Holt County, Missouri (Condra and Reed, 1937.) The upper part is bluish-gray in color and typically clayey with some brachiopods and bryozoans present. With increasing depth, the Holt Member grades into a hard, black fissile shale containing brachiopods and conodonts. Varying little in thickness, between .5 to 1 meter (1.5 and 3 feet,) this shale is a distinctive member of the Topeka.

Coal Creek Limestone Member

The upper unit of the Topeka Formation, generally .6 to 2 meters (2 to 6 feet) in thickness, was named by Condra in 1927, from exposures on Coal Creek, .8 kilometers (1/2 mile) north of Union, Cass County, Nebraska, east of Lincoln (Condra and Reed, 1937.) Exposures in northern Kansas, Nebraska and Iowa, the Coal Creek Member consists of dark-blue, somewhat thick, massive bedded limestone with dark blue to nearly black nodules of chert. Upon weathering, these rocks alter to a light bluish-gray to brownish-gray coloration. Although only identified locally, southern exposures tend to show an irregular thin, wavy bedded, light bluish-gray limestone separated by calcareous shale partings. Usually fossiliferous and in most cases exceptionally well preserved, both limestone and shale beds contain similar faunal characteristics. Some beds contain a profusion of fusulinids but are lacking in other invertebrates. Other units within the member yield a large variety of brachiopods and bryozoans with relatively few fusulinids. Fossils within the calcareous shale often weather free (Moore, 1949.)

III.

CYCLOTHEMS

Development of the Cyclothem Concept

The cyclic nature of Pennsylvanian strata has been recognized by geologists since the early 1900's. In 1912, Udden was one of the first to identify Pennsylvanian cycles and suggest an explanation of the recurring pattern he observed in rock sequences found in the Peoria Quadrangle, of the Illinois Basin. He noted that each stage in a cycle was similar to its respective stage in other cycles. Udden defined four stages within each cycle in ascending order as: "1) accumulation of vegetation; 2) deposition of calcareous material; 3) sand importation; and finally, 4) aggradation to sea-level and soil-making." The cause of these cycles was interpreted to be an alternation of subsidence and sediment accumulation in which sediment from a distant source rapidly filled the region to sea level, thereby allowing extensive vegetation to accumulate before inundation recurred. Udden placed the boundaries of each successive cycle below stage 1 and above stage 4 (Udden, 1912.)

Stage 1 of a cycle, the accumulation of vegetation, was the result of shallow water entering a swamp environment, bringing suspended mud with it. Udden described this stage to be comprised of a coal bed followed by a transition zone of "bone coal", miner's slate and dark laminated shale. Deposition of carbonates in stage 2 was interpreted to have fluctuated in length from one cycle to the next due to the varying thickness of carbonate beds. Near the end of stage 2, currents would transport in silt and later sand as stage 3 began. Udden noted that laterally, the thickness of sandstone in each cycle varied little, indicating that the sandstone was deposited up to sea-level. He suggested an inversely proportionate relationship between carbonate thickness in stage 2 and sandstone thickness in stage 3. Thickening carbonates resulted in decreased accommodation space, with less sandstone deposited. Conversely, the sandstone beds thickened as the underlying lime decreased proportionally. Nearing the end of stage 3, the sandstone was deposited close to the surface of the sea thereby reducing sand carrying currents. The finer sized clay and silt began accumulating forming Udden's final stage in which shales, underclays and soils were deposited. Overlying this soil horizon, vegetation began accumulating, initiating the start of another cycle (Udden, 1912.)

Further recognition ensued by various other workers as Pennsylvanian cyclic deposits were described in other areas of the Midcontinent. In 1930, Weller defined a typical Pennsylvanian cycle to consist, in ascending order of the following:

Unconformity

Continental:
5. Sandstone
6. Sand and micaceous shale
7. Fresh-water limestone
8. Underclay, which may contain concretionary or bedded fresh-water limestone
9. Coal

Marine:
10. Black "fissile" shale
11. Calcareous shale
12. Limestone
13. Shale, containing "ironstone" bands in upper part and thin limestone beds in the lower part

In contrast with Udden, Weller placed his boundaries of cycles at the base of the massive sandstone instead of the base of the coals. He indicated that prior to sandstone accumulation both nondeposition and erosion occurred resulting in unconformities. These natural boundaries represent the occurrence of diastrophic events. His hypothesis of the probable cause of the cycles was a result of a combination of diastrophism and climatic variation. In subsequent research, Weller (1956) suggested that the unique black fissile shale unit of each cyclothem was the "key to the cyclical relations of the Pennsylvanian strata in Illinois and Kansas."

Weller postulated that the diastrophic cycle began with uplift of the North American continent resulting in exposure of the Midcontinent region and subsequent erosion as the sea retreated. Uplift continued in the Appalachians but abated westward. This allowed siliclastic sediments to accumulate in the Midcontinent until the Appalachians subsided. Although the mechanism was not addressed by Weller, he stated that fresh-water limestones were deposited locally, in shallow basins within the region. This was followed by a substantial period of tectonic stability in which the Midcontinent was subject to erosion. As the influx of sediments decreased from the Appalachians, drainage and sediment accumulation decreased in the Midcontinent. Vegetation proliferated during this period, causing even more regression of drainage and the development of swamps. These wet, restricted environments were conducive for the formation of coal deposits described by Weller as the last stage in his continental cycle. As the shallow, epicontinental sea began to transgress across the Midcontinent, black fissile shales were deposited in "stagnant conditions generally inhospitable to normal marine life." As subsidence continued and the transgressing sea encroached farther into the Midcontinent, Weller's second and third stage of his cycle were produced by the accumulation of "calcareous sediments containing the remains of typical marine organisms." Renewed uplift in the Appalachians occurred with the shallow sea retreating and fine sediments deposited forming marine shales. According to Weller's definition, this ended the last stage of a cycle and the beginning of a new one (Weller, 1930.)

Weller is credited with the introduction of the term "cyclothem" to describe "a series of beds deposited during a single sedimentary cycle," representing a single major advance and retreat of the sea. In a joint effort Weller and Wanless (1932) noted that the cycles previously described in Illinois were extensive and were correlatable with cycles in the Midcontinent region. They concluded that the mechanism responsible for the cyclical patterns was extensive and affected both areas simultaneously (Wanless & Weller, 1932.)

As Weller developed his theories of the cyclic deposits, Moore (1931) studied repetitious sequences found in an extensive line of exposures extending through Iowa, western Missouri, Nebraska, Kansas and northern Oklahoma. Consistent with earlier research, Moore noted repeating sequences of alternating marine and nonmarine units. "Evidence of cyclic sedimentation is seen in frequent and rather regular alternations from marine to nonmarine conditions but especially in a peculiar sequence of distinctive types of limestones and shale that is repeated several times. Building on Weller's new terminology, Moore coined the term "megacyclothem" to refer to a "repeated succession of cyclothems of different character" as is found in the more complex Midcontinent sequences (Moore, 1936.) Moore did not attempt to explain the mechanism causing the cyclicity of the rock sequences but he did recognize that the "repetition of the described succession of beds is not fortuitous and meaningless" (Moore, 1931.)

Wanless and Shepard (1936) disagreed with previous explanations for causality of the development of the cycles in the Pennsylvanian. They objected to the hypothesis of alternating cycles of subsidence followed by sedimentation as it omitted the process of uplift. Secondly, subsidence and sedimentation was not sufficient to explain the amount of erosion apparent at the base of some of the channel sands and crustal wrinkling that would be present in regional diastrophism was not evident.

As opposed to large-scale rhythmic movements of the earth, Wanless and Shepard (1936) favored the rhythmic changes in sea level. They introduced the concept of the variation of climate, caused by glaciation and deglaciation as the controlling factor in the deposition of the cyclical sequences. Their research along with others helped resurrect the poorly accepted theory of glacial-eustatic control on sedimentation proposed in the early part of the nineteenth century. Glaciation would provide a plausible mechanism for global climatic and eustatic sea-level changes that could account for the repeated alternation between erosion and sedimentation. Basin subsidence or movement of the sea floor was discounted as the primary cause as these events do not typically produce large scale, rhythmic changes in the sea-level.

In 1937, Elias presented evidence of cyclic repetition of alternating marine and nonmarine units based on faunal content. He noted the occurrence and diversity of fauna in the various units within the cycles and compared the results with modern fauna found in certain depths. A decrease in faunal diversity is generally an indication of decreasing water depth. Elias also addressed other factors that may effect faunal distribution such as temperature, salinity and food supply but determined that these factors were not as effective as depth at determining faunal zonation since the area of deposition was relatively flat (Elias, 1937.)

In a continued effort to understand cyclical sequences through the use of fauna, Israelsky (1949) studied foraminifera recovered from four bore-holes drilled within a developed gas field in Louisiana. For correlation purposes, the forams were classified as either benthonic or pelagic and if benthonic, they were sub-classified as arenaceous or calcareous in origin. The relative depth significance of each group was plotted against habitats of known species. For each well sample, the total number of specimens from each species was tallied and then percentages were calculated for benthonic and pelagic. These percentages were plotted based on their depth of recovery resulting in a chart which exhibited an oscillating profile of the relative changes in water depth at time of deposition (Figure 9.) A sudden shift of a dominate assemblage could indicate missing strata due to faulting or an unconformity. Although Israelsky research was very limited in scope it substantiated work by Elias and others.

Once the validity of using biostratigraphy as a tool in determining depositional environments was established, multiple researchers began applying these methods to the cyclic Pennsylvanian deposits of the Midcontinent. The use of conodonts has been particularly useful in the development of the more current cyclothem models. These microfossils were apparently prolific organisms and often cosmopolitan in nature, with worldwide distribution allowing recognition of global event horizons. One of the most popular concepts accounting for the pattern distribution was proposed by Seddon and Sweet (1971.) Their model described possible depth zonations for a variety of species, as derived from correlation with the inferred environment of deposition of the rocks. Heckel and Baeseman (1975) provided greater clarification to this depth-zonation model in regards to the Pennsylvanian megacyclothems, especially in relation to anoxic

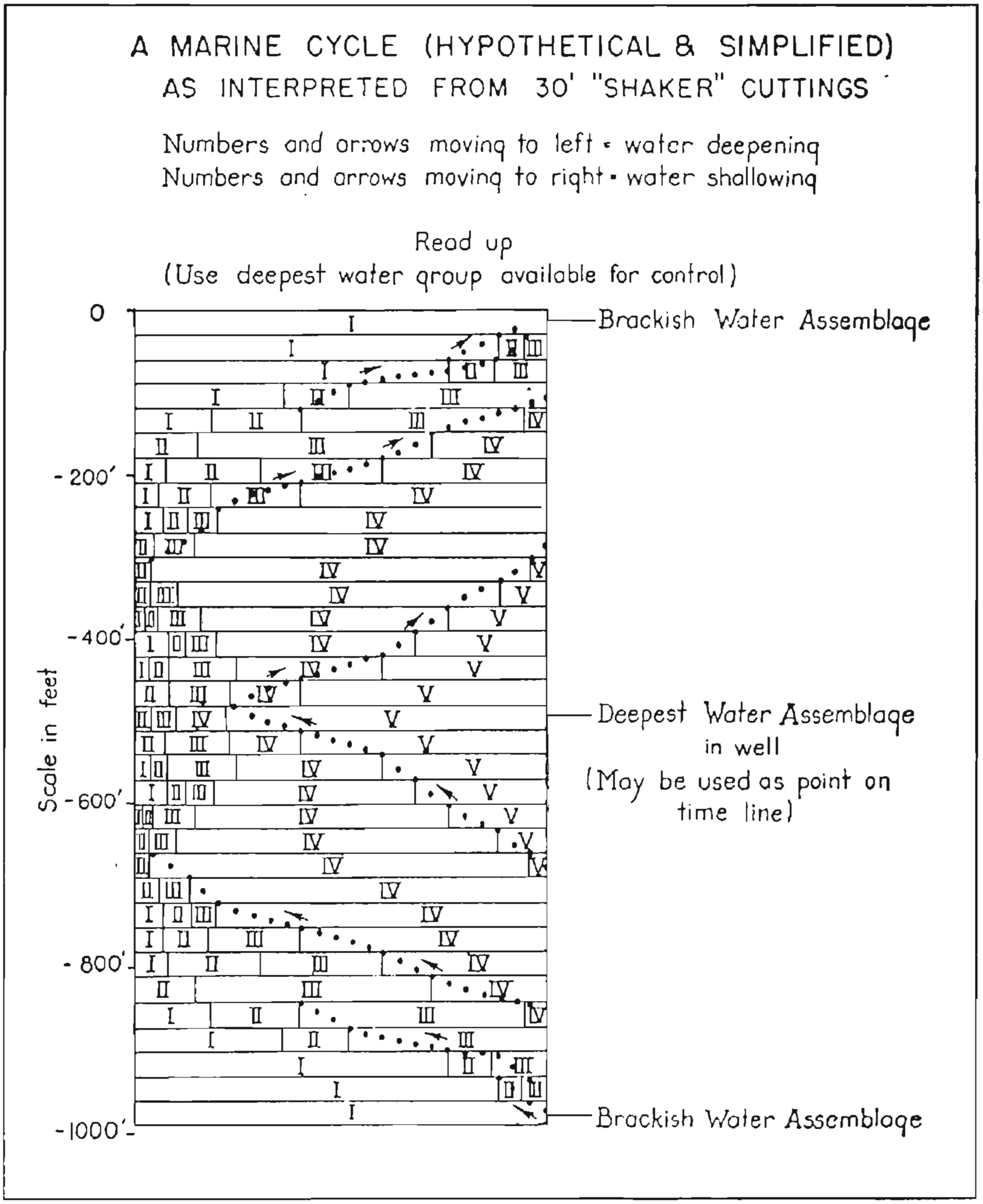


Figure 9.
Marine cycle oscillation chart (Israelsky, 1949.)

bottom conditions and the development of black shales. Boardman and Nestell (1993) continued the refinement of the depth-zonation paleoecological model by defining five distinct conodont biofacies and also incorporating several other fossil groupings (Figure 10.) These five biofacies correlate directly with the five sections of a cyclothem defined earlier by Heckel.

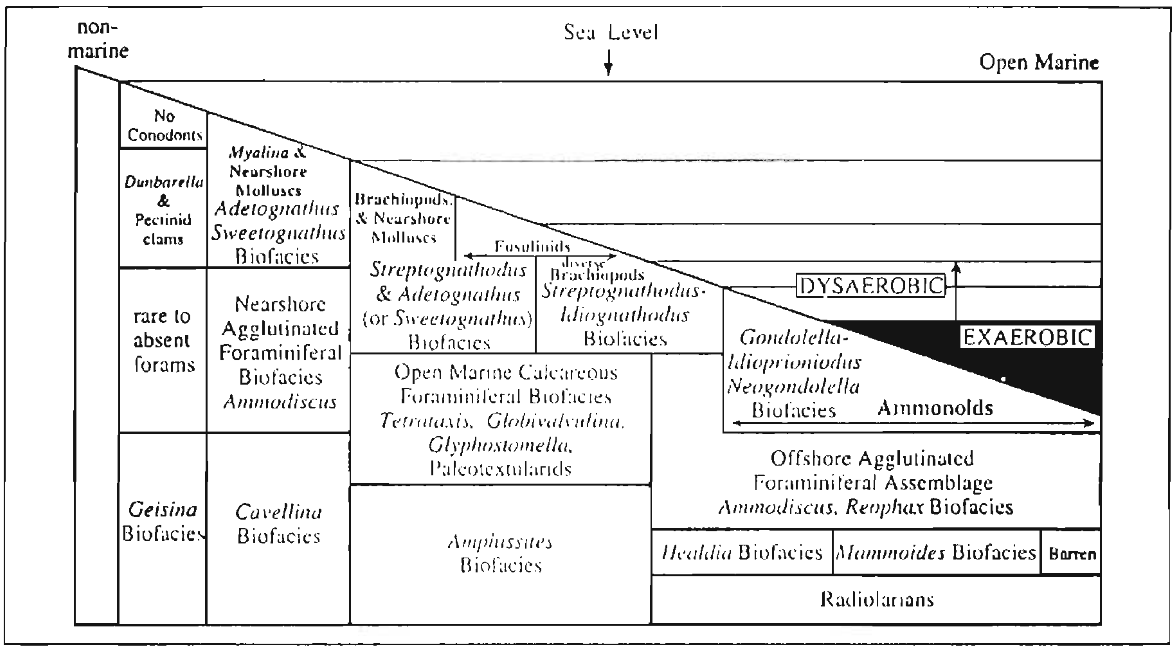


Figure 10.
Model for Pennsylvanian depth and oxygen related biofacies (Boardman and Nestell, 1993.)

One of the more significant usage of conodonts was to aid Heckel (1977) in his work on defining the origins of Midcontinent Pennsylvanian black shales. The 'black shale member' of Heckel and Baeseman was described to represent deep water fauna in their paleoecologic model. They noted that maximum conodont diversity and abundance occurred:

"...near the lower middle of the limestone formation, specifically in the black shale member and commonly in the adjacent parts of the two limestone members as well." (Heckel and Baeseman, 1975)

This section was designated by Heckel as the "core" shale of the cyclic deposition of specific lithofacies, or cyclothem. The lowest abundance and diversity of conodonts typically occurs within the "outside" shale. The units between these shales are transitional in the abundance and diversity of conodonts (Heckel and Baeseman, 1975.) In 1977, Heckel developed his interpretation of the "Kansas cyclothem" as more lithologic and paleontology data was gathered by himself and other workers. His refined model consisted of a succession of the following phases in ascending order:

1. Thick, sandy nearshore to non marine *outside* shale.
2. Thin, transgressive *middle* limestone.
3. Thin, offshore *core* shale, commonly black, fissile and phosphatic.
4. Thicker regressive *upper* limestone.
14. Thick, sandy nearshore to non marine *outside* shale.

This vertical succession of units is produced by a single transgressive-regressive event, representing one cyclothem. Moore's term, megacyclothem, is utilized in cyclical successions in which evidence of more than one transgressive-regressive episode is apparent (Heckel, 1977.) The boundary of the basic cyclothem was interpreted to be within the outside shale. Therefore, the lower part of the outside shale represents the end of one cyclothem followed by the beginning of a new cyclothem in the upper part of the shale.

Each of these units was interpreted by Heckel (1977) to define a particular depositional phase. The outside (nearshore) shale "... represent the times of lowest sea-level stand at maximum regression between the marine inundations (Heckel, 1983.) These outside shales are typically a thick, sparsely fossiliferous, sandy unit. Deposition occurred as the shoreline gradually regressed and the influx of detrital material increased. Numerous lateral facies variations indicative of rapid changes are characteristic of this unit. Channels, deltas, lagoons, tidal flats, beaches, etc. would be found in this type of environment. In areas where the sediments are non-marine, gray to red blocky mudstones and paleosols are present. Coal beds may also be locally developed, overlying the mudstone.

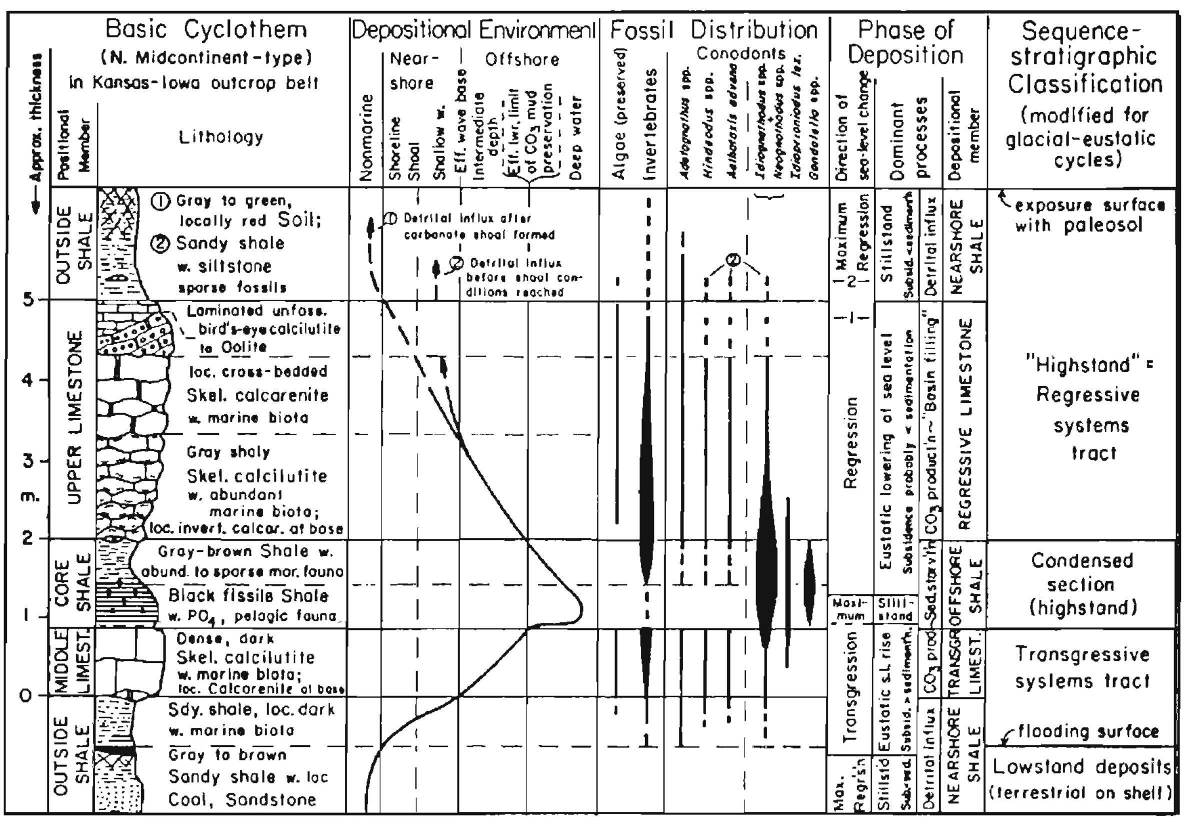


Figure 11.
Basic "Kansas cyclothem" of the Upper Pennsylvanian (Heckell, 1990.)

The middle limestone of Heckel's simplified Kansas cyclothem was deposited during a period of increased eustatic sea-level signifying the transgressive phase of the cycle. This member of the cyclothem is thin (<1 meter) due to the short span of carbonate formation under deepening water. Lithologically, the rock is generally a dense, skeletal limestone with diverse fauna (Heckel, 1983.)

The core (offshore) shale member is deposited in the sediment starved offshore environment during the period of maximum marine inundation in the latter stages of transgression. These core shales are primarily dark gray and black but have been noted to be lighter in color locally. Heckel explained core shales containing greenish-gray facies to be deposited during intermediate depths while the core shales containing the black facies to be deposited in deeper water. The black shales usually contain an abundant assemblage of diverse conodont fauna but are much less diverse in other faunal content, lacking benthic fauna and evidence of bioturbation. Phosphate in the form of nodules and some laminae is characteristic of the black fissile core shales, reflecting an anoxic sea floor established in deep water with circulation of phosphate rich water beneath a strong thermocline. Although not always present in this shale member, the phosphatic black shale facies has not been found present in any other Upper Pennsylvanian rocks in eastern Kansas (Heckel, 1977.)

Heckel and Baeseman (1975) interpreted the upper limestone to be shoaling upward units that were deposited during the regressive phase of the cycle. This limestone may represent the end of deposition of a cyclothem or may be overlain by the upper nearshore shale that formed in a more shoreward position. The limestone unit tends to be considerably thicker (up to 30 meters) than the middle limestone due to the intensified carbonate formation in shallow water and the increased supply of terrigenous siliciclastic sediment. Heckel and Baeseman (1975) explained, in situations in which the amount of siliciclastic sediment was greater than the rate of sea-level fall, delta-plain deposits are developed. If the amount of siliciclastic sediments was less than the rate of sea-level fall, prodeltaic deposits are observed.

The upper "outside" shale was deposited as the sea-level decreased and the shoreline prograded seaward. Terrestrial sediments of various lithologies commonly overlie this shale ending deposition of the cyclothem.

Moore's megacyclothem model for the upper Pennsylvanian is more complex in that it adds 3 shale units and 2 limestone units to a specific cycle (Figure 12.) In ascending order the megacyclothem is defined (after Moore 1936) to contain the following:

1. Sandy, outside shale, paleosol, underclay or coal at the base, marine at the top.
2. Lower limestone
3. Shale, unfossiliferous, blocky, locally red at the base, gray and fossiliferous at the top.
4. Thin, middle limestone.
5. Black core shale.
6. Thick upper limestone.
7. Marine to non-marine shale.
8. Super limestone.
9. Thick outside shale, often containing plant fossils.
10. Thin fifth limestone.
11. Sandy, outside shale, may contain plant fossils and paleosol

The upper and lower boundaries of each megacyclothem are placed within the adjacent sandy shale beds in the "outside" shales. In the ideal megacyclothem in which all five limestone members are recognized only the middle and upper are present in most Pennsylvanian cyclothems. These are the two units that are separated by the very distinct "core" shale. The super, lower and fifth limestone members occur with considerably less frequency (Heckel and Baeseman, 1975.)

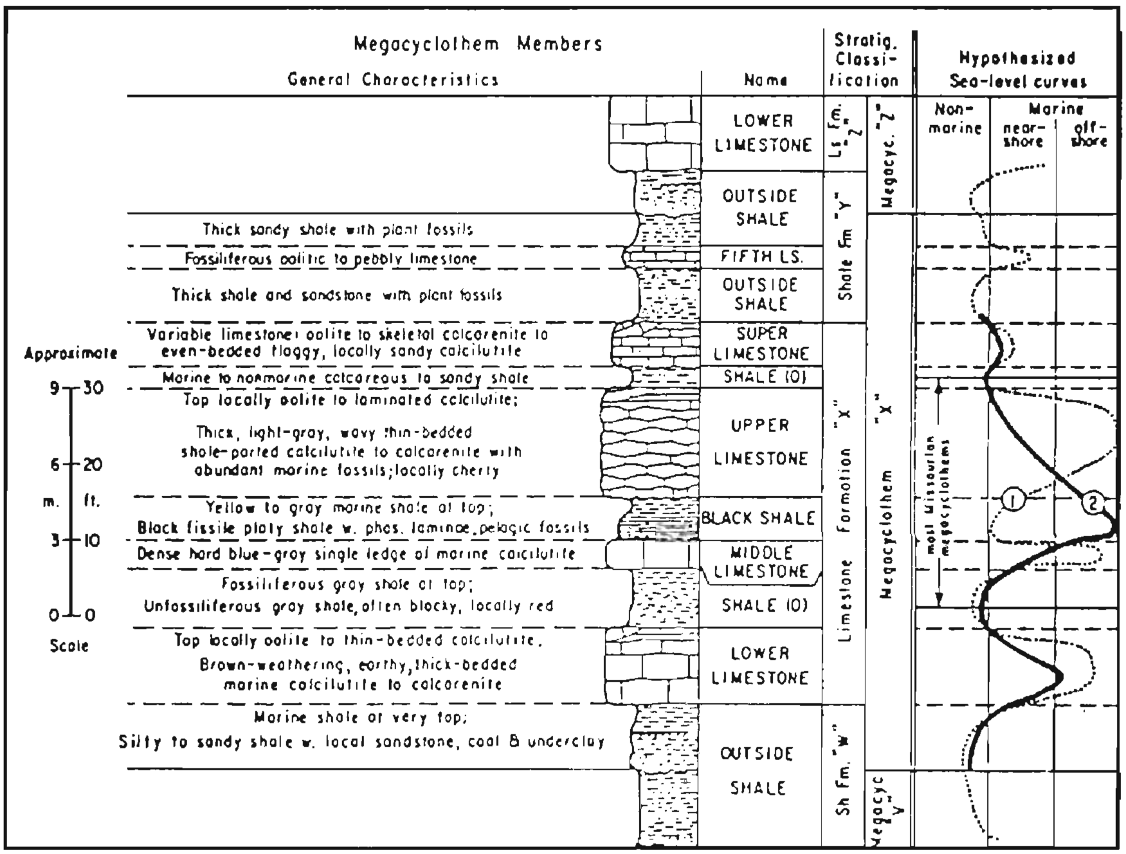


Figure 12.
Ideal Upper Pennsylvanian megacyclothem of Midcontinent
(from Heckel and Baeseman, 1975.)

Allocyclicity Versus Autocyclicity

The sequence stratigraphy of sedimentary strata is governed by the creation and removal of accommodation space resulting in transgressive-regressive events. Allocyclic and autocyclic processes are the controlling mechanisms for the deposition of these transgressive-regressive sequences. Autocyclic operate in a specific depositional environment, such as delta lobe switching and channel migration. Because these environments are so specific, autocyclic processes tend to be local in scale. Allocyclic processes affect numerous depositional environments at the same time, such as a glacio-eustatic sea-level change. As a result, allocyclic processes tend to be large (basin or global) in scale. Many workers have stated that stratigraphic sequences are due to either allocyclic, autocyclic or a combination of both (Busch et al., 1985.) However, after characterizing deep-marine systems and the complex interplay between a range of both of these controls, including sea-level fluctuations, basinal tectonics and the rate, type and nature of the sediment supply, it is apparent that the processes are rarely mutually exclusive and are more commonly interdependent. As a result, no single universal model can be used to describe and predict the facies and the stratigraphic architecture of deep marine systems.

Transgressive-Regressive Units

Eustatic sea-level changes are the major controls in the distribution of lithofacies. Sequence classification is based on concepts of the sequence scale (thickness) and duration of these sea-level variations. There are six orders of transgressive-regressive units that are hierarchical in character with the shorter term cycles superimposing the longer term cycles (Figure 13.) The first three orders were described by Vail et al., (1977) as the major transgressive-regressive events in both scale and time duration. The first order is defined to have a periodicity of 200 to 500 million, with 10 to 100 million years in the second and .01 to 10 million years in the third (Figure 14.) Bush and Rollins (1984) introduced three minor transgressive-regressive units which more readily define the high-frequency cyclicity found in strata of the Upper Pennsylvanian. The fourth order transgressive-regressive unit has a periodicity of .8 to 1.5 my, the fifth order 300,000 to 500,000 years (Heckel's Kansas cyclothem) and the sixth order units are on a scale of tens of thousands of years (Heckel's minor transgressive-regressive sequences) (Figures 14, 15.) They have "systematic, vertical succession of facies, cycle and sequence stacking patterns." The fifth order cycles are "composed of shallowing upward packages of dominantly subtidal shelf carbonates with sharp cycle boundaries (either exposure or flooding surfaces.) Fifth-order cycles are packaged into fourth-order sequences (type 1) bounded by regionally correlative subaerial exposure surfaces." Fifth and fourth-order cycles may be packaged together into third-order sequences (Goldhammer, 1994.)

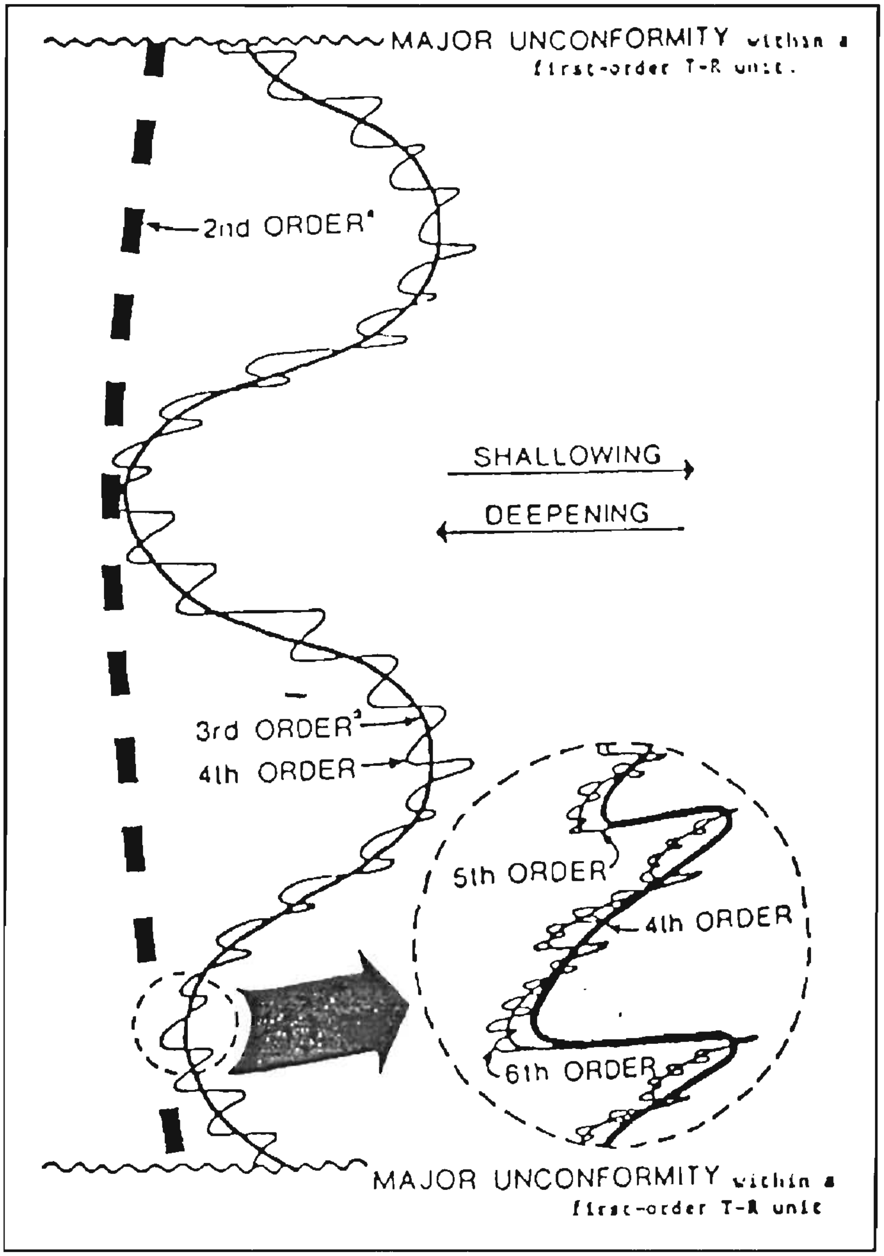
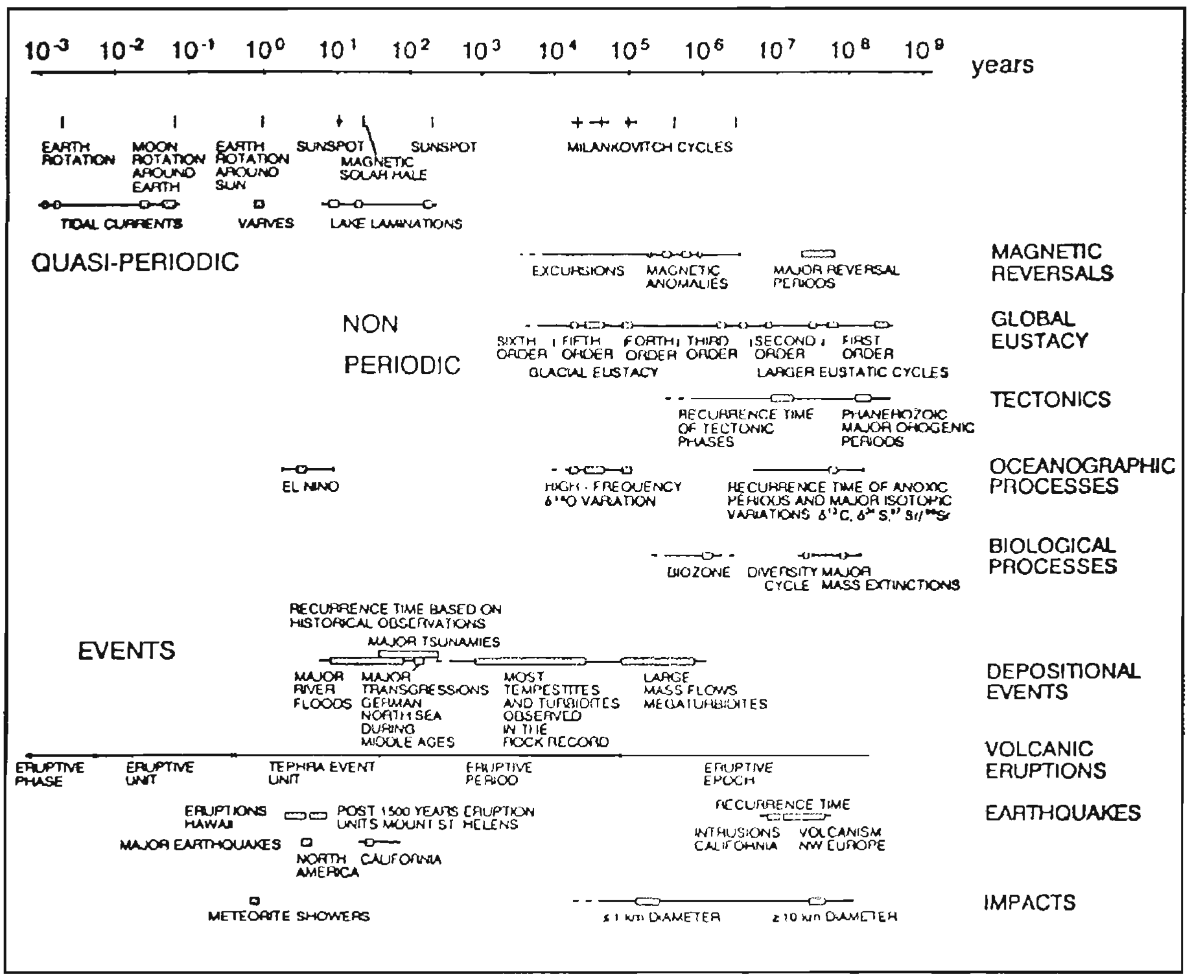


Figure 13.
Hierarchy of transgressive-regressive units
(Vail et al., 1977)

Sequence type	Duration (m.y.)	Other terminology
A. Global supercontinent cycle	200–500	1st-order cycle (Vail et al. 1977)
B. Cycles generated by continental-scale mantle thermal processes (dynamic topography), and by plate kinematics, including: 1. Eustatic cycles induced by volume changes in global midoceanic spreading centers 2. Regional cycles of basement movement induced by extensional downwarp and crustal loading.	10–100	2nd-order cycle (Vail et al. 1977), supercycle (Vail et al. 1977), sequence (Sloss 1963)
C. Regional to local cycles of basement movement caused by regional plate kinematics, including changes in intraplate-stress regime	0.01–10	3rd- to 5th-order cycles (Vail et al. 1977). 3rd-order cycles also termed: megacyclothem (Heckel 1986), mesothem (Ramsbottom 1979)
D. Global cycles generated by orbital forcing, including glacioeustasy, productivity cycles, etc.	0.01–2	4th- and 5th-order cycles (Vail et al. 1977), Milankovitch cycles, cyclothem (Wanless and Weller 1932), major and minor cycles (Heckel 1986)

Figures 14, 15.
Stratigraphic cycles and their causes (Miall, 1997.)



