THE SEQUENCE STRATIGRAPHY OF THE UPPER COUNCIL GROVE GROUP (PERMIAN) FROM THE NORTH AMERICAN MIDCONTINENT

By

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Bachelor of Science

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Ypsilanti, Michigan

1995

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
May, 1998

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ACKNOWLEDGMENT

I would like to express my sincere gratitude to my thesis advisor Dr. Darwin Boardman for his patience, his support, his thoughtful recommendations, and his encouragement throughout the development of this thesis. Thanks also to the rest of my committee: Dr. Zuhair Al-Shaieb and Dr. Gary Stewart for their inspiration and valuable suggestions.

I would like thank my family for their unfailing support. I wish to sincerely thank Dr. Puckette, Syed Y. Mehdi, Harry Delong, Tom Marshall, and Joseph Hall for their technical support as well as their friendship throughout my research.

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INTRODUCTION

Purpose

The purpose of this study is to develop a sequence stratigraphic framework for the Beattie Limestone through the Speiser Shale (Upper Council Grove Group) (Figure 1).

Stratigraphic Scope and Location

Stratigraphic scope of this study includes the Beattie Limestone through the Speiser Shale, upper Council Grove Group, Upper Asselian to Lower Sakmarian (Figure 1). This stratigraphic interval contains four shale formations and four limestone formations. The shale formations are the Stearns Shale, Easly Creek Shale, Blue Rapids Shale, and Speiser Shale. The limestone formations are the Beattie Limestone, Bader Limestone, Crouse Limestone, and Funston Limestone.

The area of this investigation includes parts of southern Kansas (Cowley County), Central Kansas (Chase County), and Northern Kansas (Riley County) (Figure 2).
Locations of outcrops are as follows:

Northern Kansas(NK):

Outcrop A (NK #1, Anderson Road Section), W/2, Section 10, T10S, R7E, Keats 7.5' Quadrangle, Riley County, Kansas (Figure 3).

Scope of Study Section

SYSTEM		SERIES	STAGE	GROUP
PERMIAN		GUADALUPIAN		
		LEONARDIAN		
		WOLFCAMPIAN	ARTINSKIAN	CHASE
			SAKMARIAN	
			ASSELIAN	COUNCIL GROVE
				ADMIRE
CARBONIFEROUS	PENNSYLVANIAN	UPPER	VIRGILIAN	WABAUNSEE
				SHAWNEE
				DOUGLAS
			MISSOURIAN	LANSING-KANSAS CITY
		MIDDLE	DESMOINESIAN	MARMATON
				CABANISS
				KREBS
			ATOKAN	
		LOWER	MORROWAN	

STUDY SECTION	
FORMATION	
SPEISER SH.	
FUNSTON LS.	
BLUE RAPIDS SH.	
CROUSE LS.	
EASLY CREEK SH.	
BADER LS.	MIDDLEBURG LS.
	HOOSER SH.
	EISS LS.
STEARNS SH.	
BEATTIE LS.	MORRILL LS.
	FLORENA SH.
	COTTONWOOD LS.
ESKRIDGE SH.	
GRENOLA LS.	
ROCA SH.	
RED EAGLE LS.	
JOHNSON SH.	
FORAKER LS.	

Figure 1. Classification of the parts of Upper Pennsylvanian and Lower Permian rocks in Kansas.

Outcrop B (NK#2, Scenic Drive Section), NW/4, Section 22, NE/4 Section 21, T10S, R7E, Keats 7.5' Quadrangle, Riley County, Kansas (Figure 3).

Central Kansas (CK):

Outcrop A (CK #1 Section), SE/4, SW/4, NW/4, Section 26, T19S, R7E, Elmdale 7.5' Quadrangle, Chase County, Kansas (Figure 4).

Outcrop B (CK #2 Section), NE/4 of Section 30, T19S, R8E, Cottonwood Falls 7.5' Quadrangle, Chase County, Kansas (Figure 5).

Outcrop C (CK #3 Section), S/2, NW/4, Section 17, T17S, R8E, Strong City 7.5' Quadrangle, Chase County, Kansas (Figure 6).

Outcrop D (CK #4 Section), c/EL Section 31, T18S, R8E, Strong City 7.5' Quadrangle, Chase County, Kansas (Figure 7).

Outcrop E (CK #5 Section), NW/4, Section 20, T18S, R8E, Strong City 7.5' Quadrangle, Chase County, Kansas (Figure 8).

Outcrop F (CK #6 Section), S/2, NE/4, Section 16, T17S, R8E, Strong City 7.5' Quadrangle, Chase County, Kansas (Figure 6).

Southern Kansas (SK) :

Outcrop A (Railroad Track Section), SE/4, SW/4, SW/4, Section 4, T31S, R8E, Grand Summit and Cambridge 7,5' Quadrangles, Cowley County, Kansas (Figure 9).

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Outcrop E (K 166-3), C/N2, Section 12, T34S, R6E, Dexter SW 7.5' Quadrangle, Cowley County, Kansas (Figure 13).

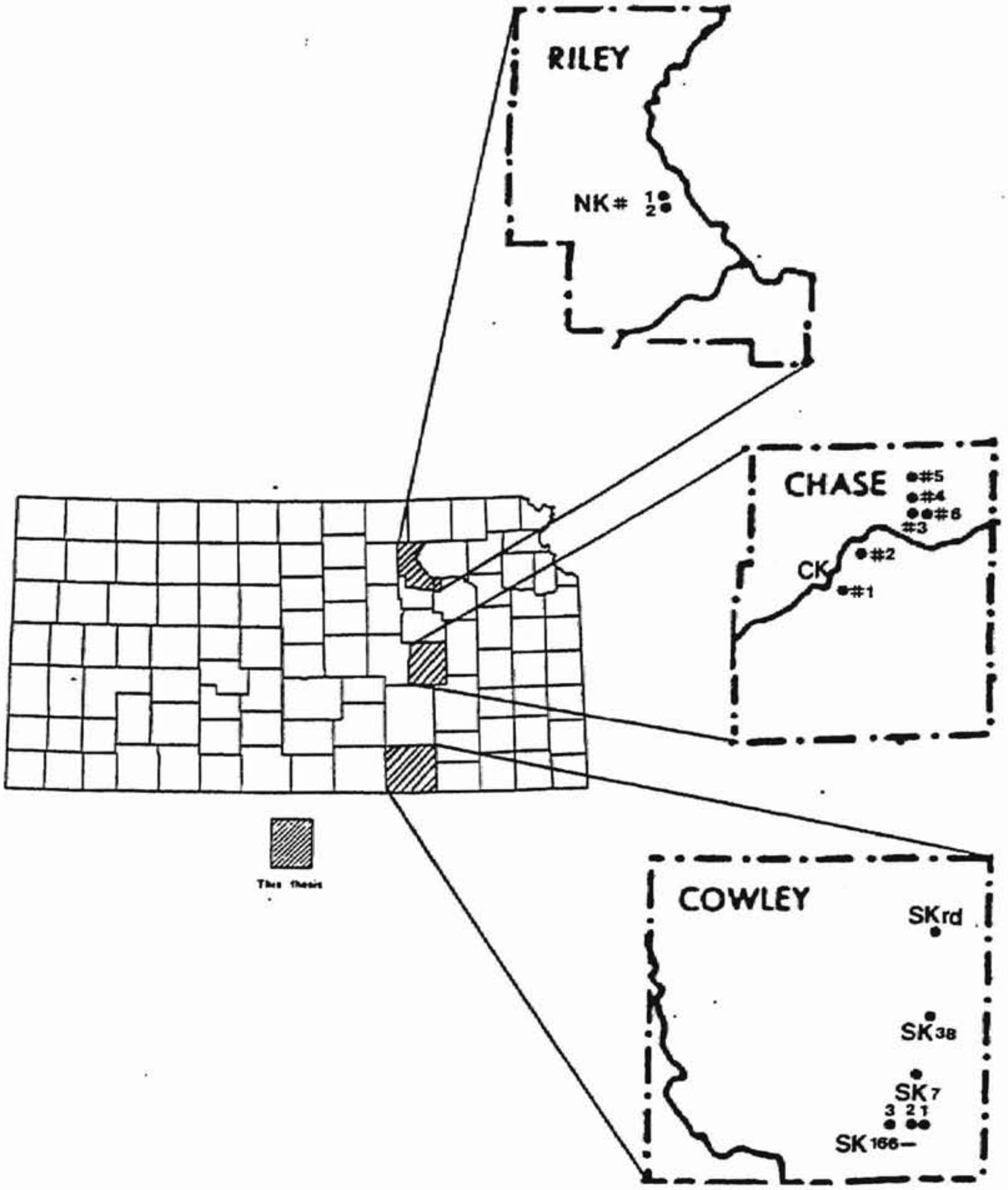
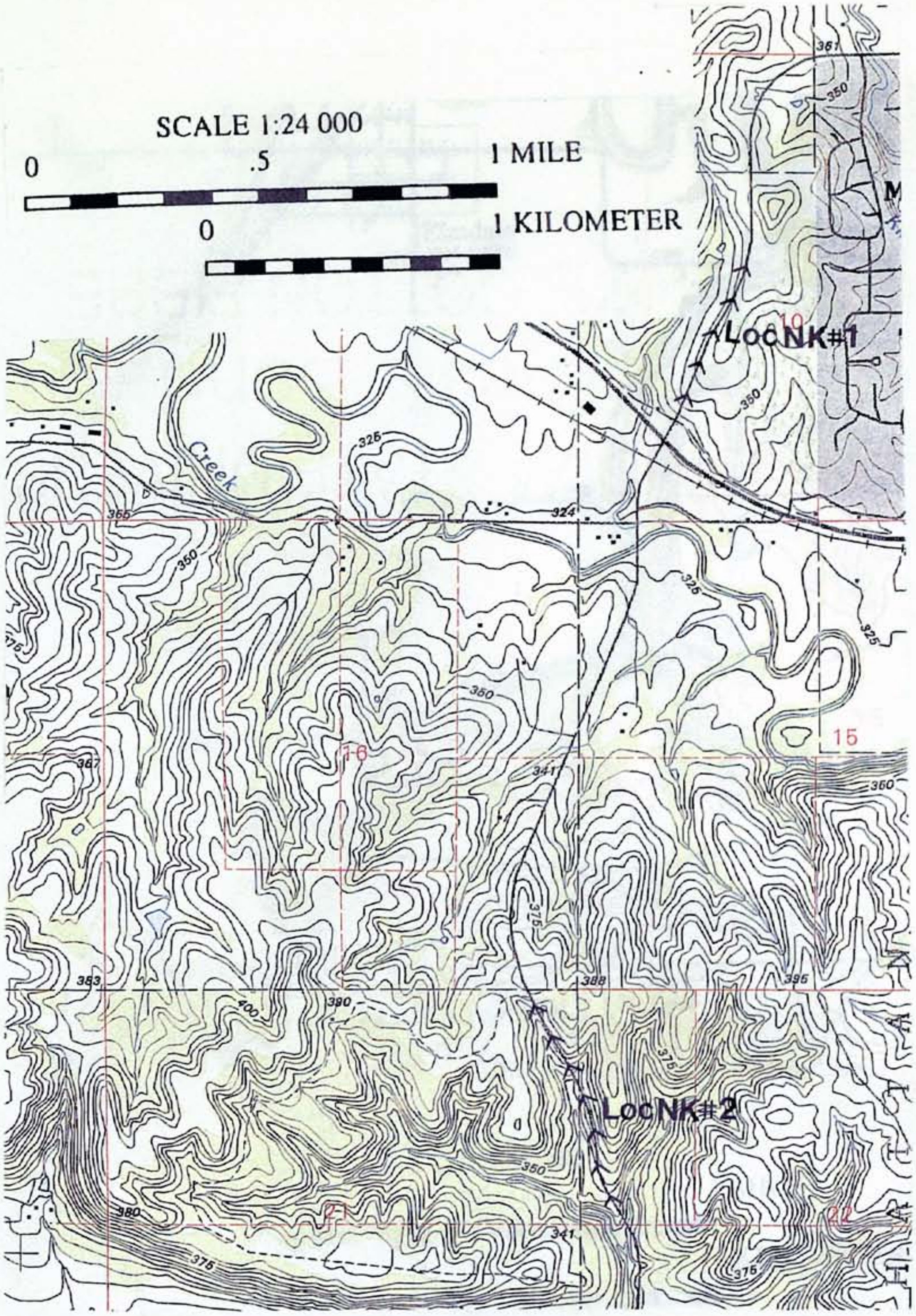


Figure 2 Index map showing the area of this investigation.
NK (Riley County), CK (Chase County), and SK (Cowley County).



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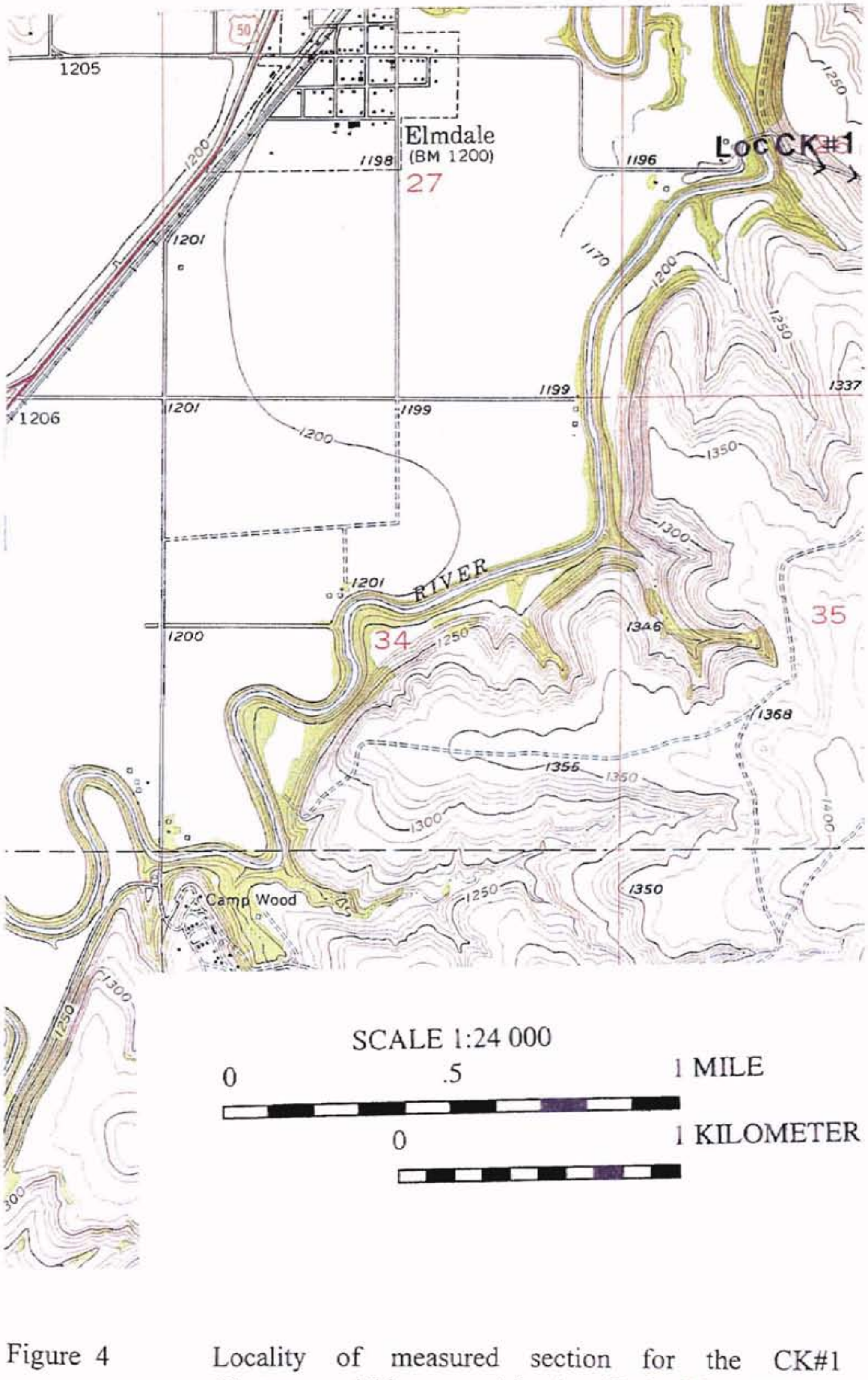
NW/4, Section 22, NE/4, Section 21, T10S, R7E, Keats 7.5' Quadrangle, Riley County, Kansas.



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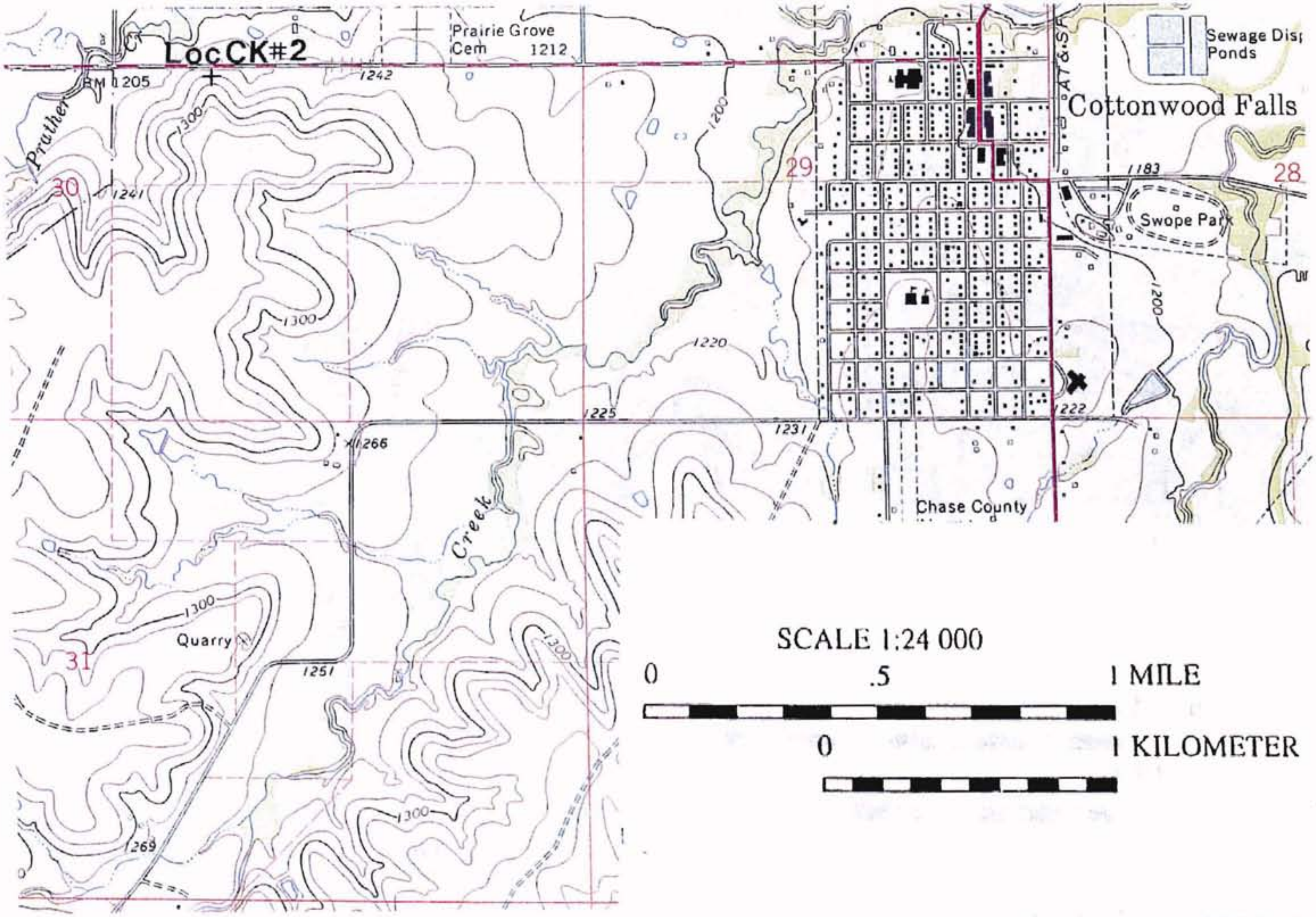

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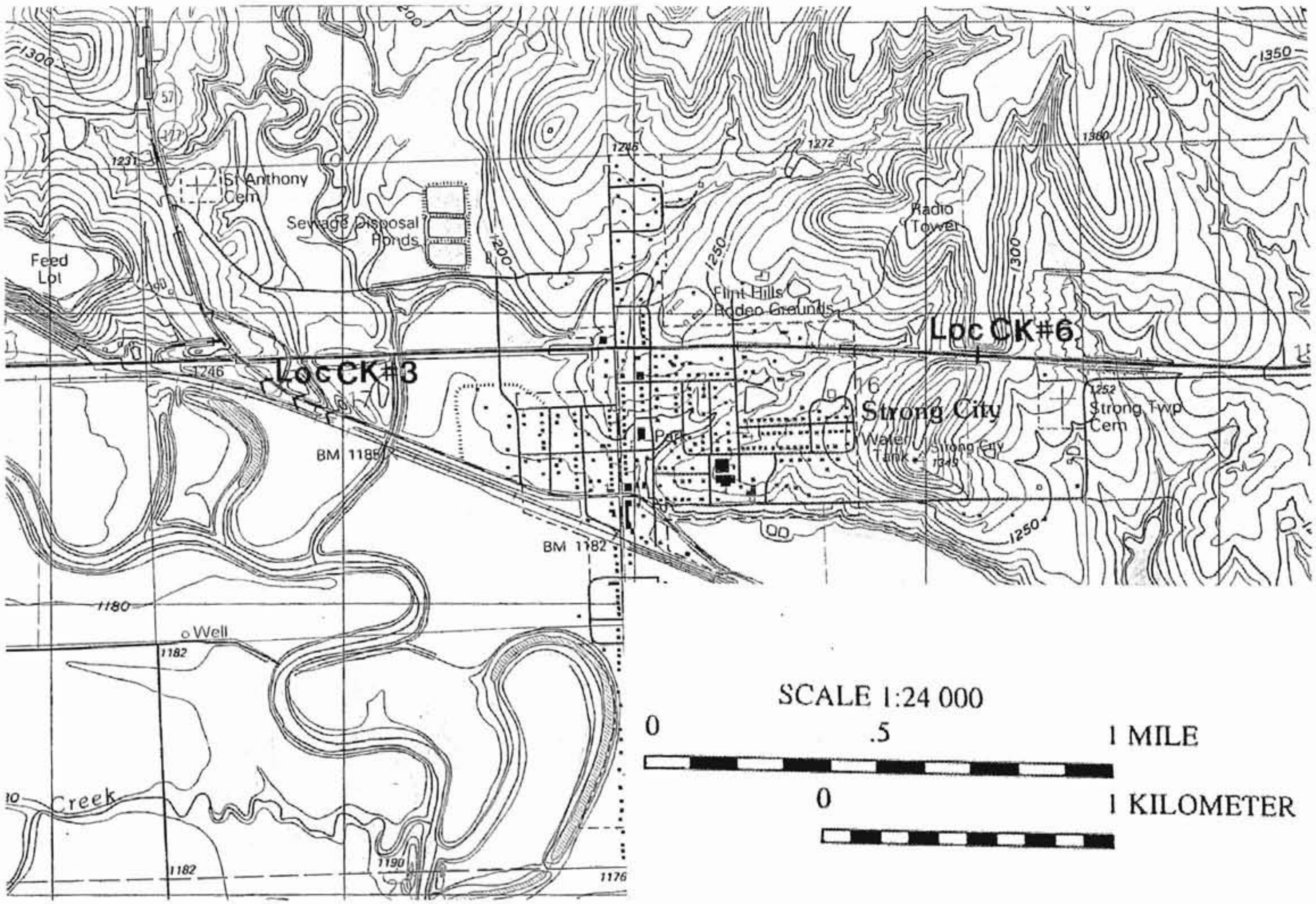
NE/4 of Section 30, T19S, R8E, Cottonwood Falls 7.5' Quadrangle, Chase County, Kansas.



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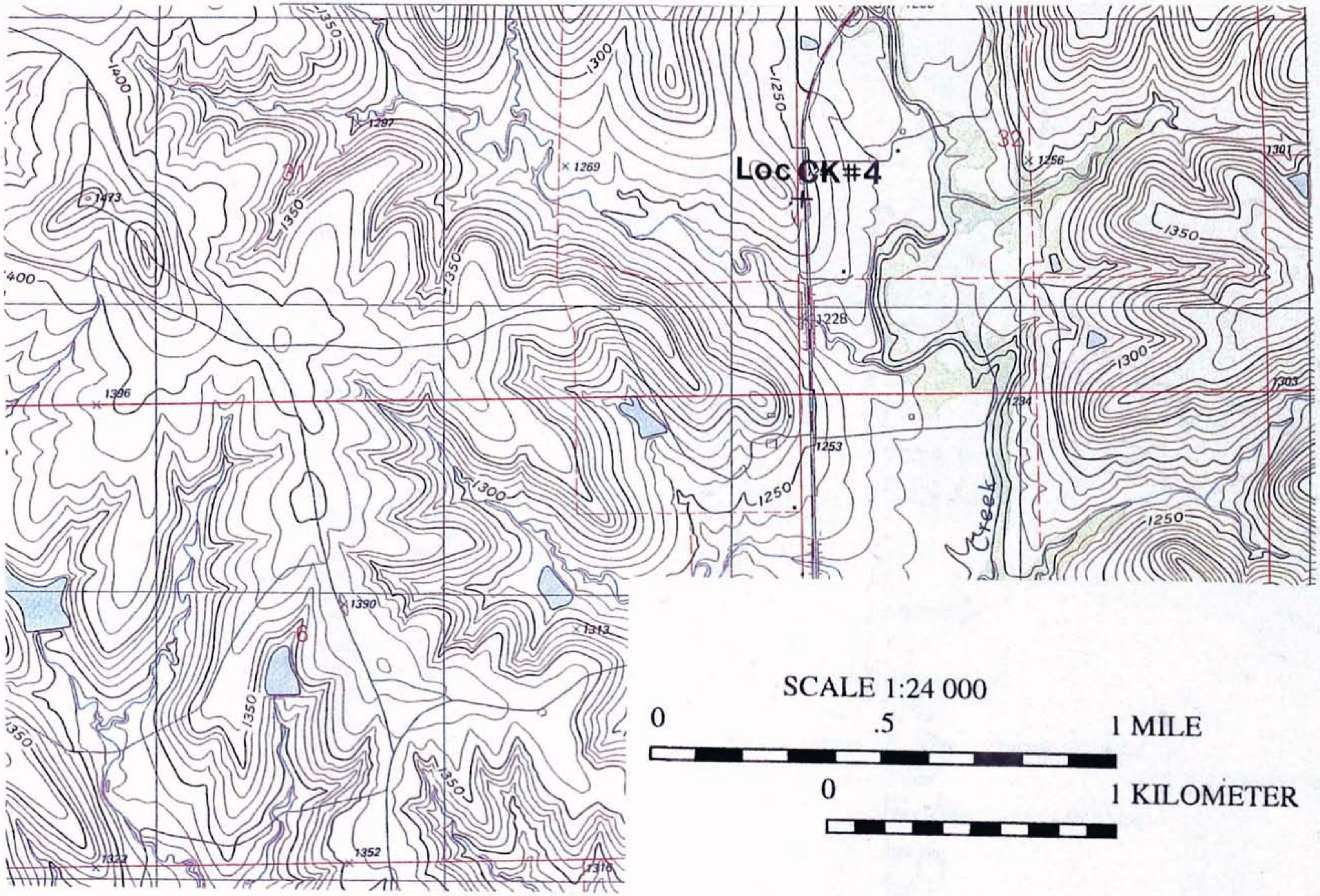
S/2, NE/4, Section 16, T17, R8E, Strong City 7.5' Quadrangle, Chase County, Kansas



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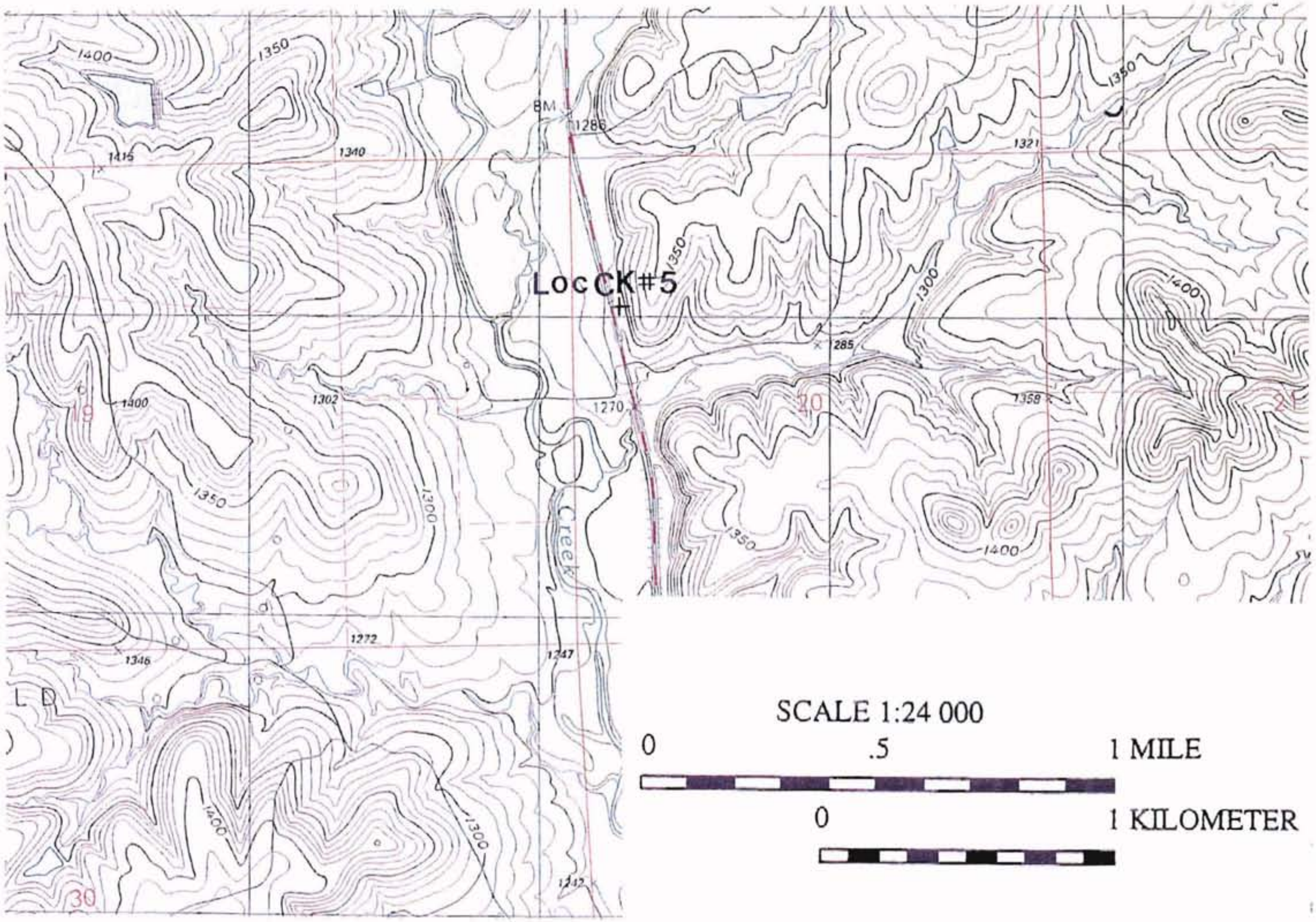

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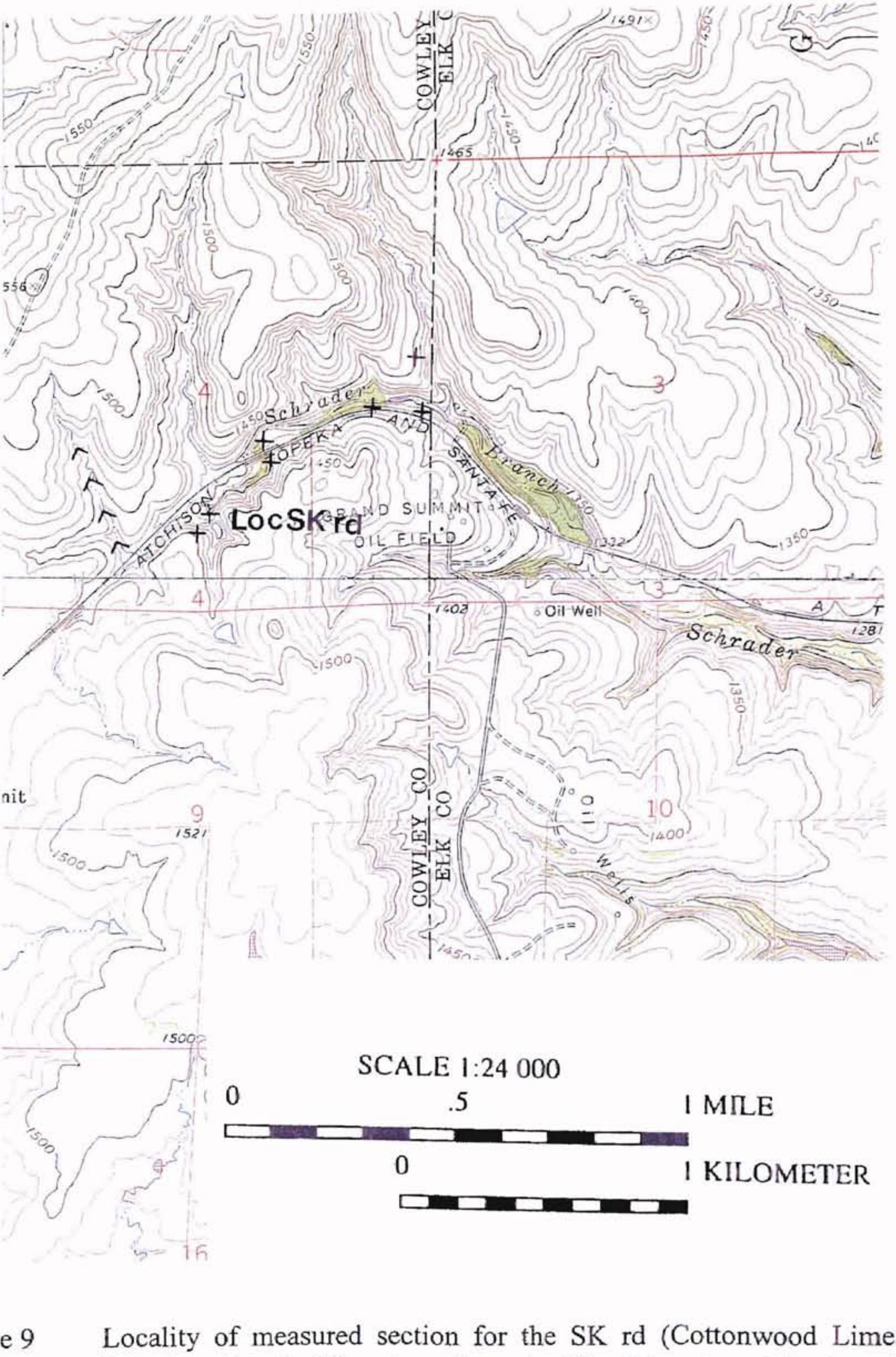

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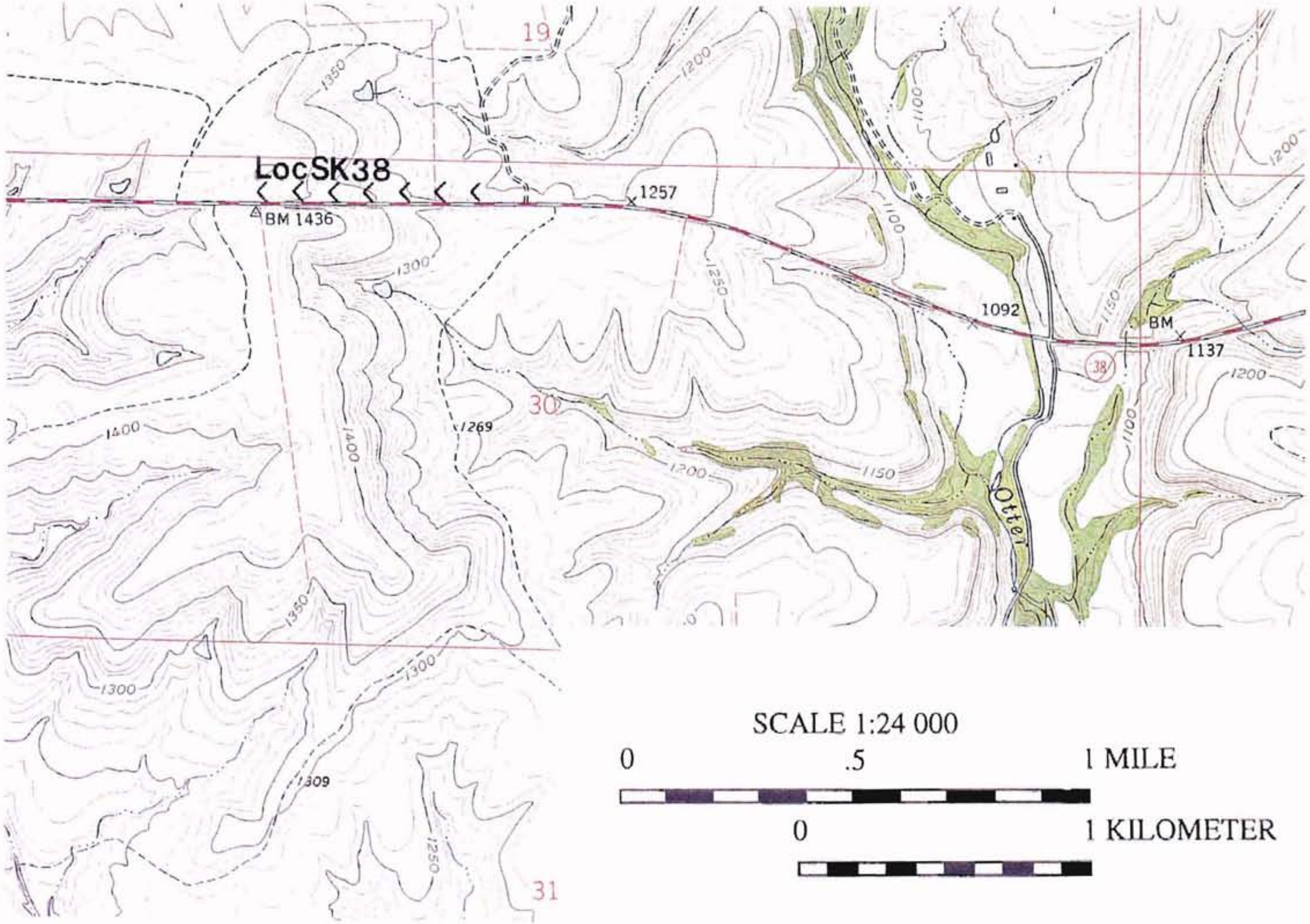
SE/4, SW/4, SW/4, Section 4, T31S, R8E, Grand Summit and Cambridge NE 7.5' Quadrangles Cowley County, Kansas.



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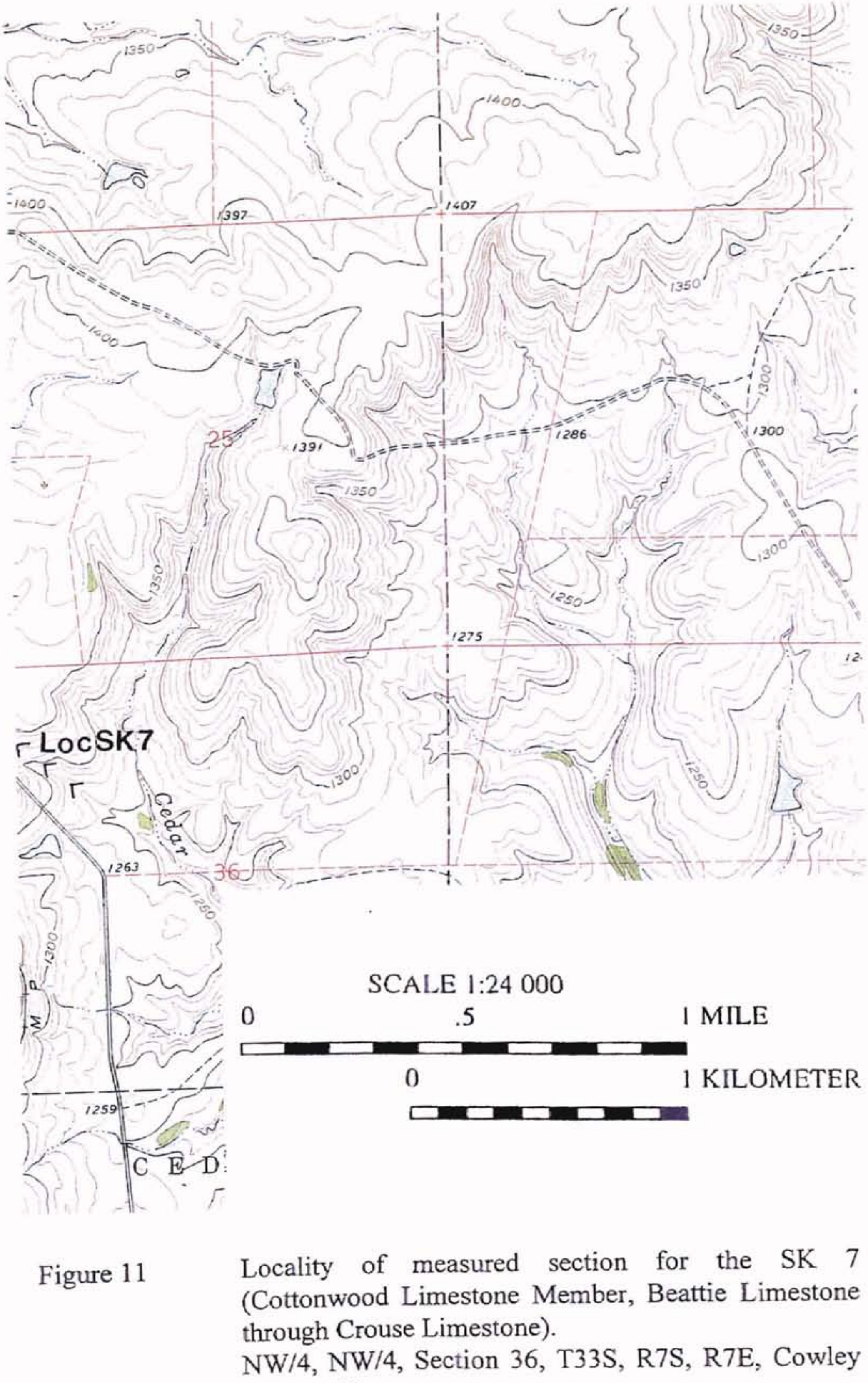

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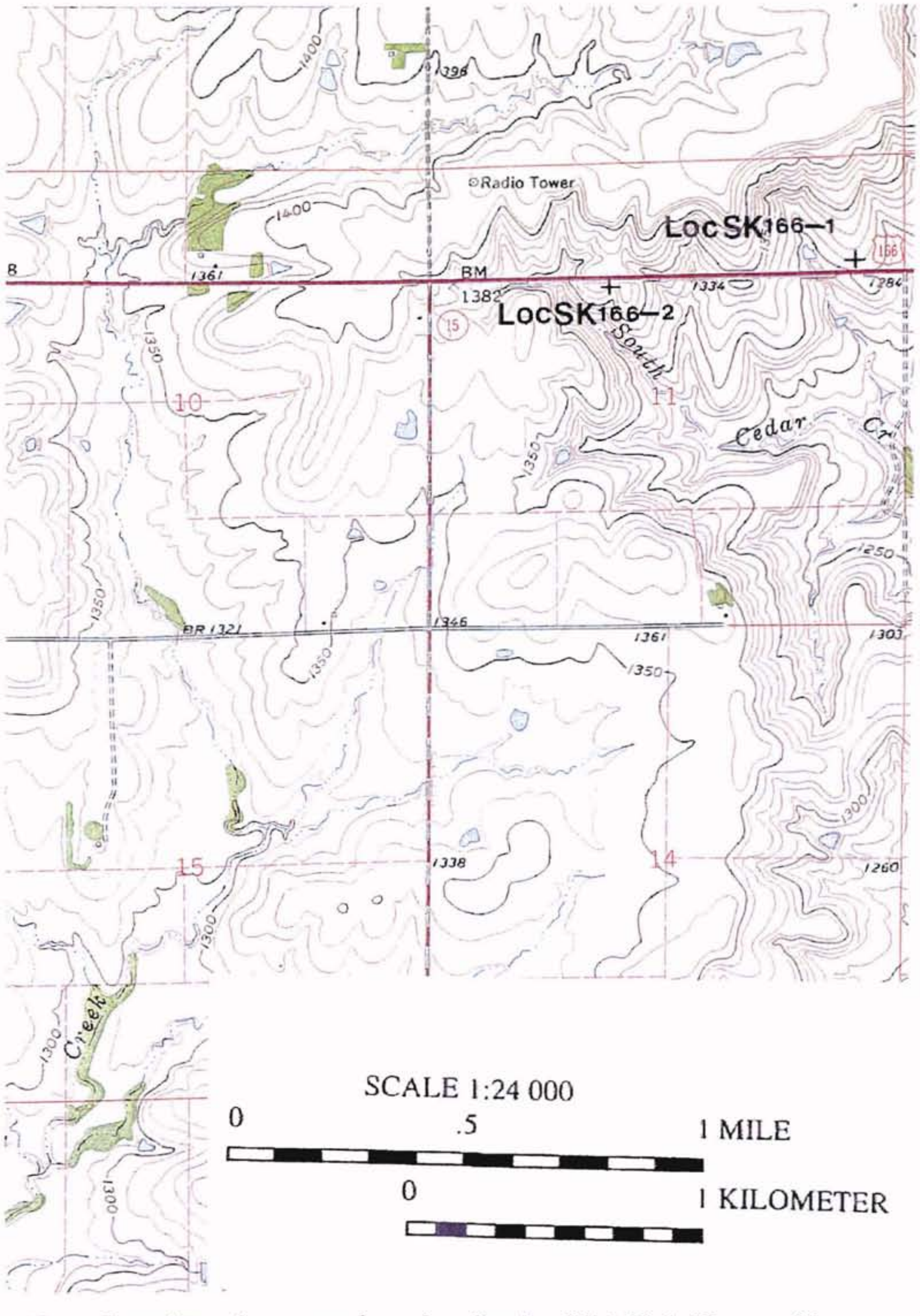

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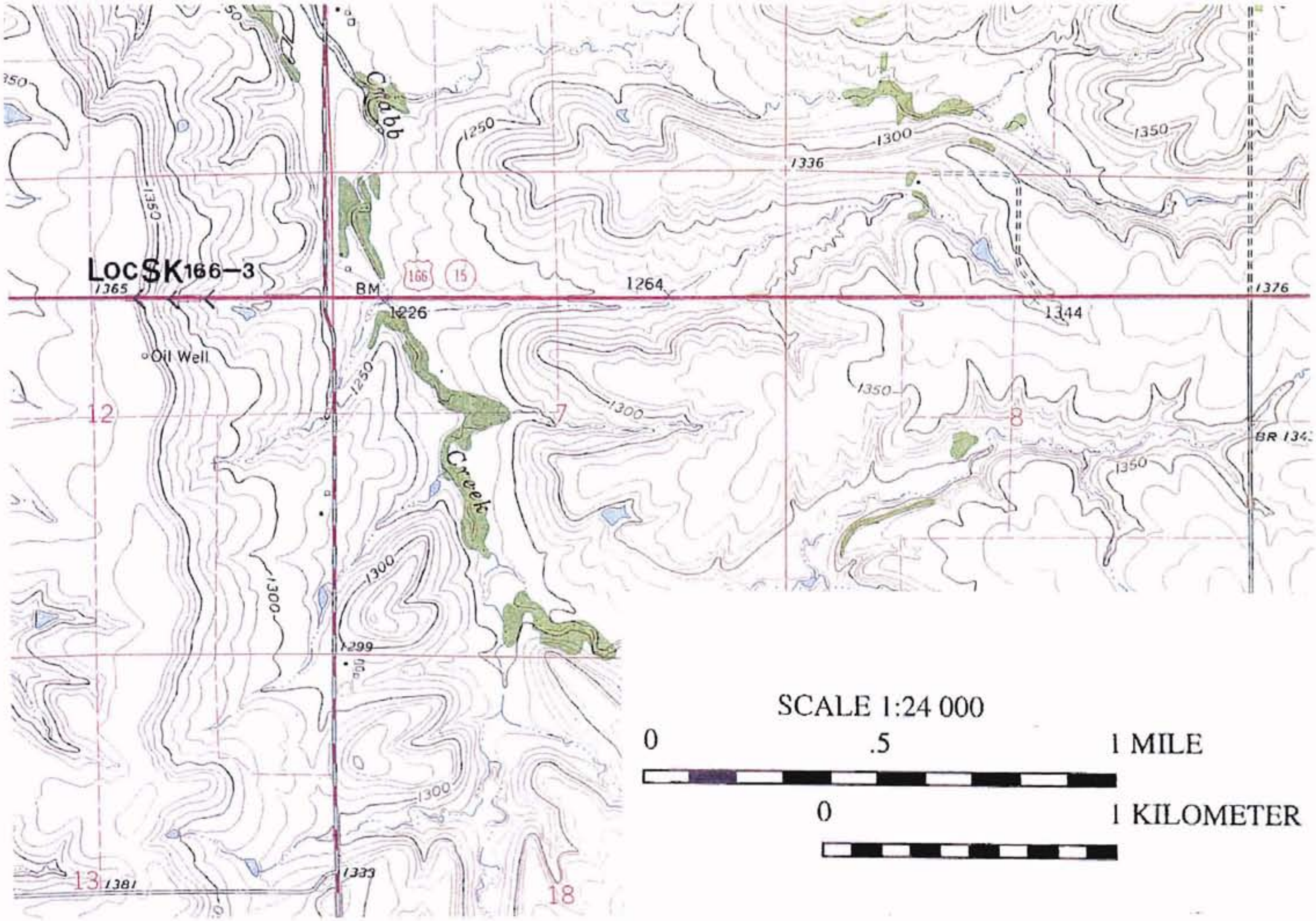
NW/4, Section 11, T34S, R7E, Dexter SW 7.5' Quadrangle, Cowley County, Kansas.



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Methodology

In order to construct a sequence stratigraphic relationship of the upper Council Grove Group, data about the lithology and the content of microfauna are required. These data are a result of examination of exposed outcrops and analysis of samples taken from those outcrops. A total of fourteen units have been measured and described from southern Kansas to northern Kansas. A total of 700 samples were collected from exposed outcrops for lab analysis. Samples mainly consist of shale or limestone.

For the shale, analysis consisted of physical description of shale color and lithic character as well as processing for analysis of microfauna. First, description of the color of shale samples were obtained by comparison with the G.S.A. Rock Color Chart (7th printing, 1991). The lithic character of the shale was described as silty or calcareous and fissile, blocky, or crumbly. Second, some important samples of shale were processed with kerosene and sieved for recovery of microfauna.

For the limestone, the lab analysis consisted of two steps; First the making of thin sections from samples, second, description microfauna and classification from analysis of thin sections. Billets from limestone samples were cut for making of thin sections. Four hundred fifty thin sections were made for this study. Each thin section was analyzed under an optical petrographic microscope for microfaunal content and classified according to Dunham's carbonate classification system (Dunham, 1962).

All available data have been compiled to construct a lithostratigraphic profile. According to the lithostratigraphic profile, complete stratigraphic sequences, including the maximum flooding surfaces and transgressive surfaces, can be interpreted to produce a sea-level fluctuation curve and to construct more completely the sequence stratigraphy of the upper Council Grove Group.

Geologic setting

The formations of this study from the Beattie Limestone through Speiser Shale (upper Council Grove Group) were deposited in the epeiric sea of the Mid-Continent U.S. during Early Permian time (Figure 14). Sedimentation patterns, vertical cyclic deposits and lateral variation of the upper Council Grove Group, were primarily controlled by tectonic structure and by eustatic rises and falls of sea level.

The tectonic fabric of the study area which affected lateral variation of the lithofacies and thickness patterns of Lower Permian rocks consists of several major structural features: Nemaha Anticline, Abilene Anticline, Irving Syncline, Cherokee Basin, and Forest City Basin (Figure 15). These structures were formed by the collision of the North American and South American plates in the middle Pennsylvanian (Rascoe et al. 1983). The structural features controlled the sources of siliciclastic detritus, resulting in lateral variation in lithofacies and thickness of these strata. For example, the Speiser Shale is interbedded with red channel-fill sandstone deposits in southern Kansas and southern Nebraska but not in central Kansas. This indicates that siliciclastic sources are nearer both the regions of southern Kansas and Nebraska than the region of central Kansas (Newton 1971). This suggests that the major sources of siliciclastics could be from both Ozark Uplift to the southern Kansas and Bourbon Arch and Nemaha to

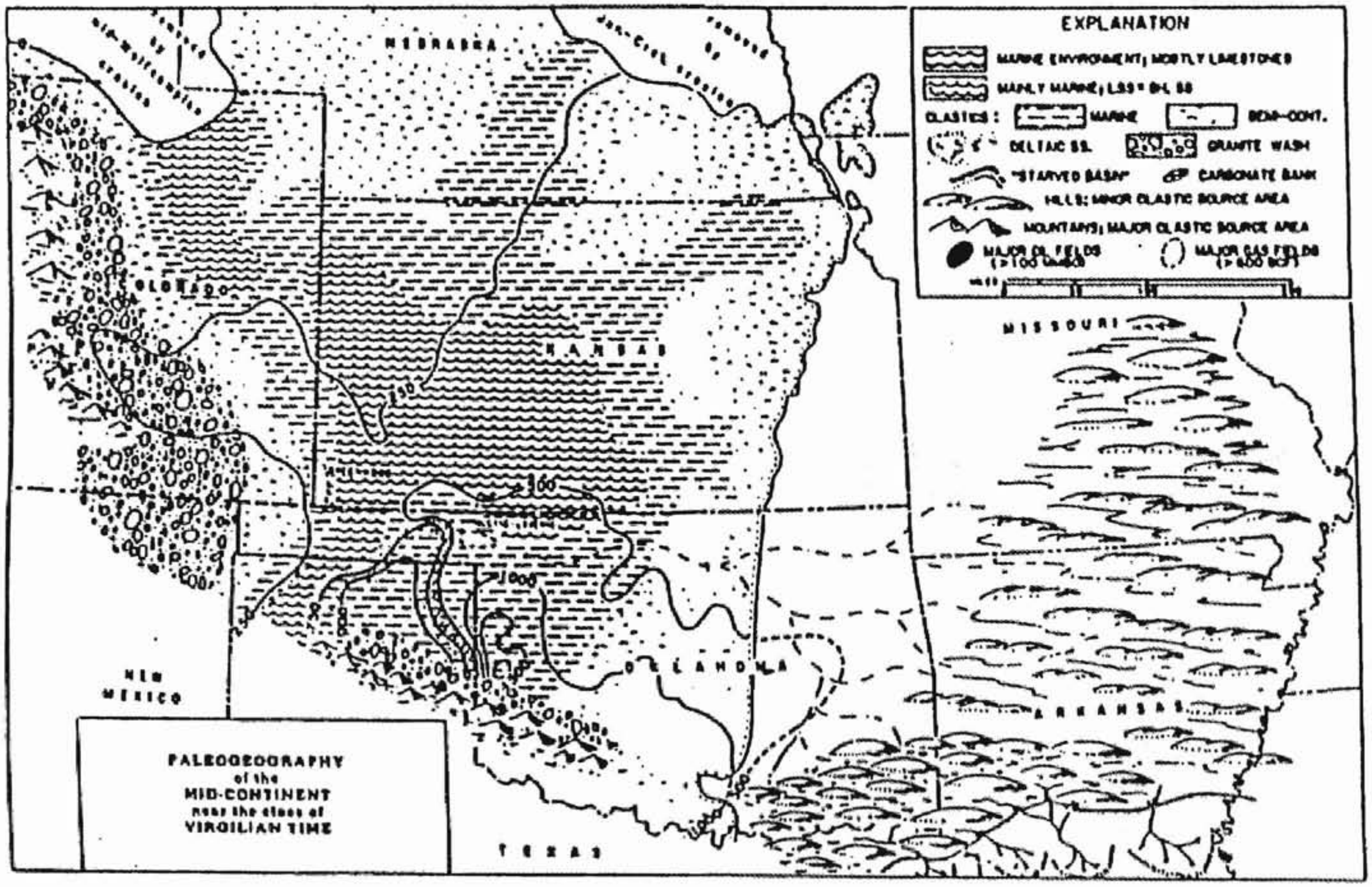


Figure 14 Paleogeography of the Mid-Continent near the close of Virgillian time. (Rascoe et al. 1983).

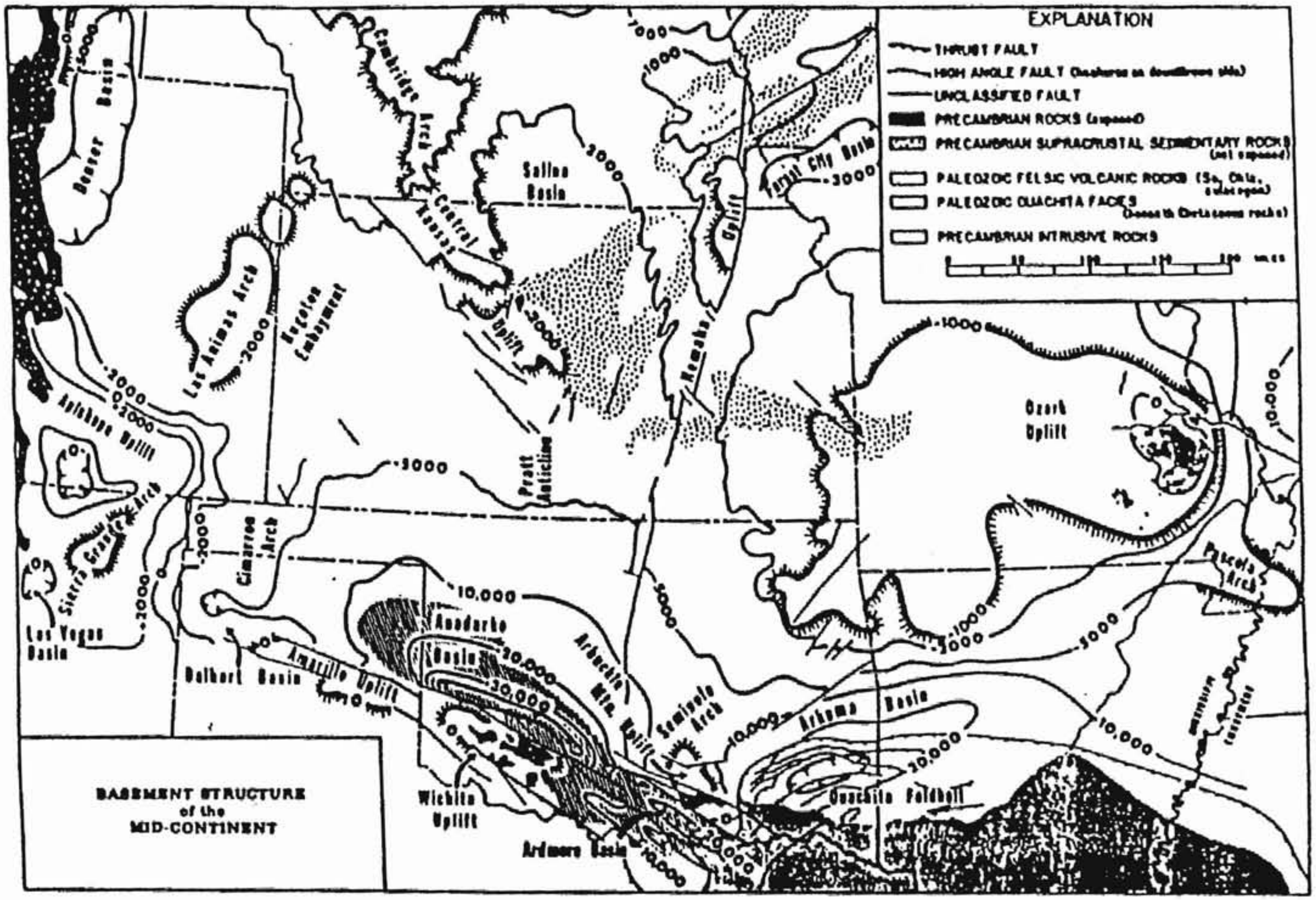


Figure 15 Basement Structure of the Mid-Continent (Rascoe et al. 1983).

southern Nebraska. The lateral variation in lithofacies and thickness pattern of lower Permian clearly was controlled by regional tectonism.

The formations of this study generally consists of alternating shales and limestone; in depositional cycles. Moore (1936, 1949) regarded couplets of successive shale and limestone formations as "cyclothems" and recognized that sequences of distinctive shale-limestone-formation couplets are repeated upward in several different limestone formations to produce cycles of cyclothems. Wanless and Shepard (1936) explained that this was because of sea-level rising and falling. The eustatic rises and falls of sea level during the Permian were controlled by glaciation related to change of climate (Wanless and Shepard, 1936). If this is true it seems that the vertically repeating pattern of lithology in this study interval indicates climates changed in cycles during deposition of the upper Council Grove Group.

Therefore, the depositional lithologic pattern of verticality and laterality in Council Grove Group commonly indicates the complication of structural features (Rascoe et al. 1983) and fluctuations of the eustatic level (Moore, 1936, 1949 and Wanless and Shepard, 1936).

Cyclothem Concepts

The cycles of deposition were first observed from Pennsylvanian strata in Peoria, district, Illinois by Udden (1912, p. 27). He stated that each cycle is comprised of "four successive stages, namely: (1) accumulation of vegetation; (2) deposition of calcareous material; (3) sand importation; and (4) aggradation to sea level and soil making" (1912, p. 48). The first stage, accumulation of vegetation, mainly is presented by a coal bed (Figure 16). The second stage, deposition of calcareous material, consists of calcareous mineral that probably is diversely fossiliferous. The third stage, sand importation, is represented by predominantly the thickness of sandstones. The fourth stage, aggradation to sea level and soil making, represents accumulation of clay and silt to form shales, underclays, and soils. Weller (1930) divided the Pennsylvanian strata of western Illinois into cycles. Each cycle consists mainly of two stages; continental and marine. Weller (1930, p. 102) described a detailed Pennsylvanian cycle composed of the following members:

Marine 8. Shale, containing "ironstone" bands in upper part and thin
    limestone layers in lower part
  7. Limestone
  6. Calcareous shale
  5. Black "fissile" shale

Continental

  4. Coal

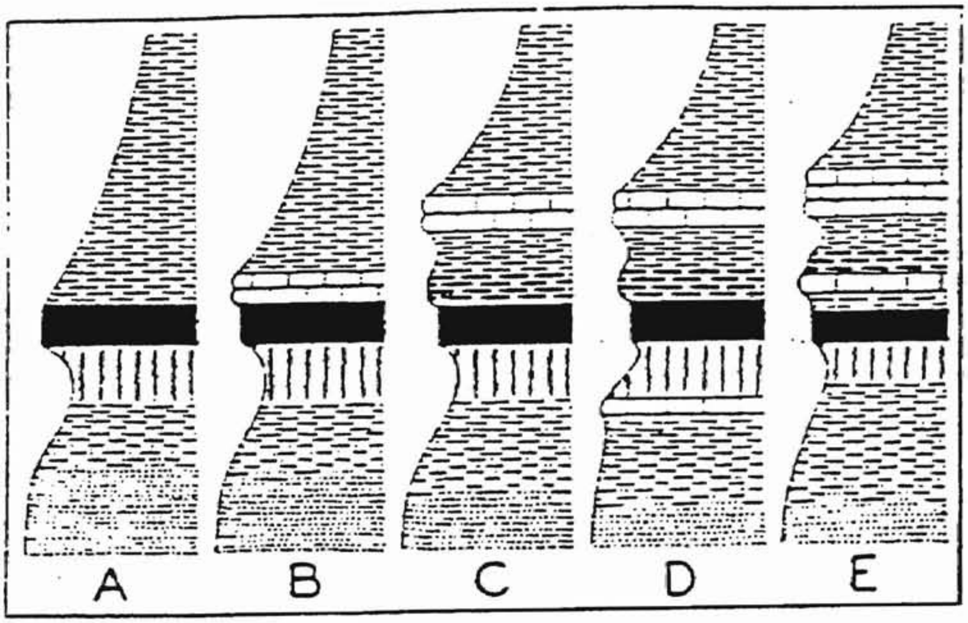


Figure 16 (from Weller, 1956). Characteristic variations of coal-bearing cyclothems. A. Simple, relatively incomplete cyclothem that may lack marine fossils. B. Like last but with upper, marine, limestone C. A common development of cyclothem, containing middle shale. D. Like last but with lower, "fresh-water" limestone. E. Cyclothem with full complement of marine members as those are developed in Illinois.

3. Underclay, not uncommonly containing concretionary or bedded fresh-water limestone

2. Sandy and micaceous shale

1. Sandstone

Unconformity

In addition, Weller believed that these depositional cycles of the Pennsylvanian strata were controlled by regional uplift and subsidence related to diastrophism; "Downwarping of any part of the ocean floor or widening of the basins would withdraw water from the shallow seas of the earth, and upwarping or narrowing of the basins would cause the extension of the epicontinental seas" (Wanless and Shepard , 1936). Wanless and Shepard (1936) objected to Weller's hypothesis and explained that "movements on the continents alone would not affect the sea level, except as they might make changes in the epicontinental seas which would be a slight factor in sea level change"(1936, p. 1190), but these sea level changes would most likely be too small to produce cycles in sedimentary strata and too less regular to be rhythmic fluctuations. They believed that these cyclic sedimentations were controlled largely by sea-level fluctuations and climatic variations related to Late Paleozoic glaciation, based on depositional environments of the sedimentary rocks. They listed several lines of evidence for this hypothesis. Tillites, associated glacial deposits, were found in various parts of earth (South America, India, Africa, Australia), indicating that during the Permo-Carboniferous time interval glaciers from an enlarged Antarctica may have extended well into equatorial regions, chilling the atmosphere in these low latitudes, a cause of the lowering of sea level. On the other hand, while glaciers were retreating from continents due to rising global temperatures, sea levels rose.

The term "cyclothem" was first used by Wanless and Weller (1932) as a description of the cyclicity of the sedimentary sequence of Pennsylvanian strata in the Illinois Basin. This ideal cyclothem, later called as Illinois-type cyclothem, contains nonmarine and marine sequences with ten lithologic units: such as sandstone, lower limestone, siltstone, clay, coal, lower gray shale, middle limestone, limy gray shale, upper limestone, and upper gray shale.