IV.

SEQUENCE STRATIGRAPHY NOMENCLATURE

Preface

Sequence stratigraphy, a subdiscipline of stratigraphy, is the study of rock relationships within a chronostratigraphic framework of repetitive, genetically related strata bounded by surfaces of erosion, non-deposition, or their relative conformities. "The subdivision of sedimentary strata into sequences, parasequences, and systems tracts provides a powerful methodology for the analysis of time and rock relationships in sedimentary strata. Sequences and sequence boundaries subdivide sedimentary rocks into genetically related units bounded by surfaces with chronostratigraphic significance. These surfaces provide a framework to predict facies relationships within the sequence. Parasequence sets, parasequences, and their bounding surfaces further subdivide the sequence and component systems tracts into smaller genetic units for detailed mapping, correlating, and interpreting depositional environments" (Van Wagoner, 1987.)

Other geological fields utilized in the study of sequence stratigraphy, includes sedimentology, seismic stratigraphy, biostratigraphy and chronostratigraphy. Lithostratigraphic correlations have no time-significance so this discipline is only useful in situations in which the stratigraphic bounding intervals are constrained by an unconformity surface (Bertram et al., 1996.)

Historical Development and Terminology

Pioneering studies by L. Sloss identified interregional unconformity surfaces that could be used to bound a series of stratigraphic "sequences" across the cratonic interior of North America. Sloss defined a sequence to be "major rock-stratigraphic units (of higher than group, megagroup or supergroup rank) which can be identified, where preserved, in all cratonic areas" of North America (Sloss, 1963.) He introduced six major cratonic stratigraphic sequences which were based on rock-stratigraphic units traceable over the major areas of the continent and bounded by unconformities of interregional limits. Sloss gave these sequences native American names to emphasize their north American derivation (Figure 16.) Craton-wide unconformities were defined and formed the basis for Sloss' separation of six major transgressive episodes in the cratonic interior which finally lap up on the margins before each closing regressive stage. These descriptions are based almost entirely on the physical relationships between the rock units with the lateral limits defined by erosion and truncation or by lateral transition into other natural sequences or groupings defined by other boundaries. Sloss' sequences are natural groupings representing significant episodes in depositional and tectonic history but are limited only to the North American craton and only large cratonic-wide unconformities.

The criteria which Sloss utilized to identify his stratigraphic sequences do not exhibit obvious characteristics when studied in the field or subsurface within a limited area. Local unconformities of much more obvious and dramatic development than the interregional unconformities with which they are interspersed can be readily established by intensive work in isolated outcrop areas (Sloss, 1963.) However, the term sequence defends the validity of sequence terminology compared to time stratigraphic terminology due to varying and extensive range of time of events.

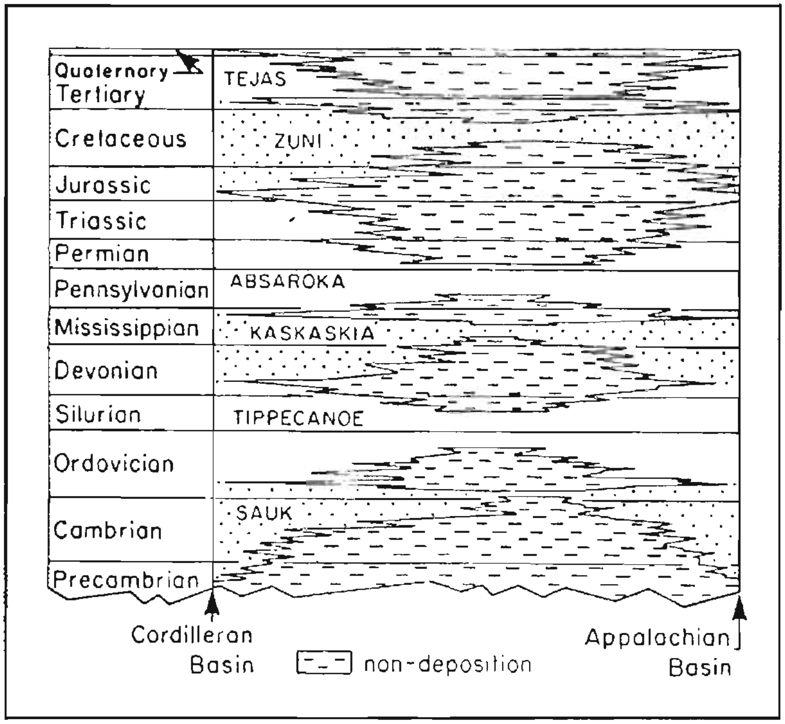


Figure 16. Time-stratigraphic relationships of the sequences in the North American craton. Black areas represent non-depositional hiatuses; white and stippled areas represent deposition (Sloss, 1963.)

The development of digitally recorded and processed multi-channel high-quality seismic data made large scale two-dimensional images through basins available. Seismic stratigraphy resulted in detailed basin analysis, the ability to define complex structures and permitted the correlation of unconformities over great distances. Utilizing seismic data increased interest in the concept of the sequence which resulted in new definitions, terminology and sequence stratigraphic models.

Mitchum et al. (1977) introduced the term depositional sequence which was defined to be "a stratigraphic unit composed of a relatively conformable succession of genetically related strata and bounded at its top and base by unconformities or their correlative conformities" (Mitchum et al., 1977) (Figure 17.) All of the strata in this unit are genetically related and were deposited within a "single episodic event". The depositional sequence is therefore chronostratigraphically significant (Mitchum et al., 1977.) This generalized terminology does not imply any particular mechanism for the formation of a sequence nor does it specify any scale duration of the correlative unconformities. However, their definition of a depositional sequence would be applicable to areas exhibiting local unconformities and aerial regions of much smaller extent than that of Sloss'.

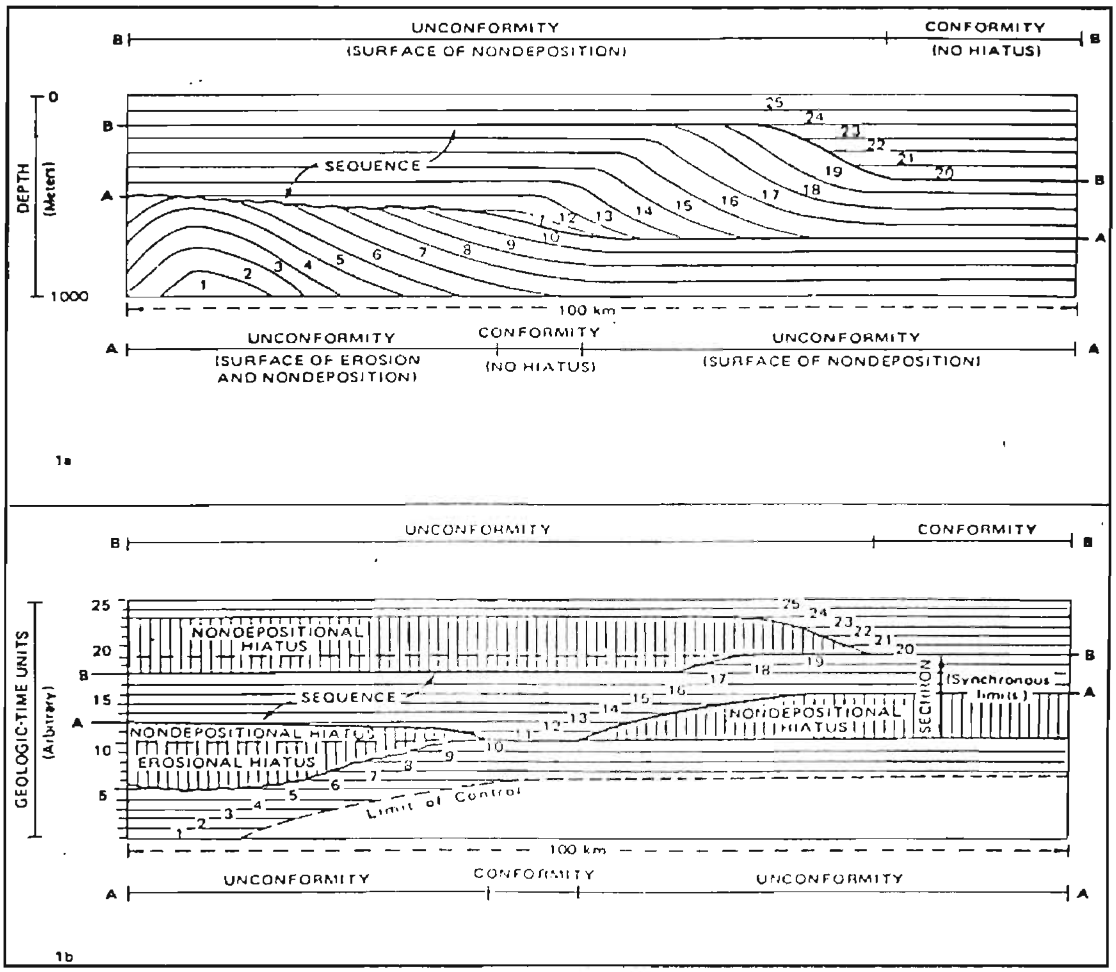


Figure 17.

Basic concepts of depositional sequence. A stratigraphic unit composed of relative conformable successions of genetically related strata and bounded at its top and base by unconformities or their correlative conformities (Vail et al., 1977)

Brown and Fisher (1977) recognized that deposition within a basin occurred in a series of discrete packages bounded by seismic reflection termination and defined these packets as 'system tracts'. Van Wagoner et al. (1987) found that these system tracts were arranged in a predictable fashion in the majority of sequences observed on seismic data. They introduced the term parasequence to encompass a relatively conformable succession of genetically related strata bounded by unconformities and their correlative conformities (Mitchum, 1977.) Parasequence sets were proposed to identify a succession of genetically related parasequences which form in distinctive stacking patterns that are generally bounded by major marine-flooding surfaces and their correlative surface (Van Wagoner et al., 1987.) The patterns of parasequences within parasequence sets are progradational, retrogradational, or aggradational (Van Wagoner, 1985), depending on the ratio of depositional rates to accommodation rates (Figure 18.) In progradational sequence sets the rate of deposition is greater than the rate of accommodation as successively younger parasequences are deposited basinward. In the retrogradational parasequence set, the rate of deposition is less than the rate of accommodation resulting in successively younger parasequences deposited landward. An aggradational parasequence set is one in which the rate of accommodation approximates the rate of deposition with virtually no lateral shifts and parasequences deposited on top of each other. These sequences were subdivided into system tracts which were further defined as linkages of contemporary depositional systems that are delineated on the basis of types of bounding surfaces, parasequence set distribution, position within a sequence, overall geometry, and facies associations (Van Wagoner et al., 1987.)

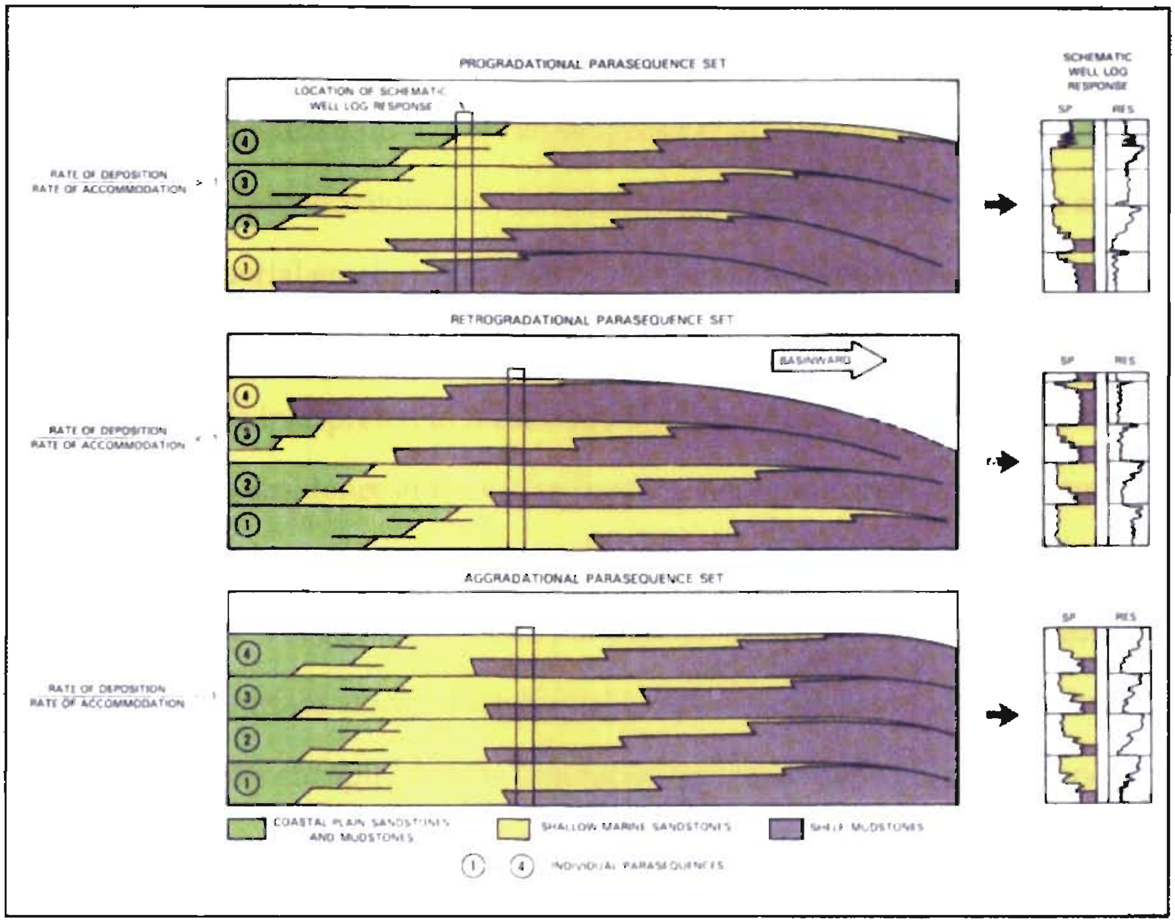


Figure 18.
Cross-section of parasequence stacking patterns in parasequence sets

Research by Van Wagoner et al. (1987) built upon the depositional sequence as the fundamental unit of sequence stratigraphy. They recognized two distinct types of sequences, type 1 and type 2, defined by erosional characteristics of the lower boundary. A type 1 sequence is bounded below by a type 1 sequence boundary and above by a type 1 or type 2 sequence boundary. A type 2 sequence is bounded below by a type 2 sequence boundary and above by a type 1 or a type 2 sequence boundary (Van Wagoner et al., 1987) (Figure 19.)

The type 1 sequence boundary is characterized by subaerial exposure and concurrent subaerial erosion associated with stream rejuvenation, a basinward shift in facies, a downward shift in coastal onlap, and onlap of overlying strata. This boundary is interpreted to form when the rate of eustatic fall exceeds the rate of tectonic subsidence at the offlap break or shoreline break, producing a fall in relative sea-level at that position (Van Wagoner et al., 1987.) Based on this definition, a type 1 sequence boundary should be characterized on the platform top by a single surface along which fluvial incision and associated stream or estuarine deposits abruptly overlie lithofacies typical of deposition on deeper water shelves, with no intervening lithofacies (Montanez and Oseleger, 1996.)

Type 2 sequence boundaries are "more subtle" (Posamentier and Vail, 1988) and are characterized by subaerial exposure of the inner platform, with no evidence of stream rejuvenation or a basinward shift in facies. The type 2 sequence boundaries should include a seaward increase in conformable stratigraphic relations, terminating at the platform edge in a ramp or shelf-margin. "Onlap of overlying strata landward of the depositional-shoreline break also marks a type 2 boundary. This is interpreted to form when the rate of eustatic fall is less than the rate of basin subsidence at the depositional-shoreline break, so that no relative fall in sea-level occurs at this shoreline position" (Van Wagoner et al., 1988) (Figure 20.) Type 2 unconformities are much more difficult to identify because they are not characterized by deep erosion or major facies shifts.

Building upon Brown and Fisher's terminology, Van Wagoner et al. (1987) divided type 1 and 2 sequences into specific 'system tracts.' The type 1 sequence was defined to include a lowstand, transgressive and highstand system tract, in ascending order (Figure 19.) A type 2 is comprised of a shelf-margin, transgressive and high-stand system tract. The development of each individual system tract was based on a specific facies, the geometry, type of bounding surfaces, position within a sequence, stacking patterns of parasequence sets, and parasequences bounded by marine flooding surfaces (Figure 20.) The systems tract nomenclature are not defined in terms of time "... or position on a cycle of eustatic or relative change of sea-level. The actual time of initiation of a systems tract is interpreted to be a function of the interaction between eustasy, sediment supply, and tectonics" (Van Wagoner et al., 1987.)

The basal, stratigraphically oldest, lowstand system tract (LST) of a type 1 sequence, is deposited during an interval of relative low sea-level on the continental slope and basin floor. This may be evidenced by stream incision and sediment bypass of the coastal plain if the shoreline rapidly progrades basinward during a period of fall in sea-level. As the relative fall of sea-level stabilizes, the infilling of incised valleys and continued shoreline progradation occurs, resulting in the formation of slope fans, basin-floor fans or a lowstand wedge which may downlap onto the basin-floor fan (Figure 21.) As relative sea-level increases, facies indicative of increasing accommodation space become apparent. The

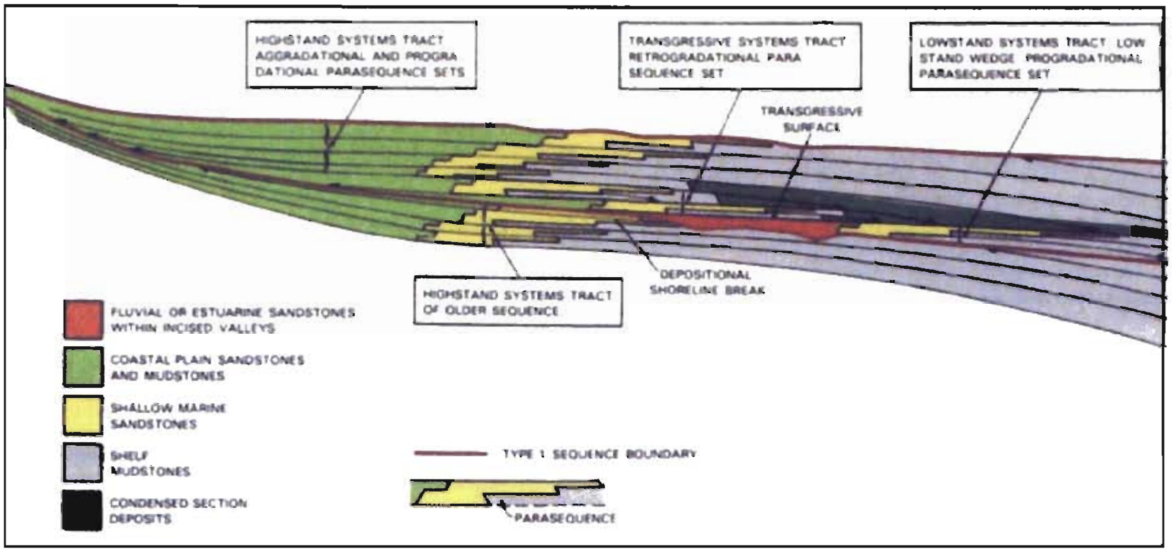


Figure 19. Stratal patterns in a type 1 sequence (Van Wagoner et al., 1988)

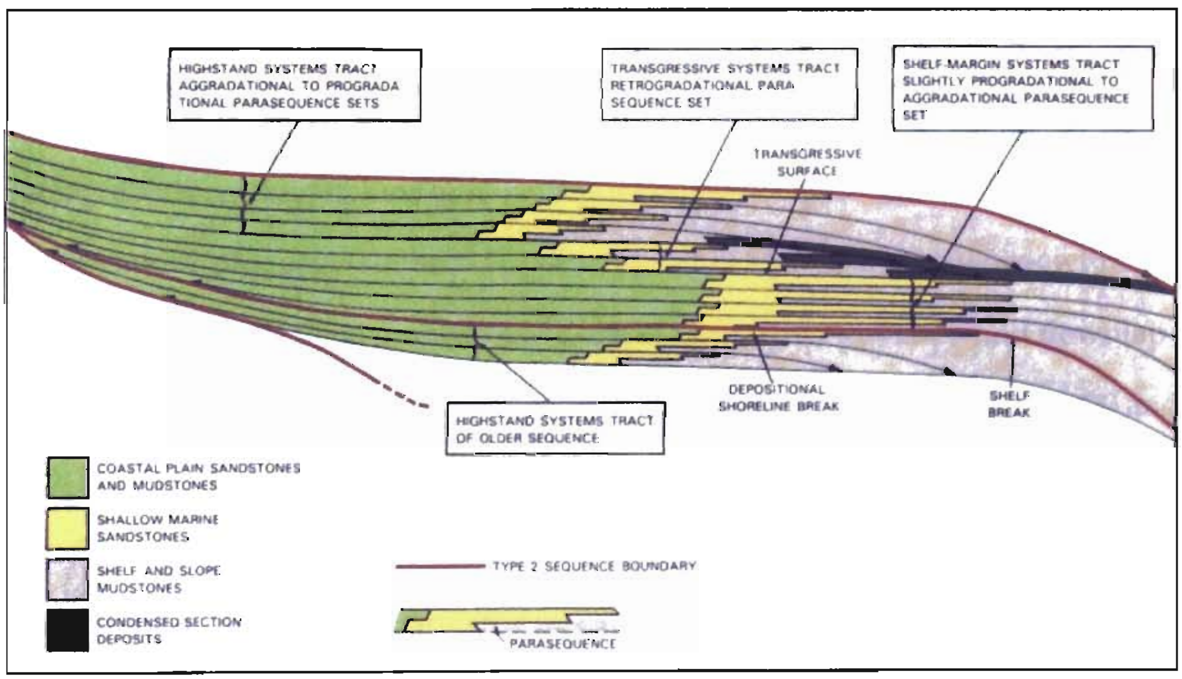


Figure 20. Stratal patterns in a type 2 sequence (Van Wagoner et al., 1988)

transition to the overlying transgressive system tract may be gradational or abrupt as progradation changes to retrogradation (Van Wagoner, et al., 1987.)

The shelf-margin systems tract (SMST) is characterized by one or more weakly progradational to aggradational parasequence sets. These sets onlap onto the sequence boundary in a proximal (landward) direction and downlap distally (basinward) onto the sequence boundary (Figure 20.) The sea-level does not drop below the edge of the continental shelf (offlap break) with the base defined by a type 2 sequence boundary. The top of the shelf-margin systems is the transgressive surface which is the middle systems tract found in both type 1 and type 2 sequences (Van Wagoner et al., 1987.)

The transgressive system tract (TST), interpreted to have been deposited during rapid eustatic rise, is characterized by topsets and is entirely retrogradational. The base of the TST, the transgressive surface, could include a very thin succession of marine shales, a basin-floor gravel lag, or it may consist of retrogradational successions of shelf deposits, including marine shale and sandstone, or platform (subtidal-supratidal) carbonates. Parasequences within the TST onlap onto the sequence boundary in a proximal direction and downlap distally onto the transgressive surface (Van Wagoner, et al., 1987) (Figures 20 and 21.) The top of the TST is a downlap surface and corresponds to the maximum flooding surface (MFS). The maximum flooding surface separates the transgressive systems tract from the overlying systems tract and represents the maximum landward distribution of diverse, open marine, cosmopolitan, plankton and deep water benthos marine conditions This occurs when the rate of rise of relative sea-level decreases to a point where it matches sediment supply signifying the maximum extent of marine flooding, and progradation and

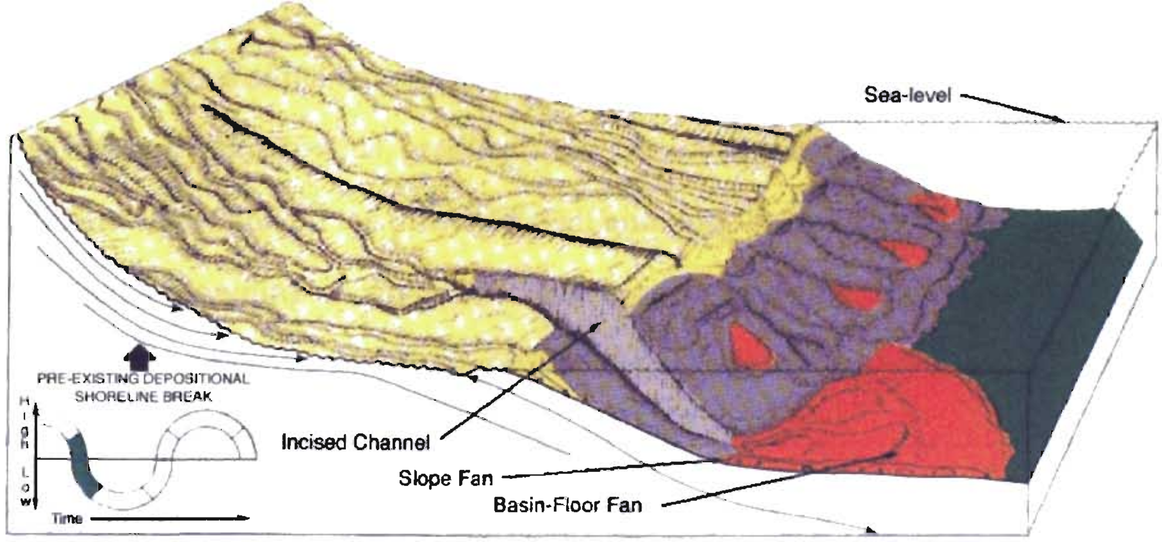


Figure 21.
LOWSTAND SYSTEMS TRACT:
1. Rate of eustatic fall exceeds rate of subsidence
2. Sea level falls to shelf break, shelf is exposed, incised valleys formed
3. Slope and basin floor fans are deposited
(from Van Wagoner et al., 1990.)

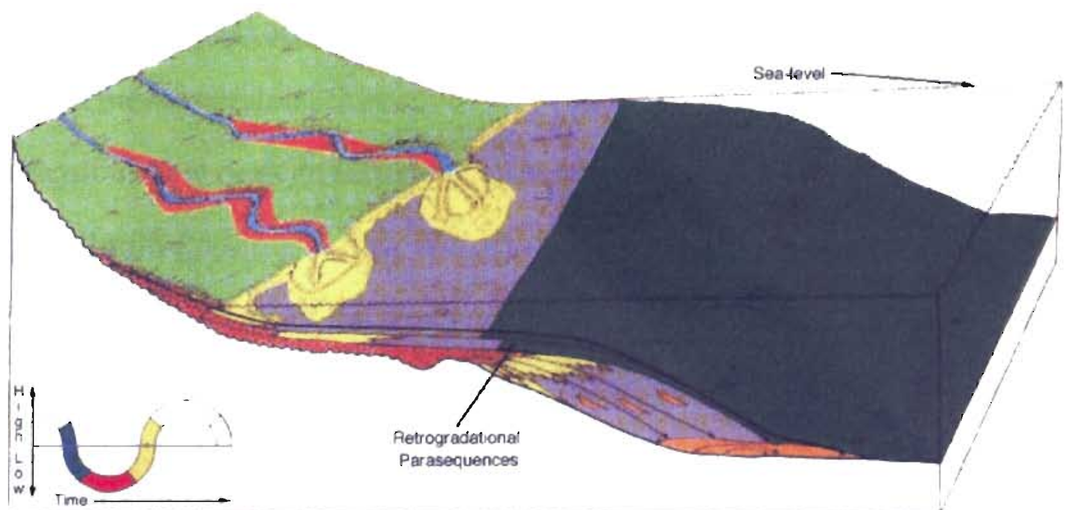


Figure 22.
TRANSGRESSIVE SYSTEMS TRACT:
1. Rate of eustatic rise is at a maximum
2. Retrogradational parasequence sets
3. Development of organic-rich facies (condensed section)

initiating the next systems tract in the sequence. In the proximal direction the maximum flooding surface may lie within an aggradational parasequence stack. Distally, at times of maximum transgression the deepest part of the shelf may pass below the photic zone, grading into a widespread condensed section due to sediment starvation on the drowned shelf and deep basin. The resulting surface is termed a drowning unconformity. The condensed section is characterized by extremely low rates of deposition and the development of condensed facies such as a glauconitic horizon, chert band, organic rich and/or phosphatic shales or pelagic carbonates (Bertram et al., 1996.) Other notable attributes of the condensed section include thin but continuous zones of burrowed or slightly lithified beds (omission surfaces) or marine hard-ground (cementation) and abundant and diverse planktonic and benthic microfossil assemblages. This section associated with the maximum flooding surface comprises a biostratigraphically distinctive horizon and has the greatest potential for being dated and correlated across a basin (and possibly globally). It may, therefore, become a more correlatable event than the sequence boundary, which sometimes is difficult to date or even recognize biostratigraphically (Galloway, 1989.) The maximum flooding surface is a downlap surface onto which the tops of prograding clinoforms of the overlying highstand systems tract (HST) downlap. This third tract forms the top of the stratigraphic sequence, although in some instances it may be considerably reduced in thickness as a result of erosion accompanying the next cycle of fall in base level. The HST, commonly widespread on the shelf, is the youngest systems tract in either a type 1 or a type 2 sequence. It is typically characterized by a decreasing rate of relative sea-level rise through time, resulting in initial aggradational and later progradational architecture. Interpreted to have been deposited during late eustatic rise, eustatic stillstand and early eustatic fall. "It may be bounded at the top by either a type 1 or type 2 sequence boundary and at the bottom by the downlap surface" (Van Wagoner et al., 1988.)

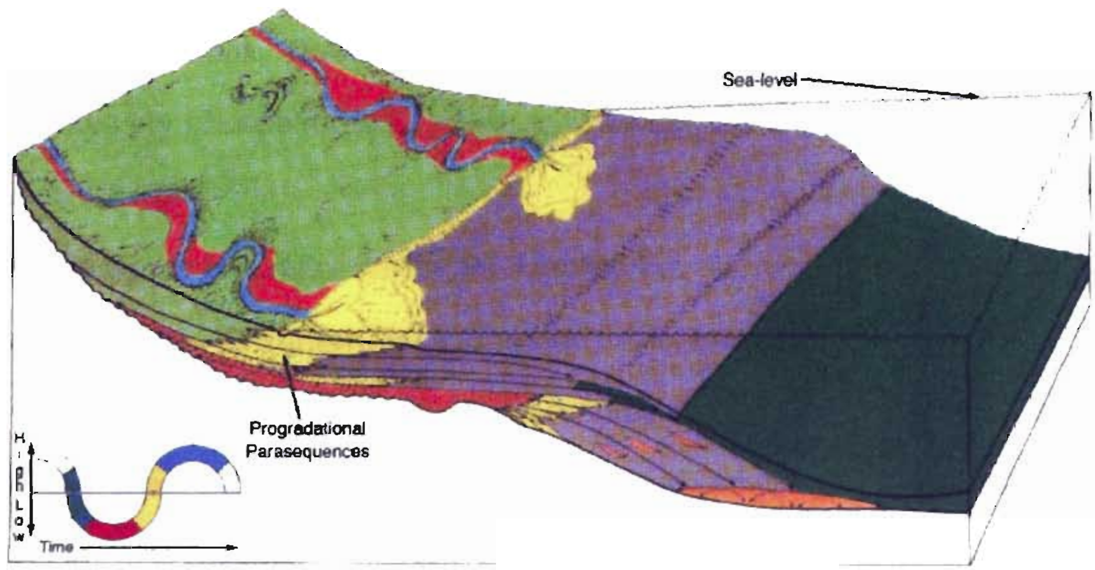


Figure 23.
HIGHSTAND SYSTEMS TRACT:

1. Rate of eustatic rise is at a minimum and in the late stages, falls slowly
2. Rate of deposition greater than rates of sea-level rise, parasequences build basinward in aggradational to progradational parasequence sets
3. Parasequences downlap onto the condensed section

CONCLUSIONS

Cyclothemic and megacyclothemic scale depositional sequences are readily identified in outcrops in southeastern Kansas. The Shawnee Group consists of six complete transgressive-regressive cycles of sedimentation forming four megacyclothems (Figure 25,) as defined by Heckel (1977.) Four cycles had sufficient water depths at or near highstand necessary to form definite marine condensed sections. These condensed sections are represented by black shales, typically very phosphatic, containing an abundance and diversity of conodonts (Figures 26-29.)

The Upper Lawrence (below the Toronto Limestone,) Snyderville Shale, Kanwaka Shale, Tecumseh Shale, Calhoun Shale, Iowa Point Shale and the Severy Shale represent lowstand deposits (outside shale.) The Snyderville Shale, Calhoun Shale and Iowa Point Shale members all contain evidence of subaerial exposure and terrestrial deposits. The Snyderville of the Oread megacyclothem contains a paleosol near the top of the member which is overlain by a thin, 4 to 7 centimeter thick limestone. This limestone probably developed nearshore as the coarse texture and presence of oöids suggests a high-energy environment.

The Calhoun Shale contains an abundance of plant remains and other organic matter. This vertical succession of plant debris is overlain by a coal seam reflecting swamp conditions in a humid climatic setting. Similarly, the Iowa Point Shale contains a coal seam but is underlain by marginal marine and silty shales. Several vertebra, approximately 3 centimeters in diameter, were recovered from this very low-grade coal horizon

The Toronto, Spring Branch, Ozawkie and Curzon limestone members represent the 'lower' limestone of the megacyclothem. These limestones overlie the 'outside' shale indicating a relative rise in sea-level. As the water continued to deepen, the second limestone of the megacyclothem was deposited. The Leavenworth Limestone, Big Springs Limestone, Rock Bluff Limestone and the DuBois Limestone members all indicate the continued transgression into an offshore marine environment below effective wave-base and near the lower limits of the photic zone.

Maximum flooding events are represented by four distinct 'core' shales including the Heebner Shale (Oread Limestone Formation,) the Queen Hill Shale (Lecompton Limestone Formation,) Larsh-Burroak (Deer Creek Limestone Formation,) and finally, the Holt Shale (Topeka Limestone Formation) which was previously believed to be absent in southeastern Kansas.

Distinctive characteristics between the 'upper' and 'super' limestone members of the megacyclothem model were not obvious in outcrops. Instead, the term 'super' limestone is used to describe the members deposited during this phase of regression. The 'super' limestones include the Plattsmouth Limestone of the Oread, the Beil Limestone of the Lecompton, the Ervine Creek Limestone of the Deer Creek and the Coal Creek Limestone of the Topeka. With the exception of the Coal Creek Limestone, these limestones are characteristically thick indicating slow regression, with the most offshore facies at the base and grading upward into increasingly nearshore facies toward the top.

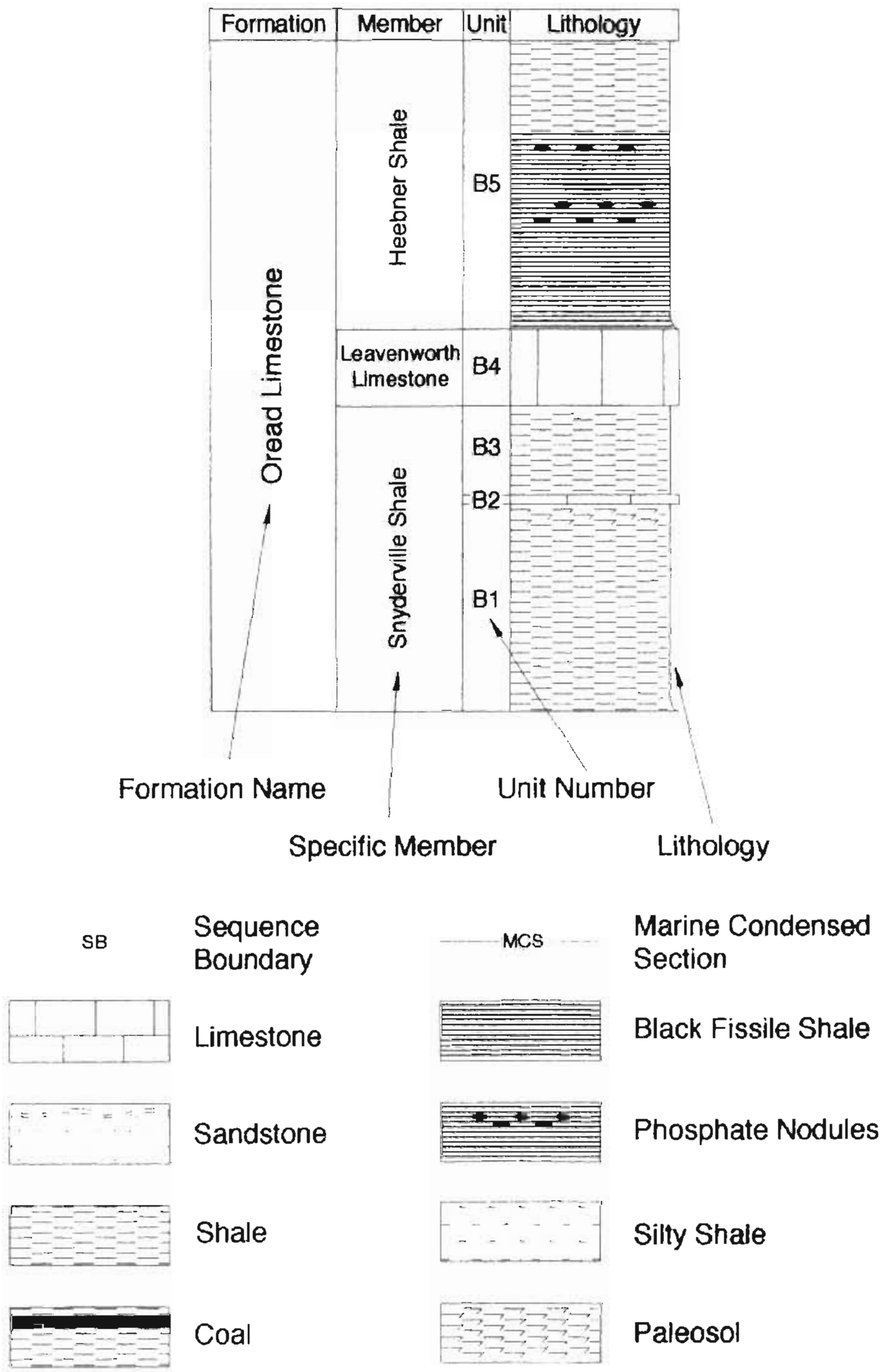


Figure 24.
Key to measured sections

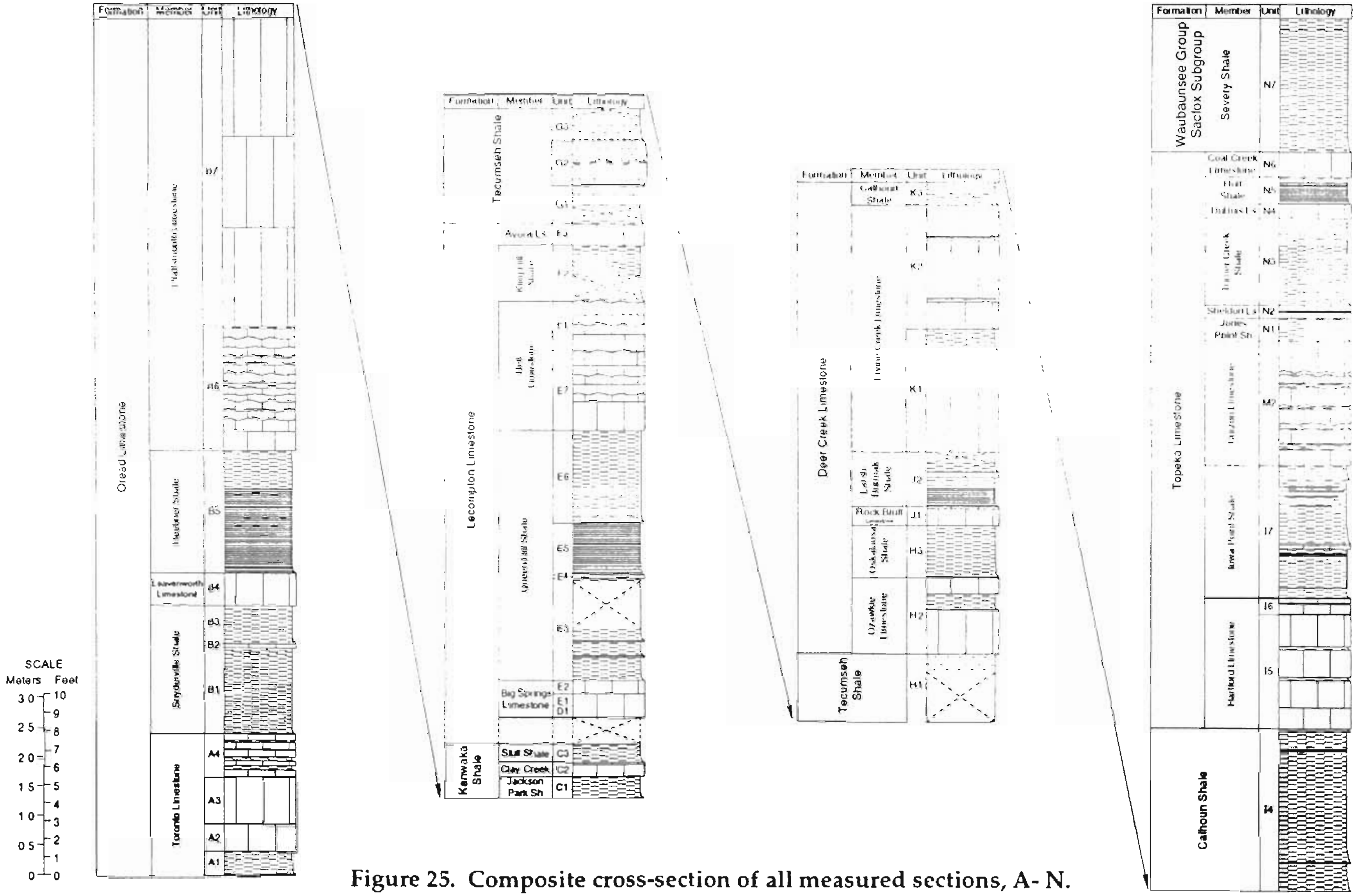


Figure 25. Composite cross-section of all measured sections, A- N.

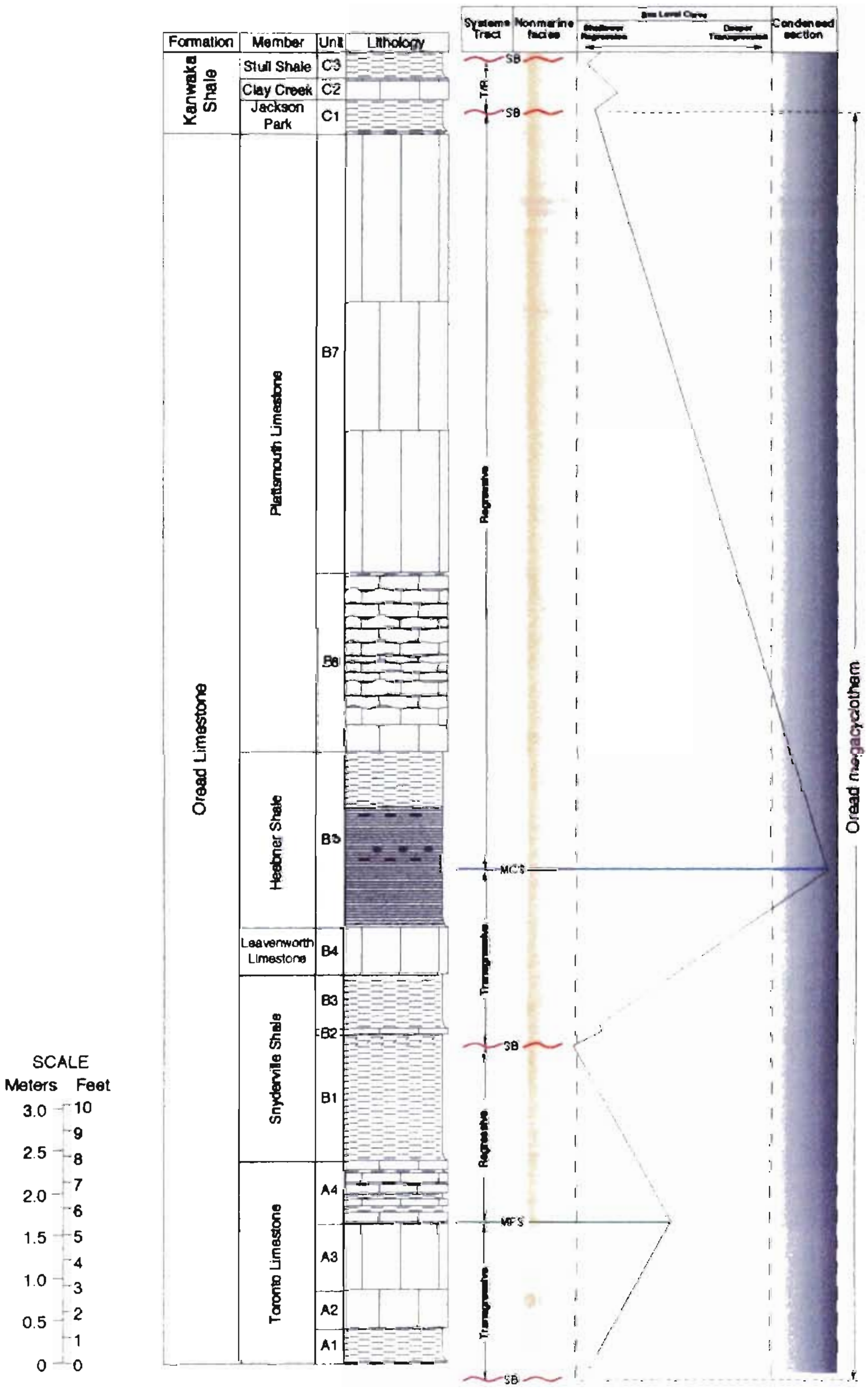


Figure 26. Composite Oread megacyclothem.

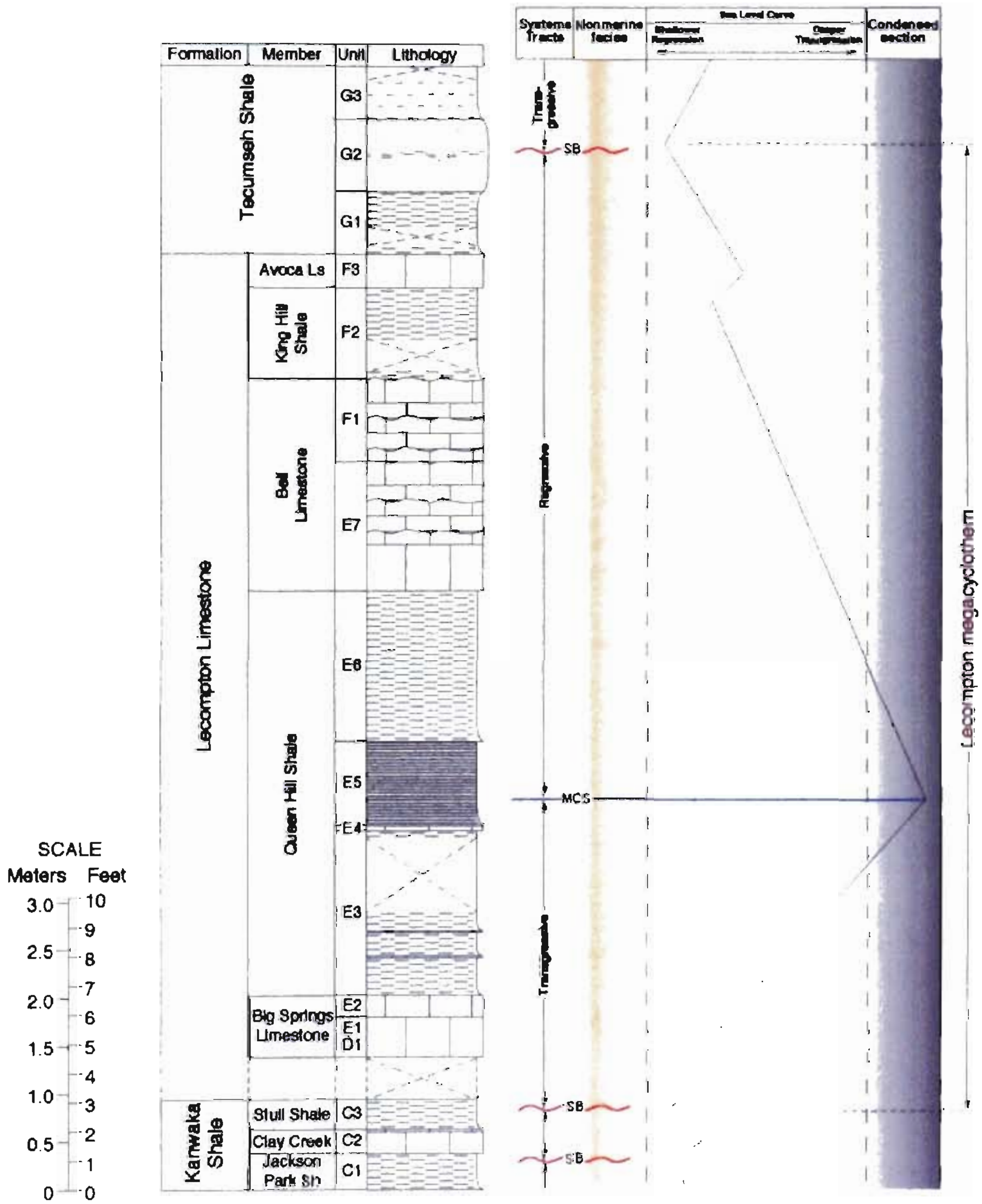


Figure 27. Composite Lecompton megacyclothem.

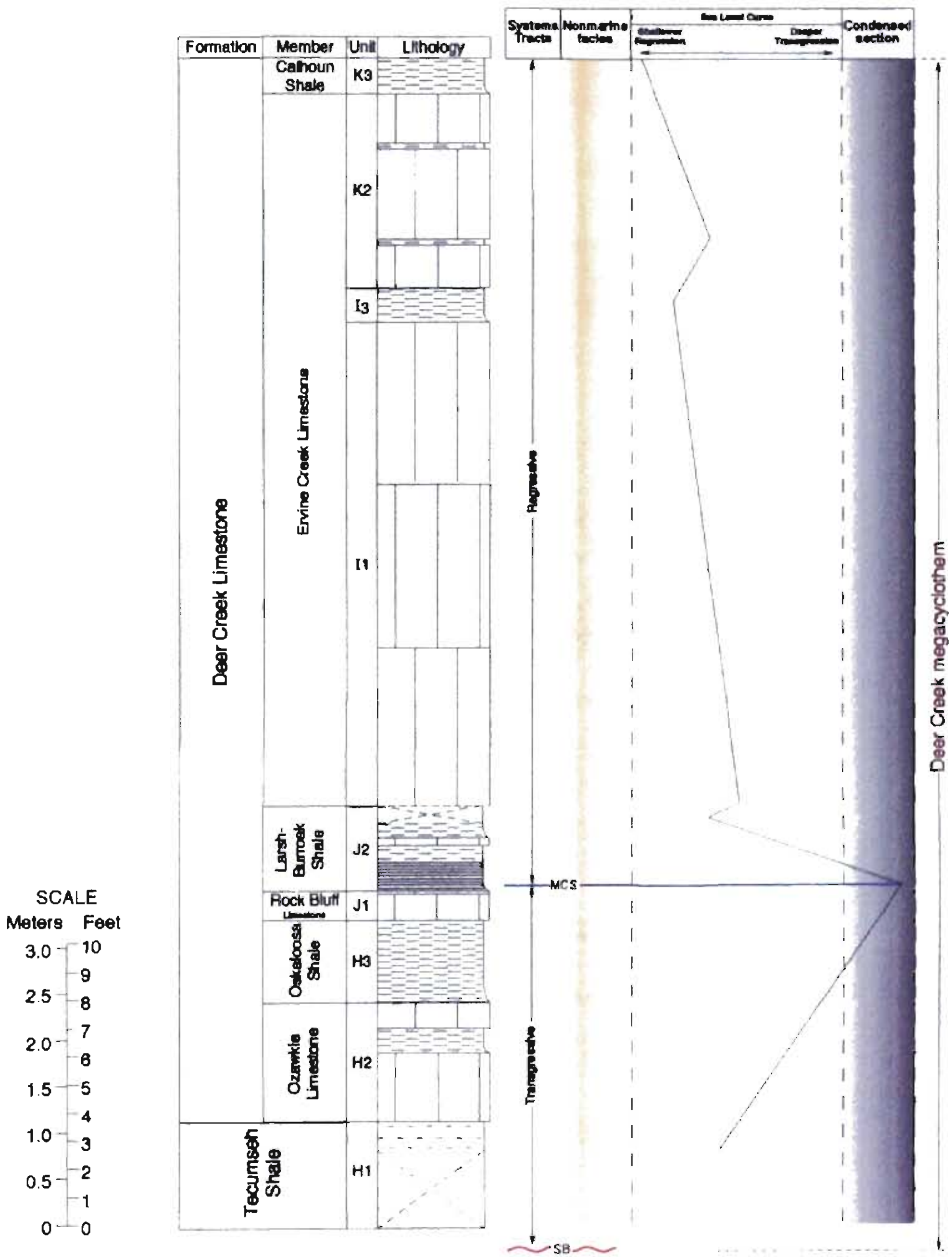


Figure 28. Deer Creek megacyclothem.

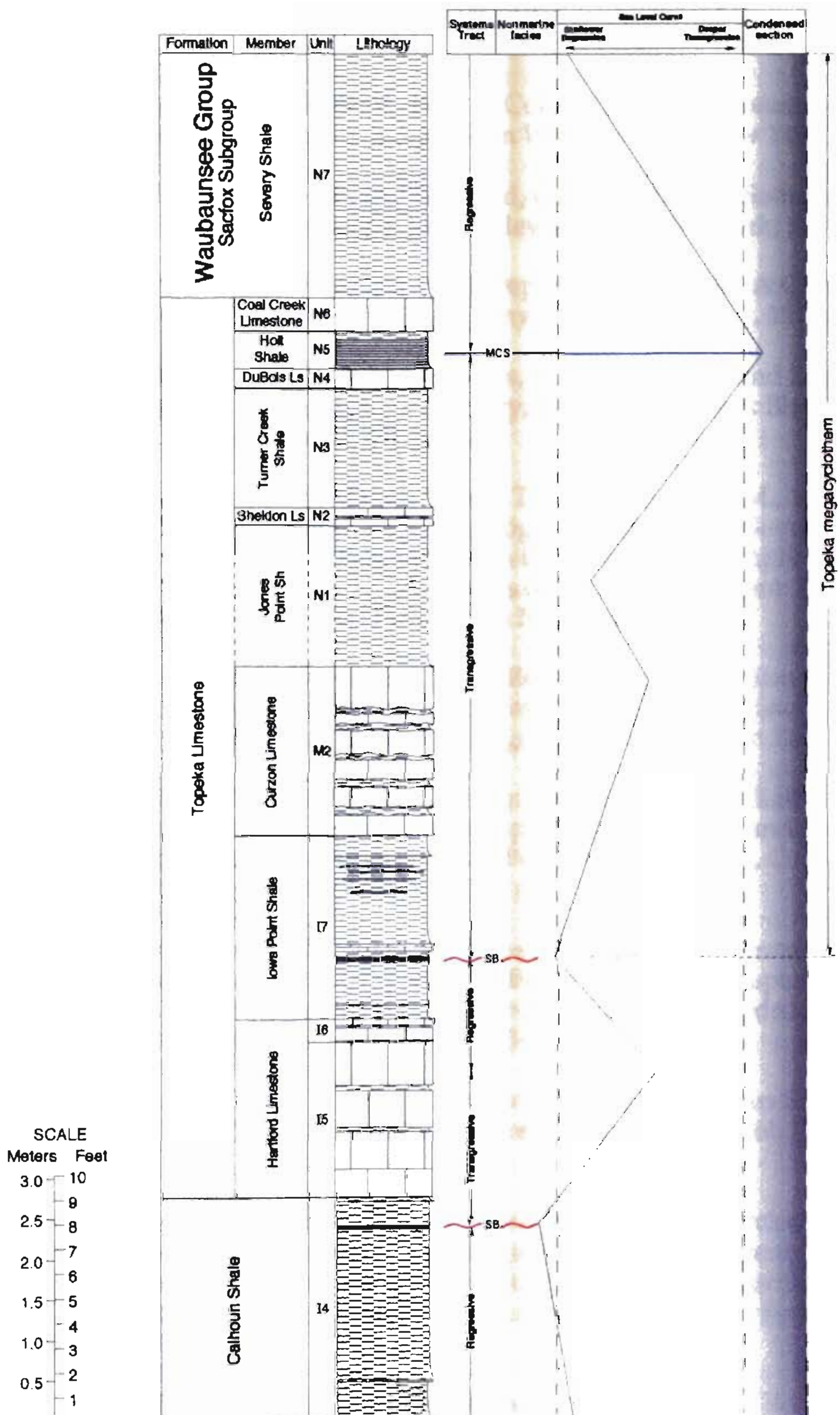


Figure 29. Composite Topeka megacyclothem.

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APPENDIX A
Outcrop Data

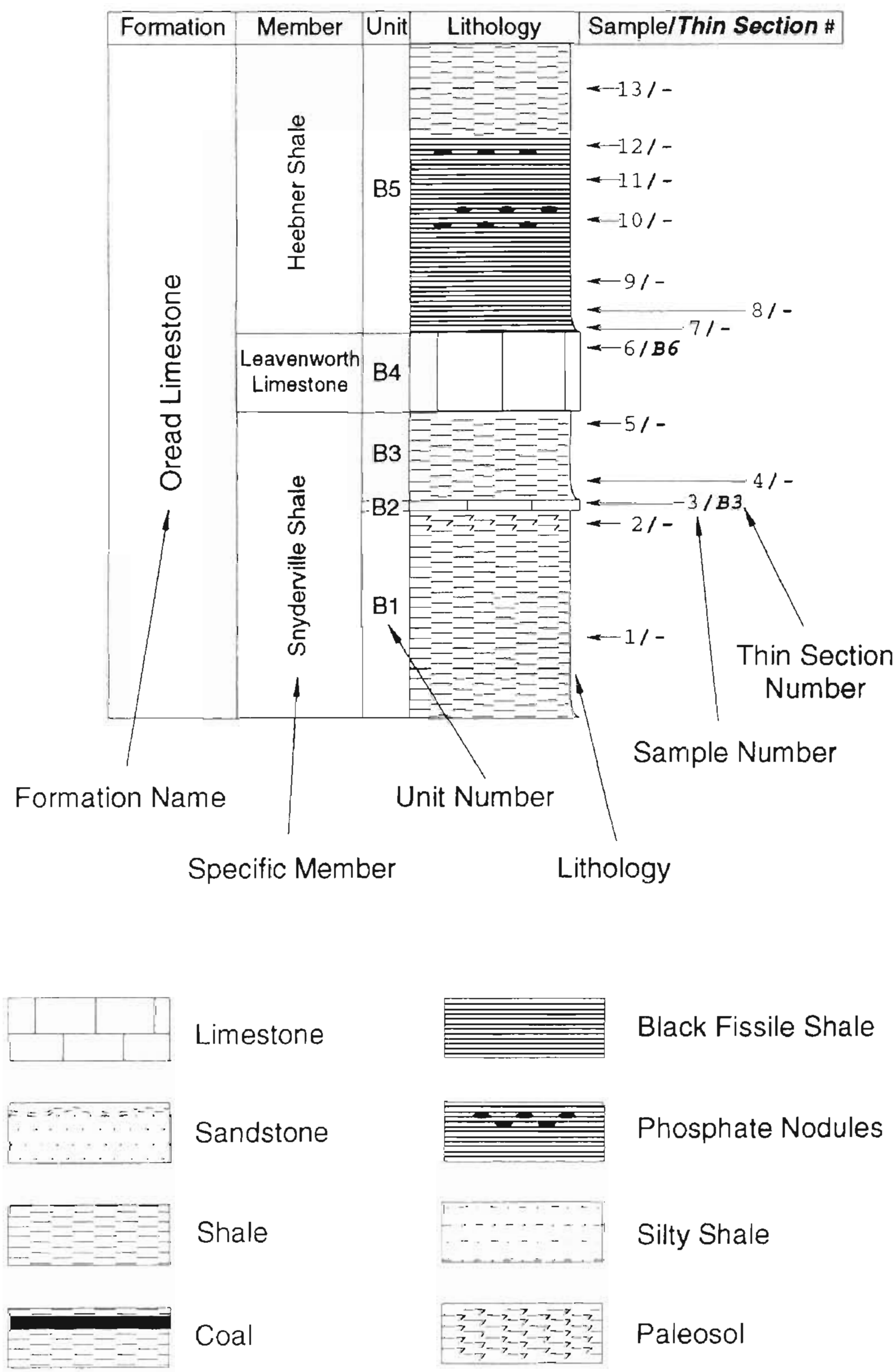

Figure 30.
Key to measured sections

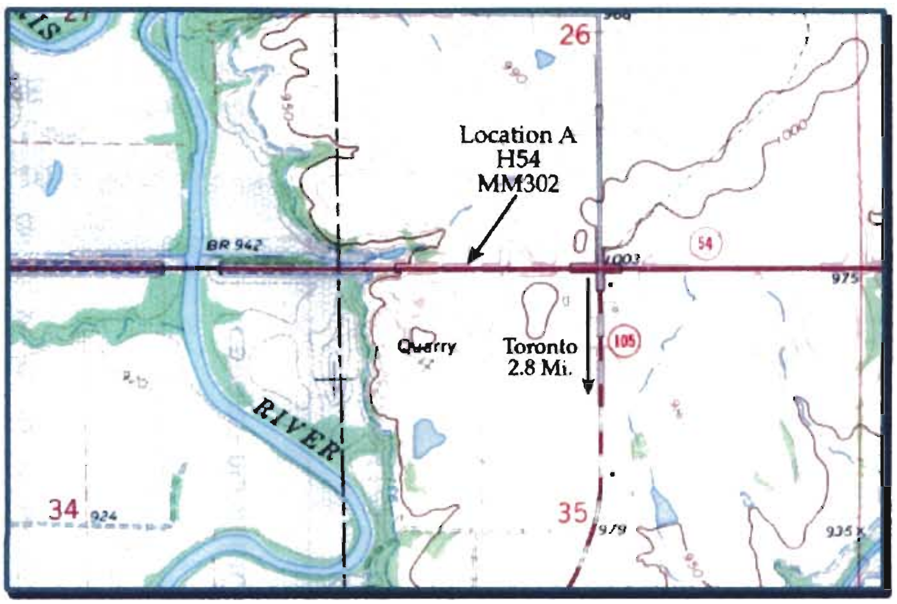

Figure 31. Map showing Location A, Oread Limestone, approx. 1/4 mile west of junction H105/H54, Woodson County, Kansas.

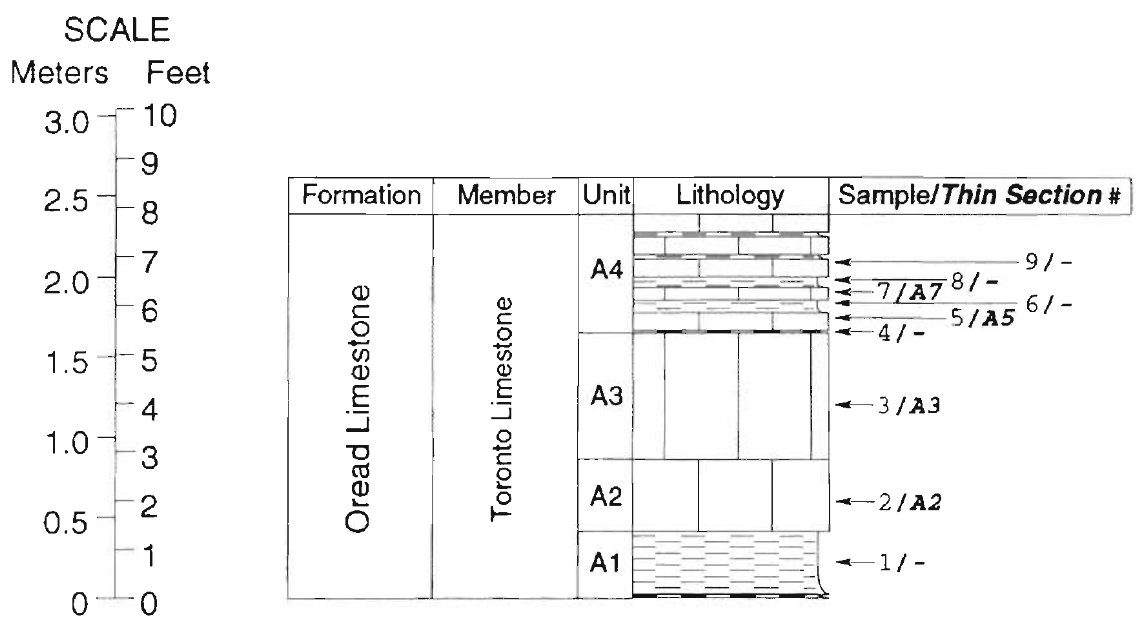

Figure 32. Measured section of location A, Highway 54, mile marker 302, Greenwood County, Kansas.

Location-A (H54-mm302)
S/2 SW/4 Sec. 26-26S-13E
Woodson County, Kansas
Longitude: 37°50.154′ (GPS)
Latitude: -96°57.281′
Toronto Limestone (type section)

Douglas Group
Lawrence Formation

1 Shale, medium gray to medium dark gray, crumbly, slightly calcareous, with fossil hash-40.6 cm/16 inches

Shawee Group
Oread Limestone Formation

Toronto Limestone Member-190.5 cm/79 inches

2 Limestone, light olive-gray, dense, wackestone, few fusulinids, pelcypods and ostracods-40.6 cm/16 inches

3 Limestone, light olive-gray, dense, wackestone, massive bedded, with abundant calcitic recrystallization, abundant fossil hash and brachiopods-78.7 cm/31 inches

4 Shale parting, pale yellowish-brown, very hard, calcareous laminations, fossil hash-1.3 cm/.5 inches

5 Limestone, light to medium olive gray, wacke- to packstone, thin bedded, very hard to dense, sparse fusulinids, some crinoid plates and columnals, sparse oöids-10.2 cm/4 inches

6 Shale parting, yellowish gray-tan, soft, blocky, calcareous-7.6 cm/3 inches

7 Limestone, light to medium olive gray, very hard to dense, wacke-packstone, sparse fusulinids, some crinoid plates and columnals, sparse oöids -5.1 cm/2 inches

8 Shale parting, olive gray, mottled, calcareous with scattered fossiliferous and limestone clasts-2.5 cm/1 inch

9 Limestone, yellowish gray to yellowish olive-gray, wackestone, thin bedded, very fossiliferous; brachiopods, crinoid plates, oöids, some fusulinids-55.9 cm/22 inches

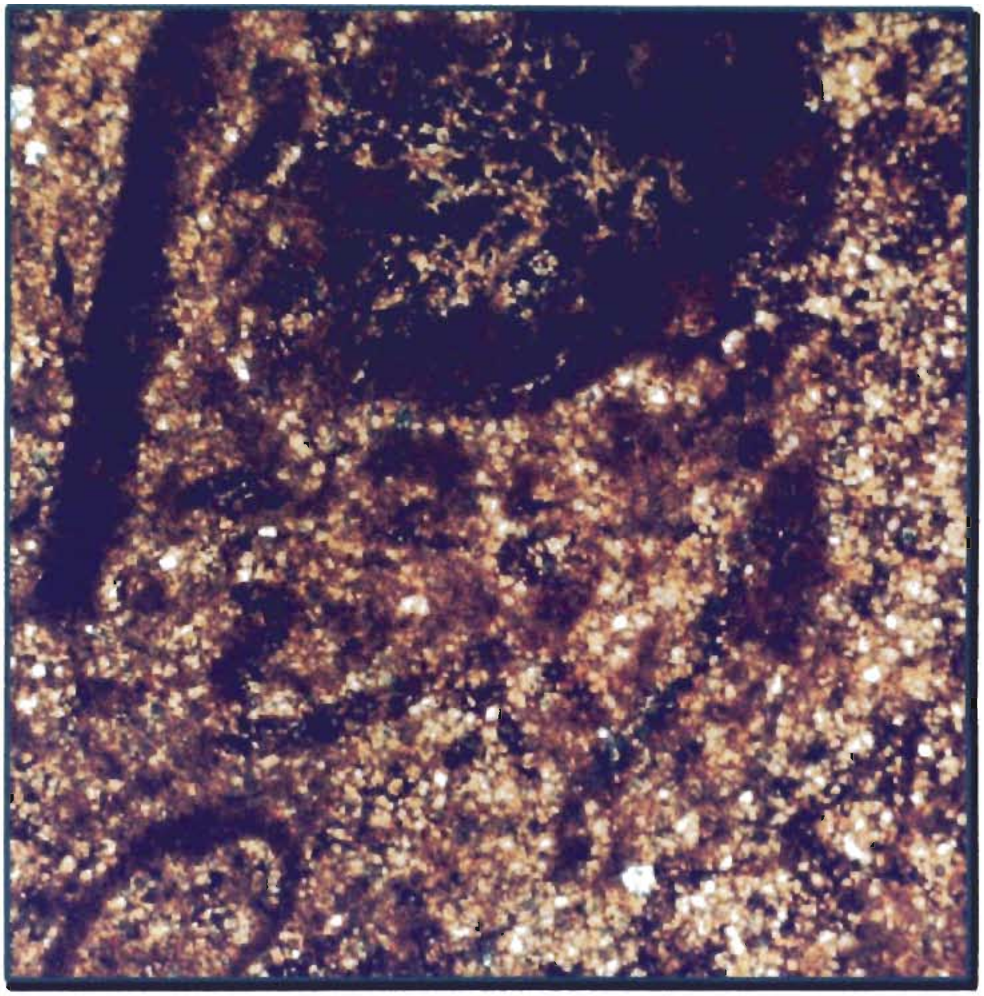

Photo 1a
Location A-mile marker 302 on H54.
Oread Limestone Formation, Toronto Limestone Member.
Thin section #A2-wackestone to packstone, fossil assemblage includes foraminifera, brachiopod, ostracod and crinoid plates.

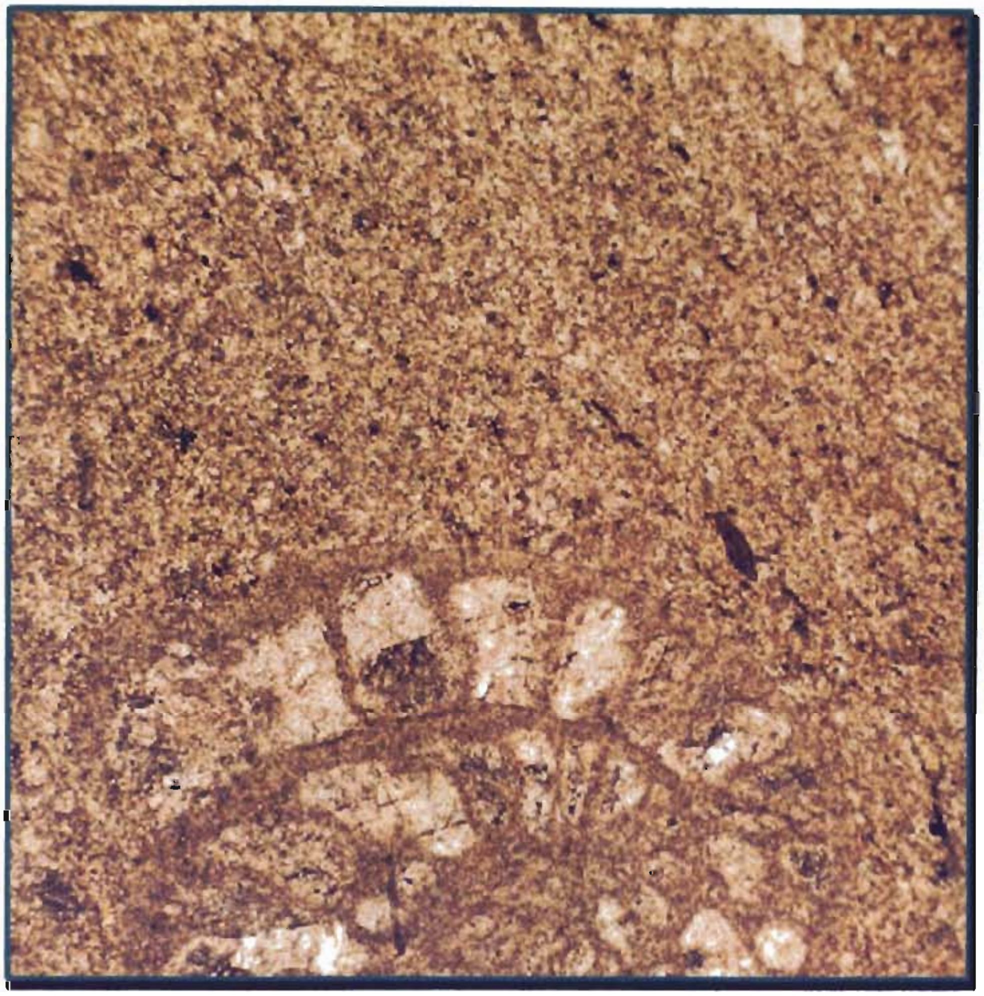

Photo 1b
Location A-mile marker 302 on H54.
Oread Limestone Formation, Toronto Limestone Member.
Thin section #A3-wackestone, fossil assemblage includes
foraminifera (increasing fusulinid,) brachiopod, and ostracod.