Jewett (1933) described cyclic sedimentation in the Permian of Kansas. He proposed the four lithologic units of the Kansas Permian cyclothem, such as varicolored nonfossiliferous shale, thin limestone, gray fossiliferous, and light-colored massive limestone. In addition, he assumed that the various units of the Permian cyclothems represented sets of conditions of which depth of water was only one probably factor, without direct evidence. Later, his ideal, in which various units of the cyclothems were affected by the sea-level changes, was supported by evidence compiled by Elias (1937). Elias (1937) interpreted the Late Paleozoic rocks of Kansas in terms of cyclic sedimentation and depth of deposition, based on comparison of distribution of organisms in the cycles of the Big Blue with the benthonic zones of modern seas. Elias (1937) constructed a depositional model for one ideal cycle of sedimentation in the Permian of Kansas (Figure 17). It contains progressive hemicycle and regressive hemicycle with several phases. In ascending order, progressive hemicycle consist of red shale, green shale, a *lingula* phase, a molluscan phase, a mixed phase, a brachiopod phase, and fusulinid phase. In ascending order, regressive hemicycles consist of a fusulinid phase, a

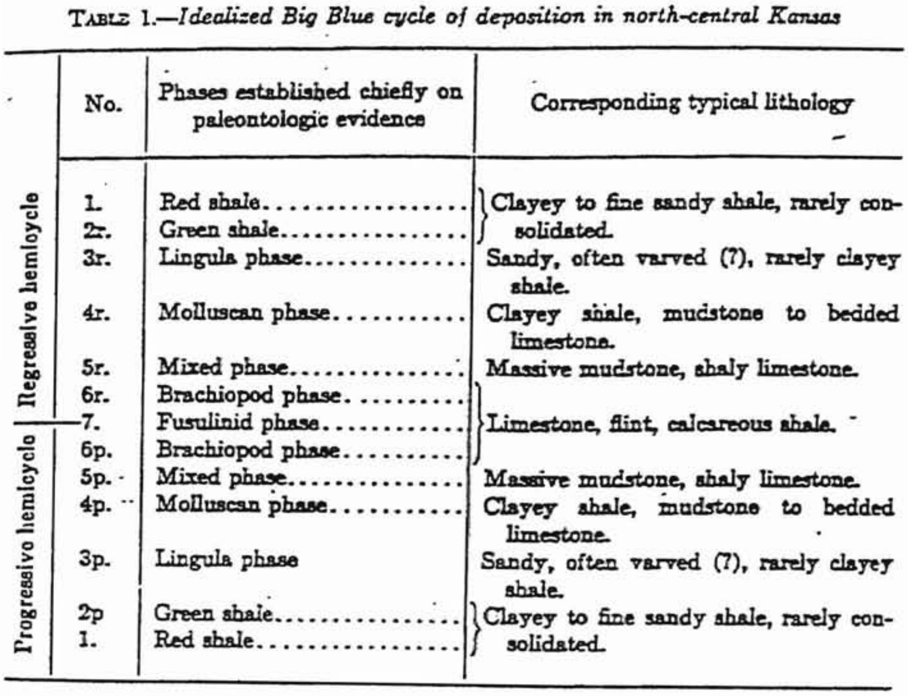


TABLE 1.—*Idealized Big Blue cycle of deposition in north-central Kansas*

	No.	Phases established chiefly on paleontologic evidence	Corresponding typical lithology
Regressive hemicycle	1.	Red shale	Clayey to fine sandy shale, rarely consolidated.
	2r.	Green shale	
	3r.	Lingula phase	Sandy, often varved (?), rarely clayey shale.
	4r.	Molluscan phase	Clayey shale, mudstone to bedded limestone.
	5r.	Mixed phase	Massive mudstone, shaly limestone.
	6r.	Brachiopod phase	Limestone, flint, calcareous shale.
	7.	Fusulinid phase	
Progressive hemicycle	6p.	Brachiopod phase	
	5p.	Mixed phase	Massive mudstone, shaly limestone.
	4p.	Molluscan phase	Clayey shale, mudstone to bedded limestone.
	3p.	Lingula phase	Sandy, often varved (?), rarely clayey shale.
	2p	Green shale	Clayey to fine sandy shale, rarely consolidated.
	1.	Red shale	

Figure 17 (from Elias, 1937). Idealized Big Blue cycle of deposition in north-central Kansas.

brachiopod phase, a mixed phase, a molluscan phase, a *lingula* phase, green shale, and red shale. Each phase represents different depths of Late Paleozoic seas: 160 to 180 feet, the fusulinid phase, 110 to 160 feet of brachiopod phase, 90 to 110 feet of mixed phase, 60 to 90 feet of molluscan phase, 30 to 60 feet of *lingula* phase, 0 to feet of the green shale unit, and subaerial exposure recorded by the red shale unit (Figure 18). According to his study on the Big Blue Series, Elias concluded particularly the following: "1. Observed cyclic repetition of sedimentary rocks and the enclosed organic remains indicate advance and retreat of sea, each cycle representing one major marine invasion. 2. Red shales that separated marine phases of two neighboring cycles are continental deposits and indicate emergence. 3. Maximum depth of the Big Blue sea did not exceed 180 feet, and the depth of the earlier Pennsylvanian sea in Kansas probably did not exceed 200 feet. 4. The Late Paleozoic benthonic organisms that characterize the phases of the Big Blue cycles were adapted to the following approximate depths: fusulinids, from 160 to 180 feet; calcareous brachiopods, from 90 to 160 feet; corals from 90 to 140 feet; bryozoans, from 75 to 160 feet; burrowing pelecypods, from 90 to 180 feet; other pelecypods, from 60 to 110 feet; and leathery sea-weeds, from 30 (or probably from shore line) to 75 feet" (Elias, 1937, p. 423). The cyclic concept of Elias (1937) served as the starting point for Heckel's later cyclothem model because cycle boundaries were first placed at disconformity surfaces, associated with red shales that represent cycle boundaries. These disconformity surfaces were viewed as cyclothem boundaries and thought to represent the changeover from regression to transgression. The Elias-type cyclothem model was constructed in one individual transgressive and regressive phase. In addition, Elias also first placed maximum depth of deposition in the middle part of

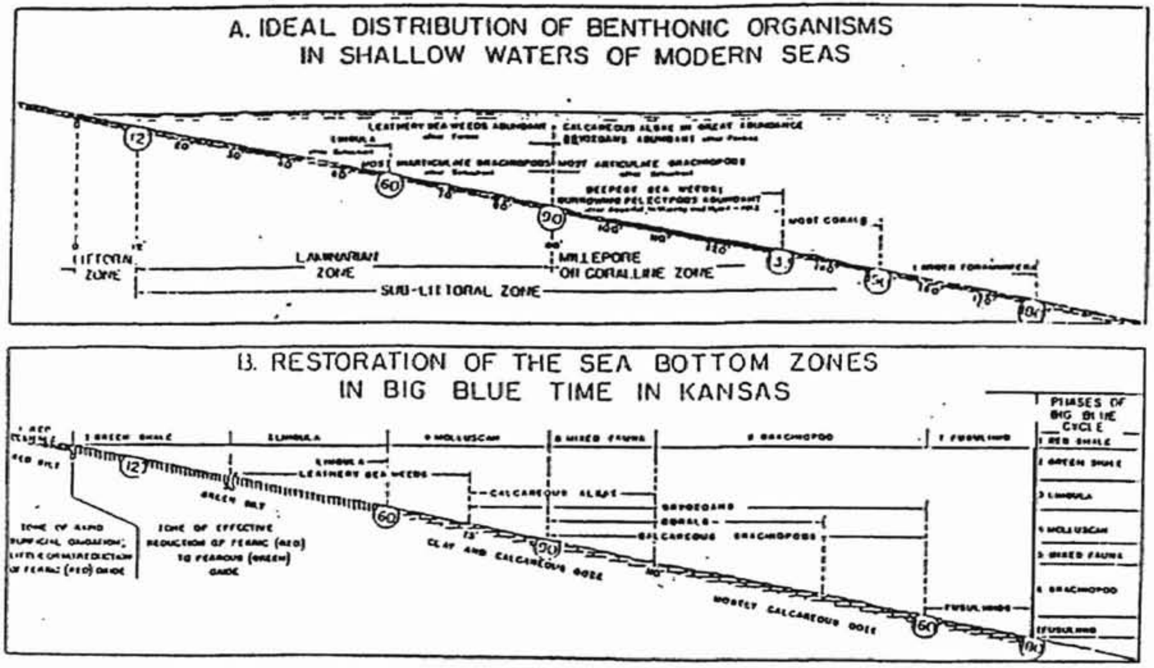


Figure 18 (from Elias, 1937). Sea-bottom zones in modern and in Big Blue seas. A. Ideal distribution of benthonic organisms in shallow waters of modern seas. B. Restoration of the sea bottom zones in Big Blue time in Kansas.

one cyclothem. Maximal depth of the Big Blue sea is indicated as the fusulinid-bearing zone: not exceeding 180 feet.

The concept of megacyclothems was introduced to describe a combination of related cyclothems or a cycle of cyclothems (Moore, 1936), based on his work on the Virgilian cycles of Kansas. Moore (1964) analyzed paleoecology of the upper Council Grove Group cyclothems from the Grenola Limestone through Funston Limestone. The organic assemblages of Pennsylvanian and Permian cyclothems in Kansas were divided into two main groups; nonmarine and marine assemblages. According to faunal assemblages, Moore proposed one megacyclothem and three cyclothems from the upper Council Grove Group; such as Grenola Megacyclothem, Beattie Cyclothem, Bader Cyclothem, Funston Cyclothem. In addition, interpretation of the sea level curve in these cyclothems was based on paleoecological analysis of the upper Council Grove Group. Other interpretation of the Beattie megacyclothem was more detailed (Elias, 1964). Elias believed that the fusulinid phase in each megacyclothem represent a culmination in a oceanic invasion. Two fusulinid phases were found at top of the Cottonwood limestone and base of the Morrill Limestone that represent transgressive maximums in the Beattie megacyclothem (Elias, 1964).

The black shales deposited in mid-continent basin had been considered as source rocks in cratonic basin particularly during the Pennsylvanian and Permian. The interpretation of the depositional environment of these black shales has long been debated whether they were deposited in a shallow-water or a deep-water environment.

Initially, the black shale of the Pennsylvanian attracted the attention of numerous writers, but little was known concerning the conditions under which it accumulated.

Many early geologists thought that the black shales of the Pennsylvanian were deposited in shallow waters with restricted circulation. Weller (1930) described that "as the black shales were the first deposits in the transgressing sea, it seems probable that they were laid down in very shallow water" (Weller, 1930, p. 127). Weller' ideal of the black-shale environment was agreed on by early geologists, until the model of the upwelling process in the mid-continental epeiric sea was introduced by Schenk (1967). He explained the black-shale depositional environment to be deep marine, based on analysis of the depositional environment of the phosphate nodules within the black shale. Before Schenk's idea about black-shale environment, Evans (1966) had proposed several kinds of evidences to indicate that the depositional environment of the black shale is not extremely shallow water or swamp environment. When Evans (1966) studied the Heebner Shale of the Oread Formation (Shawnee Group, Virgilian Age, Pennsylvanian Period), he doubted that the depositional environment of the black shales was in very shallow water. Evans listed several characteristics of the black shales as evidence that the shales were not deposited in the shallow water of a swampy environment. First, disruptive root systems had not been recorded within the black shale units. If the black shale had been deposited in swamp environment, well developed root systems should have been preserved within the black shale units. Because no disruptive root systems have been found within the black shales units, this indicates that black shales were not deposited in swampy environments. Second, unconformities are absent immediately above or below the black shale units. If the black shale had been deposited in a shallow marine environment, sea level would have possibly had to drop to form erosional surface during deposition of the black shales. Because no erosional surface has been found immediately above or below the black shale units, the black shales are interpreted as not having been deposited in a shallow or regressional environment. In addition, Evans also listed another evidence to support of his idea of the black-shale deposition from consideration of regional geology "The well established southward decline in organic content, oil yield ratio and uranium content, as well as the physical thinning of black shale itself, appear to be associated with increasing nearness to a land area. Of particular importance is the reduction in oil yield ratio, which most likely reflects variation in the chemical composition of the preserved organic material. Such a compositional difference may be related to an increasing influx of terrestrially derived plant material or to partial and preferential oxidization of the parent organic substances as a result of increasing shallowness of the sea. Although the latter explanation seems more probable, both theories support a basinal origin for the black shale. Even more conclusive in this regard is the occurrence, between the southern terminus of the black shale unit and continental equivalents to the south, of light colored calcareous shales that contain a rather diverse marine fauna. Evidence of more normal marine conditions between the area of pronounced restriction and a known terrestrial environment certainly does not favour a paludal origin" (Evans, 1966, p. 121). Evans concluded that the black-shale environment is in considerably deeper water (Figure 19).

Schenk (1967) studied the Altamont Limestone. The Altamont Limestone is the marine and major portion of the Altamont megacyclothem. "This megacyclothem includes, in ascending order, the upper part of the Bandera Shale (variegated terrigenous detritus usually with coal), the entire Altamont Limestone (carbonate, overlain by marine shale and these carbonate) and the lower part of the Nowata Shale (variegated

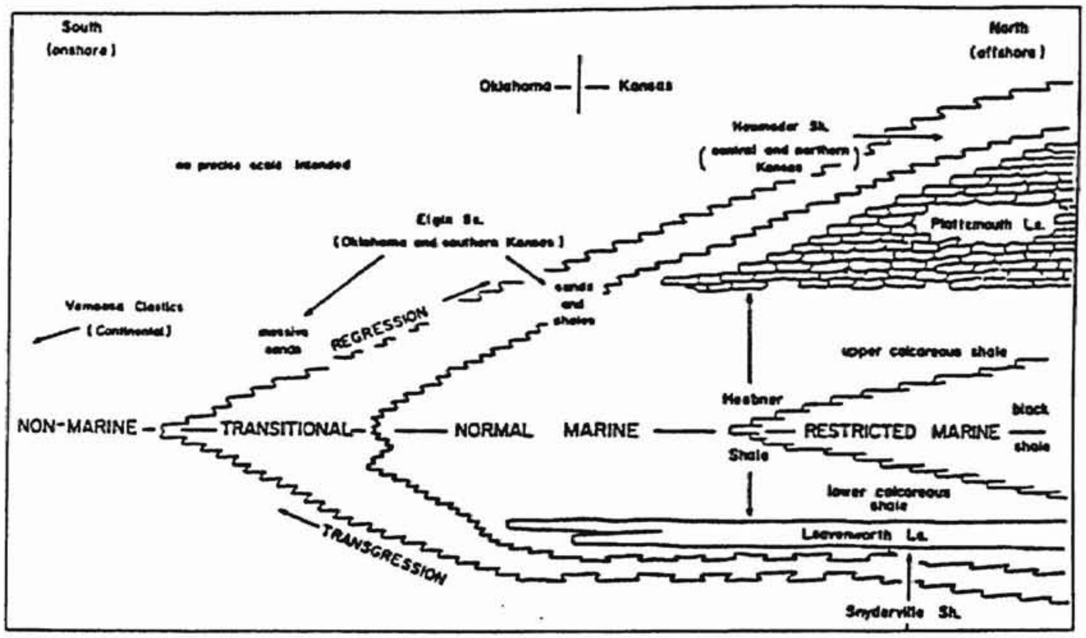


Figure 19 (from Evans, 1966). Interpreted facies relationships in southern Kansas and northern Oklahoma.

terrigenous detritus, often with a coal)" (1967, p. 1370). He divided several biofacies of the Altamont megacyclothem; Shelly, Coral, Fusulinid, Platy Algal, Brachiopod, and *Ammovertella* Biofacies. The paleoenvironment of the Shelly Biofacies probably was "fairly shallow, normal marine, and well suited to organic activity" (Schenk, 1967, p. 1377). Environmental condition of the Coral Biofacies is usually cited as "…relatively extensive coral activity are less than 150 feet of well-oxygenated, circulation, turbulent, normal marine water between 16° and 21° C" (Schenk, 1967, p. 1377). The Fusulinid facies, composed of corroded and fragmented fusulinids were found in these areas and the population generally is not as diverse as in the shelly biofacies. "This impoverished fauna and evidence of high energy may reflect restriction of circulation and shoaling" (Schenk, 1967, p. 1377). Oncolitic biofacies was formed in shallow water with abnormal salinity and high turbulence. Platy algae, as Platy Algal biofacies, were "concentrated in shallow sunlit water on flanks and over shoals, where they dampened turbulence and circulation" (Schenk, 1967, p. 1377). Brachiopod biofacies was formed in fairly shallow, normal marine, well suited to organic activity (Schenk, 1967). *Ammovertella* biofacies, containing foraminifera (*Ammovertella* and *Ammodiscus*), conodonts, ostracods, echinods, and black shale with phosphate nodules, was formed in a deep-marine environment. Schenk (1967) believed that the black shale and phosphatic nodules were deposited during the maximum transgression. Schenk stated " The upwelling, phosphate-rich waters nurtured luxuriant organic growth in the zone of photosynthesis of both near-surface waters directly above the lithotope and shallow, carbonate-precipitating water.… Nektonic and planktonic organic remains settling to the bottom were phosphatized" (Schenk, 1967, p. 1379). He assumed that the water depth of these phosphate nodules deposits was at least 200 m and that they represented maximum marine transgression of the sequence. A diagram shows the lateral movement of the Altamont megacyclothem facies (Figure 20). The marine environment of the Altamont megacyclothem in general lay to west of the outcrop belt and this regional setting of the Altamont megacyclothem "was modified by four relatively positive tectonic features which were orientated in a northwesterly direction across the outcropbelt. These features strongly modified the deltaic and carbonate member but did not affect the deeper water shales and phosphorite. The most effective arch was the most southern - the Bourbon arch. More rapid facies changes and higher energy levels on the southern than on northern flanks of these arches suggest more normal marine conditions to the south, northerly moving currents, and/or a southerly wind. The intervening basins were sheltered, lagoonal areas between these relatively positive features" (Schenk, 1967, p. 1380). Schenk concluded that black shale and phosphorite indicate transgressive maximum as a deepest marine environment, and delta sediments record the regressive maximum. Schenk's valuable interpretative model of the Altamont megacyclothem can be applied to other cyclic deposits of mid-continent of the Late Paleozoic.

Since Schenk (1967) stated that black shale is a deep marine deposit, a greater diversity of conodonts within black shale was also recognized as evidence of accumulation in sediments in deep water instead of in shallow water (Basemann, 1973). Schenk's and Basemann's concepts were applied to construct the Heckel-type cyclothem model (Heckel et al., 1975).

Heckel agreed with Schenk's and Basemann's ideal and stated that "the deeper water is not only poor in oxygen, but also rich in phosphate, which has been concentrated

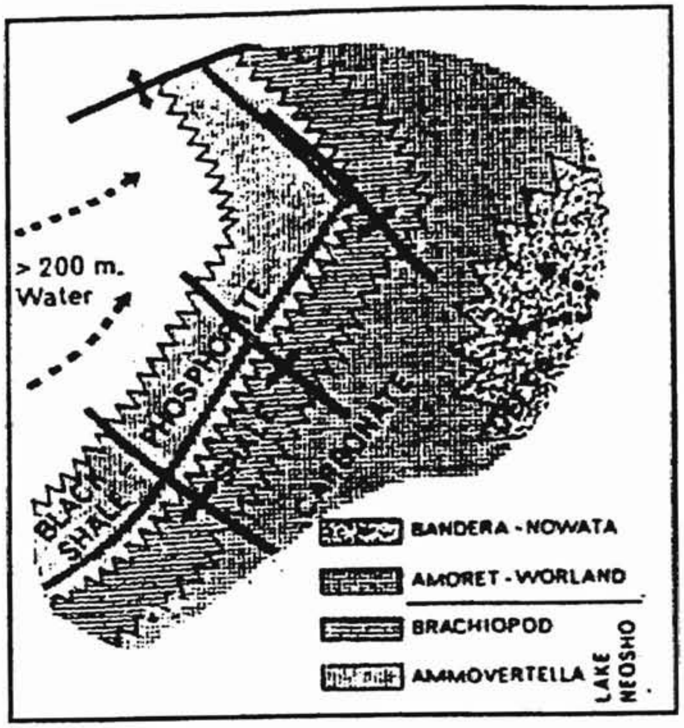


Figure 20 (from Schenk, 1967). Depositional environment at maximum transgression. Present outcrop belt of formation is cross lined; water movement direction is dashed lined; positive tectonic features are solid lined. At this time, phosphorite was precipitated along present outcrop belt. Bandera, Amoret, and lower half of Lake Neosho units have been deposited during rapid marine transgression. Upper halves of the Lake Neosho, Worland, and Nowata units will be deposited during slow marine regression. Lithotopes and biotopes move east-west.

in the oxygen-minimum zone from decay of settling organic matter (Figure 21). As this deeper water upwells, it replenishes phosphate in the oxygenated sunlit surface water...." (Heckel, 1977 p. 1055). Heckel (1975) and Basemann (1975) further explained that if all black shales were interpreted as outside shale (nearshore marine deposits), they reflect simple short-term oscillation (Figure 22). Short-term oscillation fails to account satisfactorily for large-scale transgression and regression on the formational level, controlled by glaciation. On the other hand, if all black shale were interpreted as deep-marine deposits, they reflect long-term oscillation. "Transgression and regression of the sea, controlled by several possible factors...seem to account fairly well for the large-scale alternation of the limestone and shale formation. A more sophisticated model proposed by Elias (1937) for the cyclic Lower Permian sequence in Kansas involves large-scale transgression and regression on the formational level, with differences among the members in the marine part of the sequence related to different depth zones in the marine environment" (Heckel et al. 1975, p. 489). Later, Heckel (1977) interpreted the black shale as core shale within the Pennsylvanian cyclothem, representing a maximum transgression.

The depositional environment of the phosphate nodules of the black shale has attracted the attention of a number of other authors, particularly Cook and McElhinny (1979) and Kidder (1985). They also believe that the favorable environment for precipitation of the phosphate in the black shale is near the anoxic aquatic environment. According to Cook and McElhinny's model of the spatial and temporal distribution of phosphate, Kidder suggested that "the phosphate nodules occur at the upper and lower

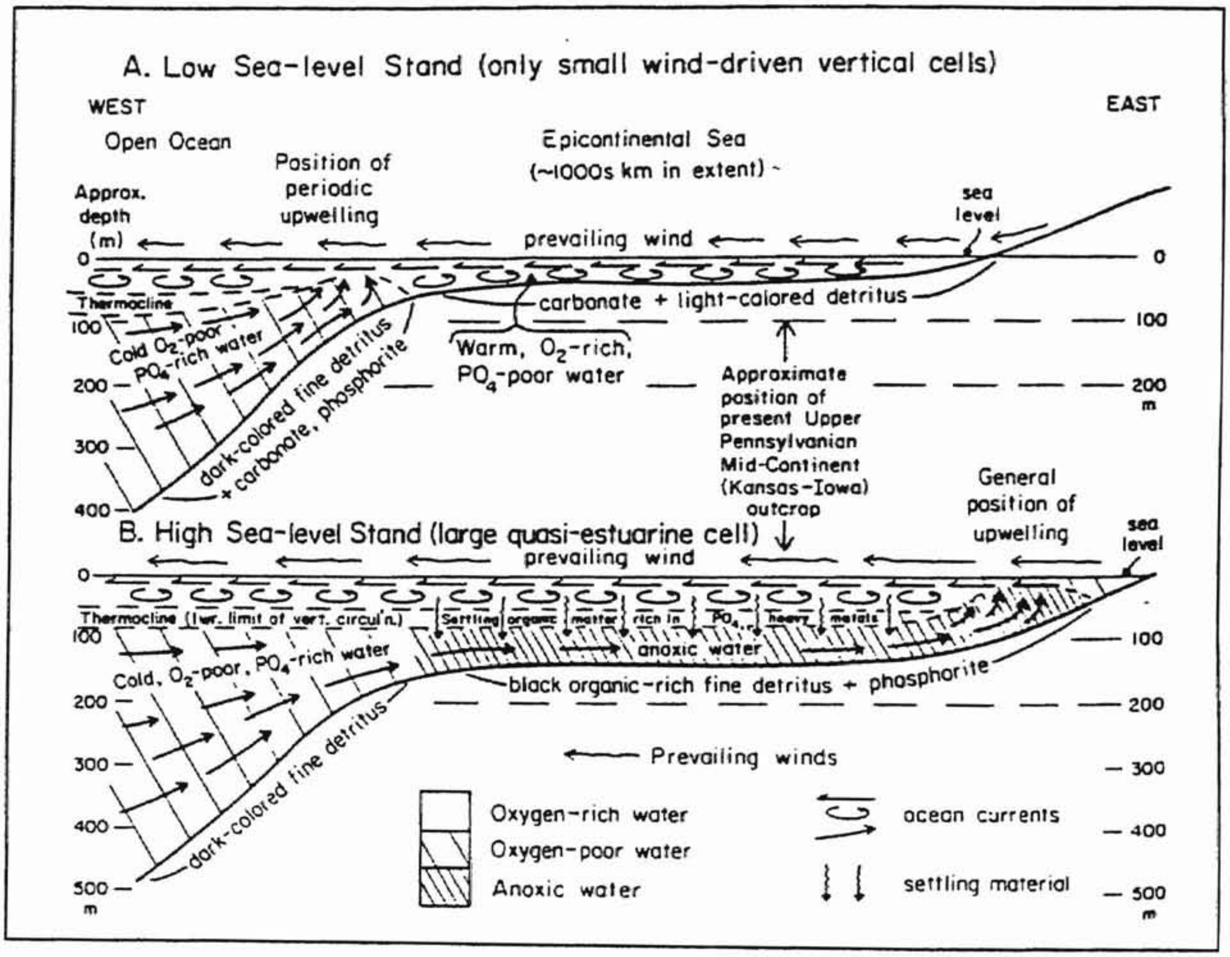


Figure 21 (from Heckel, 1977). Vertical circulation patterns of upwelling process.

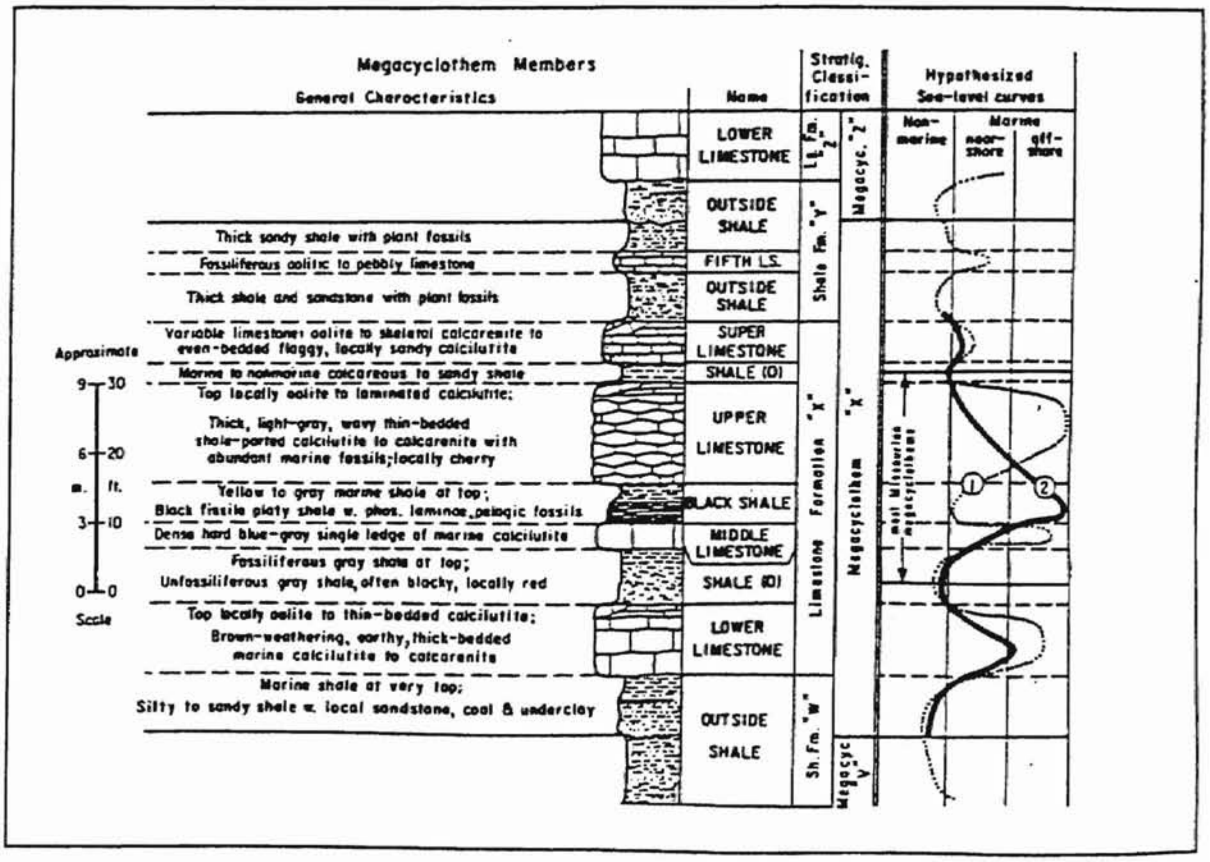


Figure 22 (from Heckel and Baesemann, 1975). Ideal Upper Pennsylvanian megacyclothem, showing complete development of all members.

boundaries of the oxygen-minimum zone" in which it could indicate the deeper marine environment.

Heckel et al. (1975) constructed the cyclothem model in Upper Pennsylvanian rocks in basins of the southern Mid-Continent, called as Kansas-type cyclothem (Figures 23 and 24). The Kansas-type cyclothems are disconformity-bounded units that are similar to the earlier model of Elias' type. The base of the black shale unit interpreted as maximum water depth on the shelf represents the boundary of the changeover from transgressive to regressive phase within the cyclothem. The Kansas-type cyclothems consist of several units based on the lithology which interprets different depositional phases related to depth of water (Heckel, 1977); for example: in ascending order outside shale, middle limestone, core shale, upper limestone, and outside shale.

According to the Heckel (1977) interpretation, the outside shale was located at the lowermost unit (lower outside shale) and uppermost unit (upper outside shale) of the cyclothem. These outside shales, defined as cyclothem boundaries, were deposited in a nearshore environment. The lithology of the outside shale is generally thick gray sandy shales related to nonmarine deposits,. The lower outside shale consists commonly of gray to brown sandy shale with local coal and sandstone at the base and sandy shale with marine bioclasts at the top. The upper outside shale consists generally of gray to green shale, and locally red sandy shale with siltstone and sparse fossils and sandy shale with siltstone and sparse fossils.

The middle limestone of the Heckel (1977) cyclothem model is a widespread deposit of variable carbonate type that is typically a few feet thick or less. The lithology of this unit is dense, dark, skeletal calcilutites with diverse and relatively abundant

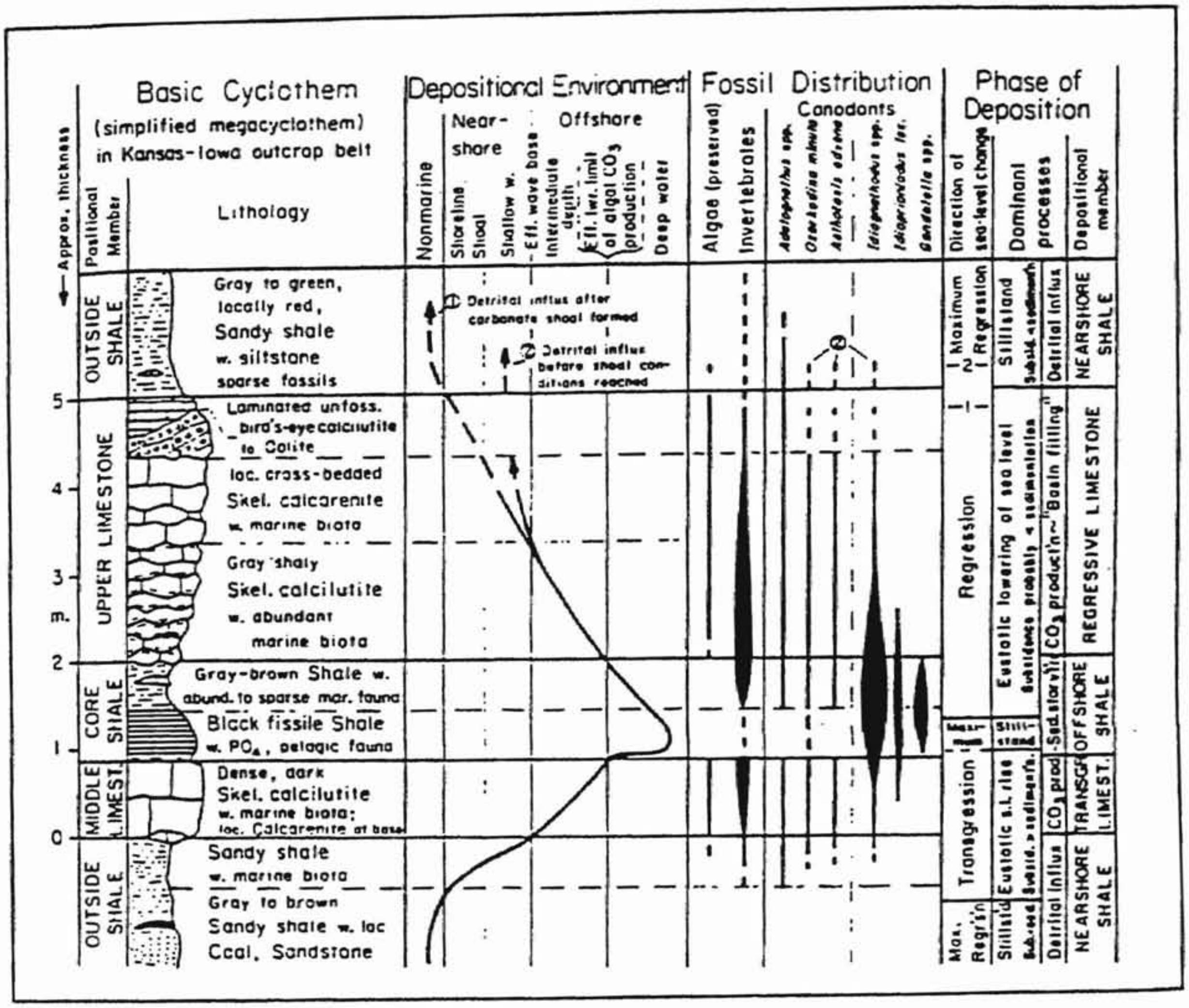


Figure 23 (from Heckel, 1977). Basic Upper Pennsylvanian individual Kansas cyclothem sequence. Environmental interpretations are based mainly on lithology and gross distribution of biota.

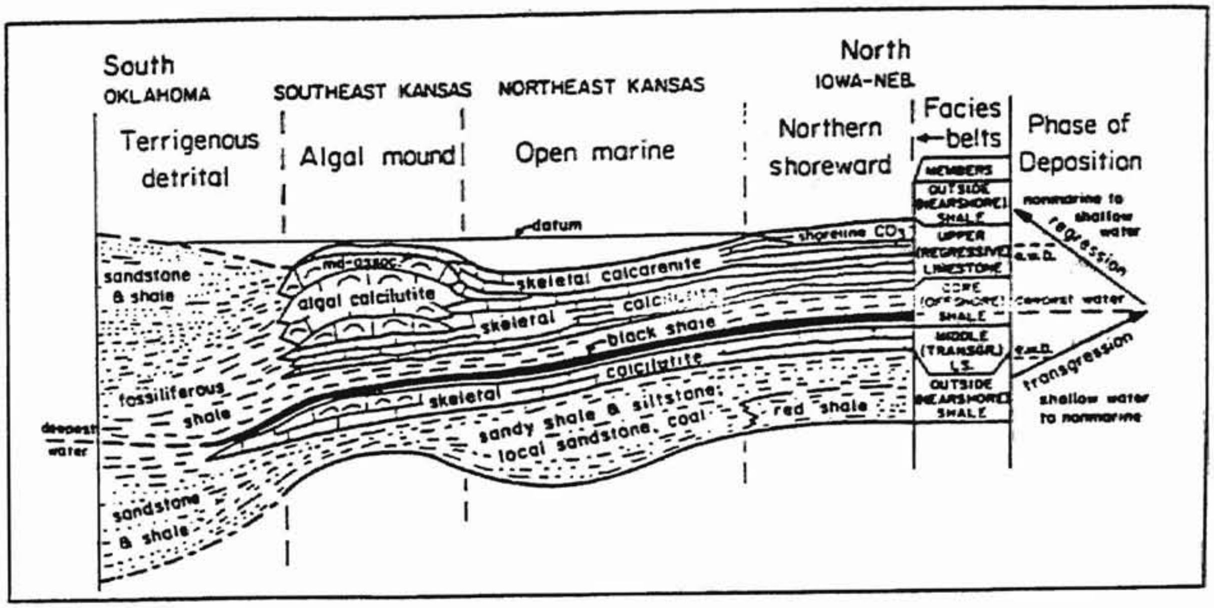


Figure 24 (from Heckel, 1977). Basic pattern of lateral change in Upper Pennsylvanian cyclothem members across facies belts exposed along mid-continent outcrop. Datum is interpreted approximated sea level at time that increased detrital influx terminated deposition of upper (regressive) limestone member. Long dashed line shows position of deposits formed in deepest water during maximum transgression; short dashed line show approximate limits of deposits formed below effective wave base (e.w.b.) in north. Southward thickening of sequence reflects greater overall subsidence in that direction. Axial direction of transgression (eastward) and regression (westward) lies roughly normal to line of outcrop.

marine fossils. The middle limestone was defined as transgressive limestone that was deposited during rapid transition from nonmarine or marginal marine conditions to an open marine environment.

The core shale is "thin (0.3 to 2.0 m), nearly nonsandy, dark, marine shale that ranges from sparsely fossiliferous to abundantly and diversely fossiliferous" (Heckel, 1977, p. 1048). The lower part of the core shale is generally black with nonskeletal phosphate and pelagic fauna, conodonts and ammonoids, while the upper part of the core shale is commonly gray-brown with abundant to sparse marine fauna. The black shales were deposited in deep marine settings with anoxic conditions, and thus they represent a maximum transgression.

The upper limestone of the Heckel-type cyclothem, representing regressive limestone, is variable in lithology, ranging in thickness from 1.5 to 9 meters and "consisting mainly of wavy-bedded shale-parted skeletal calcilutites with an abundant and diverse marine biota throughout" (Heckel, 1977, p. 1048). The depositional environment of the upper limestone member ranges from a quite offshore open-marine environment in the lower part to shoal-water and shoreline environment in the upper part. Heckel (1977) described that gray shaly skeletal calcilutites with abundant marine biota are at the base of the upper limestone member, laminated unfossiliferous bird-eye calcilutites with oolites are at the top of the upper limestone, and local cross-bedded skeletal calcarenite with marine biota are commonly at the middle of the upper limestone member.

Boardman et al. (1995) constructed a depth-related microfaunal biofacies model which provides a useful method for interpretation of Upper Carboniferous to Lower

Permian cyclothems in Mid-continent North America, based on their paleoecologic analysis (Figure 25). Three types of the biofacies were introduced to identify vertical changes in relative water depth within the sequence, including conodonts, ostracodes, and foraminifers. The paleoecologic models are described by Boardman et al. as follows. The conodont paleoecologic model: "This model assumes a pelagic life mode for conodonts with different taxa living in different water masses that are vertically differentiated. It also predicts that nearshore assemblages are of low diversity in contrast to deep shelf assemblages that exhibit high diversity. The depth stratification model provides the best overall explanation for the observed stratigraphic distribution of conodonts within cyclothems...The succession of conodont genera from nearshore to offshore is as follows: *Adetognathus, Hindeodus, Aethotaxis, Idiognathodus* and *Streptognathodus, Idioprioniodus*, and *Gondolella.* The most offshore bioassemblage contains all genera of conodonts but is dominated by *Idiognathodus*, *Idioprioniodu*, and *Gondolella"* (p. 97).

The ostracodes paleoecologic model, "Ostracodes are often present in large numbers in certain lithic members of Mid-Continent Pennsylvanian and Lower Permian cyclothem...Melynk and Maddocks (1988) detailed the distribution of some 226 Permo-Carboniferous ostracode species along an onshore-offshore gradient by means of an independent coenocline derived from what they considered to be paleoecologically significant taxonomic units.. They concluded that *Manmoides mammillata, Healdia simplex, Healdia elegans*, and *Pseudobythocypris pediformis* inhabited nearshore environments, whereas *Amphissites centronotus, A. girtyi, and Aurikirkbya knighti* lived offshore" (P. 105-106). Boardman et al. recognized five distinct ostracode biofacies

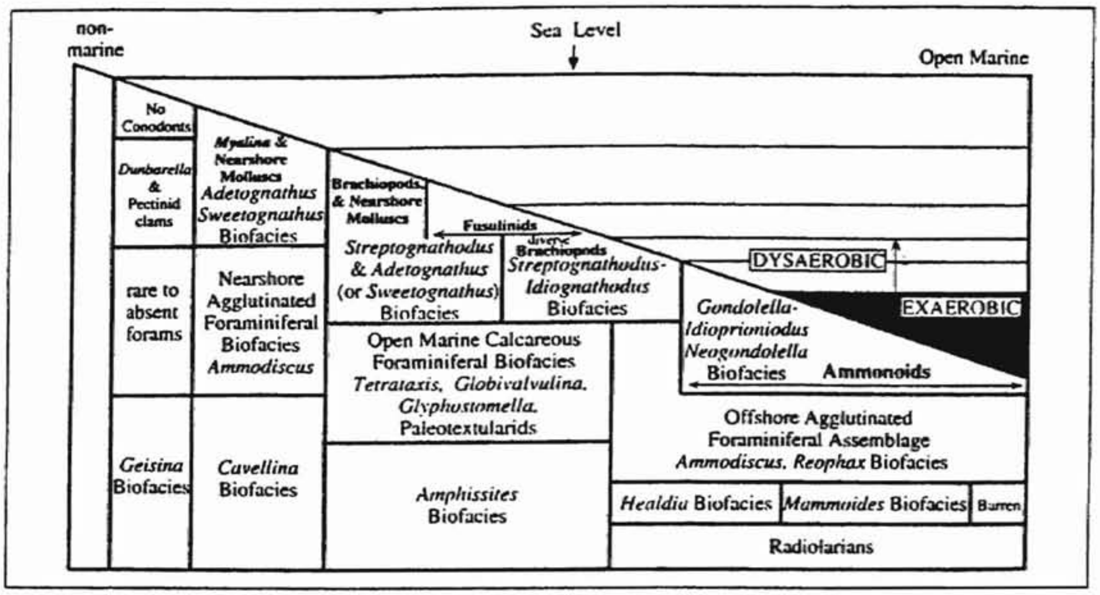


Figure 25 (from Boardman et al. 1995). Onshore-offshore model for Pennsylvanian depth and oxygen related biofacies associations related.

within Pennsylvanian and Lower Permian cyclothem. From the most nearshore to off-shore, the following biofacies are recognized: *Geisina spinosa* Biofacies (restricted bodies of water), *Cavellina* Biofacies (nearshore with fully marine condition), *Amphissites* Biofacies (open marine), *Healdia* Biofacies (deep-shelf marine with dysaerobic condition), and the *Mommoides cf. M. mammillata* Biofacies (deep-shelf marine with exaerobic condition).

The foraminifers paleoecologic model: Boardman et al. recognized three bioassemblages from their analysis. The shallow bioassemblage of the foraminifers is dominated by a few species, sometimes with high numbers, such as *Ammodiscus* cf. A. *semiconstrictus* var. *regularis*. "Intermediate depth bioassemblages are highly diverse and contain taxa that occupy a variety of life modes. For example, *Tetrataxis* and *Globivalvulina* are epifaunal. Other taxa present include ammodiscids, large paleotextularids (*Climacammina, Deckerella*), endothyranellids (*Endothyra, Endothyranella*), *Ammobaculites*, and fusulinaceans" (p. 109). The deep-shelf bioassemblage contains several common taxa, such as *Reophax fittsi*, *Ammodiscus semiconstrictus, Sansabaina*, *Hyperammina*, *Earlandia*, *Nodosinella*, and *Endothryanella*.

Boardman et al. also constructed composite lithofacies and biofacies models from Late Carboniferous to Lower Permian cyclothems of the North American Mid-Continent. . These models, showing lithofacies and microfossil distribution, provide valuable methods for interpretation of the Late Paleozoic cyclothem of the Mid-continent.

Miller and West (1993) described the Wolfcampian cyclothems from the Roca Shale through Matfield Shale in northeastern Kansas, including parts of the Council

Grove and Chase Groups. Ten cyclothems from the Wolfcampian Series of northeastern Kansas were interpreted based on concept of Heckel-type cyclothems. The ten cyclothems are as follows: Lower Grenola cyclothem (from top of the Roca Shale Member through base of the Salem Point Shale Member), Upper Grenola cyclothem (from the base of the Neva Limestone Member through the middle of the Eskridge Shale), Eskridge cyclothem (from the middle of the Eskridge Shale through the top of the Eskridge Shale), Beattie Cyclothem (from the base of the Cottonwood Limestone through the top of the Stearns Shale), Lower Bader cyclothem (from the base of the Eiss Limestone Member through the top of the Hooser Shale Member), Upper Bader cyclothem (from the base of the Middleburg Limestone Member through the middle of the Easly Creek Shale), Crouse cyclothem (from the middle of the Easly Creek Shale through the top of the Blue Rapids Shale), Funston Limestone (from the base of the Funston Limestone through top of the Speiser Shale), Lower Wreford Cyclothem (from the top of the Speiser Shale through the middle of the upper Havensville Shale Member), and Upper Wreford Cyclothem (from the middle of the upper Havensville Shale Member through the top of the Wymore Shale Member).

According to Heckel's (1977) and Miller's and West's study of Kansas cyclothems, Kansas-type cyclothems can be divided into two different types of cyclothems: Pennsylvanian and Permian cyclothem based on the various lithologies. For example, black shale is uncommon in the Permian rocks exposed along the Mid-continent outcrop. Heckel (1977) stated that phosphatic black shale is commonly present in the Pennsylvanian strata but is absent in the Kansas Permian, except in Lower Council Grove Group. Heckel (1977) explain that absence of phosphatic black shale in the upper

Council Grove Group in the Kansas Permian may reflect lesser depths of the Permian sea during maximum transgression, which covered much less of the Mid-continent than during the Pennsylvanian. In addition "Much more red shale is present in the nearshore Permian shales of Kansas. This greater abundance of nonmarine deposits in Kansas at this phase of deposition than during the Pennsylvanian suggests shallower water deposition for the more marine phases" (Heckel, 1977, p. 1065). Miller and West (1993) also point out the difference between Permian cyclothems and Pennsylvanian cyclothems, based on their study of the Lower Permian cyclothems. The proportion of red shale tends to be increasing upward through the Lower Permian cyclothem. On the other hand, red shales were more developed and thicker in the Permian strata than in Pennsylvanian strata. "Gypsum is a significant component of limestone and mudstone facies and becomes increasingly common upward through the Lower Permian Sequence" (p. 3). Miller and West (1993) explained that "The Early Permian was a time of major climatic change on which the cyclothems were superimposed. Gondwana glaciation was waning in the Early Permian...and aridity was consistently increasing in North America. These long-time climate trends are recorded by the increased proportion of red terrigenous clastics, evaporites, and carbonates in the Lower Permian relative to the Upper Pennsylvanian.... Such changes are consistent with continuing assembly of Pangea...the mid-continent drifting into drier latitudes during this time" (p. 3). According to these lithologic characteristics, the epicontinental sea was getting shallower upward from Late Pennsylvanian through the Permian. Therefore, the Permian sea was much shallower than the Pennsylvanian sea. Although Permian cyclothems lack black shale, analogies can be drawn with depositional phases of the upper Pennsylvanian cyclothems, of the Heckel type.

In contrast, Weller-type cyclothems and Heckel-type cyclothems are mainly different in lithofacies; the pattern of the Weller-type cyclothem represents marine and nonmarine deposits related to coal and coarse-grained siliciclastics, whereas the Heckel-type cyclothems were dominantly marine carbonate rocks and clay or silt-sized siliciclastics. The black shale represents a widespread marine marker in Heckel-type cyclothem, whereas coal strata are the indicators in the Weller-type cyclothem. In addition, cycle boundaries for Weller-type cyclothems are placed at base of the fluvial sandstone where it is a local disconformity surface with no time significance, whereas cycle boundaries for Heckel-type cyclothem are placed at erosional base of the first regionally distributed marine transgressive limestone or sheet sandstone where it represents a regionally significant disconformity surface. Because of moderate tectonic activity in the cratonic interior, Heckel-type cyclothems were formed in response to eustatic changes in sea level driven by glaciation, but the origin of the Weller-type cyclothems is both eustatic and tectonic. The Elias-type cyclothem is similar to the Heckel-type cyclothem, but different in the transgressive maximum. The transgressive maximum is recognized as the fusulinid phase in the Elias-type cyclothem, rather than a phosphatic black shale, as in Heckel-type cyclothem.

The Chase Group cyclothem of the Wolfcampian Series in south-central Kansas has been described by Mazzullo et al. (1994, 1995). They divided the Chase Group cyclothem into seven cyclothems: Threemile, Schroyer, Kinney, Florence-Fort Riley, Towanda, Winfield, and Krider-Paddock-Herington cyclothems, in ascending order.

These cyclothems were deposited in inner shelf to outer shelf environments on a broad ramp-type platform. Mazzullo et al. (1995) described that the depositional environment of the Chase Group cyclothem is major marine environmental zones on the ramp which are "(1) inner shelf facies, which variously included (a) marginal marine, mostly siliciclastic-dominated deposits; (b) peritidal carbonate-dominated deposits, and locally siliciclastics; (c) shallow subtidal, variously low-energy and high-energy deposits; (2) middle shelf facies, which mainly include carbonate deposits, and locally some shales representing low-energy, subtidal facies of moderate depth; and (3) outer shelf facies, mostly represented by cherty limestones" (1995, p. 221).

Later in the study, cyclothem development was interpreted in terms of modern sequence-stratigraphic terminology and inferred origin. For example, Puckette et al. (1995) studied the stratigraphic sequence of the Council Grove Group in the southern mid-continent. Although they used the term "sequence" instead of cyclothem, their study of the Council Grove Group can be considered as the cyclothem analysis.

The Council Grove Group was interpreted in a more detailed fashion by Puckette et al. (1995), including the Grenola sequence of the lower Council Grove Group and Beattie, Bader, Crouse, and Funston Sequence of the upper Council Grove Group (Figure 26). Puckette et al. point out two distinct types of sequences within the Council Grove Group. They stated that the sequences in the lower part (Foraker through Crenola Formations) consist of (1) a basal transgressive surface, (2) a shallow marine limestone with a marine condensed section that represents the transgressive and highstand systems tracts, (3) shallow water carbonates with a weathered upper surface (exposure surface) that represents forced regression, and (4) red, caliche-bearing, blocky claystones and

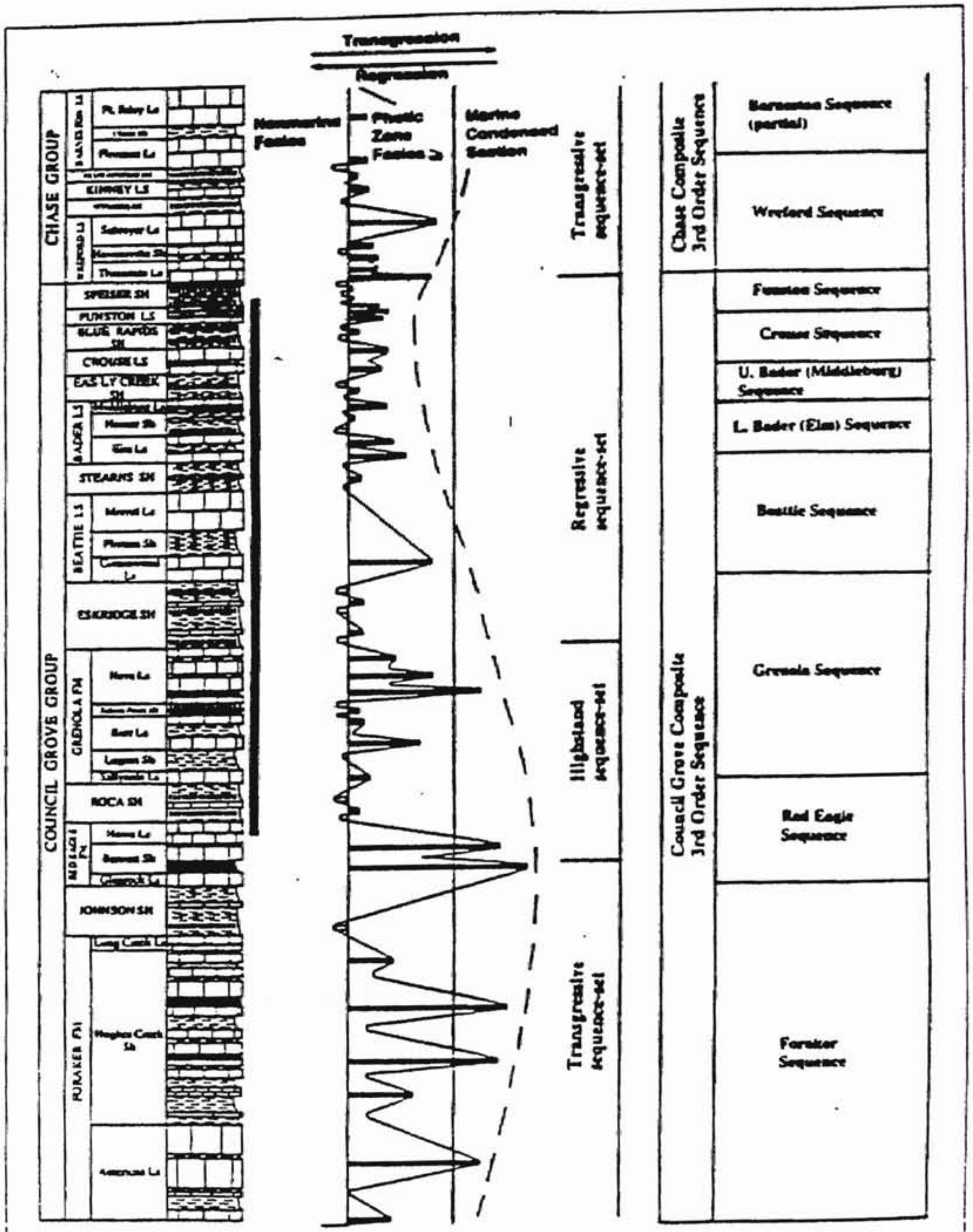


Figure 26 (from Puckette et al. 1995). Sequence stratigraphy of the Council Grove Group. Dashed line represents relative sea-level curve of a third-order composite sequence composed of transgressive, early highstand, and regressive sequence sets. Fourth-order sequences are listed in the right column.

siltstones (red beds) that may correspond to the lowstand systems tract of the shelf margin. Sequences in the upper part (Beattie Limestone through Speiser Shale) are similar to those in the lower Council Grove, but lack the marine condensed section that represents a well defined high stand systems tract" (1995, p. 269). Thin transgressive lag deposits, separating the limestones from the underlying nonmarine red beds, were recognized as the lower sequence boundaries of the Council Grove Group. A carbonate marine condensed section with glauconitic, skeletal phosphate, and abundant conodonts commonly represents a maximum flooding surface within the sequence. "The upper surfaces of the regressive carbonate units and overlying nonmarine claystones and siltstones exhibit evidence of subaerial exposure....The succeeding claystones are red and contain nodular caliche" (Puckette et al., 1995, p. 269). Puckette et al. (1995) concluded particularly "(1) The Council Group is composed of repetitive cycles of shallow marine carbonates and siliciclastics and nonmarine red beds that document sea-level oscillations. (2) Depositional sequences in the Council Grove display a vertical facies succession (L-WP through RC) that documents flooding and deepening, followed by a general shallowing phase that culminated in subaerial exposure, karsting, and redbed deposition. A complete succession of these genetically related strata is considered a fourth-order depositional sequence. (3) The differences in the character of the fourth-order sequence reflect general trends in facies that help define sequence sets. The Council Grove consists of three sequence sets (transgressive, highstand, and regressive) that compose a third-order composite sequence." (p. 290).

In recent years the term "sequence stratigraphy" has been widely accepted since Exxon-type sequence was developed by Vail (1977). Exxon-type sequences are disconformity-bounded, and in many instances, actually represent the Heckel cyclothem model. "Stratigraphic sequence and cyclothem share a common trait (Rascoe, 1995)" that is central reason for their existence and that both of them are discussed in the paper. A detailed concept of sequence stratigraphy will be discussed in a later chapter.

II.

Stratigraphy

Lithostratigraphy

General Statement

Since the middle 1800's strata of the Permian of the mid-continent region have been investigated by early geologists such as Swallow (1855), Morcou (1864), Hayden and Meek (1872, 1873), and Warren (1875). These early geologists described the rocks in local outcrops from Kansas or Nebraska, but did not apply formal stratigraphic names. During 1868 to 1936, the nomenclature and classification of the rocks in the Mid-continent region were developed and redefined by Broadhead (1968), Hay (1887), Keyes (1896) , Haworth (1894), Prosser (1902), Condra (1927; 1931), Upp (1931), and Moore (1936).

The term "Council Grove Stage" was proposed by Prosser (1902). It originally included "Alma Limestone (Cottonwood Limestone)", and "Garrison Formation". Later, Condra and Upp (1931) used this term "Council Grove" as a Group. The "Garrison Formation" was a lithostratigraphic entity containing the mudrock and limestone units above the Cottonwood Limestone and below the Wreford Limestone. Condra and Upp (1927, 1931) redivided the Garrison Formation as Florena Shale, Morrill Limestone Stearns Shale, Eiss Limestone, Hooser Shale, Middleburg limestone, Easly Creek Shale, Crouse Limestone, Blue Rapids Shale, Funston Limestone, and Speiser Shale Member. Moore (1936) abandoned the term "Garrison" Formation and elevated the subdivisions of the Garrison Formation to the rank of formation. Definitions and type section of the formation will be discussed in the next section.

In following decades, several geologists contributed to a study of the Late Carboniferous-Early Permian. Elias (1937) was among the first workers to deal with depositional environments of Lower Permian rocks in Kansas. He discussed the cyclic deposits of these rocks according to faunal and lithologic changes. Paleoecology of the Cottonwood Limestone and Florena Shale members of Council Grove Group were first described more completely by Imbrie (1955) and Laporte (1962). Imbrie and Laporte (1964) also classified the Beattie Limestone into ten facies based on lithic and faunal characteristics: Osagia, Shelly, Platy Algal, Fusuline, Bioclastic, Kaolinite, Chonetid, Dolomitic Shale, Algal-biscuit, and Boxwork facies. The Osagia facies consists of "a significant proportion of grains coated by the algal-foraminiferal consortium Osagia" (Imbrie and Laporte, 1964, p. 221). The Platy Algal facies present "an unusually diverse and well-preserved fauna occurring in thin layer of calcareous shale and limestone (Imbrie and Laporte, 1964)". Platy algal facies is characterized by pure limestones with the platy alga *Anchicodium* as the dominant organism. The fusuline facies is described as limestones with nodular chert and abundant fusulines, mostly *Schwagerina*. The Bioclastic facies is composed of limestone consisting of nodular chert and an assemblage of finely broken fossils, dominated by Osagia facies. The Kaolinite facies is characterized by "calcareous shales in which kaolinite forms a significant proportion of the clay minerals (Imbrie and Laporte, 1964, p. 221)". The Chonetid facies is characterized by a fauna dominated by brachiopods, bryozoans, crinoids, and echinoids in calcareous shales and argillaceous limestones. The Dolomitic Shale facies consists of the high percentage of dolomite, as microscopic rhombohedra in a matrix of clay and calcite grains. The Algal-biscuit facies is characterized by "dense, pure limestones containing concentrically laminated, biscuit-shaped algal colonies an inch or more in diameter (Imbrie and Laporte, 1964, p. 221)". The Boxwork facies is reworked carbonate rock consisting of "dolomitic limestone and dolomite, unfossiliferous limestone with pink or reddish brown chert, dove-colored lime mudstones with small vertical burrows, and laminated dolomitic limestone with mudcracks (Imbrie and Laporte, 1964, p. 221)". Paleoecology of the entire Council Grove Group was analyzed more completely by Lane (1964). Lane recognized and described thirty-seven kinds of microfossils in the Council Grove Group of the Permian of mid-continent. This study of paleoecology of the Council Grove Group provides a basis for the interpretation of paleoenvironments of the shale and the relating of these ancient environments to Lower Permian cyclothems. More detailed description of the stratigraphy of the Lower Permian rocks was done by Mudge et al. (1962) and Jewett et al. (1968). Several theses at Kansas State University and The University of Kansas and Nebraska have dealt more fully with the investigation of the upper Council Grove Group; examples are the Cottonwood Limestone (Pecchioni, 1978), Beattie Limestone through Funston Limestone (Parish, 1952, Wilbur, 1954), Beattie Limestone through Stearns Shale (Snyder, 1968), Stearns Shale through Speiser Shale (Dishman, 1969), Eiss Limestone (Dietsch,1956, Dowling, 1967), Bader Limestone through Easly Creek Shale (Lorenzen, 1967), Crouse Limestone (Huber,1965, Voran, 1977), Crouse Limestone through Speiser Shale (Bigelow, 1954), Blue Rapids Shale (Asmussen, 1958), Blue Rapids Shale through Speiser Shale (Empie, 1964), and Speiser Shale (Cunningham, 1989).

Formation History and Type Section

Formations included in this study are in the upper part of the Council Grove Group, upper Asselian to lower Sakmarian Stages, Wolfcampian Series, Permian System. The Council Grove Group consists of approximately 300 feet of thin beds consisting of fossiliferous marine shale, limestone, nomarine shale, and sandstone (Zeller, 1968). In ascending order the upper Council Group consists of the Beattie Limestone, Stearns Shale, Bader Limestone, Easly Creek Shale, Crouse Limestone, Blue Rapids Shale, Funston Limestone, and Speiser Shale.

The Beattie Limestone

The Beattie Limestone was proposed by Moore (1936, p. 50). Moore combined three units into one formation; two limestone members and a shale member, namely the Cottonwood Limestone Member, Florena Shale Member, and Morrill Limestone Member, in ascending order. Thickness of the formation ranges from about 10 to about 25 feet.

Cottonwood Limestone Member

The Cottonwood Limestone Member was named as Cottonwood Falls Limestone by Haworth and Kirk (1894) from quarries near Cottonwood Falls, Kansas. The Cottonwood Limestone overlies the Eskridge Shale and underlies the Florena Shale Member. Prosser (1859) renamed it as the Cottonwood Formation, including the overlying shale (Florena Shale Member). Before 1902, this formation was refered to by several names at several different places: such as Fusulina limestone, Cottonwood stone, Cottonwood Falls Limestone, Alma Limestone, and Manhattan Limestone. Prosser (1902) divided this renamed formation into the Cottonwood Limestone and Florena Shale. The Cottonwood Limestone Member was proposed as part of the Beattie Limestone Formation (Moore 1936). The type section Prosser designated and described (1904, p. 2) is as follows and in Florena Shale section:

"This is a massive, light gray to buff colored, forminiferal limestone, frequently composed of two layers having a total thickness of 6 feet. The limestone on a fresh fracture is yellowish-gray to buff in color, weathering to light gray. Generally it appears along the side of the moderately steep bluffs as a series of large, smooth, rectangular blocks which have broken off from the main ledge. It is not , as was at one time thought, magnesian in character."

"The constant lithologic character of this limestone and its line of outcrop, frequently marked by a row of massive, light gray, rectangular blocks filled with *Fusulina secalica* (Say) Beede?, make it one of the most important stratigraphic horizons in the upper Paleozoic rocks for at least two-thirds of the distance across Kansas and into southeastern Nebraska."

Florena Shale Member

The Florena Shale was part of the Cottonwood Falls Limestone (Haworth et al., 1894 p. 712) or Cottonwood Formation (Prosser, 1894). Prosser (1902) divided and renamed the overlying shale in the Cottonwood Formation as the Florena Shale. It includes the zones between the Cottonwood Limestone below and Morrill Limestone above. In latter times, the Florena Shale Member was classified as member of the

Beattie Limestone (1936, p. 50). The type section Prosser designated and described (1904, p. 3) is as follows:

> "The lithologic composition of the Garrison formation as it exists in the Cottonwood Falls Quadrangle is well shown by the section of Crusher Quarry Hill, Supplemented by the exposures in Fox Creek quarry and the second railroad cut to the west, northwest of Strong the whole making a section extending from the Cottonwood below to the Wreford above."

General section of the Garrison formation

		Feet.
Neosho Member	16 Shales, yellowish fine at top, containing Florena shale fauna; the lower shales are coarser	23
	15. Limestone, Massive, in some localities 4 feet thick and occasionally quarried	3+-
	14. Shales, mainly yellowish, some greenish with thin shaly limestone	36
	13. Limestone, at tope, containing *Pseudomonoties* 2 feet 10 inches thick one layer of the limestone contains numerous small iron concretions and below are shales.	10 2/3
	12. Limestone, light gray containing *Pseudomonoties*	1 1/3
	11. Shales, green and Chocolate colored	20
	10. Limestones, light gray, shaly, containing *Pseudomonoties* and other fossils.	4
	9. Shales about 4 feet or more in thickness	4
	8. Limestone, dark gray, siliceous, on weathered surface very irregular with rough jagged prominence	2 +-
	7. Shales, yellowish argillaceous, containing some of the Florena shale fauna	6
	6. Shales yellowish, blocky, containing lamellibranch fauna of *Pseudomonoties* and *Aviculopecten*, which in some localities appear to form a massive rough limestone similar to No. 8	5
	5. Shale, greenish	7
	4. Shales, chocolate and drab	4
	3. Limestone, Shaly	4
Florena Member	2. Shale, buff containing but few fossils and small geodes partly filled with gypsum (?)	5 5/6
	1. Shales, yellowish containing and abundance of fossils	7 1/6

Morrill Limestone Member

Condra (1927) named the Morrill Limestone from exposures northwest of Morrill, Kansas. It was originally proposed as part of the "Garrison Formation". Moore (1936) reproposed the Morrill Limestone Member as part of the Beattie Formation. This limestone is defined as the interval between the Stearns Shale above and Florena Shale

Member below. The type section Condra designated and described (1927, p. 237) is as follows:

SECTION TWO MILES WEST AND ONE-HALF MILE NORTH
OF Morrill, KANSAS
I. Permian System, Council Grove Formation
1. Garrison Shale Member::
    (1). Eiss Limestone, 9' or More
        a. Limestone, weathered slabby, 2' exposed
        b. Shale, gray, calcareous, 6' 6".
        c. Limestone, with many specimens of bryozoa largely of the genus Theamniscus, 1' 6" to 1' 10".
    (2). Stearns Shale, blue, about 16'; upper 6' blue; middle 4' chocolate; basal 6' or more, bluish and poorly exposed, 1' to 2'.
    (3). Morrill Limestone, yellowish, poorly exposed, 1' to 2'.
    (4). Florena Shale, in slope, probably 5
2. Cottonwood Limestone member, poorly shown above covered slope, 5' or more.

Stearns Shale

The Stearns Shale was named by Condra (1927) for exposures near the town of Humboldt, Nebraska. It was originally proposed as part of the "Garrison Formation". Moore (1936) raised the Stearns Shale to formation rank. The unit was described as the shale bounded above by the Eiss Limestone and below by the Morrill Limestone Member. The type section Condra designated and described (1927, p. 234) is as follows:

SECTION NORTHEAST OF HUMBOLDT
Based On exposures along Spring Creek, in sections 1, 2, and 36 of T. 2N., R. 13 E.
I. Permian System, Council Grove Formation
1. Garrison member, about 40' exposed:
    (1). Easly Creek Shale, 11' 6''
        a. Limestone, along the Spring Creek Road, in sections 1 and 30, gray, blocky, shattered, weathered buff, 2'.
        b. shale, grayish green, massive, weathers sponge-like near top; bedded at the base, 9' 6''
        c. Shale, maroon, with grayish limy seams, 2'.
    (2). Eiss Limestone, 9' 6":
        a. Limestone, forms small waterfall in gutter aling Spring Creek road, light gray with small black specks, weathers rusty in some exposures 1' or more.
        b. Gray, bedded, weathers light colored, 6' 6"
        c. Limestone, shaly, quite fossiliferous, 2'. Fauna: Pectenoid.
    (3). Stearns Shale, 14':
        a. Greenish gray, bedded, calcareous, 4' 6"

b. Maroon with purplish tint, massive, jointed, 1'.

c. Variegated greenish brown, massive, nodular, leaches gray, 2'.

d. Gray, earthy, silty, massive, resists weathering, resembles limestone, 1'.

g. maroon, with greenish gray lenses, massive, 4'.

h. gray, bedded, quite calcareous, leaches withe, 1' 6''.

(4). Morrill Limestone, 2' 6".

a. Limestone, dense, hard, brittle, 5".

b. Shale, light gray, calcareous, massive, 8".

c. Limestone, 1' 4"; upper 4" weathers rusty and silty; basal 1' breaks into two or three hard, yellowish beds.

(5) Florena Shale, Poorly shown grayish, fossiliferous, 6" or more exposed, thickness probably 3'.

2. Cottonwood Limestone member, in section 36 and south in the escarpment in sections 1 and 2. The stone is typical, thickness 5' to 6'. It holds a bench.

Bader Limestone

Moore (1936) proposed Bader Limestone Formation, and abandoned "Garrison Formation". The Eiss Limestone Member, Hooser Shale Member, and Middleburg Limestone Member were classified as members of the Bader Limestone (Moore, 1936). The thickness ranges from about 5 to about 20 feet.

Eiss Limestone Member

Condra (1927) named the Eiss Limestone Member defining it as the limestone overlying the Hooser Shale and underlying the Stearns Shale, for exposures at the Eiss farm located 8 miles south of Humboldt, Nebraska. Condra originally recognized this formation as an unit of the old "Garrison Formation". The Eiss Limestone was proposed as a member of the Bader Limestone Formation by Moore (1936, p. 50). The type section Condra designated and described (1927, p. 229) is as follows:

SECTION, FIVE AND ONE-HALF MILES SOUTH OF HUMBOLDT.
Made on beds dipping eastward in sections 3 and 9 of T. 1 N., R. 13 E.

1. Garrison Shale member, about 34' exposed in the Eiss Hill in the northwest quarter of Section 3, T. 1 N, R. 13E.;

(1). Easly Creek Shale, weathered buff to brownish, about 5' of the lower portion shown in which is a cavernous, gypsiferous zone.
(2). Eiss Limestone, 9' 10"
  a. Limestone, one layer, dark gray, siliceous, hard, massive, forms large rectangular blocks, 1' 3" to 2'. This holds the rim of the Escarpment.
  b. Shale, bluish, argillaceous, with fine calcareous material, quite fossiliferous, about 7'. Fauna: Chonetes granulifer, Rhombopora lepidodendroides, etc.
  c. Limestone, dark gray, earthy, becomes hard on exposure and shatters, 1' 4". Fauna: Chonetes granulifer, pelecypods and many specimens of Thamniscus, Fenestella, and Rhombopora at the top.
(3). Stearns Shale, 18' 3":
  a. Dark gray, with a calcareous crust at the base, 6'.
  b. Dark maroon, argillaceous, 6'.
  c. Gray, slabby, calcareous, 6' 3".
(4). Morrill Limestone, Gray, hard, massive, 1' to 1' 3".
(5). Florena Shale, light gray, very calcareous, 2' to 3' 6".

2. Cottonwood Limestone Member, light gray, with many Fusulina, forms large, rectangular blocks, 6' to 7'.

Hooser Shale Member

The Hooser Shale Member was named by Condra and Upp (1931, p. 20) from exposures near the town of Hooser in Cowley County, Kansas. The unit was described as the shale overlain by the Middleburg Limestone and underlain by the Eiss Limestone. The Hooser Shale was part of the "Garrison Formation". Moore (1936, p. 50) classified the Hooser Shale as a member of the Bader Limestone. The type section Condra designated and described (1927, p. 234) is as follows:

SECTION

The Council Grove Group at Hooser, Kansas. Made on outcrops in slopes, in the railroad and highway cuts, and in the ravines; thickness 140': members:

1. Speiser Shale, poorly shown, tip zone gray; middle zone largely red with a bed of sandstone near the middle; basal zone gray; combined thickness, about 34'-35'.
2. Funston Limestone, exposed in railroad cuts and in ravine south of station, best shown in cut just north of station, 11' 4": zones:
  (1) Limestone, bluish-gray, massive, dense, 2' exposed.
  (2) Limestone, bluish, in layers separated by shale seams, with Thamniscus, Septopora, Polypora, Fenestella, Productus cora, etc., 3' 6".
  (3) Limestone, blue, dense, fossiliferous, 6".
  (4) Shale, bluish to nearly black, 2'.
  (5) Limestone, badly shattered and weathered, fossiliferous, 1' 6".
  (6) Limestone, gray, mottled dark, massive, dense, blocky, with small stringers of chert near top at places: top 1"- 1 1/2" and slabby; combined +thickness, 1' 10".
3. Blue Rapids Shale, weel shown in railroad cut southeast of station, 15' 6"; zones:

(1) Shale, olive, argillaceous, 4'.
(2) Shale, gray and red, argillaceous, 3'.
(3) Shale, gray, argillaceous, 2'.
(4) Shale, slabby, calcareous, 2'.
(5) Shale, olive, argillaceous, 4' 6".