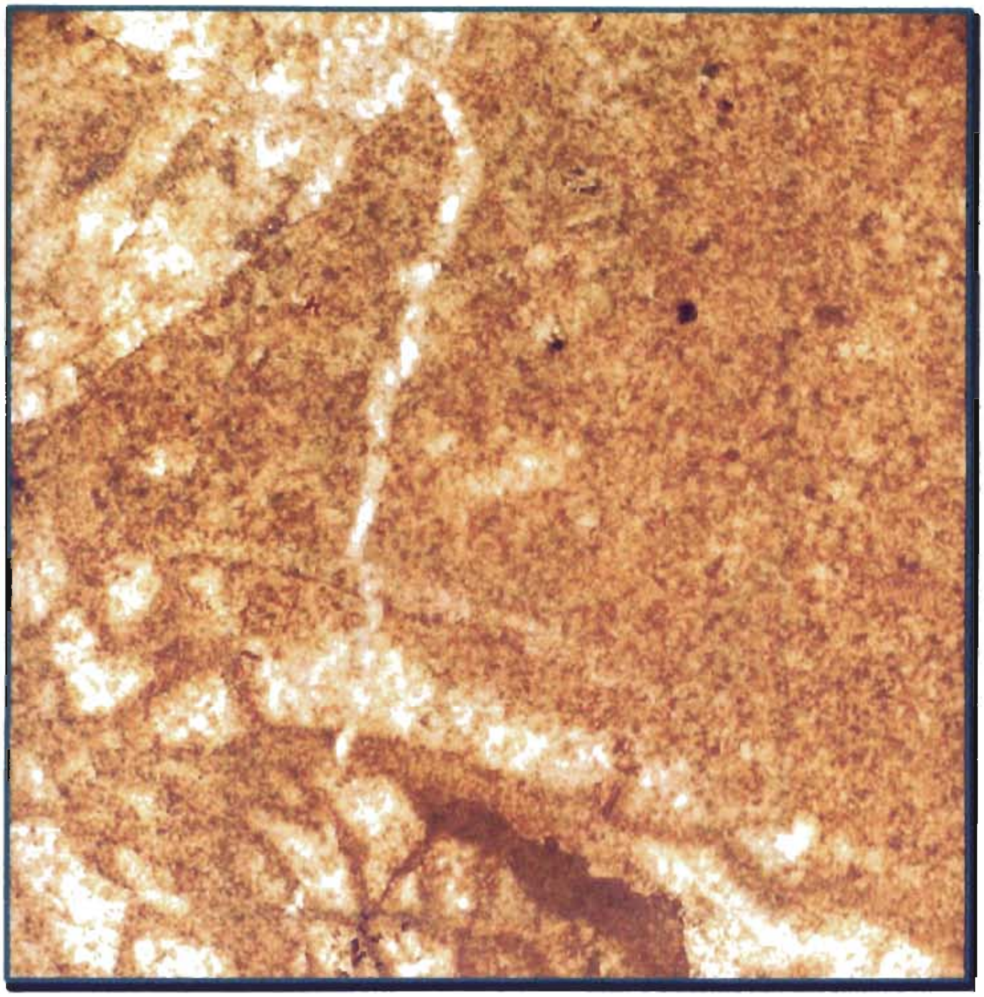

Photo 1c
Location A-mile marker 302 on H54.
Oread Limestone Formation, Toronto Limestone Member.
Thin section #A7-wackestone, fossil assemblage includes
foraminifera (abundant fusulinid,) brachiopod and brachiopod spines.

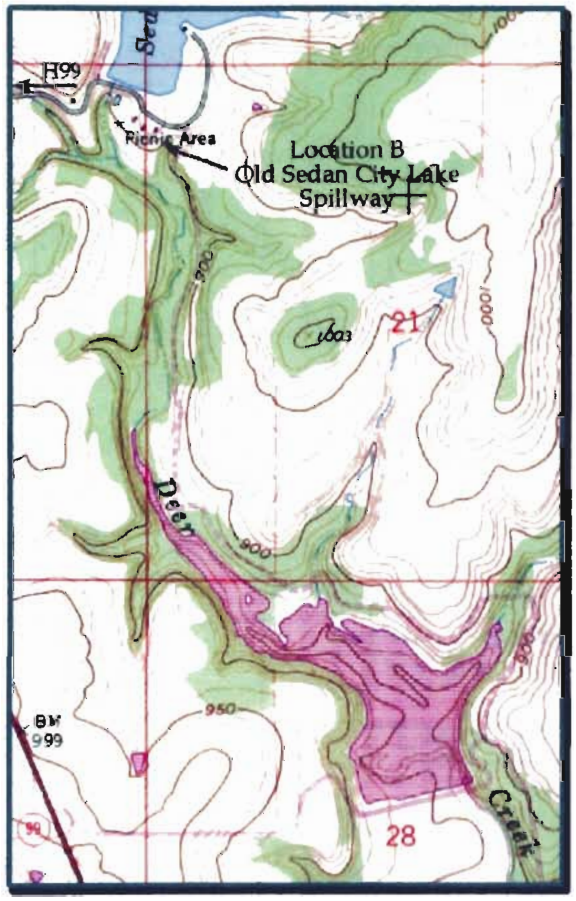

Figure 33. Map showing Location B, Oread Limestone, approximately 4 miles north of Sedan on H99, 1/2 mile east, Chautauqua County, Kansas.

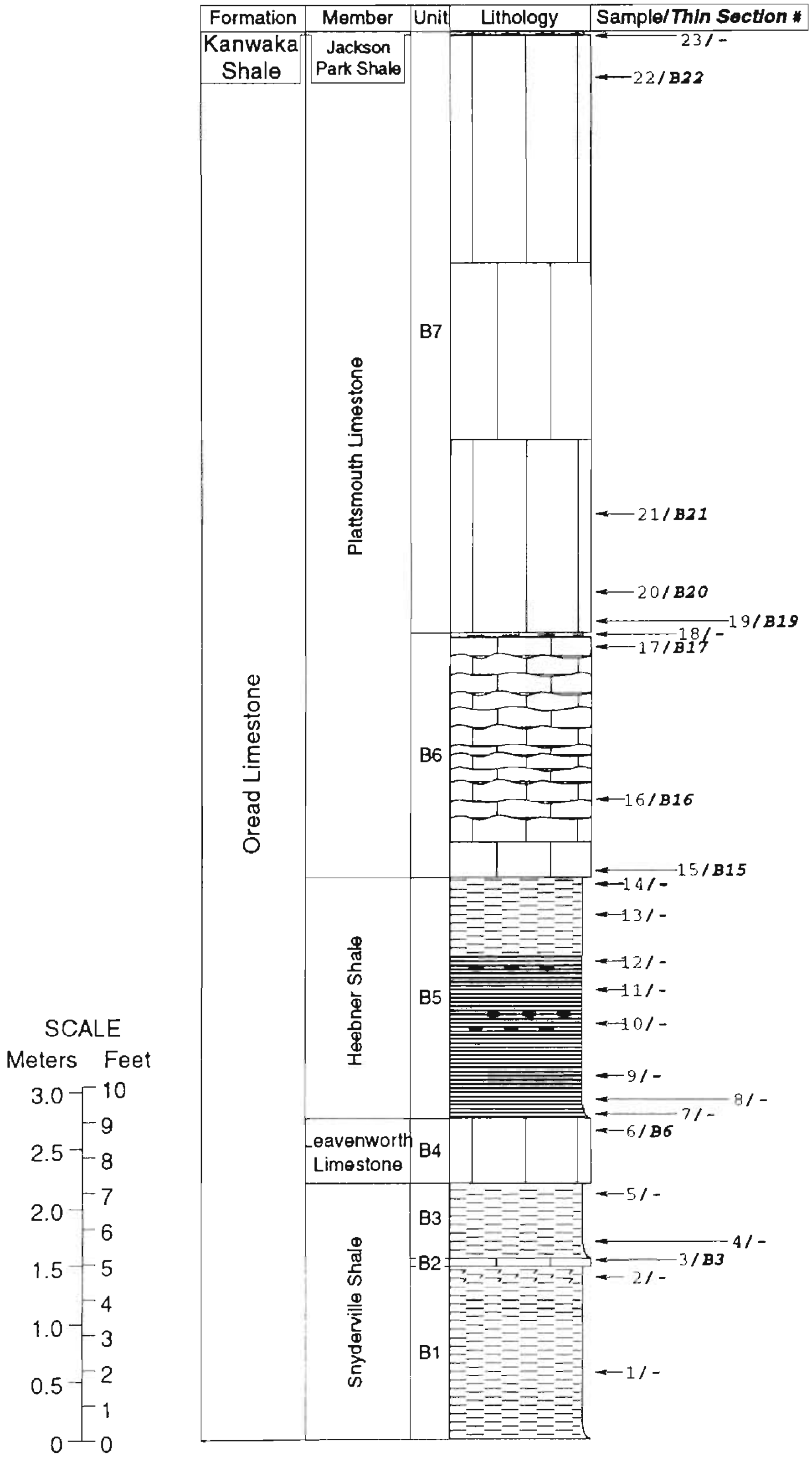

Figure 34. Measured section of location B, Old Sedan City Lake Spillway, Chautauqua County, Kansas.

Location-B (Old Sedan City Lake Spillway)
W/2 NW/4 Sec. 21-33S-11E
Chautauqua County, Kansas
Longitude: 37°07.642′ (GPS)
Latitude: -96°11.082′

Oread Limestone Formation

Snyderville Shale Member-213.4 cm/84 inches

1 Shale, medium dark gray, platy to blocky, slightly calcareous-121.9 cm/48 inches

2 Shale, medium dark gray, firm, blocky, calcareous-20.3 cm/8 inches

3 Limestone, medium gray, very hard to dense, wackestone, slightly argillaceous, oölitic-7.6 cm/3 inches

4 Shale, medium greenish-gray to medium dark greenish-gray, platy to blocky-58.4 cm/23 inches

5 Shale, medium gray to medium olive gray, soft, blocky, slightly calcareous-5.1 cm/2 inches

Leavenworth Limestone Member-53.3 cm/21 inches

6 Limestone, medium gray to medium olive-gray, dense, mud- to wackestone, sparse fossils-53.3 cm/21 inches

Heebner Shale Member-134.6 cm/53 inches

7 Shale, dark gray, platy to fissile, very fossiliferous; brachiopods, slightly calcareous-5.1 cm/2 inches

8 Shale, dark gray to black, fissile, fossiliferous; conodonts, very abundant brachiopods, phosphate nodules-10.2 cm/4 inches

9 Shale, dark gray, very fissile, slighty calcareous, conodonts-22.9 cm/9 inches

10 Shale, dark gray to black, fissile, phosphate nodules-30.5 cm/12 inches

11 Shale, dark gray, blocky grading back to fissile-10.2 cm/4 inches

12 Shale, medium dark gray, crumbly-fissile, very abundant brachiopod shell fragments-10.2 cm/4 inches

13 Shale, medium gray to medium dark gray, fissile, fossiliferous; spines, brachiopods, phosphate nodules-33 cm/13 inches

14 Shale, medium gray, platy, brachiopod fragments, slightly calcareous-50.8 cm/20 inches

Plattsmouth Limestone Member-6.63 m/262 inches

15 Limestone, medium olive-gray to medium light gray, wackestone, very finely crystalline-63.5 cm/25 inches

16 Limestone, light olive-gray, dense, wackestone, extensive wavy bedding, mudstone, some calcitic filled fractures, sparse fusulinids-144.8 cm/57 inches

17 Limestone, light yellowish-gray to pinkish-gray, very hard to dense, mudstone and wackestone, wavy bedded, sparse shell fragments-15 cm/6 inches

18 Limestone, pale yellowish-brown, wackestone, thinly bedded, finely crystalline-2.5 cm/1 inches

19 Shale parting, dusky brown, calcareous, coarse fragments-clasts? –1.3 cm/.5 inches

20 Limestone, yellowish-gray to light olive-gray, dense, mudstone, scattered brachiopod shells-20.3 cm/8 inches

21 Limestone, yellowish-gray, very hard, massive bedded, wackestone, calcitic filled, finely crystalline, brachiopods, weathers orangish-brown-182.9 cm/72 inches

22 Limestone, light olive-gray, very hard, finely to coarsly crystalline, predominantly massive bedded, calcitic filling, abundant shell fragments-213.4 cm/84 inches

Kanwaka Shale Formation

Jackson Park Shale Member

23 Shale, medium reddish-brown, arenaceous-2 cm/.5 inch

Photo 1.
Location B-Old Sedan City Lake spillway. Oread Formation.

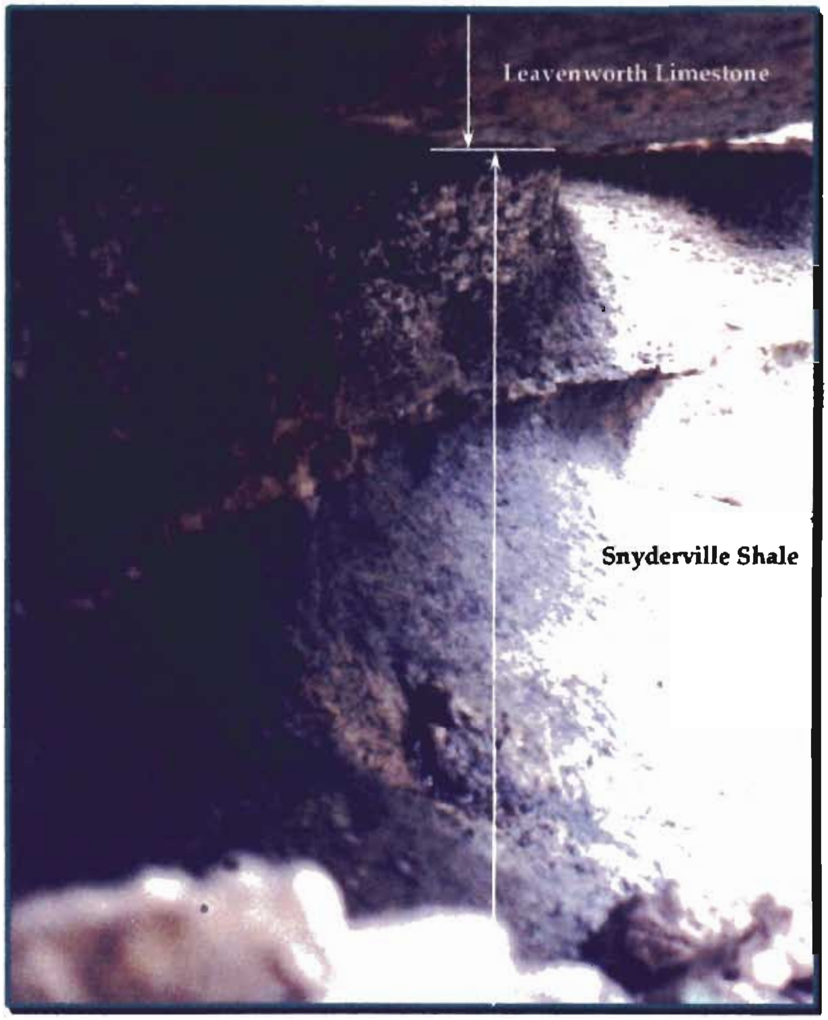

Photo 2.
Location B-Old Sedan City Lake spillway.
Oread Formation, Snyderville Shale Member.

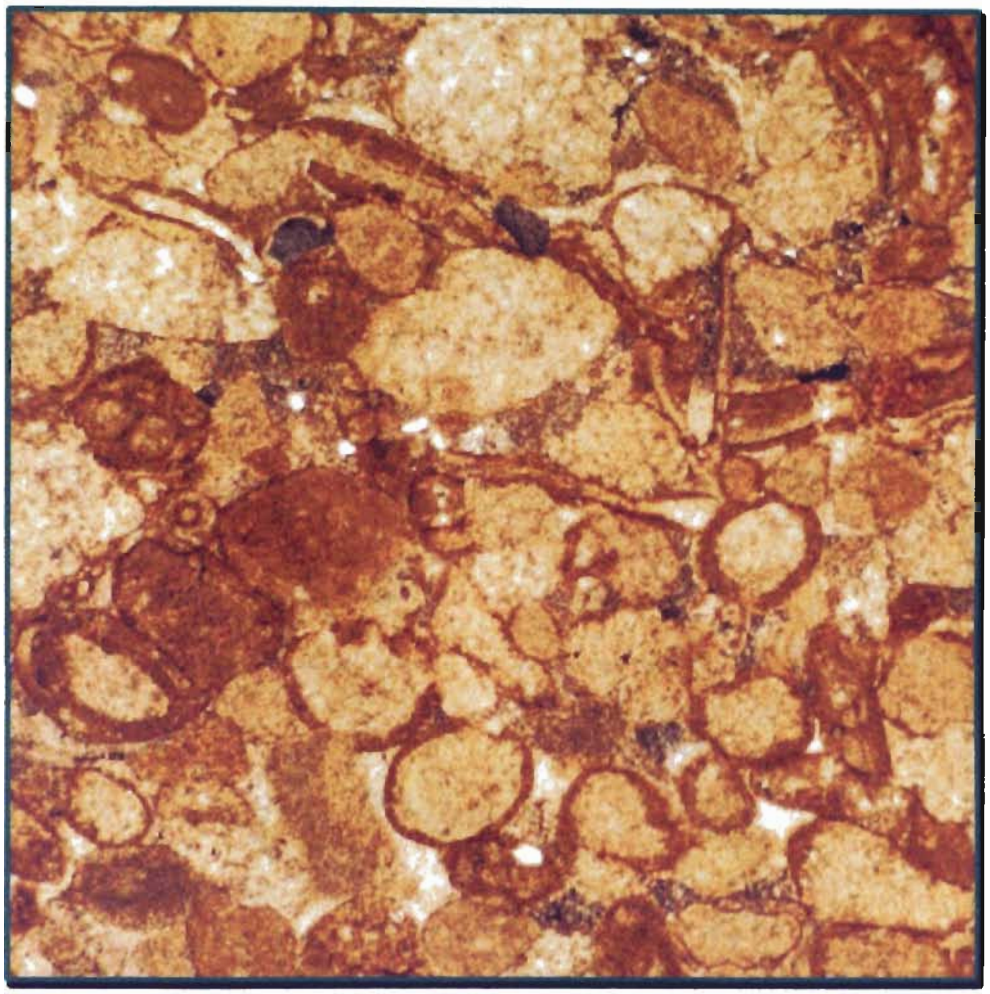

Photo 3
Location B-Old Sedan City Lake spillway.
Oread Limestone Formation, Snyderville Shale Member.
Thin section #B1-packstone, fossil assemblage includes
oöids and few brachiopod .

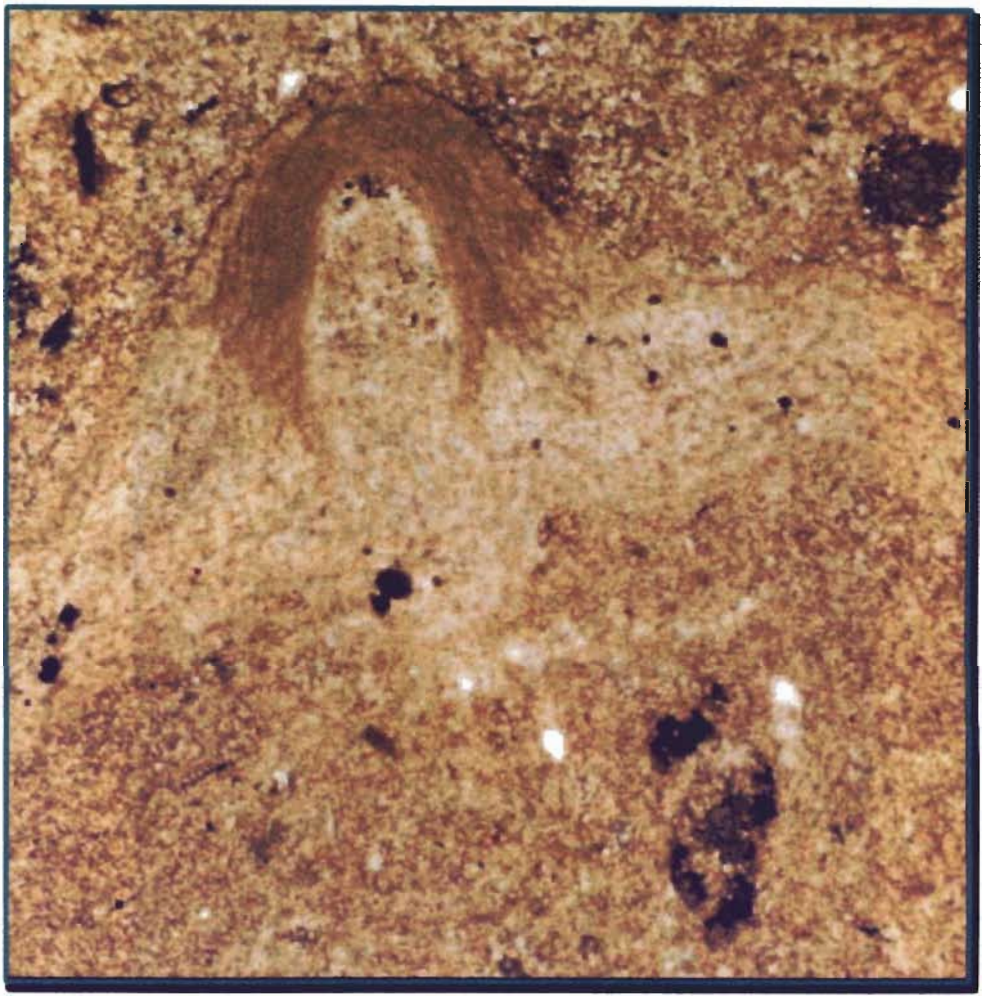

Photo 4
Location B-Old Sedan City Lake spillway.
Oread Limestone Formation, Leavenworth Limestone Member.
Thin section #B2-wackestone, fossil assemblage includes
brachiopod and foraminifera-primarily fusulinid.

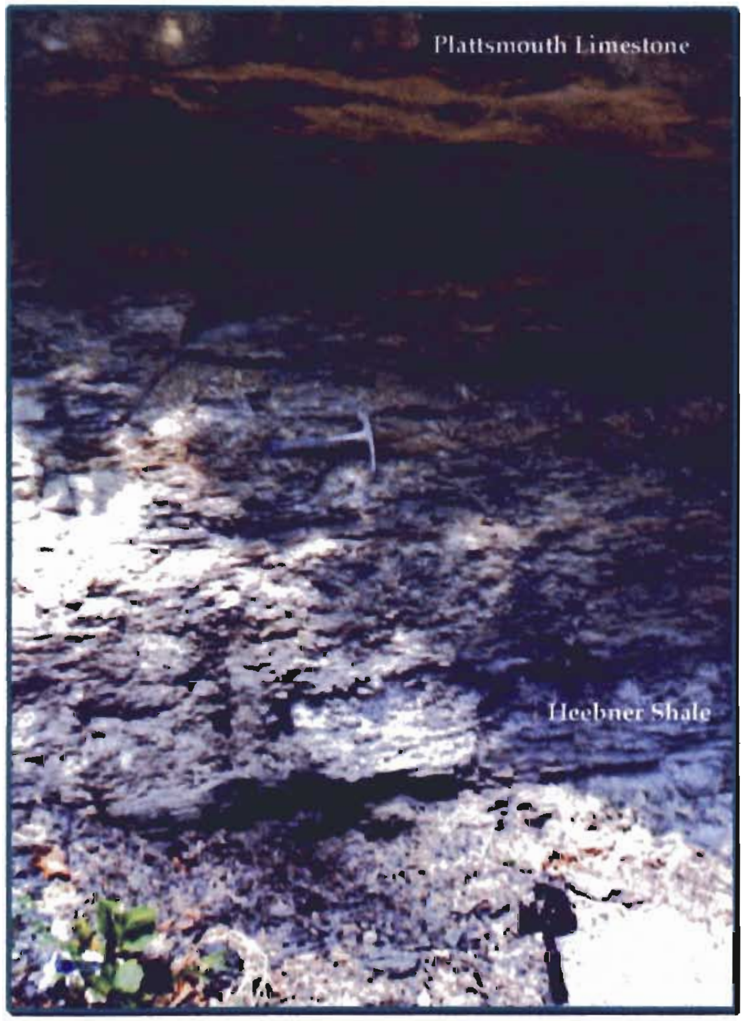

Photo 5
Location B-Old Sedan City Lake spillway.
Oread Limestone Formation, Heebner Shale Member.

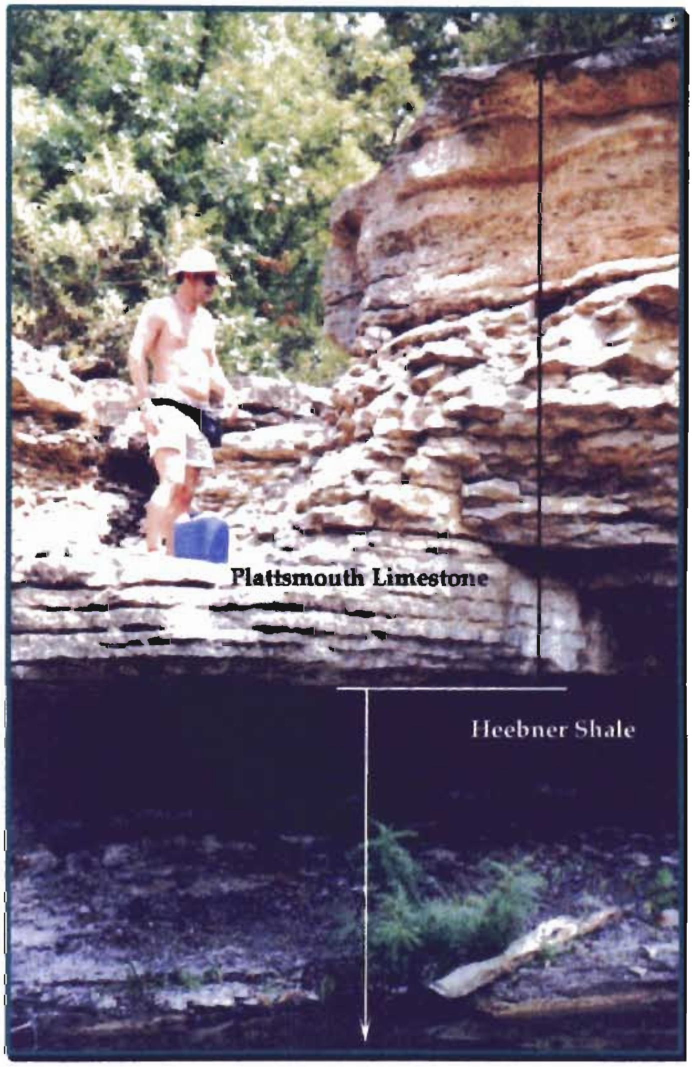

Photo 6
Location B-Old Sedan City Lake spillway.
Oread Limestone Formation, Plattsmouth
Limestone Member.

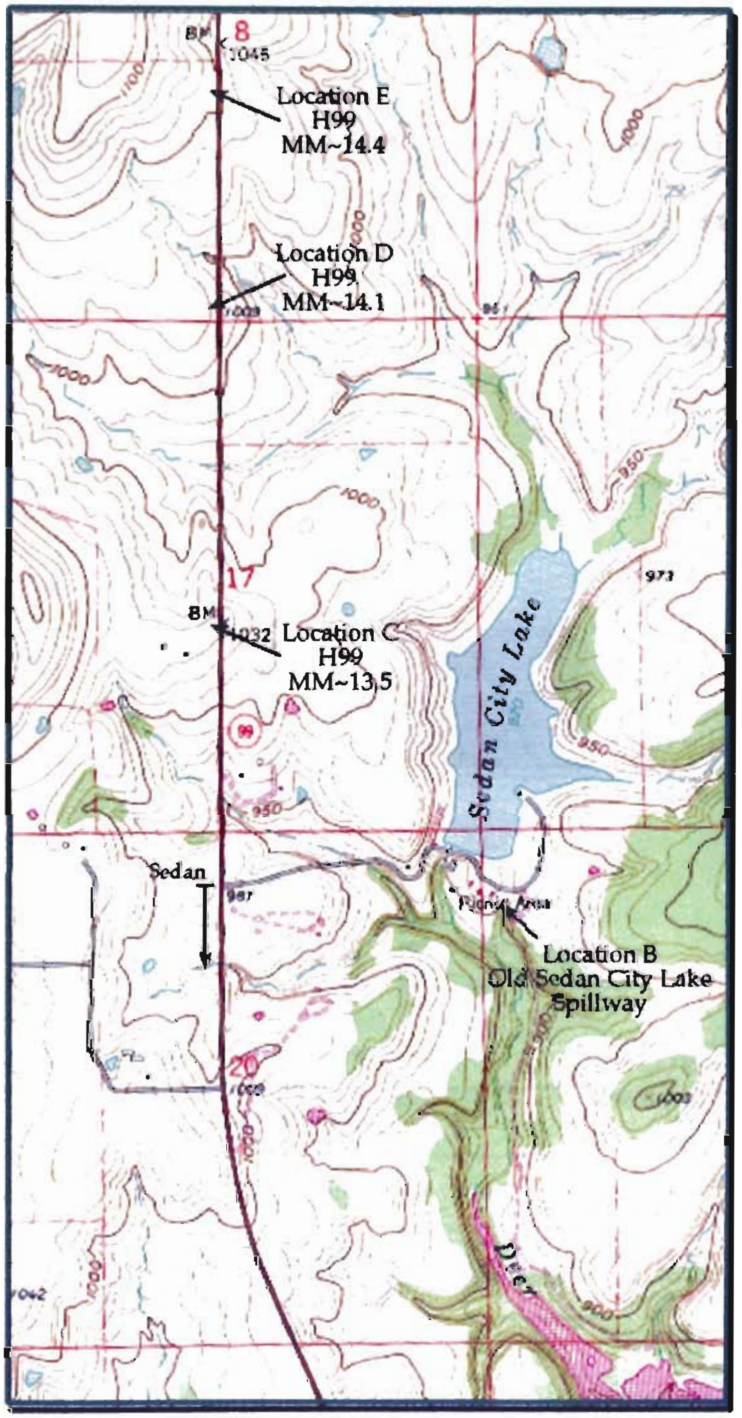

Figure 35. Map showing Locations C, Kanwaka Shale, D and E, Lecompton Limestone, H99 north of Sedan, Chautauqua County, Kansas.

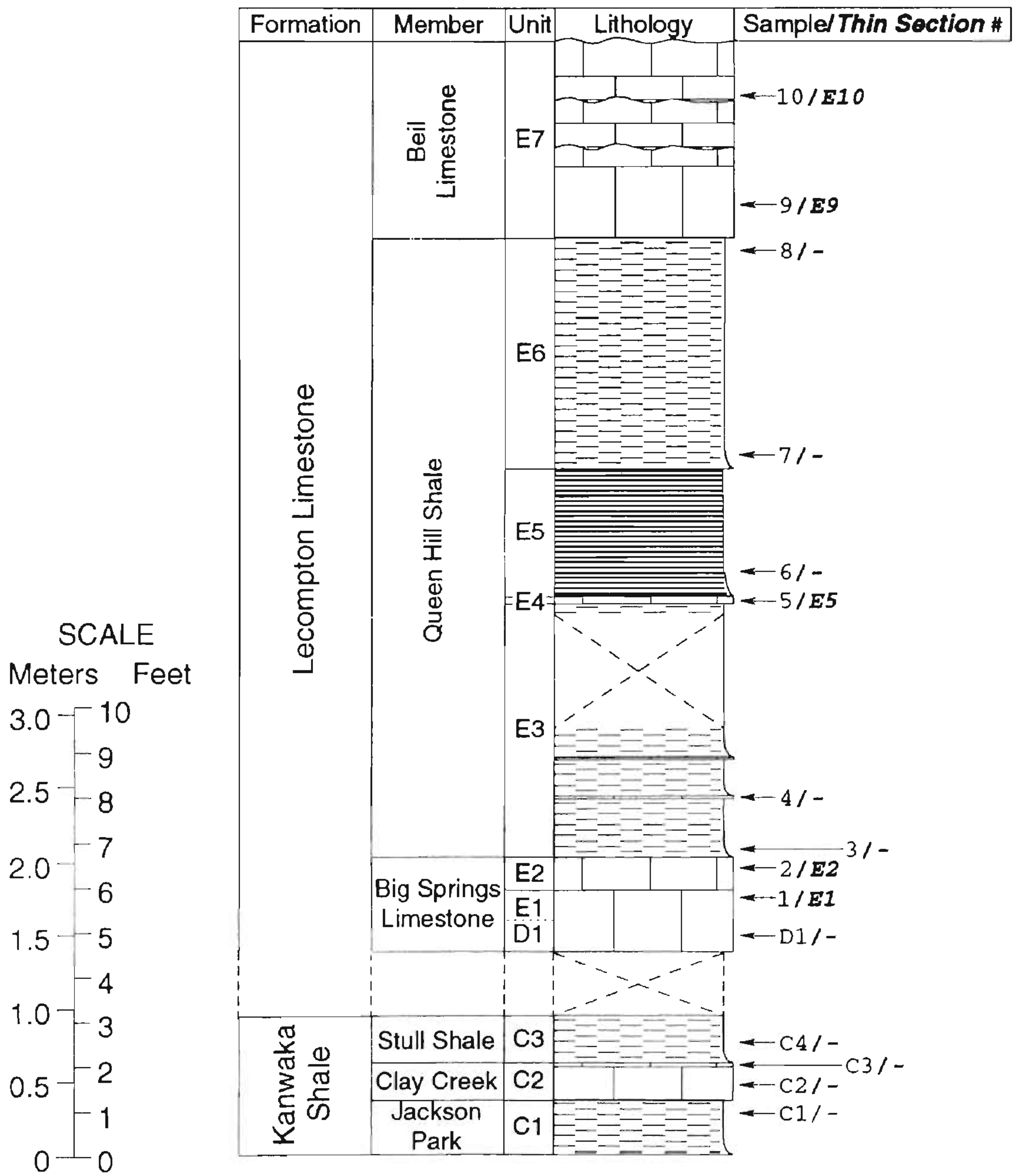

Figure 36. Measured section of locations C, D, and E, Highway 99, mile markers 13.5 through 14.5, Chautauqua County, Kansas.

Location C (H99 ~mm13.5)
E/2 SW/4 Sec. 17-33S-11E
Chautauqua County, Kansas
Longitude: 37°50.154′ (Calculated)
Latitude: -95°57.281'

Kanwaka Shale Formation

Jackson Park Shale Member-35.6 cm/14 inches

1 Shale, yellowish gray, silty-35.6 cm/14 inches

Clay Creek Lime Member-20.3 cm/8 inches

2 Limestone, dark yellowish brown, very hard to dense, wackestone, thin bedded, abundant fossils; crinoid plates, brachiopod shell fragments, bryozoan, echinoid spines, oöids-17.8 cm/7 inches

3 Limestone, medium yellowish-gray, silty wackestone, grading to arenaceous, no fossils present-2.5 cm/1 inch

Stull Shale Member-27.9 cm/11 inches

4 Shale, yellowish-brown, slightly calcareous, silt decreasing upwards-27.9 cm/11 inches

Location D (H99 ~mm14.1)
E/2 SW/4 Sec. 8-33S-11E
Chautauqua County, Kansas
Longitude: 37°11.099′ (Calculated)
Latitude: -96°13.609′

Lecompton Limestone Formation

Spring Branch Limestone Member-38.1 cm/15 inches

1 Limestone, medium gray, very hard, wackestone, fusulinids, few molluscs, significant diagenetic alteration-38.1 cm/15 inches

Location E (H99 ~14.4mm)
Longitude: 37°11.468′??? (Calculated)
Latitude: -96°13.609′

Lecompton Limestone Formation

Big Springs Limestone Member-45.7 cm/18 inches

1 Limestone, medium gray, dense, wackestone, massive bedded, fossiliferous; pelycepods, sparse brachiopods, fusulinids-25.4 cm/10 inches

2 Limestone, medium gray, hard, packstone, thin bedded, very fossiliferous; crinoid plates, pelatoids, sparse gastropods, very abundant fusulinids. Very thin shale parting, calcareous, brachiopod spines, bryozoan-20.3 cm/8 inches

Queen Hill Shale Member-419.1 cm/165 inches

3 Shale, olive-gray, firm, blocky to slightly platy, sparse mollusc fragments-45.7 cm/18 inches

4 Interbedded limestone, thin <1/2", medium gray and medium grayish-brown, sparse fossil fragments and shale, yellowish-brown to yellowish-gray, some silty to arenaceous, trace very fine and fine grained, sub-well rounded quartz grains-132 cm/52 inches

5 Limestone, brownish-gray to olive-gray, wackestone, thin bedded, scattered mollusc shell fragments, ammoniod-5.1 cm/2 inches

6 Shale, dark grayish-black, very fissile, scattered spine fragments, sparse conodonts, foraminifera, sparse clusters finely disseminated pyrite-83.4 cm/34 inches

7 Shale, platy to blocky, grades to bluish-gray with decreasing depth. Interbedded yellowish-gray, near top, no fossils~134.6 cm/53 inches

8 Shale, yellowish-tan, very clayey, no fossils~15.2 cm/6 inches

Beil Limestone Member-104.1 cm/41 inches

9 Limestone, light olive-brown, wackestone, massive bedded, finely crystalline, fusulinids, abundant rugose corals (*Caninia*),-68.6 cm/27 inches

10 Limestone, pale yellowish-brown, wacke- to packstone, thin bedded, very abundant fusulinids in upper 9", decrease in rugose corals (*Caninia*), abundant calcitic fracture infilling-35.6 cm/14 inches

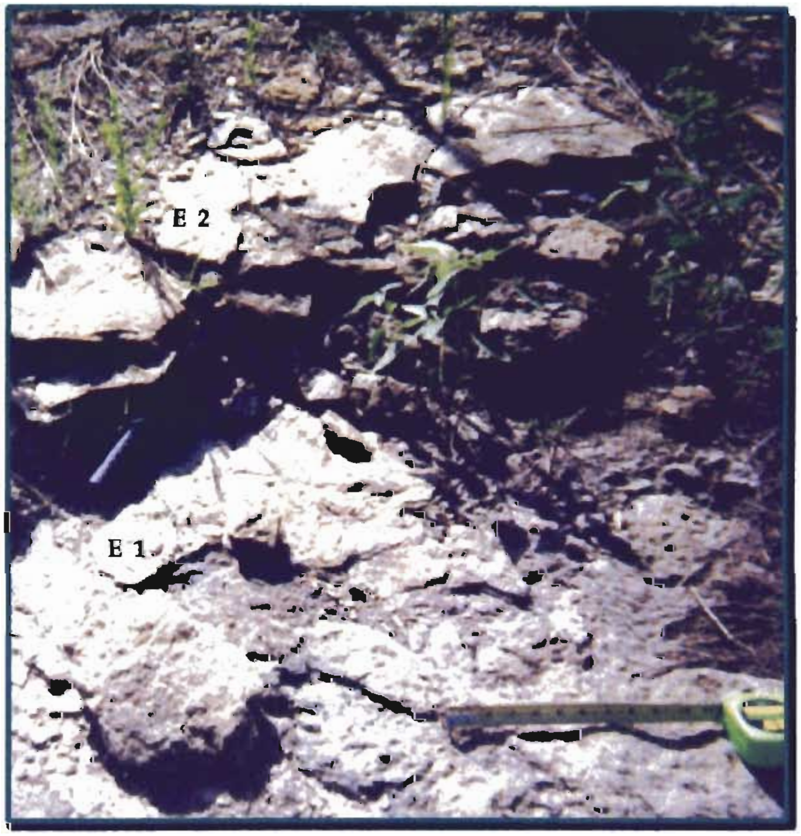

Photo 7
Location E-mile 13.5 through 14.5-I-199.
Lecompton Limestone Formation, Big Springs
Limestone Member.

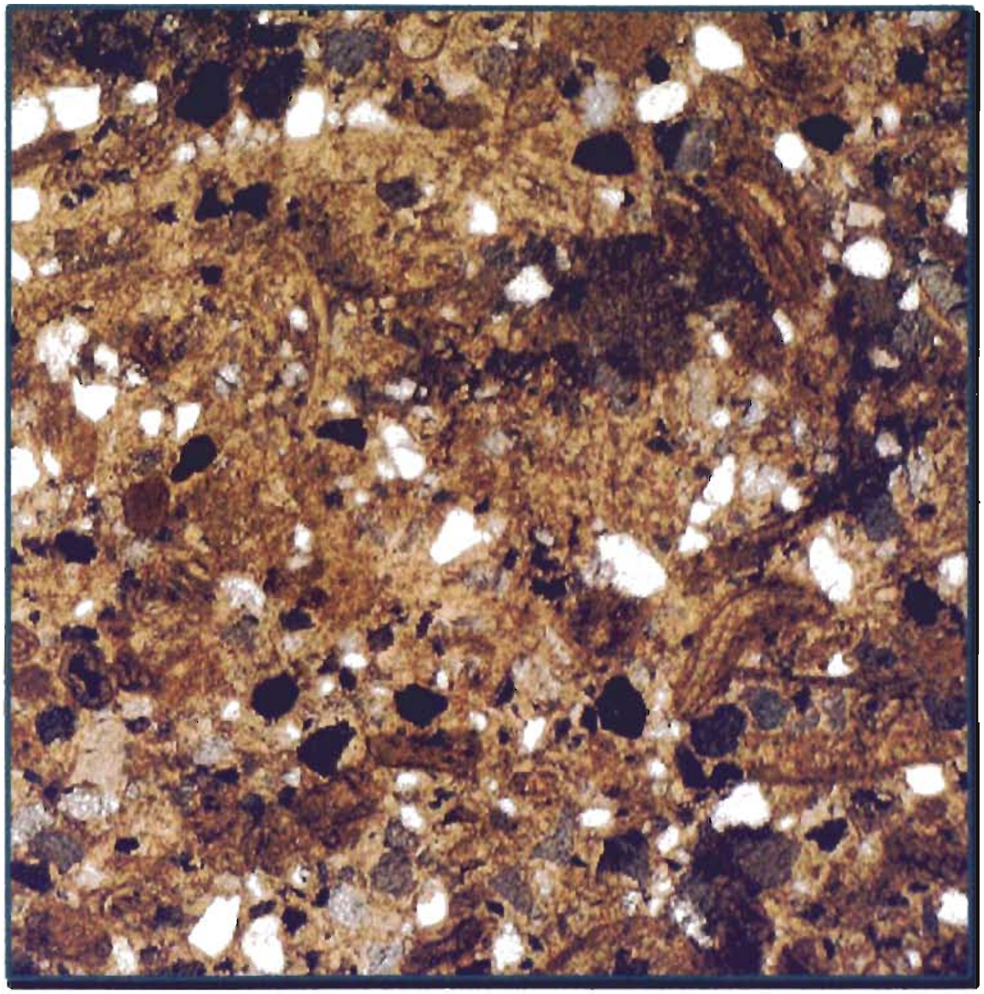

Photo 7
Location E-H99.
Lecompton Limestone Formation, Spring Branch Limestone Member.
Thin section #E7-packstone, fossil assemblage includes foraminifera, brachiopod, bryozoan, abundant hash.

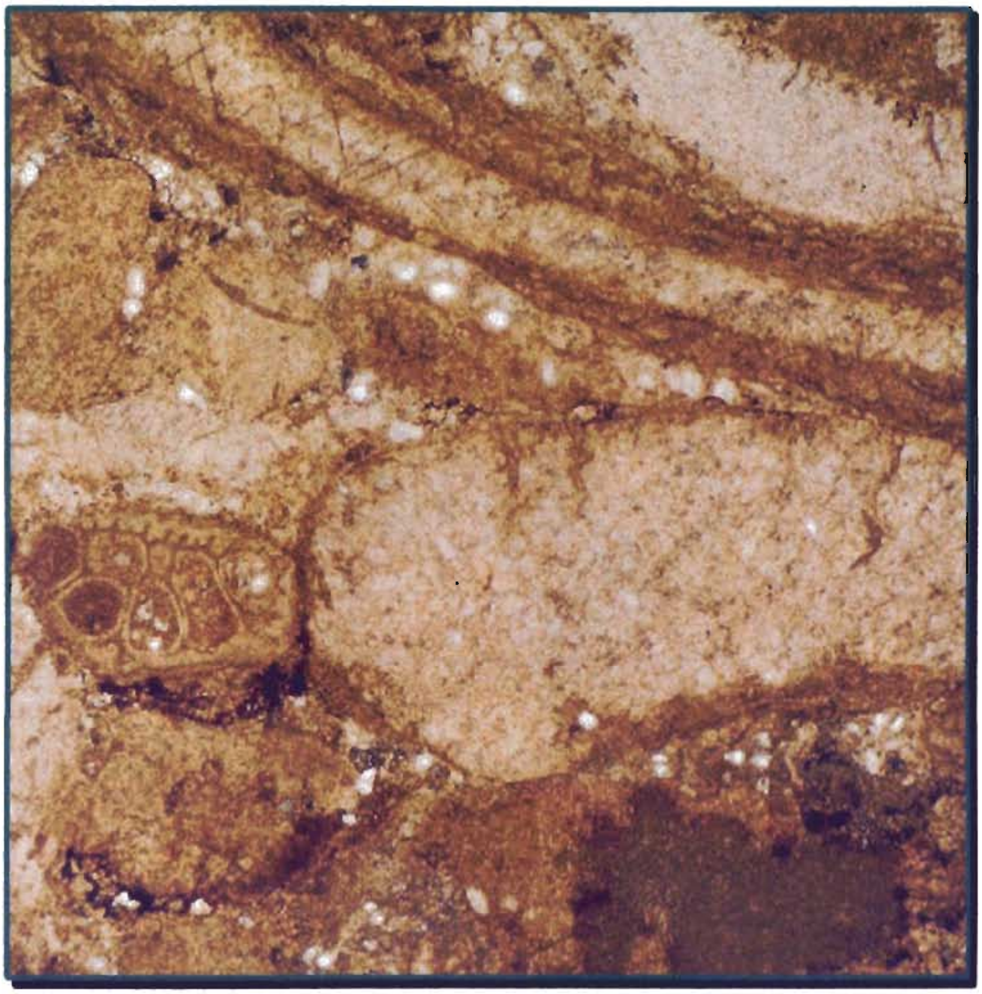

Photo 8
Location E-H99.
Lecompton Limestone Formation, Spring Branch Limestone Member.
Thin section #E2-packstone, fossil assemblage includes
foraminifera (abundant fusulinids,) brachiopod, and bryozoan, .

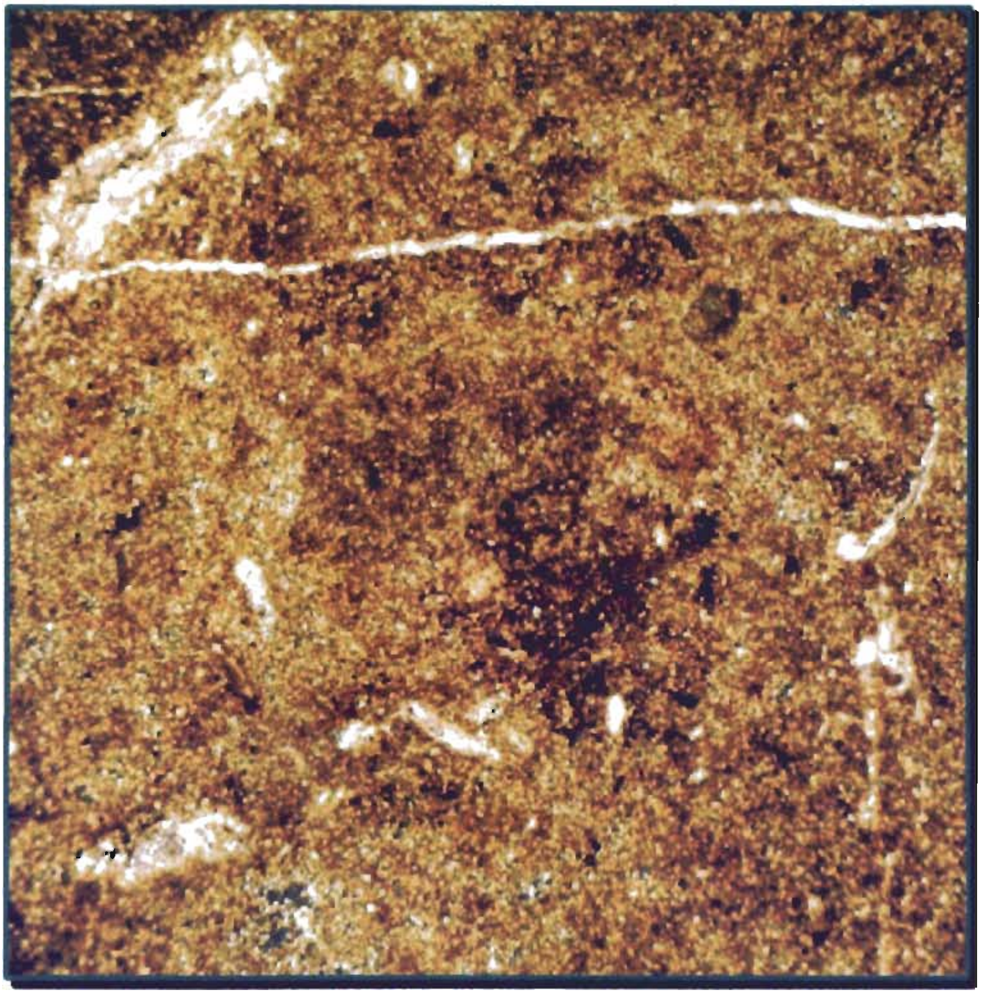

Photo 9
Location E-H99.
Lecompton Limestone Formation, Beil Limestone Member.
Thin section #E5-wackestone, fossil assemblage include brachiopod, sponge spicules.

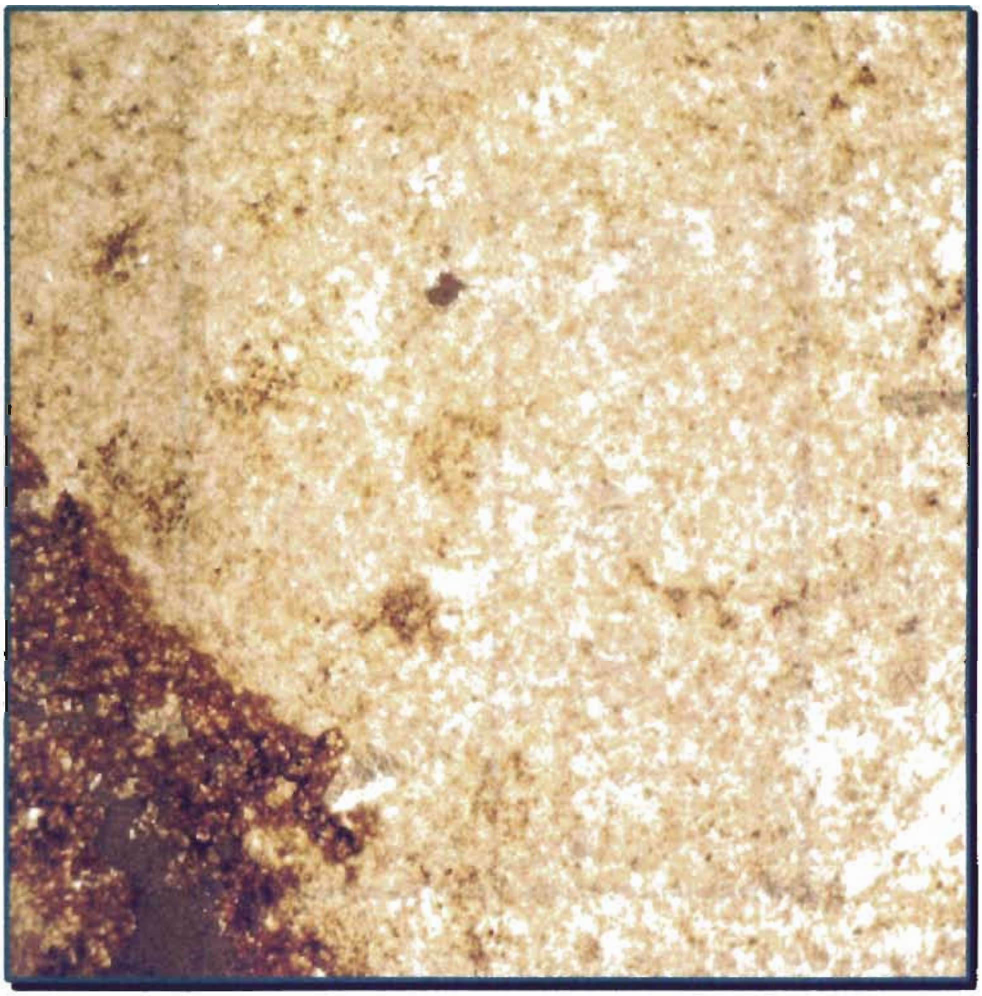

Photo 10
Location E-H99.
Lecompton Limestone Formation, Beil Limestone Member.
Thin section #E10-wackestone, fossil assemblage include fusulinids, bryozoan, and brachiopod.

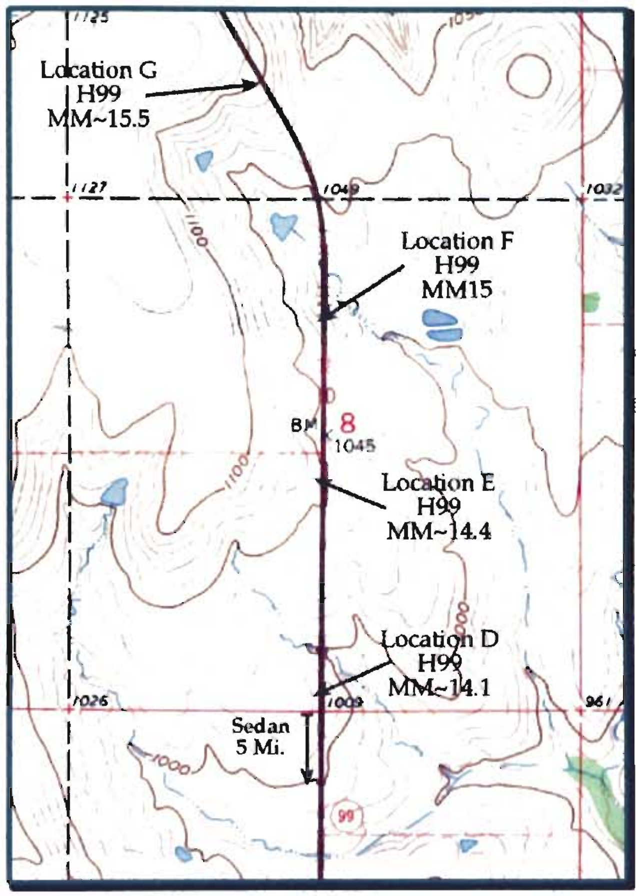

Figure 37. Map showing Locations D, E, F, and G, Lecompton Limestone, Tecumseh Shale, H99 north of Sedan, Chautauqua County, Kansas.

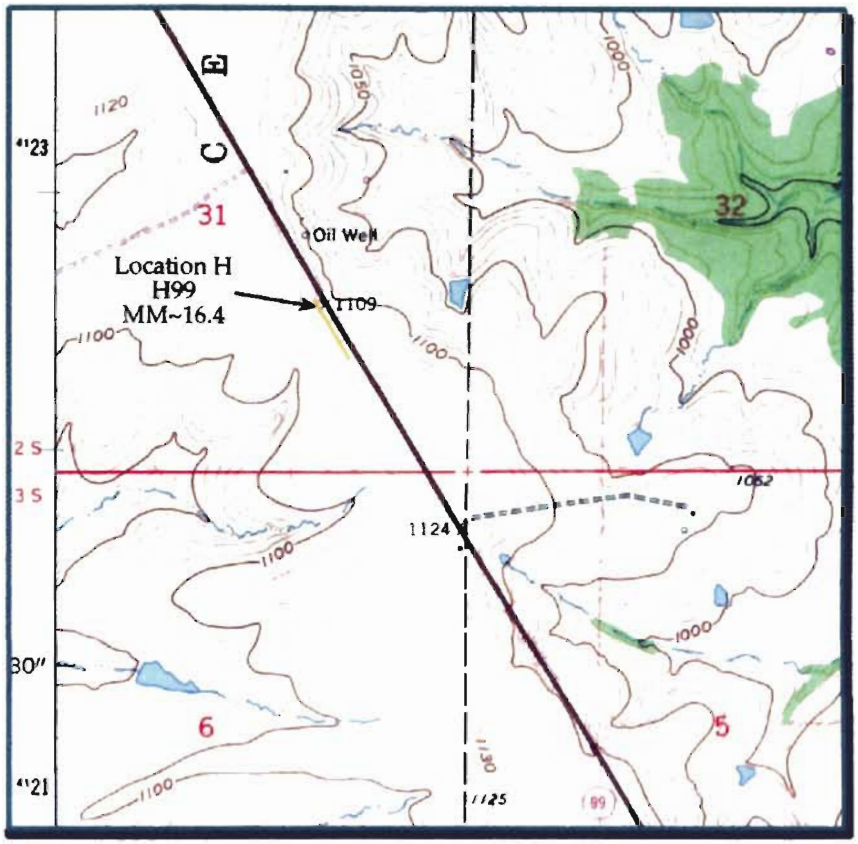

Figure 38. Map showing Location H, Deer Creek Limestone & Tecumseh Shale, ~7.5 miles north of Sedan, Chautauqua County, Kansas.

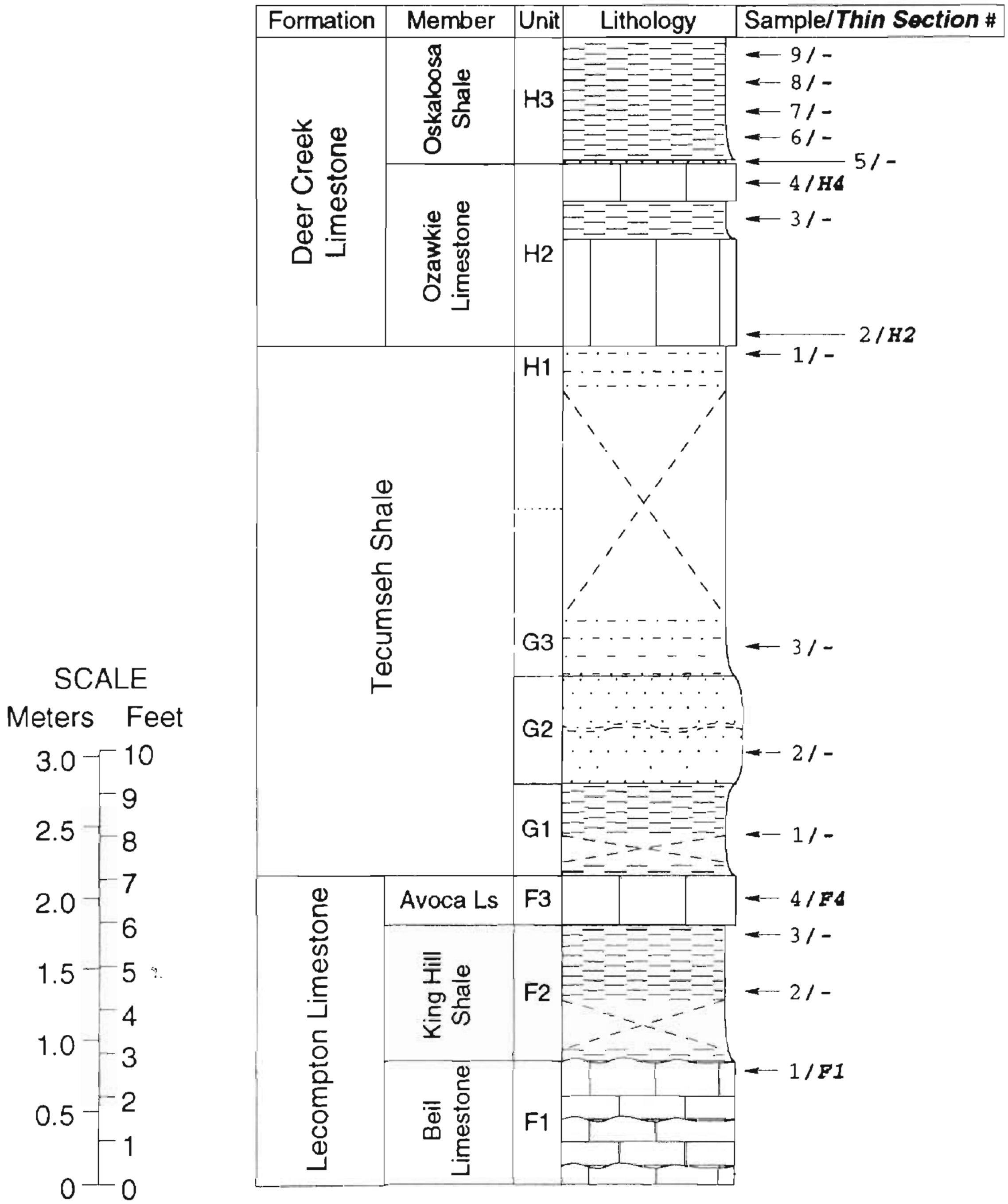

Figure 39. Measured section of locations F, G and H, Highway 99, mile markers 15.5, 16.4, Chautauqua County, Kansas.

Location F (H99 ~mm15)
E/2 NW/4 Sec. 8-33S-11E
Chautauqua County, Kansas
Longitude: 37°11.468' (Calculated)
Latitude: -96°13.609'

Lecompton Limestone Formation

King Hill Shale Member-73.7 cm/29 inches

1 Shale, light olive-gray, blocky-33 cm/13 inches

2 Shale, yellowish-brown, blocky, calcareous, fossil hash-40.6 cm/16 inches

Avoca Limestone Member-33.0 cm/13 inches

3 Limestone, olive-gray, wackestone, very hard, with criniod plates, few small rugose corals, mollusc shell fragments on lower contact-33.0 cm/13 inches

Location G (H99 ~mm15.5)
SE/4 SW/4 Sec. 5-33S-11E
Chautauqua County, Kansas
Longitude: 37°11.468' (Calculated)
Latitude: -96°13.609'

Tecumseh Shale Formation-332.7 cm/131 inches

1 Shale, medium gray, blocky, grading to greenish-gray and yellow grayish-brown then to reddish gray-brown, capped by orange-tan slightly platy-63.5 cm/25 inches

2 Sandstone, yellowish-gray, very fine grained, slightly calcareous, no bedding, few ripple marks-73.7 cm/29 inches

3 Shale, yellowish-gray, silty, some fissle bedding-195.6 cm/75 inches

Location H (H99 ~mm16.4)
Longitude: 37°11.468' (Calculated)
Latitude: -96°13.609'

Tecumseh Shale Formation~5.1 cm/2 inches

1 Shale, reddish-brown, soft, calcareous, crumbly, gradational from below~5.1 cm/2 inches

Deer Creek Limestone Formation

Ozawkie Limestone Member-124.5 cm/49 inches

2 Limestone, yellowish-gray to orangish-tan, very dense, wackestone, massive bedded, few foraminifera on surface-73.7 cm/29 inches

3 Shale-no sample-25.4 cm/10 inches

4 Limestone, very dense, wackestone, yellowish-tan and light olive-gray-25.4 cm/10 inches

5 Shale, greenish-gray, silty to arenaceous, very thin-1 cm/<.5 inch

Oskaloosa Shale Member-78.7 cm/37 inches

6 Shale, red to reddish-brown, blocky-22.9 cm/9 inches

7 Shale, green to greenish-gray, blocky-20.3 cm/8 inches

8 Shale, reddish-brown, blocky-43.2 cm/17 inches

9 Shale, medium to dark gray-22.9 cm/3 inches

Photo 11
Location F-mile 15.5 on H99.
Lecompton Limestone Formation, Beil Limestone Member.

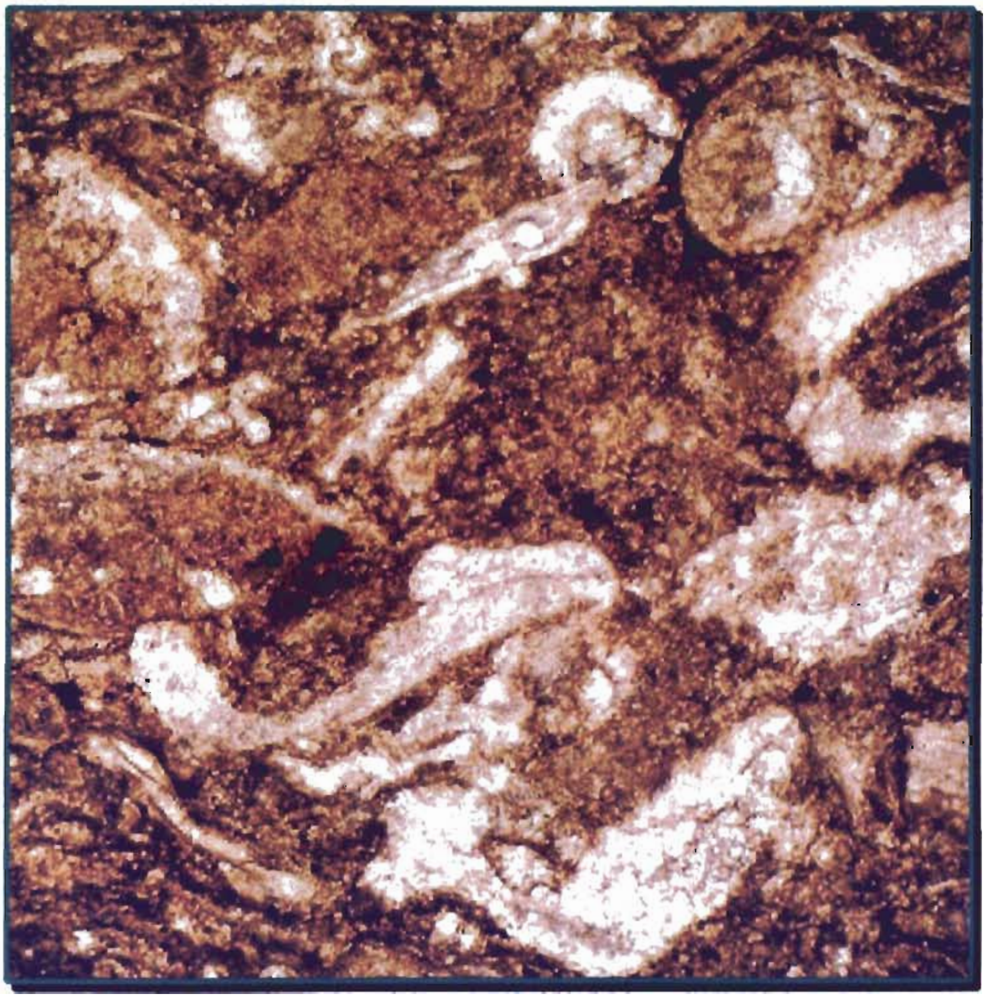

Photo 11
Location F-H99.
Lecompton Limestone Formation, Beil Limestone Member.
Thin section #F1-wackestone, fossil assemblage include
rugose coral and abundant fusulinid.

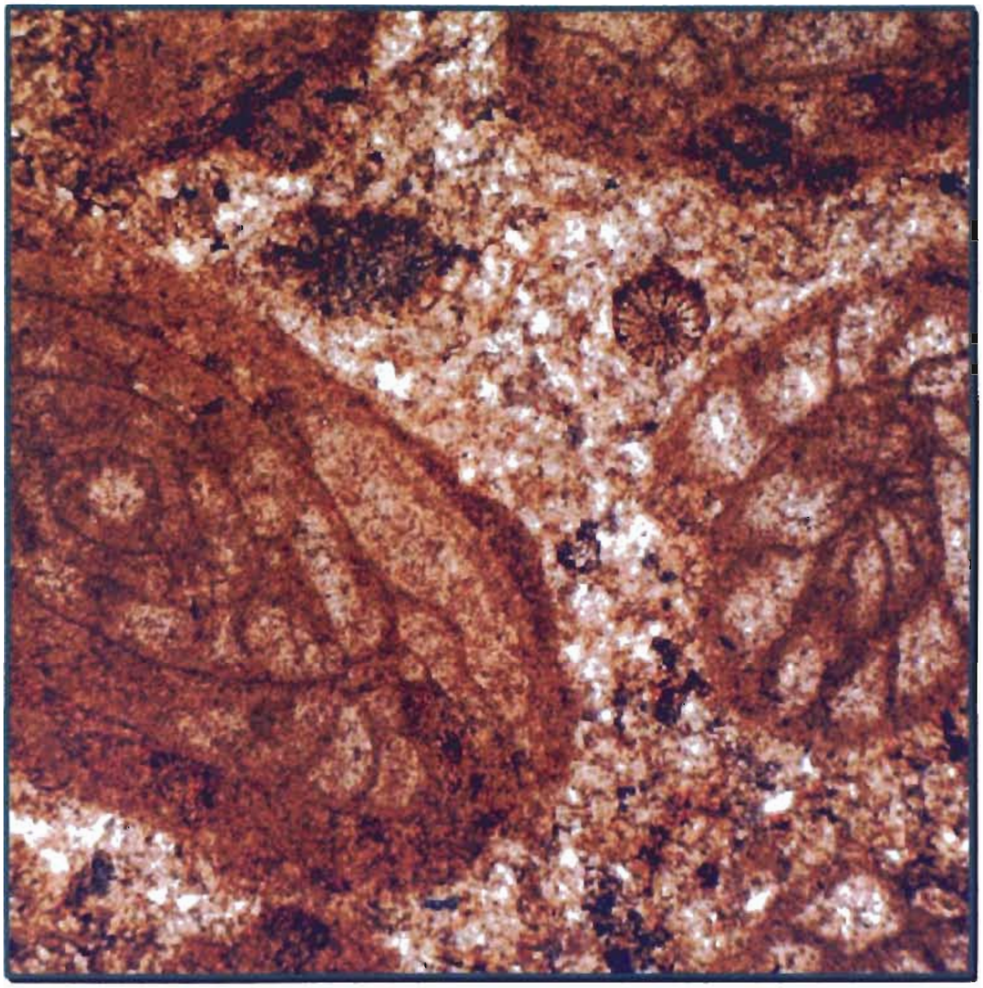

Photo 12
Location F-H99.
Lecompton Limestone Formation, Beil Limestone Member.
Thin section #F4-wackestone to packstone, fossil assemblage include abundant fusulinid.

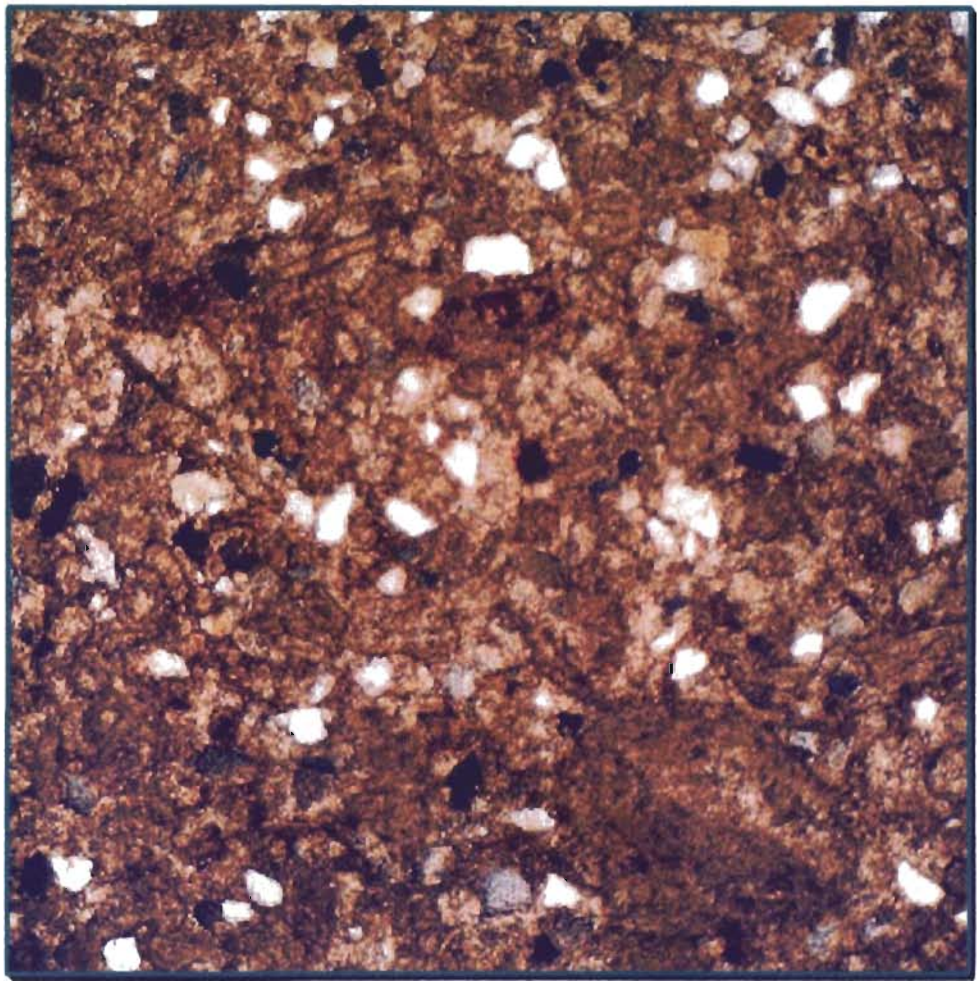

Photo 13
Location H-H99.
Deer Creek Limestone Formation, Ozawkie Limestone Member.
Thin section #H2-packstone, fossil assemblage include
foraminifera-abundant fusulinid, brachiopod and ostracod.