4. Crouse Limestone, in railroad cut southeast of station and on highway east, about 12'; zone:
   (1) Limestone, light gray, massive, some chert, 5'.
   (2) Limestone, shattered, and some shale with Osagea, Compositas, Thamniscus, etc., 2' 6".
   (3) Shale, greenish-gray, with limy layers, small flat concretions, 2'.
   (4) Limestone, Gray, massive, earthy at base, with pelecypods, 2'-3'.
5. Easly Creek Shale, in highway gutter and in ravine east, 11'-12': zones;
   (1) Shale, gray, 2'-3'.
   (2) Shale, red, argillaceous, 8'.
   (3) Shale, gray, calcareous, 1'-2'.
6. Middleburg Limestone, about 8' 6"; zones:
   (1) Limestone, gray, one bed or broken by slabby layers, 2'.
   (2) Shale, gray, stained pink, argillaceous but filled with sand-lime seams, fossiliferous, 5'.
   (3) Limestone, two evenly bedded layers separated by s shale seam, lower bed disintegrated: combined thickness, 1' 4".
7. Hooser Shale, 11'; zone:
   (1) Shale, gray above and pink to red below, 2'.
   (2) Shale, gray, with lime seams, very fossiliferous, 3' 6".
   (3) Shale, olive, 3'.
   (4) Shale, in bands of red and gray, nodular at base, 2' 6".
8. Eiss Limestone, 7' or more; zones;
   (1) Limestone, dark gray, dense, with some chert, nodular, weathers yellowish, 3'.
   (2) Shale, gray above, pinkish below, very fossiliferous, 2'.
   (3) Limestone, gray, disintegrated, shaly at top and bottom, very fossiliferous, 2'.
9. Stearns Shale, about 10'; zones:
   (1) Shale, gray, with limy seams, fossiliferous, Myzlina, Chonetes, etc., 2' 9".
   (2) Shale, olive, 1' 6".
   (3) Shale, red, 5'-6'.
10. Morrill Limestone, gray, dense, top crumpled: middle shattered: basal part massive, weathered with vertical openings, stained yellowish-brown; combined thickness, 7'-8'.
11. Florena Shale, best shown 2 miles south and 1/4 mile west of Hooser, gray, argillaceous, with other fossiliferous limy layers in lower party, about 7'-8'; grading into the limestone below.
12. Cottonwood Limestone, gray badly broken down, with shale partings, about 4'.

Middleburg Limestone Member

The Middleburg Limestone Member was named by Condra and Upp (1931, p. 20) from exposures near the Middleburg School in Richardson County, Nebraska. This was bounded above the Easly Creek Shale and below by the Hooser Shale. The Middleburg Limestone was part of the "Garrison Formation". Later, the Middleburg Limestone Member was proposed as part of the Bader Limestone by Moore (1936, p. 50). The type section Condra designated and described (1931, p. 24) is as follows:

SECTION NUMBER (5)

The council Grove Group in Nebraska, near state line, about 10 miles south and 2 miles east of Humboldt, Nebraska; thickness about 137'; members:

1. Speiser Shale, largely argillaceous, 18'- 19'; zones:
    (1) Shale, olive colored, with thin limy-sandy seams, 2'.
    (2) Limestone, gray, blocky, 6"-8".
    (3) Shale, gray to live, argillaceous, 3'-4'.
    (4) Shale, gray, gray-pink, or largely red, argillaceous, 6'.
    (5) Shale, gray, argillaceous, 2'-3'.
    (6) Shale, gray-red or red, argillaceous, 2'-3'.
    (7) Shale, gray or olive, argillaceous, 1'.
2. Funston Limestone, about 8'; zones:
    (1) Limestone , light gray, massive, dense, blocky; forms rounded boulders, 1'-1' 6".
    (2) Shale, bright olive colored, argillaceous, crumbly, 3'-4'.
    (3) Limestone, gray, Massive, weathers irregular at base, 1'.
    (4) Shale, dark gray, irregular, 2"-6'.
    (5) Limestone, ray, somewhat arenaceous, weather yellowish- brown and irregular, 1' 6".
3. Blue Rapids Shale, 22'; the section is on the north-south road at the head of Honey Creek, 3/4 mile south of the state line. This is about 9 1/4 miles south and 1 mile west of Dawson, Nebraska; zones:
    (1) Shale, greenish-gray, massive, argillaceous, 4'-5'.
    (2) Sandy-lime, weathered buff and irregular, 8"-10".
    (3) Shale, olive colored, massive, argillaceous, with chocolated-0red seam near base 4".
    (4) Mudstone, light gray to buff, somewhat arenaceous, weathers bedded, 2'.
    (5) Shale, gray, bedded, argillaceous, 1' 2".
    (6) Shale, chocolated-maroon, massive, blocky, argillaceous, 2' 6".
    (7) Shale, greenish-gray, largely bedded, argillaceous and crumbly,
    with some mudstone and vesicular boxwork at places 5'-6'.
    (8) Mudstone, greenish-gray, limy, arenaceous, indurated, weathers light gray, 1'.
    (9) Shale, dark gray , 1'.
4. Crouse Limestone, 11'; zones:
    (1) Limestone, light gray but dark gray on surface, massive, granular, weathering gray-buff and at places pitted, 2'-3'.
    (2) Shale, olive colored, with some sandy seams and calcareous aggregate, 7'.
    (3) Limestone, dark gray, earthy, shattered or slabby quite fossiliferous, 1' 6".
5. Easly Creek Shale, about 14'; zones:
    (1) Shale, olive, argillaceous, weathers grayish, 4'.
    (2) Shale, maroon-gray more or less mixed, about 10'.
6. Middleburg Limestone about 4'; zones:
    (1) Limestone, gray, massive, granular, dense, weathers buff-gray, about 1' 4".
    (2) Limestone, variegated light to dark gray, massive, tough, with many small dark-colored, high-
    spired gastropods, 1' 6".
    (3) Shale, olive, 6"-1'.
    (4) Limestone, dark gray, blocky, dense, 2"- 3".
7. Hooser Shale, 11'; zones:
    (1) Shale, olive, calcareous-argillaceous, fossiliferous, weathers buff, 2'.
    (2) Shale, weathered buff, with boxwork at paces, 1'.
    (3) Shale, grayish, with calcareous concretionary subzone near base and a reddish subzone below the middle, about 8'.
8. Eiss Limestone about 9' 6"; zones:
    (1) Limestone, grayish, massive, siliceous, granular, dense; weathers gray-buff, 1' 3"-2'.
    (2) Shale, olive, argillaceous, massive, with some lime aggregate, fossiliferous at base, 5'-7'.
    (3) Limestone, dark gray, shaly, especially so at top, very fossiliferous, 1' 6"-2'.

9. Stearns Shale, about 17'; zones:
    (1) Shale, olive, massive, crumbly, largely argillaceous, with some calcareous aggregated, weathers
        gray, 5'-6'.
    (2) Mudstone, not well developed, 4".
    (3) Shale, lavendar-maroon, about 5'.
    (4) Boxwork, gray, irregular, weathers buff, 1'.
    (5) Shale, olive, with some calcareous material, 5' or more.
10. Morrill Limestone, two gray limestone separated by a thin shale; stone weathers brownish; about 3'-4'.
11. Florena Shale, olive colored at top; middle and base light gray with much calcitic material and quite fossiliferous; Chonetes granulifer abundant, 5'-10'.
12. Cottonwood Limestone, light gray, massive to slabby, with some small bodies of chert; quite fossiliferous at places, 6'-11'.

Easly Creek Shale

The Easly Creek Shale was named by Condra and Upp (1931, p. 19) from exposures on Easly Creek , Richardson County, Nebraska. The unit was described as the shale bounded above by the Crouse Limestone and below by the Middleburg Limestone. The Easly Creek Shale was originally recognized as an unit of the "Garrison Formation". Later, the Easly Creek Shale was promoted to formation rank by Moore (1936, p. 50). The type section Condra designated and described (1927, p. 232) is as follows:

COMBINED SECTION BETWEEN EASLY CREEK AND SABETHA, KANSAS

Between Section 35 and 36, T. 1 N., R. 13 E., about 8 miles south and 2 1/2 miles west of Dawson and northeast of Sabetha. This section, run primarily to show the thickness and character of the Permian beds, is as follow:

I. Permian System: Chase and Council Grove Formations, about 118' exposed

1. Wreford Limestone member, in high upland, altitude of base 1,280' on the east, dropping to 1,255' or 1,260' in the exposures farthest west and north. The stone has much bluish gray flint, which, being released through the disintegration of the limestone, litters the slopes below. Only the lower porting of the member is shown. Fauna: several species of bryozoa, brachiopods, Pinna, etc.

2. Garrison Shale member, 112':
    (1). Speiser Shale, about 47:
        a. shale, 19':
            (a). Greenish blue, with small calcareous bodies, about 9'.
            (b). Bluish and reddish bands, argillaceous, 10'.
        b. Limestone and Shale, 7' to 8':
            (a). Limestone, light gray, dense, forms conspicuous, small boulders which weather pitted, 1' or more. Fauna: Pseudomorphs of gastropods in places.
            (b). Shale, light gray, calcareous, 4' to 5'.

(c). Limestone, gray, weathers yellowish brown and cavernous, 1' 6" to 2'.

c. Shale, bluish or bluish ray, with a thin band of maroon near the base, small calcareous concretions in the grayish zones, 18' to 23'.

(2). Sabetha Limestone, about 12':

a. Limestone, gray, weathering gray or yellowish brown, 3' to 4'; upper and lower portions tabular; middle portion massive, granular, with oolitic appearance, forms large rounded boulders. This holds a well defined rock terrace. Fauna: Gastropods, a few brachiopods, and fragments of bellerophons and pelecypods.

b. Shale, bluish gray, calcareous, with limy nodules, 6' to 7'.

c. Limestone, gray, 2' to 3'; upper portion shaly and very fossiliferous; lower portion dense massive. In places there are shale and limestone seams at the base. Fauna: Thamniscus, common; Aviculopecten, Echinoid spines, brachiopods, etc.

(3). Easly Creek Shale; about 26':

a. Shale, in blue, gray, greenish-gray, and reddish bands, part quite calcareous, 12'.

b. Limestone, gray, 2' to 4'; massive and hard above; somewhat earthy and shattered below, with myriads of small gastropods in the basal portion at places.

c. Shale, 10' to 12':

(a). Shale, buff gray, massive, 1'.

(b) Limestone, blocky, 2" to 3".

(c). Shale, weathered buff, massive, 1' 10".

(d). Shale, limy, irregular, like box-work in places, 10".

(e). Shale, grayish, with small calcite concretions, about 7' to 8'. This has a reddish band at places.

(4). Eiss Limestone, about 9':

a. Limestone, dark gray, massive, siliceous at places, forms irregular blocks; no fossils observed, 1' 3" to 2'.

b. Shale, bluish, argillaceous, with some small calcareous concretions; fossiliferous, about 5' 6".

c. Limestone, dark gray, earthy, forms fine debris; with may bryozoa, brachiopods, etc., in a crust on the upper surface, 1' 6" to 2'. Thamniscus common; some small gastropods.

(5). Stearns Shale, 14' to 18':

a. Grayish, calcareous, 1' 6" to 2'.

b. Bluish gray argillaceous, crumbly, 4' to 6'.

c. Chocolate or reddish, argillaceous, 5' to 8'.

d. Light gray, limy, loosely indurated, 2'.

(6). Morrill Limestone, grayish, quite hard, 1' 6" to 3'; irregular above, weathering grayish; basal portion weathering brownish and cavernous.

(7). Florena Shale, light gray, calcareous, with many Chonetes granulifer and a few other species, 3' to 5'. At some points this unit is quite firmly indurated becoming limestone which grades into the cottonwood, forming with the latter nearly solid ledge.

2. Cottonwood Limestone member, holds rock bench, and forms large light gray blocks, 6' to 7'. This unit is in much of the upland south of the upland south of the South Fork Nemaha.

Crouse Limestone

The Crouse Limestone was named by Heald (1917, p. 21-22) from an exposure at Crouse Hill in the northwest part of the Foraker Quadrangle in Osage County, Oklahoma. The Crouse Limestone is defined as the interval between the Easly Creek Shale below and Blue Rapids Shale above. Condra (1927) named and described this limestone as "Sabetha Limestone." Condra did not know Sabetha is correlative with the Crouse Limestone. It was not until Base (1929, p. 66) traced the "Sabetha Limestone" into Oklahoma that the fact became clear that the Crouse and Sabetha were the same formation. The Crouse Limestone originally was recognized as part of the "Garrison Formation". Moore (1936) elevated this limestone to formation rank. The type section Heald designated and described (1917, p. 22) is as follows:

> Section of Crouse Limestone in the SW, NE of Sec. 23, T. 29 N., R. 5E., Foraker Quadrangle Osage County, Oklahoma.
>
> "A prominent limestone about 3 feet thick, the Crouse, lies approximately 70 feet below the base of the Wreford. Its outcrop is almost invariably conspicuous, and the rock is distinctive enough to make it easily recognizable. The characteristic features of this limestone are the form of the outcrop, which shows many large, massive blocks, the absence of recognizable fossils in any abundance, with the exception of small Fusulinas, which are plentiful, and the presence of many smooth, round holes that are vertical or steeply inclined to the bedding. There are similar holes in other limestones of this region, but nowhere were they noted in such numbers as in the Crouse limestone" (Heald, 1917, p. 22).

Blue Rapids Shale

Condra and Upp (1931, p. 22) named the Blue Rapids Shale for exposures just north of Blue Rapids, Kansas. This shale was bounded above by the Funston Limestone and below by the Crouse Limestone. The Blue Rapids Shale originally was recognized as part of the "Garrison Formation". Later, the Blue Rapids Shale was raised to formation rank by Moore (1936, p. 50). The type section Condra designated and described (1931, p. 22) is as follows:

SECTION NUMBER 3

Blue Rapids Shale, 1 1/4 miles north of Blue Rapids, Kansas, 21':; zones:

1. Shale, gray, argillaceous; dark and bedded at middle; calcareous and very fossiliferous in basal 1' which carries many specimens of Thamniscus octonarius, an some specimens of Septopora, Derbya, etc.; thickness, 6'.
2. Limestone, gray fossiliferous, with high-spired gastropods, Thamnicus, Polypora, Fenestella, Septopora, etc., about 1'.
3. Shale, gray, probably 1'.
4. Limestone, gray, blocky, granular, with gastropods and some ostracods, 5".
5. Shale, olive colored, with nodular lime at top, 1' 6".
6. Shale, not so plastic as division 5, weathers buff, 1' 10".
7. Shale, red, with some gray, 3'.
8. Shale, gray, with platy seams, 1' 6".
9. limestone, gray, with crinoid joints in upper portion, 1'.
10. Shale, gray with some calcareous material, 1' 6".
11. Mudstone, dark gray, bedded, loosely indurated, 2' 6".

Funston Limestone

The Funston Limestone was named by Condra and Upp (1931, p. 23) from exposures Camp Funston, Riley County, Kansas. The Funston Limestone is defined as the interval between the Blue Rapids Shale below and the Speiser Shale above. Condra and Upp originally recognized this limestone as an unit of the "Garrison Formation". Moore (1936) raised the Funston Limestone to formation rank. The type section Condra and Upp designated and described (1931, p. 22) is as follows:

The Funston is about 8 feet thick at the type locality as follow:

1. Limestone, gray, massive, fossiliferous, 1' 6"
2. Shale, badly covered, greenish-gray, argillaceous, about 1'.
3. Limestone, gray, massive, fossiliferous, 1' 6".
4. Shale, greenish, 6"-1'.
5. Limestone, medium dark gray, massive, blocky, sandy at places, 3'.

Speiser Shale

The Speiser Shale was named by Condra and Upp (1931, p. 22) from exposures in Speiser Township, Richardson County, Nebraska. The unit was described as the shale overlain by the Wreford Limestone and underlain by the Funston Limestone. The Speiser

Shale originally included the series of shales and limestones between the Crouse Limestone and Wreford (1927, p. 234) and was recognized as part of the "Garrison Formation" (1927, p. 234). Later, the term Speiser was restricted to the uppermost shale unit of the Council Grove Group (Condra et al., 1931), but also the Speiser Shale was raised to formation rank by Moore (1936, p. 50). The type section Condra designated and described (1931, p. 24) is as follows:

SECTION NUMBER 4

The Speiser Shale, exposed southeast of Randolph, thickness, about 17' 6"; zones:

1. Shale, dark gray fossiliferous, 1'.
2. Limestone, dark gray, earthy, fossiliferous, 5".
3. Shale, dark gray, fossiliferous, 1' 6".
4. Limestone, dark gray, earthy, fossiliferous, 6"-8".
5. Shale, olive, argillaceous, 2' 6".
6. Shale, chocolate and some gray, 6".
7. Shale, gray, 1'.
8. Shale, in gray and red bands, 10'.

Formations of the Study Section

The Council Grove Group consists of about 310 to 330 feet (94 to 100 meters), of which the upper 124 to 160 feet (38 to 49 meters) from the Beattie Limestone through Speiser Shale are discussed in this report. Lithologically this part of the Council Grove Group is mainly silty to calcareous shale and flaggy to massive limestone; it contains localized beds of sandstone and siltstone. The limestone is generally thick, light in color, and fossiliferous. The shale is quite variable in thickness, fossil content, color, and structure. Thickness of this interval of the upper Council Grove Group, from the Beattie Limestone through the Speiser Shale ranges from 124 feet (38 meters) in northern

Kansas to 160 feet (49 meters) in southern Kansas. The selected exposures from the Beattie Limestone through the Speiser Shale were measured and described from southern Kansas through central Kansas to northern Kansas. A total of thirty-eight intervals have been described and investigated from eleven exposures.

Beattie Limestone

The entire or partial section of the Beattie Limestone Formation was found in five exposed outcrops (Nk#1, Ck#1and 3, SK-7, and Sk-rd). This formation consists of the Cottonwood Limestone Member, Florena Shale Member, and Morrill Limestone Member. Thickness of the Beattie ranges from about 17 to 36.5 feet (5.2 to 11.2 meters).

Cottonwood Limestone Member

The Cottonwood Limestone is massive limestone; light buff, weathering light gray in northern and central Kansas (Nk#1, Ck#1). The limestone beds are poorly developed in southern Kansas. In the Cowley County outcrop area (Sk-rd) the Cottonwood Limestone varies from thin beds of soft light-colored sparsely fossiliferous limestone with many shale partings to a sparsely fossiliferous silty mudstone. Fusulinids are fairly common in the upper part , whereas gastropods, pelecypods, and brachiopods are common in the lower portion of this limestone. The Cottonwood Limestone Member averages 7 feet (2.1 meters) in thickness. A maximum of 11 feet (3.4 meters) was seen in Cowley County; a minimum of 4 feet (1.2 meters) was observed in Chase County.

Florena Shale Member

The Florena Member is consists of brownish gray, calcareous shale that is abundantly fossiliferous. In southern outcrops, several thin nodular limestone beds are in the upper part of the Florena shale. Fauna of the Florena contains numerous species of pelecypods, brachiopods, and trilobites. In general, the variety of fossils is greater in southern outcrops than in northern or central Kansas. The interval of this shale thins into the northern outcrop area. It ranges from 3 feet (0.9 meters) in Riley County to more than 17 feet (5.2 meters) in Cowley County. Throughout the observed area, the Florena Shale Member thins to the north.

Morrill Limestone Member

The Morrill Member is brownish gray wavy-thin to massive limestone with vugs, containing a yellowish gray or olive-gray shale parting. Vugs are commonly filled with crystalline calcite and siliceous mineral in the central and northern outcrops (Nk#1 and Ck#3). In general, brachiopods and gastropods are common in the lower portion of this limestone, but the upper limestone is mostly rarely fossiliferous. In southern Kansas (SK-rd), the Morrill contains many fusulinids in the lower limestone and algal limestone in the upper limestone. The Morrill averages about 7 feet (2.1 meters) in thickness; it ranges from 4.5 feet (1.4 meters) in Chase County to 8 feet (2.4 meters) in Cowley County and thickens both north and south from Chase County

Stearns Shale

The entire thickness of the Stearns Shale was measured from three localities (Nk#1, CK#3, and SK-rd). The Stearns is mostly gray to olive-gray shale, containing red shale in the lower part of northern outcrop. The shale, rarely fossiliferous, is generally crumbly in the southern outcrop area (Sk-rd) and blocky in the central and northern outcrop area (Ck#3 and Nk#2). Locally, it contains thin beds of limestone in Riley (NK#2) and Cowley County (Sk-rd). Brachiopods and gastropods are common in these thin-bedded limestones. Vertically-oriented columnal carbonate mass was observed in the lower part of the central outcrop. The Stearns averages 15.5 feet (4.7 meters) in thickness. It thickens both northward and southward from Chase County, where it is about 7.3 feet (2.2 meters) thick. A maximum of about 23 feet (7 meters) was observed in Riley County.

Bader Limestone Formation

Complete or partial exposures of the Bader Limestone were found in seven localities (Nk#1, Ck#1 through 4, Sk7, and Sk-rd). This formation consists of the Eiss Limestone Member, Hooser Shale Member, and Middleburg Limestone Member. Thickness of this formation ranges from 16 to 27 feet (4.9 to 8.2 meters).

Eiss Limestone Member

The Eiss is comprised of lower, middle, and upper limestones separated by crumbly shale. The lower limestone is shaly, thin-bedded, and fossiliferous. The middle part is shale or siltstone, gray to olive, and locally fossiliferous. This middle unit thickens into Chase County. The upper part is massive limestone, containing chalcedony in the northern outcrop (Nk#2) and vugs in the central outcrop (Ck#3 and 4). Gastropods, brachiopods, echinoderms, and crinoid columnals are common in the limestone.

Thickness of the Eiss limestone is quite variable; it ranges from less than 5 feet (1.5 meters) in Riley County to as much as 17 feet (5.2 meters) in Chase County. It thins both north and south from Chase County, where it is about 4 feet (1.2 meters) in thickness.

Hooser Shale Member

The Hooser Member consists of gray to grayish-green and red shale, locally containing thin beds limestone in the northern outcrop. Pelecypods are the predominant fossil. The Hooser averages 6 feet (1.8 meters) in thickness. Its maximum measured thickness is 9.5 feet (2.9 meters) in Riley County, whereas the minimum measured thickness was 3.5 feet (1.1 meters), in Cowley County. In general this limestone unit thickens to the north.

Middleburg Limestone Member

The Middleburg Member is comprised of an upper and a lower limestone separated by grayish black shale The shale is silty, calcareous, and laminated and can be traced across Kansas. The lower part is yellowish brown or gray massive fossiliferous limestone, containing fairly abundant gastropods. The upper portion of this limestone is thin to massive, and includes localized vugs in Riley County (Nk#1). Generally, more variation between localities was observed in the upper limestone unit. Pelecypods, brachiopods, and crinoid columnals are in the basal limestone layer whereas algae occur locally in the upper bed. The Middleburg Limestone Member averages about 4.5 feet (1.4 meters) in thickness. The maximum thickness of 6.5 feet (2 meters) was observed in Cowley County and the minimum of 3.5 feet (1.1 meters) was seen in Riley County. In general this limestone unit is somewhat thicker in the south than in the north.

Easly Creek Shale

The complete thickness of the Easly Creek Shale was measured from four exposed outcrops (NK#2, Ck#2, Sk-38, and Sk-7). The shale is predominantly red and green and unfossiliferous. The gray to green shale generally is blocky and the red shale commonly is crumbly, without apparent structure. Localized thin argillaceous limestone was found in the northern outcrop of the Easly Creek Shale. The Easly Creek Shale is comparatively uniform in thickness throughout the outcrop. In northern Kansas, it is 13 feet (4 meters) thick, but it is 15 feet (4.6 meters) thick in central Kansas, and thickens to about 16 feet (4.8 meters) in southern Kansas.

Crouse Limestone

Complete and partial exposures of the Crouse Limestone was found in five localities (NK#2, Ck#2, Sk38, Sk7, and Sk166-1). In the northern and central localities, this formation has two divisions of limestone separated by several feet of dark gray and yellowish gray silty and blocky shale. The Cowley County outcrop is comprised a single continuous carbonate unit of the Crouse Limestone. The lower part generally is medium to laminated bedded limestone containing high-spired gastropods and discoidal fossil algal colonies, which at least in part are coatings on clam shells. The upper part of the Crouse Limestone is laminated and platy limestone that is sparsely fossiliferous in Riley County (Nk#2) whereas it is massive limestone with vugs in Chase and Cowley Counties (Ck#3 and Sk-7). The Crouse averages about 15 feet (4.6 meters) in thickness, ranging from 12 to 19 feet (3.7 to5.8 meters), it thins somewhat both north and south from Chase County where It is about 19 feet (5.8 meters) thick.

Blue Rapids Shale

Complete or partial exposure of the Blue Rapids Shale was observed at four localities (Nk#1, Ck#5, Sk38, and Sk166-2). The Blue Rapids is composed of vari-colored shale with gray, green and red being the common colors. The green and red shale in this formation commonly is crumbly, gray shale generally is fissile. Several thin-bedded limestones were found in this formation, but not in measured section SK 166-2. These limestones commonly are argillaceous limestone that is poorly fossiliferous, but locally the rock contains gastropods and brachiopods in the Chase County outcrop (Ck#5 and 6). Thickness of this shale is almost uniform; it averages about 14.5 feet (4.4 meters). Thickness ranges from 11 to about 16 feet (3.4 to 4.9 meters). In general this limestone unit is somewhat thicker in central Kansas than in southern and northern Kansas.

Funston Limestone

The complete Funston Limestone was measured from five exposed outcrop localities (Nk#2, Ck#5 and 6, Sk38, and Sk166). This formation is comprised of three carbonate units separated by gray to brown shale. Locally, the shale is calcareous and contains nodular and partly fossiliferous limestone. The lower unit is massive limestone in Chase and Cowley Counties (Sk 166-2 &3, Sk38, and Ck#5 &6) and thin-bedded limestone in Riley County (Nk#2). Brachiopods, gastropods, bryozoa, algae, and intraclasts are common in the lower unit. The middle unit of the Funston is more variable from exposure to exposure, ranging from massive to thin-bedded limestone in the Riley and Chase County outcrops to siltstone, fine-grained sandstone, and limestone in Cowley County outcrop (Sk166-3). The upper unit of this formation is thin to laminated limestone beds interbedded with silty shale or massive limestone. The Funston Formation ranges from about 7.5 to 23 feet (2.3 to 7 meters) in thickness, averaging about 15 feet (4.6 meters) across the exposure, but thickening to the north.

Speiser Shale

The entire interval of the Speiser Shale was investigated from four exposed outcrops (Nk#2, Ck#6, Sk38, and Sk166-3). This unit generally is crumbly to blocky silty shale with several thin beds of limestone. Generally, the lower portion is sparsely fossiliferous red shale with caliche, and the upper portion is an unfossiliferous green shale. Some laminated siltstone and massive sandstone were found locally in the southern Kansas outcrop (SK 166-3). Beds of thin limestone occur generally in the upper portion of the Speiser Shale and contain fairly abundant gastropods and brachiopods. The Speiser Shale averages 22.5 feet (6.9 meters) in thickness. In northern Kansas it is about 16.5 feet (5 meters) thick, thickening southward to as much as 31 feet (9.4 meters) in Cowley County.

Detailed descriptions of the formations are on the following pages.

Lithology Symbols

▦ Limestone

▩ Red Shale

⠿ Sandstone

▨ Green Shale

▤ Siltstone

☰ Shale

Facies Abbreviation

(1). CSa: Channelized Sandstone Facies
(2). RGPa: Red or Green Paleosol Facies
(3). SS: Silty Shale and Siltstone Facies
(4). PeP: Peloid Packstone Facies
(5). SiCh: Siliceous Chalcedony Facies
(6). IWP: Intraclast Wackestone to Packstone
(7). OsM: Ostracod Mudstone Facies
(8). GWP: Gastropod Wackestone to Packstone Facies
(9). BGWP: Brachiopod-Gastropod Wackestone to Packstone Facies
(10). BBzOWP: Brachiopod-Bryozoan Oncoid Wackestone to Packstone Facies
(11). BBzWP: Brachiopod-Bryozoan Wackestone to Packstone Facies
(12). FoS: Fossiliferous Shale Facies
(13). FWP: Fusulinid Wackestone to Packstone Facies

Sequence Abbreviation

TS 〰〰	Transgressive Surface (Sequence Boundary)
MFS	Maximum Flooding Surface
LST	Lowstand Systems Tract
HST	Highstand Systems Tract
TST	Transgressive Systems Tract

Figure 27. Key to symbols and abbreviations in measured sections.

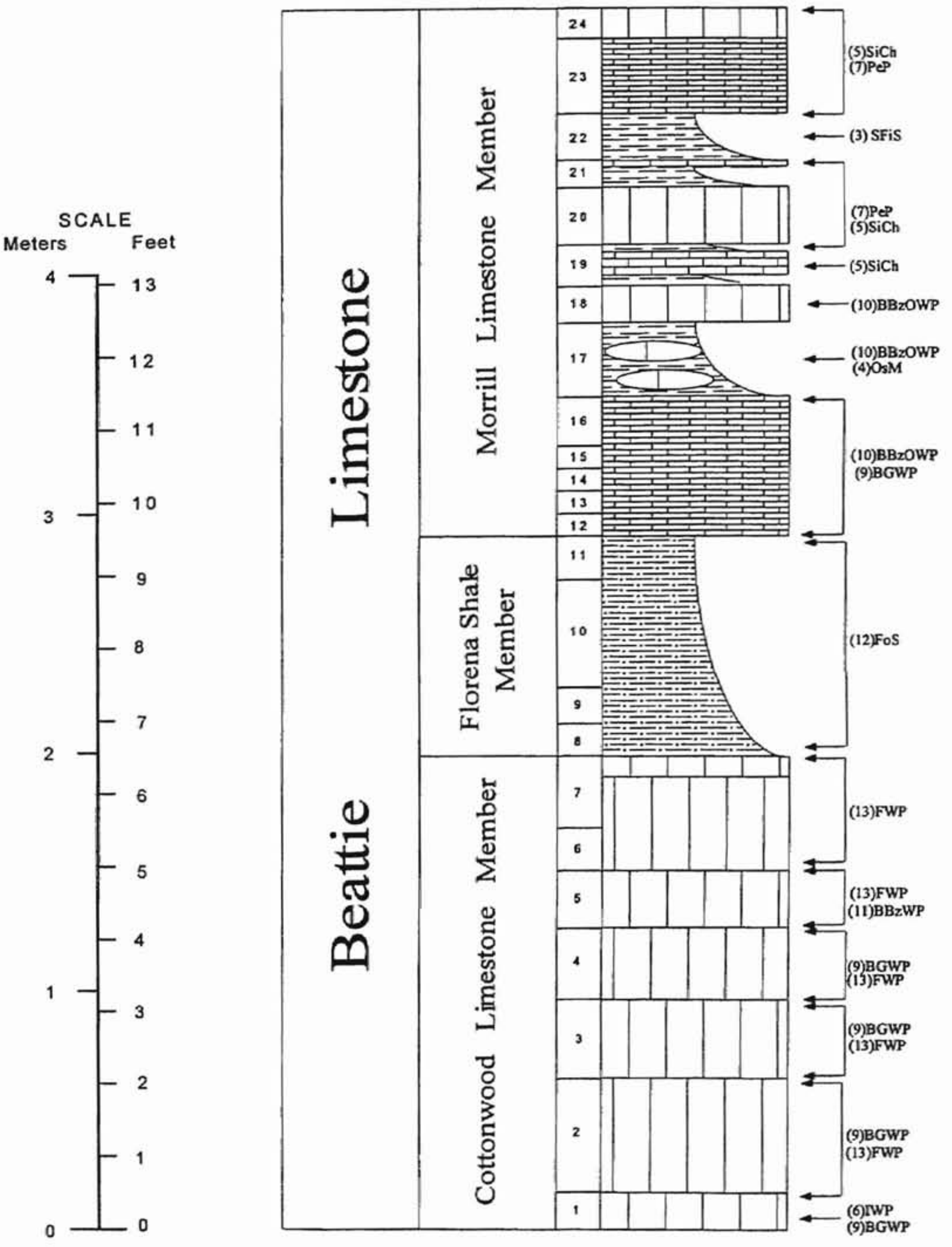


Figure 28. Measured Section NK #1, Beattie Limestone.

State: Kansas County: Riley

Locality Description:

Roadcut on both west and east sides of Anderson Road in Manhattan, Kansas,
W/2, Section 10, T10S, R7E, Keats 7.5' Quadrangle, Riley County, Kansas.

UNIT DESCRIPTION

Beattie Limestone

Morrill Limestone

24	0.5 ft.	wackestone, peloid, algae, chalcedony, moderate yellowish gray
23	1 ft.	wackestone, peloid, algae, micrite, yellowish gray
22	0.7 ft.	shale light olive brown, fissile
21	0.3 ft.	shale with limestone limestone: mudstone, micrite, hematitic, chalcedony, gray shale, dark yellowish orange
20	0.8 ft.	wackestone, peloid, algae, micrite, chalcedony, yellowish gray
19	0.4 ft.	shale with limestone limestone: mudstone, micrite, chalcedony
18	0.5 ft.	mudstone to wackestone, brachiopods, bryozoa, echinoderms, algae, micrite, hematitic, yellowish gray
17	1 ft.	shale with nodular limestone nodular limestone: mudstone, brachiopods, micrite shale: yellowish gray, calcareous, fissile
16	0.7 ft.	wackestone to packstone, brachiopods, echinoderms, ostracodes, algae, micrite, dark medium gray
15	0.3 ft.	mudstone, peloid, brachiopods, trilobites, micrite, dark medium gray
14	0.3 ft.	wackestone, brachiopods, echinoderms, bryozoa, ostracodes, micrite, dark medium gray
13	0.3 ft.	wackestone to packstone, brachiopods, bryozoa, echinoderms, trilobites, dark medium gray, flaggy
12	0.3 ft.	wackestone, peloid, brachiopods, gastropods, echinoderms, micrite, dark medium gray

UNIT DESCRIPTION

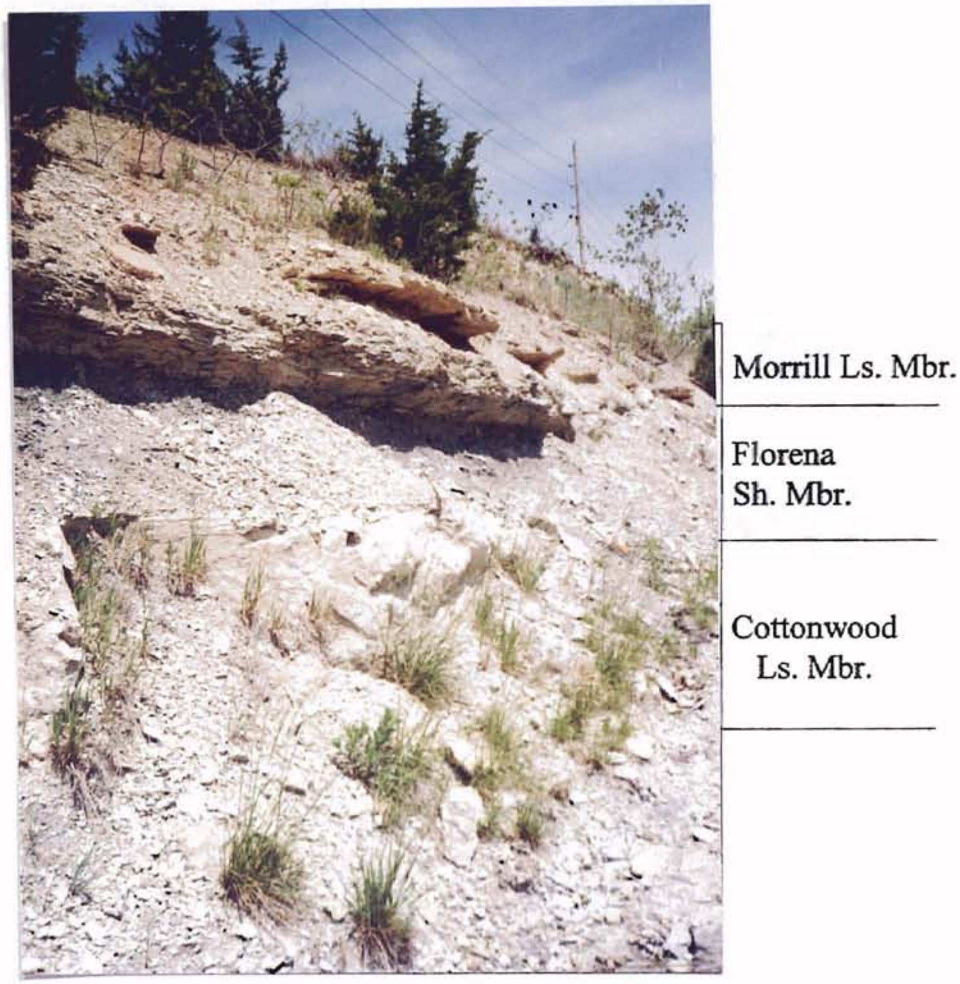
Florena Shale

11	0.5 ft.	shale, moderate dark gray, fissile
10	1.5 ft.	shale, grayish black, calcareous, fissile
9	0.5 ft.	shale, dark gray, calcareous, fissile
8	0.5 ft.	shale, dark olive gray, calcareous, fissile

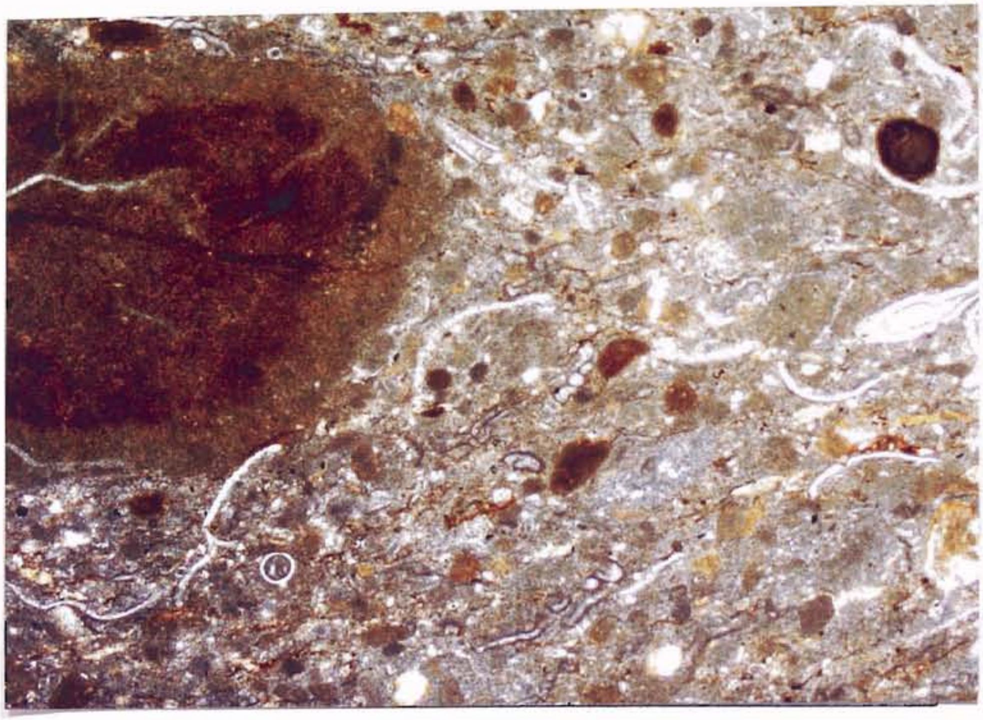
UNIT DESCRIPTION

Cottonwood Limestone

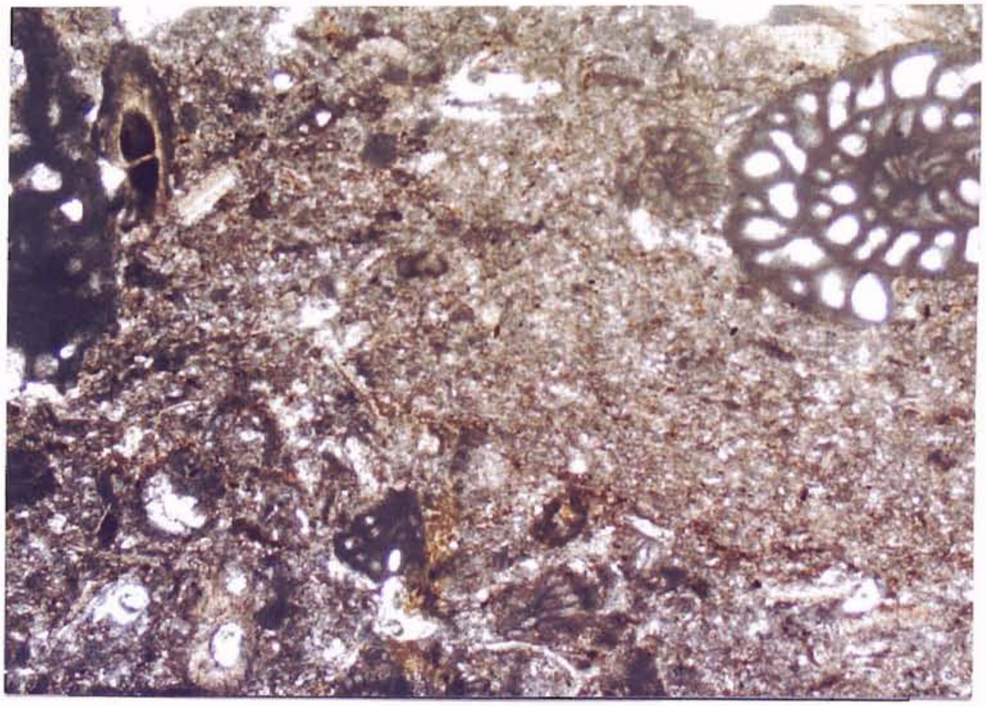
7	1 ft.	packstone, fusulinids, echinoderms, algae, micrite, ostracodes, micrite, bryozoa, light brownish gray
6	0.6 ft.	wackestone, fusulinids, trilobites, ostracodes, algae, micrite, light brownish gray
5	0.8 ft.	wackestone, to packstone, fusulinids, bryozoa, ostracodes, algae, micrite, light brownish gray
4	1 ft.	mudstone to wackestone, gastropods, bryozoa, fusulinids, trilobites, algae, micrite, light brownish gray
3	1.1 ft.	wackestone, oncoid, fusulinids, coral, bryozoa, algae, echinoderms, micrite, yellowish gray
2	1.6 ft.	wackestone, oncoid, gastropods, fusulinids, bryozoa, trilobites, echinoderms, ostracodes, brachiopods, algae, micrite, light gray
1	0.5 ft.	wackestone, intraclasts, brachiopods, ostracodes, algae, micrite, yellowish brown to light gray



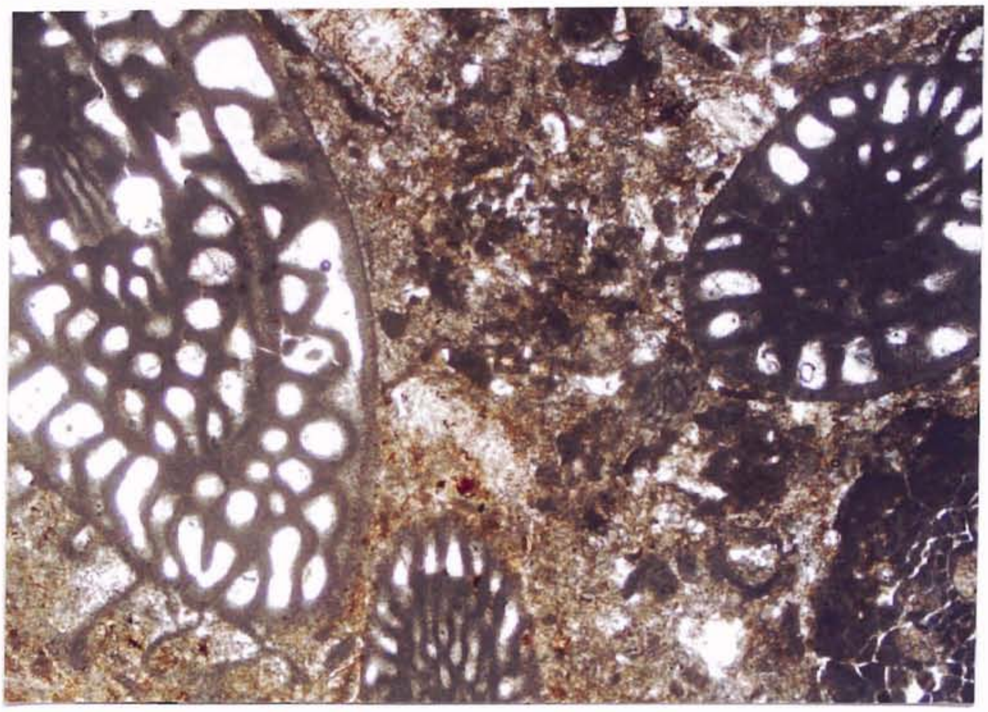
Photograph 1 NK#1 Beattie Limestone
Taken along Anderson Road in Manhattan, Kansas. the lower limestone (medium to thick bedded) in the photo is the Cottonwood Limestone member, the middle shale is The Florena Shale, and the upper limestone (flaggy) is the Morrill Limestone Member.



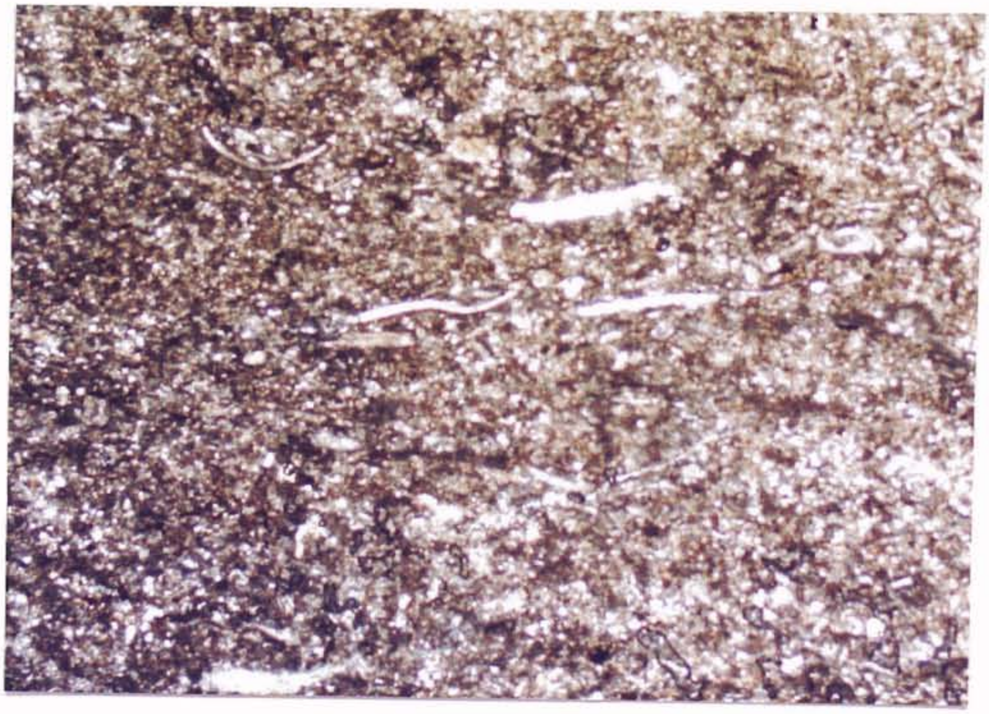
Photograph 2, NK#1, Cottonwood Limestone Member, Unit: 1
wackestone intraclasts, brachiopod, ostracode, algae.



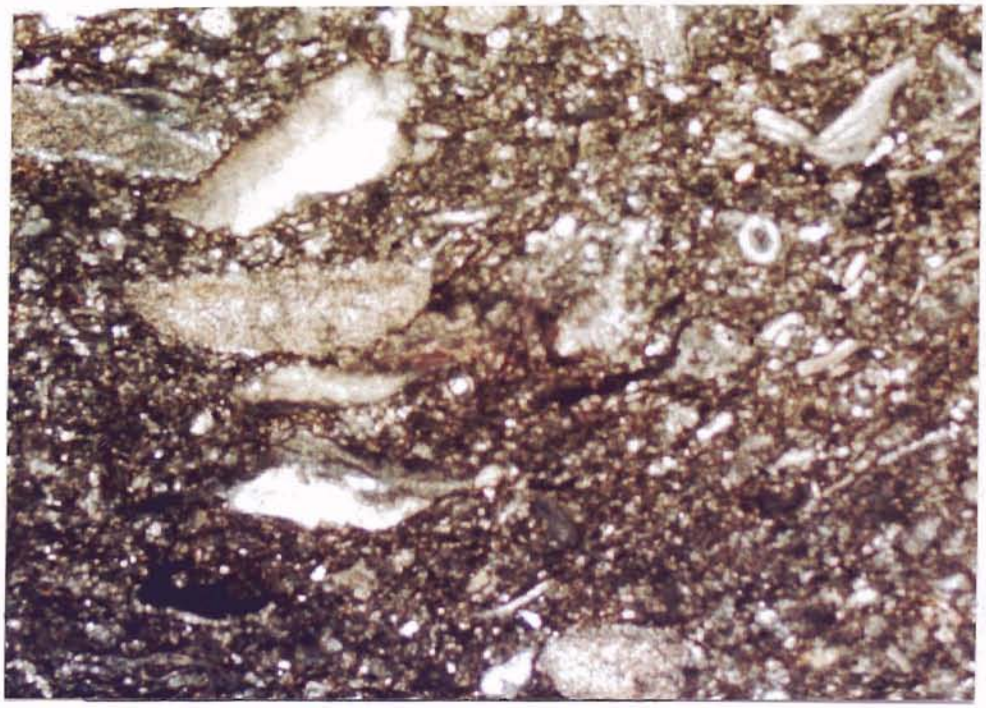
Photograph 3, NK#1, Cottonwood Limestone Member, Unit: 4
wackestone, fusulinid, bryozoan, trilobite, algae.



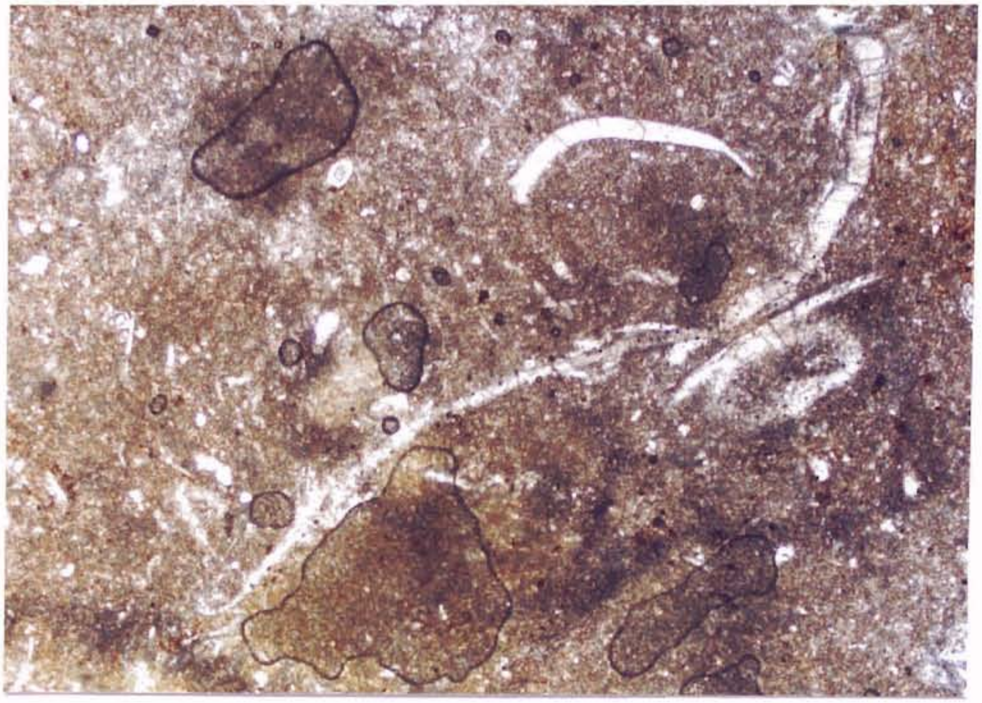
Photograph 4, NK#1, Cottonwood Limestone Member, Unit: 6
packstone, fusulinid, trilobite, ostracode, algae.



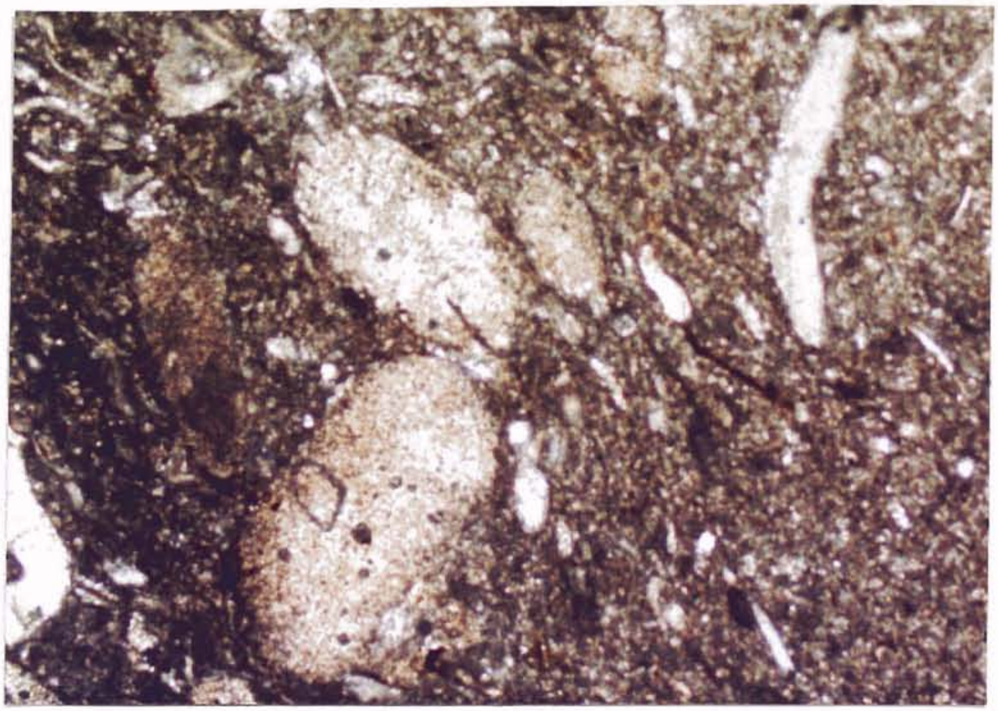
Photograph 5, NK#1, Morrill Limestone Member, Unit: 12
wackestone, peloid, ostracode.



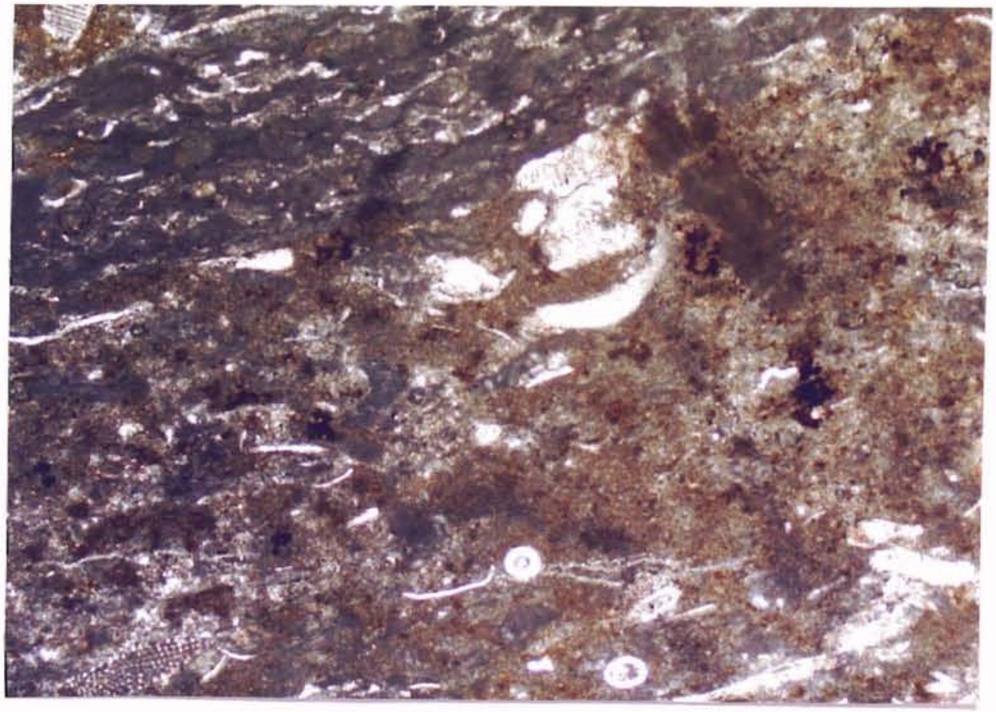
Photograph 6, NK#1, Morrill Limestone Member, Unit: 13
wackestoe, brachiopod, echinoderm, trilobite.



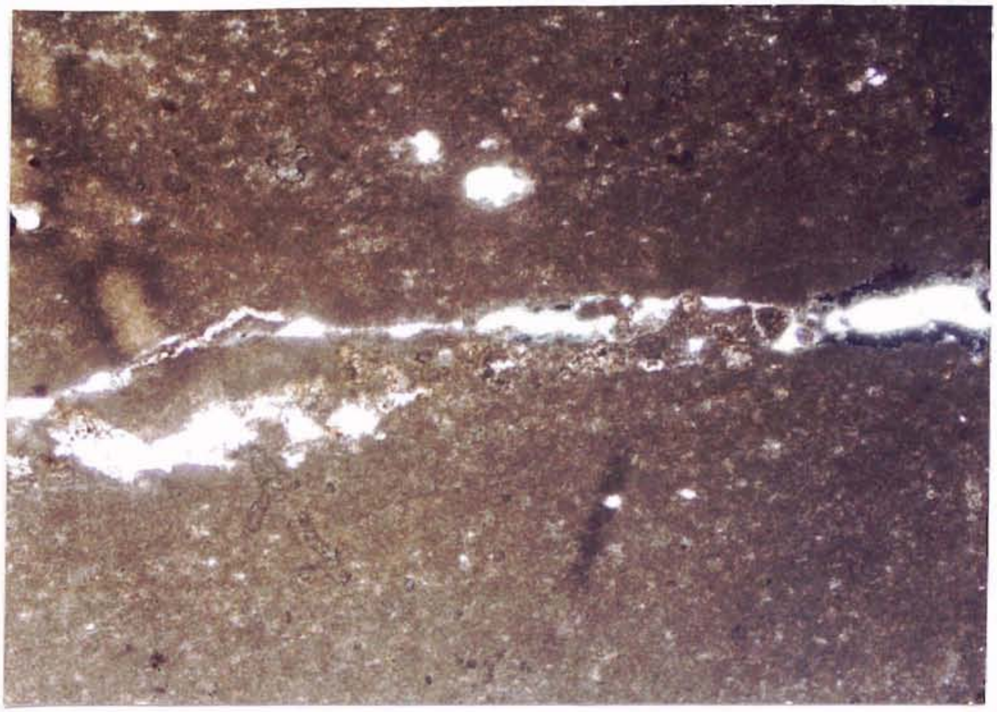
Photograph 7, NK#1, Morrill Limestone Member, Unit: 15
mudstone, trilobite, bioclast.



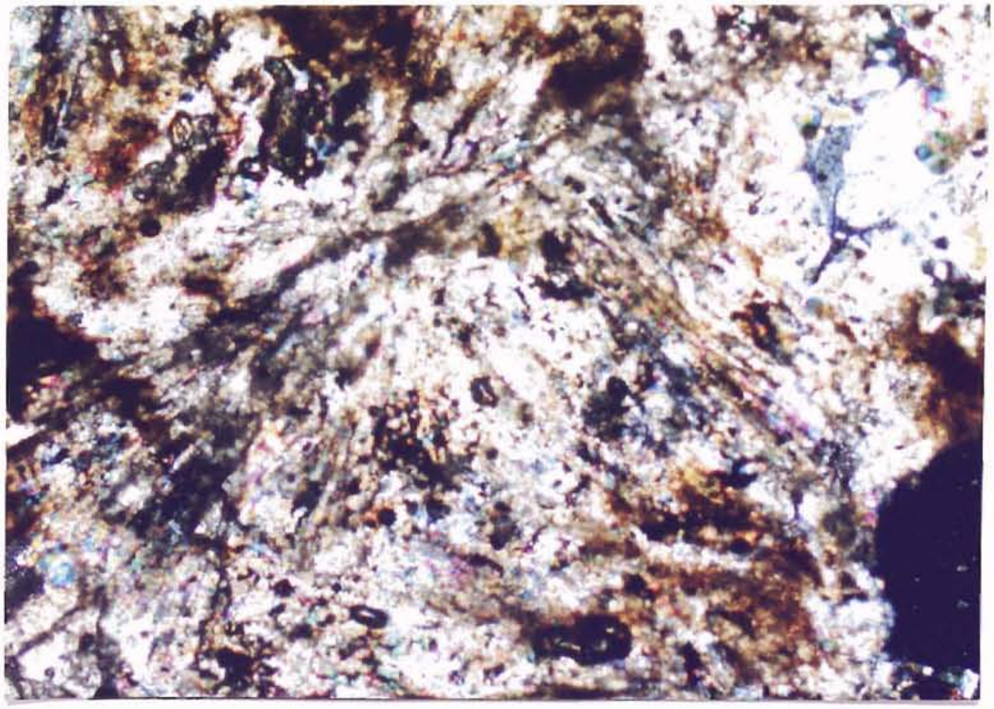
Photograph 8, NK#1, Morrill Limestone Member, Unit: 16
wackestone, brachiopod, echinoderm, ostracode.



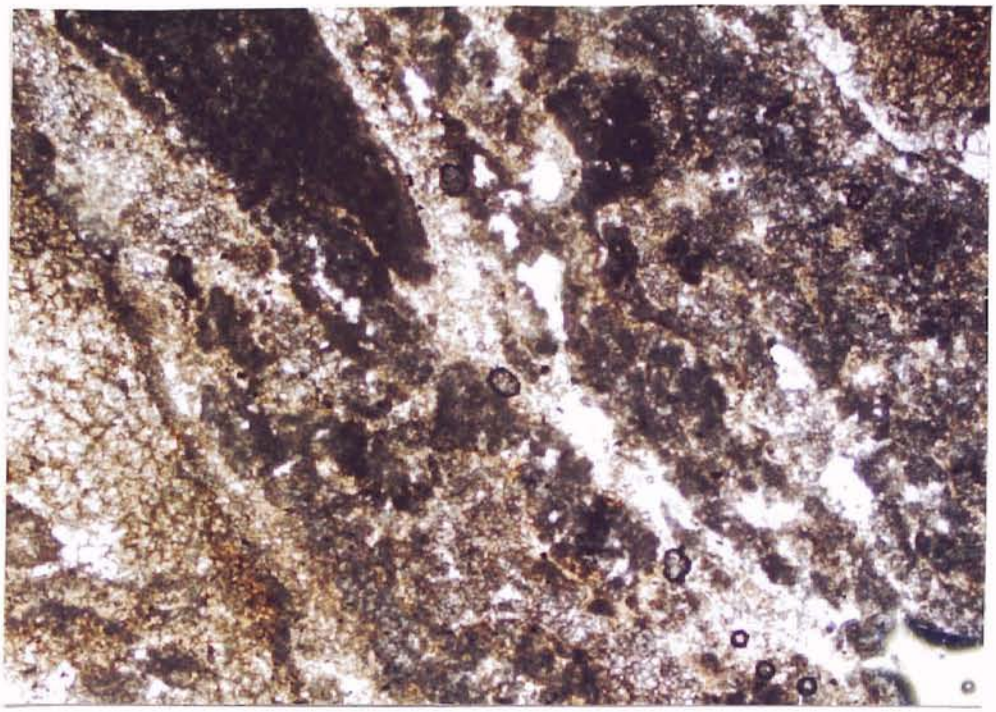
Photograph 9, NK#1, Morrill Limestone Member, Unit: 18
wackestone, brachiopod, echinoderm, algae, hematitic.



Photograph 10, NK#1, Morrill Limestone Member, Unit: 20
wackestone, peloid, algae.



Photograph 11, NK#1, Morrill Limestone Member, Unit: 21
chalcedony



Photograph 12, NK#1, Morrill Limestone Member, Unit: 23
wackestone, peloid, algae

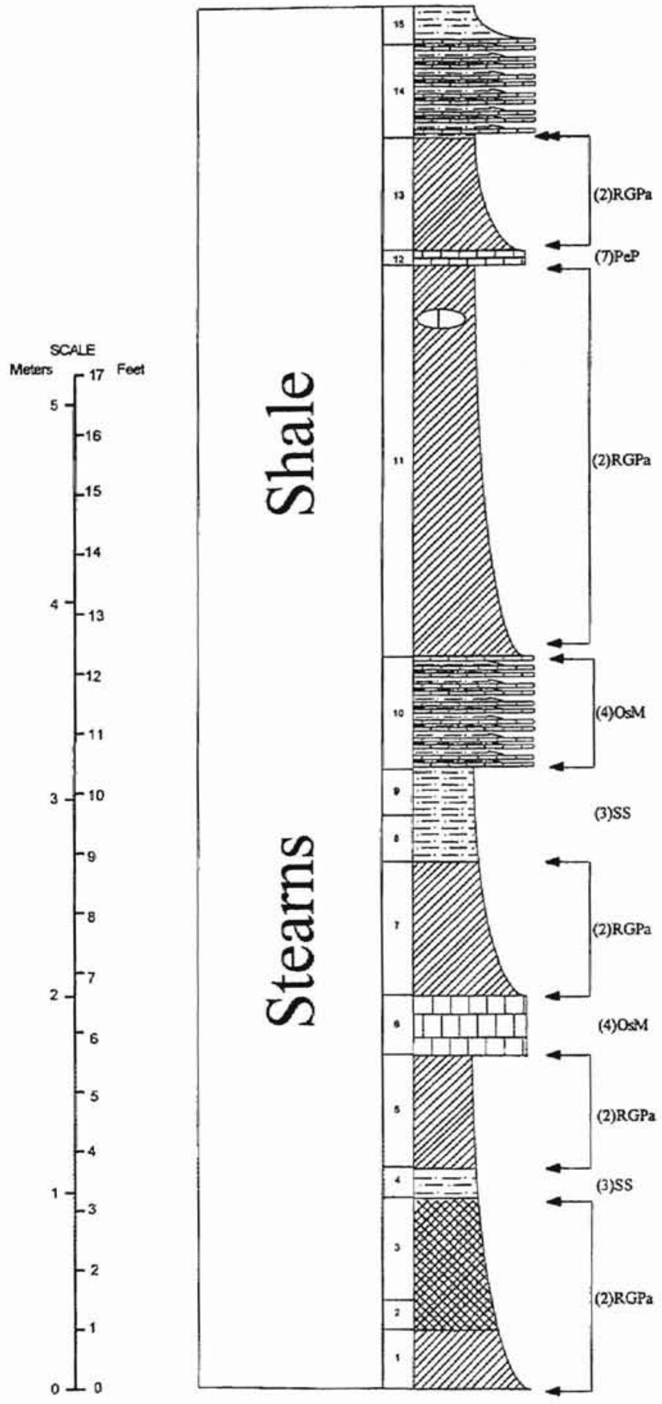


Figure 29. Measured Section NK #1, Stearns Shale.

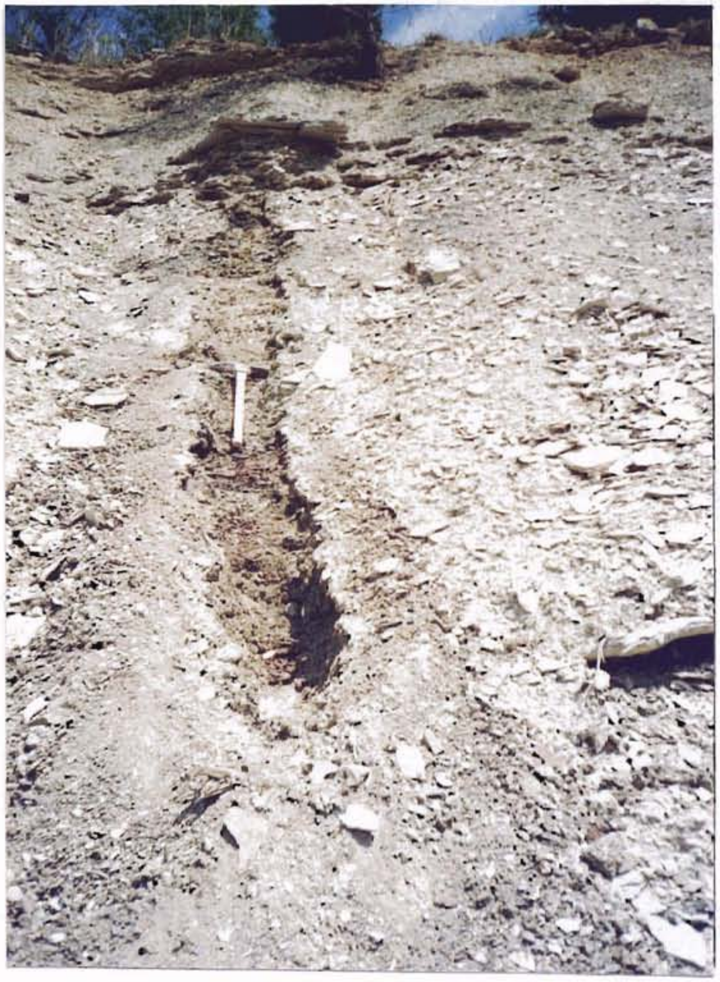
State: Kansas County: Riley

Locality Description:
Roadcut on both west and east sides of Anderson Road in Manhattan, Kansas,
W/2, Section 10, T10S, R7E, Keats 7.5' Quadrangle, Riley County, Kansas.