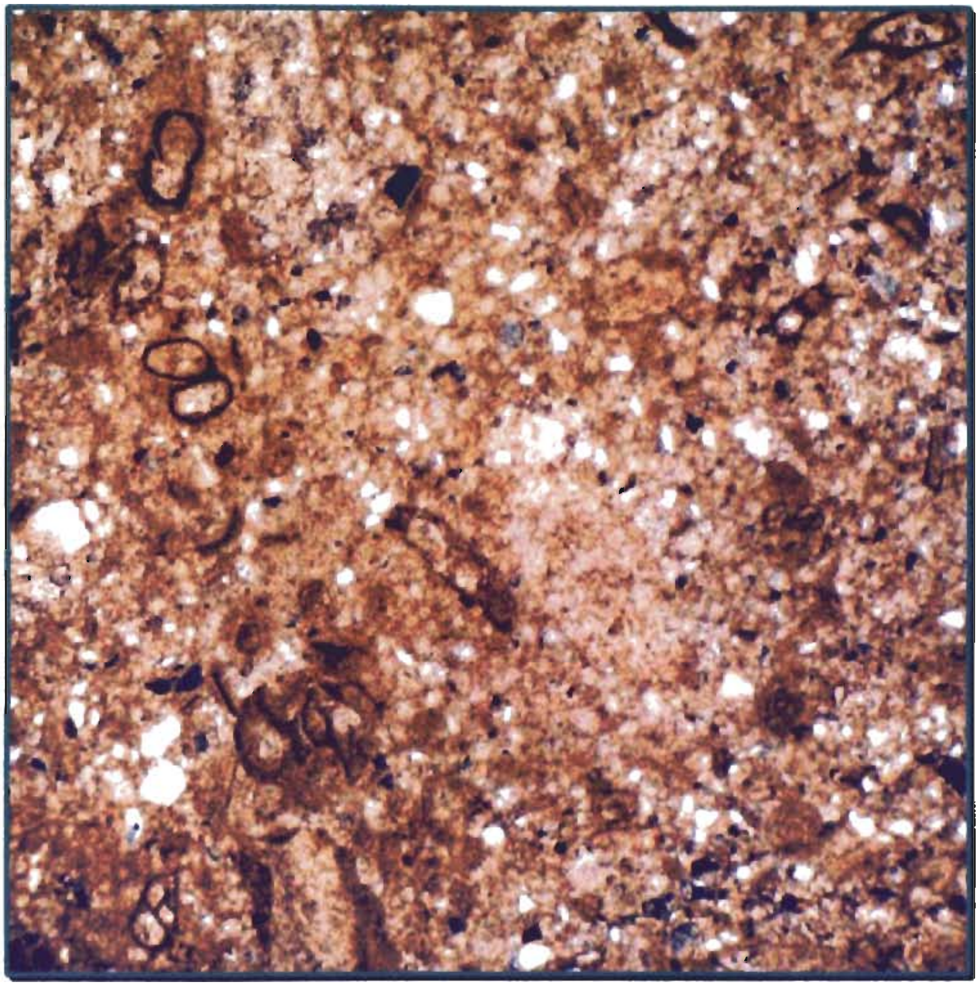

Photo 14
Location H-H99.
Deer Creek Limestone Formation, Ozawkie Limestone Member.
Thin section #H4-wackestone, fossil assemblage include brachiopod and spines, foraminifera, and ostracod.

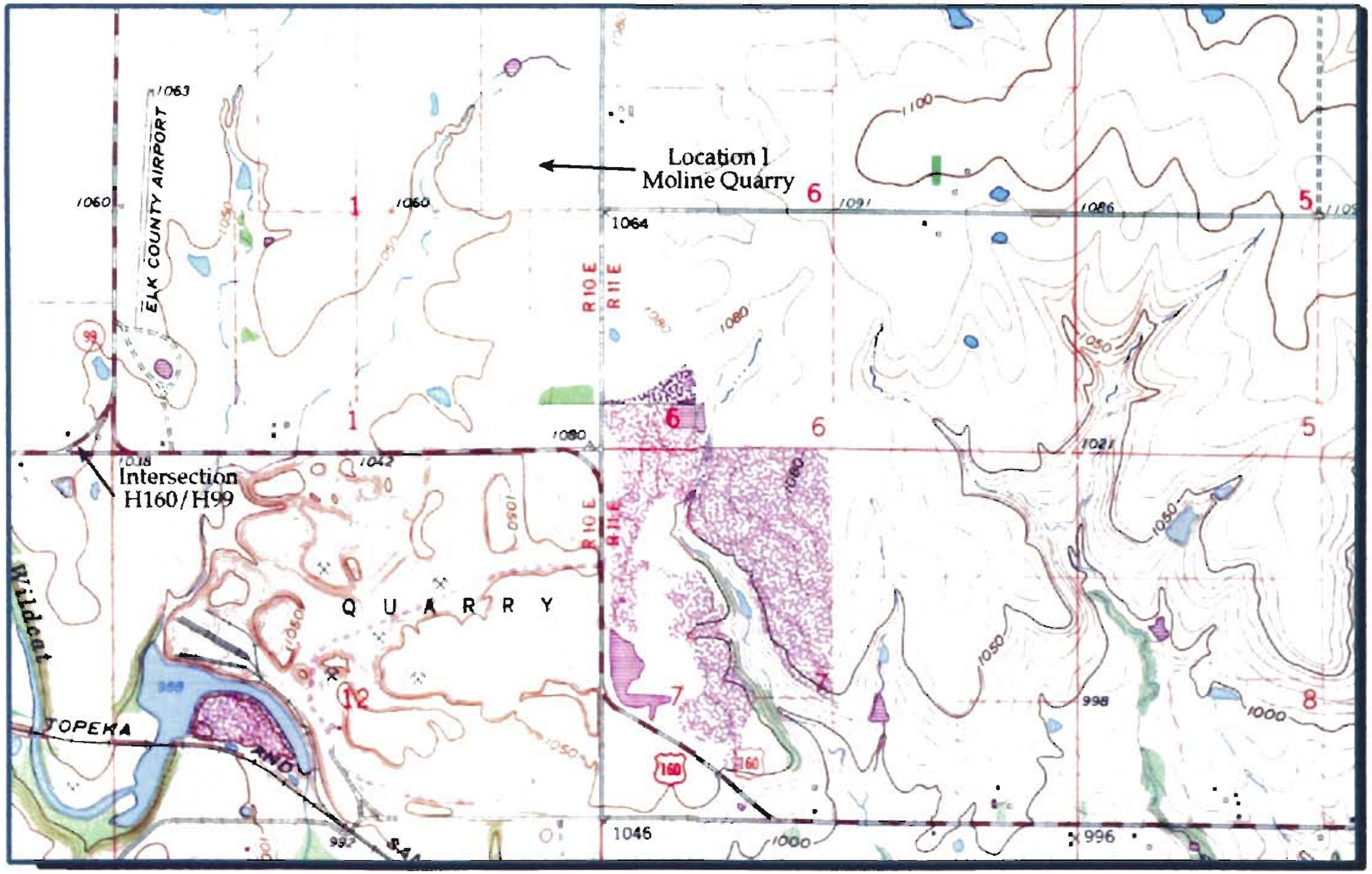

Figure 40. Map showing Location I, Deer Creek Limestone, Calhoun Shale, Topeka Limestone, Moline Aggregate Quarry, Elk County, Kansas.

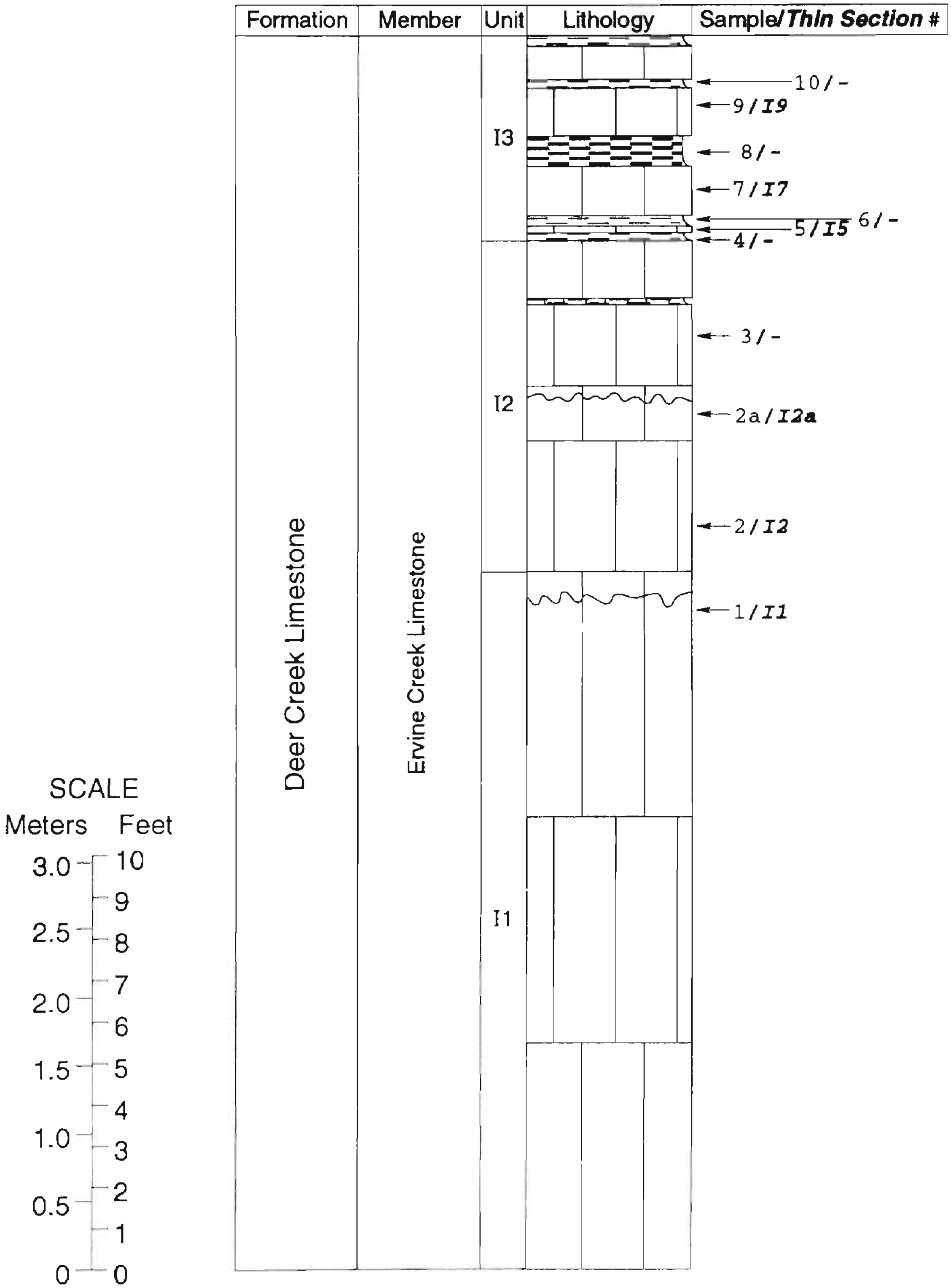

Figure 41. Measured section of location I-a, Moline Aggregate Quarry, Elk County, Kansas.

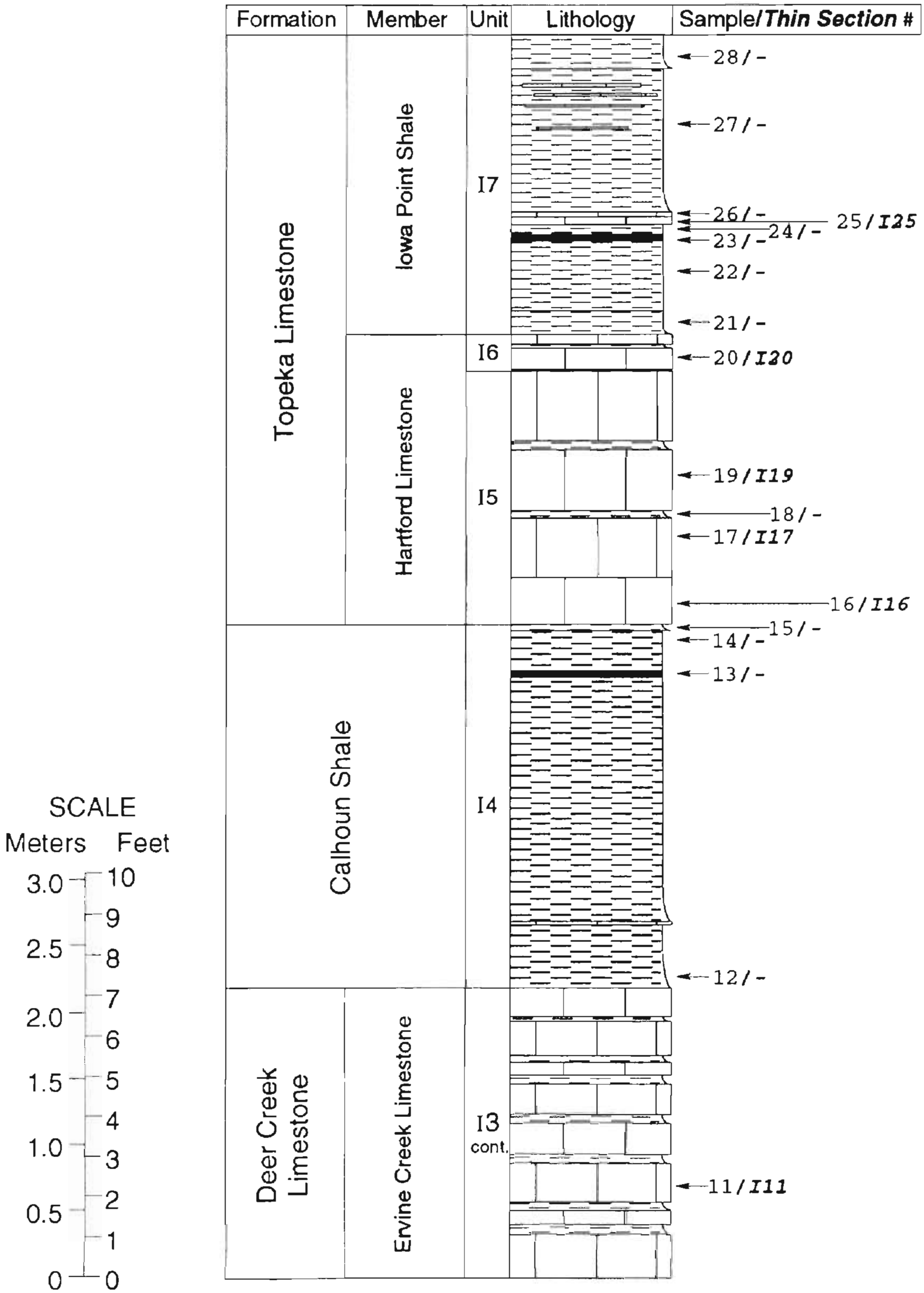

Figure 42. Measured section of location I-b, Moline Aggregate Quarry, Elk County, Kansas.

Location I (Quarry north of Moline)
SE/4 NE/4 Sec. 1-31S-10E
Elk County, Kansas
Longitude: 37°22.655′ (GPS)
Latitude: -96°15.630′

Deer Creek Limestone Formation

Ervine Creek Limestone Member-914 cm/360 inches

1 Limestone, very light gray, wackestone, very hard, finely crystalline, massive bedded, abundant recrystallized fracture filling, some styolites, fossiliferous; abundant fusulinids, brachiopods, fenestrate bryozoan-549 cm/216 inches

2 Limestone, medium gray, very hard, packstone, fossiliferous; fenestrate bryozoan and abundant fusulinids, recalcified fracture filling. Contains thin, 5 cm, olive black, lime with abundant tabulate coral. Top of interval grades to medium brownish-gray, hard to very hard, slightly argillaceous limestone-36 cm/14 inches

3 Shale, medium to dark gray, hard, platy, slightly fossiliferous; brachiopods, crinoid plates-5 cm/2 inches

4 Limestone, medium to medium dark gray, wackestone, thin bedded with abundant brachiopod shell fragments-5 cm/2 inches

5 Shale, dark gray, hard, platy, slightly fossiliferous; brachiopods, crinoid plates-8 cm/3 inches

6 Limestone, light to medium gray, dense, wackestone, thin bedded, brachiopods-36 cm/14 inches

7 Shale, very dark gray, soft, fissile at base grading to clayey-20 cm/8 inches

8 Limestone, light to medium gray, very dense, wackestone, thin bedded, finely crystalline, scattered fusulinids and mollusc shell fragments. Contains numerous thin shale partings, medium gray, platy with abundant shell fragments-257 cm/101 inches

Calhoun Shale Formation

9 Shale, medium to dark gray, fissile to platy, abundant carbonaceous material and plant fragments in top-46 cm/18 inches

10 Limestone, very thin, medium brownish-gray-2 cm/1 inch

11 Shale, medium to dark gray, platy grading upward to blocky and crumbly, very carbonaceous with abundant plant fragments throughout. Thin, 2.5 cm coal seam 30 cm from top of unit-218 cm/86 inches

Topeka Limestone Formation

Hartford Limestone Member-117 cm/46 inches

12 Shale, light to medium gray, blocky, slightly calcareous-2 cm/1 inch

13 Limestone, very dense, massive bedded, wackestone, medium gray–35.6 cm/14 inches

14 Limestone, dense, light to light medium gray, wackestone, massive bedded, abundant fusulinids, upper 10 cm abundant large *Aviculapinna, Myalina*--46 cm/18 inches

15 Shale, medium light gray, platy, slightly calcareous-5 cm/2 inches

16 Limestone, dense, medium gray, wackestone, massive bedded, fossiliferous-53 cm/21 inches

17 Shale, medium gray, blocky, calcareous-2 cm/1 inch

18 Limestone, dense, medium gray to medium brownish-gray, wackestone and packstone, finely crystalline, wavy laminar appearance, ostracods-15 cm/6 inches

19 Shale, medium grayish brown-2 cm/1 inch

20 Limestone, dense, medium gray to medium brownish-gray, wackestone and packestone, wavy laminar appearance, ostracods-8 cm/3 inch

Iowa Point Shale Member-109 cm/43 inches

21 Shale, medium yellowish-brown to brownish-gray, soft, blocky-clayey, very calcareous-15 cm/6 inches

22 Shale, medium dark gray, soft, clayey, abundant carbonaceous and plant fragments, interbedded very thin, yellowish-tan laminations-53.3 cm/21 inches

23 Coal, dark gray, very abundant plant fragments, scattered 3 cm vertebrae-5.0 cm/2 inches

24 Shale, yellowish-gray, blocky, some silty, scattered carbonaceous fragments-8 cm/3 inches

25 Limestone, hard medium gray to yellowish-brown, slightly silty, wackestone-5 cm/2 inches

26 Limestone, thin bedded, medium olive-gray, very hard, wackestone, abundant brachiopods, scattered spines-3 cm/1 inch

27 Shale, pale yellowish-orange, firm, blocky, calcareous, fusulinids interbedded with a noncontiguous limestone, hard, thin bedded, yellowish-tan, grainstone, with very abundant fusulinids and crinoid plates. With shallowing depth alternating shale and thin limestone, yellowish-orange, packstone, very abundant fusulinids, brachiopods and brachiopod spines-107 cm/42 inches

28 Shale, yellowish-orange to yellowish-tan, firm, blocky, fusulinids-23 cm/9 inches

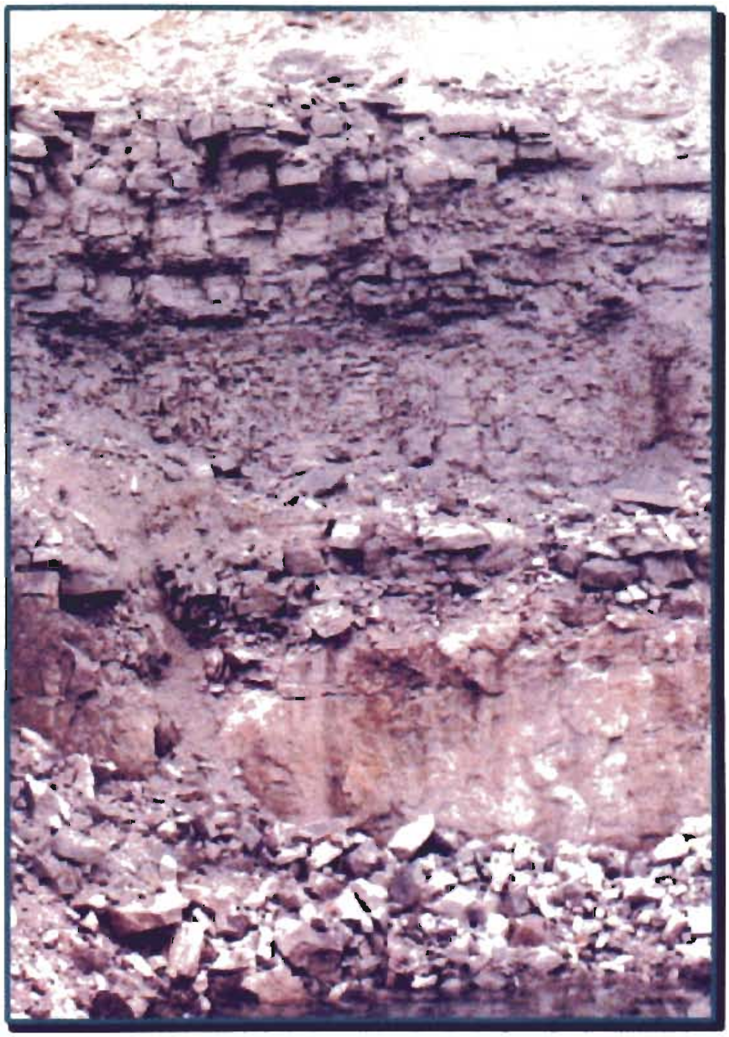

Photo 15
Location I-Moline Aggregate Quarry.
Deer Creek Limestone Formation, Ervine Creek
Limestone Member.

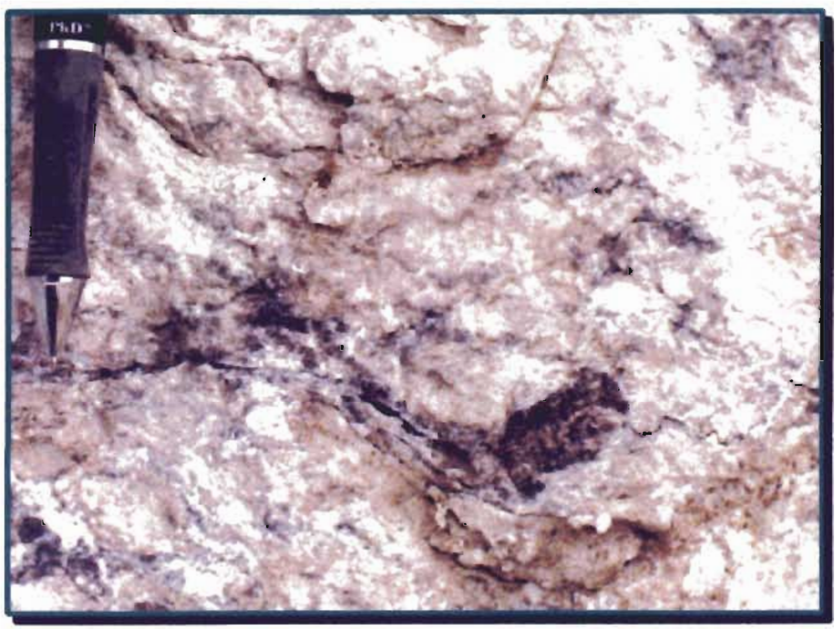

Photo 16
Location I-Moline Aggregate Quarry.
Deer Creek Limestone Formation, Ervine Creek
Limestone Member. Recrystallized calcite.

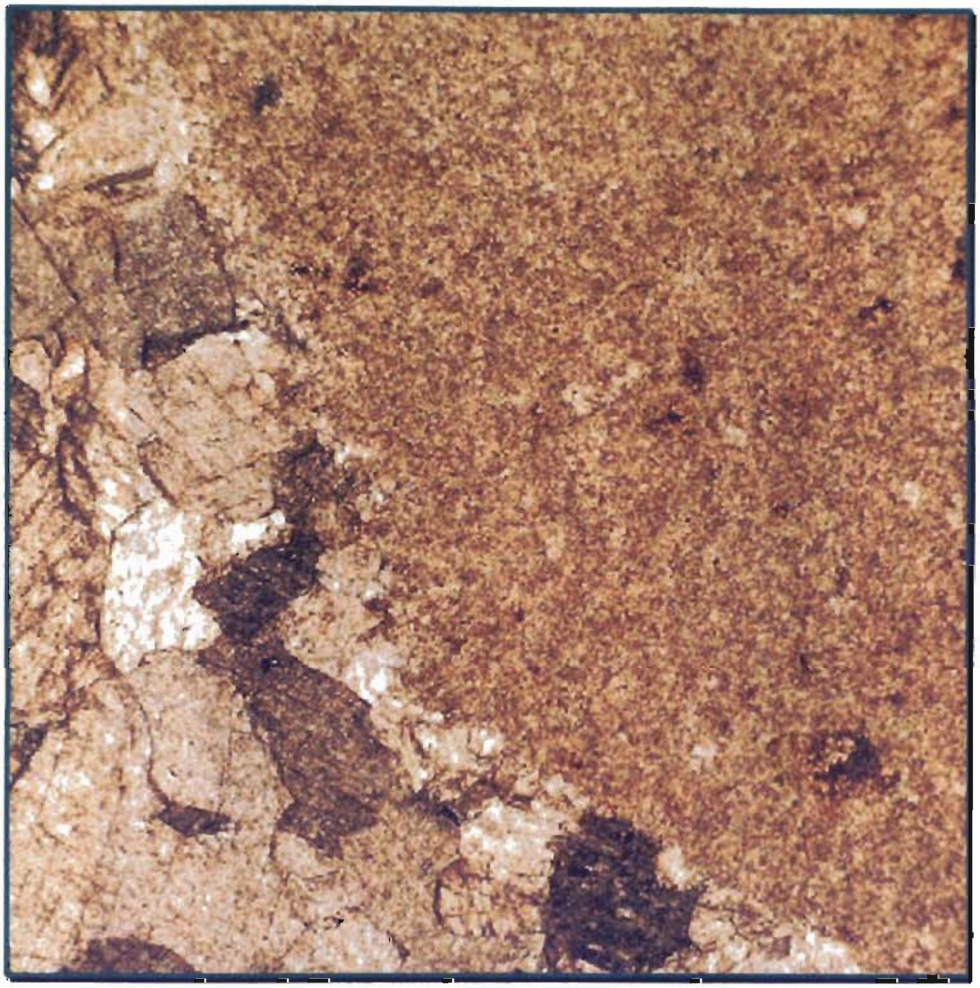

Photo 17
Location I-Moline Aggregate Quarry.
Deer Creek Limestone Formation, Ervine Creek Limestone Member.
Thin section #I1-wackestone, some styolites, fossil assemblage include brachiopod and abundant fusulinid.

Photo 18
Location I-Moline Aggregate Quarry.
Deer Creek Limestone, Calhoun Shale and
Topeka Limestone Formations.

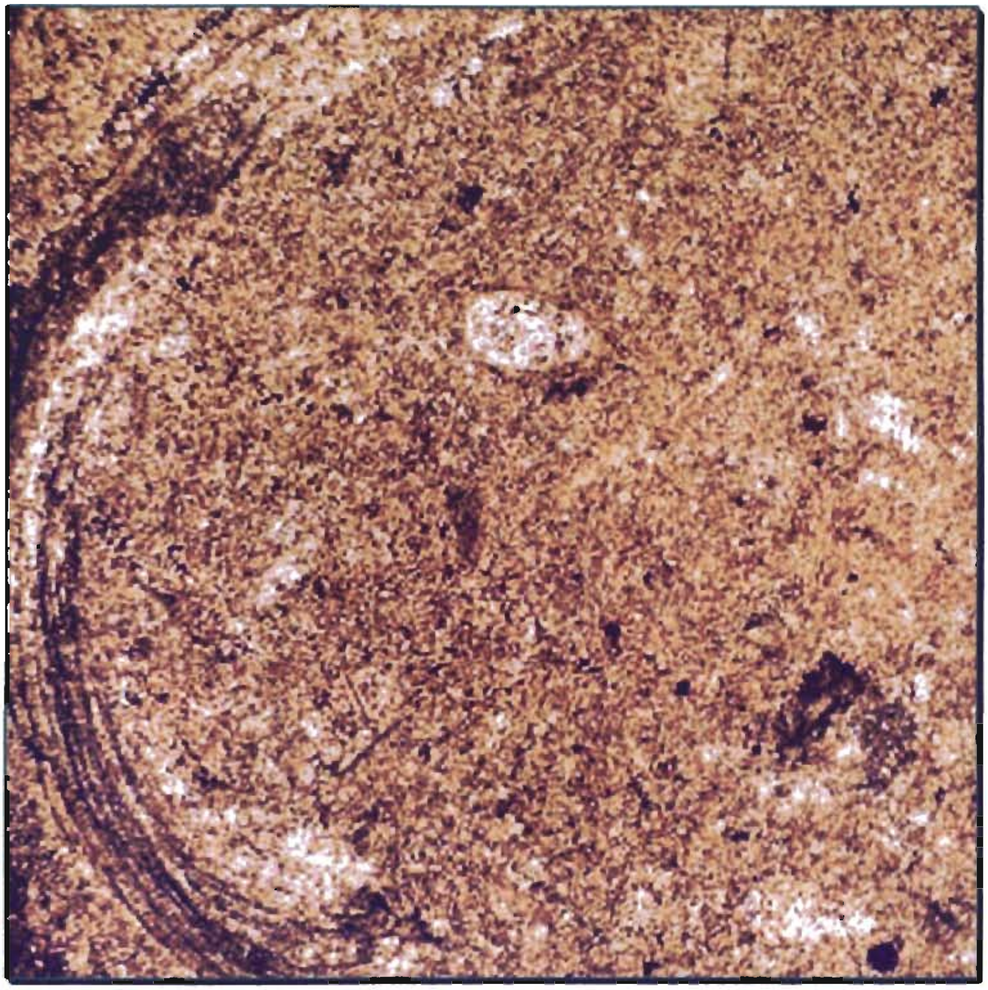

Photo 19
Location I-Moline Aggregate Quarry.
Deer Creek Limestone Formation, Ervine Creek Limestone Member.
Thin section #I9-wackestone, fossil assemblage include
brachiopod, bryozoan and abundant foraminifera.

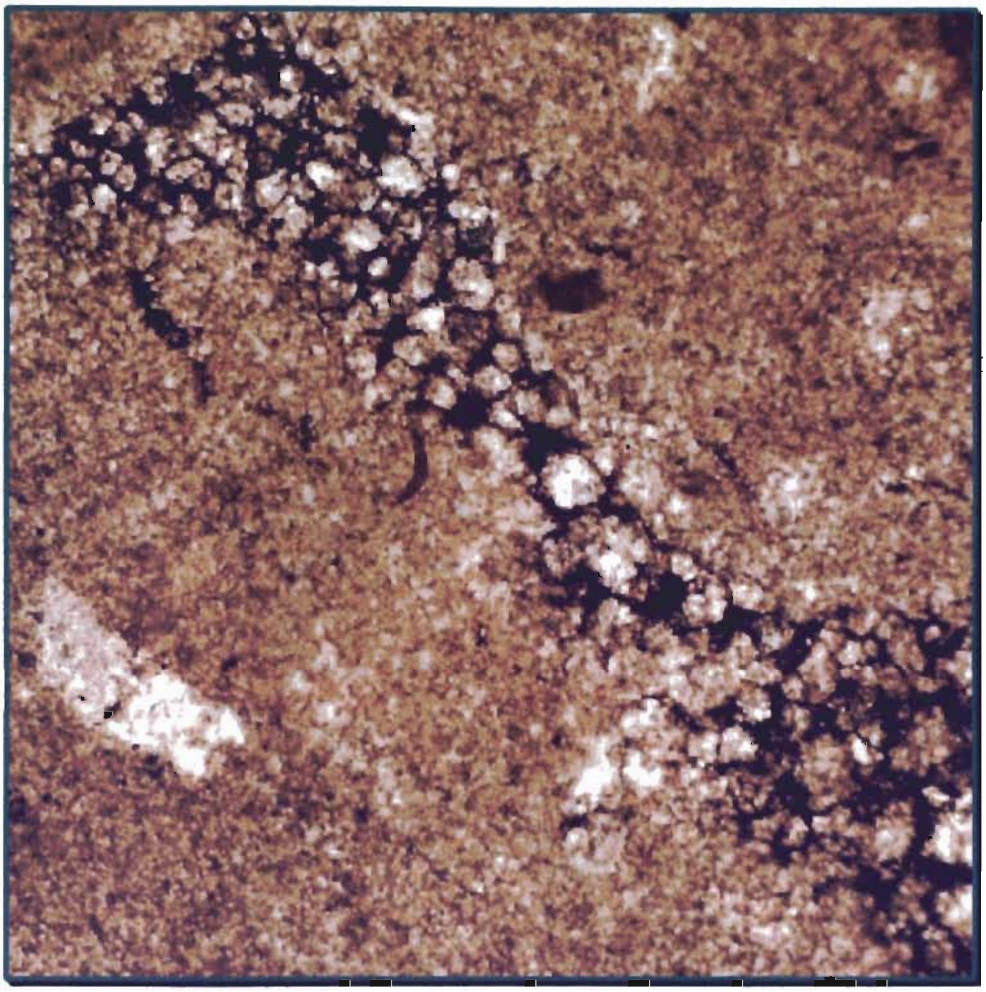

Photo 20
Location I-Moline Aggregate Quarry.
Deer Creek Limestone Formation, Ervine Creek Limestone Member.
Thin section #I11-wackestone, fossil assemblage include
brachiopod and foraminifera.

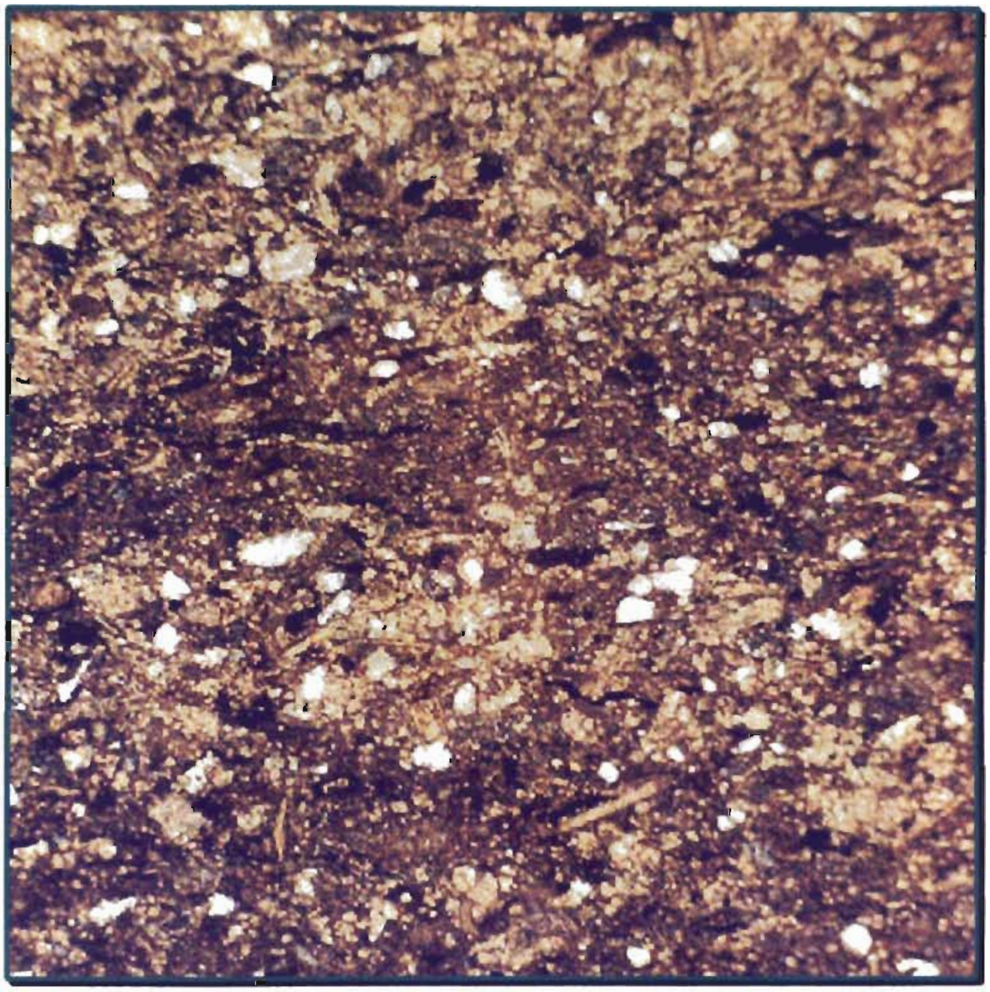

Photo 21
Location I-Moline Aggregate Quarry.
Topeka Limestone Formation, Hartford Limestone Member.
Thin section #I20-packstone, fossil assemblage includes
brachiopod and laminated debris.

Photo 22
Location I-Moline Aggregate Quarry.
Topeka Limestone Formation, Iowa Point Shale Member.