UNIT DESCRIPTION

Stearn Shale

15	0.5 ft.	shale, pale yellowish brown, calcareous, crumbly
14	1.5 ft.	shale with limestone limestone: wackestone, brachiopods, gastropods, trilobites, gastropods, bryozoa, echinoderms, micrite, bioclasts, dusky yellowish gray
13	2 ft.	shale, light olive gray, calcareous, blocky
12	0.3 ft.	wackestone, peloid, algae, micrite, silica, yellowish gray
11	6.5 ft.	shale, light olive gray, silty to calcareous, blocky to crumbly
10	1.8 ft.	shale interbedded with laminated limestone limestone: mudstone, recrystallized micrite, yellowish gray
9	0.8 ft.	shale, dark yellowish brown, silty, fissile
8	0.8 ft.	shale, grayish black, silty, fissile
7	2.2 ft.	shale, olive gray to light olive gray, silty and calcareous, blocky, fissile
6	1 ft.	mudstone, ostracodes, micrite, pale yellowish brown
5	2 ft.	pale olive gray to light olive gray silty, blocky
4	0.5 ft.	shale, grayish black, silty, blocky
3	1.7 ft.	shale, grayish red with light olive gray, silty, blocky
2	0.5 ft.	shale, reddish gray, silty, blocky
1	1 ft.	shale, light olive gray, calcareous, crumbly



Photograph 13 NK#1 Stearns Shale
Taken along Anderson Road in Manhattan, Kansas. The Stearns Shale is below the Eiss Limestone Member of the Bader limestone, which is near the top of the road cut.

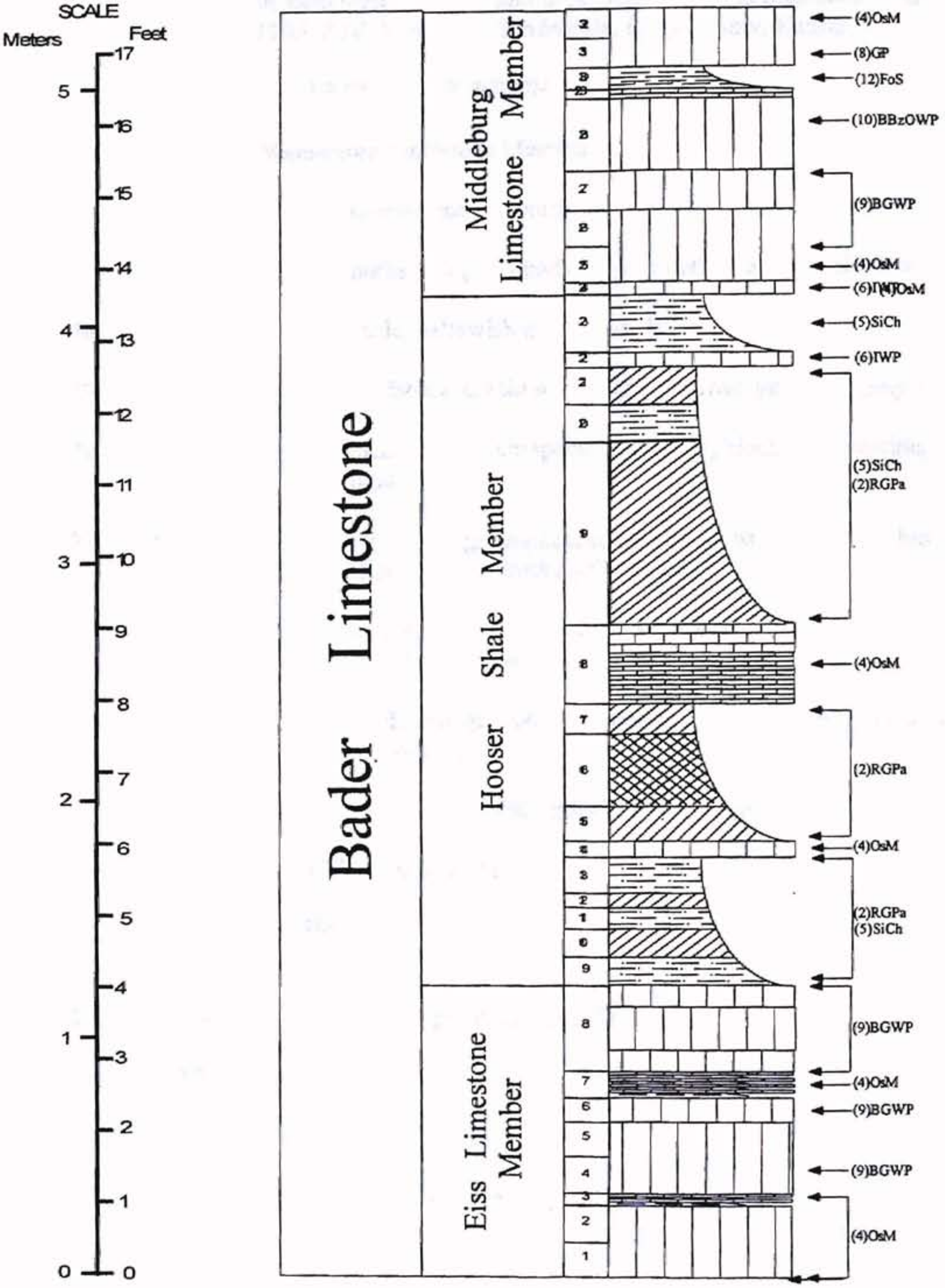


Figure 30. Measured Section NK #1, Bader Limestone.

State: Kansas County: Riley

Locality Description:

Roadcut on both west and east sides of Anderson Road in Manhattan, Kansas, W/2, Section 10, T10S, R7E, Keats 7.5' Quadrangle, Riley County, Kansas.

UNIT DESCRIPTION

Middleburg Limestone Member

32	0.4 ft.	micrite, red brownish gray
31	0.4 ft.	packstone gastropods, algae, micrite, red brownish gray
30	0.3 ft.	shale, yellowish gray, crumbly
29	0.15 ft.	mudstone, brachiopods, algae, micrite, yellowish gray
28	1 ft.	mudstone, brachiopods, ostracodes, bioclasts, hematitic, micrite, light gray
27	0.55 ft.	mudstone, gastropods, echinoderms, ostracodes, brachiopods, algae, micrite, dusky yellow gray
26	0.5 ft.	wackestone, brachiopods, gastropods, echinoderms, algae, micrite, light brown gray
25	0.5 ft.	mudstone, gastropods, ostracodes, algae, micrite, hematitic, light brown gray
24	0.2 ft.	packstone, peloid, intraclasts, ostracodes, algae, micrite,

UNIT DESCRIPTION

Hooser Shale Member

23	0.8 ft.	shale, light olive gray, silty, blocky
22	0.2 ft.	limestone, packstone, intraclasts, ostracodes light olive brown
21	0.5 ft.	light olive gray, silty, blocky
20	0.5 ft.	shale, light brown, gray
19	2.5 ft.	light olive gray to light olive brown, silty, blocky
18	1.2 ft.	limestone, mudstone, micrite, mud pellet, flaggy, yellowish gray
17	0.4 ft.	shale, light olive gray, silty, fissile
16	0.9 ft.	shale, dark reddish brown, silty, blocky

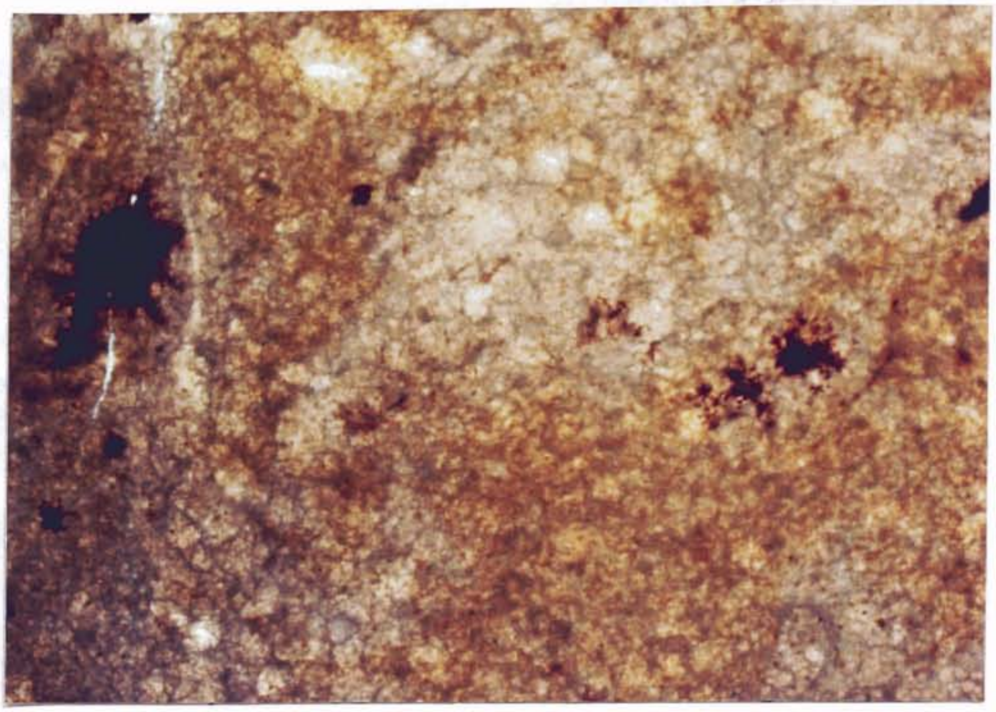
15	0.5 ft.	shale, light olive gray, silty, fissile
14	0.25 ft.	shale, calcareous, brownish medium gray
13	0.5 ft.	shale, dark gray, silty, silty
12	0.2 ft.	shale, light olive, silty, blocky
11	0.3 ft.	shale, dark gray, silty, blocky
10	0.4 ft.	shale, light olive gray, silty, blocky
9	0.4 ft.	shale, brownish gray, silty, blocky

UNIT DESCRIPTION

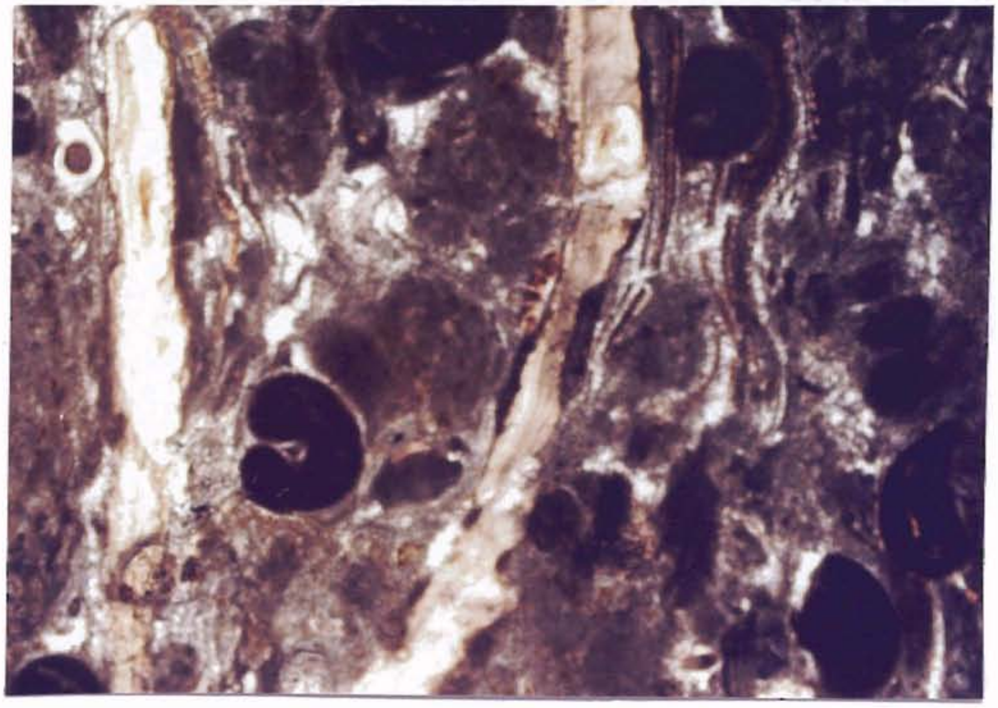
Eiss Limestone Member

8	1.2 ft.	mudstone, brachiopods, bioclasts, micrite, light gray to dark gray
7	0.4 ft.	mudstone, micrite, light gray
6	0.5 ft.	mudstone, ostracodes, algae, micrite
5	0.5 ft.	mudstone, ostracodes, micrite, hematitic, yellowish gray
4	0.5 ft.	packstone, brachiopods, gastropods, ostracodes, micrite, hematitic, yellowish brown gray
3	0.15 ft.	wackestone, echinoderms, trilobites, recrystallized micrite, yellowish gray
2	0.15 ft.	wackestone, echinoderms, trilobites, recrystallized micrite, yellowish gray
1	1 ft.	mudstone, echinoderms, ostracodes, algae, micrite, hematitic, orange yellowish gray

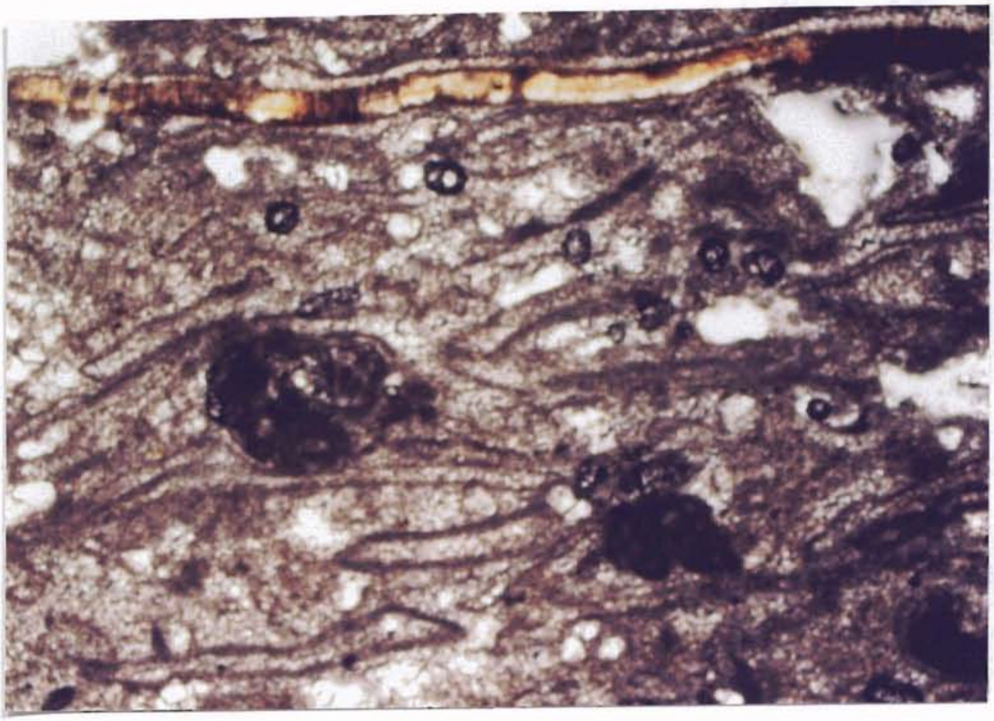
Photo 14 NK#1 Bader Limestone
Taken along Anderson Road in Manhattan, Kansas. The lowest limestone (medium to thick beds) is the Eiss Limestone, middle shale is Hooser Shale Member. The upper limestone (medium to thick beds) is the Middleburg Limestone Member.



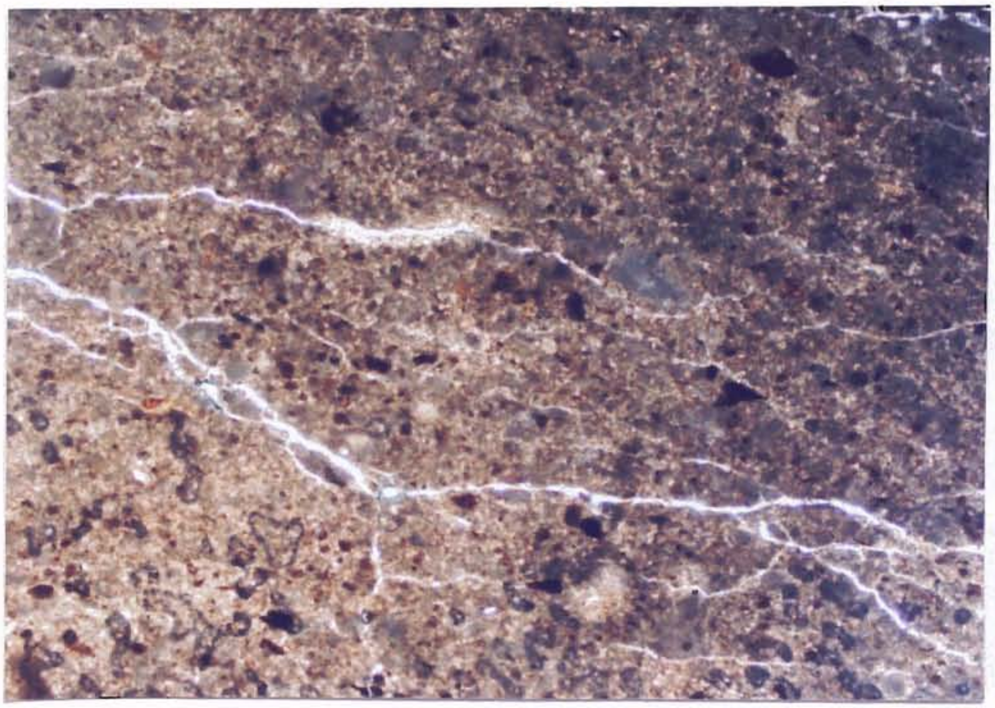
Photograph 15, NK#1, Eiss Limestone Member, Unit: 1
mudstone, micrite, hematitic



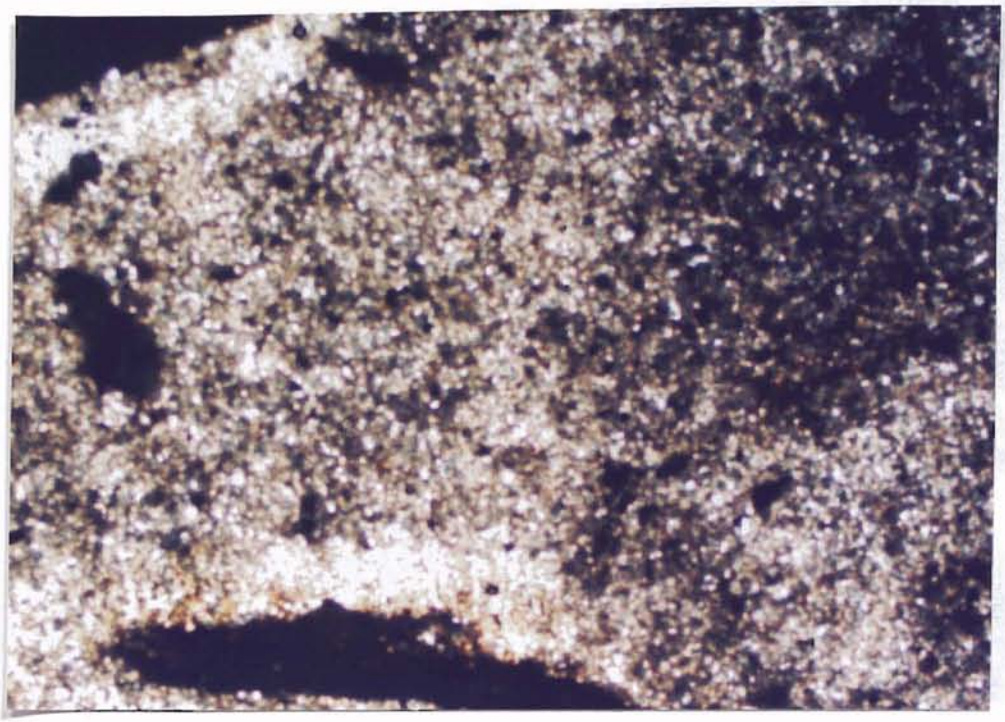
Photograph 16, NK#1, Eiss Limestone Member, Unit: 3
packstone, gastropod, brachiopod, micrite.



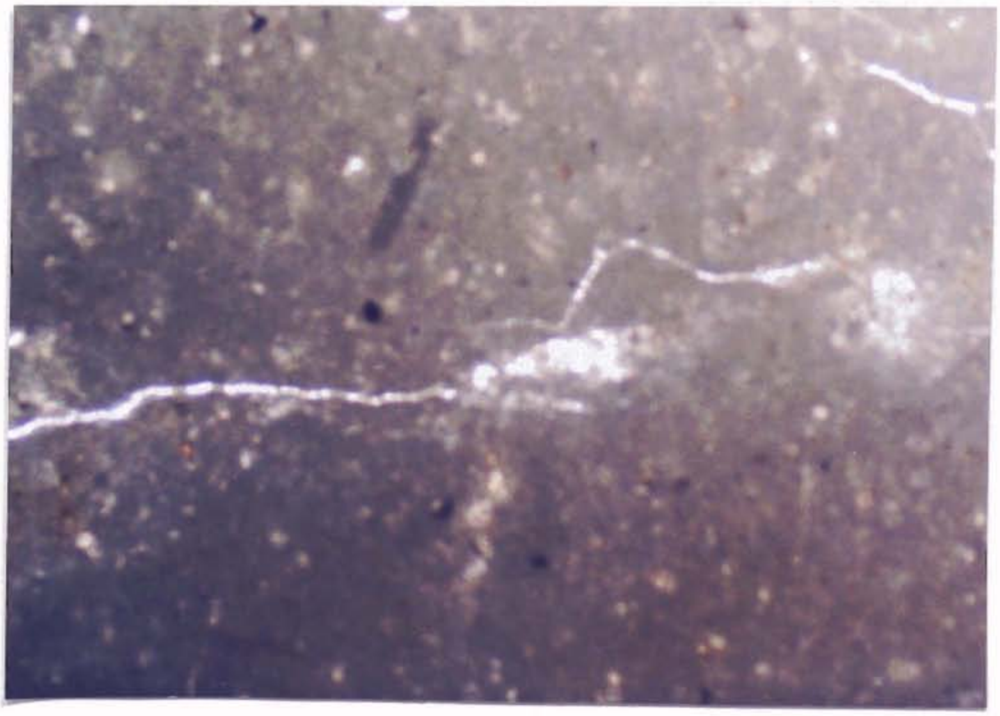
Photograph 17, NK#1, Eiss Limestone Member, Unit: 6
wackestone, ostracode, algae, micrite.



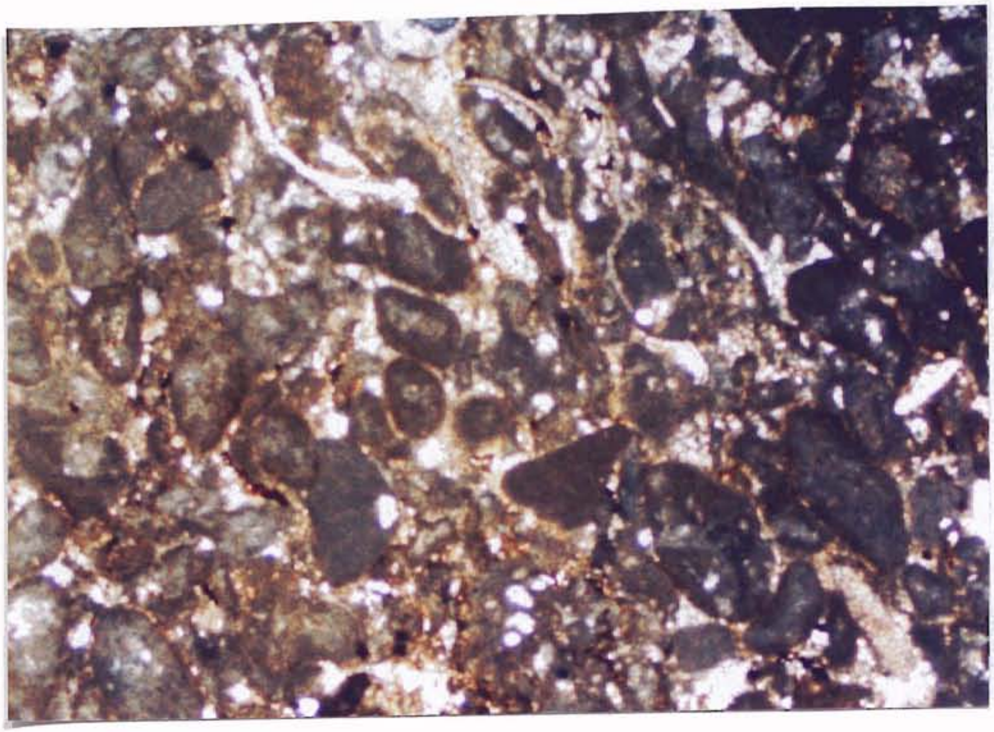
Photograph 18, NK#1, Eiss Limestone Member, Unit: 8
mudstone, bioclast, peloid, micrite.



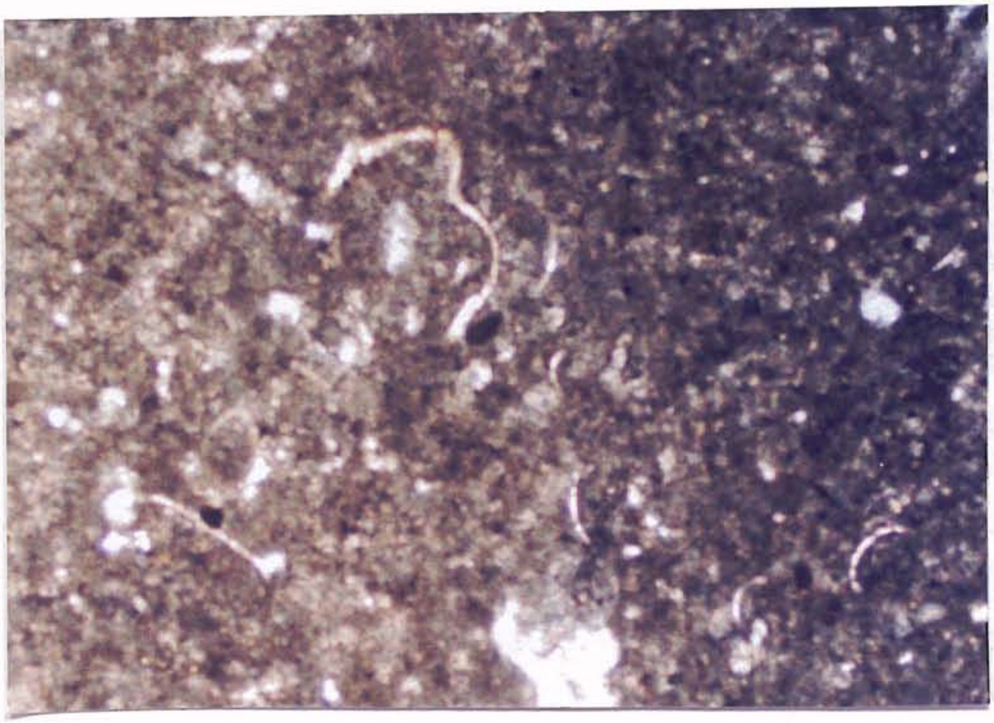
Photograph 19, NK#1, Hooser Shale, Unit: 18
mudstone, recrystallized micrite.



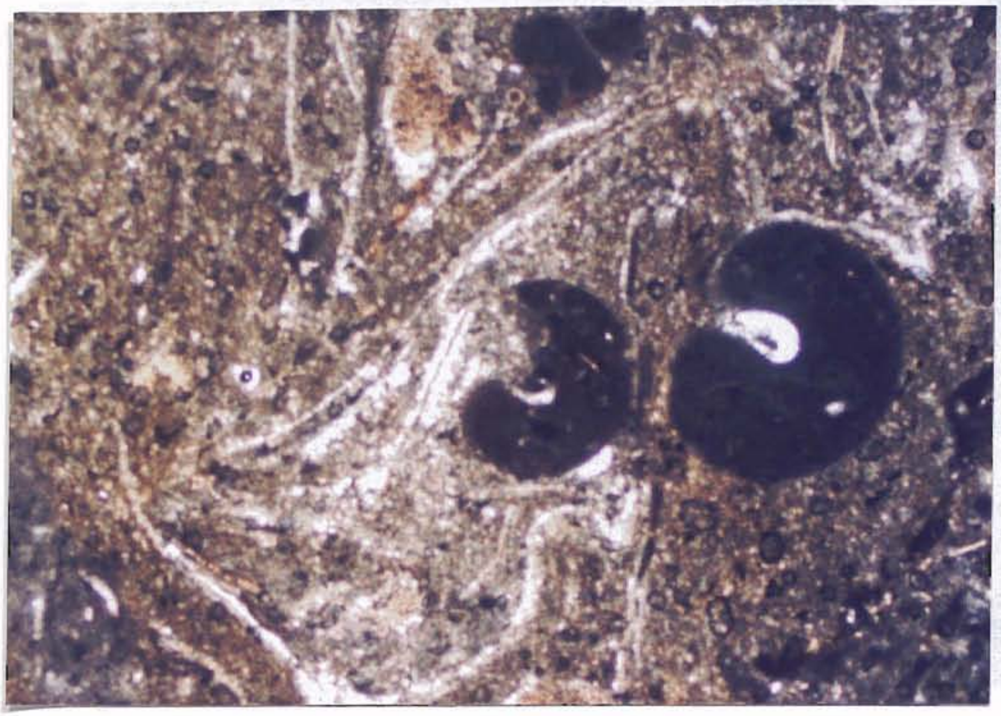
Photograph 20, NK#1, Hooser Shale, Unit: 20
wackestone, peloid, micrite.



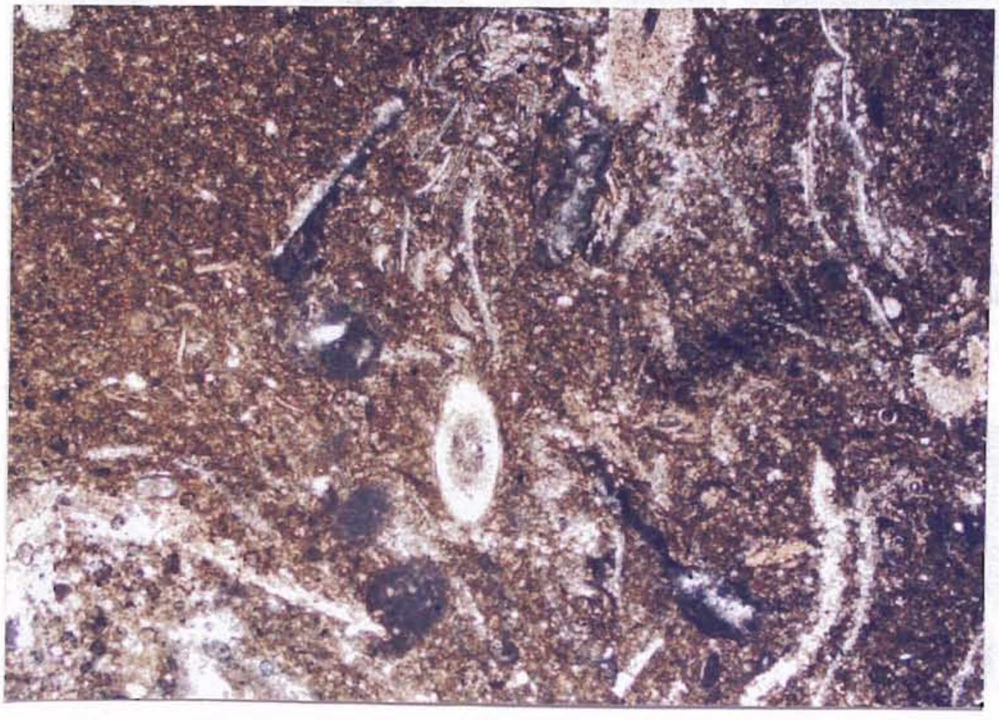
Photograph 21, NK#1, Hooser Shale, Unit: 22
packstone, intraclast, micrite.



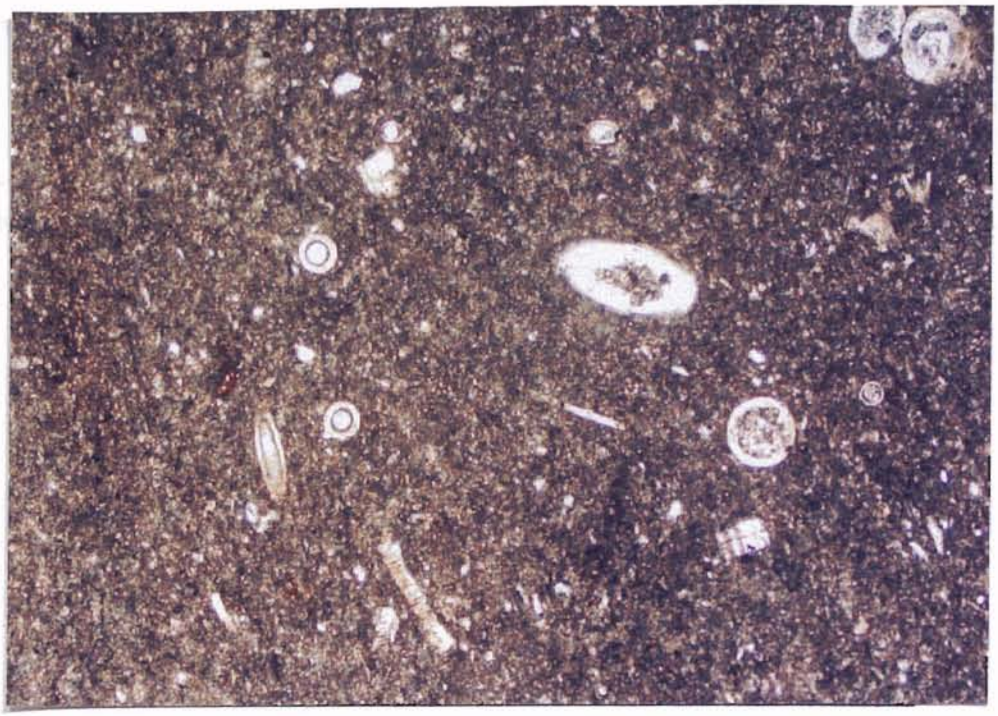
Photograph 22, NK#1, Middleburg Limestone, Unit: 24
wackestone, intraclast, ostracode, micrite.



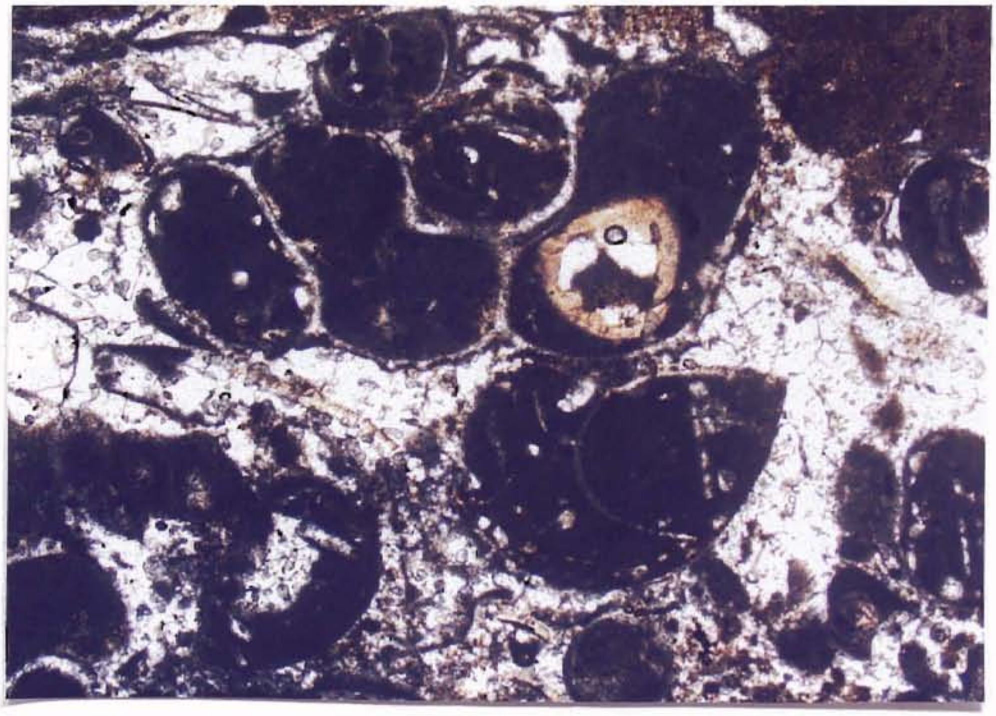
Photograph 23, NK#1, Middleburg Limestone, Unit: 26
wackestone, gastropod, echinoderm, micrite



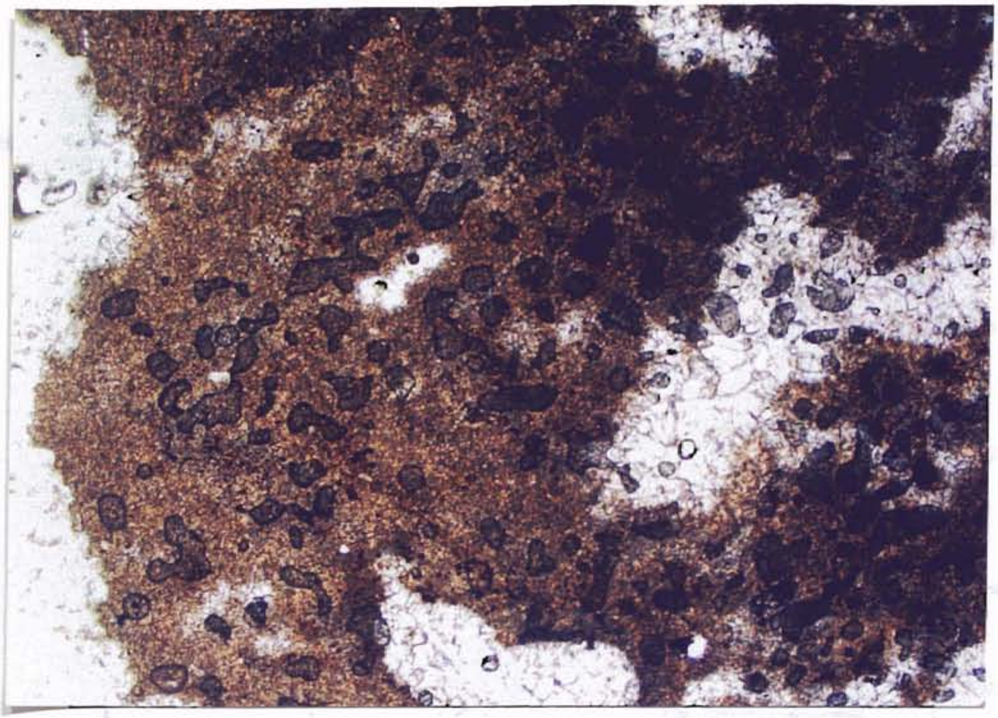
Photograph 24, NK#1, Middleburg Limestone, Unit: 27
wackestone, echinoderm, algae, micrite.



Photograph 25, NK#1, Middleburg Limestone, Unit: 29
mudstone, brachiopod, algae, micrite.



Photograph 26, NK#1, Middleburg Limestone, Unit: 31
packstone, gastropod, micrite.



Photograph 27, NK#1, Middleburg Limestone, Unit: 32
mudstone, micrite,

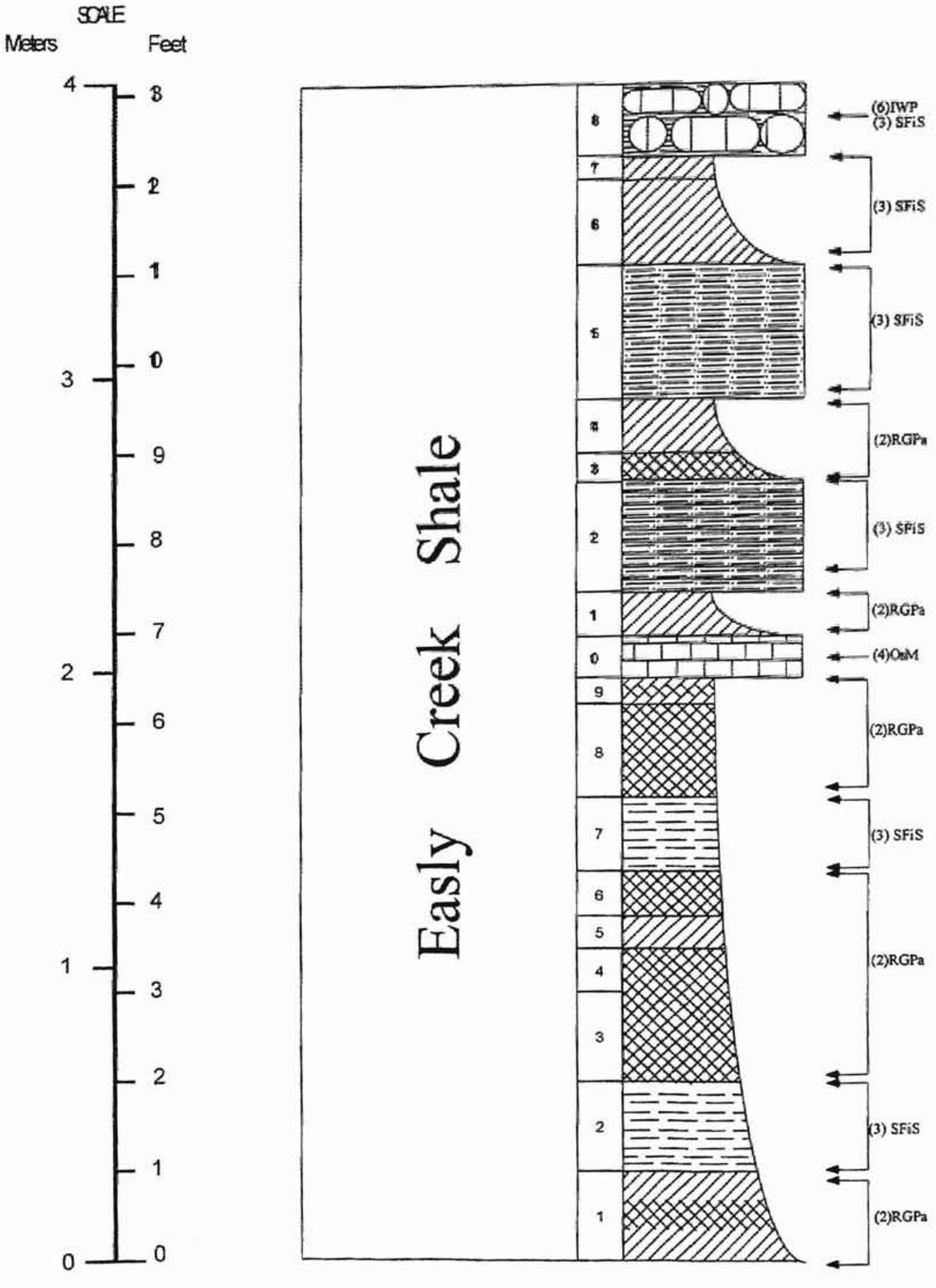


Figure 31. Measured Section NK #2, Easly Creek Shale.

State: Kansas County: Riley

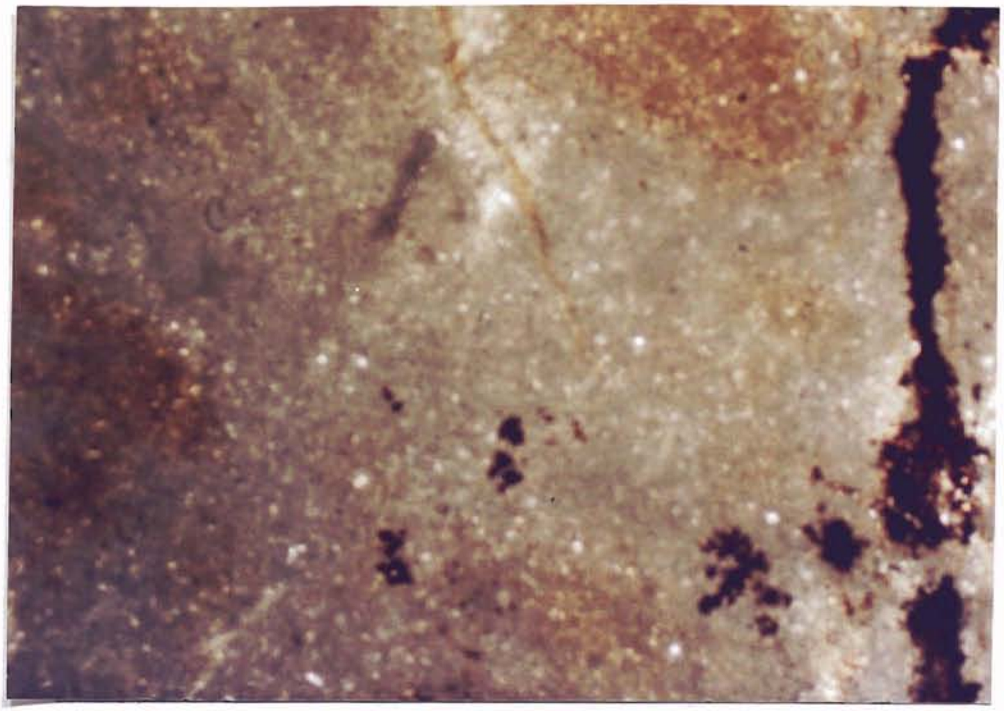
Locality Description:
Roadcut on east side of Scenic Drive in Manhattan, Kansas,
NE/4 Section 2, T10S, R7E, R7E, Keats 7.5' Quadrangle, Riley County, Kansas.

UNIT DESCRIPTION

Easly Creek Shale

18	0.8 ft.	shale with nodular limestone, moderate greenish yellow to moderate yellow nodular limestone: mudstone, intraclasts, hematite, micrite
17	0.3 ft.	shale, light olive brown calcareous, silty , blocky
16	1 ft.	shale, light olive brown, calcareous, blocky
15	1.5 ft.	siltstone, dusky yellow
14	0.6 ft.	shale, light olive gray, calcareous, fissile
13	0.2 ft.	shale, grayish red, silty, blocky
12	1.3 ft.	siltstone, moderate brown
11	0.5 ft.	shale, light olive gray, calcareous, blocky
10	0.4 ft.	mudstone, recrystallized micrite, yellowish gray
9	0.3 ft.	shale, light olive gray & grayish red
8	1 ft.	shale, dark reddish brown, silty, blocky
7	0.8 ft.	shale, light brown, calcareous, blocky
6	0.5 ft.	shale, dark reddish brown, calcareous, blocky
5	0.3 ft.	shale, light olive gray silty, blocky
4	0.5 ft.	shale, dark reddish brown, silty, blocky
3	1 ft.	shale, dark reddish brown, silty, blocky
2	1 ft.	shale, grayish red & pale olive gray, fissile
1	1 ft.	shale, pale olive gray & grayish red, blocky

Photo 28 NK#1 Easly Creek Shale
Taken along Scenic Drive in Manhattan, Kansas,. The Easly Creek Shale is between the Middleburg Limestone Member at the base (the lowest limestone in the photo) and the Crouse Limestone, at the top.



Photograph, 29, NK#1, Easly Creek Shale, Unit: 18
mudstone, micrite, hematitic

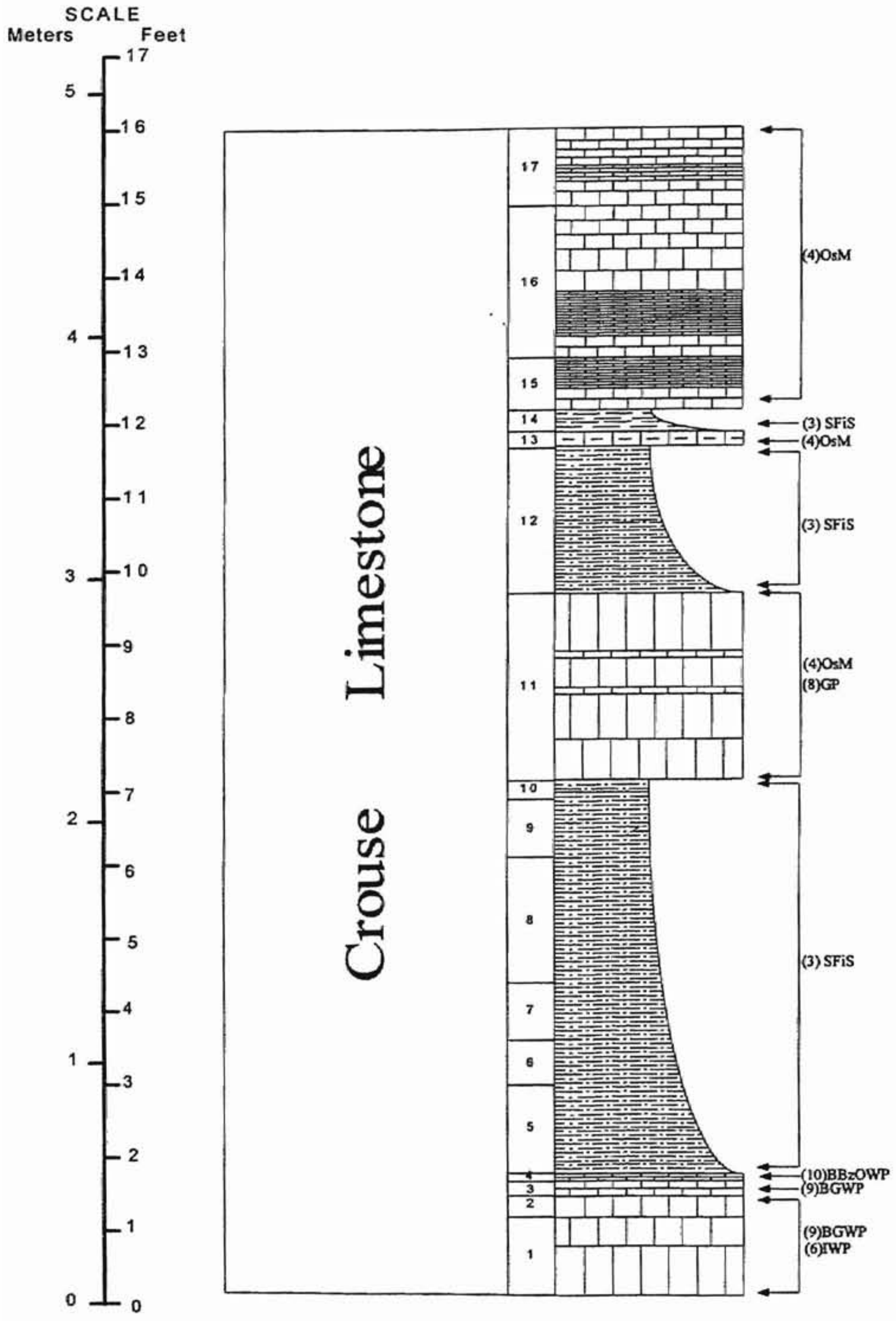


Figure 32. Measured Section NK #2, Crouse Limestone

State: Kansas County: Riley

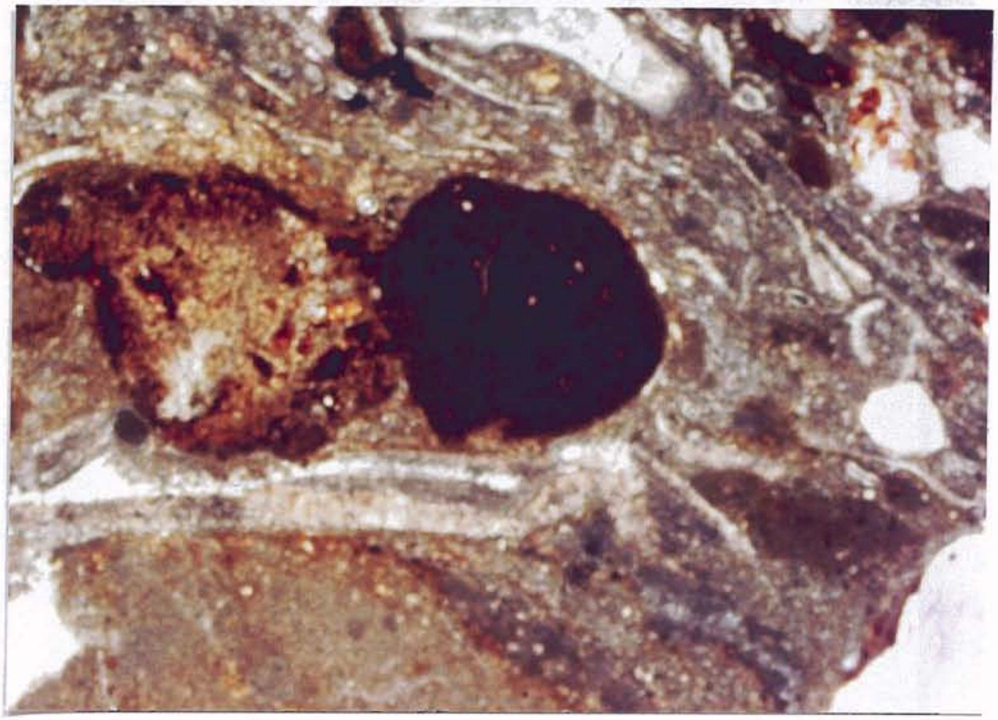
Locality Description:
Roadcut on east side of Scenic Drive in Manhattan, Kansas,
NE/4 Section 2, T10S, R7E, R7E, Keats 7.5' Quadrangle, Riley County, Kansas

UNIT DESCRIPTION

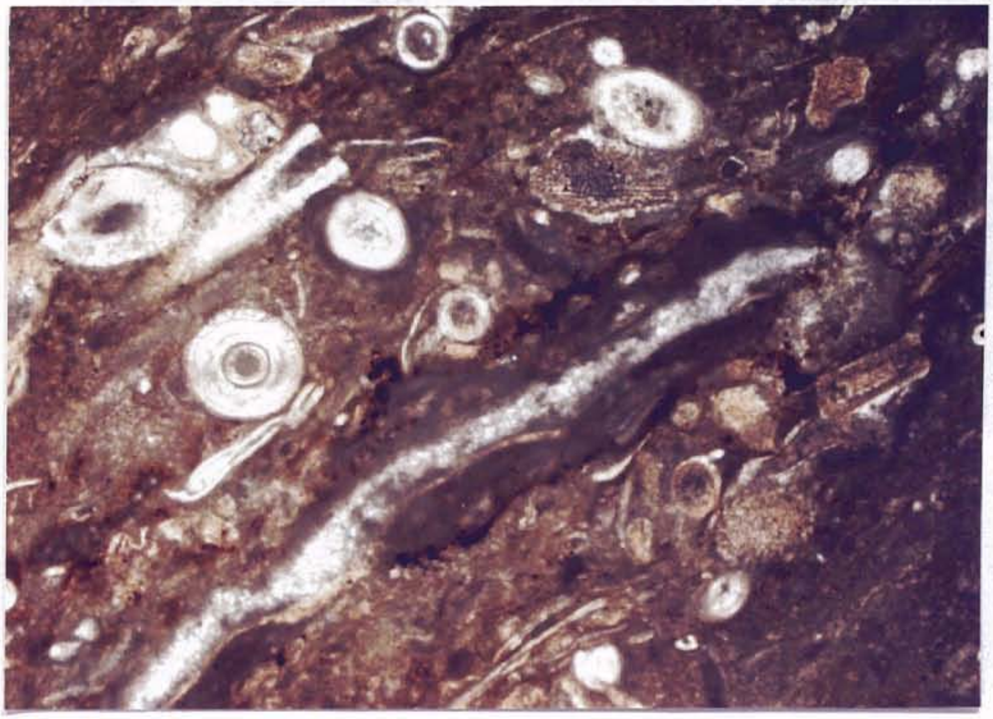
Crouse Limestone

17	1 ft.	wackestone, ostracodes, hematitic, fissile, buff
16	2 ft.	mudstone, ostracodes, hematitic, micrite, buff
15	0.7 ft.	mudstone to wackestone, ostracodes, micrite yellow to buff
14	0.3 ft.	shale, moderate yellow, silty, fissile,
13	0.15 ft.	packstone, gastropods, bioclasts, buff yellow
12	2 ft.	shale, yellowish gray, silty, blocky, caliche
11	2.5 ft.	wackestone, gastropods, ostracodes, trilobites, intraclasts, micrite, , gray,
10	0.3 ft.	shale, light olive brown, silty, fissile, caliche,
9	0.8 ft.	shale, moderate yellow, silty, fissile
8	1.7 ft.	shale, dark gray to medium gray, silty, blocky
7	0.8 ft.	shale, grayish olive , silty, fissile
6	0.6 ft.	shale, dark gray, silty, blocky
5	1.2 ft.	shale, yellowish gray to dusky yellow, silty, blocky
4	0.15 ft.	packstone, brachiopods, bryozoa, ostracodes, echinoderms, algae, micrite
3	0.2 ft.	wackestone, trilobites, bryozoa, brachiopods, ostracodes, micrite
2	0.3 ft.	packstone, bryozoa, brachiopods, ostracodes, intraclasts, bivalve, micrite, gray
1	1.1 ft.	packstone, intraclasts, gastropods, brachiopods, ostracodes, greenish gray

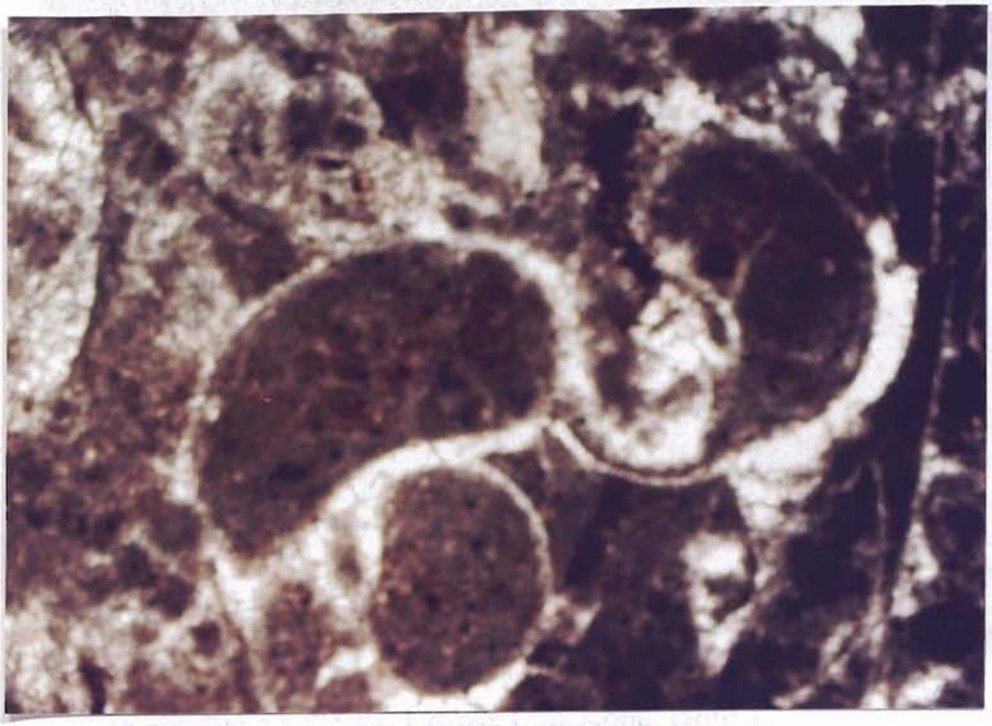
Photo 30 NK#2 Crouse Limestone
Taken along Scenic Drive in Manhattan, Kansas. The Crouse Limestone includes three parts: the lower limestone (thin to medium beds), a middle shale, and an upper limestone (very thin to thin beds).



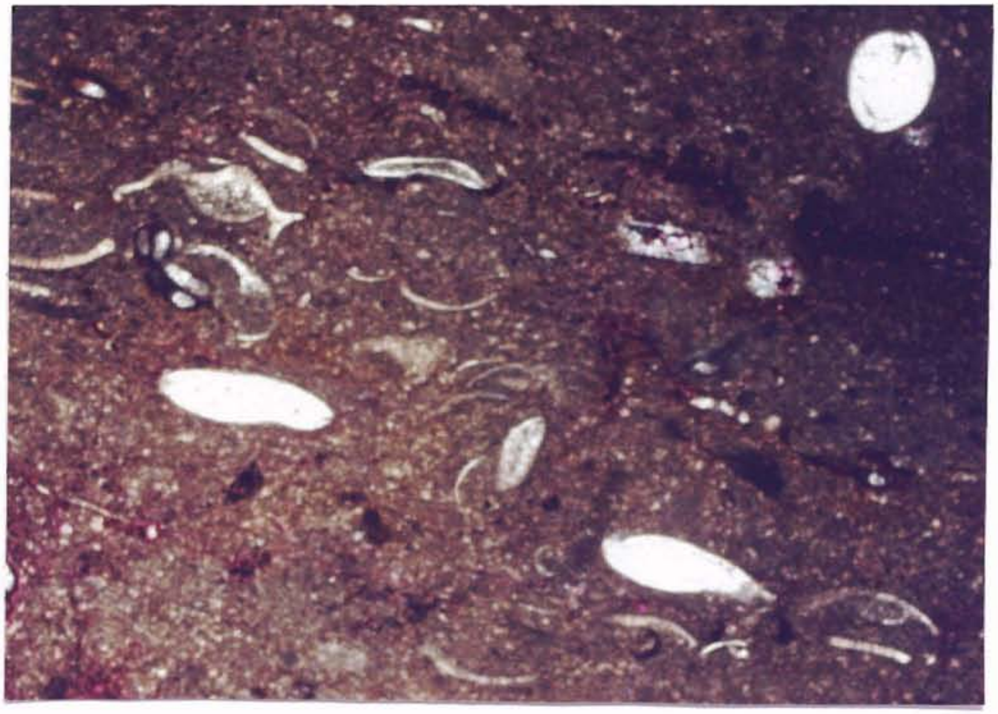
Photograph 31, NK#1, Crouse Limestone, Unit: 1
packstone, intraclast, trilobite, ostracode, micrite.



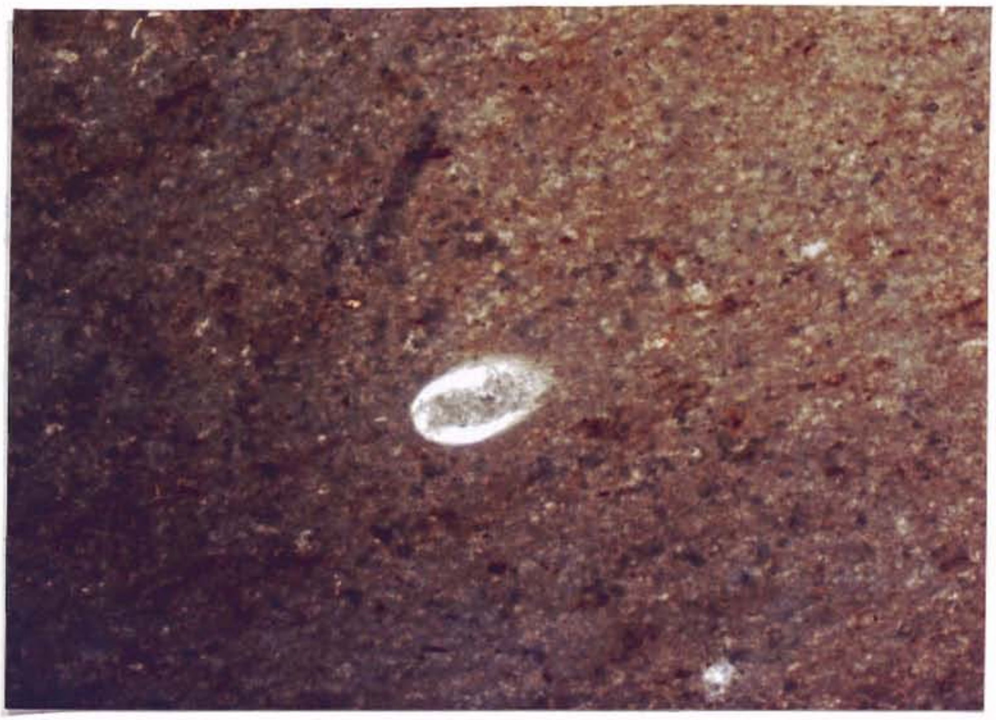
Photograph 32, NK#1, Crouse Limestone, Unit: 3
wackestone, brachiopod, trilobite, oncoid, micrite, algae.



Photograph 33, NK#1, Crouse Limestone, Unit: 13
packstone, gastropod, bioclast, micrite.



Photograph 34, NK#1, Crouse Limestone, Unit: 15
wackstone, ostracode, micrite hematitic.



Photograph 35, NK#1, Crouse Limestone, Unit: 17
mudstone, ostracode, micrite.

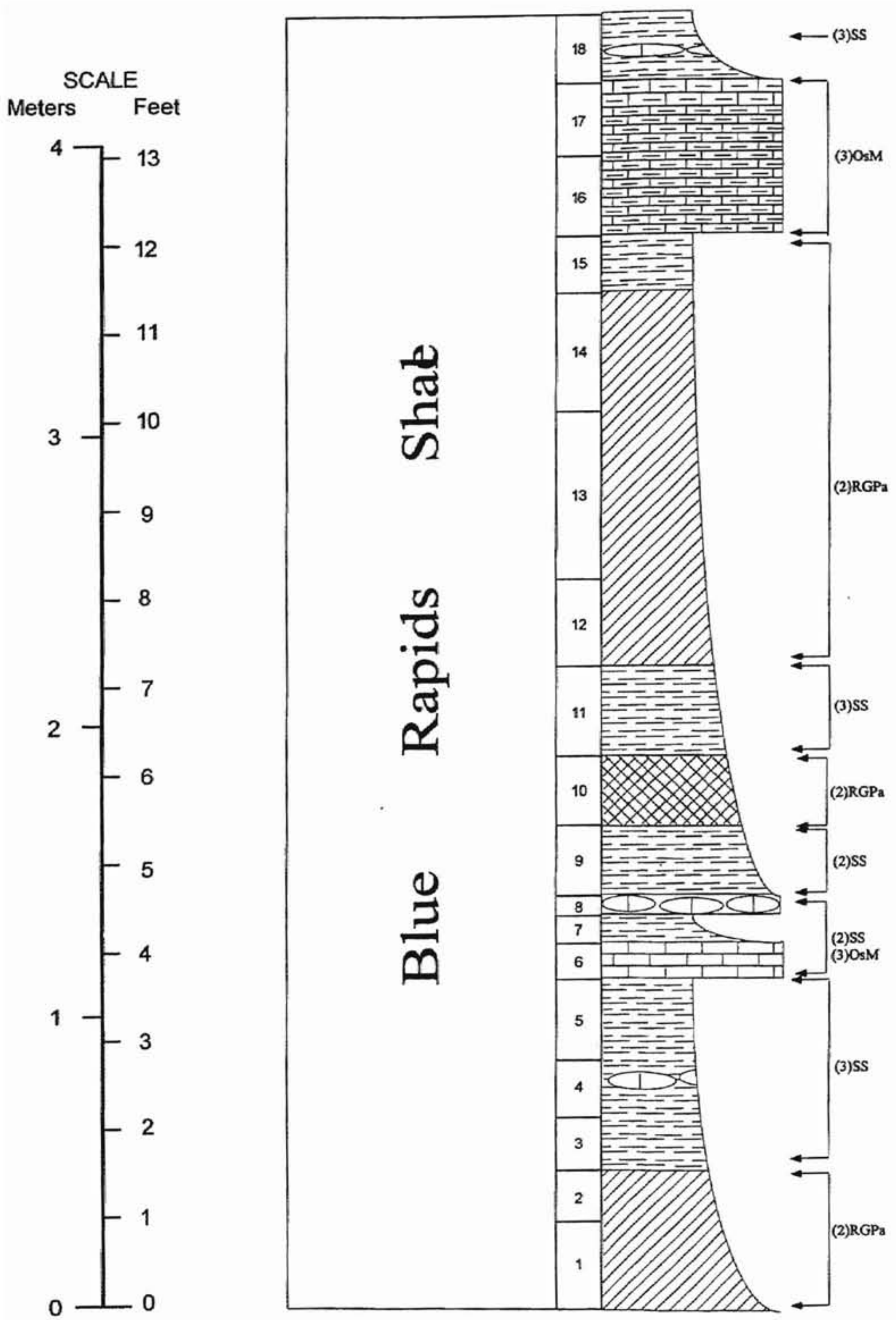


Figure 33. NK #2 Measured Section NK #2, Blue Rapids Shale.

State: Kansas County: Riley

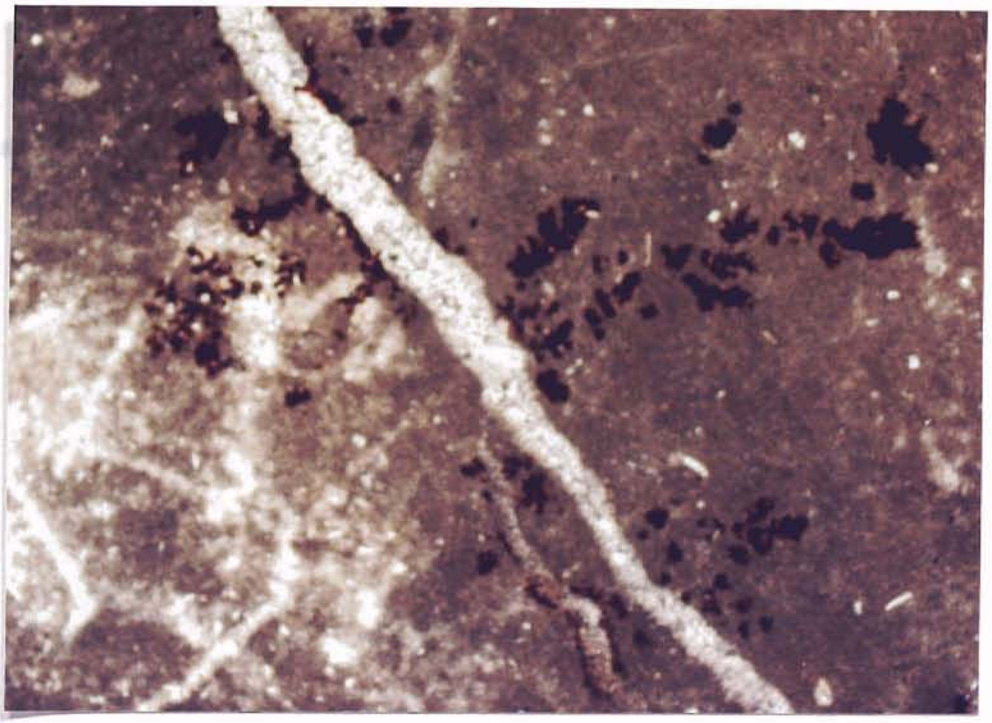
Locality Description:
Roadcut on east side of Scenic Drive in Manhattan, Kansas,
NE/4 Section 2, T10S, R7E, R7E, Keats 7.5' Quadrangle, Riley County, Kansas.

UNIT DESCRIPTION

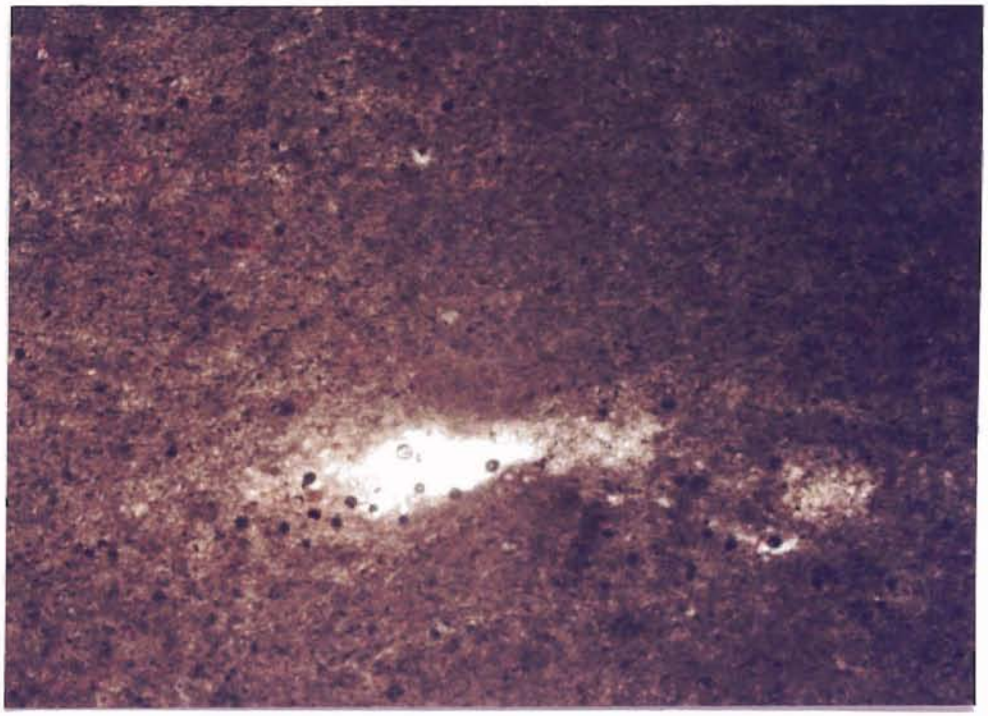
Blue Rapids Shale

18	0.9 ft.	shale, light gray with nodular limestone, fissile
17	0.9 ft.	mudstone, micrite, light gray
16	0.9 ft.	shaly limestone, yellowish gray
15	0.65 ft.	shale, greenish yellow, silty, blocky to crumbly
14	1.4 ft.	shale, greenish gray, calcareous, blocky
13	1.9 ft	shale, light olive gray, calcareous, fissile to blocky, caliche
12	1 ft.	shale, dusky yellowish green, silty, blocky
11	1 ft.	shale, greenish gray, calcareous, blocky
10	0.8 ft.	shale, grayish brown, silty blocky
9	1 ft.	shale, dark greenish gray, silty, blocky
8	0.15 ft.	shale, grayish yellow with nodular limestone, crumbly
7	0.3 ft.	shale, grayish brown with nodular limestone
6	0.4 ft	mudstone, ostracodes, micrite, grayish brown
5	0.9 ft.	shale, moderate gray, silty, blocky
4	0.6 ft.	shale, olive gray, silty, blocky
3	0.6 ft.	shale, grayish brown, silty, blocky
2	0.6 ft.	shale, greenish olive, blocky
1	1 ft.	shale, grayish olive, sandy, blocky

Photo 36 NK#2 Blue Rapids Shale
Taken along Scenic Drive in Manhattan, Kansas. The Blue Rapids Shale is below the basal Funston Limestone (the limestone uppermost in photo).



Photograph 37, NK#1, Blue Rapids Shale, Unit: 6
mudstone, micrite, hematitic



Photograph 38, NK#1, Blue Rapids Shale, Unit: 17
mudstone, micrite.

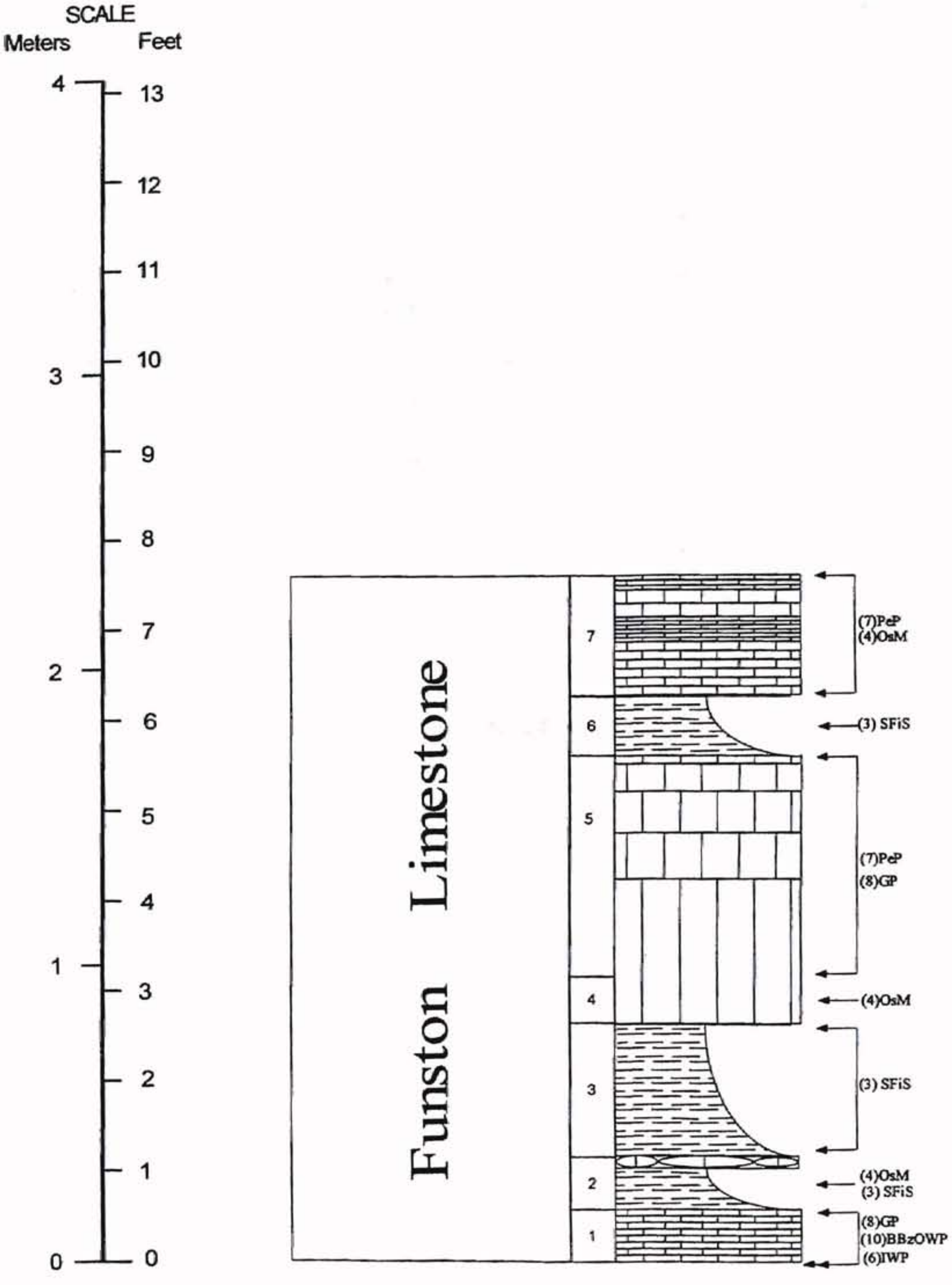


Figure 34. NK #2 measured Section, Funston Limestone

State: Kansas County: Riley

Locality Description:
Roadcut on east side of Scenic Drive in Manhattan, Kansas,
NE/4 Section 2, T10S, R7E, R7E, Keats 7.5' Quadrangle, Riley County, Kansas.

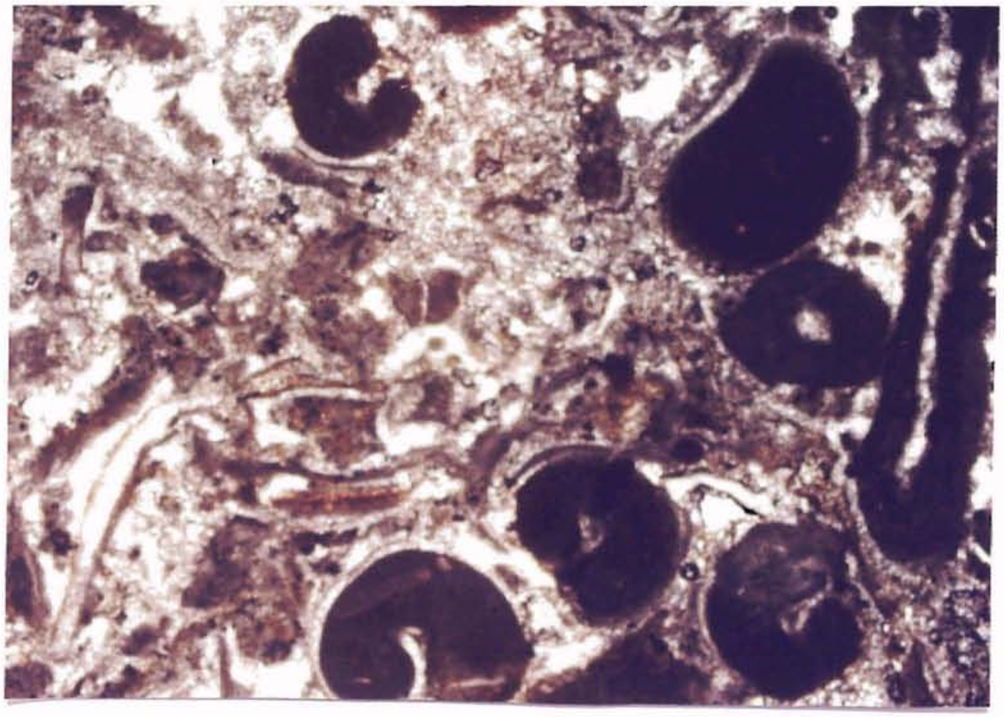
UNIT DESCRIPTION

Funston Limestone

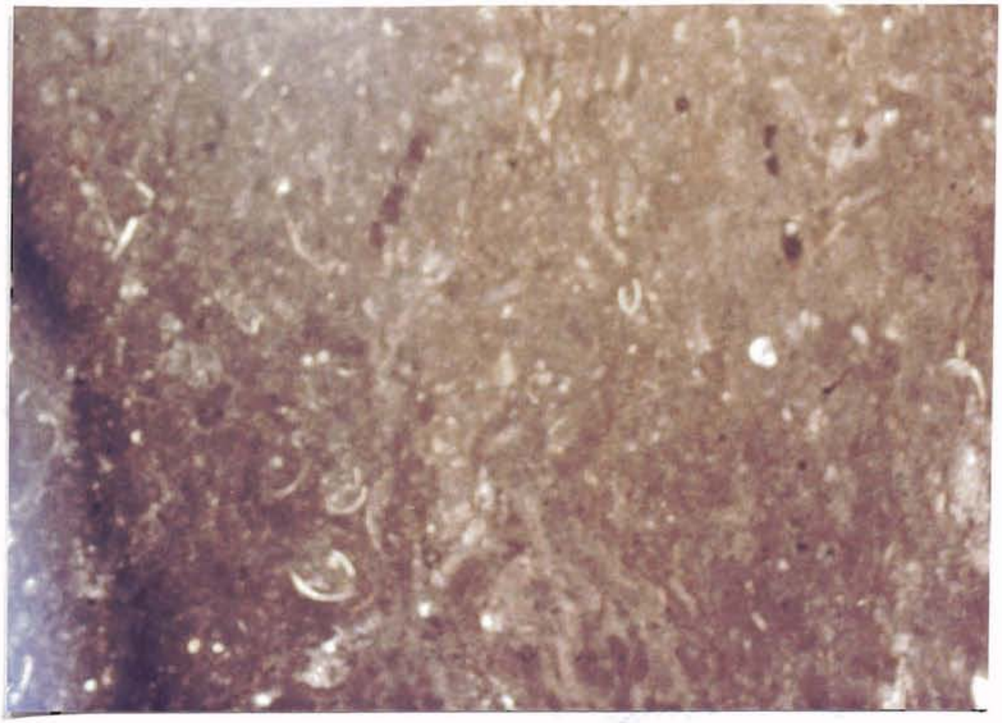
7	1.3 ft.	mudstone, peloid, ostracodes, recrystallized micrite, hematitic, brown gray to light brown olive
6	0.45 ft.	shale, pale greenish yellow with nodular limestone, blocky, calcareous,
5	2.5 ft	packstone /boundstone, peloid, gastropods, ostracodes, algae, micrite, moderate yellow
4	0.5 ft.	mudstone, bioclasts, recrystallized micrite, hematitic, moderate yellow
3	1.5 ft.	shale, grayish yellow green to moderate yellow, calcareous, crumbly to blocky
2	0.6 ft	shale, yellowish gray with nodular limestone, crumbly nodular limestone: mudstone, micrite
1	0.6 ft.	packstone /boundstone, oncoid, intraclasts, brachiopods, gastropods, bryozoa, echinoderms, algae, micrite

Photo 39 NK#2 Funston Limestone
Taken along Scenic Drive in Manhattan, Kansas. The Funston includes the three limestone ledges in the middle of the photograph. Upper shale is Speiser Shale, lower shale is upper part of Blue Rapids Shale.

Photograph 40, NK#1, Funston Limestone, Unit: 2
mudstone, micrite, hematitic.



Photograph 41, NK#1, Funston Limestone, Unit: 5
packstone, gastropod, ostracode, bioclast, micrite.



Photograph 42, NK#1, Funston Limestone, Unit: 7
wackstone, peloid, ostracode, micrite.

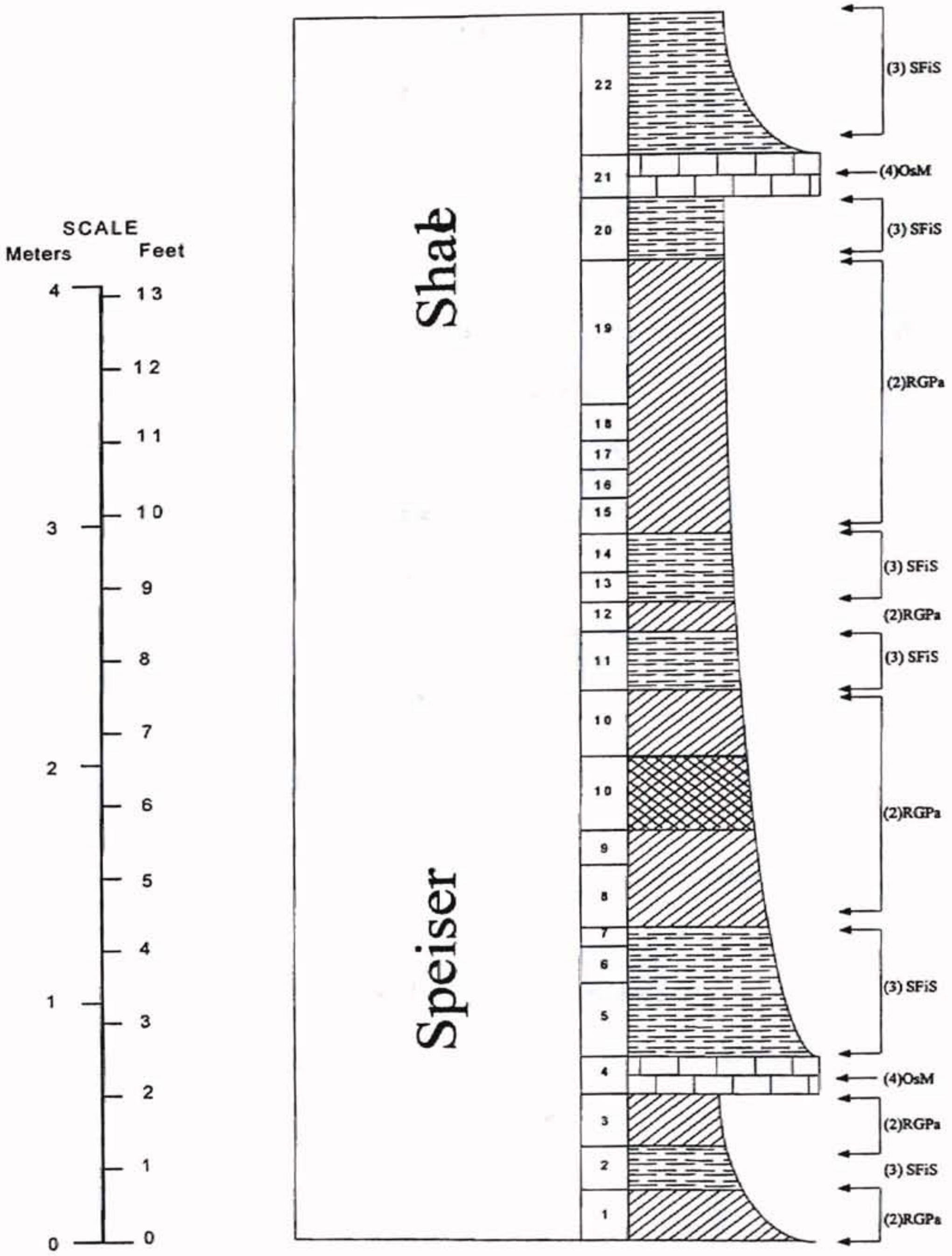


Figure 35. NK #2 Measured Section, Speiser Shale.

State: Kansas County: Riley

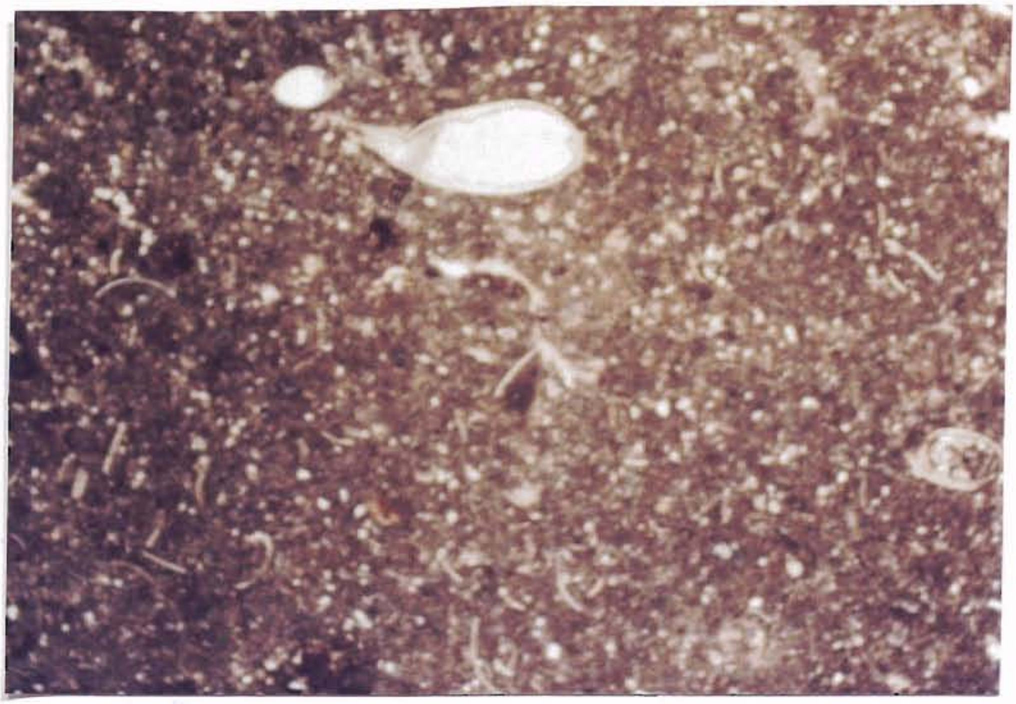
Locality Description:
Roadcut on east side of Scenic Drive in Manhattan, Kansas,
NE/4 Section 2, T10S, R7E, R7E, Keats 7.5' Quadrangle, Riley County, Kansas.

UNIT DESCRIPTION

Speiser Shale

22	1.9 ft.	shale, dusky yellow to yellow gray, calcareous, blocky to fissile
21	0.6 ft.	wackestone, micrite, light gray,
20	0.85 ft.	shale, yellow gray, crumbly,
19	1,85 ft.	shale, dusky yellow green to pale olive, silty, blocky to crumbly
18	0.6 ft.	shale, light olive gray, calcareous, blocky
17	0.4 ft.	shale, greenish gray, blocky
16	0.5 ft.	shale, light olive gray, calcareous, blocky
15	0.4 ft.	shale, brown, calcareous, blocky
14	0.4 ft.	shale, grayish brown, calcareous, blocky
13	0.4 ft.	shale, light olive gray, calcareous, blocky
12	0.8 ft.	shale, moderate brown, calcareous, blocky
11	0.9 ft.	shale, light olive gray, calcareous, blocky
10	1 ft.	shale, dark reddish brown, calcareous, blocky
9	0.7 ft.	shale, pale olive, sandy, blocky
8	0.85 ft.	shale, olive gray, silty, blocky
7	0.25 ft.	shale, dark gray, calcareous, crumbly
6	0.5 ft.	shale, dusky yellow/green, crumbly, caliche
5	1 ft.	shale, moderate brown, calcareous, blocky, caliche
4	0.5 ft.	wackestone, intraclasts, ostracodes, micrite, gray
3	0.5 ft.	shale, light olive, calcareous, blocky
2	0.6 ft.	shale, dusky gray, calcareous, blocky
1	0.7 ft.	shale, pale olive, calcareous, blocky

Photo 43 NK#2 Speiser Shale.
Taken along Scenic Drive in Manhattan, Kansas. The Speiser Shale is below the Threemile Limestone (limestone in the upper part of the photo).



Photograph 44, NK#1, Speiser Shale, Unit: 4
wackestone, peloid, ostracode, micrite.

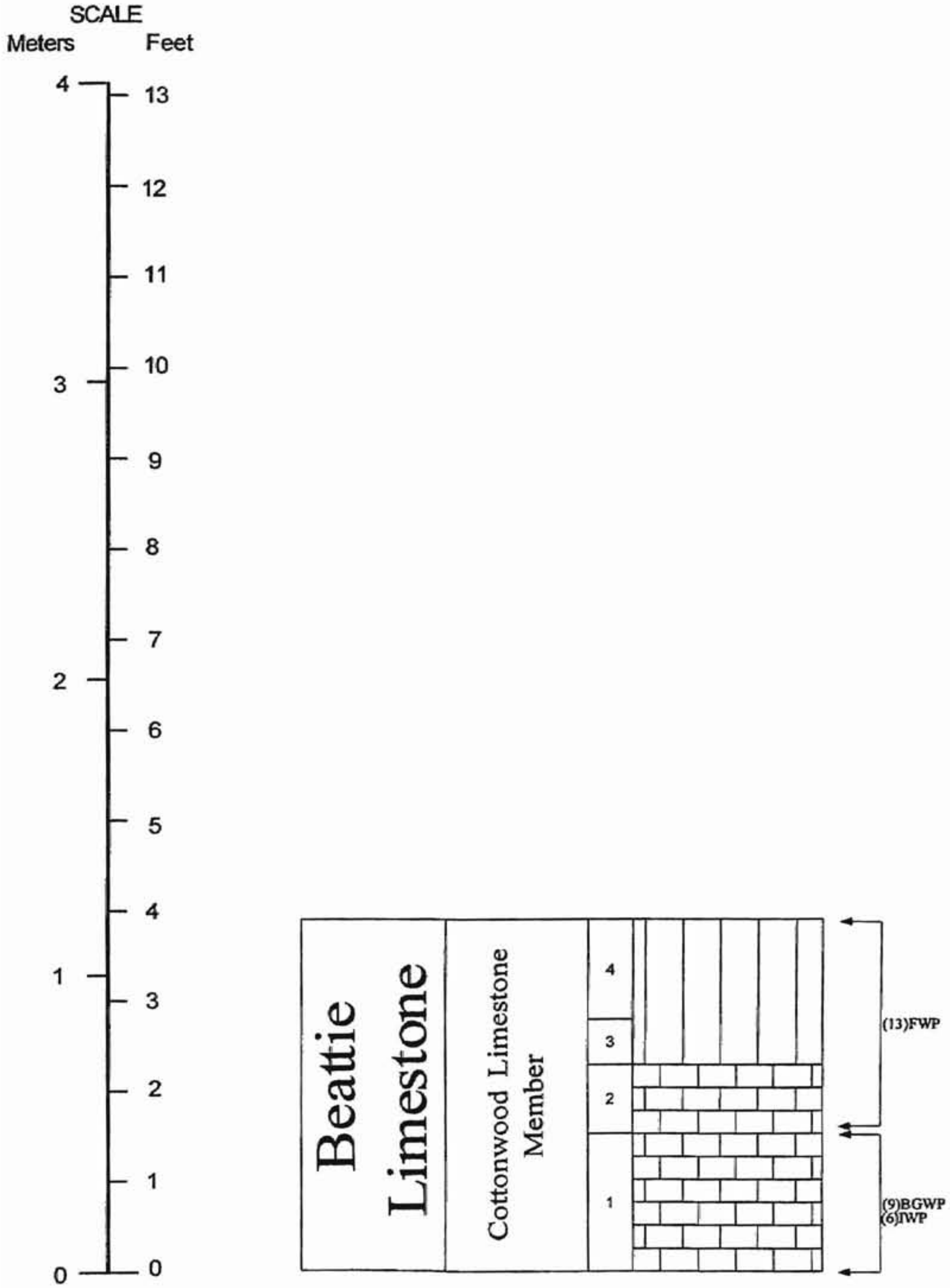


Figure 36. Measured Section CK #1, Cottonwood Limestone.

State: Kansas County: Chase County

Locality Description:
Roadcuts on north side of road from Elmdale to Cottonwood Falls.
SE/4, SW/4, NW/4, Section 26, T19S, R7E, Elmdale 7.5' Quadrangle, Chase County, Kansas.

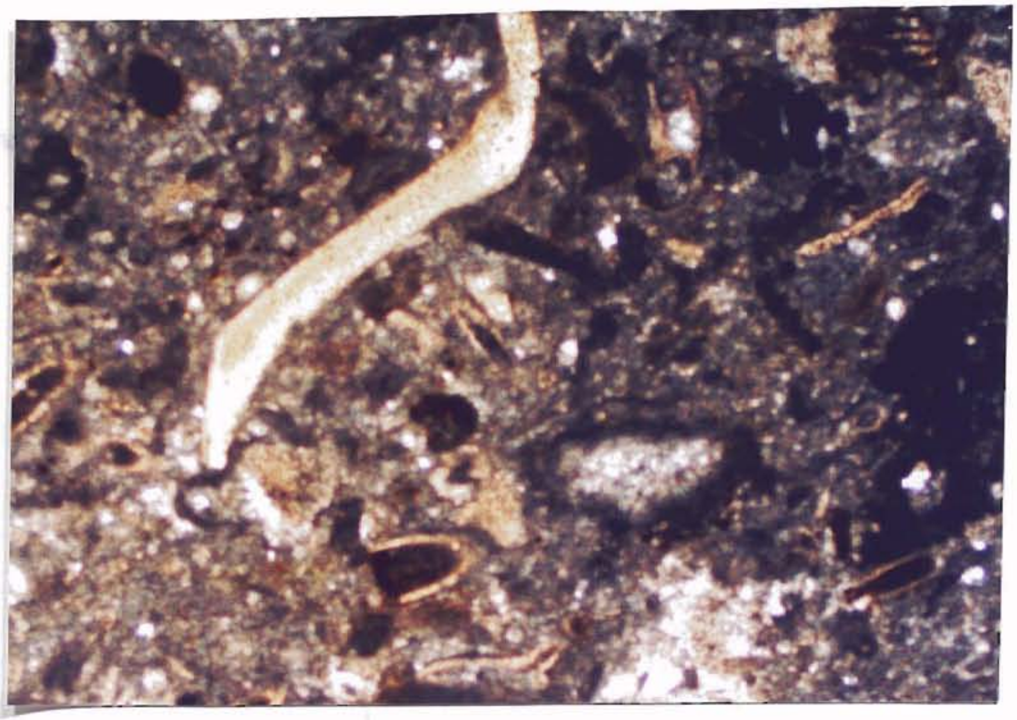
UNIT DESCRIPTION

Beattie Limestone

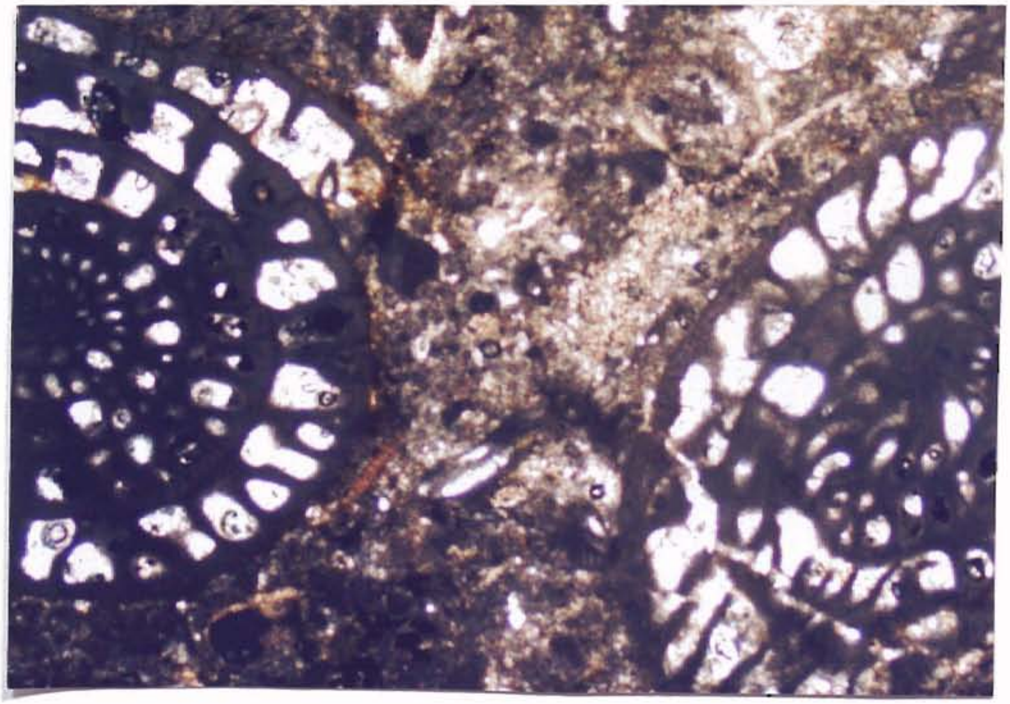
Cottonwood Limestone Member

4	1 ft.	packstone, fusulinids, algae, trilobites, ostracodes, micrite, light yellow gray
3	0.5 ft.	packstone, fusulinids, algae, micrite, light yellowish gray
2	0.7 ft.	wackestone, fusulinids, algae, micrite, brownish gray
1	1.5 ft.	wackestone, oncoid, brachiopods, gastropods, bivalve, algae, fusulinids, intraclastss, ostracodes, bryozoa, micrite, light yellow gray

Photo 45 CK#1 Cottonwood Limestone
Taken along road from Elmdale to Cottonwood Falls, Chase County, Kansas. The Cottonwood Limestone at this locality is thin to thick bedded limestone with weathering vugs.



Photograph 46, CK#1, Cottonwood Limestone Member, Unit: 1
wackestone, oncoid, intraclast, brachiopod, algae,micrite.



Photograph 47, CK#1, Cottonwood Limestone Member, Unit: 4
packstone, fusulinid, trilobite, aglade, micrite.

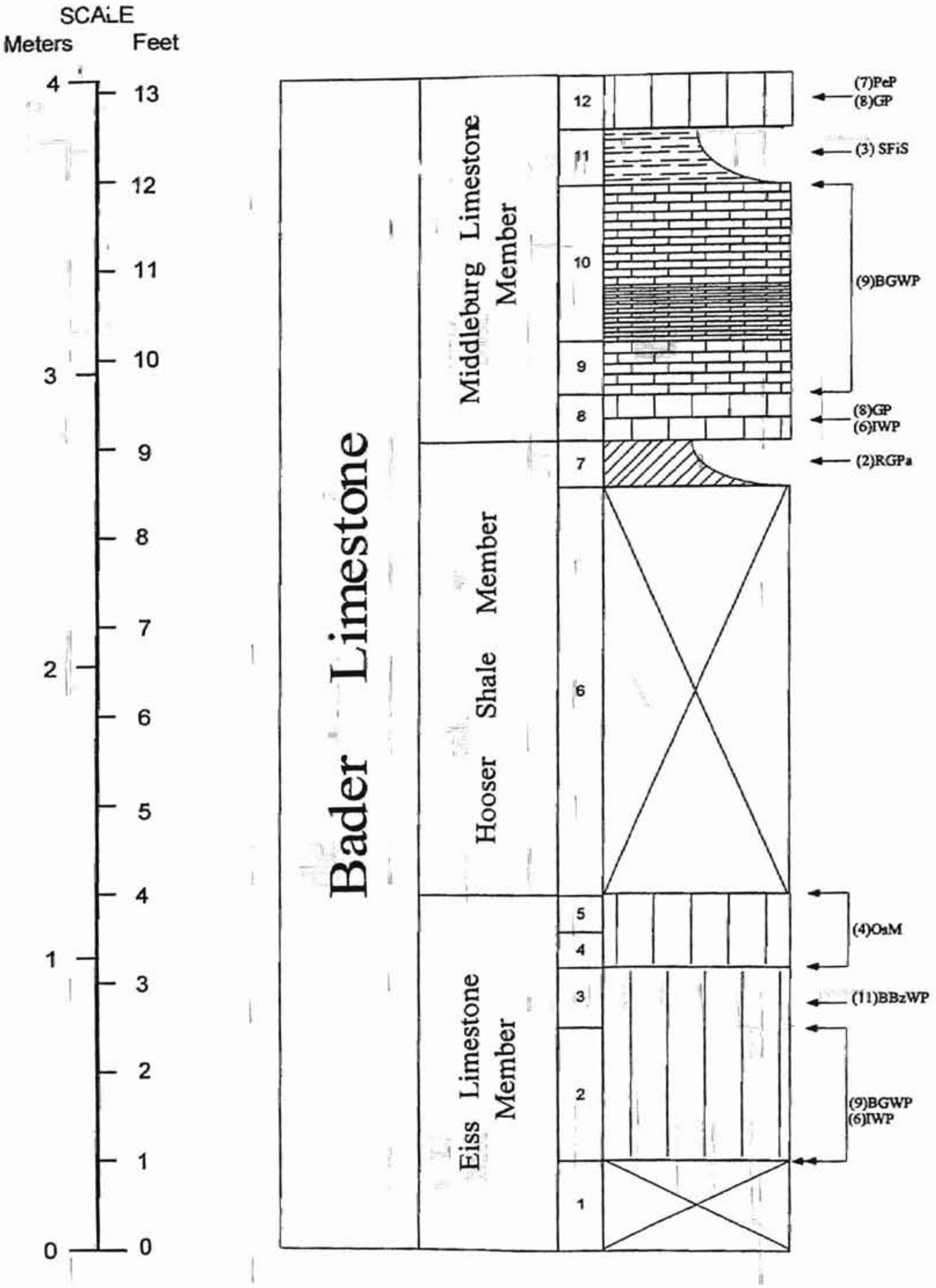


Figure 37. Measured Section CK #2, Bader Limestone.

State: Kansas County: Chase County

Locality Description:
Roadcuts on south side of road from Elmdale to Cottonwood Falls, 1.8 miles west of intersection with US highway 177.
NE/4 of Section 30, T19S, R8E, Cottonwood Falls 7.5' Quadrangle, Chase County,

UNIT DESCRIPTION

Bader Limestone

Middleburg Limestone Member

12	0.6 ft.	wackestone, peloid, gastropods, ostracodes, algae, light gr
11	0.6 ft.	shale, grayish black, crumbly
10	1.7 ft.	wackestone, brachiopods, bryozoa, echinoderms, trilobites, ostracodes, gastropods, micrite, dark gray to brownish gray
9	0.6 ft.	packstone brachiopods, peloid, gastropods, echinoderms, al micrite, medium gray
8	0.5 ft.	wackestone, intraclasts, gastropods, ostracodes, algae, micri brownish gray

Hooser Shale Member

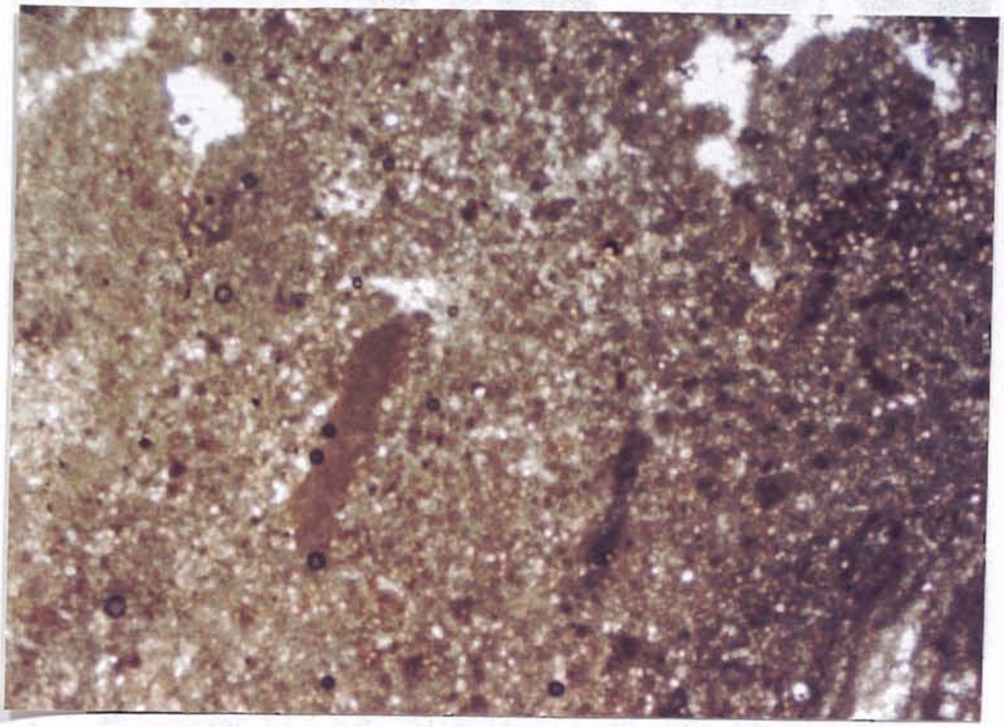
7	0.5 ft.	shale, light olive brown, crumbly
6	4.5 ft.	cover

Eiss Limestone Member

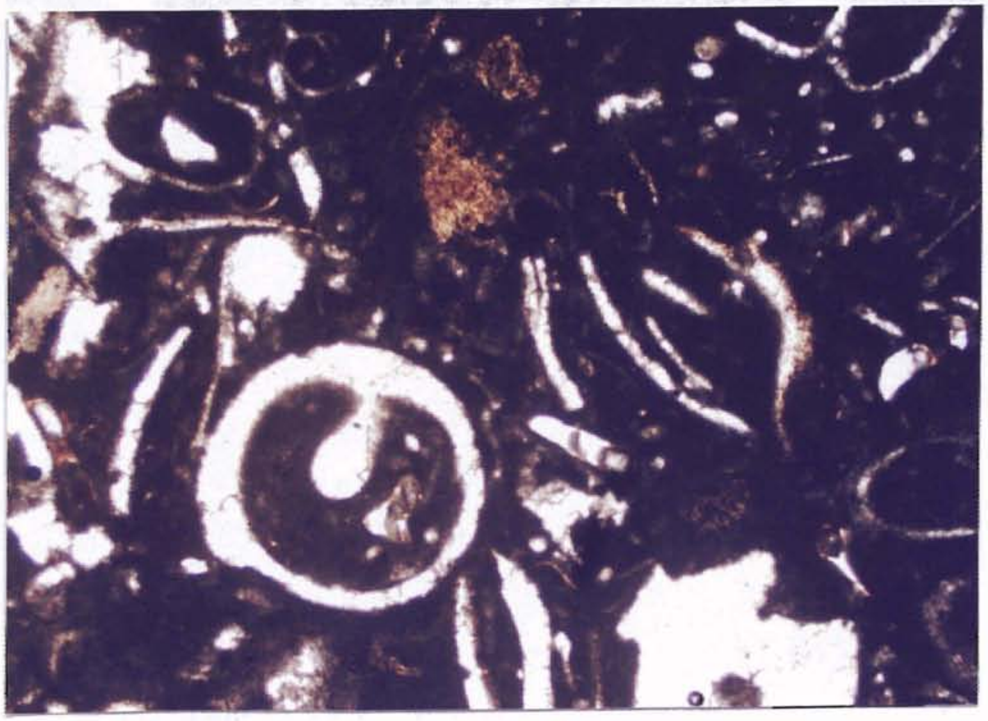
5	0.4 ft.	mudstone, intraclasts, micrite, hematitic, light buff
4	0.4 ft.	wackestone, intraclasts, micrite, hematitic, buff
3	0.6 ft	packstone, brachiopods, echinoderms, ostracodes, algae, mic yellowish gray
2	1.5 ft.	wackestone, intraclasts, gastropods, brachiopods, ostracodes, echinoderms, algae, micrite, yellowish gray
1	? ft.	cover

Photo 48 CK#2 Eiss Limestone
Taken along road from Elmdale to Cottonwood Falls, Chase County, Kansas. The Eiss Limestone at this locality is medium to thick bedded limestones.

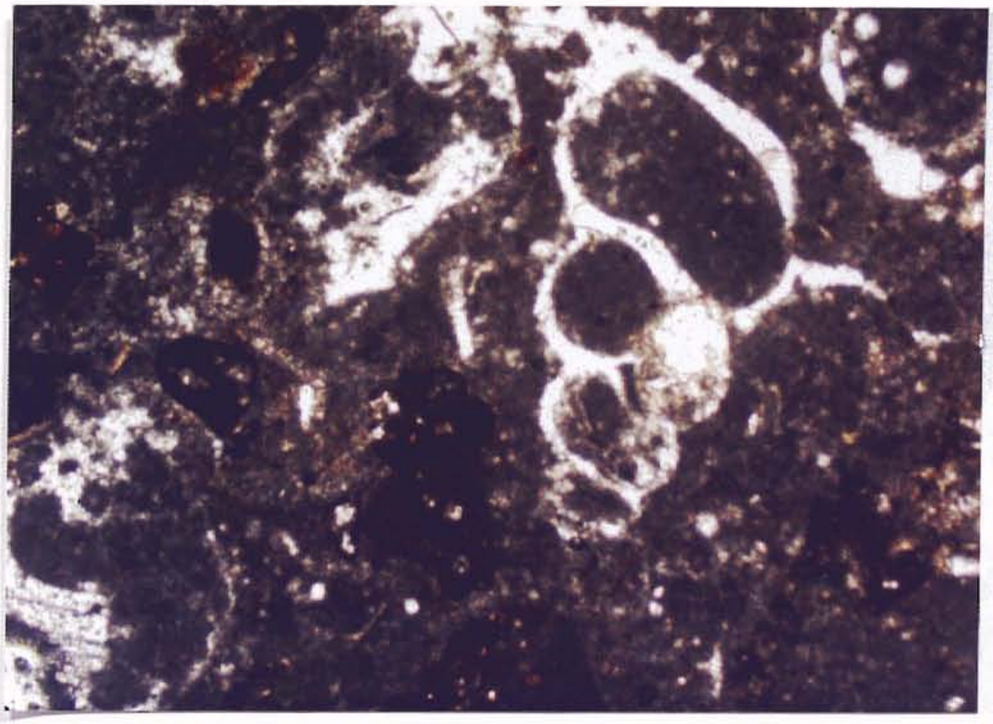
Photo 49 CK#2 Middleburg Limestone
Taken along road from Elmdale to Cottonwood Falls, Chase County, Kansas. The Middleburg Limestone at this locality is flagy limestone.



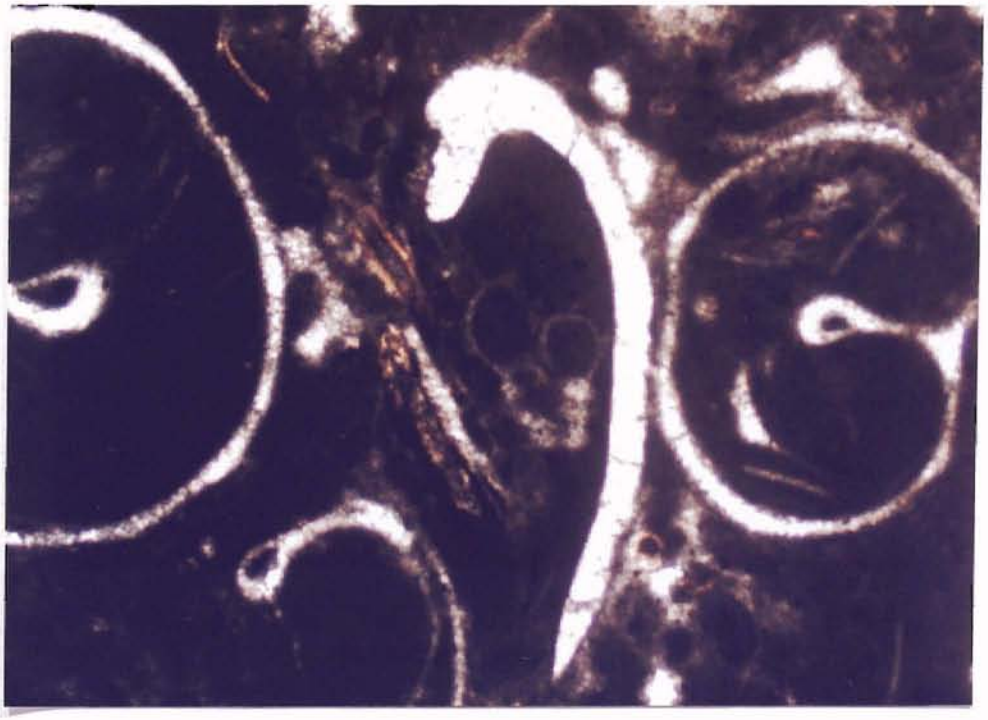
Photograph 50, CK#3, Eiss Limestone Member, Unit: 1
mudstone, intraclast, bioclast, micrite.



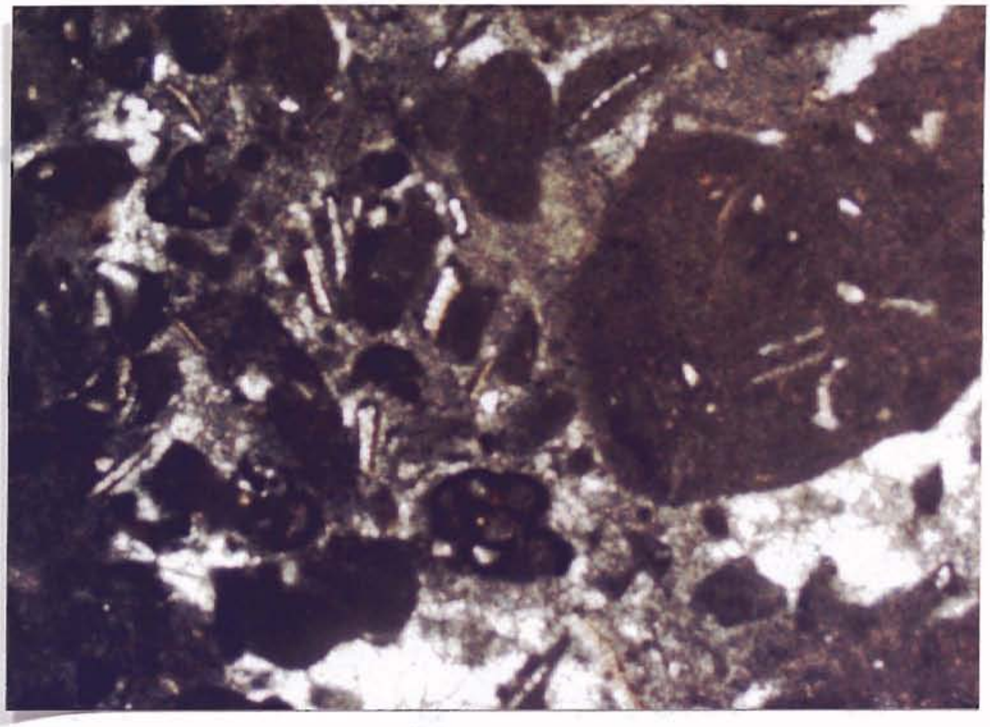
Photograph 51, CK#3, Eiss Limestone Member, Unit: 11
wackestone, gastropod, ostracode, micrite,



Photograph 52, CK#2, Middleburg Limestone Member, Unit: 8
wackestone, intraclast, gastropod, algae.



Photograph 53, CK#3, Middleburg Limestone Member, Unit: 9
packstone, gastropod, ostracode,



Photograph 54, CK#2, Middleburg Limestone Member, Unit: 12
wackestone, intraclast, bioclast, micrite.

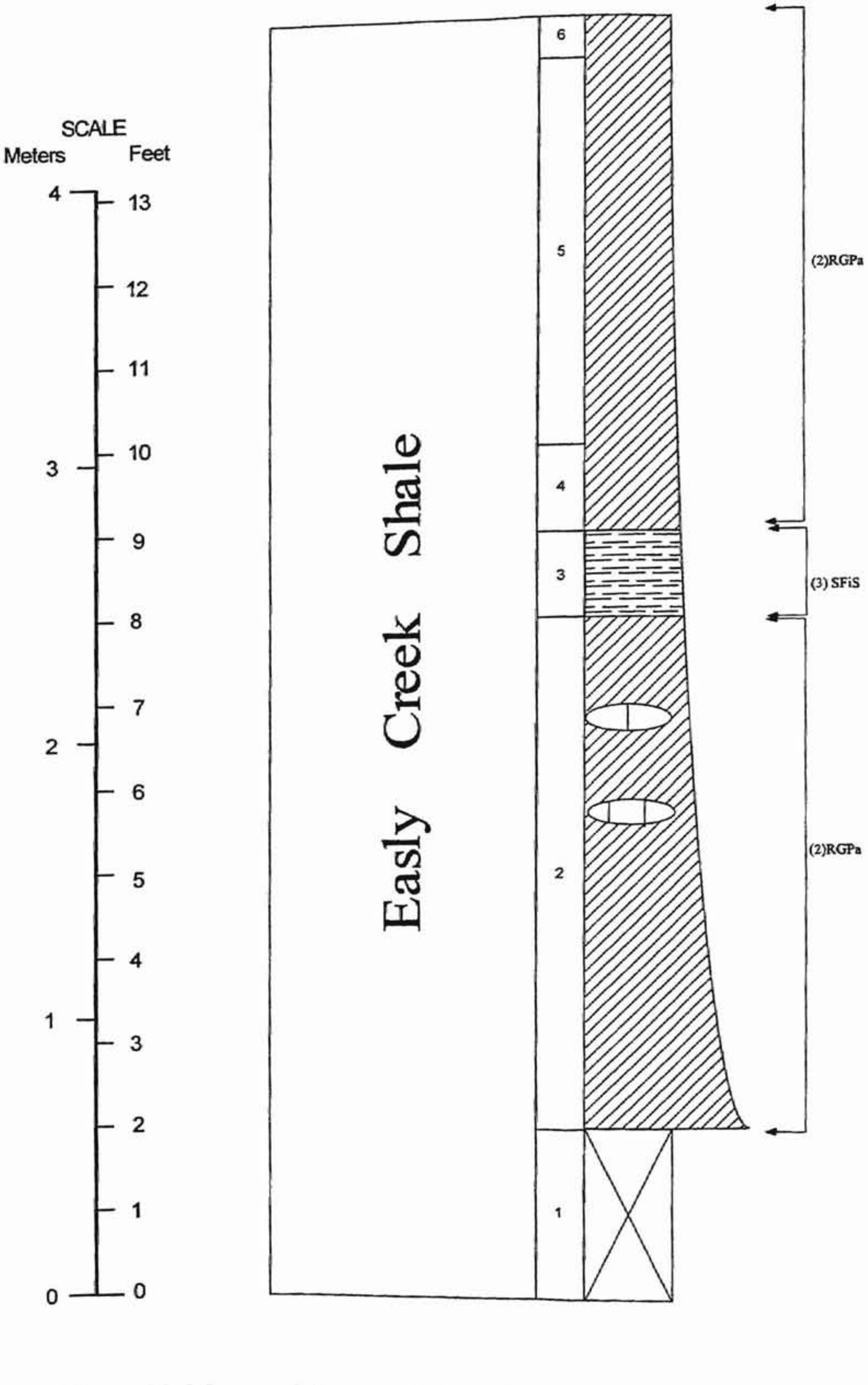


Figure 38. Measured Section CK #2, Easly Creek Shale.

State: Kansas County: Chase County

Locality Description:
Roadcuts on south side of road from Elmdale to Cottonwood Falls, 1.8 miles west of its intersection with US highway 177.
NE/4 of Section 30, T19S, R8E, Cottonwood Falls 7.5' Quadrangle, Chase County, Kansas.

UNIT DESCRIPTION

Easly Creek Shale

6	0.5 ft.	shale, pale olive, blocky to crumbly
5	4.5 ft.	shale, light olive, calcareous, blocky
4	1 ft.	shale, grayish green, calcareous, blocky
3	1 ft.	shale, brownish gray, calcareous, blocky
2	6 ft.	shale, dusky yellow green with nodular limestone, crumbly
1	? ft.	cover

Photo 55 CK#2 Easly Creek Shale
Taken along road from Elmdale to Cottonwood Falls, Chase County, Kansas. The Easly Creek Shale is below the basal Crouse Limestone (the upper limestone in photo).

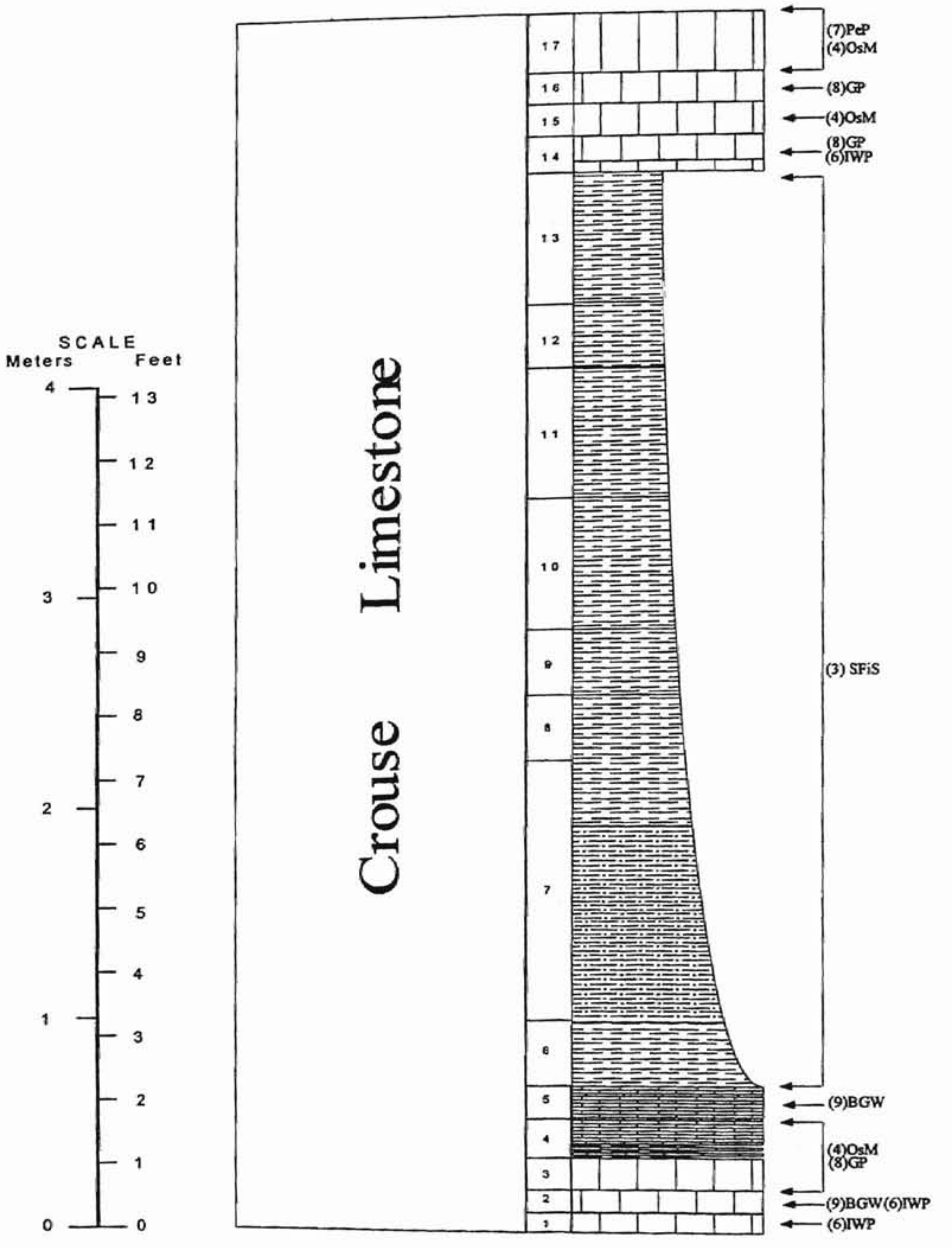


Figure 39. Measured Section CK #2, Crouse Limestone.

State: Kansas County: Chase County

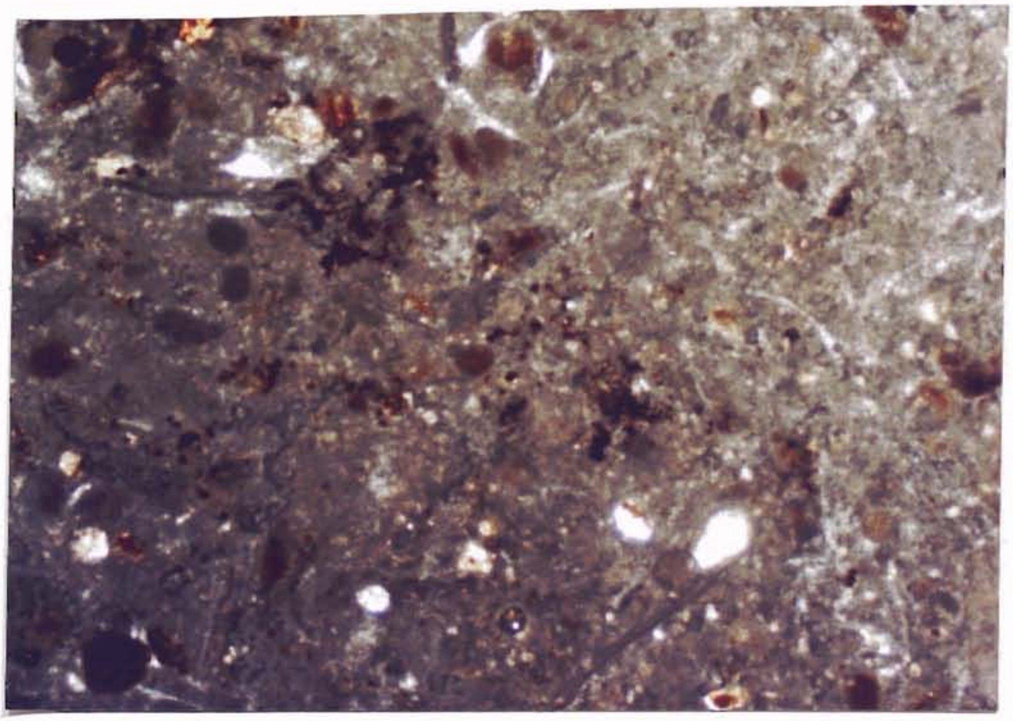
Locality Description:
Roadcuts on south side of road from Elmdale to Cottonwood Falls, 1.8 miles west of its intersection with US highway 177.
NE/4 of Section 30, T19S, R8E, Cottonwood Falls 7.5' Quadrangle, Chase County, Kansas.

UNIT DESCRIPTION

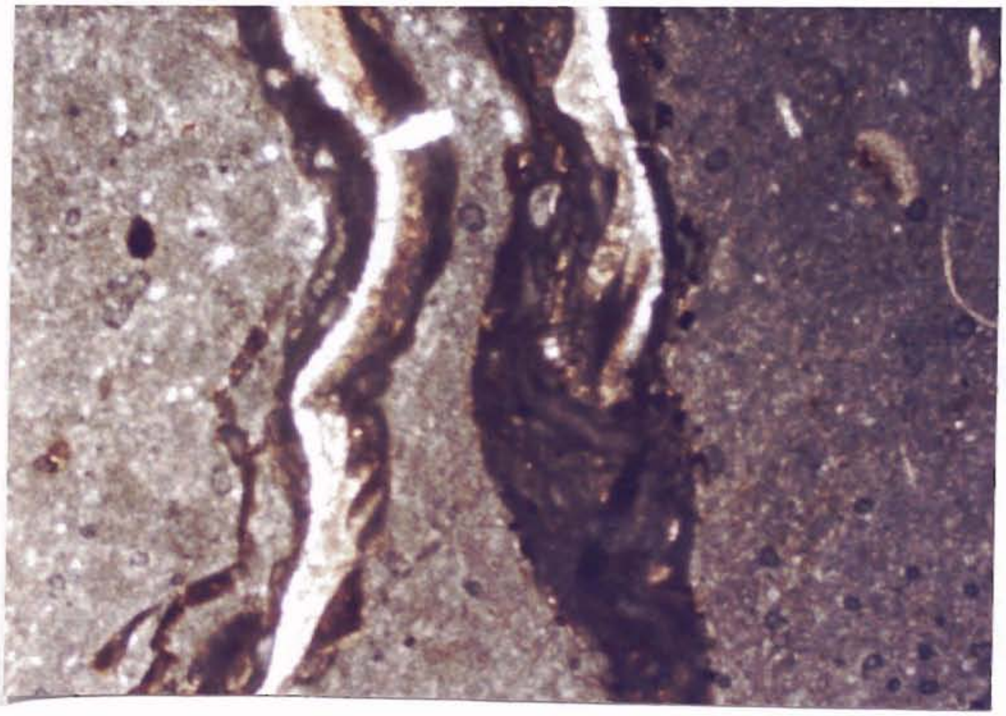
Crouse Limestone

17	0.9 ft.	mudstone, peloid, ostracodes, algae, micrite, hematitic, light yellowish brown
16	0.5 ft.	wackestone, oncoid, gastropods, algae, micrite, grayish brown
15	0.5 ft.	mudstone, micrite, light yellowish gray
14	0.6 ft.	wackestone or boundstone, intraclasts, gastropods, ostracodes, micrite, dark yellowish orange to buff l
13	2 ft.	shale, dusky yellow to moderate yellowish brown , calcareous, blocky, caliche (top)
12	1 ft.	shale, moderate olive brown, caliche, blocky
11	2 ft.	shale, dusky yellow, calcareous, blocky
10	2 ft.	shale, moderate olive brown, calcareous, blocky
9	1 ft.	shale, grayish black, blocky
8	1 ft.	shale, light olive gray, blocky
7	4 ft.	shale, moderate olive brown to light olive brown, calcareous, silty, blocky to fissile
6	1 ft.	shale, light olive gray, calcareous, crumbly
5	0.5 ft.	packstone or boundstone, brachiopods, gastropods, bryozoa, echinoderms, micrite, light yellowish gray
4	0.6 ft.	mudstone, bryozoa, hematitic, micrite, yellowish gray brown
3	0.5 ft.	mudstone, oncoid, gastropods, ostracodes, algae, micrite, buff dusky yellow
2	0.35 ft.	wackestone, intraclasts, brachiopods, gastropods, trilobites, micrite, buff dusky yellow
1	0.3 ft.	wackestone, intraclasts, algae, micrite, light yellowish gray

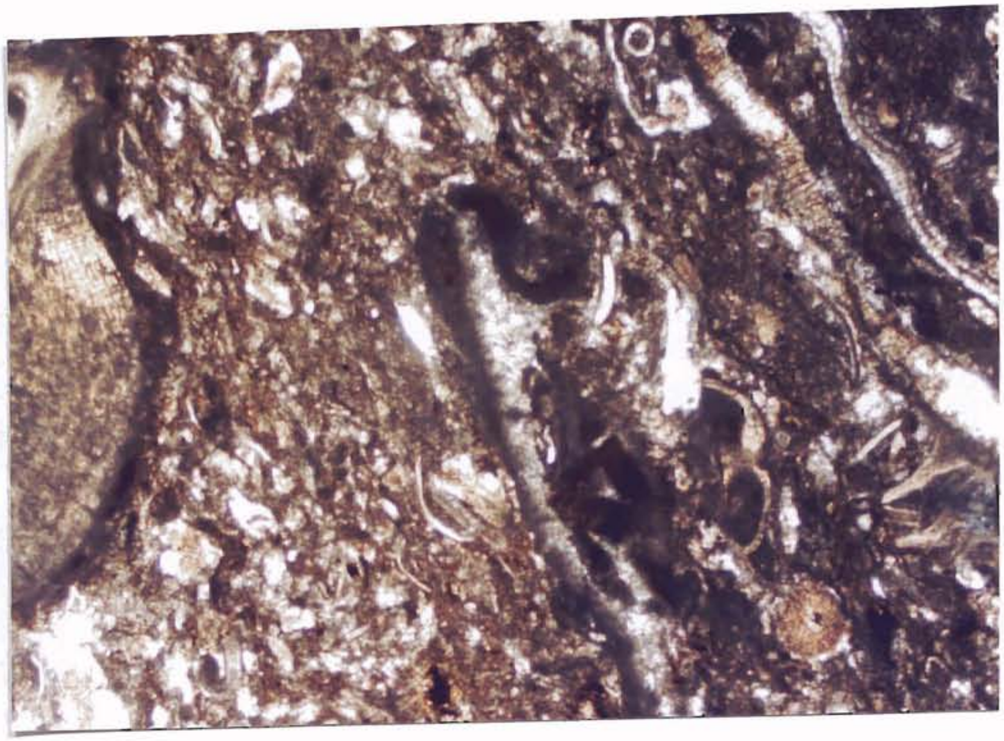
Photo 56 CK#2 Crouse Limestone
Taken along road from Elmdale to Cottonwood Falls, Chase County, Kansas. The Crouse Limestone at this locality includes the three parts; the lower limestone, middle shale, and upper limestone. The photo shows the middle shale, and upper limestone (thin to medium beds).