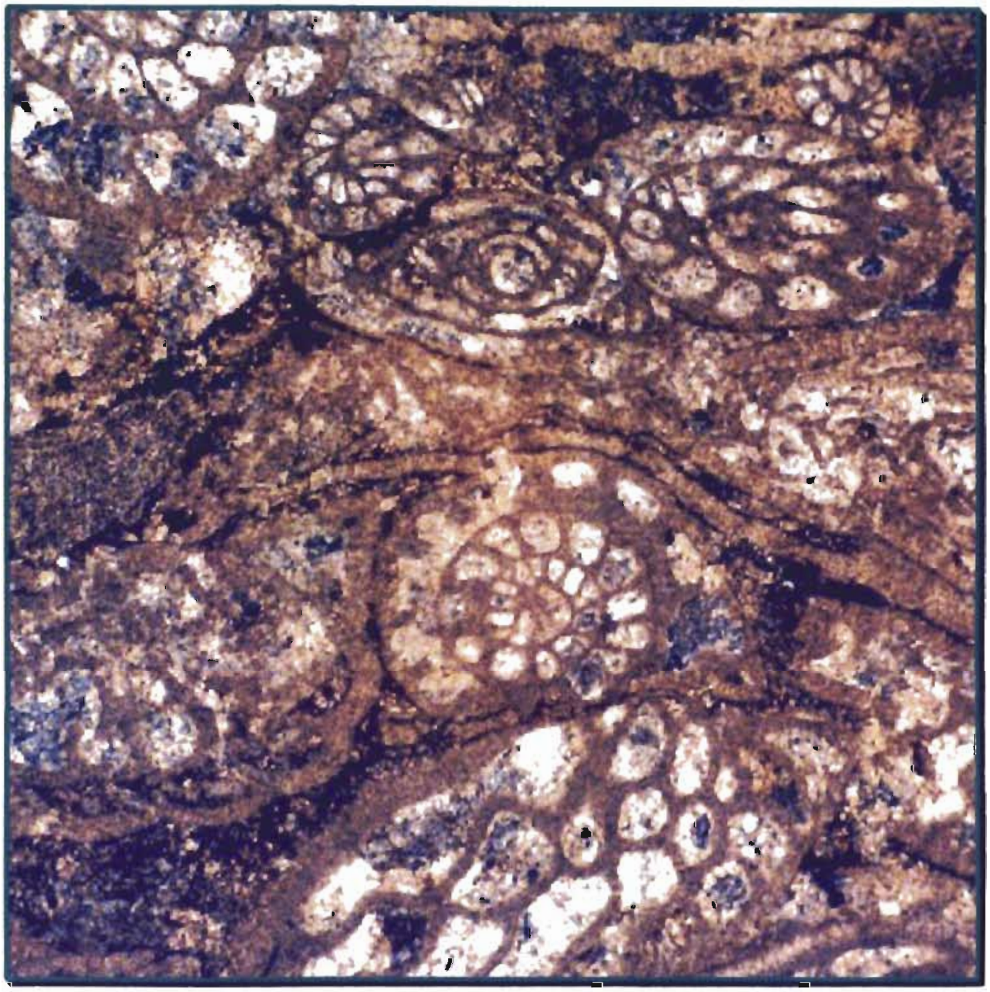

Photo 23
Location I-Moline Aggregate Quarry.
Topeka Limestone Formation, Iowa Point Shale Member.
Thin section #I28-packstone, fossil assemblage includes very abundant fusulinids.

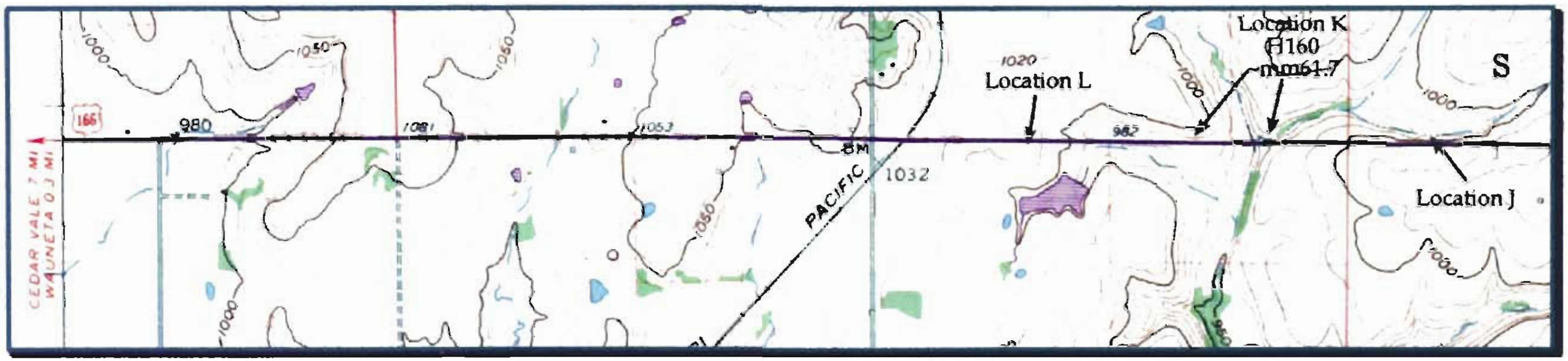

Figure 43. Map showing Locations J, K, and L, Deer Creek Limestone, H166, mile marker 61 through 63, Chautauqua County, Kansas.

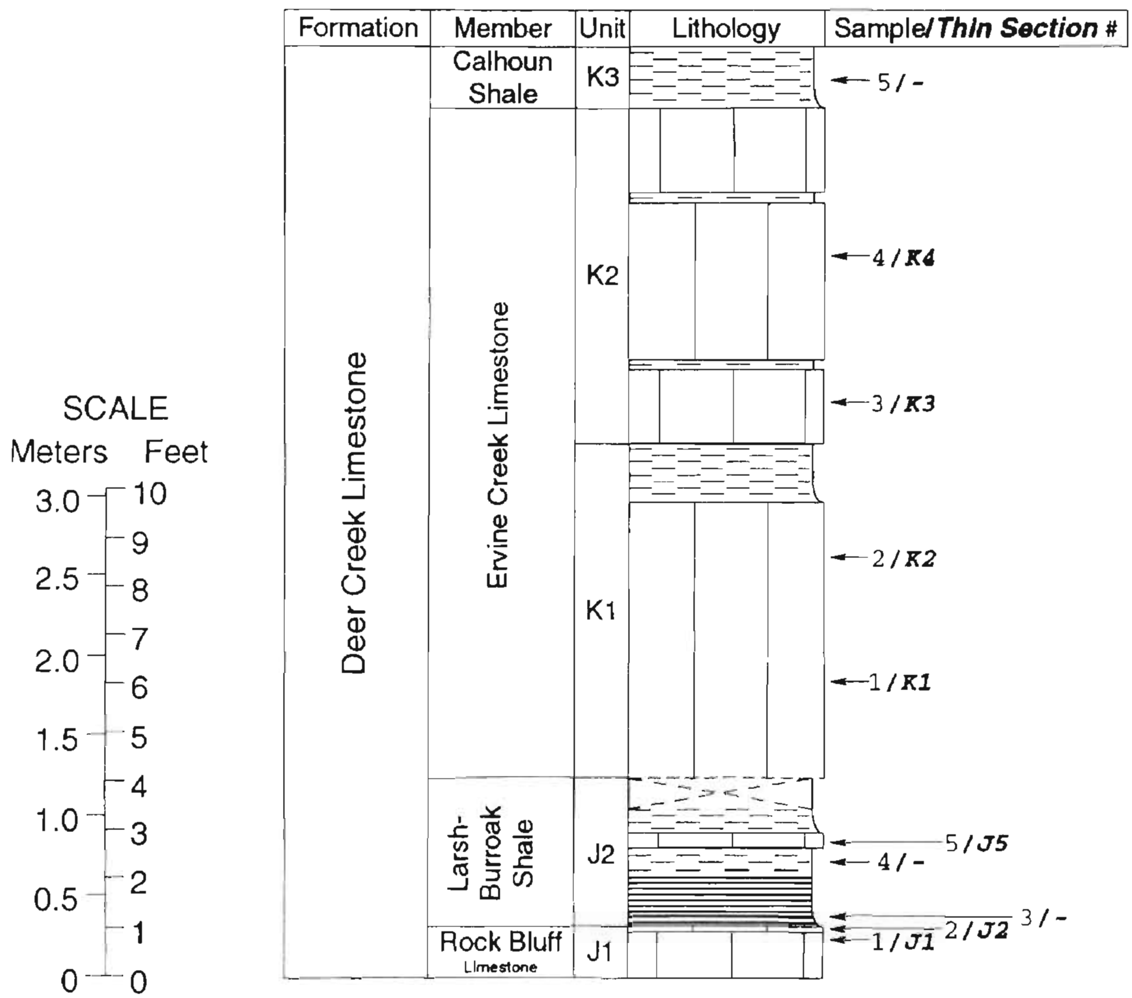

Figure 44. Measured section of locations J and K Highway 166, mile markers 61.5 through 64.5, Chautauqua County, Kansas.

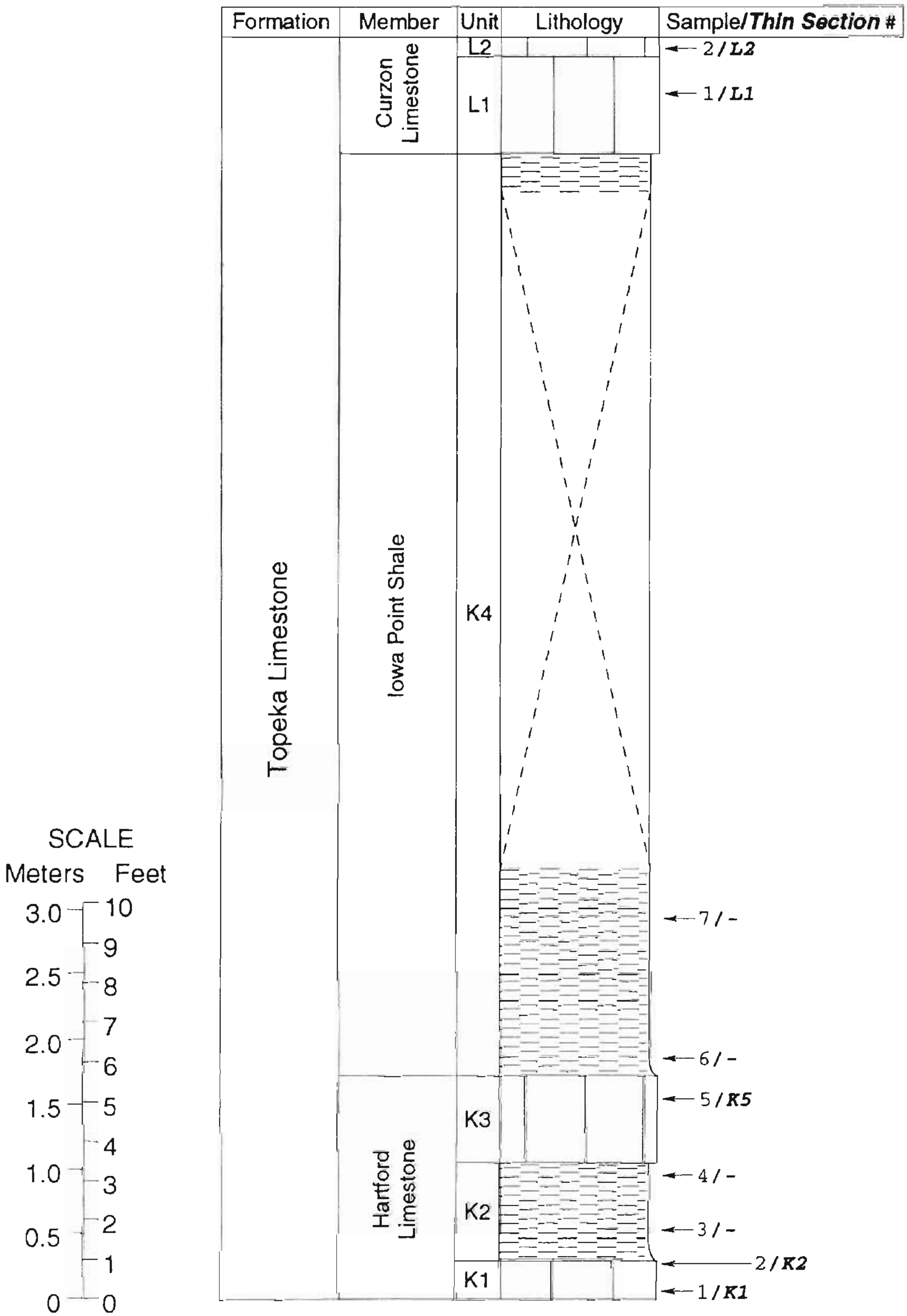

Figure 45. Measured section of locations K and L Highway 166, mile marker 61-62, Chautauqua County, Kansas.

Location J (H166~mm62)
S/2 SW/4 Sec. 4-34S-10E
Chautauqua County, Kansas
Longitude: 37°06.384' (GPS)
Latitude: -96°15.630'?-ck

Deer Creek Limestone Formation

Rock Bluff Limestone Member-12.7+ cm/5+ inches

1 Limestone, medium gray to medium brownish-gray, dense, wackestone, massive bedding, finely crystalline, vertical fractures, fossiliferous; brachiopod and pelecypod shell fragments, top very abundant burrow traces, shell fragments- 10.2+ cm/4+ inches

2 Limestone hardground, medium brownish-gray, hard, wacke- to packstone, very abundant fossils; pelecypods and brachiopod shell fragments, spines, burrow traces on lower surface-2 cm/<1 inch

Larsh & Burroak Shale Members-69 cm/27 inches

3 Shale, black, fissile at base, conodonts, grades to platy and blocky, very thin lamination of grayish-tan shale-27.9 cm/11 inches

4 Shale, brownish-gray, platy to blocky with fine laminations yellowish-tan shale-40.6 cm/16 inches

Ervine Creek Limestone Member-10 cm/4 inches

5 Limestone, medium to dark bluish-gray, very hard, wackestone, coarsly crystalline, calcite xtals, fe staining. Weathers brownish-yellow-10 cm/4 inches

Location K (H166~mm61.5)
S/2 SE/4 Sec. 5-34S-10E
Chautauqua County, Kansas
Longitude: 37°06.384' (GPS)
Latitude: -96°19.863'

Deer Creek Limestone Formation

Ervine Limestone Member-381 cm/150 inches

1 Limestone, medium gray, very hard, wackestone, some calcitic filling, abundant fossils; brachiopods, sponges, crinoid columns, few rugose coral. Styolitic 50 cm from base -81 cm/32 inches

2 Limestone, light olive-gray, wackestone, thin and medium wavy bedded, with scattered shale partings, sparse fossils, calcitic crystallization. Weathers orange-tan-140 cm/55 inches

3 Limestone, light to medium gray, dense, wacke- to packstone, abundant fusulinids-31 cm/12 inches

4 Limestone, dark blue-gray, dense, wackestone, fossil hash; fenestrate bryozoans, brachiopod spines, brachiopod shell fragments, fusulinids increasing in abundance upwards-130 cm/51 inches

Calhoun Shale Formation-66 cm/26 inches

5 Shale, pale yellowish-brown, blocky, slightly calcareous-66 cm/26 inches

Topeka Limestone Formation

Hartford Limestone Member-178 cm/70 inches

6 Limestone, medium dark gray, very hard, wackestone, small fossil fragments; spines, ostracods, oolitic-31 cm/12 inches

7 Limestone, dark gray, very hard, wackestone, large pelecypods, burrows-5 cm/2 inches

8 Shale, dark gray, fissile grading upward to blocky-64 cm/25 inches

9 Shale, dark brownish-gray, blocky-10 cm/4 inches

10 Limestone, medium dark gray, very hard, wackestone, massive bedded, fossiliferous; brachiopods, Calcisponges, some recalcification-69 cm/27 inches

Iowa Point Shale Member-7.2 m/281 inches

11 Shale, medium to dark gray, fissile and platy, slightly calcareous, abundant fossil fragments; brachiopod and small pelecypod shell fragments-15 cm/6 inches

12 Shale, medium gray-brown, massive, generally blocky, thin arenaceous and calcareous laminations, apparently unfossiliferous-7.1 m/278 inches

Location L (H166-mm61m)

S/2 SW/4 Sec. 5-34S-10E
Chautauqua County, Kansas
Longitude: 37°06.384' (GPS)
Latitude: -96°19.863'?ck

Topeka Limestone Formation

Curzon Limestone Member-97 cm/38 inches

1 Limestone, medium yellowish-brown, very hard to dense, wackestone, some fusulinids, calcitic recrystallization, weathers distinct orangish-yellow-79 cm/31 inches

2 Limestone, medium yellowish-brown, very hard, packstone, very abundant fusulinids, weathers orangish-yellow-18 cm/7 inches

Photo 24
Location J-mile 62 on H166. Deer Creek Limestone Formation, Rock Bluff Limestone and Larsh-Burroak Shale members.

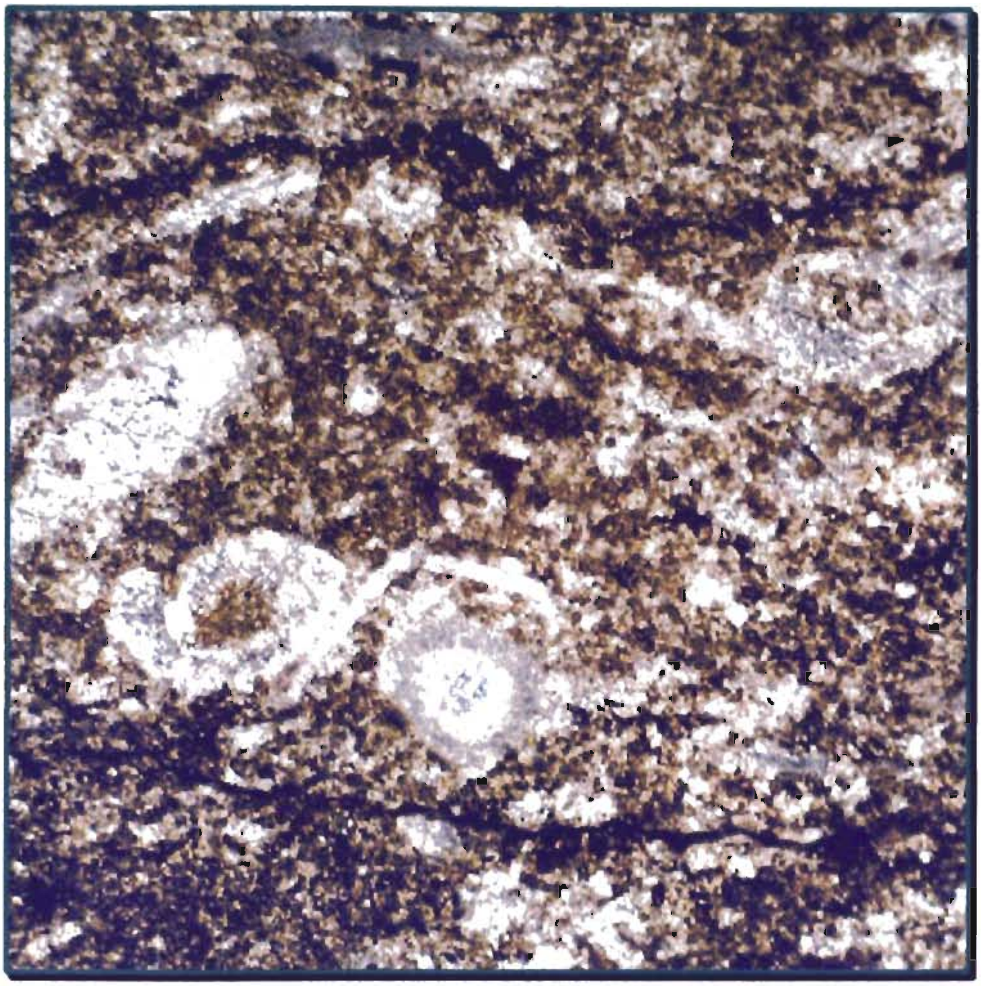

Photo 25
Location J-H166.
Deer Creek Limestone Formation, Rock Bluff Limestone Member.
Thin section #J1-wackestone, fossil assemblage includes
brachiopod, pelecypod, burrow traces and foraminifera.

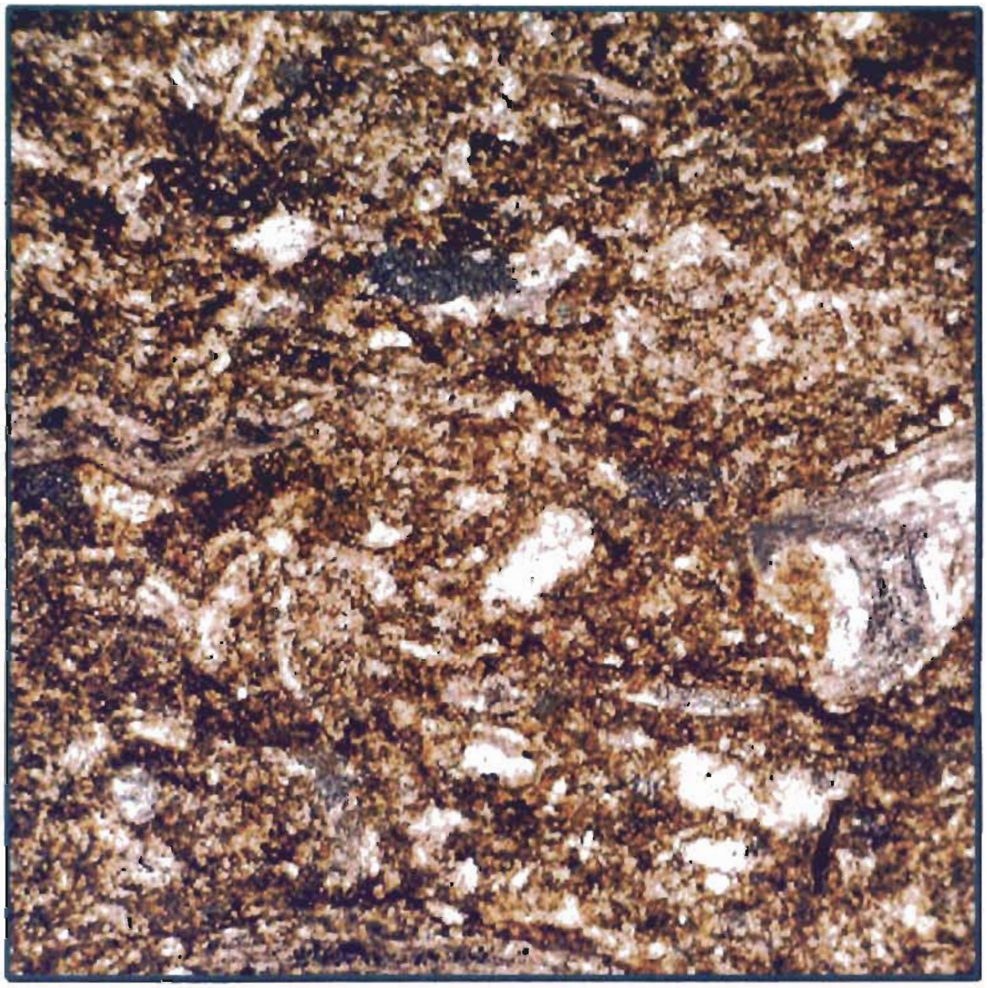

Photo 26
Location J-H166.
Deer Creek Limestone Formation, Rock Bluff Limestone Member.
Thin section #J2-wackestone to packstone, fossil assemblage includes abundant bivalves.

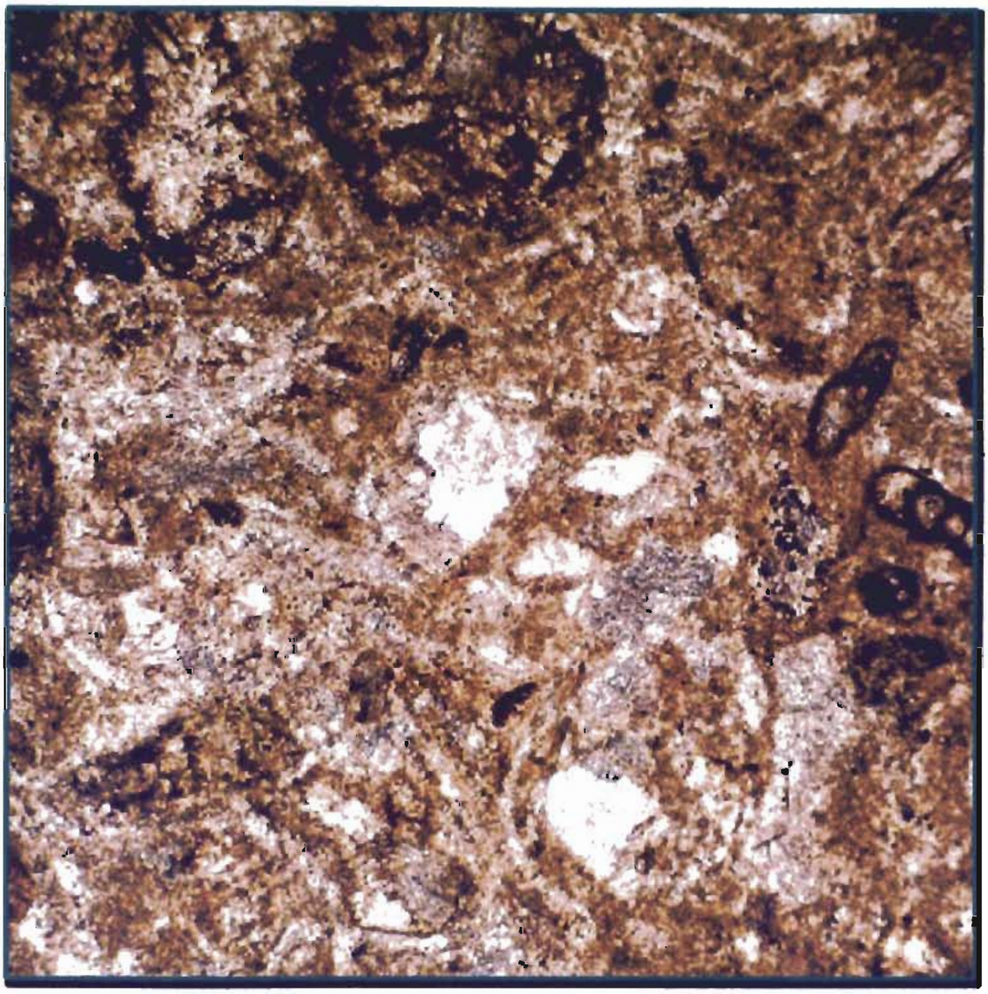

Photo 27
Location J-H166.
Deer Creek Limestone Formation, Larsh-Burroak Shale Member.
Thin section #J3-wackestone to packstone, fossil assemblage includes foraminifera and oöids.

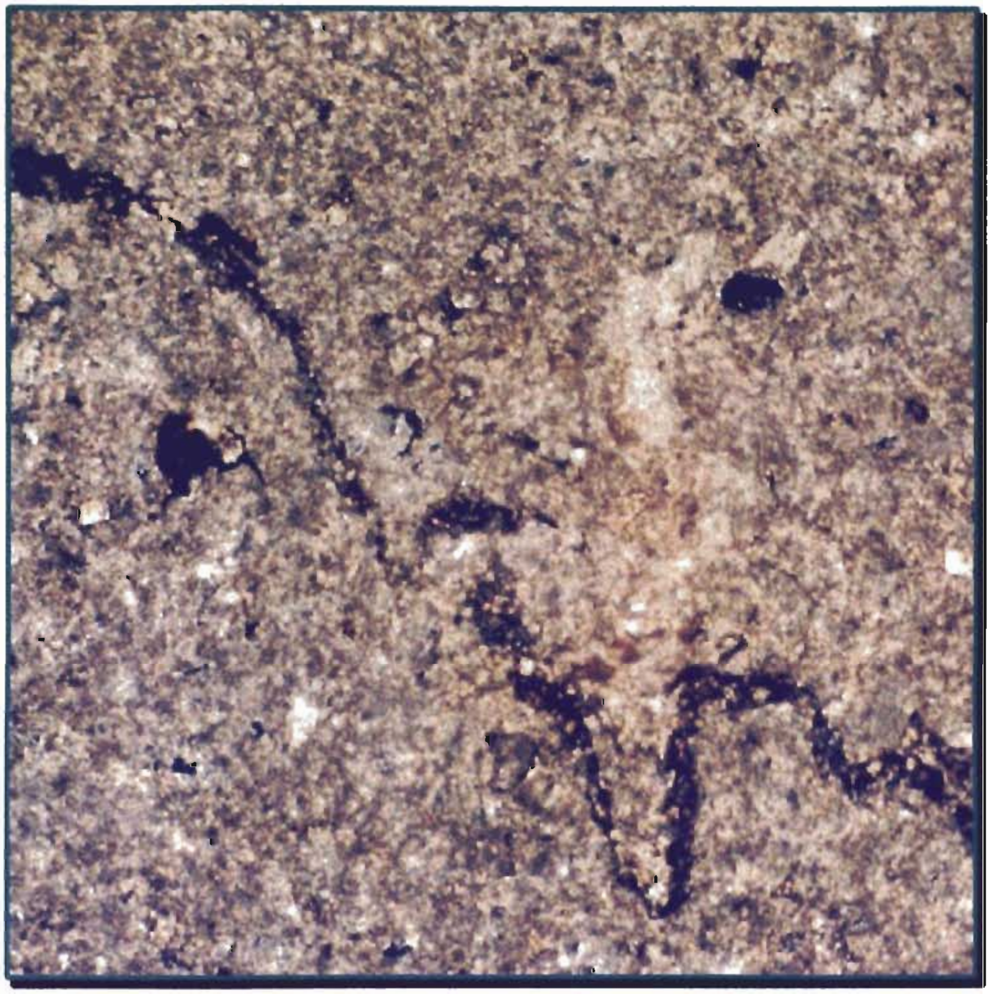

Photo 28
Location K-H166.
Deer Creek Limestone Formation, Ervine Creek Limestone Member.
Thin section #K1-wackestone, fossil assemblage includes
brachiopod, fusulinid, and ostracod.

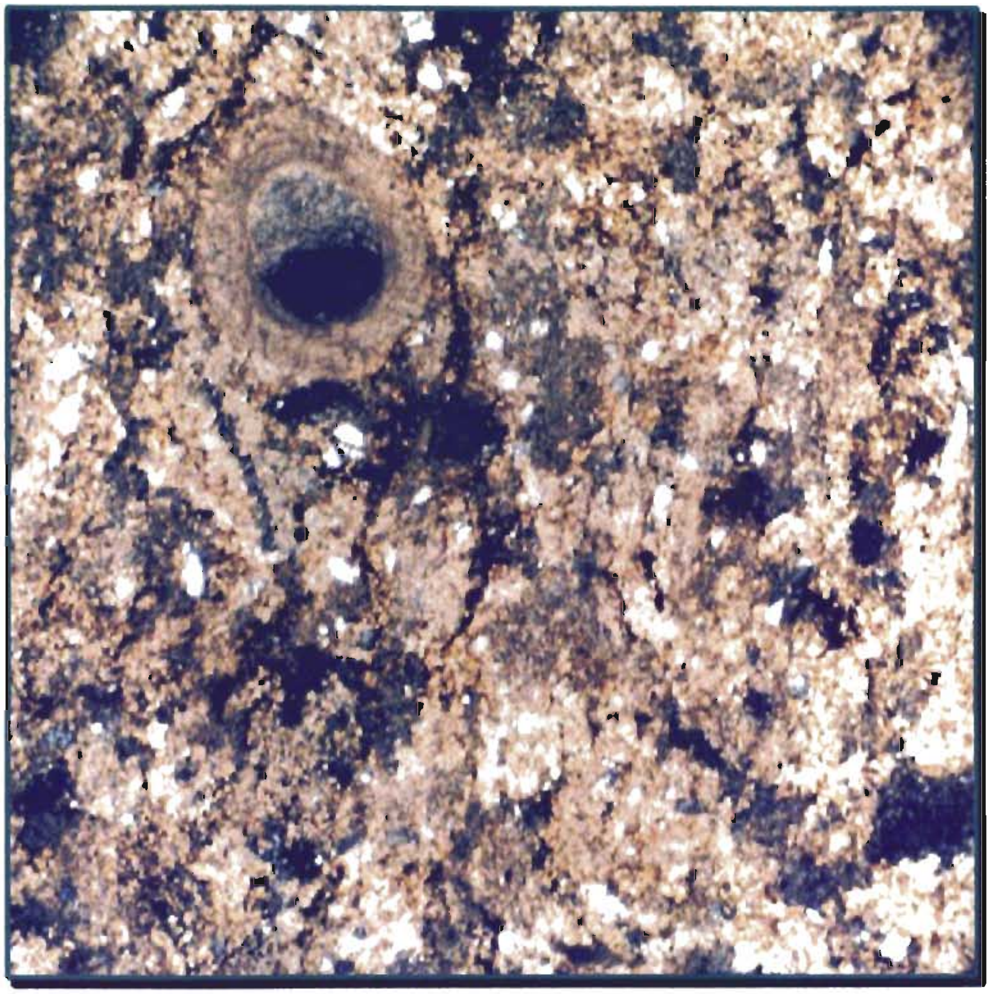

Photo 29
Location K-H166.
Deer Creek Limestone Formation, Ervine Creek Limestone Member.
Thin section #K3-wackestone, fossil assemblage includes
brachiopod and brachiopod spines.

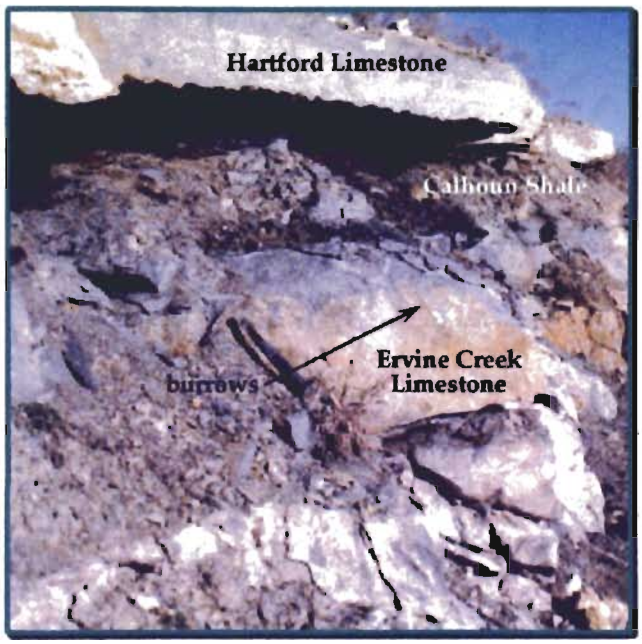

Photo 30
Location K-H166. Deer Creek Limestone Formation,
Ervine Creek Limestone Member.

Photo 31
Location K-H166. Deer Creek Limestone Formation, Ervine Creek Limestone Member.

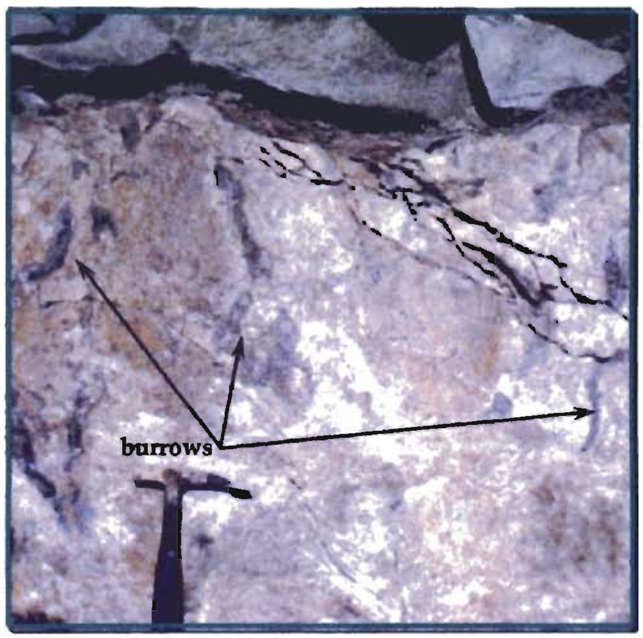

Photo 32
Location K-H166. Deer Creek Limestone Formation, burrows in Ervine Creek Limestone Member.

Photo 33
Location J-H166. Deer Creek and Topeka Limestone Formations. Ervine Creek Limestone, Hartford Limestone and Iowa Point Shale members.

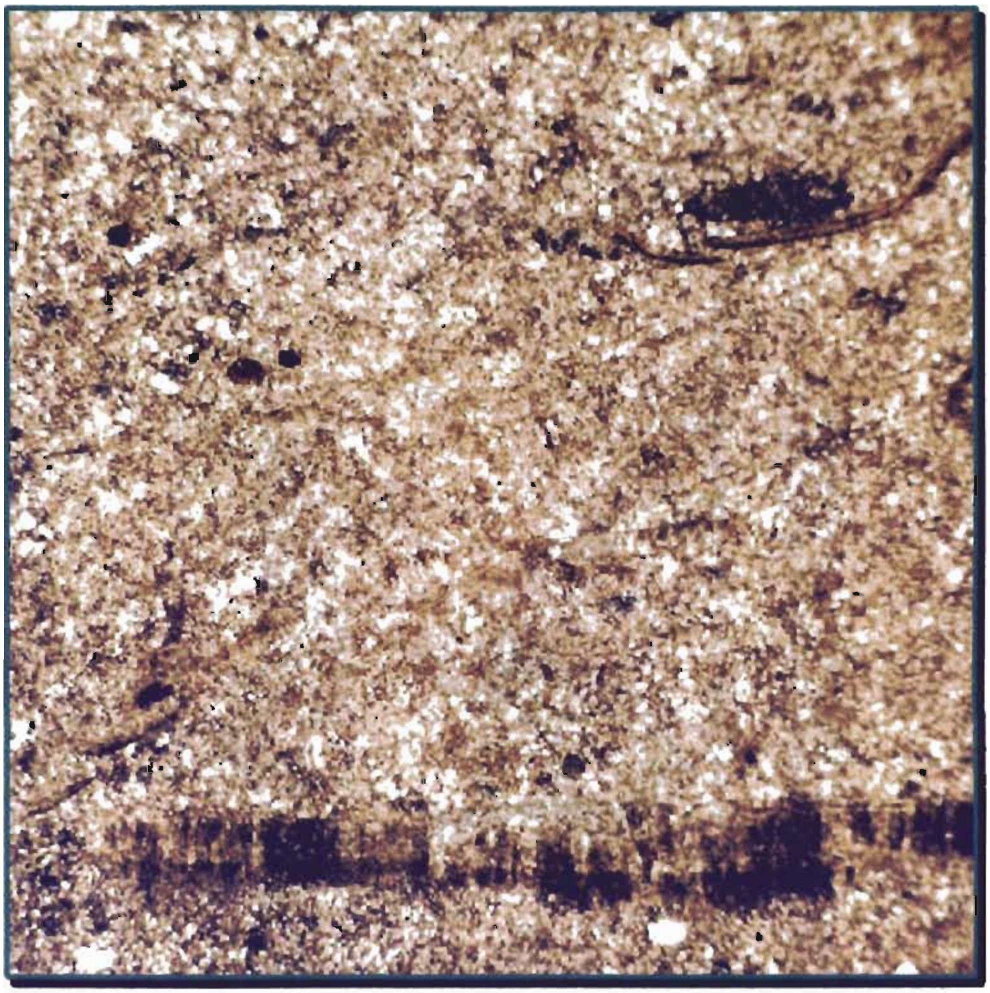

Photo 34
Location JK-H166.
Topeka Limestone Formation, Hartford Limestone Member.
Thin section #K3-wackestone, fossil assemblage includes brachiopod.