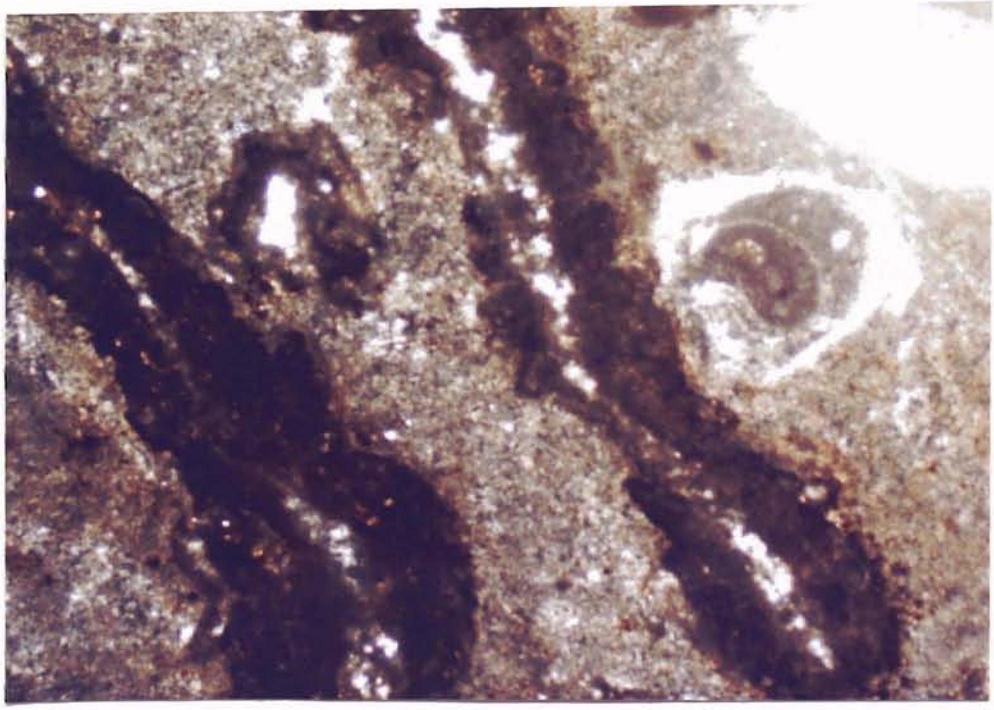
Photograph 57, CK#2, Crouse Limestone, Unit: 1
wackestone, intraclast, algae.



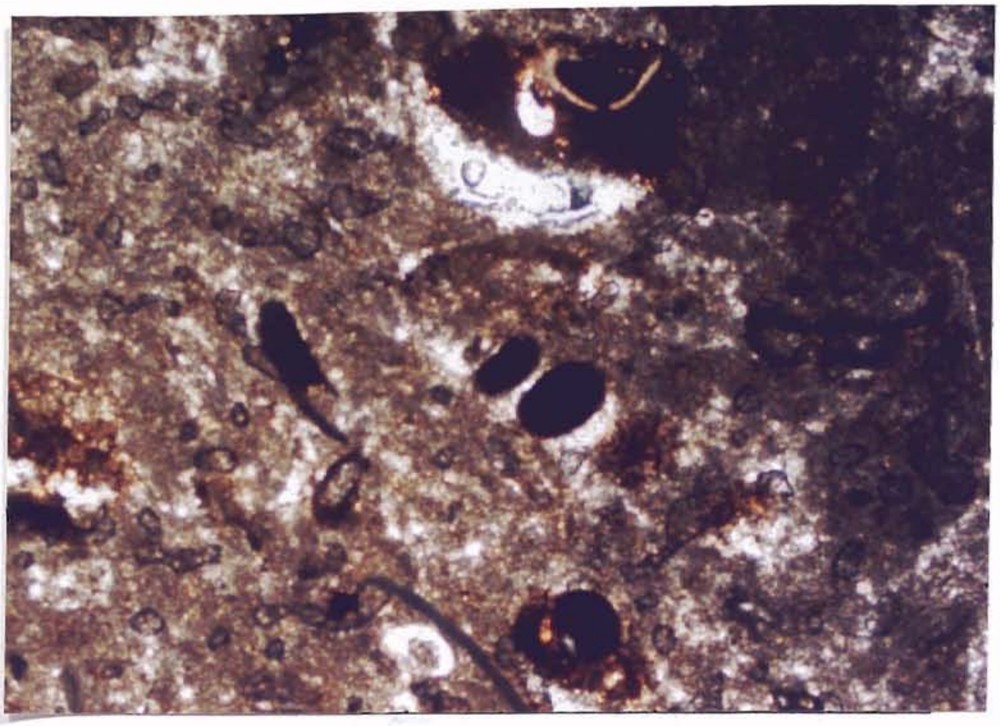
Photograph 58, CK#2, Crouse Limestone, Unit: 3
mudstone, oncoid, ostracode, algae, micrite.



Photograph 59, CK#2, Crouse Limestone, Unit: 5
packestone, brachiopod, bryozoan, echinoderm, micrite.



Photograph 60, CK#2, Crouse Limestone, Unit: 16
wackestone, oncoid, algae, bioclast, micrite.



Photograph 61, CK#2, Crouse Limestone, Unit: 17
wackestone, gastropod, ostracode.

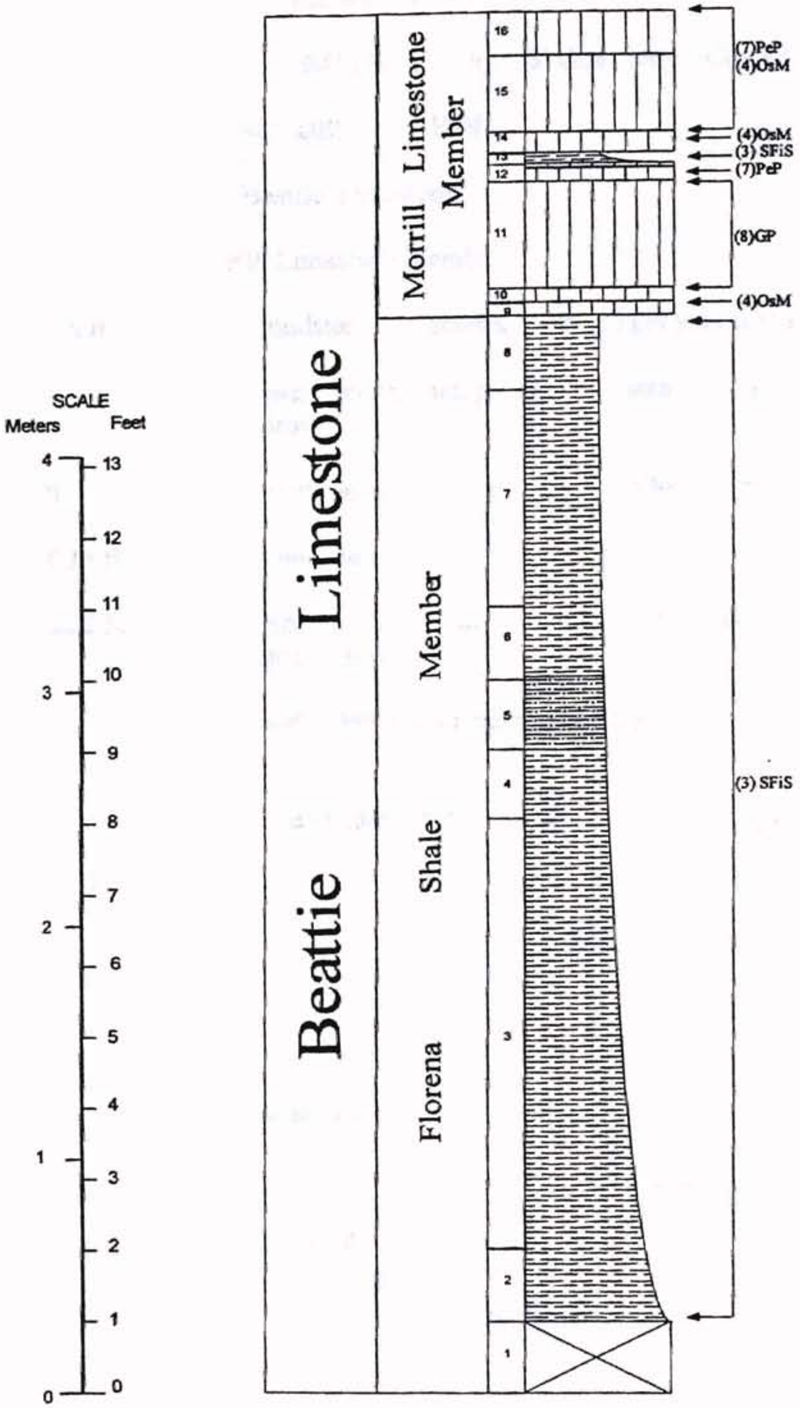


Figure 40. Measured Section CK #3, Beattie Limestone.

State: Kansas County: Chase County

Locality Description:
Roadcuts on east side of US Highway 177 at a point 5.3-5.5 miles north of its intersection with US Highway 50.
S/2, NW/4, Section 17, T17S, R8E, Strong City 7.5' Quadrangle, Chase County, Kansas.

UNIT DESCRIPTION

Beattie Limestone

Morrill Limestone Member

16	0.6 ft.	mudstone, ostracodes, micrite, light yellow gray
15	1.1 ft.	packstone, peloid, gastropods, ostracodes, algae, micrite, light brown
14	0.3 ft.	mudstone, ostracodes, micrite, yellowish gray
13	0.15 ft.	shale, yellowish gray, fissile
12	0.25 ft.	wackestone, peloid, echinoderms, ostracodes, algae, micrite, orangish buff
11	1.5 ft.	packstone, peloid, echinoderms, gastropods, ostracodes, algae, micrite, brown gray
10	0.2 ft	boundstone, echinoderms, algae, micrite, light olive
9	0.2 ft.	mudstone, echinoderms, hematitic, micrite

Florena Shale Member

8	1 ft.	shale, yellowish gray, calcareous, blocky
7	3 ft.	shale, light olive gray, calcareous, blocky
6	1 ft.	shale, dusky yellow green, calcareous, blocky
5	1 ft.	shale, olive gray, silty, blocky,
4	1 ft.	shale, light olive gray, fissile
3	6 ft.	shale, dusky yellow, calcareous, fissile to blocky
2	1 ft.	shale, light olive gray, calcareous, fissile
1	? ft.	cover

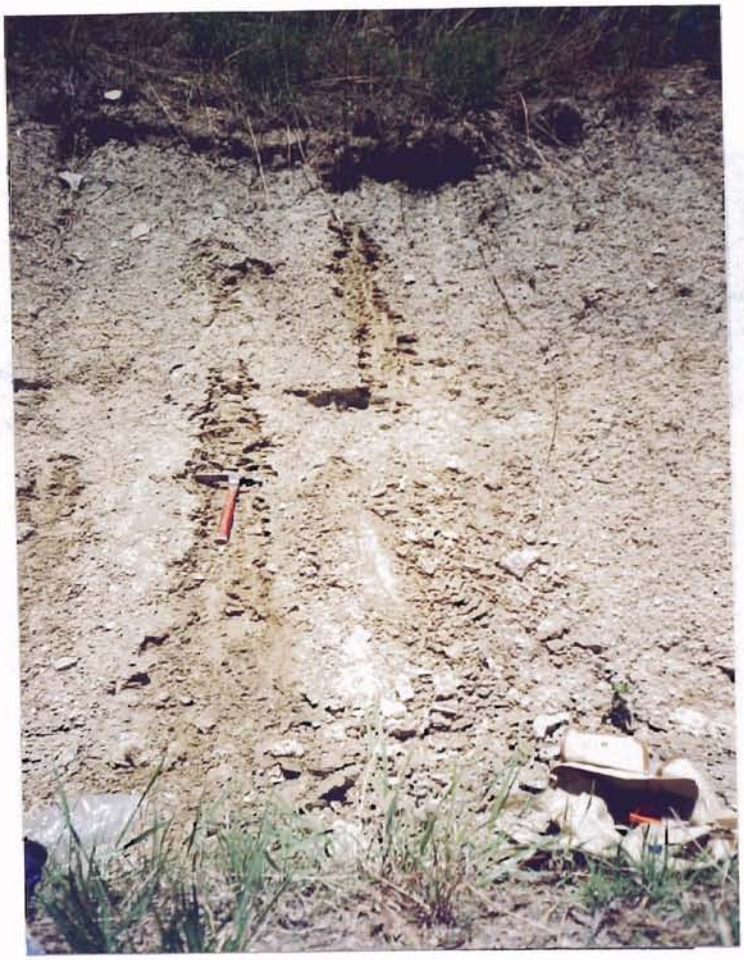
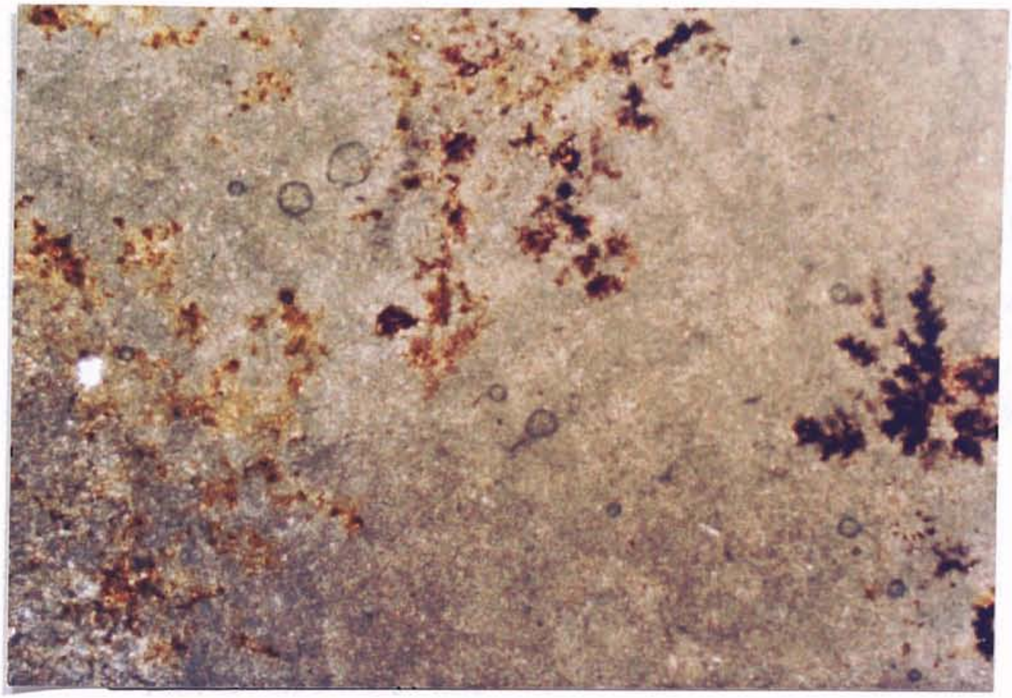
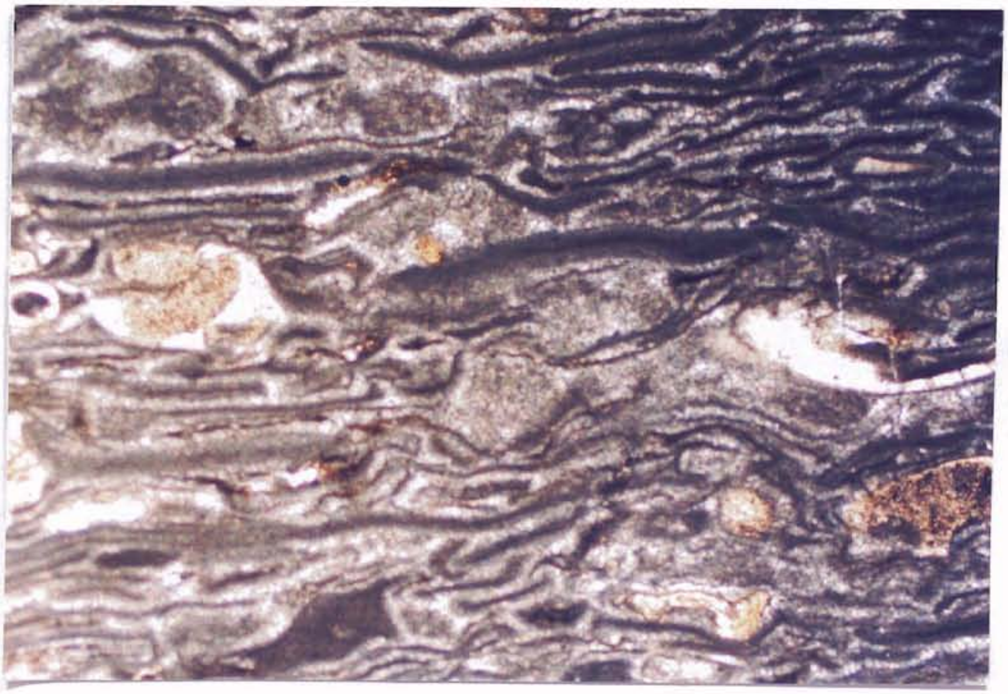


Photo 62 CK#3 Florena Shale
Taken along Highway 177 on the northwest side of Strong City, Chase County, Kansas. The Florena Shale is below the basal Morrill Limestone (the upper limestone in the photo).

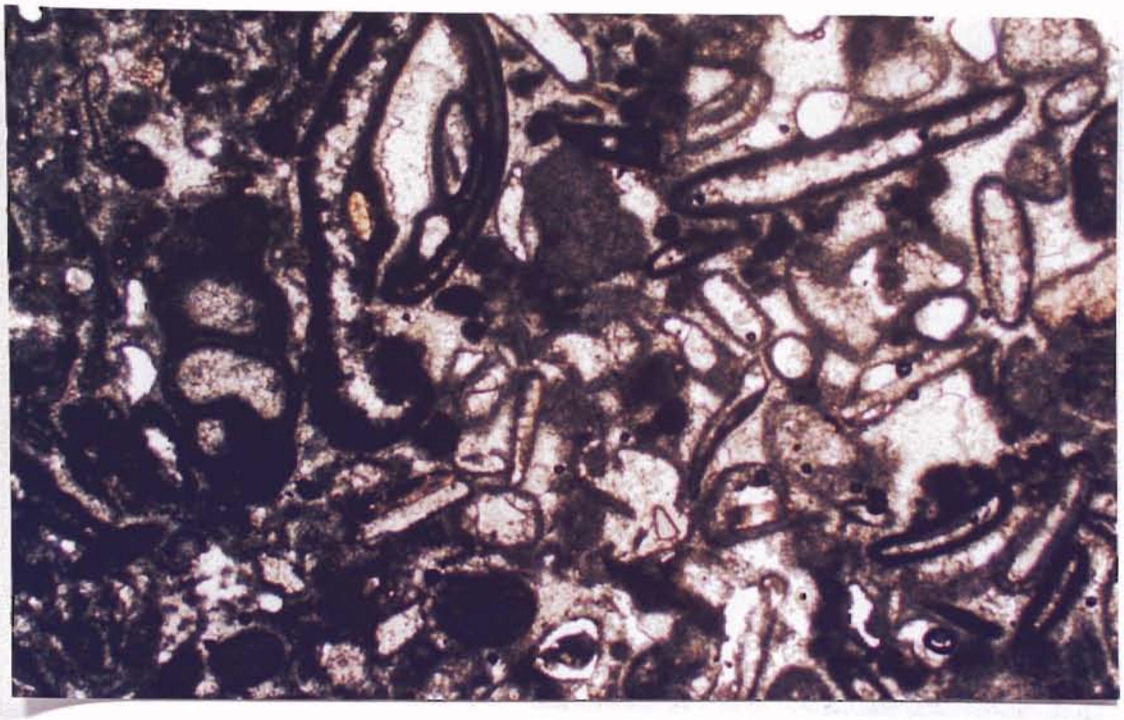
Photo 63 CK#3 Morrill Limestone
Taken along Highway 177 on the northwest side of Strong City, Chase County, Kansas. The Morrill Limestone is thin to thick-bedded limestones.



Photograph 64, CK#3, Morrill Limestone Member, Unit: 9
mudstone micrite, hematitic.

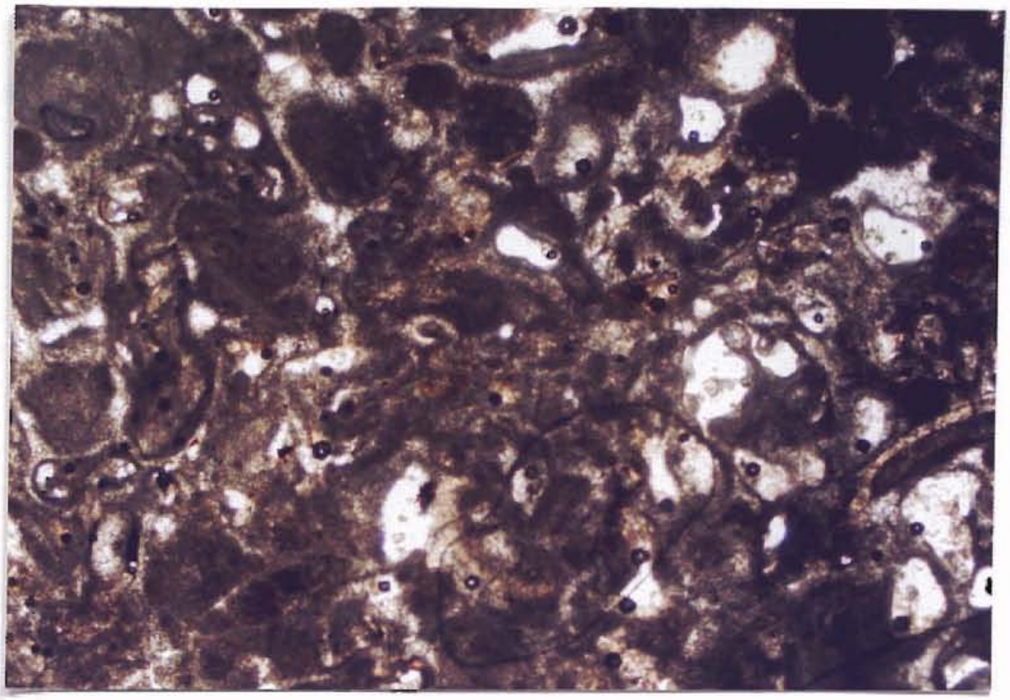


Photograph 65, CK#3, Morrill Limestone Member, Unit: 10
Boundstone, echinoderm, algae, micrite.

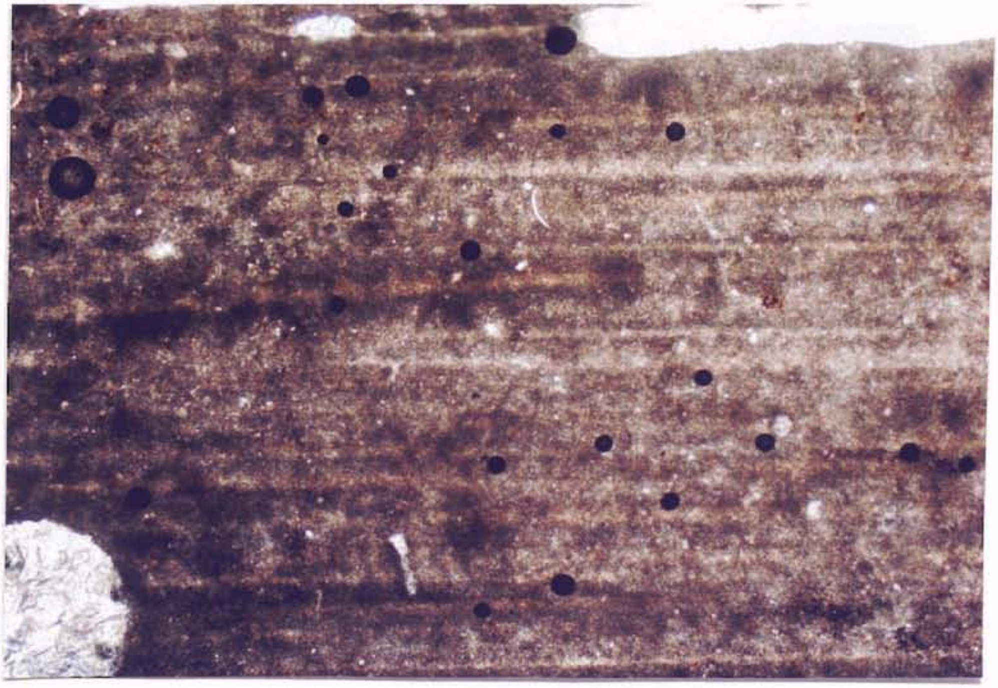


Photograph 66, CK#3, Morrill Limestone Member, Unit: 11
packstone, gastropod, ostracode, algae, micrite.

Photograph 67, CK#3, Morrill Limestone Member, Unit: 12
Wackstone, peloid, algae, ostracode, micrite.



Photograph 68, CK#3, Morrill Limestone Member, Unit: 15
packstone, peloid, gastropod, ostracode, micrite.



Photograph 69, CK#3, Morrill Limestone Member, Unit: 16
mudstone, ostracode, micrite.

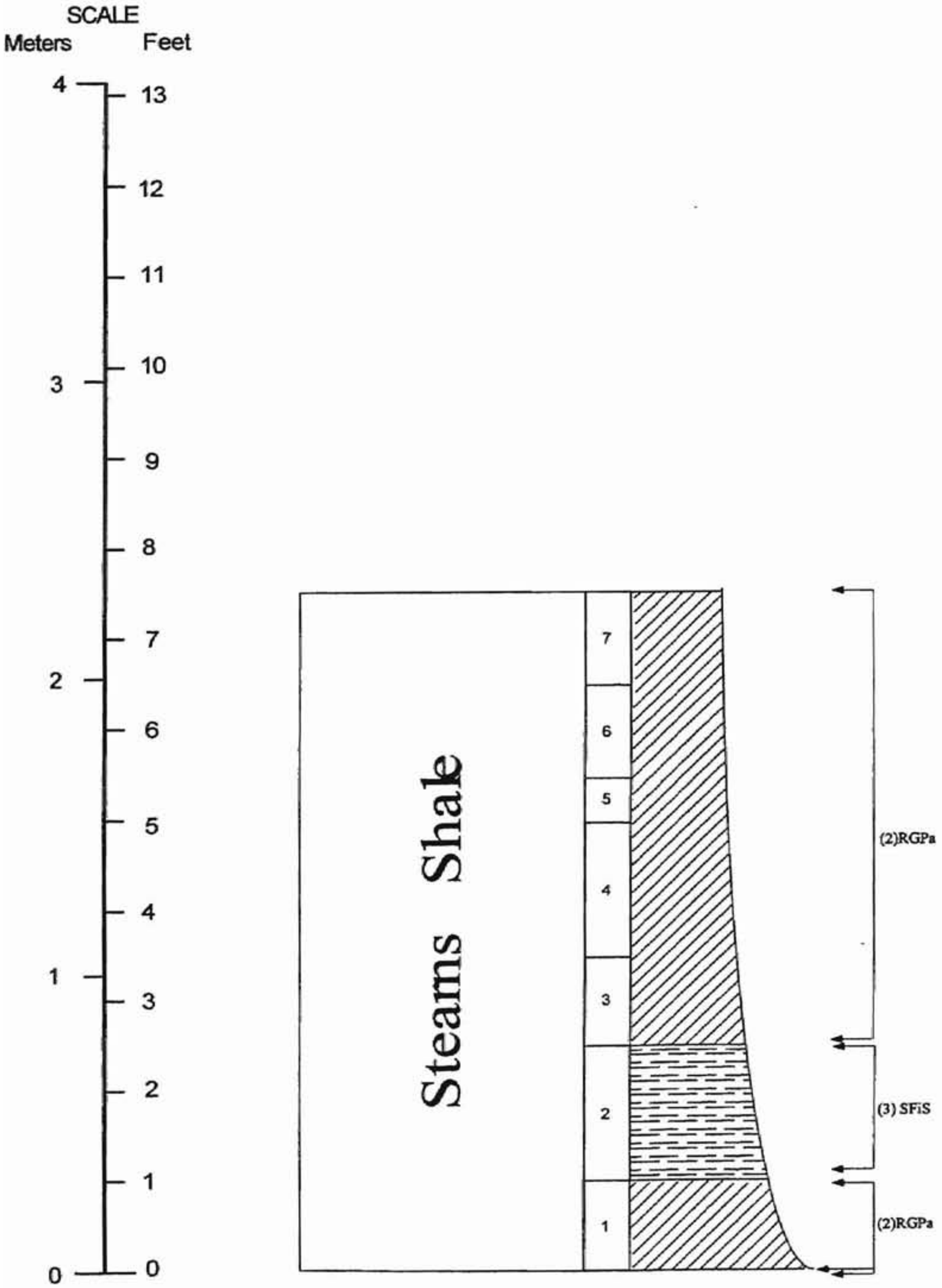


Figure 41. Measured Section CK #3, Stearns Shale.

State: Kansas County: Chase County

Locality Description:
Roadcuts on east side of US Highway 177 at a point 5.3-5.5 miles north of its intersection with US Highway 50.
S/2, NW/4, Section 17, T17S, R8E, Strong City 7.5' Quadrangle, Chase County, Kansas.

UNIT DESCRIPTION

Stearns Shale

7	1 ft.	shale, grayish olive green, silty, blocky
6	1 ft.	shale, dusky yellow green, silty, blocky
5	0.5 ft.	shale, grayish green, silty, blocky
4	1.5 ft.	shale, dusky yellow green, silty , blocky
3	1 ft.	shale, grayish green, silty, blocky
2	1.5 ft.	shale, grayish yellow, calcareous, blocky
1	1 ft.	shale, brownish greenish gray, silty, fissile

Photo 70 CK#3 Stearns Shale
Taken along Highway 177 on the northwest side of Strong City, Chase County, Kansas. Basal limestone is top of Morrill limestone, and upper limestone is Eiss Limestone.

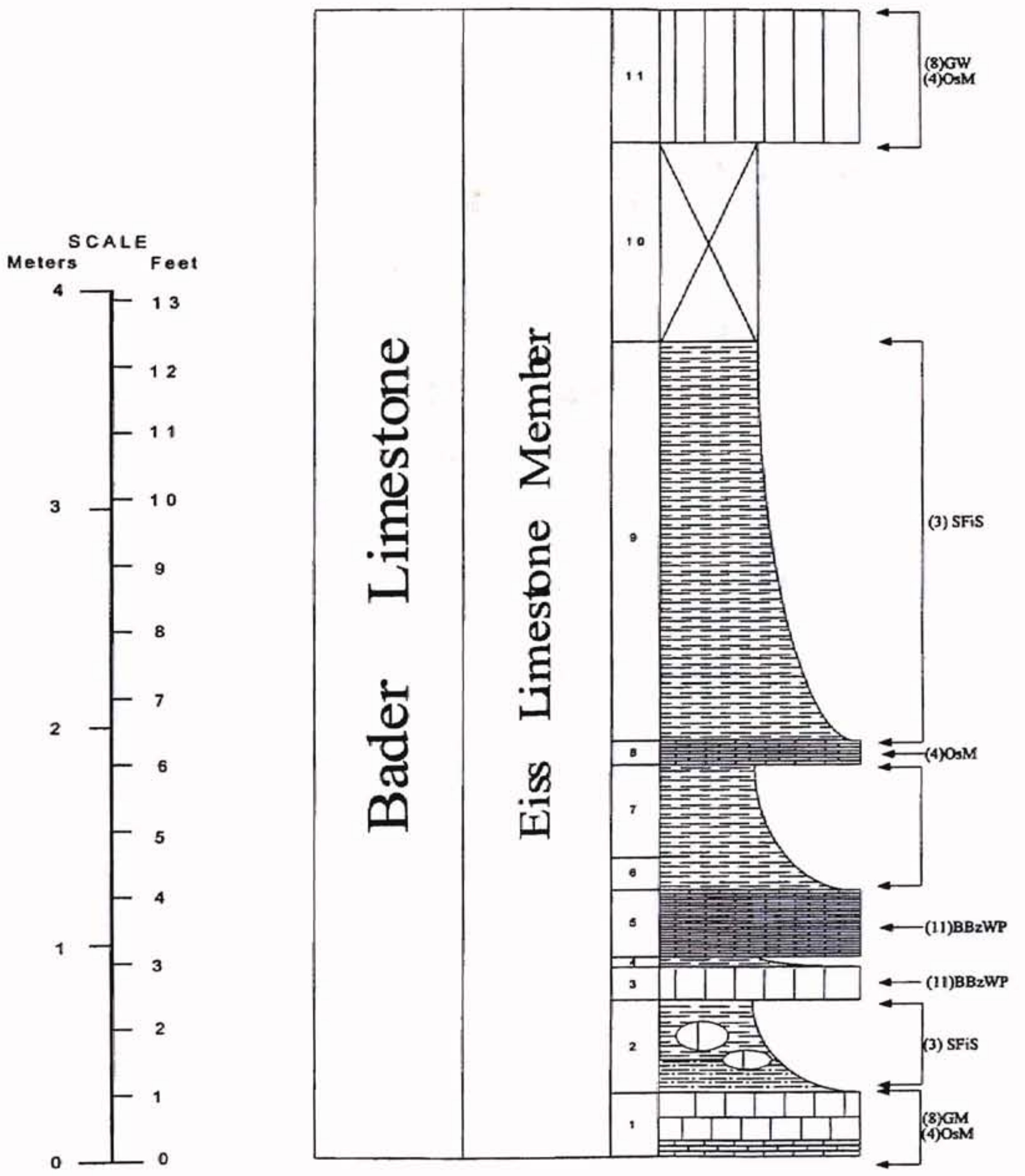


Figure 42. Measured Section CK #3, Eiss Limestone.

State: Kansas County: Chase County

Locality Description:
Roadcuts on east side of US Highway 177 at a point 5.3-5.5 miles north of its intersection with US Highway 50.

UNIT DESCRIPTION

Bader Limestone

Eiss Limestone Member

11	2 ft.	wackestone, intraclasts, ostracodes, gastropods, algae, gastropods, micrite, light yellow gray
10	3 ft.	cover
9	6 ft.	shale, light olive brown to moderate olive brown, blocky
8	0.35 ft.	shaly limestone, light olive brown
7	1.4 ft.	shale, light olive brown, blocky
6	0.5 ft.	shale, dark gray, blocky
5	1 ft.	packstone, brachiopods, coral bryozoa, micrite, chalcedony, hematitic, dark gray
4	0.15 ft.	shale, dark grayish brown, crumbly
3	0.5 ft.	mudstone, brachiopods, bryozoa, ostracodes, micrite, grayish yellow
2	1.4 ft.	shale, dark gray to dark yellowish gray with nodular limestone, blocky to fissile,
1	1 ft.	mudstone, bioclasts, gastropods, ostracodes, micrite, hematitic, light gray

Photo 71 CK#3 Eiss Limestone
Taken along Highway 177 on the northwest side of Strong City, Chase County, Kansas. The Eiss Limestone includes the three parts: the lower limestone, middle shale, and upper Limestone. The photo shows the middle shale and upper limestone (thick beds).

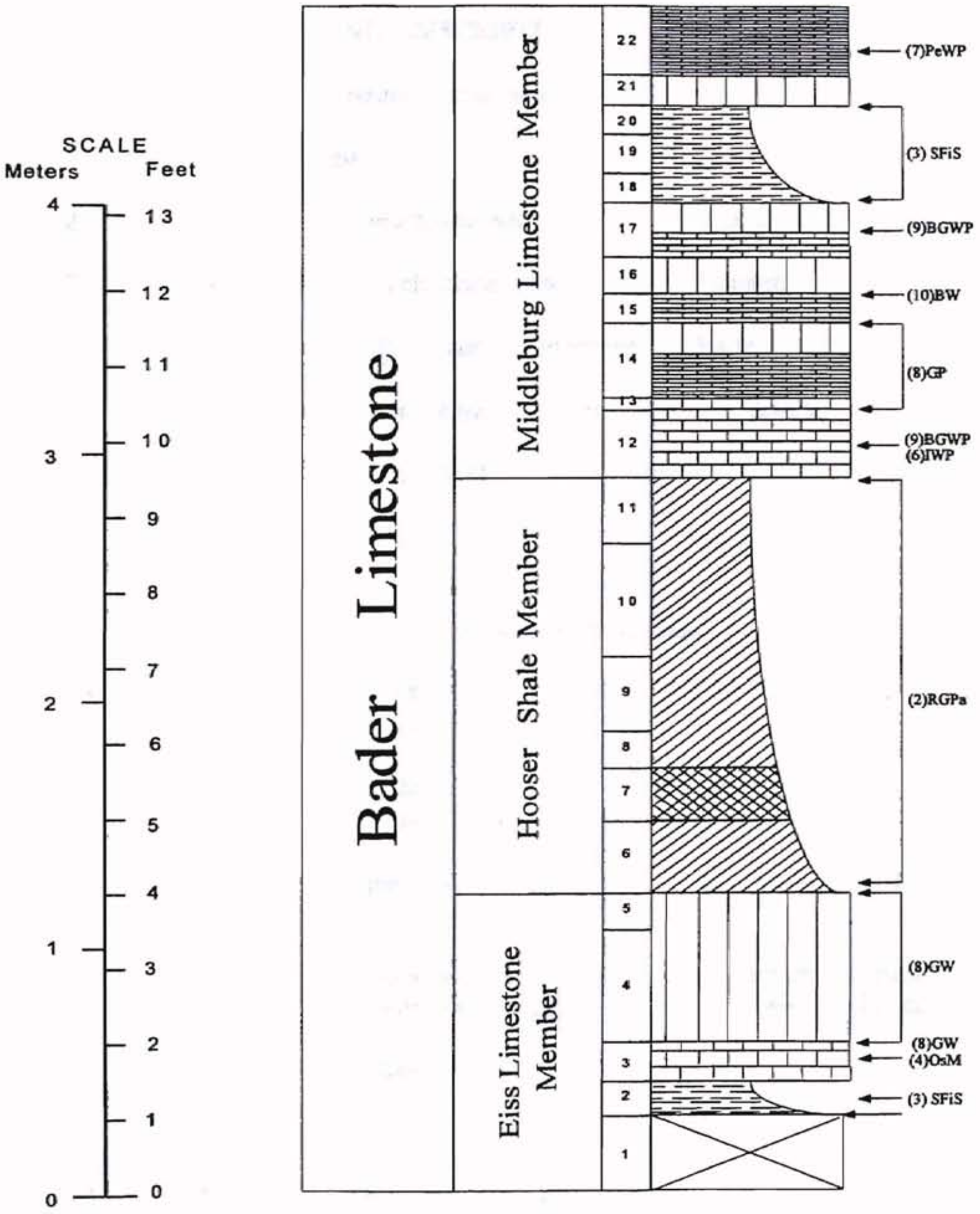


Figure 43. Measured Section CK #4, Bader Limestone.

State: Kansas County: Chase County

Locality Description:
Roadcut on west side of US highway 177 at a point 2.9 miles north of its intersection with US Highway 50.
C/EL Section 31, T18S, R8E, Strong City 7.5' Quadrangle, Chase County, Kansas

UNIT DESCRIPTION

Bader Limestone

Middleburg Limestone Member

22	0.9 ft.	mudstone, peloid, micrite, light gray
21	0.4 ft.	wackestone, peloid, micrite, hematitic, light gray brown
20	0.3 ft.	shale, pale yellowish brown, fissile
19	0.5 ft.	shale, dark gray to black siltstone, fissile
18	0.4 ft.	shale, light olive brown, fissile
17	0.7 ft.	wackestone, brachiopods, bryozoa, ostracodes, algae, micrite, medium gray to dusky yellow
16	0.5 ft.	mudstone, oncoid, brachiopods, echinoderms, dusky yellow
15	0.4 ft.	mudstone, brachiopods, echinoderms, algae, micrite, hematitic, dusky buff yellow
14	1 ft.	wackestone, brachiopods, echinoderms, gastropods, ostracodes, algae, micrite, dusky yellow
13	0.2 ft.	packstone or wackestone, peloid, gastropods, echinoderms, algae, micrite, light brown olive
12	0.9 ft.	wackestone, oncoid, intraclasts, brachiopods, algae, ostracodes, gastropods, echinoderms, recrystallized micrite, dark grayish brown

Hooser shale Member

11	0.8 ft.	shale, moderate olive brown, blocky
10	1.5 ft.	shale, light olive gray to light olive, calcareous, crumbly to blocky
9	1 ft.	shale, dark greenish yellow, calcareous, blocky to crumbly
8	0.5 ft.	shale, light olive brown, blocky
7	0.7 ft.	shale, reddish moderate brown, blocky
6	1 ft.	shale, moderate olive brown, crumbly

Eiss Limestone Member

5	0.5	grainstone, intraclasts, brachiopods, micrite light yellow gray
4	1.5 ft.	wackestone, gastropods, echinoderms, ostracodes, micrite, light yellow gray
3	0.4 ft.	mudstone, gastropods, echinoderms, ostracodes, intraclasts, light greenish brown
2	0.5 ft.	shale, moderate greenish yellow, crumbly
1	? ft.	cover

Photo 72 CK#4 Eiss Limestone
Taken along Highway 177 northwest of Strong City, Chase County, Kansas. The upper Eiss Limestone is thin to thick siliceous limestones with abundant vugs.

Photo 2 CK#4 Hooser Shale
Taken along Highway 177 northwest of Strong City, Chase County, Kansas. The Hooser Shale is below the Middleburg Limestone (the upper limestone in the photo).

Photo 73 CK#4 Middleburg Limestone
Taken along Highway 177 northwest of Strong City, Chase County, Kansas. The Middleburg Limestone at this locality is very thin to thin bedded limestones.

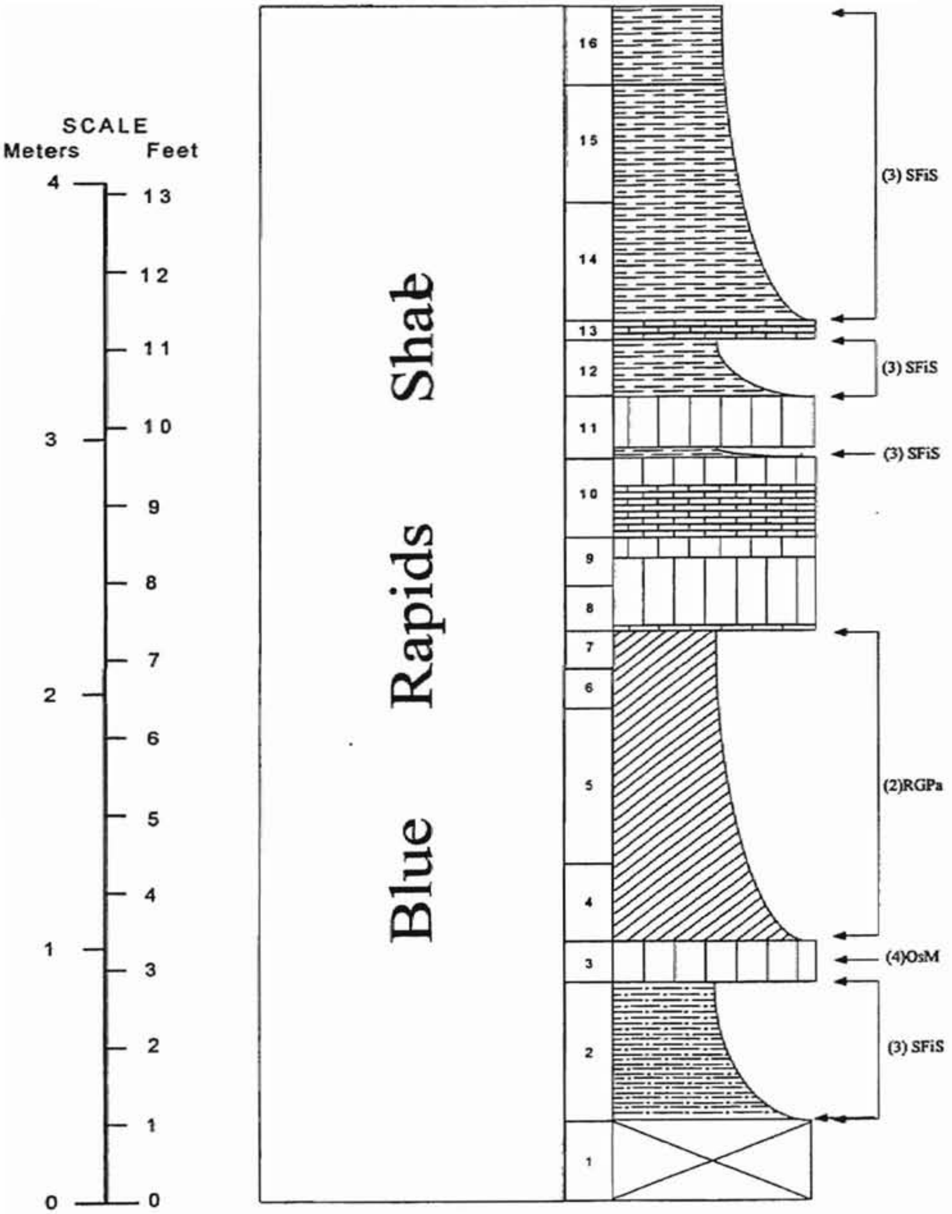


Figure 44. Measured Section CK#5, Blue Rapids Shale.

State: Kansas County: Chase County

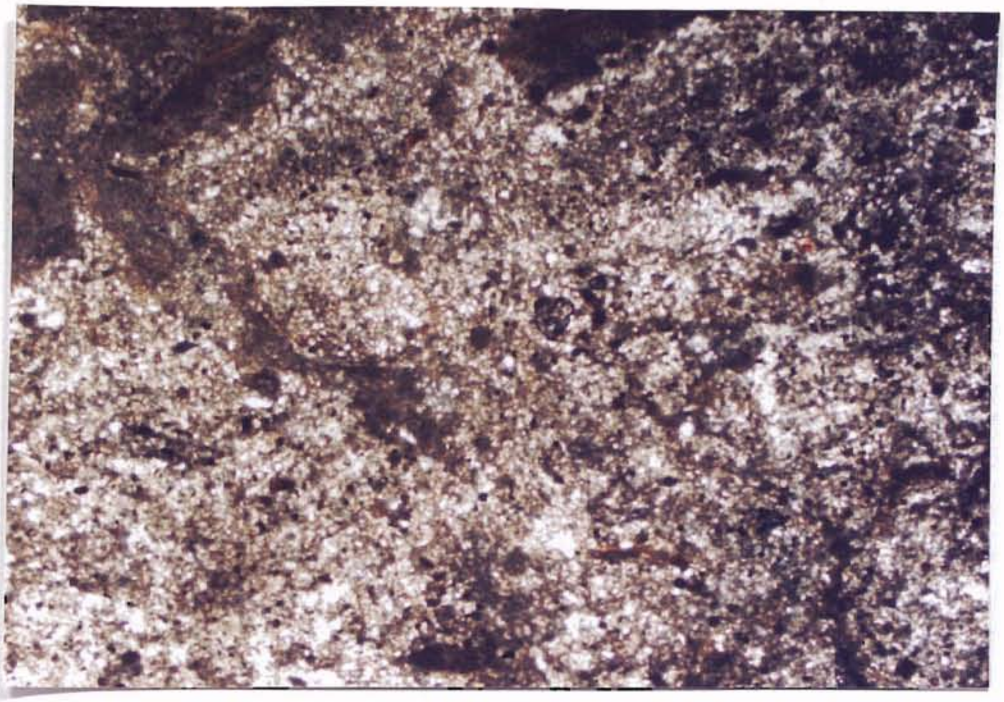
Locality Description:
Roadcut on seat side of US Highway 177 at a point 5.3-5.5 miles north of its intersection with US Highway 50.
NW/4, Section 20, T18S, R8E, Strong City 7.5' Quadrangle, Chase County, Kansas.

UNIT DESCRIPTION

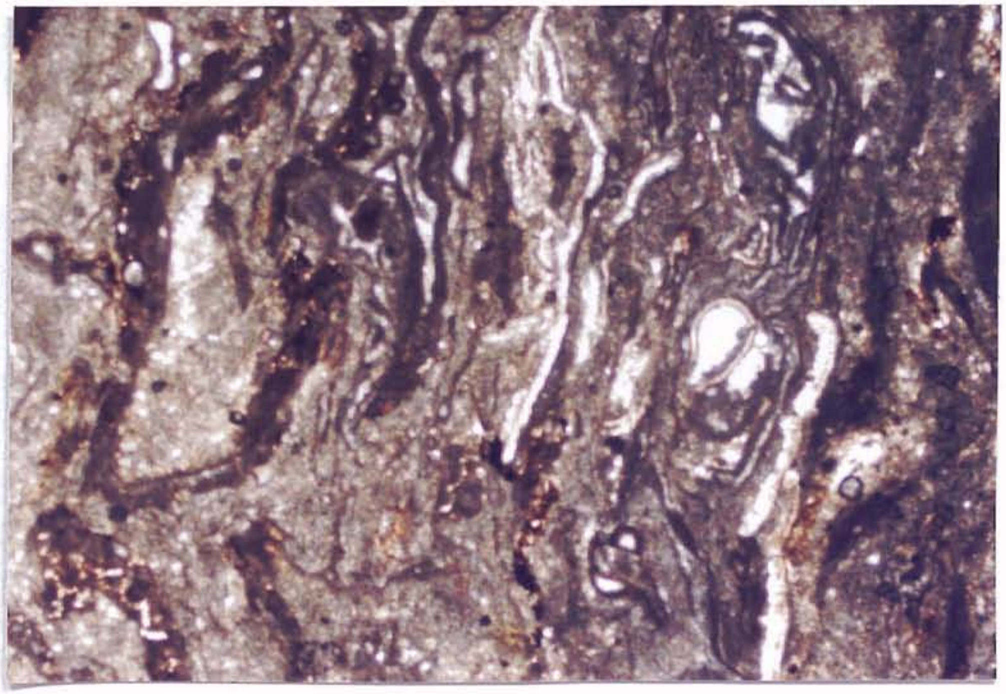
Blue Rapids Shale

16	1 ft.	shale, dusky yellow, caliche, crumbly
15	1.5 ft.	shale, light olive brown, fissile, caliche
14	1.5 ft.	shale, light olive gray, fissile
13	0.25 ft.	very thin bed limestone, light olive gray
12	0.75 ft.	shale, light olive brown, crumbly to blocky
11	0.9 ft.	mudstone, ostracodes, micrite, calcareous, hematitic, light gray to yellowish gray
10	0.95 ft.	wackestone, peloid, ostracodes, bioclasts, hematitic, hematitic, micrite
9	0.6 ft.	mudstone, bioclasts, recrystallized micrite, yellowish gray
8	0.6 ft.	wackestone, bioclasts, brachiopods, ostracodes, algae, micrite, orangish yellow gray
7	0.5 ft.	shale, grayish olive green, silty, crumbly
6	0.5 ft.	shale, dusky yellow green, silty, crumbly
5	2 ft.	shale, grayish green to light olive green, silty ,crumbly
4	1 ft.	shale, dusky yellow green, sandy and silty, crumbly to blocky
3	0.5 ft.	mudstone, recrystallized micrite, light orangish gray
2	1.8 ft.	shale, grayish black, silty, blocky
1	? ft.	cover

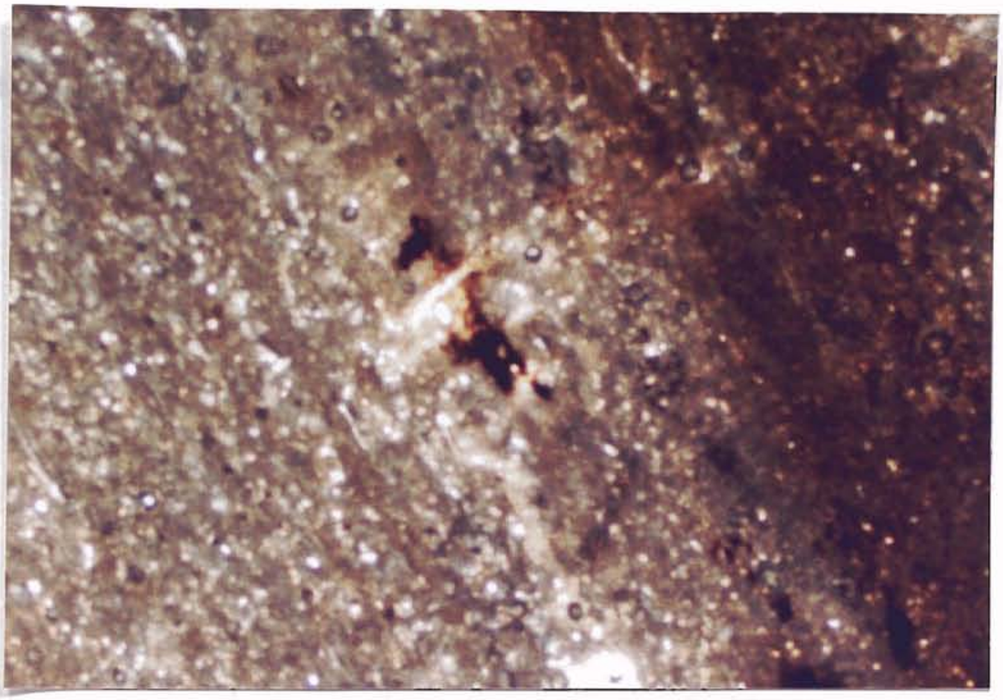
Photo 74 CK#5 Blue Rapids Shale
Taken along Highway 177 northwest of Strong City, Chase County, Kansas. The Blue Rapids at this locality Shale is crumbly mudstone.



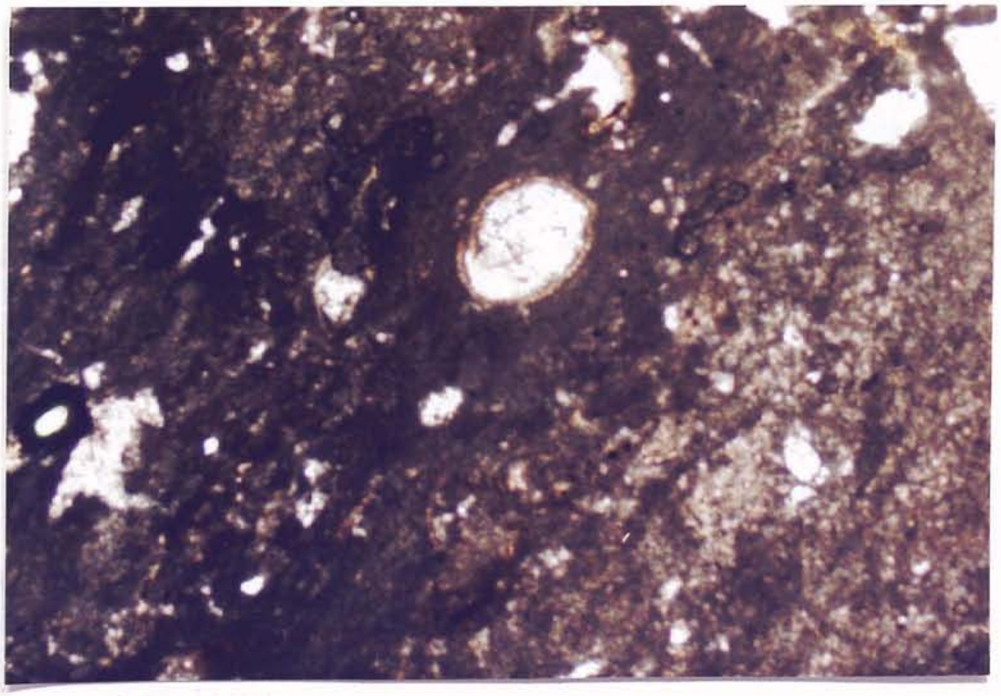
Photograph 75, CK#5, Blue Rapids Shale, Unit: 3
mudstone, recrystallized micrite.



Photograph 76, CK#5, Blue Rapids Shale, Unit: 8
wackestone, bioclast, brachiopod, ostracode, algae, micrite.



Photograph 77, CK#5, Blue Rapids Shale, Unit: 10
wackestone, peloid, ostracode, bioclast, hematitic.



Photograph 78, CK#5, Blue Rapids Shale, Unit: 11
mudstone, ostracode, hematitic.

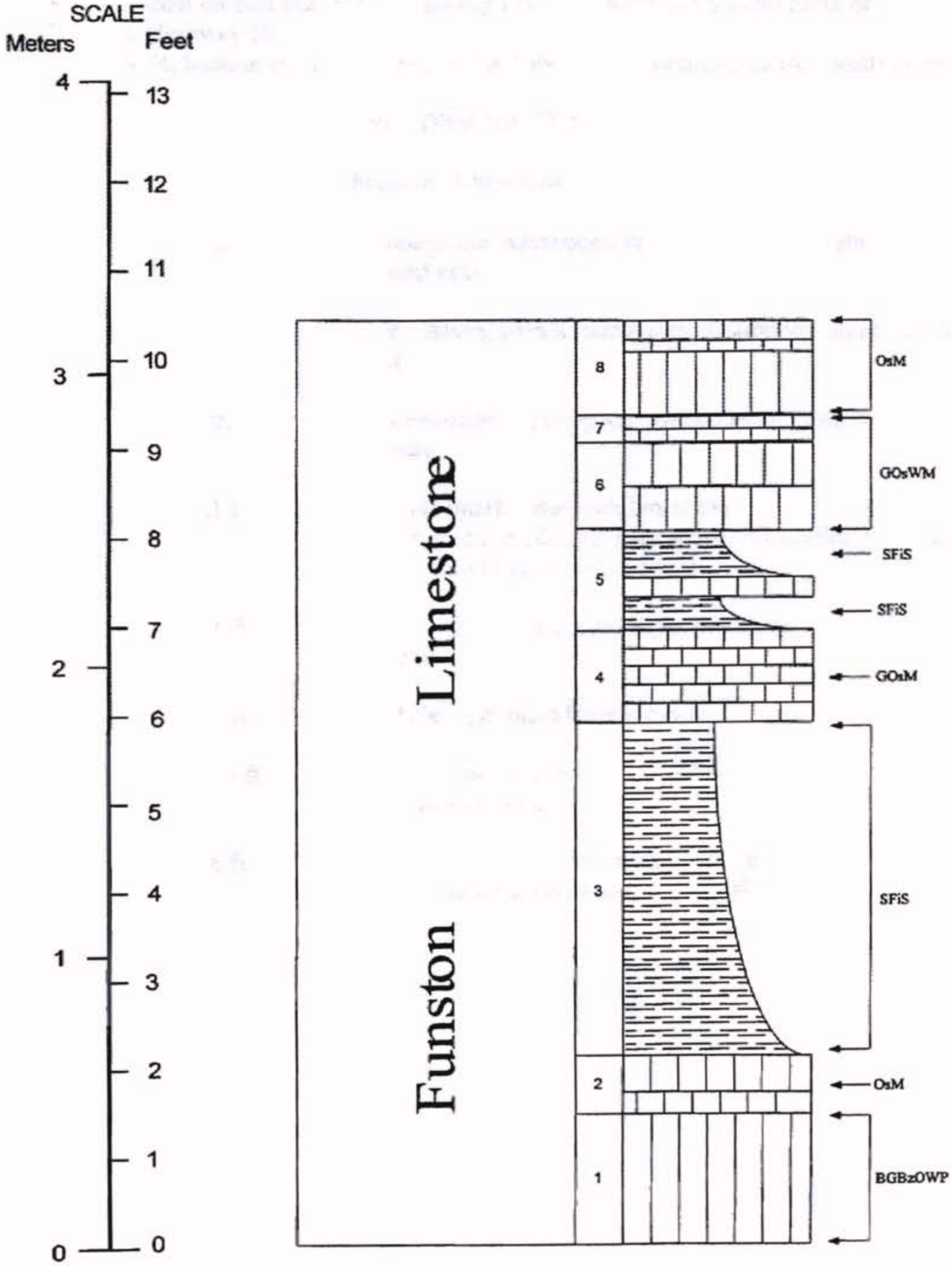


Figure 45. Measured Section CK #5, Funston Limestone.

State: Kansas County: Chase County

Locality Description:
Roadcut on seat side of US Highway 177 at a point 5.3-5.5 miles north of its intersection with US Highway 50.
NW/4, Section 20, T18S, R8E, Strong City 7.5' Quadrangle, Chase County, Kansas.

UNIT DESCRIPTION

Funston Limestone

8	1 ft.	mudstone, ostracodes, hematitic, micrite, light gray to moderate buff gray
7	0.3 ft.	mudstone, peloid, ostracodes, gastropods, algae, hematitic, medium gray
6	1 ft.	wackestone, gastropods, ostracodes, micrite, hematitic, yellowish gray
5	1.1 ft.	shale interbedded with limestone limestone: mudstone, gastropods, ostracodes, recrystallized micrite shale: light olive brown fissile
4	1.1 ft.	mudstone, gastropods, algae, ostracodes, micrite, hematitic, yellow gray
3	3.8 ft.	shale, light olive brown, fissile
2	0.65 ft.	mudstone, echinoderms, trilobites, peloid ostracodes, hematitic, yellow brownish gray
1	1.6 ft.	wackestone, oncoid, brachiopods, gastropods, bryozoa, algae, recrystallized micrite, light yellowish gray

Photo 79 CK#5 Funston Limestone
Taken along Highway 177 northwest of Strong City, Chase County, Kansas. The Funston at this locality is thick to medium bedded limestones.

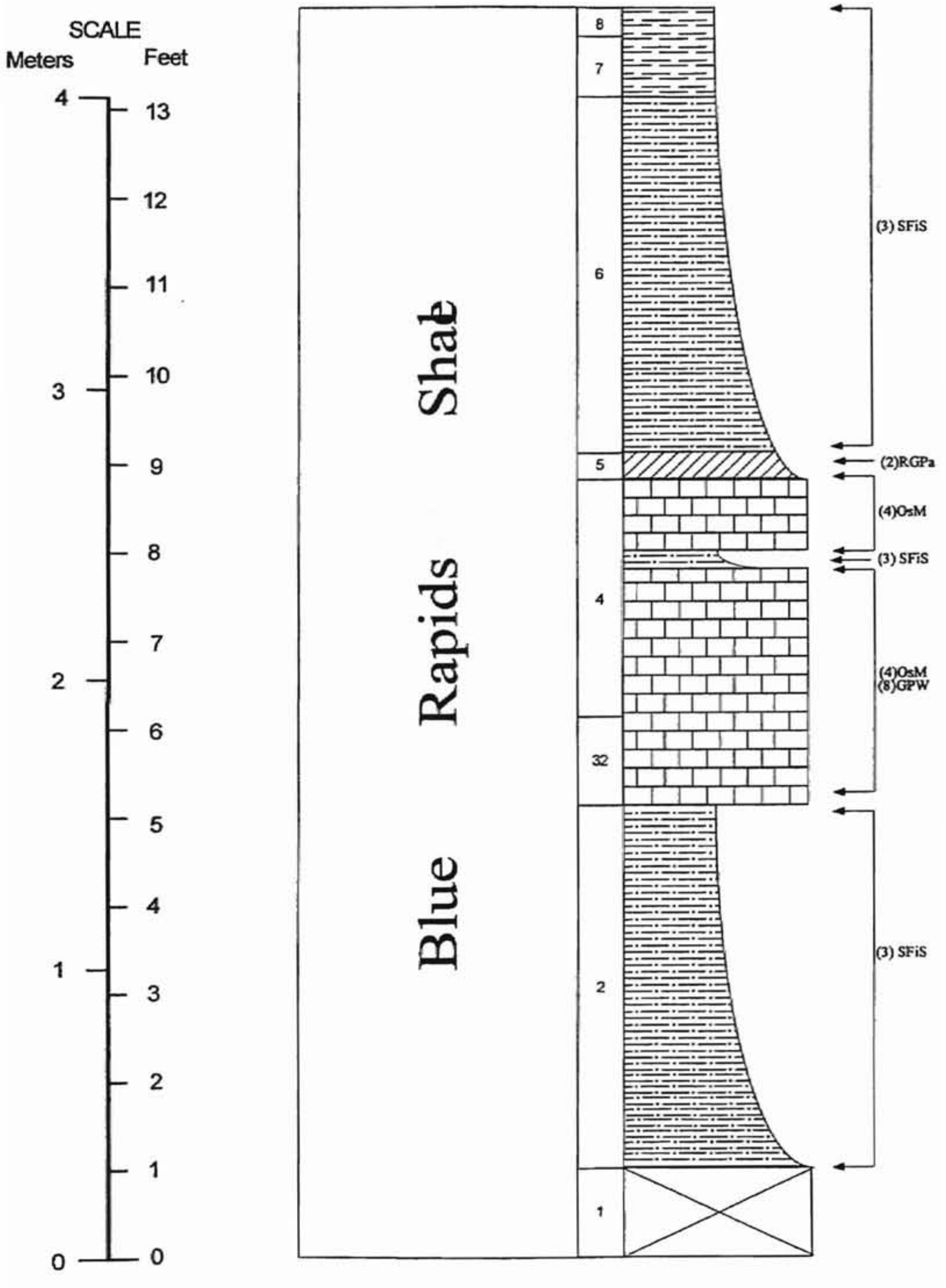


Figure 46. Measured Section CK #6, Blue Rapids Shale.

State: Kansas County: Chase County

Locality Description:

Roadcut on both south and north sides of US Highway 50 on east side of Strong City.

S/2, NE/4, Section 16, T17, R8E, Strong City 7.5' Quadrangle, Chase County, Kansas

UNIT DESCRIPTION

Blue Rapids Shale

8	0.3 ft.	shale, brownish black, crumbly, fissile
7	0.7 ft.	shale, brownish black, crumbly
6	4 ft.	shale, grayish black, silty, crumbly
5	0.4 ft.	shale, olive black, crumbly
4	27 ft.	mudstone, bioclasts, ostracodes, hematitic, micrite, olive brown gray
3	1 ft.	wackestone, peloid, bioclasts, ostracodes, gastropods, algae, micrite, hematitic
2	4.1 ft.	shale, grayish black, silty, crumbly
1	? ft.	cover

Photo 80 CK#6 Blue Rapids Shale
Taken along Highway 50 on the east side of Strong City, Chase County, Kansas. The upper Blue Rapids Shale at this locality is thin-bedded limestones.

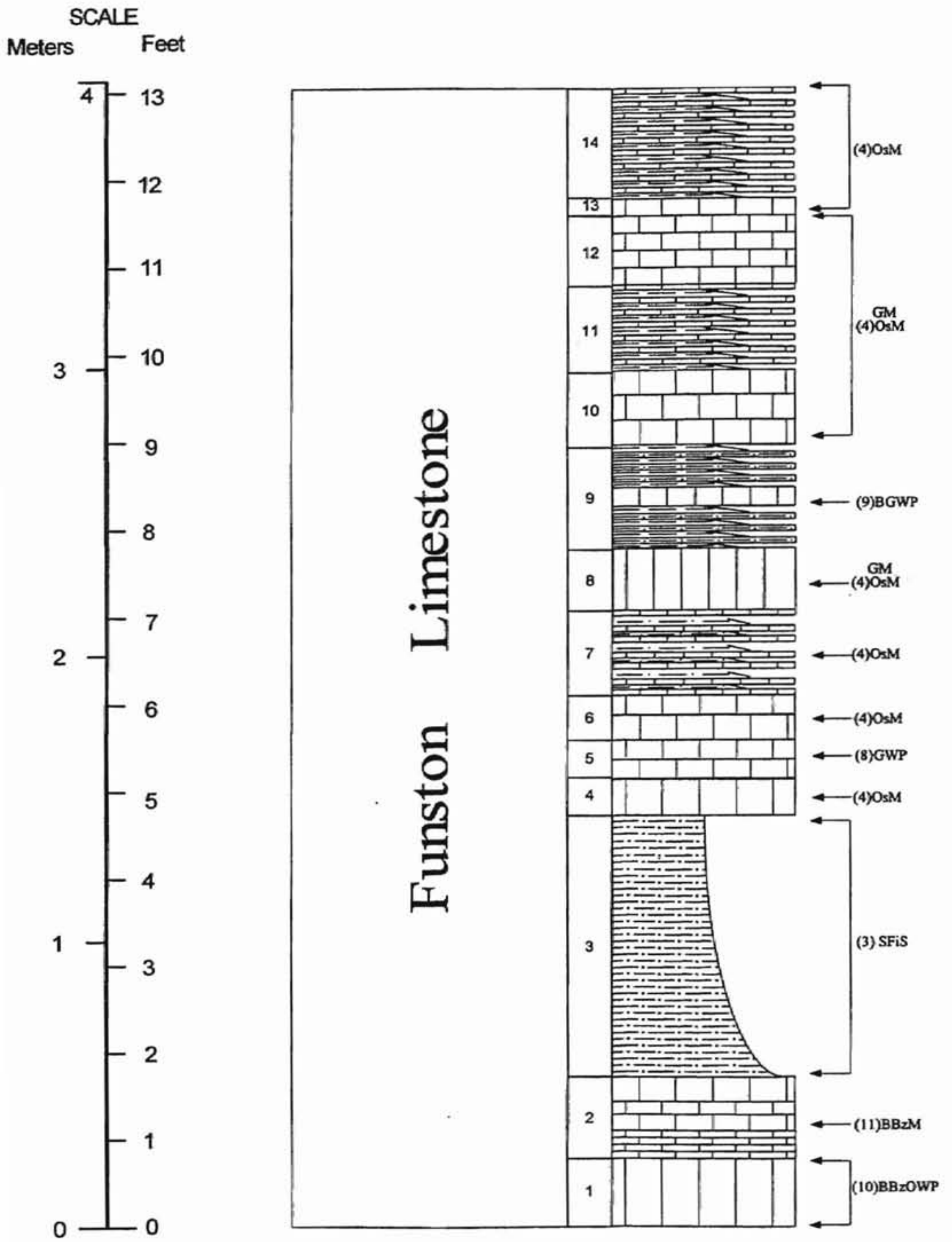


Figure 47. Measured Section CK #6, Funston Limestone.