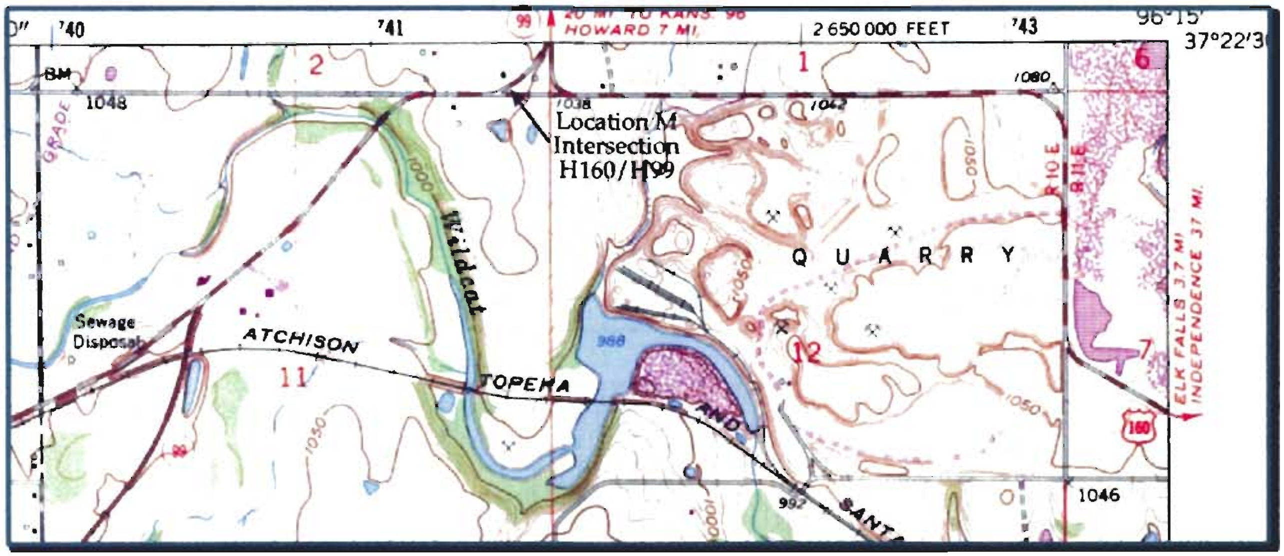

Figure 46. Map showing Location M, Topeka Limestone, intersection of H99/H160, Elk County, Kansas.

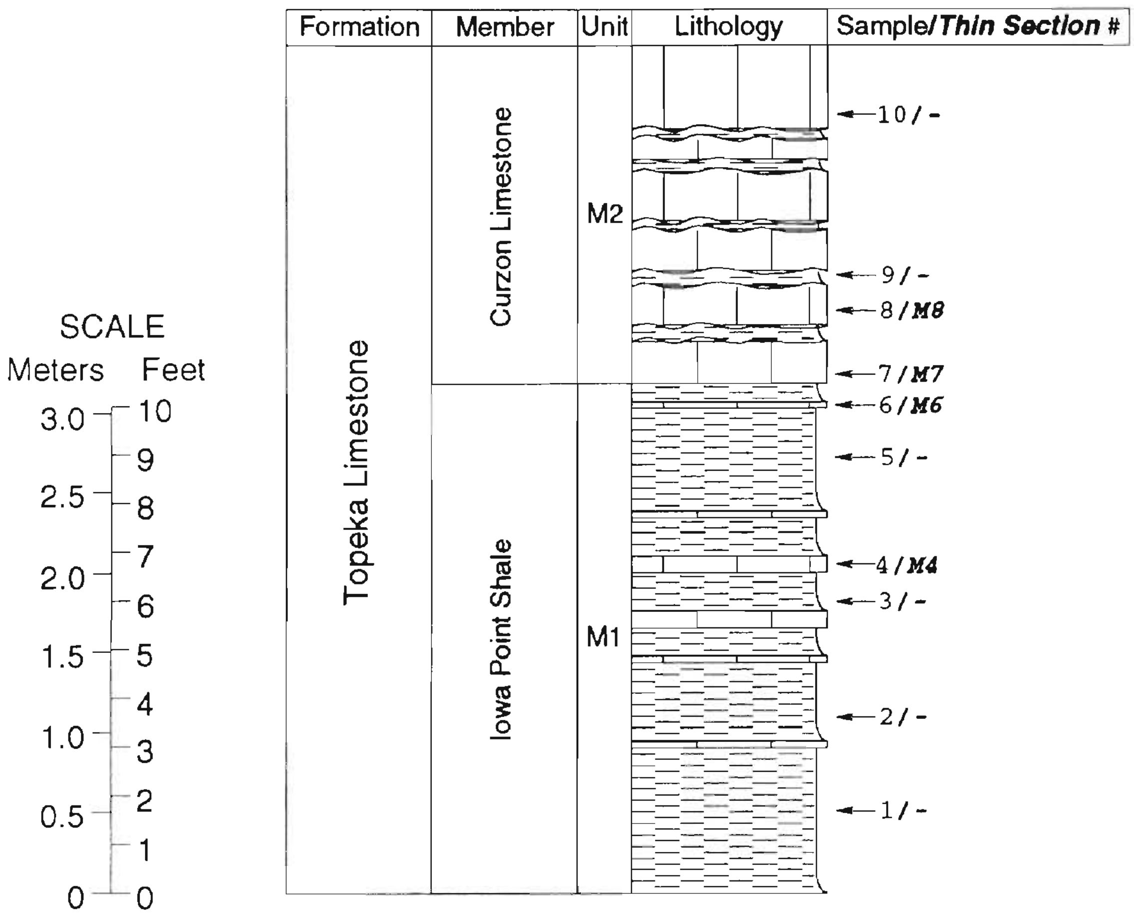

Figure 47. Measured section of location M, intersection of highways 160/99, Elk County, Kansas.

Location M (Intersection H160/H99)
SE/4 SE/4 Sec. 2-31S-10E
Elk County, Kansas
Longitude: 37°22.437′ (GPS)
Latitude: -96°16.532′

Topeka Limestone Formation

Iowa Point Shale Member-185 cm/73 inches

1 Shale, medium dark gray, blocky, slightly calcareous, interbedded limestone-56 cm/22 inches

2 Shale, medium light olive gray, platy, abundant forams, interbedded limestone laminations-25 cm/10 inches

3 Shale, medium dark gray, platy to fissle, slightly calcareous-15 cm/6 inches

4 Limestone, olive-gray, thin, very hard, wackestone, fossiliferous; brachoipods, fusulinids, few high spiral gastropods-2 cm/1 inches

5 Shale, light grayish-brown, abundant fossils; brachiopods (some large), fusulinids, increased limestone laminations-18 cm/7 inches

6 Limestone/shale, medium dark olive-gray, very thin layer, alternating beds-69 cm/27 inches

Curzon Limestone Member-224 cm/88 inches

7 Limestone, olive-gray, very hard to dense, wackestone and packestone, finely crystalline, brachiopods near base grading to fusulinids at top-25 cm/10 inches

8 Shale, yellowish-brown, blocky, very calcareous-5 cm/2 inches

9 Limestone, light olive-gray, dense, massive to thin bedded separated by 1-2″ shale beds, very abundant fusulinids throughout. Uppermost bed contains bryozoans, brachiopods, echinoid spines and gastropods. Weathers yellowish-brown-193 cm/76 inches

Photo 35
Location M-Intersection H99/H160.
Topeka Limestone Formation,
Iowa Point Shale Member.

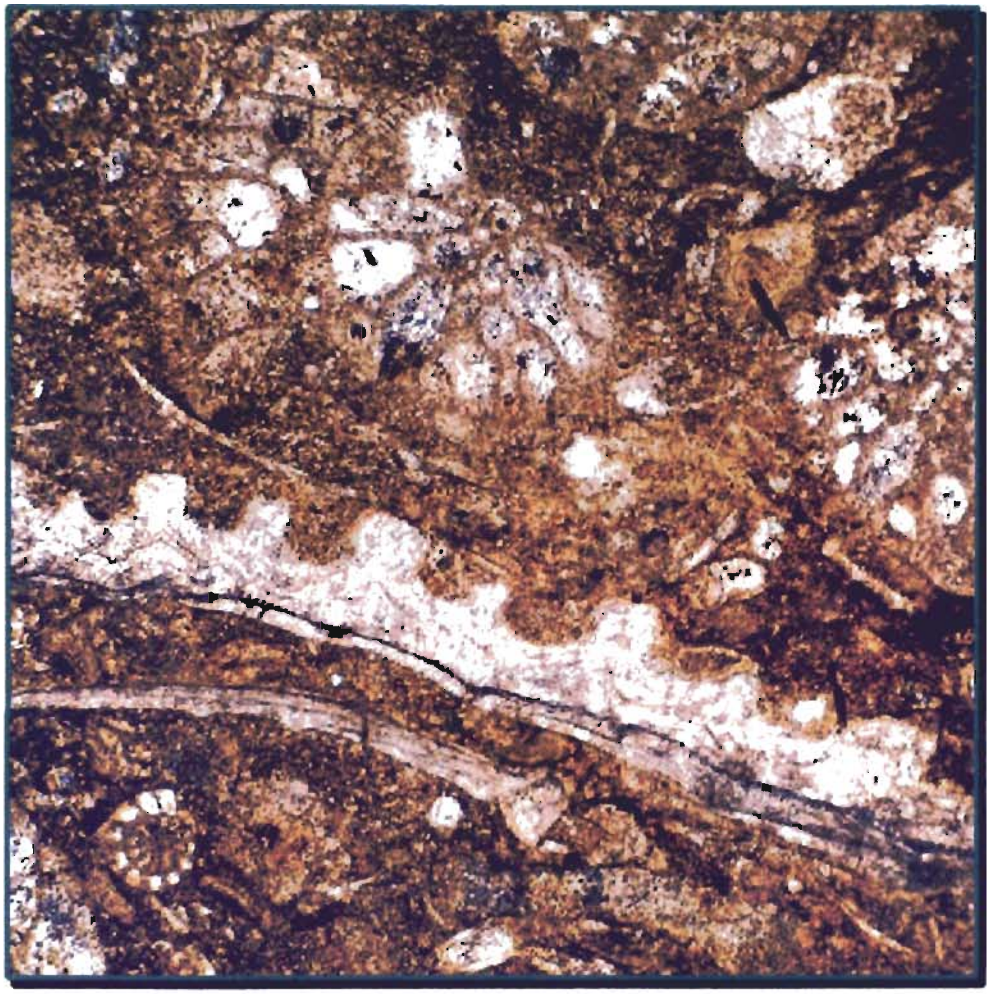

Photo 36
Location M-Intersection H99/H160.
Topeka Limestone Formation, Iowa Point Shale Member.
Thin section #M4-packstone, fossil assemblage includes
brachiopod, echinoid spine and abundant fusulinid.

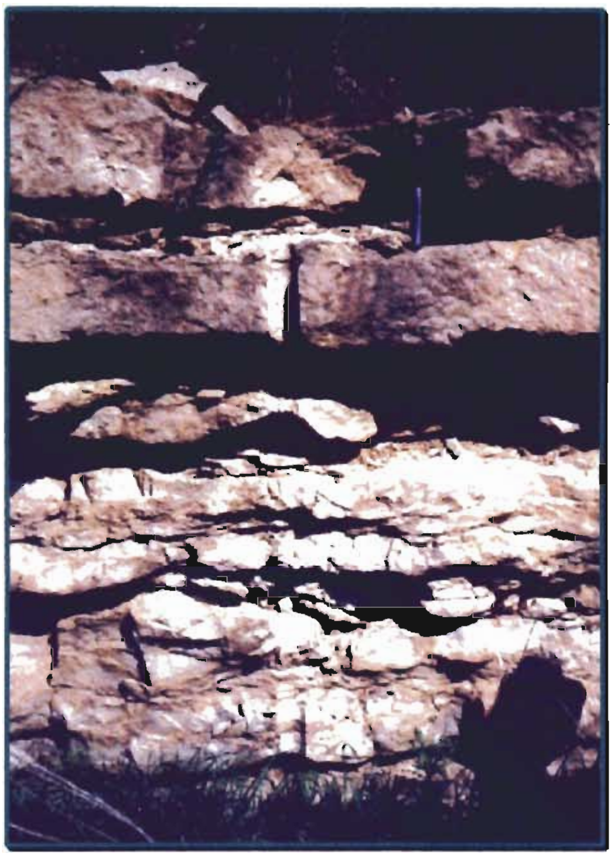

Photo 37
Location M-Intersection H99/H160.
Topeka Limestone Formation,
Curzon Limestone Member.

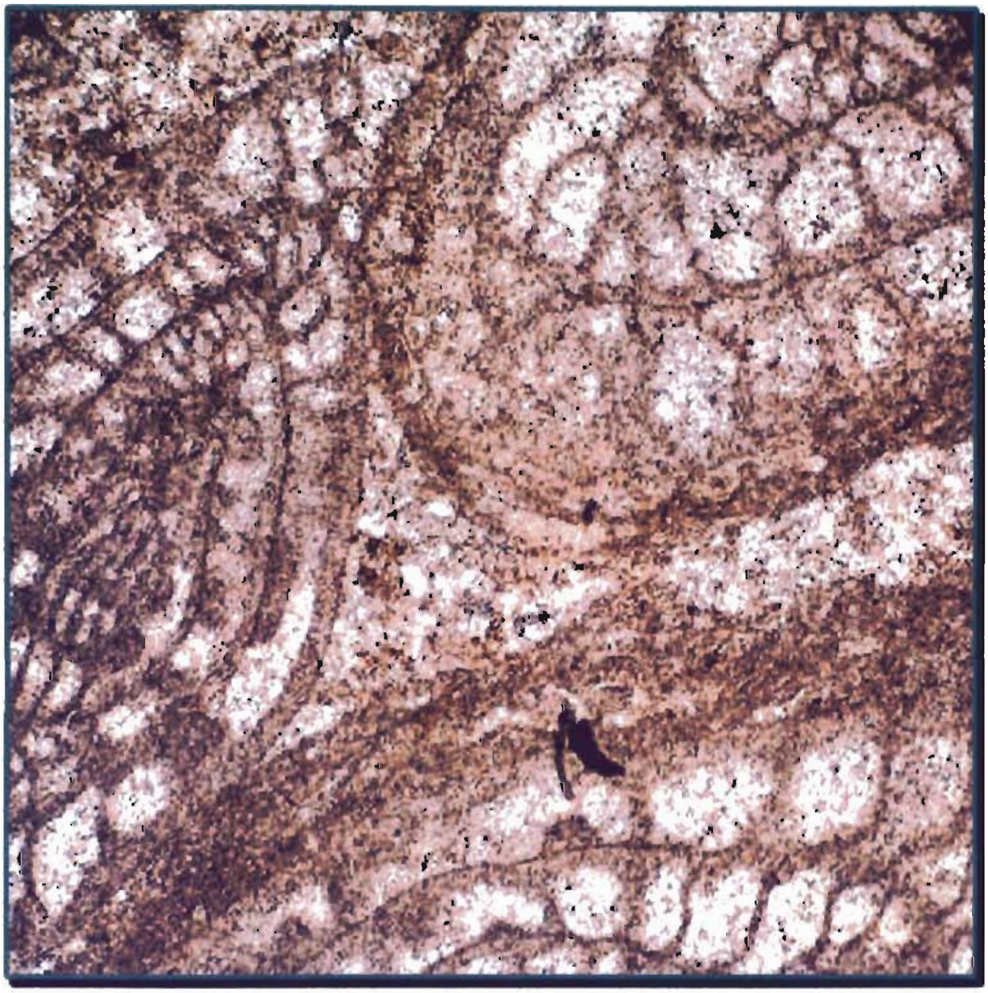

Photo 38
Location M-Intersection H99/H160.
Topeka Limestone Formation, Curzon Limestone Member.
Thin section #M7-packstone, fossil assemblage includes abundant fusulinid.

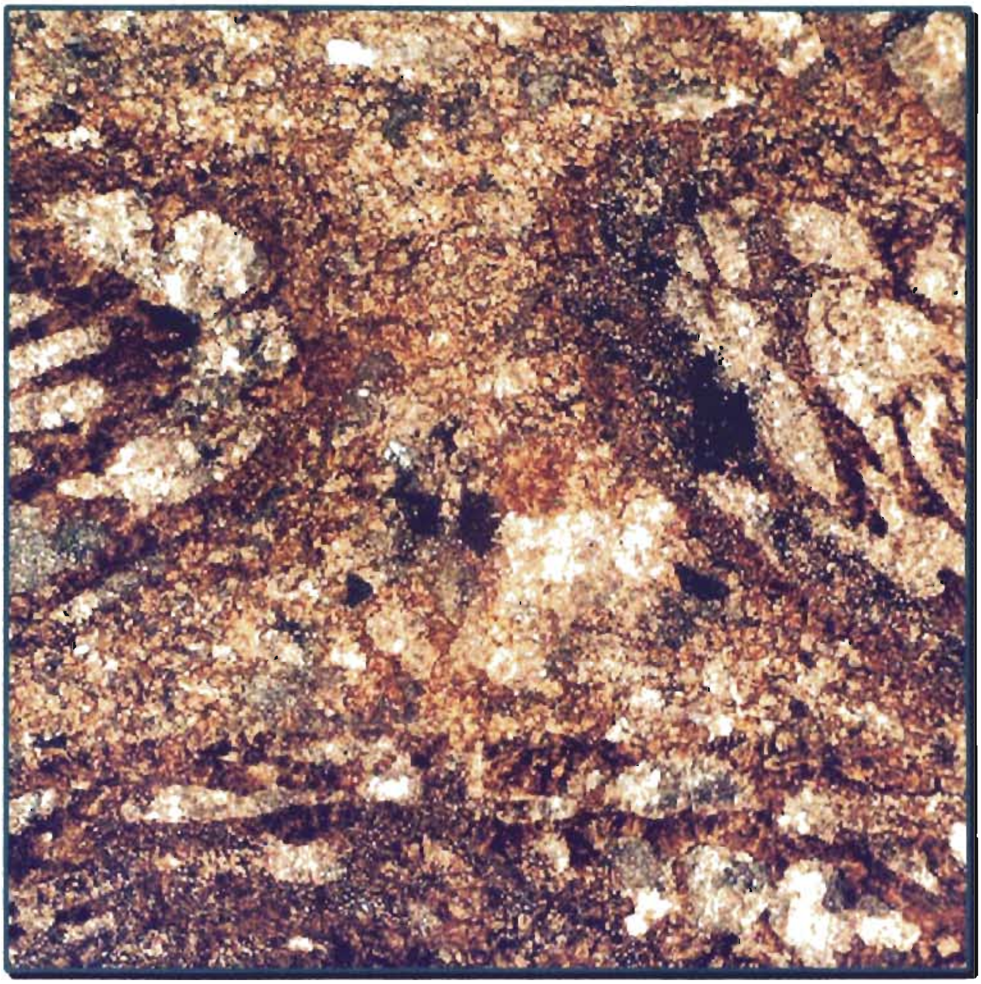

Photo 39
Location M-Intersection H99/H160.
Topeka Limestone Formation, Curzon Limestone Member.
Thin section #M8-packstone, fossil assemblage includes
brachiopod and abundant fusulinid.

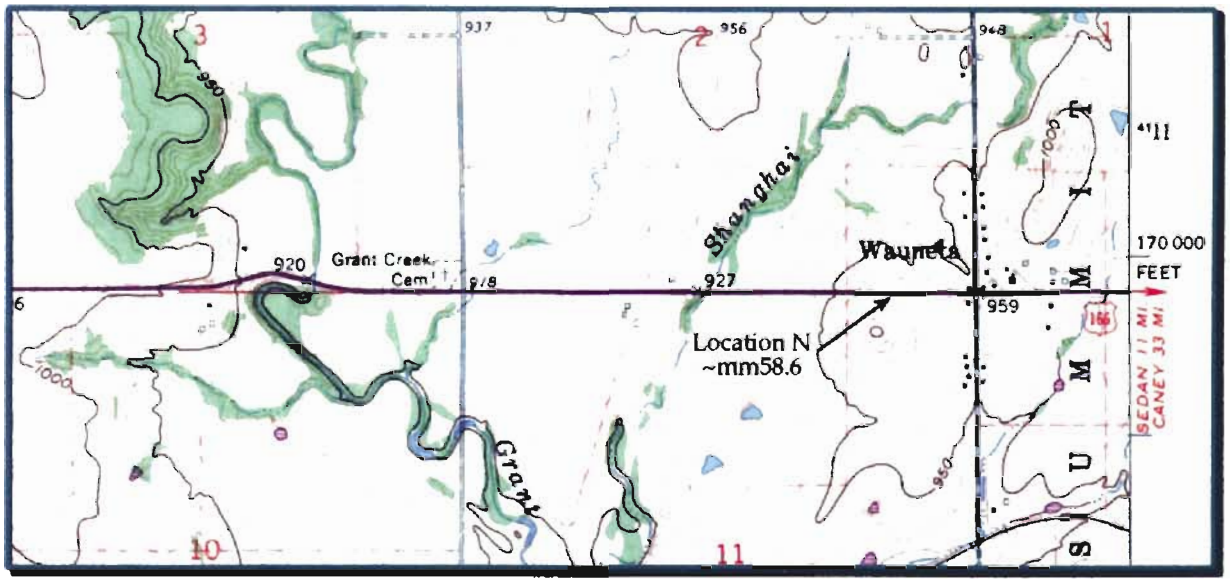

Figure 48. Map showing Location N, Topeka Limestone, H166, approximately 58.6 mile marker, Chautauqua County, Kansas.

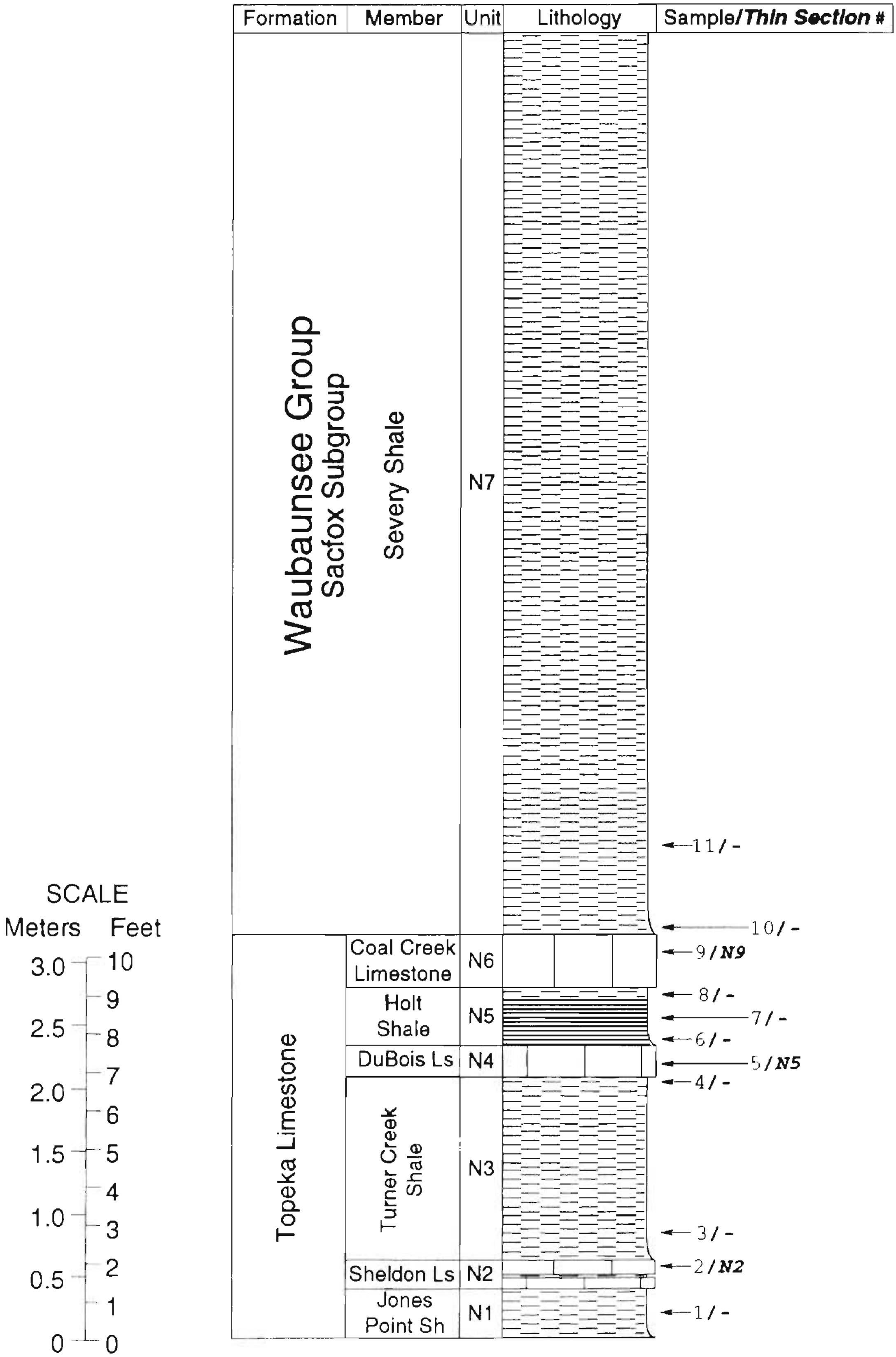

Figure 49. Measured section of location N, Highway 166, mile marker 58.8, Chautauqua County, Kansas.

Location N (Intersection H160/H99)
N/2 NE/4 Sec. 11-34S-9E
Longitude: 37°22.437' (GPS)
Latitude: -96°16.532'

Topeka Limestone Formation

Jones Point Shale Member-31 cm/12 inches

1 Shale, medium to dark gray, blocky to platy, slightly calcareous, small pelecypods

Sheldon Limestone Member-20 cm/8 inches

2 Limestone, medium light gray, wackestone, finely crystalline, thin bedded, hard to very hard, trace of carbonaceous detritus, very thin interbedded shale

Turner Creek Shale Member-130 cm/51 inches

3 Shale, medium light gray, blocky, calcareous-10 cm/4 inches

4 Shale, medium to medium dark gray, platy to fissile, calcareous, sparse very small pelecypods-120 cm/47 inches

Du Bois Limestone Member-23 cm/9 inches

5 Limestone, single bedded, dark gray, finely crystalline, hard to very hard, wackestone to packstone, small brachiopods

Holt Shale Member-43 cm/17 inches

6 Shale, black, fissile grading to platy, phosphate nodules, some conodonts, very small high spiral gastropods and small brachiopods-10 cm/4 inches

7 Grayish black, platy to fissile, small pelecypods, sparse high spiral gastropods, conodonts-18 cm/7 inches

8 Shale, light olive gray, very fine calcareous laminations with abundant fossil hash; crinoids, shell fragments grades upward to argillaceous limestone-15 cm/6 inches

Coal Creek Limestone Member-41 cm/19 inches

9 Limestone, thinly bedded, medium grayish-brown to brownish-gray, dense, wackestone to packstone, abundant fossils–41 cm/16 inches

10 Shale, medium dark gray, blocky to slightly platy, slightly calcareous, very abundant fossil hash; fusulinids, brachiopods, crinoids plates-8 cm/3 inches

<u>Waubaunsee Group</u>-*Severy Shale Formation*-927 cm/365 inches

11 Shale-lowermost 10 cm, very dark gray, platy, very fossiliferous; ostracods, echinoids, sharp contact between 10/11. Shale becomes lighter in color with increasing silt content.

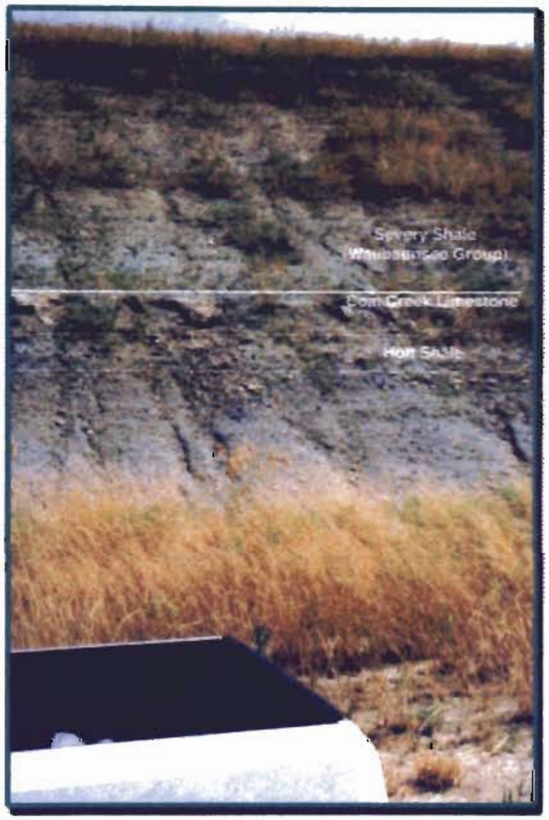

Photo 40
Location N--~mile marker 59 H160.
Topeka Limestone Formation.

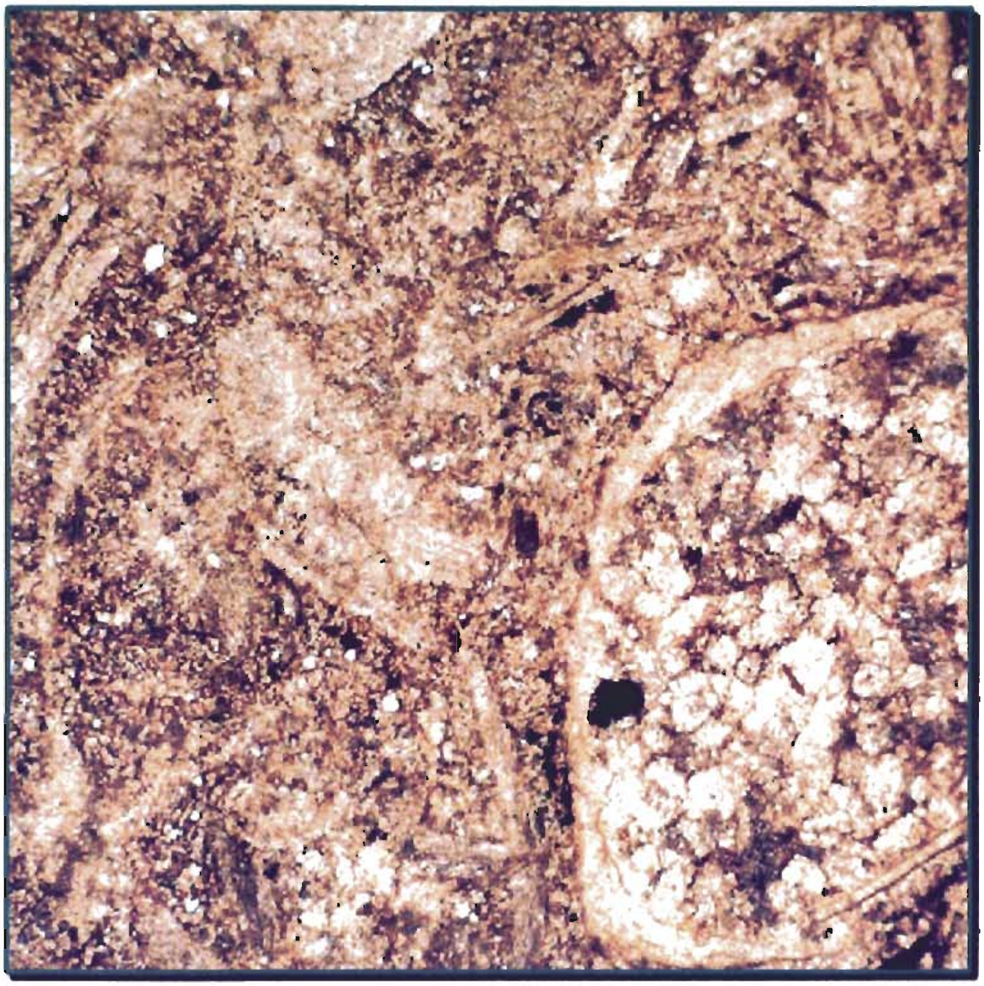

Photo 41
Location N--~mile marker 59 H166.
Topeka Limestone Formation, DuBois Limestone Member.
Thin section #N5-wackestone to packstone, fossil assemblage includes brachiopod and foraminifera

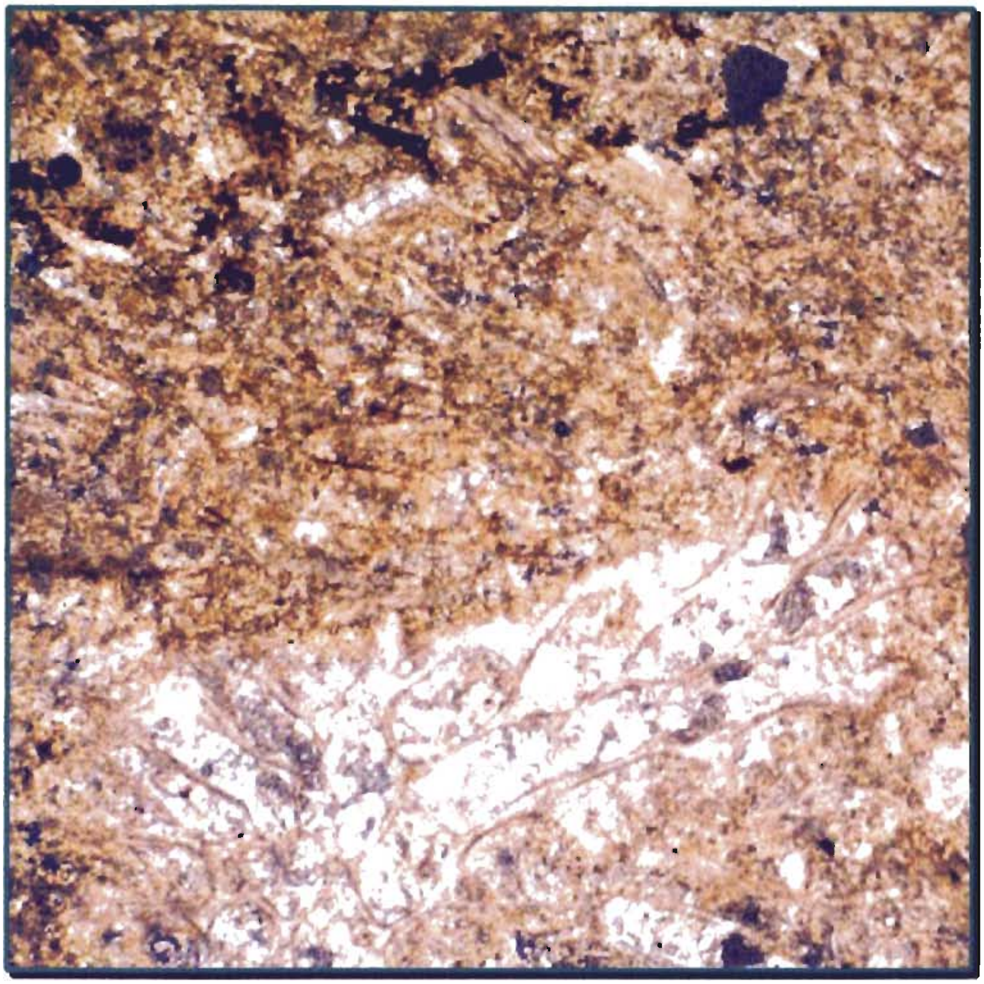

Photo 42
Location N-~mile marker 59 H166.
Topeka Limestone Formation, Coal Creek Limestone Member.
Thin section #N9-wackestone to packstone, fossil assemblage includes oncoids and foraminifera

VITA

Mark William Bryan

Candidate for the Degree of

Masters of Science

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Experience: Employed as a field geologist for private petroleum geology consulting firm. Formed partnership, Geo-Logic Consultants, with former employer and acted as manager and geologist from 1982 to 1988. Employed as petroleum geologist for independent oil in Enid, Oklahoma 1988 to present.

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