State: Kansas County: Chase County

Locality Description:
Roadcut on both south and north sides of US Highway 50 on east side of Strong City.
S/2, NE/4, Section 16, T17, R8E, Strong City 7.5' Quadrangle, Chase County, Kansas

UNIT DESCRIPTION

Funston Limestone

14	1.3 ft.	limestone interbedded with grayish red shale limestone: mudstone, recrystallized micrite, hematitic, light olive gray
13	0.2 ft.	mudstone to wackestone, recrystallized micrite, brownish gray
12	0.8 ft.	mudstone, gastropods, coral, algae, recrystallized micrite, brownish gray
11	1 ft.	mudstone, gastropods, ostracodes, recrystallized micrite, pinkish brownish gray
10	0.9 ft.	mudstone, peloid, gastropods, ostracodes, micrite, pinkish brownish gray
9	1.2 ft.	wackestone to mudstone gastropods, ostracodes, brachiopods, algae, grayish black
8	0.7 ft.	mudstone, gastropods, ostracodes, brownish moderate gray
7	1 ft.	limestone interbeded with brownish moderate gray shale limestone: mudstone, micrite, recrystallized micrite
6	0.5 ft.	mudstone, ostracodes, algae, recrystallized micrite, light brown
5	0.4 ft.	wackestone, gastropods, foraminifer, algae, micrite, dark gray
4	0.4 ft.	mudstone, oncoid, echinoderms, micrite dark gray
3	3 ft.	shale, grayish black, silty, fissile to crumbly
2	0.9 ft.	mudstone, brachiopods, bryozoa, dolomite, micrite, grayish black
1	0.8 ft.	wackestone, oncoid, brachiopods, echinoderms, bryozoa, algae, micrite, gray red

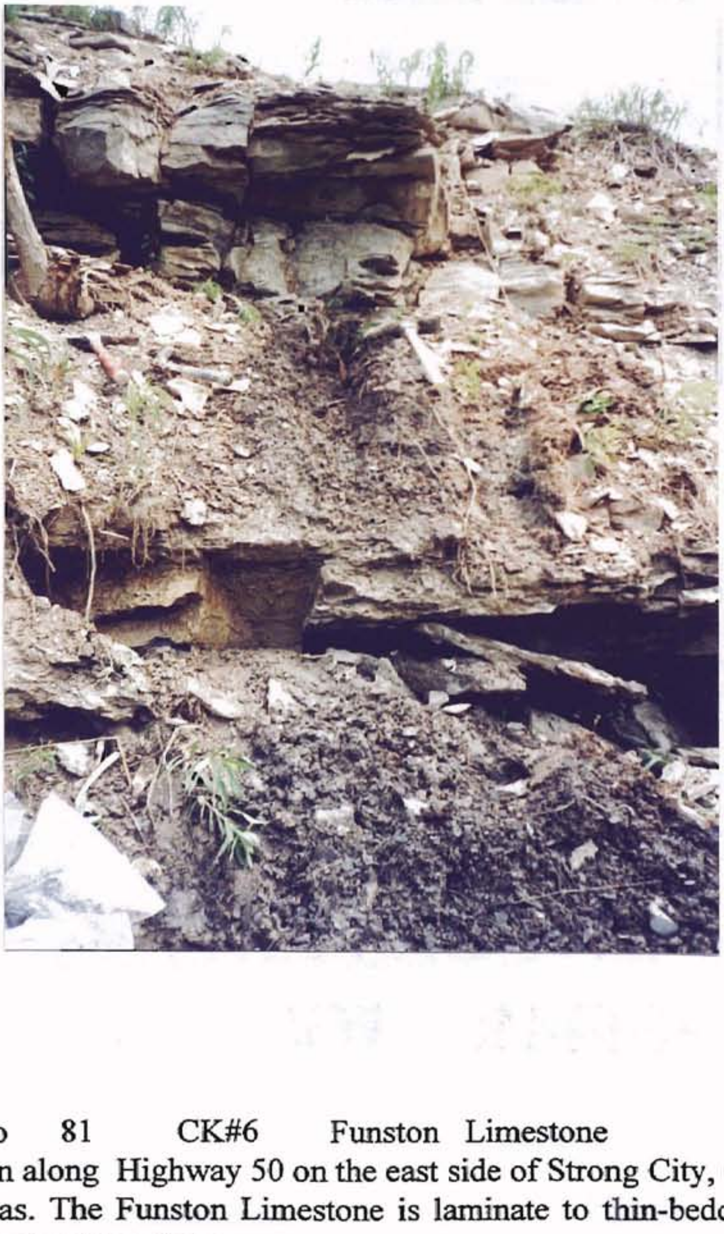
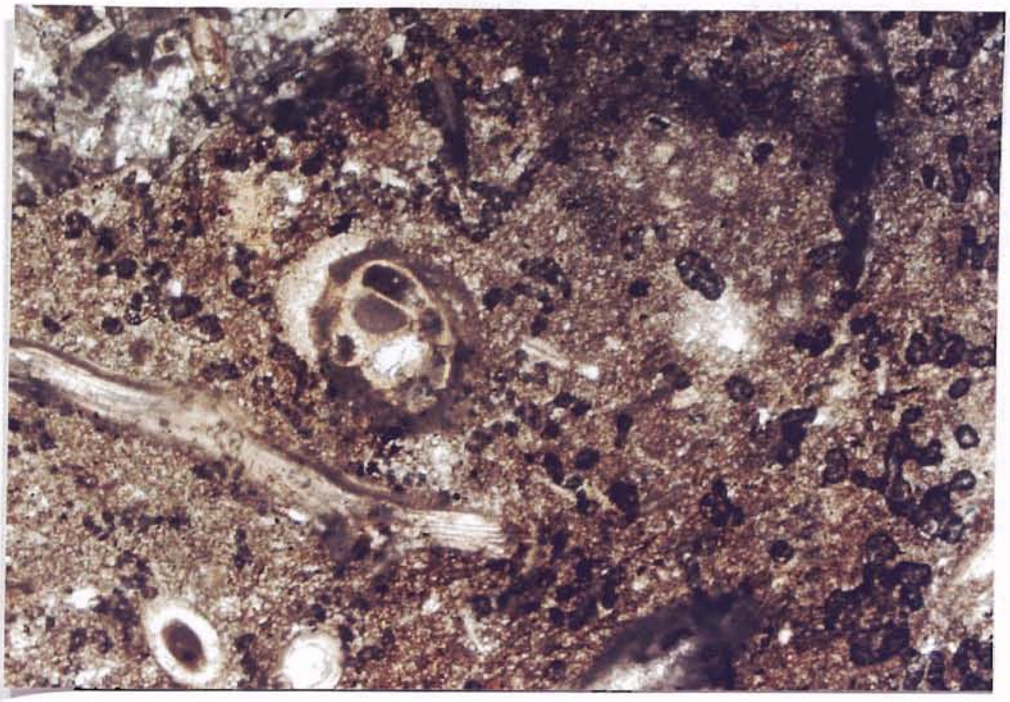
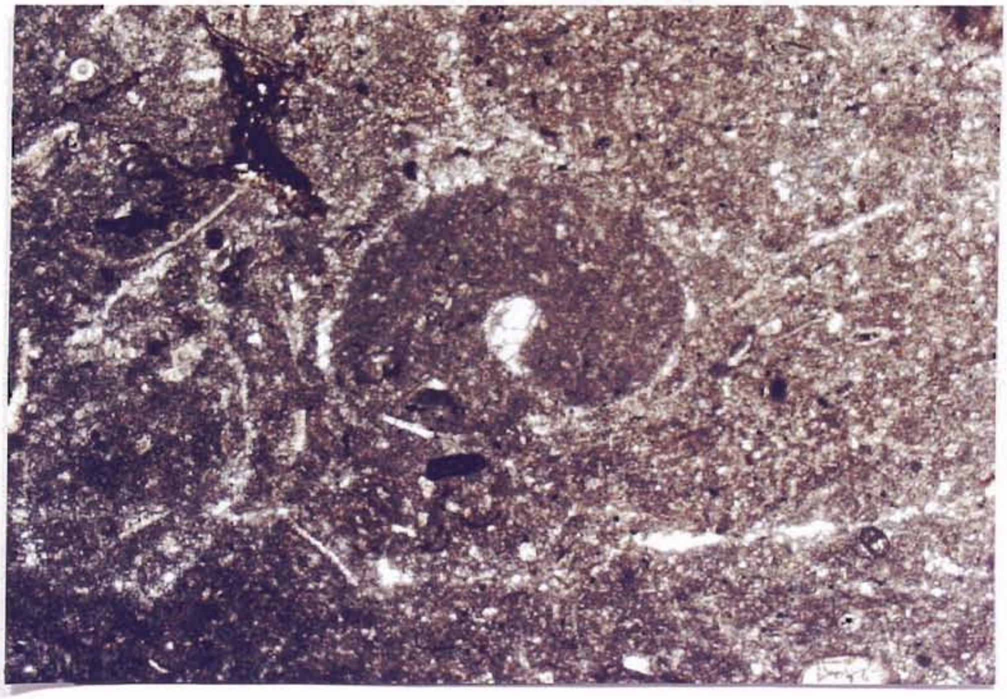


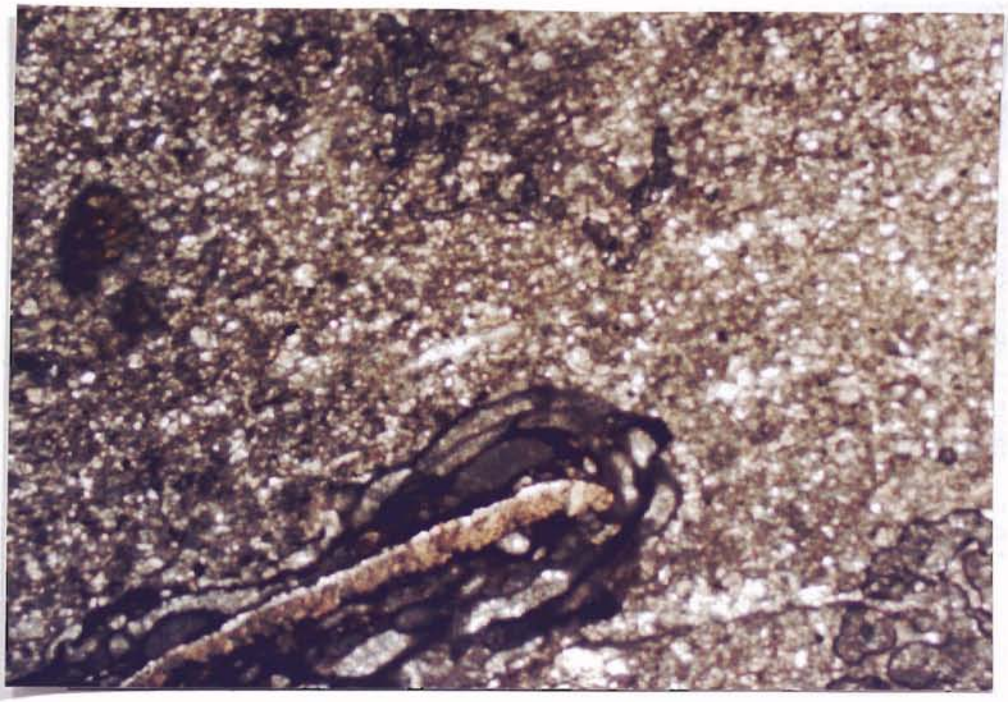
Photo 81 CK#6 Funston Limestone
Taken along Highway 50 on the east side of Strong City, Chase County, Kansas. The Funston Limestone is laminate to thin-bedded limestones with separating shales.



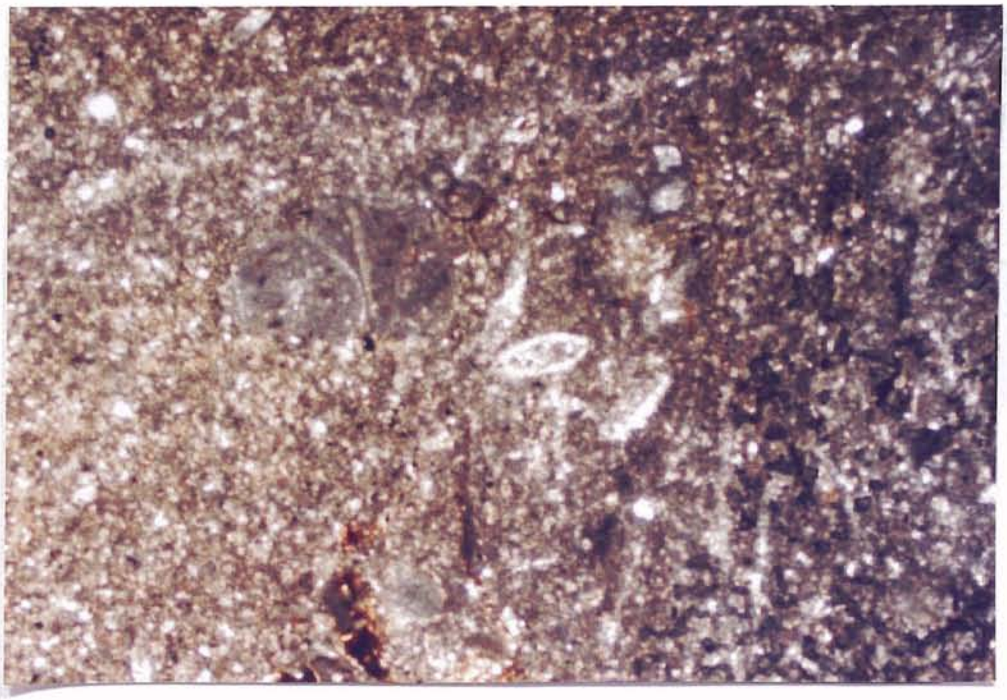
Photograph 82, CK#6, Funston Limestone, Unit: 1
wackestone, oncoid, brachiopod, bryozoan, algae, micrite.



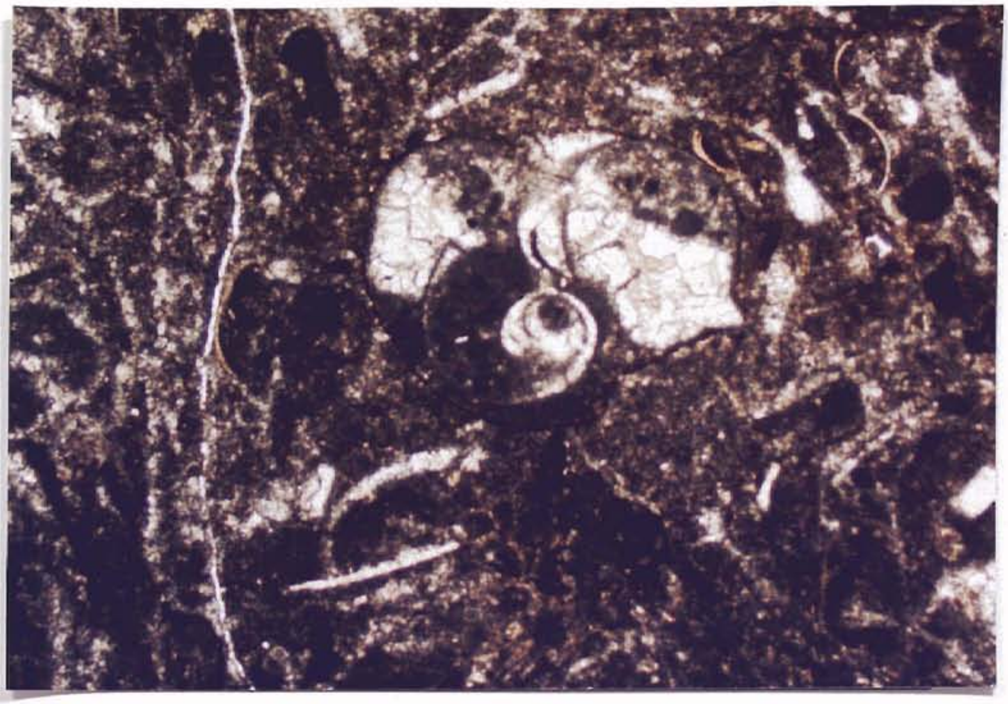
Photograph 83, CK#6, Funston Limestone, Unit: 5
wackestone, gastropod, algae, micrite.



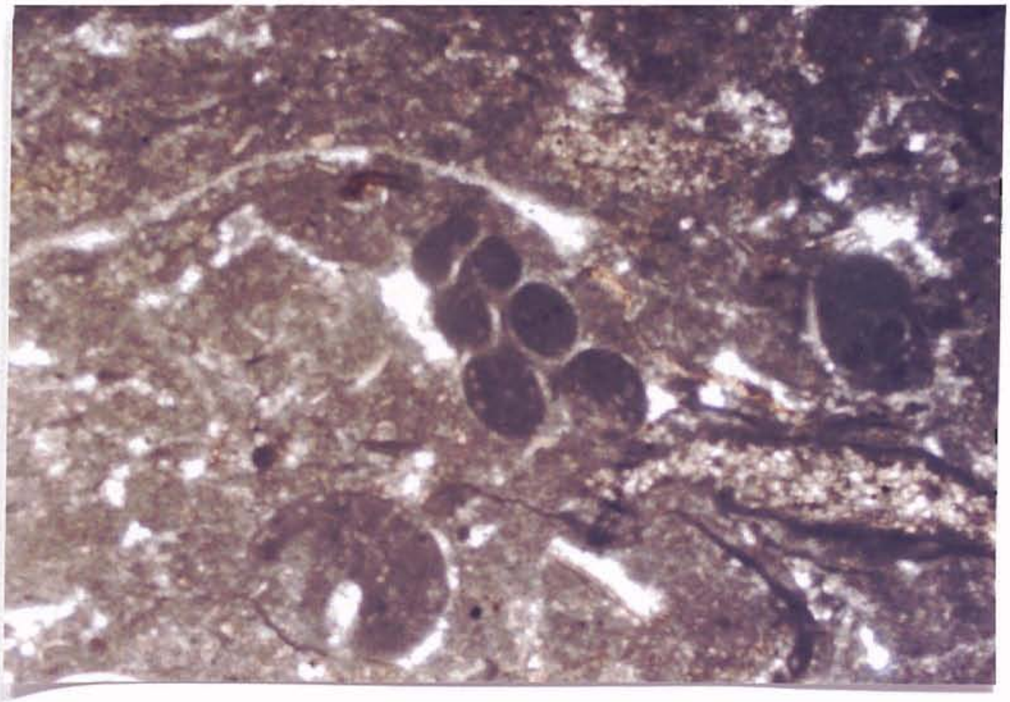
Photograph 84, CK#6, Funston Limestone, Unit: 6
mudstone, oncoid, micrite.



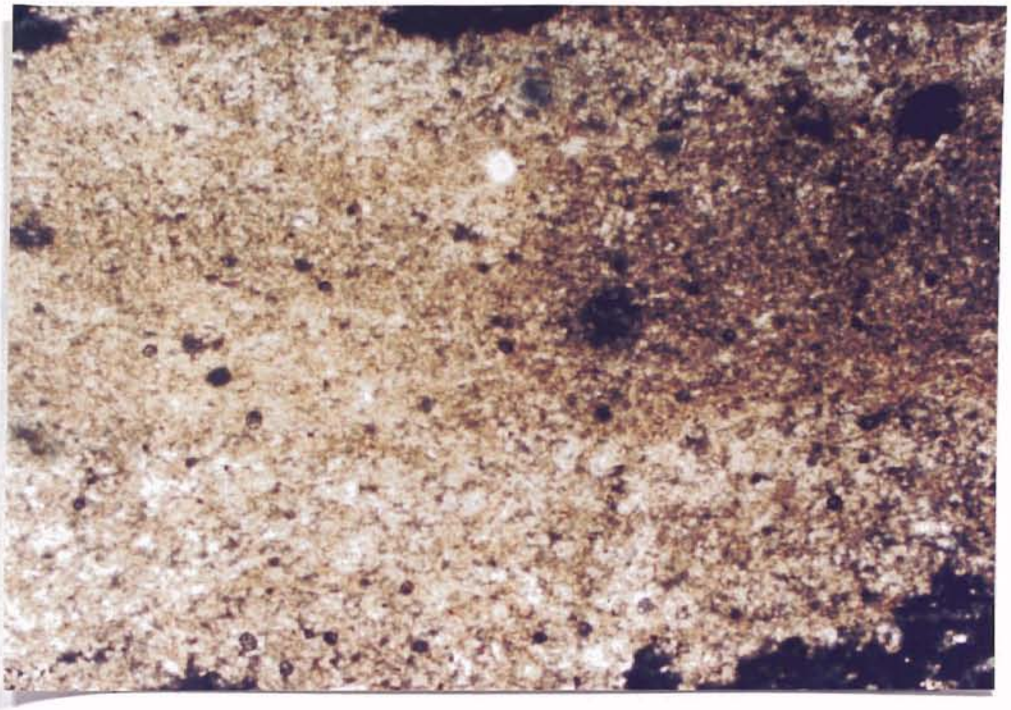
Photograph 85, CK#6, Funston Limestone, Unit: 8
mudstone, echinoderm, trilobite, algae, micrite.



Photograph 86, CK#6, Funston Limestone, Unit: 9
wackestone, gastropod, ostracode, bioclast, micrite.



Photograph 87, CK#6, Funston Limestone, Unit: 12
wackestone, gastropod, algae, micrite.



Photograph 88, CK#6, Funston Limestone, Unit: 14
mudstone, recrystallized micrite.

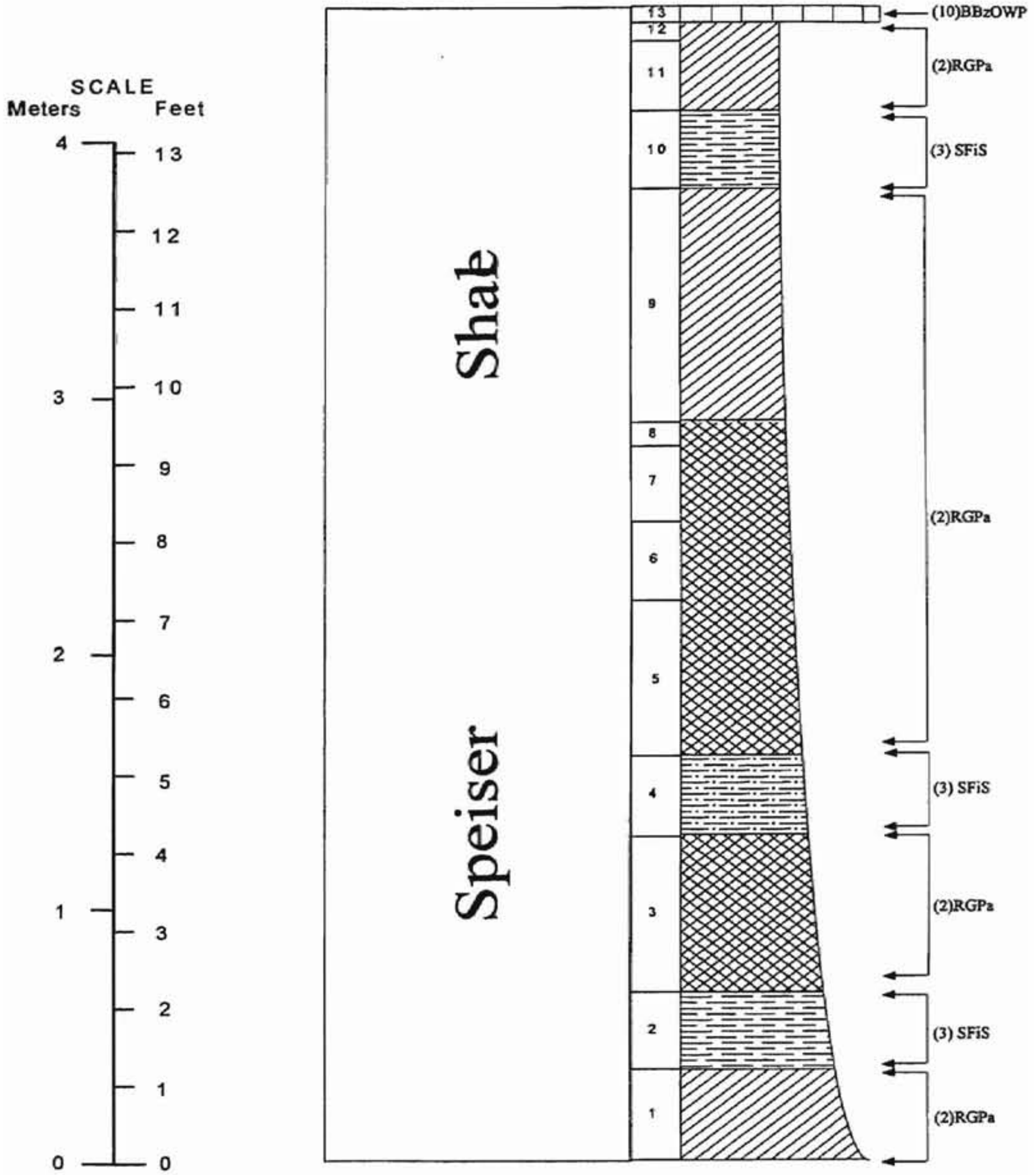


Figure 48. Measured Section CK #6, Speiser Shale.

State: Kansas County: Chase County

Locality Description:
Roadcut on both south and north sides of US Highway 50 on east side of Strong City.
S/2, NE/4, Section 16, T17, R8E, Strong City 7.5' Quadrangle, Chase County, Kansas

UNIT DESCRIPTION

Speiser Shale

13	0.3 ft.	wackestone, oncoid, peloid, brachiopods, gastropods, algae, dusky yellow
12	0.3 ft.	shale, dusky yellow green, calcareous, crumbly
11	1 ft.	shale, light olive gray to dusky olive green, calcareous, crumbly, fissile to blocky
10	1 ft.	shale, dusky yellow, calcareous, crumbly
9	2.8 ft.	shale, pale olive to light olive gray , calcareous, fissile crumbly
8	0.5 ft.	shale, dark red brown, silty, blocky
7	1 ft.	shale, grayish red, calcareous, crumbly
6	1 ft.	shale, dark reddish brown, silty, blocky
5	2 ft.	shale, grayish red, silty, blocky
4	1 ft.	shale, dark yellowish brown, silty, crumbly
3	2 ft.	shale, grayish red, silty, blocky to crumbly
2	1 ft.	shale, brownish gray, calcareous, crumbly
1	1.2 ft.	shale, grayish olive, silty, crumbly

Photo 89 CK#6 Speiser Shale
Taken along Highway 50 on the east side of Strong City, Chase County, Kansas. The Speiser is crumbly or blocky mudstones below the Threemile Limestone.

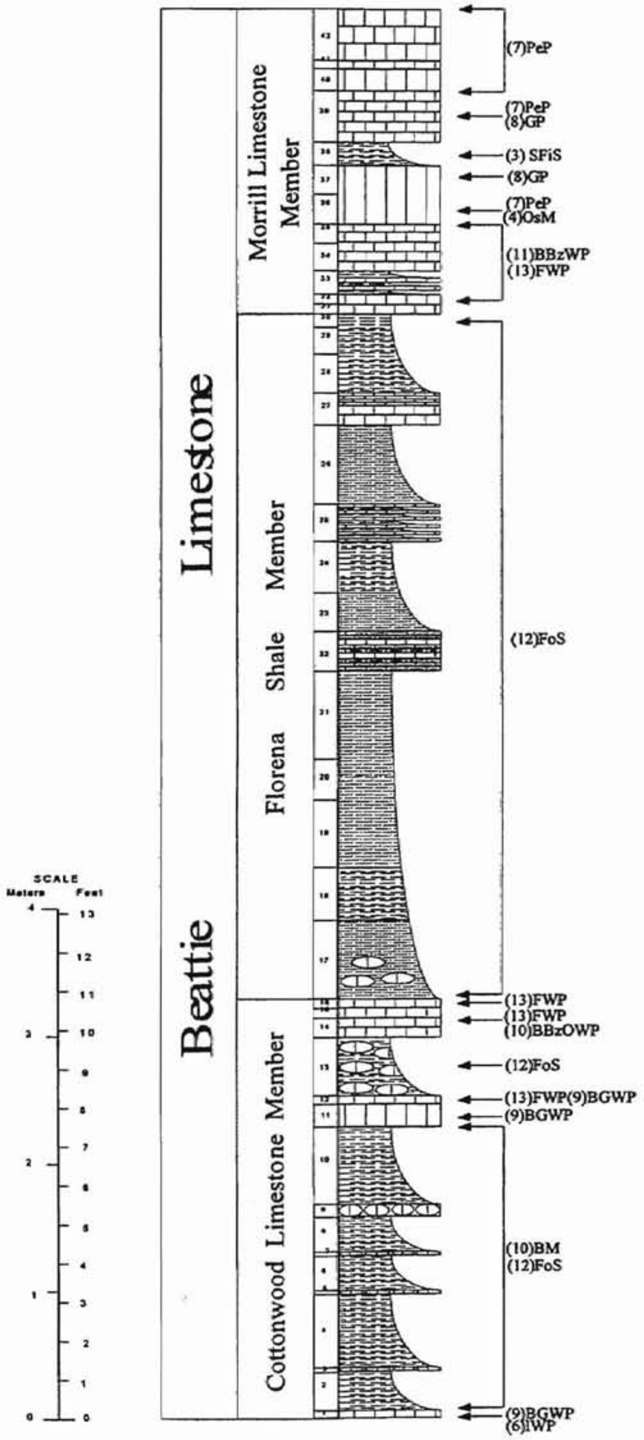


Figure 49. Measured Section SK rd, Beattie Limestone.

State: Kansas County: Cowley County

Locality Description:
Railroad cuts, Stream cut bank, and hillside exposures.
SE/4, SW/4, SW/4, Section 4, T31S, R8E, Grand Summit and Cambridge NE 7.5'
Quadrangles Cowley County, Kansas

UNIT DESCRIPTION

Beattie Limestone

Morrill Limestone Member

42	1.3 ft	packstone, peloid, bivalve, micrite, light gray to buff
41	0.2 ft	wackestone, peloid, brachiopods, micrite, light gray to buff
40	0.55 ft.	packstone, peloid, micrite, light gray to buff
39	1.3 ft.	packstone, peloid, bryozoa, oncoid, trilobites, gastropods, micrite, light gray
38	0.6 ft.	shale with nodular limestone (wackestone bryozoa, bivalve, echinoderms, micrite, hematitic), olive gray to light gray
37	0.75 ft.	packstone, oncoid, bivalve, gastropods, bryozoa, echinoderms, micrite, light gray to buff
36	0.75 ft.	wackestone, ostracodes, recrystallized micrite, light gray to buff
35	0.5 ft.	wackestone, bivalve, bryozoa, echinoderms, micrite, dolomite, dark brown to orangish gray
34	o.7 ft.	packstone, coral, bryozoa, echinoderms, algae, micrite, orangish brown to buff
33	0.6 ft	packstone, fusulinids, bryozoa, trilobites, light gray to light brown
32	0.25 ft	packstone, oncoid, brachiopods, fusulinids, micrite, chalcedony, buff to light gray
31	0.25 ft	wackestone, fusulinids recrystallized micrite, hematitic, buff to light gray,

Florena Shale Member

30	0.3 ft.	shale, light olive brown, calcareous, crumbly
29	0.7 ft.	shale, yellowish gray, calcareous, crumbly
28	1 ft.	shale, light olive brown calcareous, crumbly

27	0.8 ft.	gray (bottom) 2 thin beds limestone, crumbly gray (top) flagy laminated limestone
26	2 ft.	dusky yellow /pale yellow brown calcareous crumbly/blocky
25	1 ft.	limestone with shale, light olive gray flagy
24	1.3 ft.	shale, calcareous with nodular limestone, olive gray, crumbly
23	1 ft.	shale, light olive gray, silty, blocky
22	2 ft.	dusky yellow thin bed limestone with shaly laminated flagy limestone
21	2.3 ft.	shale, light olive gray, calcareous, blocky
20	1 ft.	shale, moderate olive brown, silty, blocky
19	1.7 ft.	shale, light olive gray/grayish olive green, calcareous/ silty crumbly to blocky
18	1.3 ft.	shale, grayish olive green (bottom), calcareous blocky shale, moderate olive brown (top), calcareous crumbly
17	2 ft.	shale with nodular limestone, olive gray, crumbly

Cottonwood Limestone Member

16	0.25 ft.	wackestone fusulinids, micrite. grayish yellow
15	0.25 ft.	wackestone brachiopods, fusulinids, echinoderms, micrite, hematitic, grayish yellow
14	0.4 ft.	packstone fusulinids, brachiopods, bryzoan, bivalves, echinoderms, recrytallized micrite, grayish yellow
13	1.5 ft.	shale with nodular limestone, light olive brown, blocky
12	0.2 ft.	wackestone fusulinids, brachiopods, bryzoan, echinoderms, micrite, dusky yellow
11	0.9 ft.	wackestone brachiopods, bryzoan, hematitic, micrite, dusky yellow
10	2 ft.	shale, pale olive calcareous
9	0.3 ft.	wackestone brachiopods, gastropods, micrite, gray
8	0.85 ft.	shale, pale olive, calcareous, blocky

7	0.15 ft.	thin bed nodular limestone, gray
6	0.85 ft.	shale, pale olive, , calcareous, blocky
5	0.15 ft.	mudstone brachiopods, micrite, gray
4	2.95 ft.	shale, pale olive calcareous blocky
3	0.05 ft.	nodular limestone, gray, very thin bed
2	1 ft.	shale, pale olive calcareous blocky
1	0.05 ft.	packstone, brachiopods, gastropods, echinoderms, intraclasts, recrystallized micrite, gray

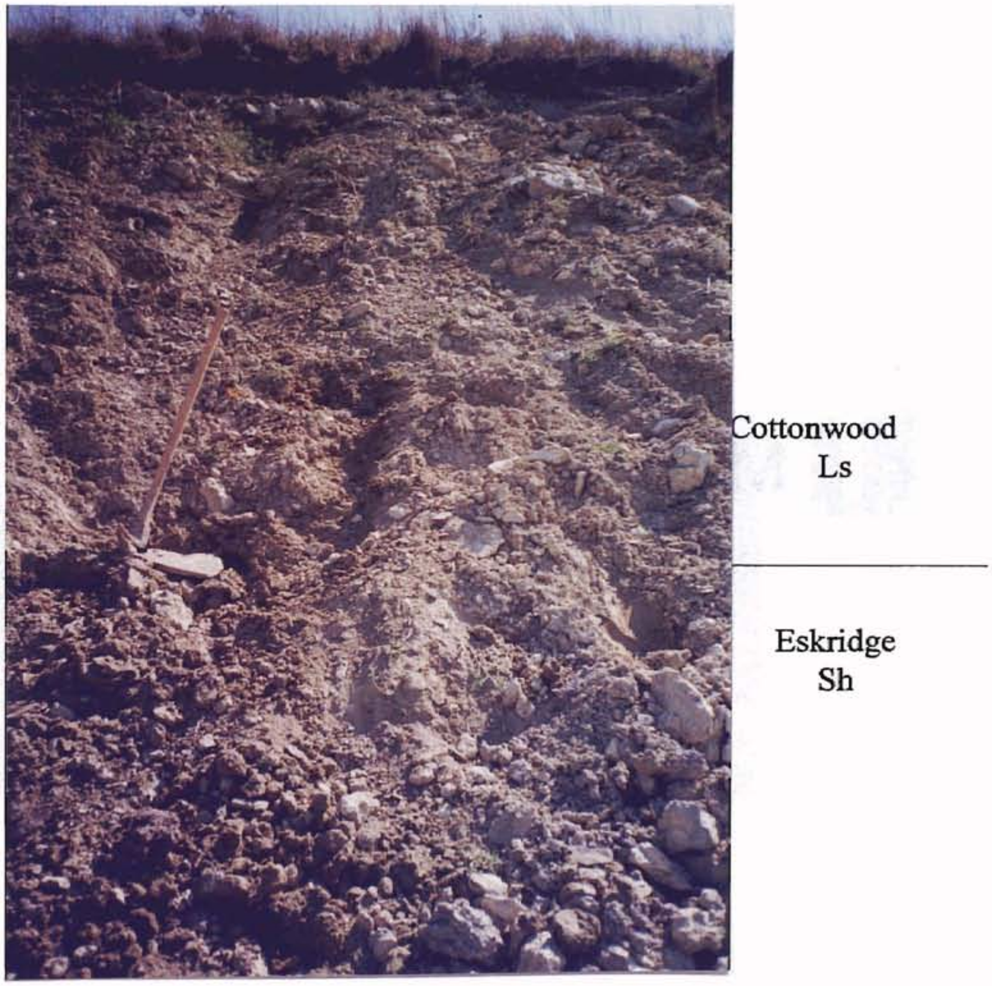
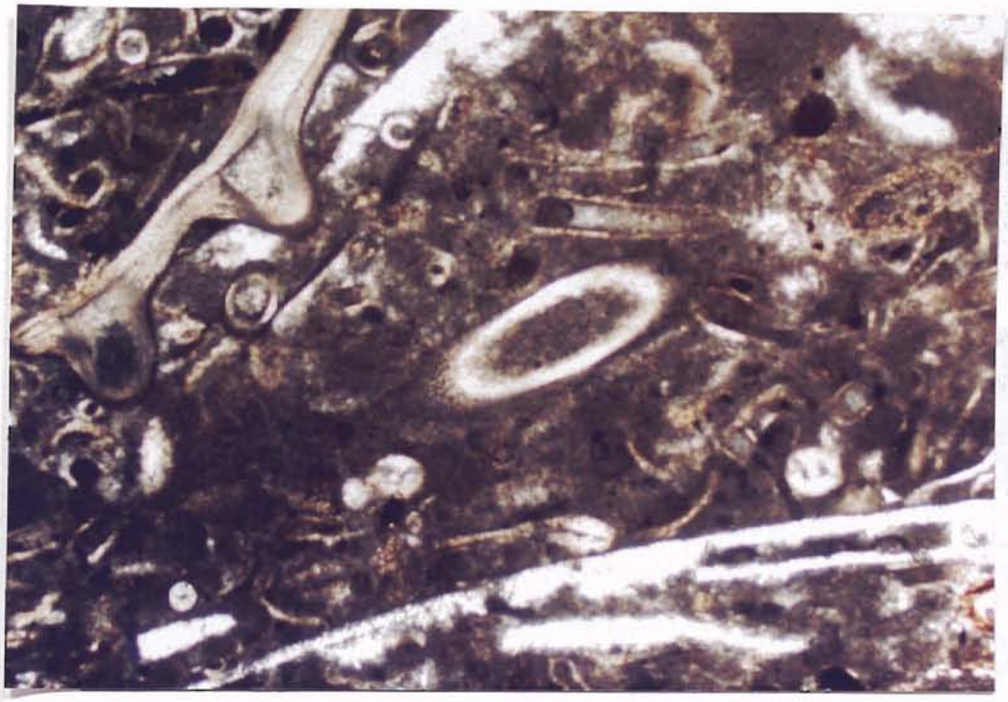


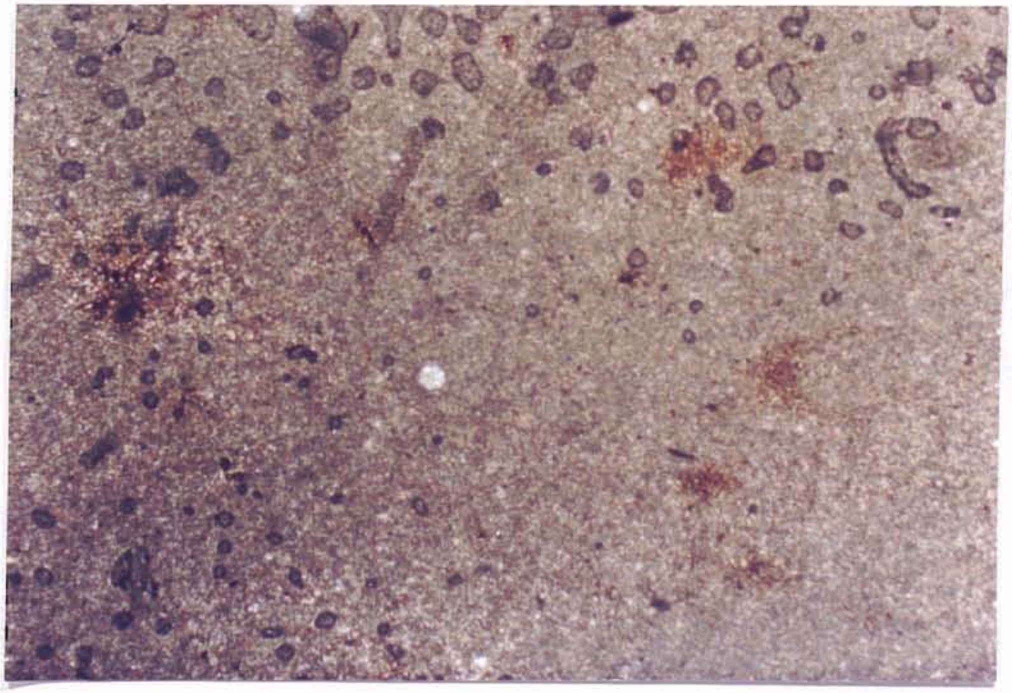
Photo 90 SK-rd Cottonwood Limestone
Taken at railroad track near Grand Summit, Cowley County, Kansas. The Cottonwood Limestone contains the lower shale and upper limestone(thin bed).

Photo 91 SK-rd Florena Shale
Taken at railroad track near Grand Summit, Cowley County, Kansas. The Florena is highly fossiliferous shale below the basal Morrill Limestone (the upper limestone).

Photo 92 SK-rd Morrill Limestone
Taken at railroad track near Grand Summit, Cowley County, Kansas. The lower Morrill Limestone is thin to thick-bedded limestone with vertical burrows.

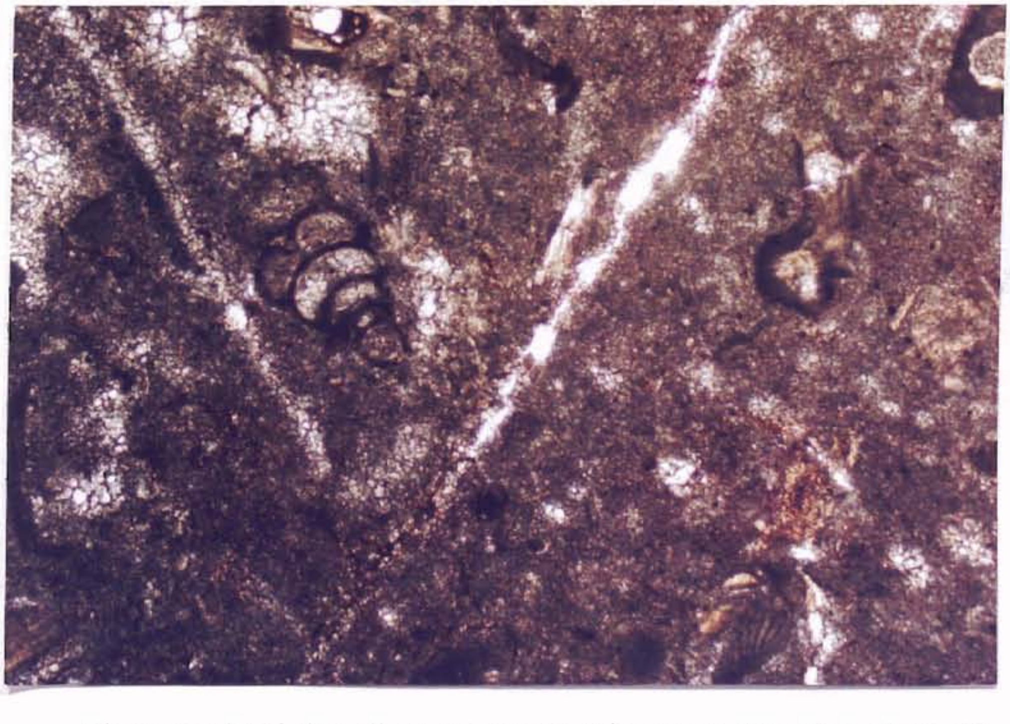


Photograph 93, SK-rd, Cottonwood Limestone Member, Unit: 1
packstone, brachiopod, micrite.

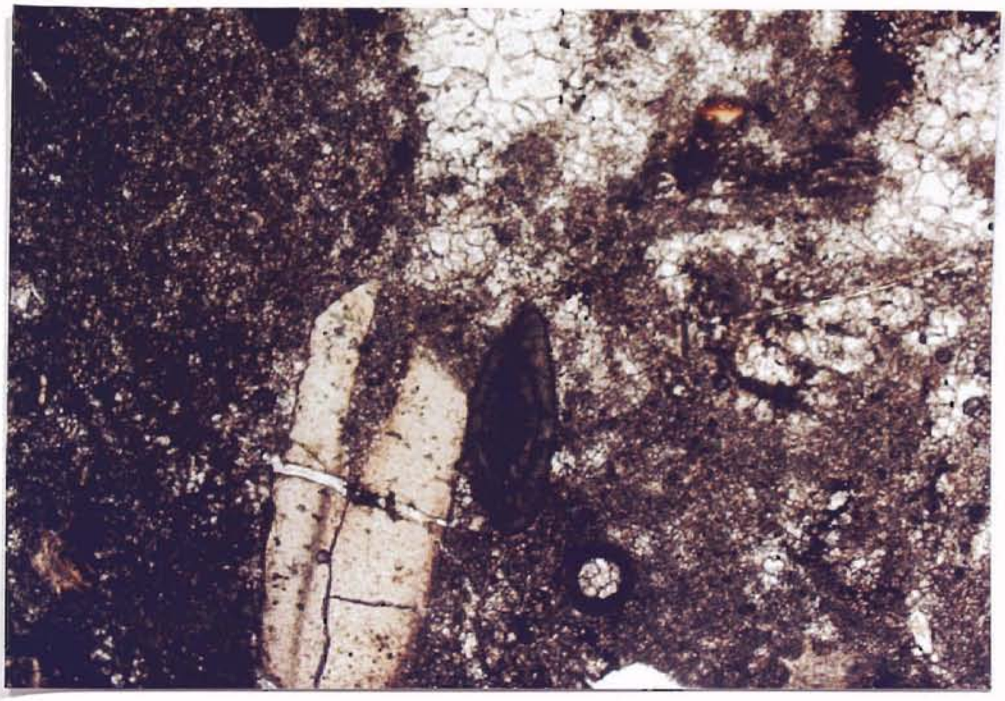


Photograph 94, SK-rd, Cottonwood Limestone Member, Unit: 5
mudstone, micrite.

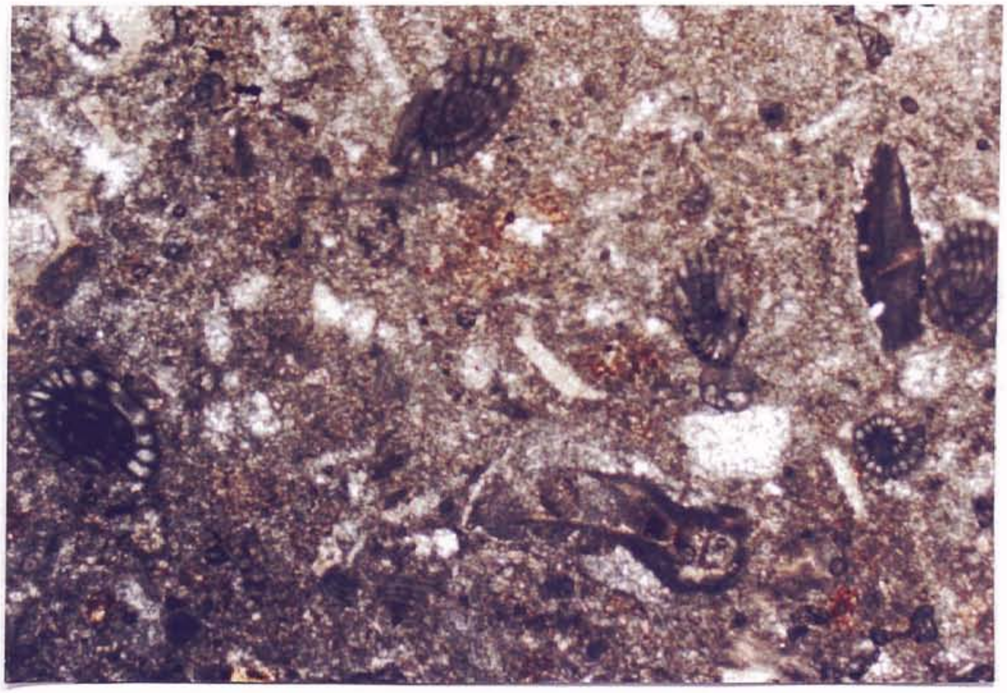
Photograph 95, SK-rd, Cottonwood Limestone Member, Unit: 9
packstone, brachiopod, gastropod, micrite,



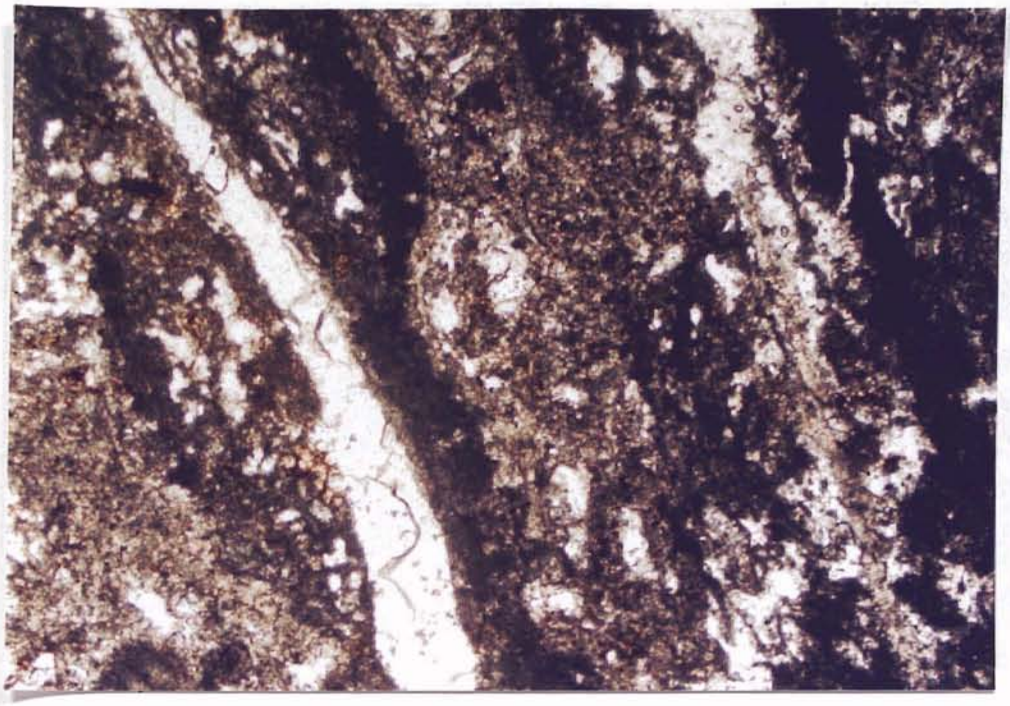
Photograph 96, SK-rd, Cottonwood Limestone Member, Unit: 12
wackestone, fusulinid, brachiopod, micrite.



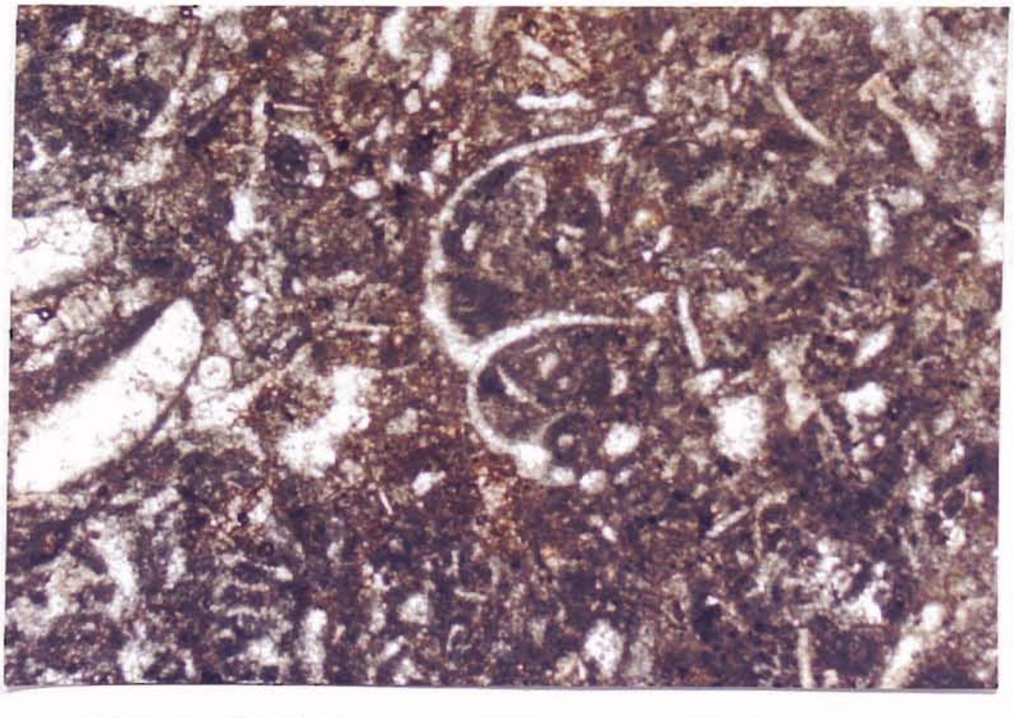
Photograph 97, SK-rd, Cottonwood Limestone Member, Unit: 12
wackestone, fusulinid, brachiopod, trilobite, micrite.



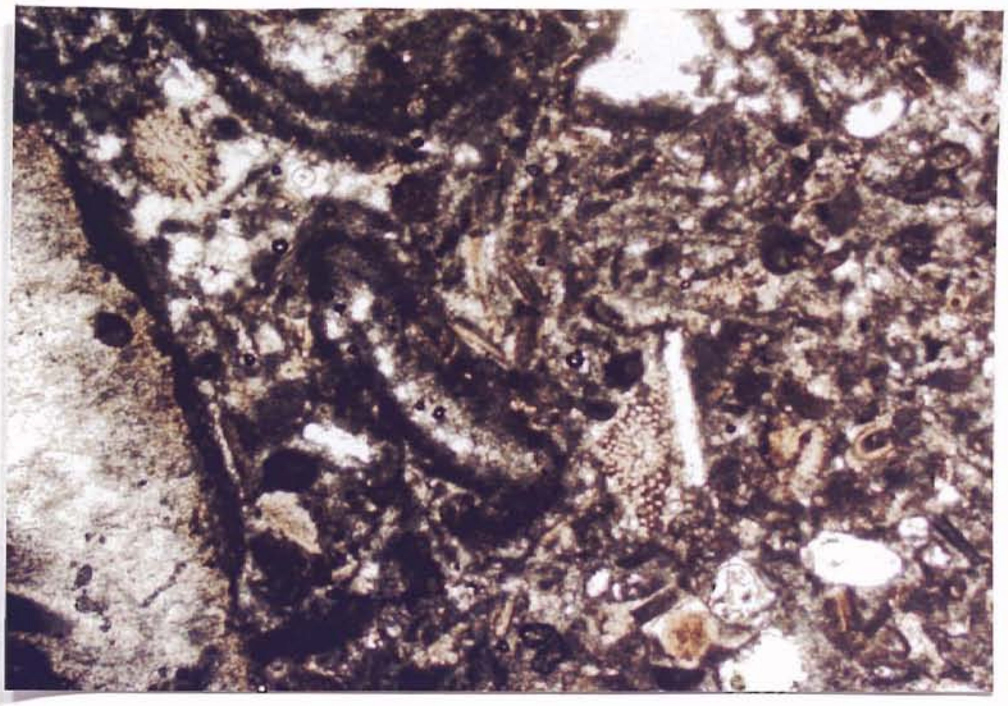
Photograph 98, SK-rd, Cottonwood Limestone Member, Unit: 16
wackestone, funulinid, bryozoan, micrite.



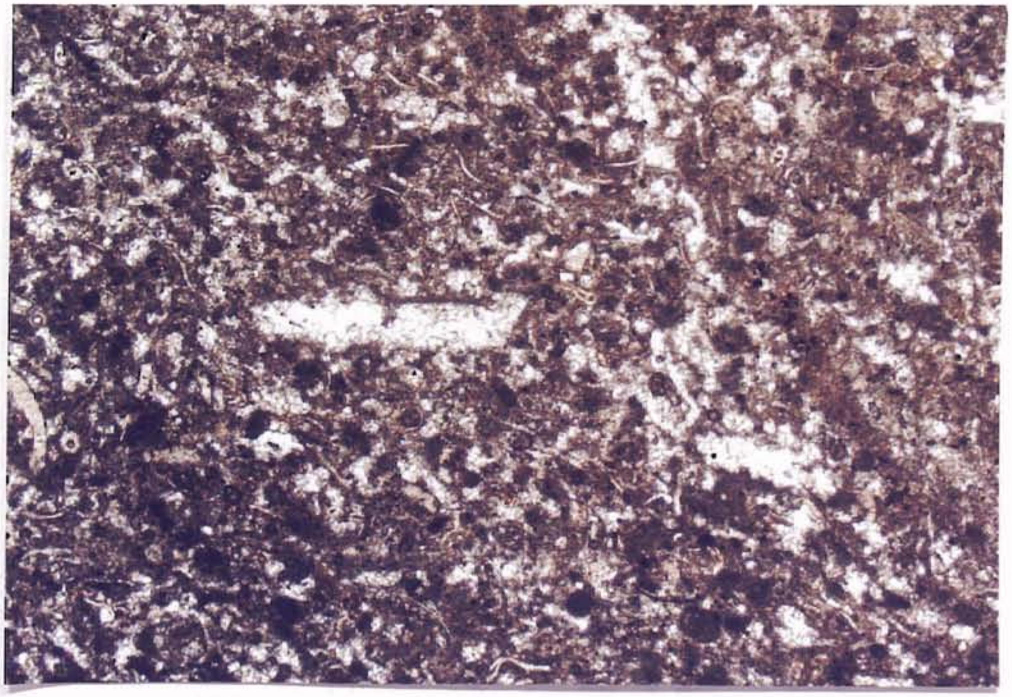
Photograph 99, SK-rd, Morrill Limestone Member, Unit: 34
wackestone, oncoid, bioclast, algae, micrite.



Photograph 100, SK-rd, Morrill Limestone Member, Unit: 37
wackestone, gastropod, echinoderm, bioclast, micrite.



Photograph 101, SK-rd, Morrill Limestone Member, Unit: 39
Packestone, echinoderm, peloid, micrite.



Photograph 102, SK-rd, Morrill Limestone Member, Unit: 42
packstone, peloid, bioclast, micrite.

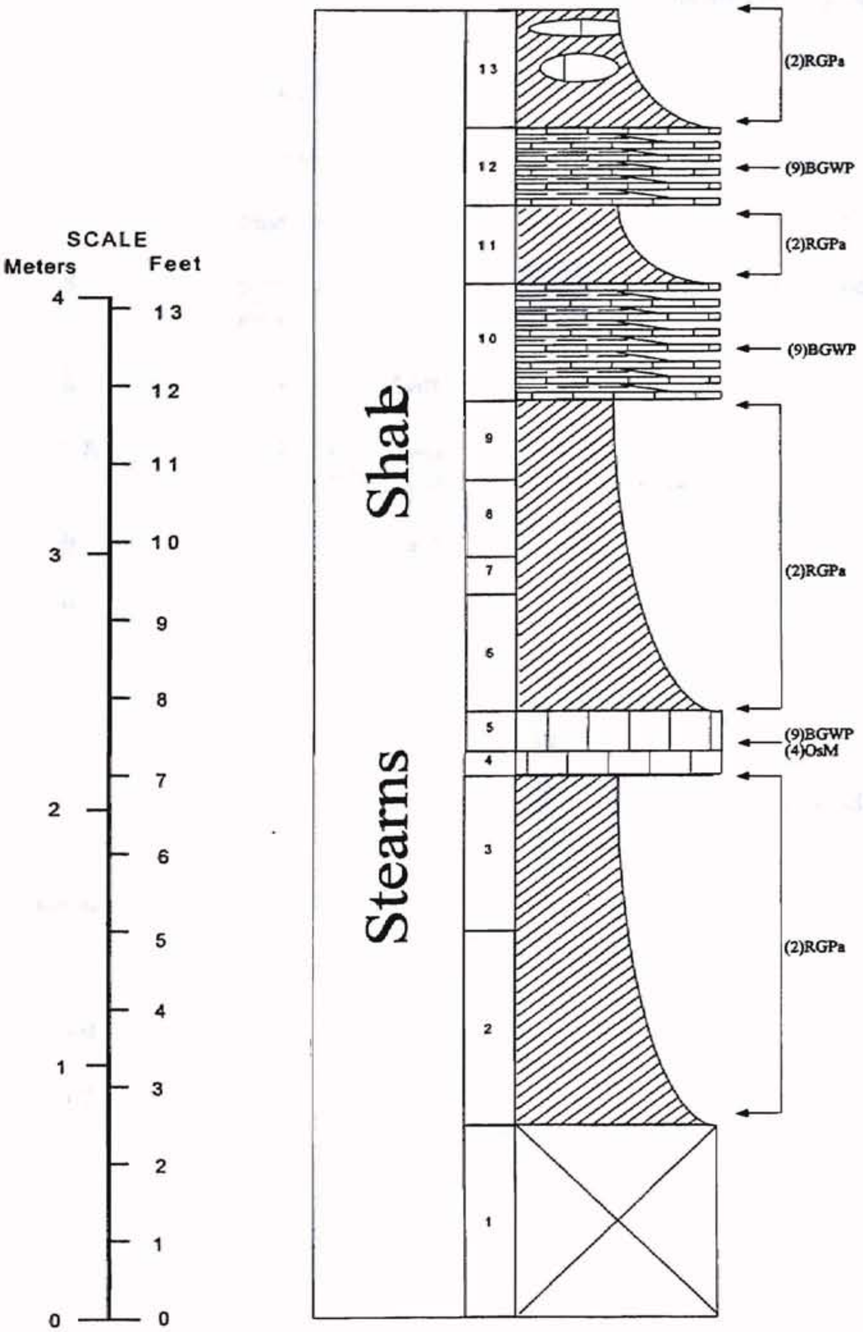


Figure 50. Measured Section SK rd, Stearns Shale.

State: Kansas County: Cowley County

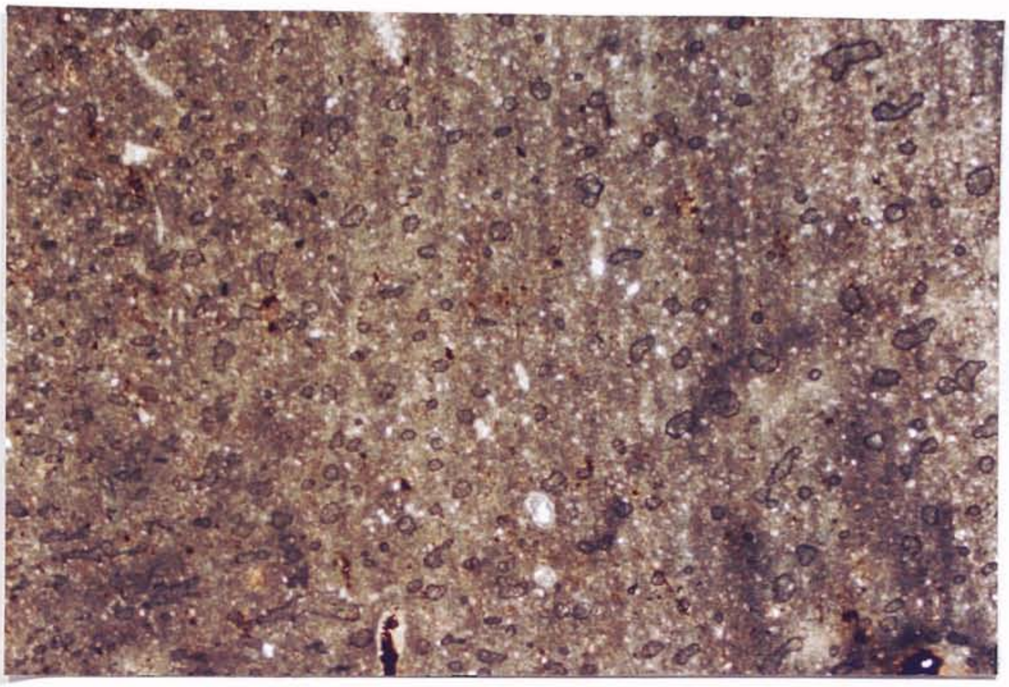
Locality Description:
Railroad cuts, Stream cutbank, and hillside exposures.
SE/4, SW/4, SW/4, Section 4, T31S, R8E, Grand Summit and Cambridge NE 7.5' Quadrangles
Cowley County, Kansas

DESCRIPTION

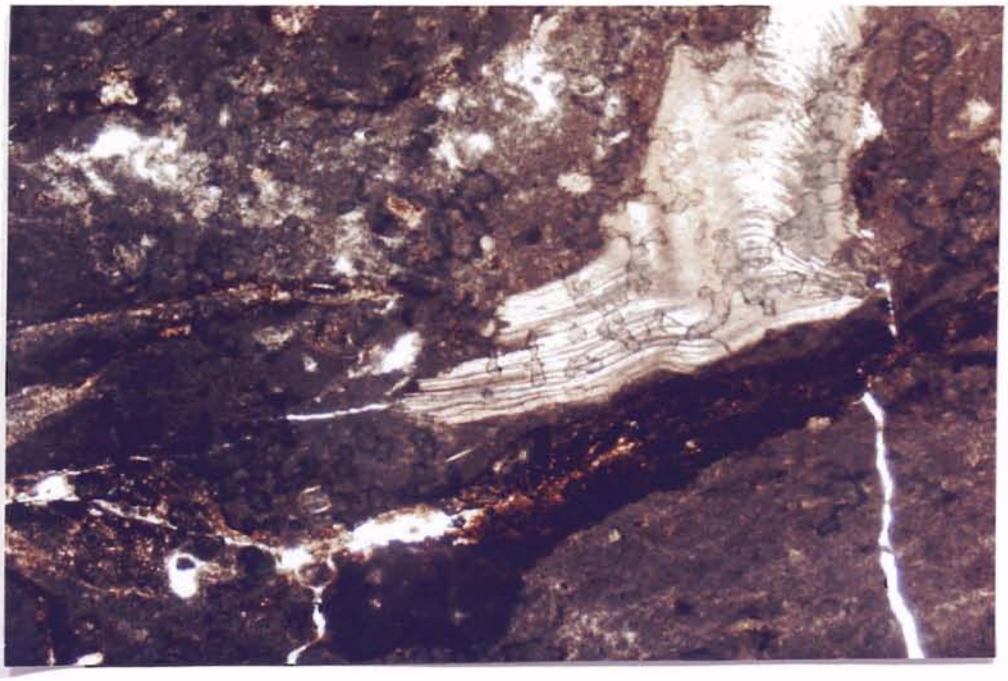
Stearns Shale

13	1.5 ft.	shale, moderate olive brown, calcareous, crumbly
12	1 ft.	wackestone or packstone, brachiopods, bryozoa, ostracodes, micrite, light olive gray
11	1 ft.	shale with nodular limestone, light olive gray, crumbly
10	1.5 ft.	wackestone, bioclasts, brachiopods, bivalve, gastropods, echinoderms, trilobites, ostracodes, algae
9	1 ft.	shale, light olive brown, calcareous, crumbly
8	1 ft.	shale, light olive, calcareous/silty, crumbly
7	0.5 ft.	shale, dark yellow orange, calcareous, calcareous, crumbly
6	1.5 ft.	shale, light olive gray, calcareous, crumbly
5	0.5 ft.	wackestone, bioclasts, brachiopods, bryozoa, gastropods, micrite, moderate gray to buff
4	0.4 ft.	mudstone, bioclasts, micrite, hematitic, moderate gray to buff
3	1 ft.	shale, moderate olive brown, calcareous, crumbly
2	3.5 ft.	shale, light olive gray, silty, crumbly
1	2.5 ft.	cover

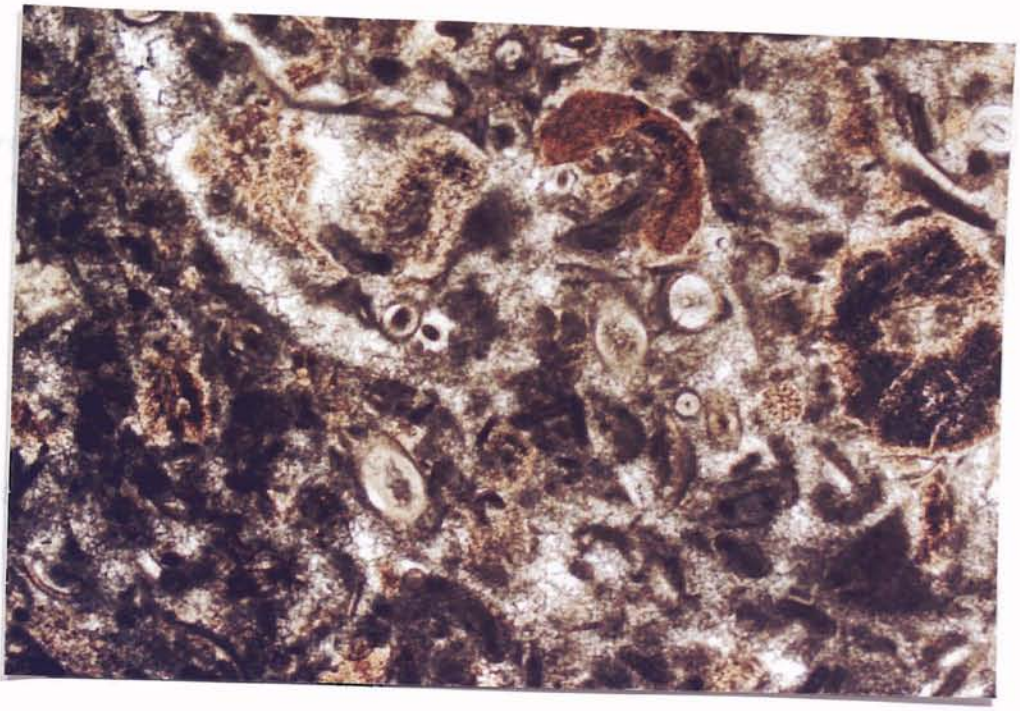
Photo 103 SK-rd Stearns Shale
Taken at railroad track near Grand Summit, Cowley County, Kansas.
The upper Stearns Shale contains very thin-bedded limestone ledges.



Photograph 104, SK-rd, Stearns Shale, Unit: 4
mudstone, ostracode, micrite.



Photograph 105, SK-rd, Stearns Shale, Unit: 5
wackestone, brachiopod, algae, micrite.



Photograph 106, SK-rd, Stearns Shale, Unit: 10 packstone, echinoderm, brachiopod, micrite.

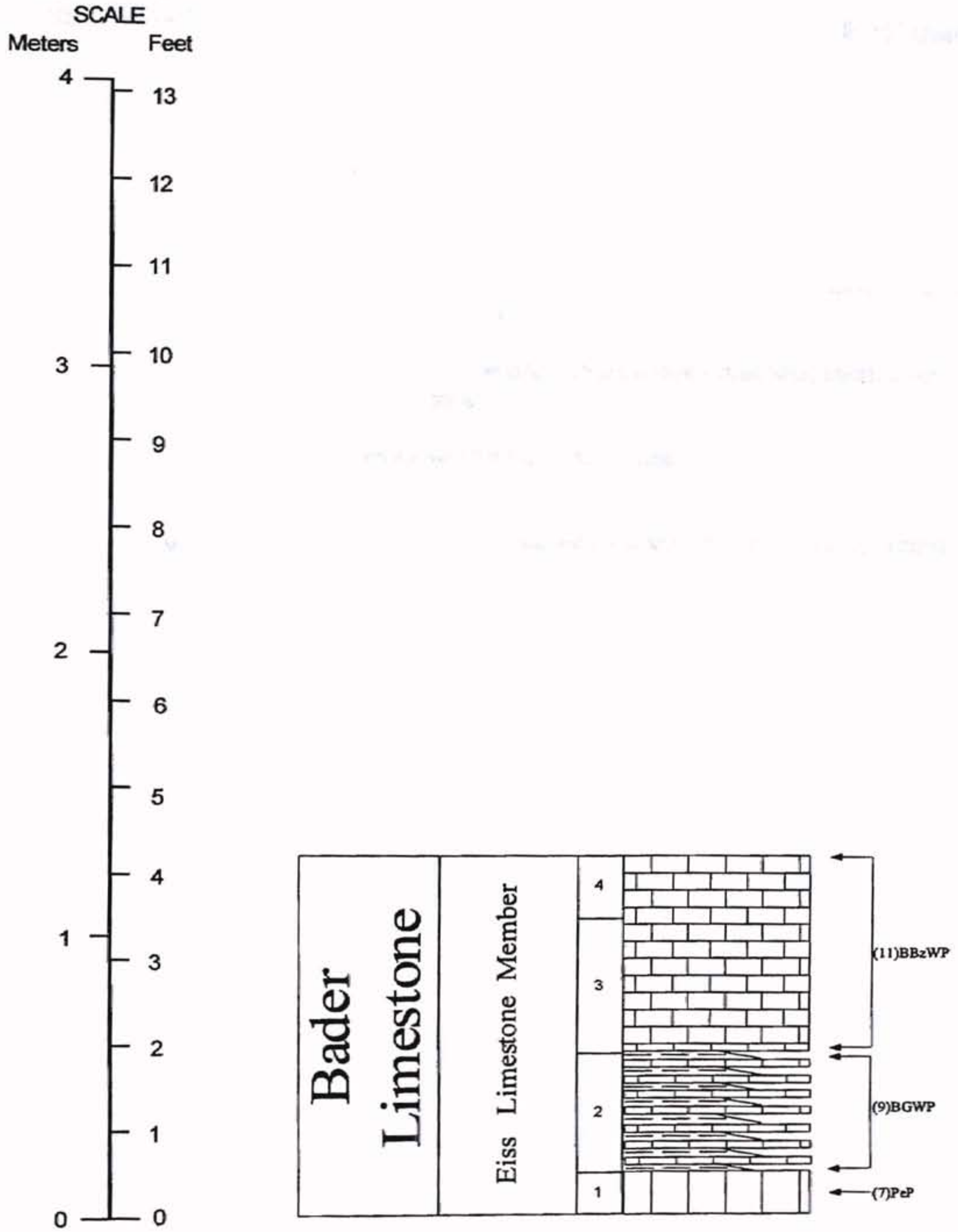


Figure 51. Measured Section SK rd, Bader Limestone.

State: Kansas County: Cowley County

Locality Description:
Railroad cuts, Stream cut bank, and hillside exposures.
SE/4, SW/4, SW/4, Section 4, T31S, R8E, Grand Summit and Cambridge NE 7.5' Quadrangles
Cowley County, Kansas

DESCRIPTION

Bader Limestone

Eiss Limestone Member

4	0.6 ft.	packstone, brachiopods, bivalve bryozoa, echinoderms, micrite, light gray to dark gray
3	1.6 ft.	packstone, bryozoa, echinoderms, ostracodes, chert, micrite, light gray to dark gray
2	1.5 ft.	packstone, brachiopods, gastropods, echinoderms, hematitic, light gray
1	0.5 ft.	packstone, bryozoa, echinoderms, hematitic, light greenish gray

Photo 107 SK-rd Eiss Limestone
Taken at railroad track near Grand Summit, Cowley County, Kansas.
The Eiss Limestone at this locality is flagy to thin-bedded Limestones.

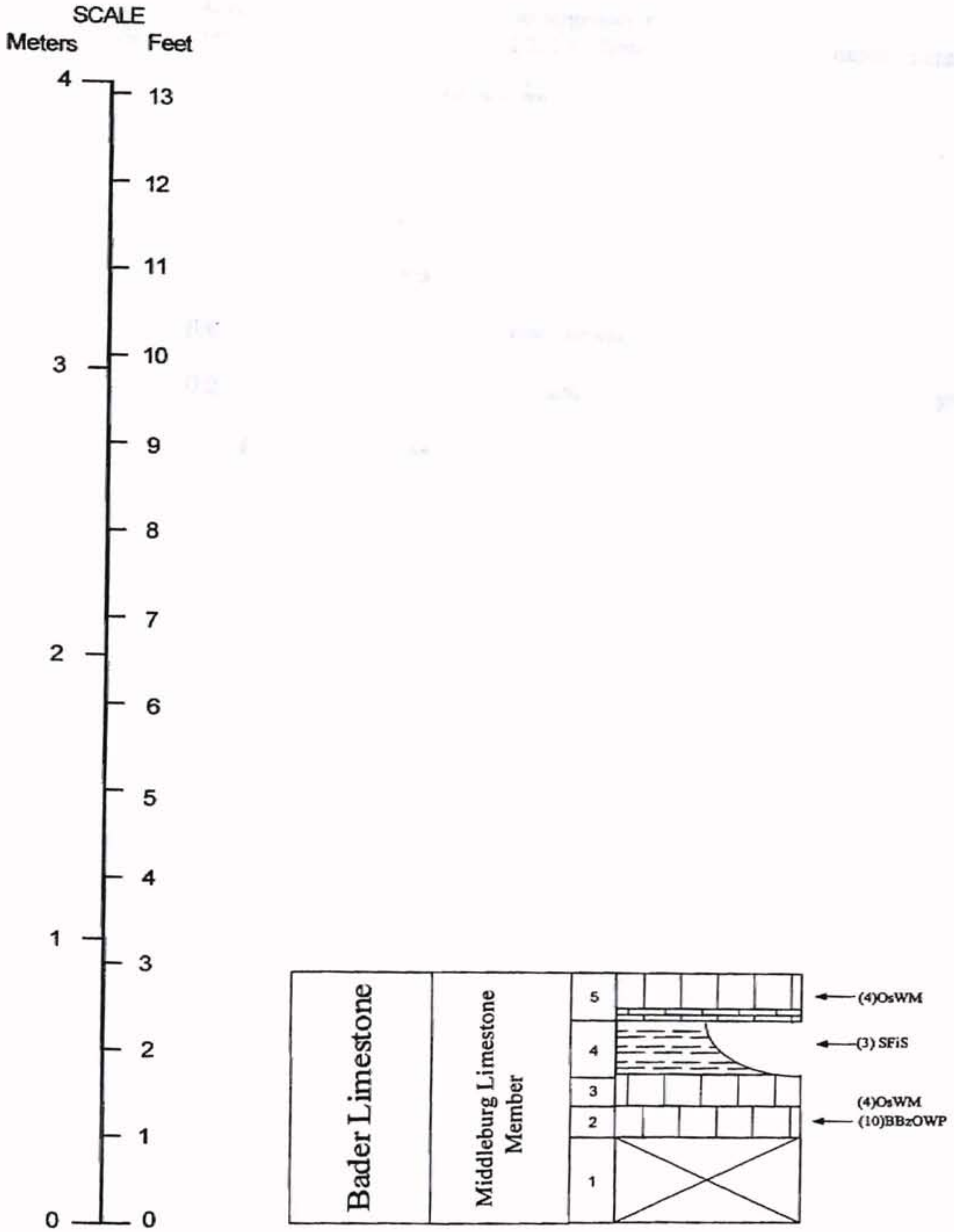


Figure 52. Measured Section SK 38, Bader Limestone.

State: Kansas County: Cowley County

Locality Description:

Roadcut on both sides of Kansas Highway K-38
NW/4, Section 30, T32S, R8E, Dexter NE 7.5' Quadrangle, Cowley County, Kansas.

UNIT DESCRIPTION

Bader Limestone

Middleburg Limestone Member

5	0.4 ft.	mudstone, peloid, calcite spar brownish gray
4	0.6 ft.	shale, olive gray, crumbly
3	0.25 ft.	packstone, ostracodes, micrite, calcite spar, brownish gray
2	0.25 ft.	packstone, oncoid, brachiopods, echinoderms, micrite, calcite spar, brownish gray
1	? ft.	cover

Photo 108 SK-38 Middleburg Limestone
Taken at Highway 38 east of the Winfield, Cowley County, Kansas.
The upper Middleburg limestone is medium bedded limestones.

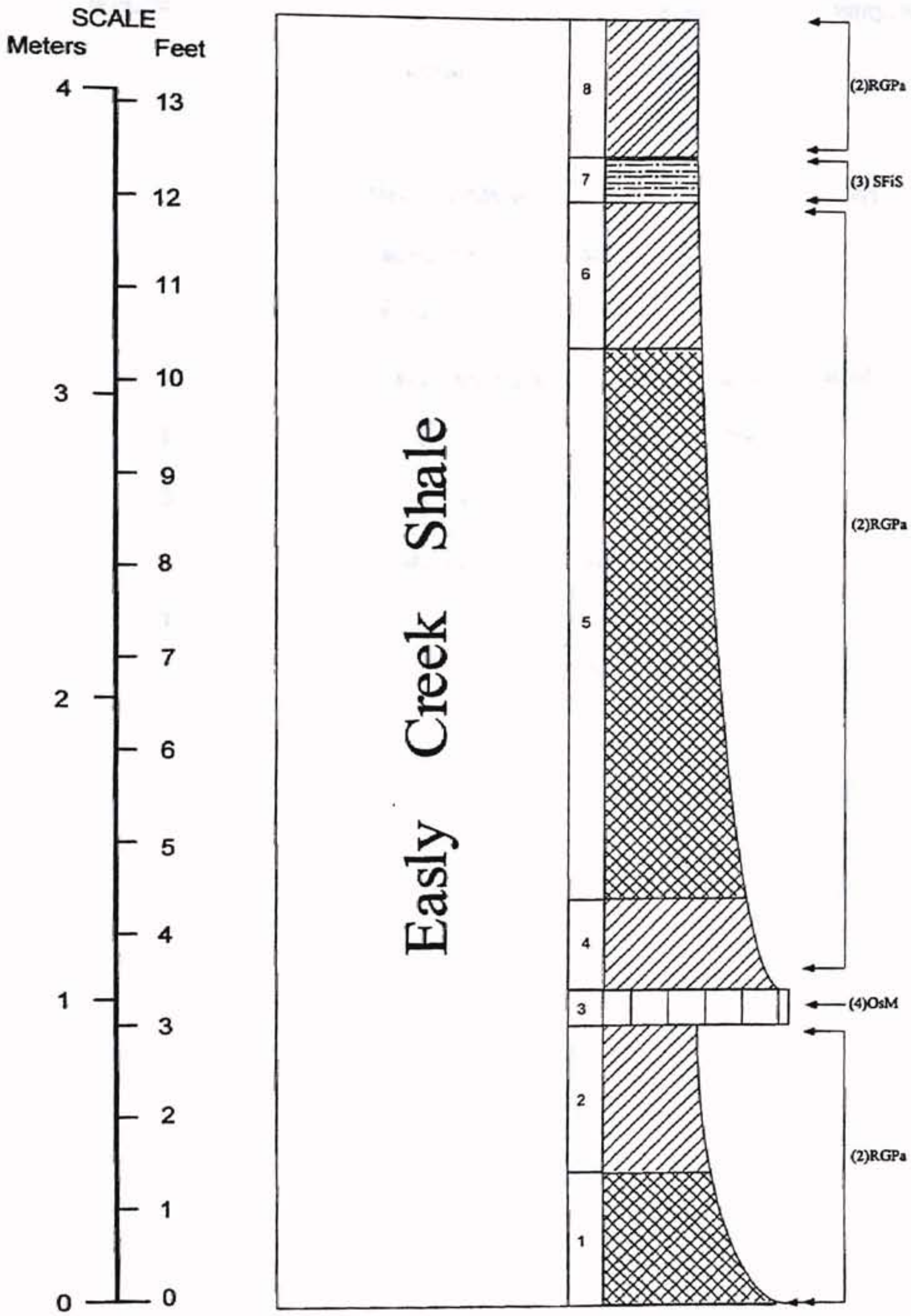


Figure 53. Measured Section SK 38, Easly Creek Shale.

State: Kansas County: Cowley County

Locality Description:

Roadcut on both sides of Kansas Highway K-38
NW/4, Section 30, T32S, R8E, Dexter NE 7.5' Quadrangle, Cowley County, Kansas.

UNIT DESCRIPTION

Easly Creek Shale

8	1.5 ft.	shale, moderate olive brown to grayish olive, crumbly to blocky
7	0.5 ft.	shale, dark yellowish brown, silty, blocky
6	1.6 ft.	shale, light olive to grayish olive, crumbly to blocky
5	6 ft.	shale, very dusky red to dark dusky red, crumbly
4	1 ft.	shale, grayish gray, caliche, crumbly
3	0.4 ft.	mudstone, micrite, olive brown.
2	1.6 ft.	shale, gray olive, crumbly
1	1.5 ft.	shale, reddish gray, crumbly

Photo 109 SK-38 Easly Creek Shale
Taken at Highway 38 east of the Winfield, Cowley County, Kansas.
The Easly Creek Shale is crumbly to blocky mudstones.

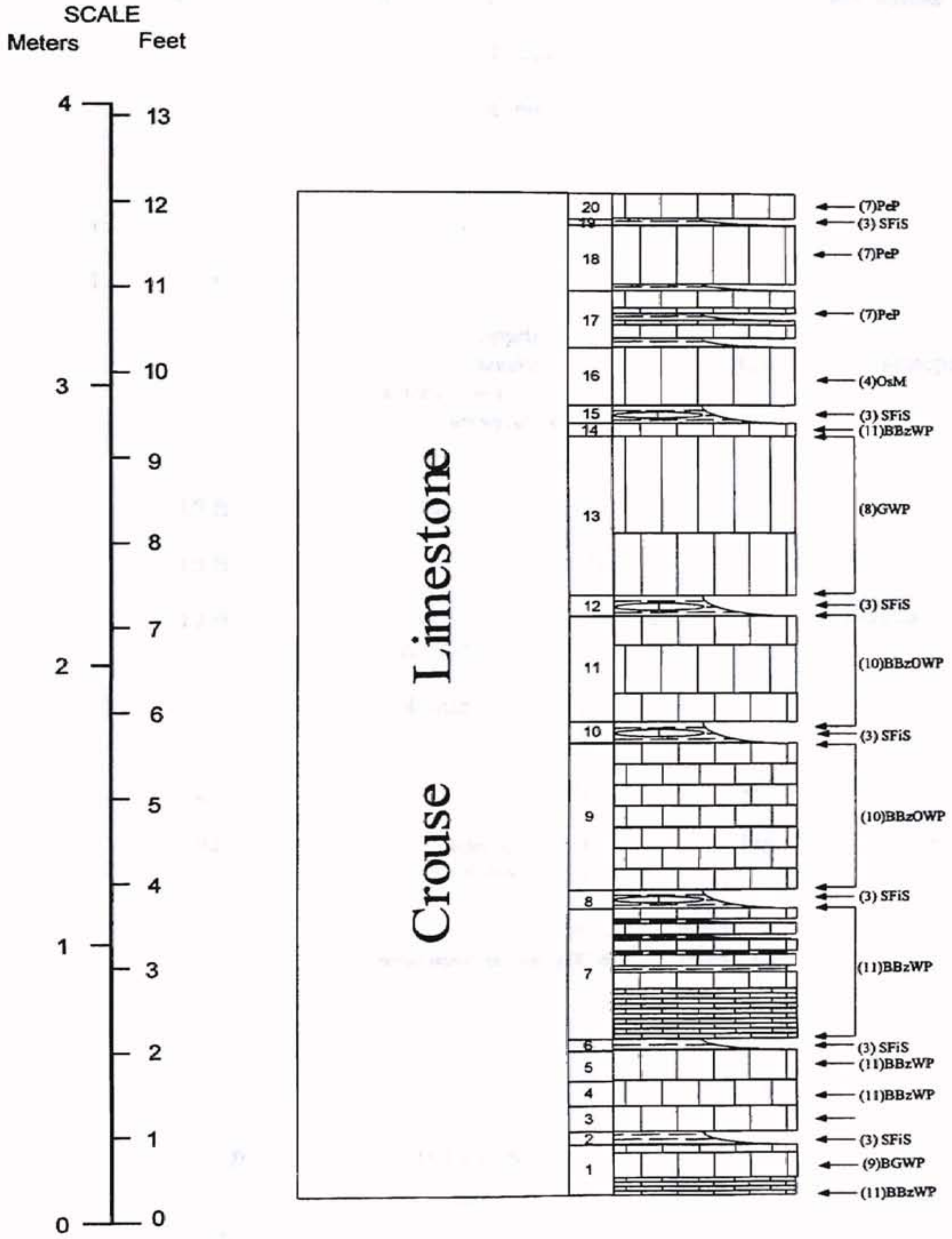


Figure 54. Measured Section SK 38, Crouse Limestone.

State: Kansas County: Cowley County

Locality Description:
Roadcut on both sides of Kansas Highway K-38
NW/4, Section 30, T32S, R8E, Dexter NE 7.5' Quadrangle, Cowley County, Kansas.

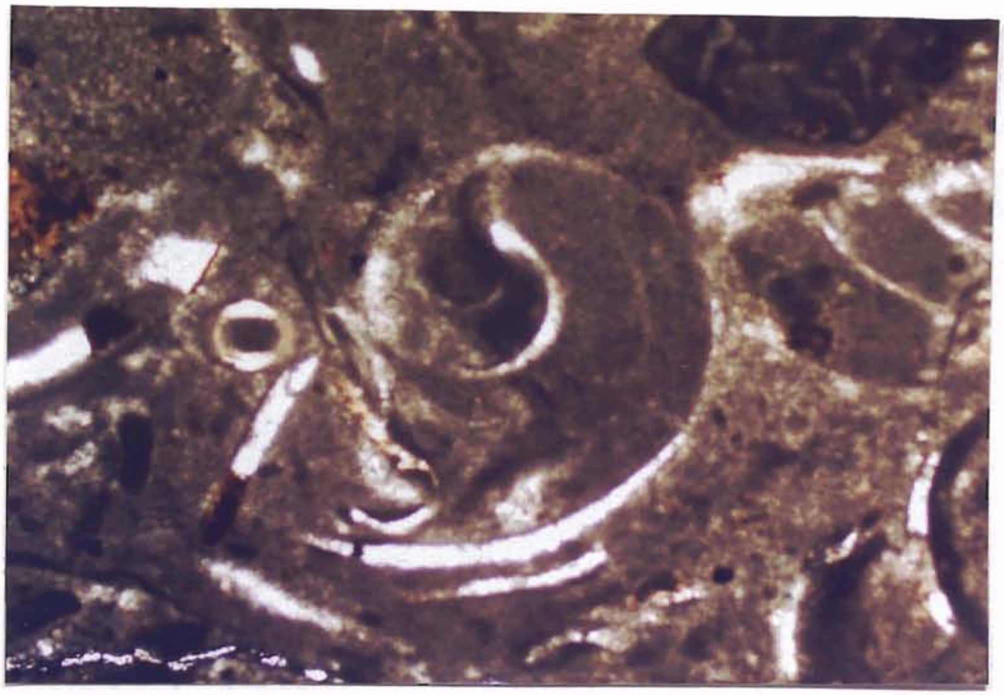
UNIT DESCRIPTION

Crouse Limestone

20	0.3 ft.	wackestone, peloid, gastropods, ostracodes, micrite, gray
19	0.05 ft.	shale, yellowish brown, crumbly
18	0.7 ft.	wackestone, peloid, brachiopods, algae, micrite
17	0.65 ft.	Limestone interbeded with shale limestone: wackestone, peloid, trilobites, algae , brachiopods, hematitic. yellowish gray Shale: yellowish brown shale, crumbly
16	0.7 ft.	mudstone, micrite, yellowish gray
15	0.2 ft.	shale with nodular limestone, grayish yellow
14	0.2 ft.	packstone & boundstone oncoid, brachiopods, gastropods, echinoderms, micrite, grayish yellow
13	1.9 ft.	wackestone, gastropods, echinoderms bryozoa, micrite, yellowish gray
12	0.25 ft.	shale with nodular limestone yellowish brown
11	1.24 ft.	wackestone, oncoid, brachiopods, echinoderms, algae, gastropods, micrite, yellowish brown
10	0.25 ft.	shale with nodular limestone,yellowish brown (packstone & boundstone oncoid echinoderms, micrite algae)
9	1.75 ft.	wackestone, oncoid, brachiopods, bryozoa, algae, trilobites, coral. bryozoa, micrite, foraminifer, yellowish gray
8	0.25 ft.	shale with Nodular limestone, light olive brown
7	1.55 ft.	wackestone, brachiopods, gastropods, echinoderms, bryozoa, ostracodes, algae, micrite, hematitic.
6	0.1 ft.	shale, moderate olive brown, calcareous fissile
5	0.35 ft.	wackestone gastropods, echinoderms, coral, bryozoa, algae, micrite, gray
4	0.3 ft.	wackestone to packstone, oncoid, brachiopods, gastropods,

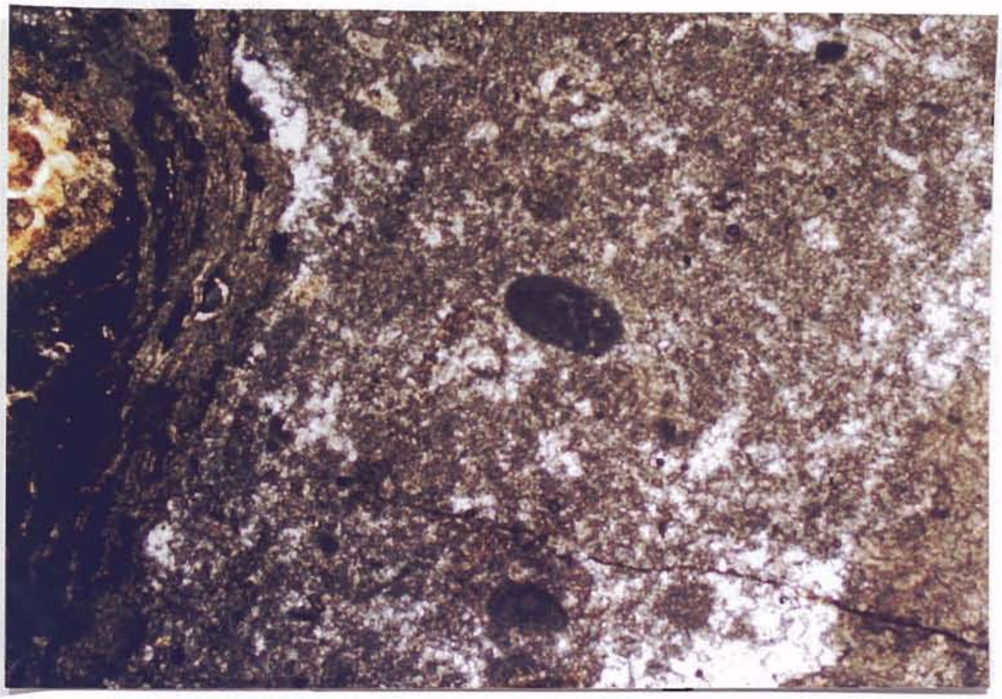
		echinoderms, trilobites, ostracodes, yellow brown
3	0.3 ft.	wackestone, gastropods, brachiopods, bryozoa, micrite gray olive
2	0.15	shale, dusky yellow, crumbly
1	0.58 ft.	packstone, oncoid, gastropods, echinoderms, bryozoa, coral, brachiopods, ostracodes, mud pellet, intraclasts, algae, yellowish gray

Photo 110 SK-38 Crouse Limestone
Taken at Highway 38 east of the Winfield, Cowley County, Kansas. The Crouse Limestone at this locality is very thin to medium-bedded limestones.

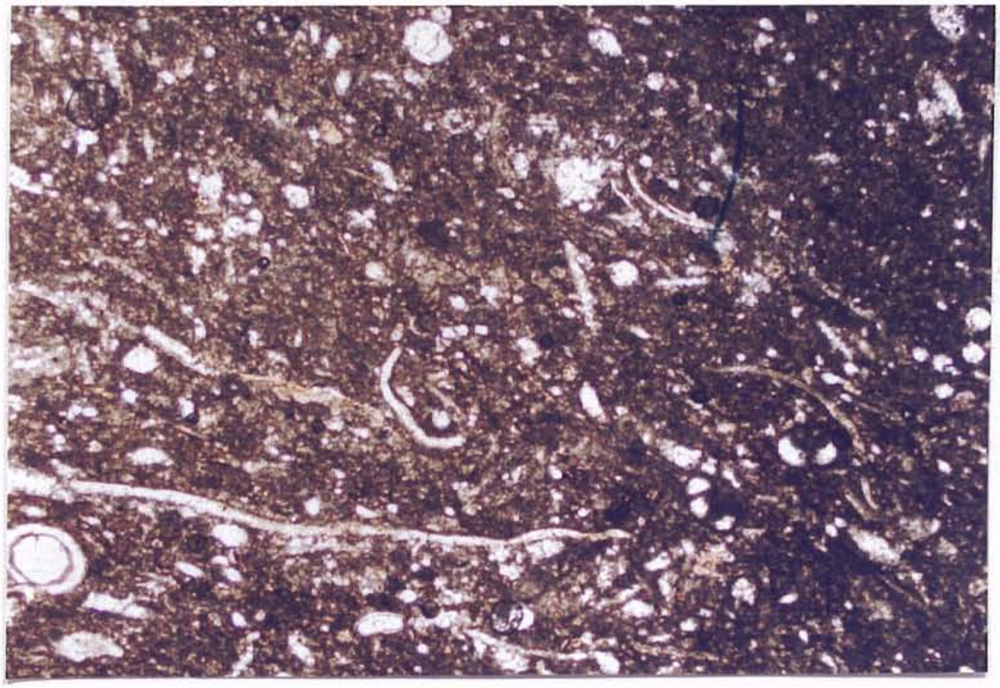


Photograph 111, SK-38, Crouse Limestone, Unit: 1
packstone, gastropod, bioclast, micrite.

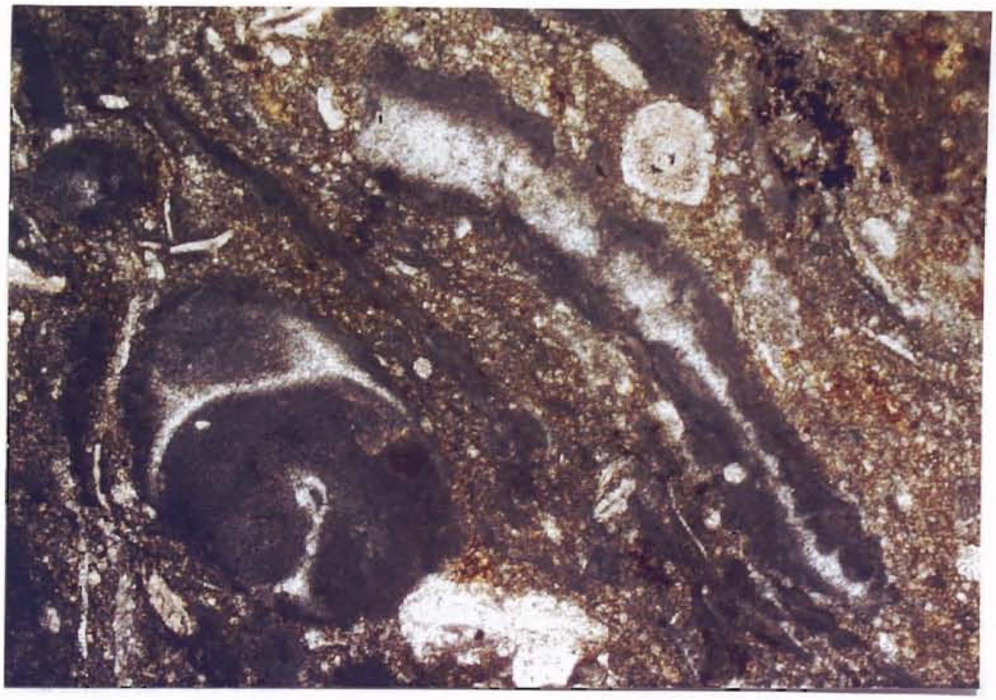
Photograph 112, SK-38, Crouse Limestone, Unit: 3
wackestone, brachiopod, oncoid, micrite,



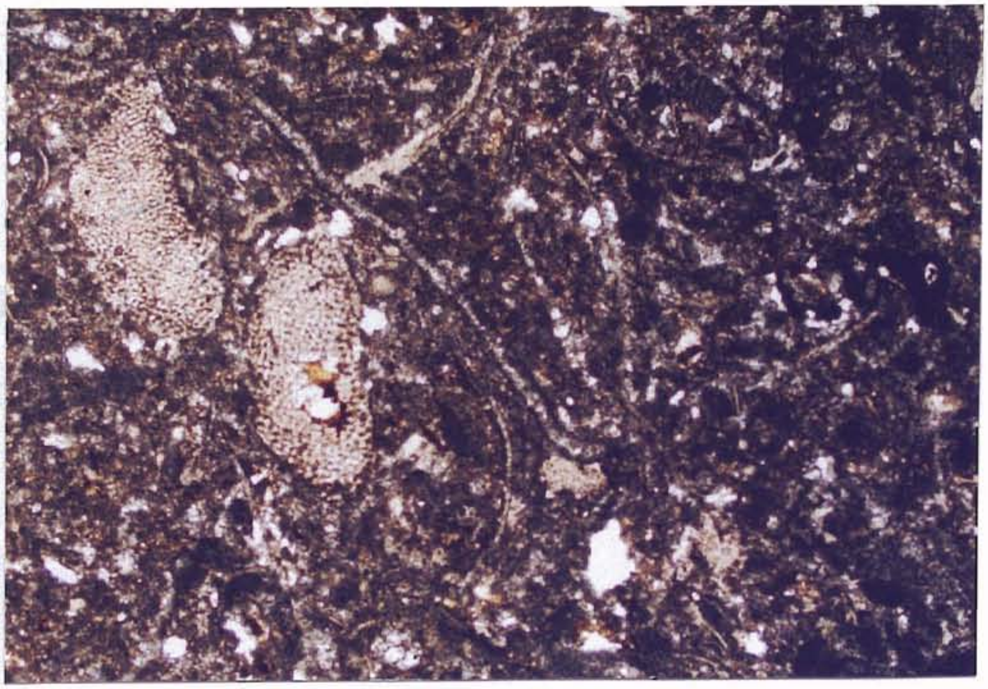
Photograph 113, SK-38, Crouse Limestone, Unit: 5
wackestone, oncoid, intraclast, bryozoan, micrite.



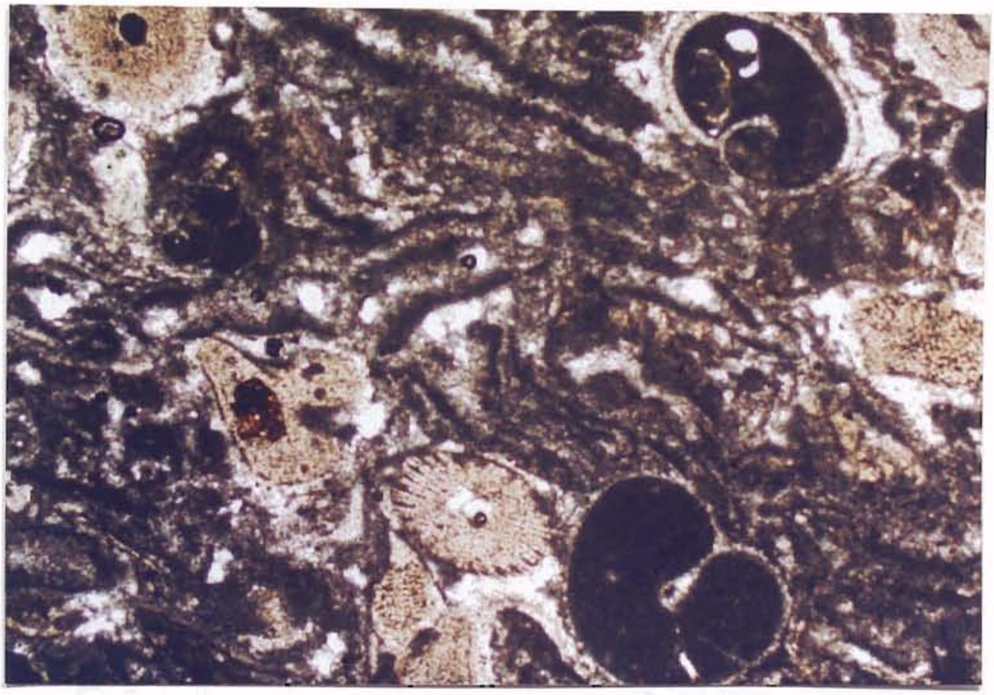
Photograph 114, SK-38, Crouse Limestone, Unit: 7
Wackstone, brachiopod, bioclast, micrite,



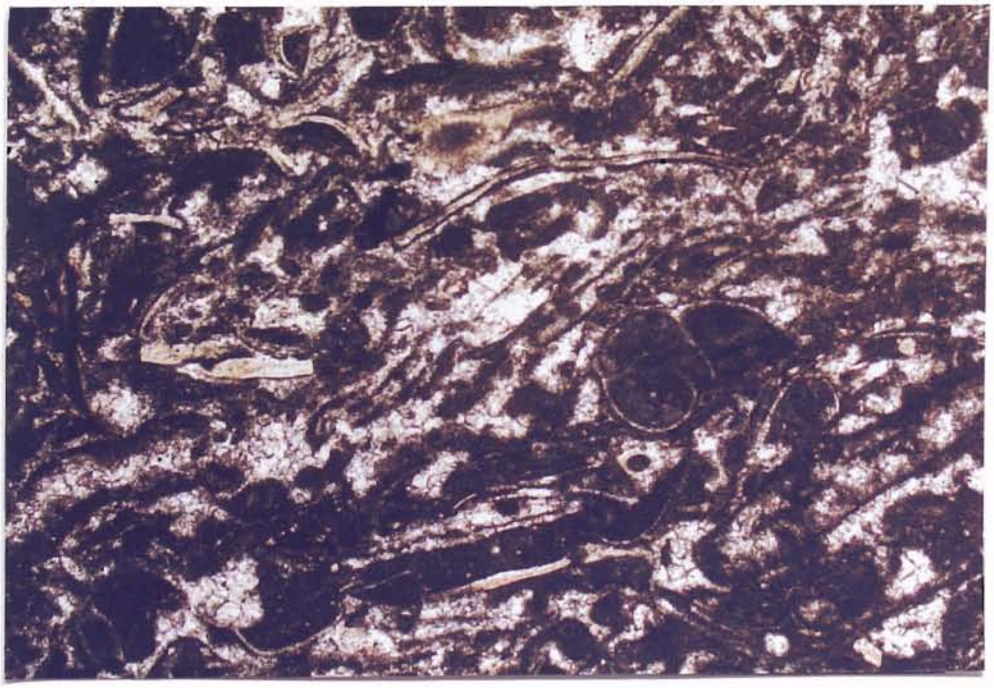
Photograph 115, SK-38, Crouse Limestone, Unit: 9
wackestone, oncoid, echinoderm, bioclast, algae.



Photograph 116, SK-38, Crouse Limestone, Unit: 13
wackestone, echinoderm, peloid, micrite.



Photograph 117, SK-38, Crouse Limestone, Unit: 14
packstone, echinoderm, gastropod, algae, micrite.



Photograph 118, SK-38, Crouse Limestone, Unit: 20
wackestone, ostracode, gastropod, algae, micrite.

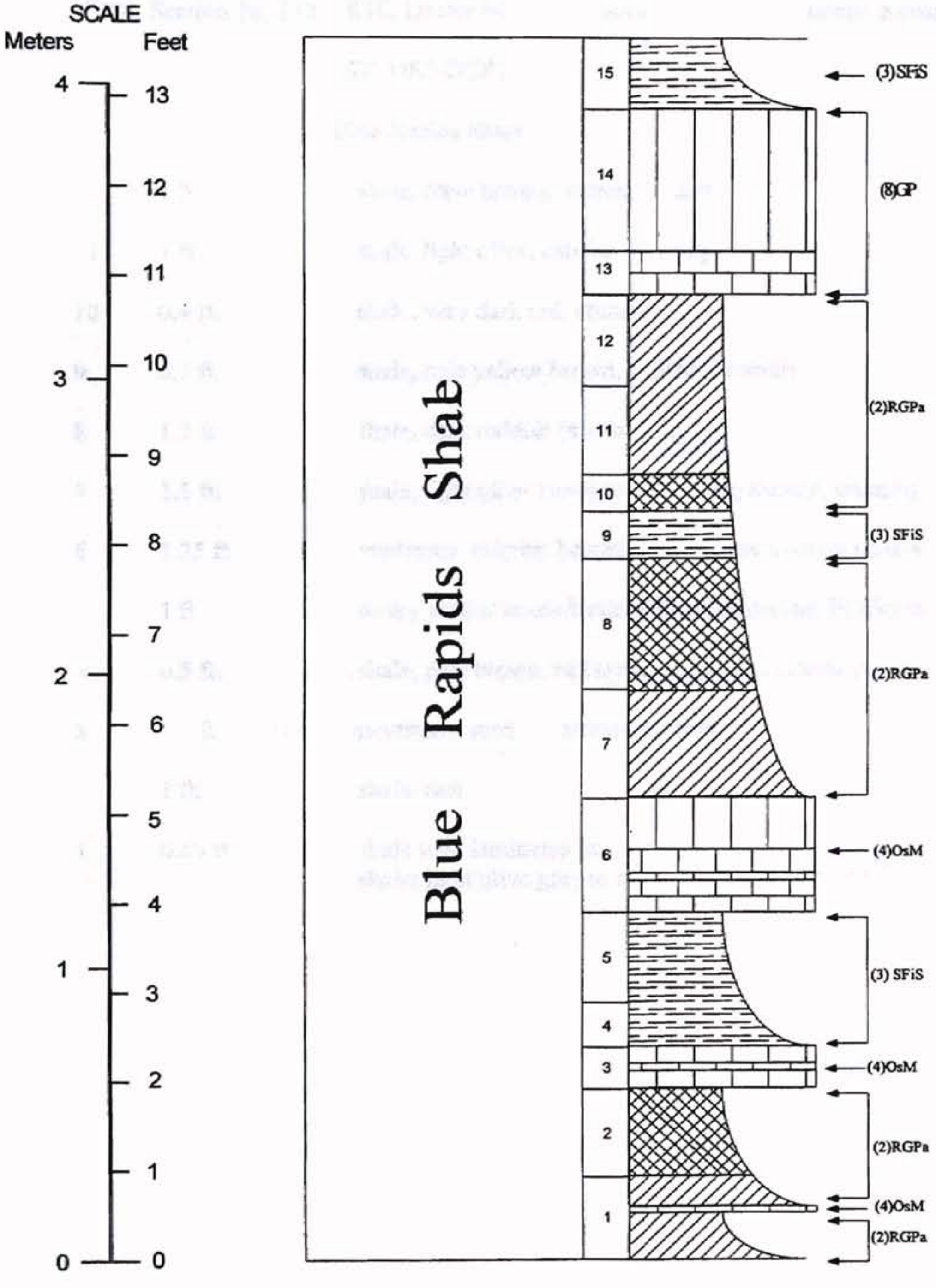


Figure 55. Measued Section SK 38, Blue Rapids Shale.

State: Kansas County: Cowley County

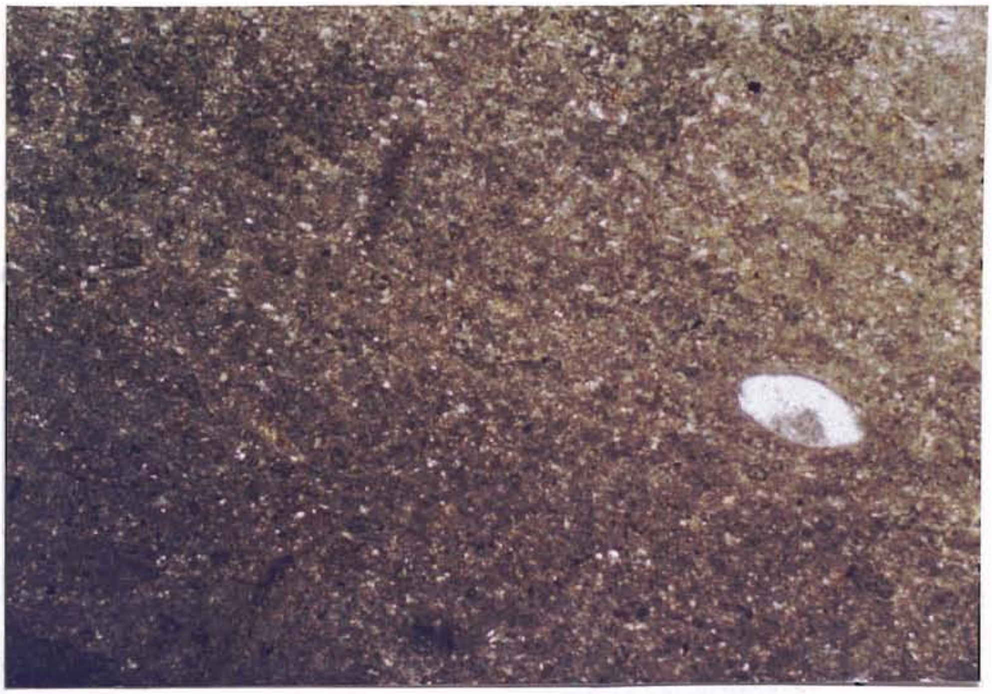
Locality Description:
Roadcut on both sides of Kansas Highway K-38
NW/4, Section 30, T32S, R8E, Dexter NE 7.5' Quadrangle, Cowley County, Kansas.

UNIT DESCRIPTION

Blue Rapids Shale

12	1 ft.	shale, olive brown, caliche, crumbly
11	1 ft.	shale, light olive, caliche, crumbly
10	0.4 ft.	shale, very dark red, crumbly
9	0.5 ft.	shale, pale yellow brown, caliche, crumbly
8	1.5 ft.	shale, dark reddish brown, crumbly
7	1.1 ft.	shale, light olive brown to pale olive, caliche, crumbly
6	1.35 ft.	mudstone, micrite, hematitic, pale gray to olive yellow
5	1 ft.	dusky yellow to moderate yellow calcareous, blocky to crumbly
4	0.5 ft.	shale, pale brown, calcareous, blocky to crumbly
3	0.6 ft.	mudstone, micrite, hematitic, fissile
2	1 ft.	shale, reddish gray, silty, fissile
1	0.85 ft.	shale with laminated limestone shale: light olive gray to pale olive shale, silty, fissile

Photo 119 SK-38 Blue Rapids Shale
Taken at Highway 38 east of the Winfield, Cowley County, Kansas.
The limestone ledges observed here are the upper Blue Rapids Shale.



Photograph 120, SK-38, Blue Rapids Shale, Unit: 3 mudstone, ostracode.

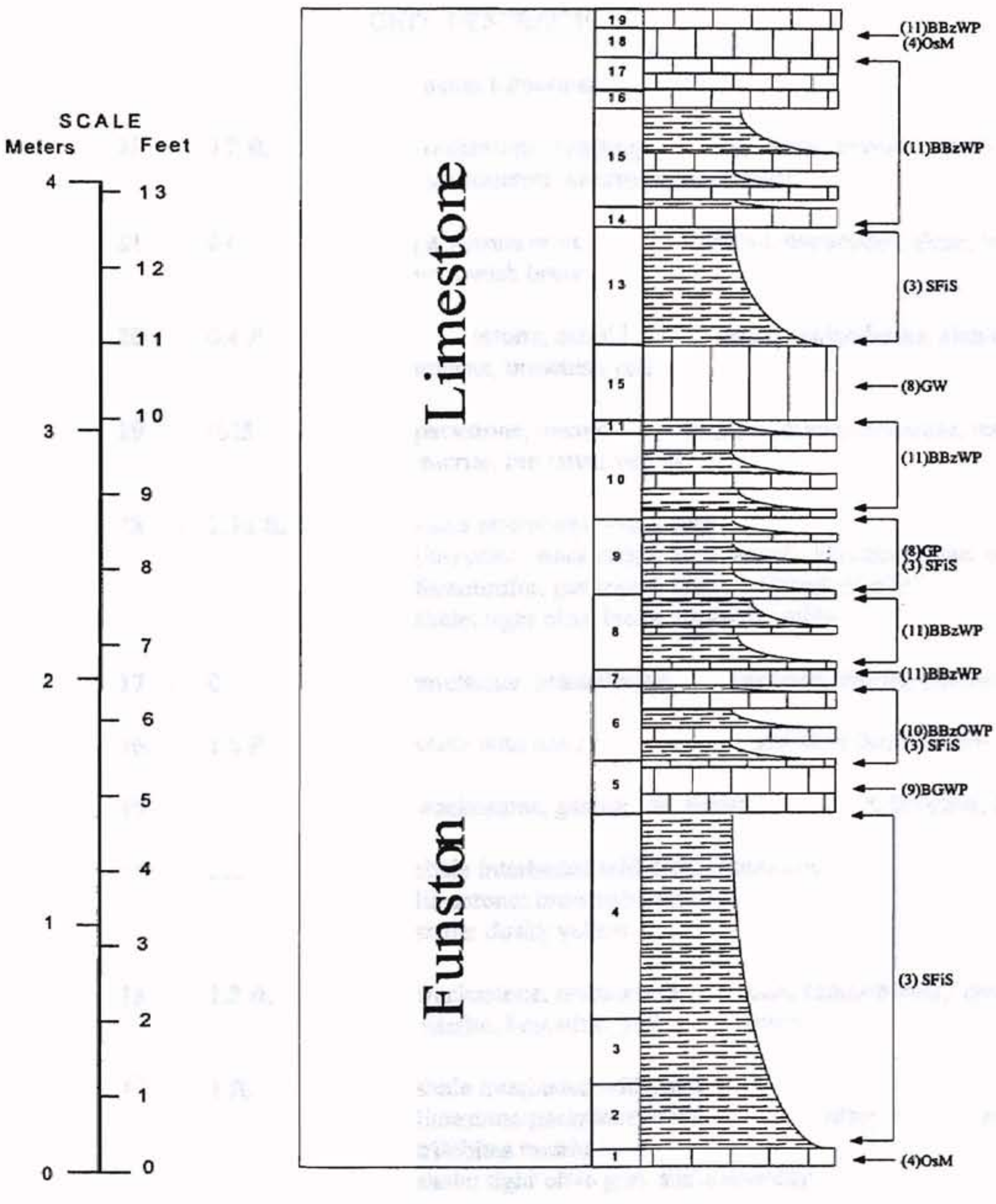


Figure 56. Measured Section SK 38, Funston Limestone.

State: Kansas County: Cowley County

Locality Description:
Roadcut on both sides of Kansas Highway K-38
NW/4, Section 30, T32S, R8E, Dexter NE 7.5' Quadrangle, Cowley County, Kansas.

UNIT DESCRIPTION

Funston Limestone

22	0.2 ft.	wackestone, brachiopods, foraminifer, bryozoa, algae, echinoderms, micrite, yellowish gray
21	0.4 ft.	packstone or boundstone bivalve, ostracodes, algae, micrite, yellowish brown
20	0.4 ft.	wackestone, oncoid, brachiopods, echinoderms, algae, ostracodes, micrite, brownish yellow
19	0.25 ft.	packstone, oncoids, brachiopods, ostracodes algae, recrystallized micrite, brownish yellow
18	1.33 ft.	shale interbeded with limestone limestone: wackestone brachiopods, bryozoa, algae, ostracodes, foraminifer, gastropods, recrystallized micrite shale: light olive brown shale, crumbly
17	0.3 ft.	mudstone, brachiopods, recrystallized micrite, yellowish gray
16	1.6 ft.	shale with nodular limestone, light olive brown,crumbly
15	1 ft.	wackestone, gastropods, foraminifer, chert, bryozoa, micrite
14	0.2 ft.	shale interbeded with shaly limestone limestone: brownish gray shale: dusky yellow
13	1.2 ft.	wackestone, brachiopods, bryozoa, echinoderms, ostracodes, micrite, hematitic, yellowish brown
12	1 ft.	shale interbeded with limestone limestone:packstone to wackestone gastropods, echinoderms, trilobites micrite shale: light olive gray shale crumbly
11	1 ft.	shale interbeded with limestone limestone:mudstone,brachiopods, micrite, yellowish gray shale: light olive gray shale, crumbly
10	0.2 ft.	mudstone, brachiopods micrite, yellowish brown to gray
9	1 ft.	limestone interbeded with shale limestone: wackestone, oncoid, brachiopods, echinoderms,algae, micrite, calcite spar

		shale: moderate olive brown shale, crumbly
8	0.7 ft.	wackestone, gastropods, echinoderms, algae, brachiopods, foraminifer, dolomite, recrystallized micrite, yellowish gray
7	2.4 ft.	shale, light olive gray to moderate olive brown, crumbly to blocky
6	0.6 ft.	shale, yellowish gray, blocky
5	0.6 ft.	shale, light olive brown, crumbly,
4	0.23 ft.	wackestone, bioclasts, recrystallized micrite, gray
3	0.8 ft.	shale, light olive gray, crumbly
2	1.6 ft.	Wackestone, gastropods, algae, micrite, hematitic, gray.
1	0.5 ft.	Wackestone, gastropods, algae, micrite, gray to light olive gray

Photo 121 SK-38 Funston Limestone
Taken at Highway 38 east of the Winfield, Cowley County, Kansas. The basal Funston Limestone at this locality is thin to thick-bedded limestones.

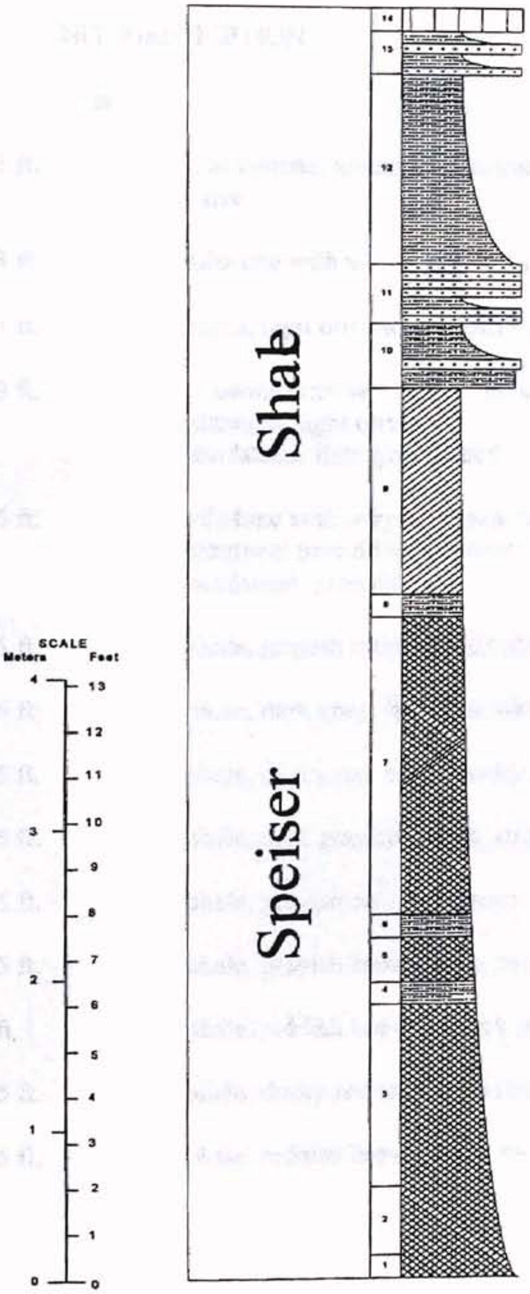


Figure 57. Measured Section SK 38, Speiser Shale.

State: Kansas County: Cowley County

Locality Description:
Roadcut on both sides of Kansas Highway K-38
NW/4, Section 30, T32S, R8E, Dexter NE 7.5' Quadrangle, Cowley County, Kansas.

UNIT DESCRIPTION

Speiser Shale

14	0.5 ft.	wackestone, gastropods, ostracodes, algae, bioclasts, micrite, pale olive
13	0.8 ft.	siltstone with very fine grain sandstone, light olive
12	4.3 ft.	shale, light olive to pale olive silty, fissile
11	0.9 ft.	siltstone with very fine grain sandstone siltstone: light olive sandstone: light gray to buff
10	1.6 ft.	siltstone with very fine grain sandstone siltstone: pale olive to brown, fissile sandstone: greenish gray
9	4.5 ft.	shale, grayish olive to light olive, crumbly
8	0.5 ft.	shale, dark grayish brown, silty, crumbly
7	6.5 ft.	shale, dusky red, silty, blocky to crumbly
6	0.5 ft.	shale, dark grayish brown, silty, crumbly
5	o.5 ft.	shale, grayish red, silty, blocky
4	0.5 ft.	shale, grayish brown, silty, blocky
3	4 ft.	shale, reddish brown to dark reddish brown, silty blocky to fissile
2	1.5 ft.	shale, dusky red to grayish red silty, blocky to crumbly
1	0.5 ft.	shale, reddish brown, silty, blocky

Photo 122 SK-38 Speiser Shale
Taken at Highway 38 the east of the Winfield, Cowley County, Kansas.
The Speiser Shale is red to green crumbly or blocky mudstones.

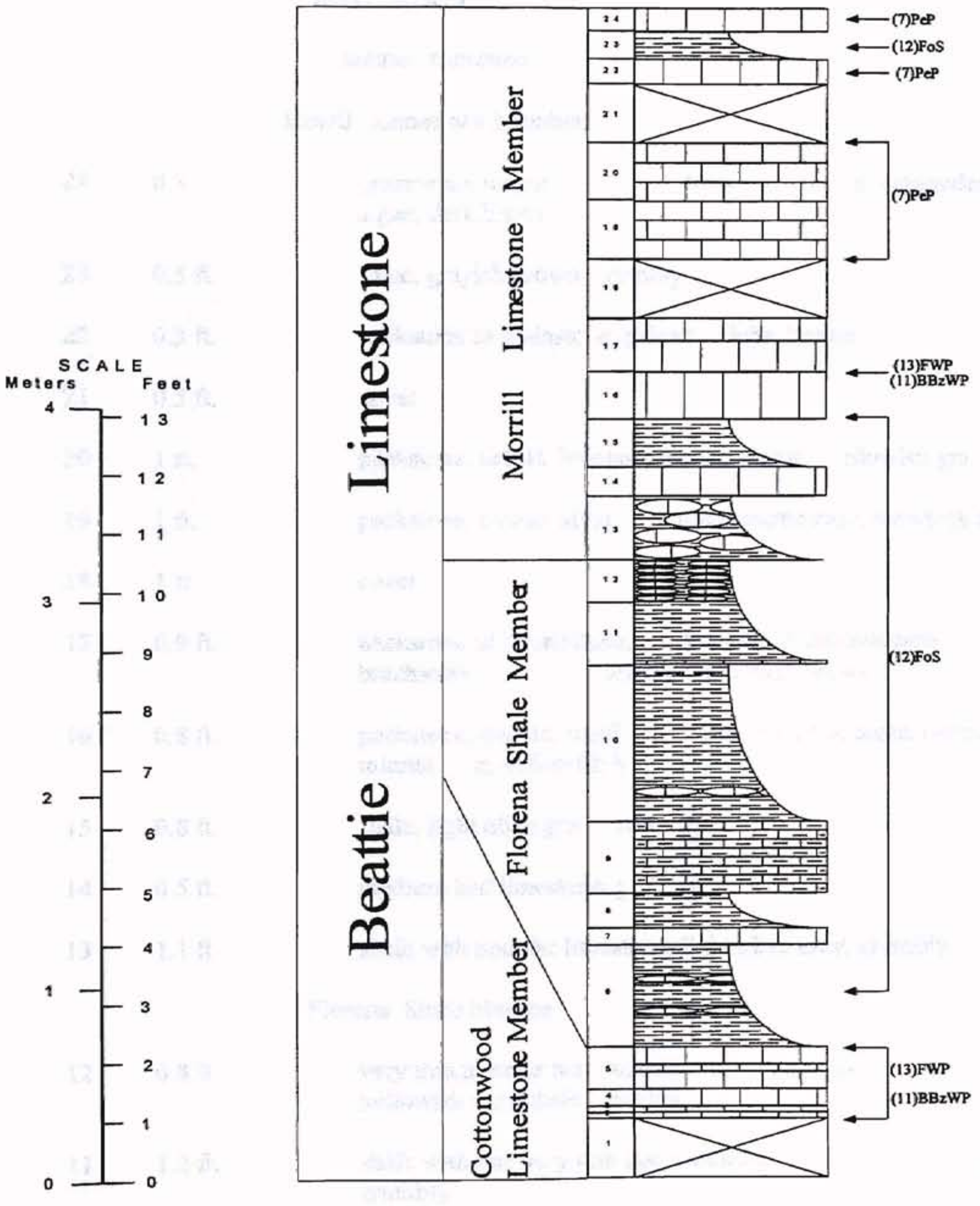


Figure 58. Measured Section SK 7, Beattie Limestone.

State: Kansas County: Cowley County

Locality Description:
Stream bank cut immediately east of Cowley County Road 7 near Hooser Kansas.
NW/4, NW/4, Section 36, T33S, R7S, R7E, Cowley County, Kansas.

UNIT DESCRIPTION

Beattie Limestone

Morrill Limestone Member

24	0.3 ft.	grainstone, oncoid, peloid, gastropods, bryzoan, echinoderms, algae, dark brown
23	0.5 ft.	shale, grayish brown, crumbly
22	0.3 ft.	packstone to grainstone, peloid, calcite, brown
21	0.5 ft.	cover
20	1 ft.	packstone, peloid, bioclasts, algae, micrite, yellowish gray
19	1 ft.	packstone, peloid, algae, bioclasts, calcite spar, brownish gray
18	1 ft.	cover
17	0.9 ft.	packstone or boundstone, oncoid, peloid, echinoderms, brachiopods, bryozoa, micrite, yellowish brown
16	0.8 ft.	packstone, oncoid, fusulinids, coral, bryozoa, algae, ostracodes, micrite, vug, yellowish brown
15	0.8 ft.	shale, light olive gray, crumbly
14	0.5 ft.	medium bed limestone, yellowish brown
13	1.1 ft.	shale with nodular limestone, light olive gray, crumbly

Florena Shale Member

12	0.8 ft.	very thin nodular bed limestone interbeded with yellowish gray shale, crumbly
11	1.2 ft.	shale with one very thin bed limestone, dusky yellow to light olive, crumbly
10	2.5 ft.	shale, light olive gray to pale olive with limestone nodular, fissile
9	1.2 ft.	thin bed limestone with shale, gray
8	0.6 ft.	shale with nodular limestone, light olive gray, crumbly

7	0.5 ft.	thin bed limestone, yellowish gray
6	1.9 ft.	shale with Nodular limestone, light olive gray crumbly

Cottonwood Limestone Member

5	0.8 ft.	wackestone, brachiopods, gastropods, fusulinids, micrite, gray to brown
4	0.3 ft.	mudstone, brachiopods, fusulinids, bryozoa, echinoderms, micrite greenish brown
3	0.1 ft.	wackestone, brachiopods, fusulinids, bryozoa, echinoderms, micrite, greenish brown
2	0.1 ft.	mudstone, brachiopods, fusulinids, bryozoa, echinoderms, recrystallized micrite, greenish gray
1	? ft.	cover

Florena
Sh

Cottonwood
Ls

Photo 123 SK-7 Cottonwood Limestone
Florena Shale

Taken at Cowley County road 7, west of Cedar Vale, Cowley County, Kansas. The lowest limestone in the photo (water level) is the upper Cottonwood Limestone, above is Florena Shale.

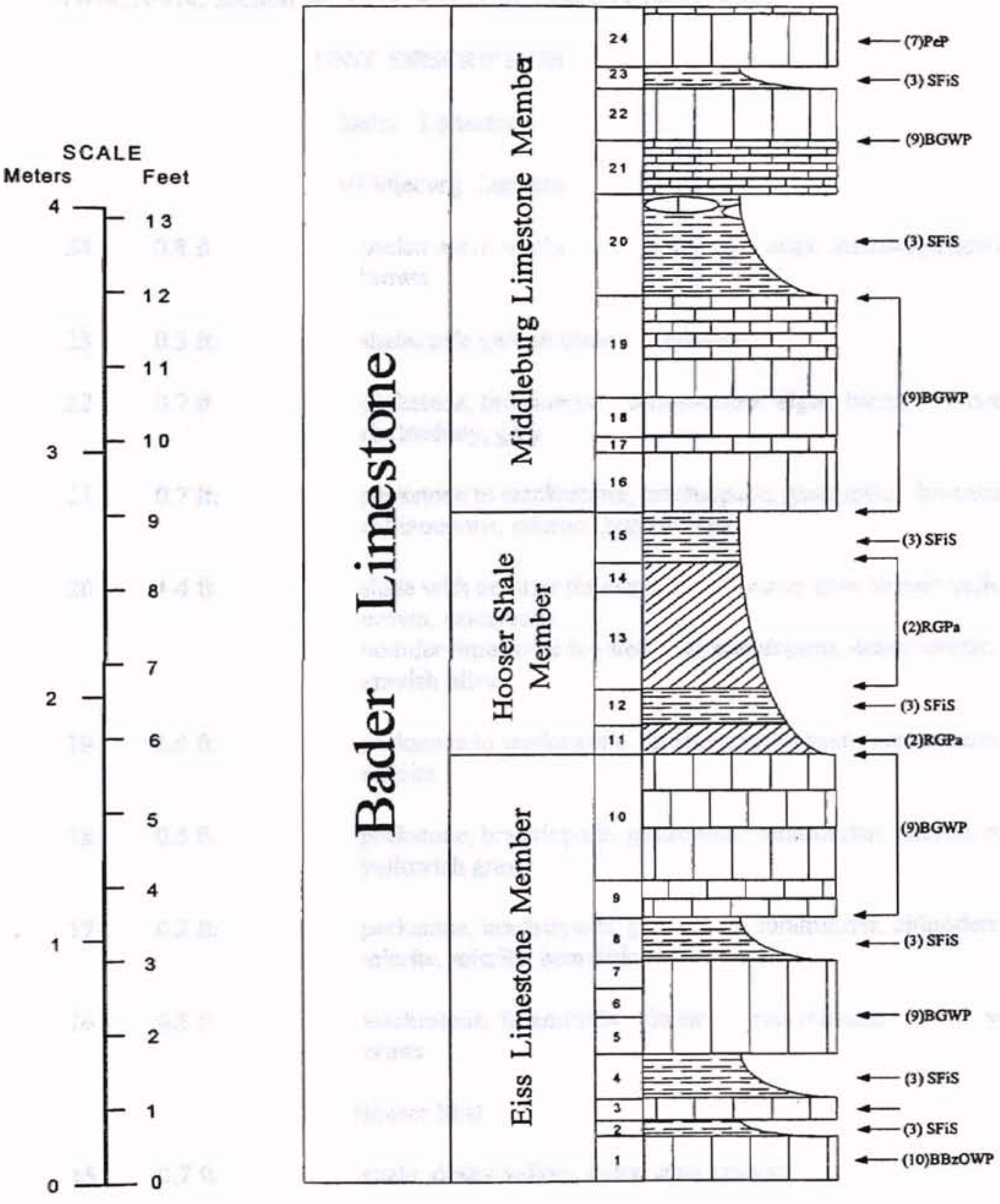


Figure 59. Measured Section SK 7, Bader Limestone.

State: Kansas County: Cowley County

Locality Description:
Stream bank cut immediately east of Cowley County Road 7 near Hooser Kansas.
NW/4, NW/4, Section 36, T33S, R7S, R7E, Cowley County, Kansas.

UNIT DESCRIPTION

Bader Limestone

Middleburg Limestone

24	0.8 ft.	packstone to wackestone, pellet, bioclastss, micrite, yellowish brown
23	0.3 ft.	shale, pale yellow brown, crumbly
22	0.7 ft.	packstone, brachiopods, echinoderms, algae, bioclastss, micrite, chalcedony, gray
21	0.7 ft.	packstone to wackestone, brachiopods, gastropods, bryozoa, echinoderms, micrite, grayish olive
20	1.4 ft.	shale with nodular limestone, light brown gray to pale yellowish brown, calcareous nodular limestone: wackestone, brachiopods, echinoderms, micrite, grayish olive
19	1.4 ft.	packstone to wackestone, oncoid, brachiopods, echinoderms, algae, micrite.
18	0.5 ft.	packstone, brachiopods, gastropods, foraminifer, micrite, dolomite, yellowish gray
17	0.2 ft.	packstone, brachiopods, gastropods, foraminifer, chinoderm, algae, micrite, micrite, hematitic
16	0.8 ft.	wackestone, foraminifer, bioclastss, recrytallized micrite, yellowish brown

Hooser Shale

15	0.7 ft.	shale, dusky yellow, calcareous , blocky
14	0.5 ft.	shale, light olive, crumbly
13	1.3 ft.	shale, light olive brown to pale olive brown, crumbly
12	0.5 ft.	shale, dusky brown, crumbly
11	0.4 ft.	shale, light olive gray, crumbly

Bader Limestone

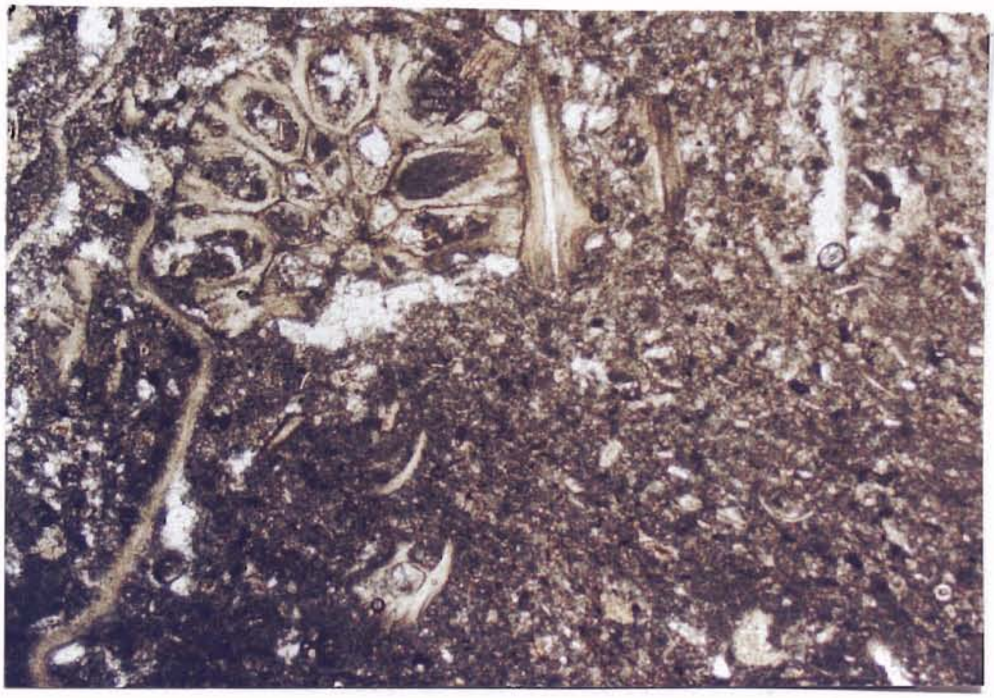
Eiss Limestone

10	1.7 ft.	wackestone, brachiopods, echinoderms, ostracodes, micrite, hematitic, brownish gray
9	0.5 ft.	packstone, brachiopods, gastropods, echinoderms, ostracodes, micrite, yellow gray
8	0.6 ft.	shale, dusky yellow, crumbly, calcareous
7	0.5 ft.	mudstone, brachiopods, bryozoa, echinoderms, hematitic, brown gray
6	0.4 ft.	wackestone, bryozoa, ostracodes, micrite, dark brown
5	0.4 ft.	packstone, oncoid, brachiopods, gastropods, bivalve, bryozoa, echinoderms, trilobites, brown purple
4	0.6 ft.	shale, yellowish gray to moderate brown, crumbly
3	0.3 ft.	packstone, brachiopods, gastropods, foraminifer, bryozoa, echinoderms, micrite, yellow gray
2	0.2 ft.	shale, light olive brown, crumbly
1	0.6 ft.	packstone to wackestone, brachiopods, bryozoa, echinoderms, ostracodes, micrite, brownish gray

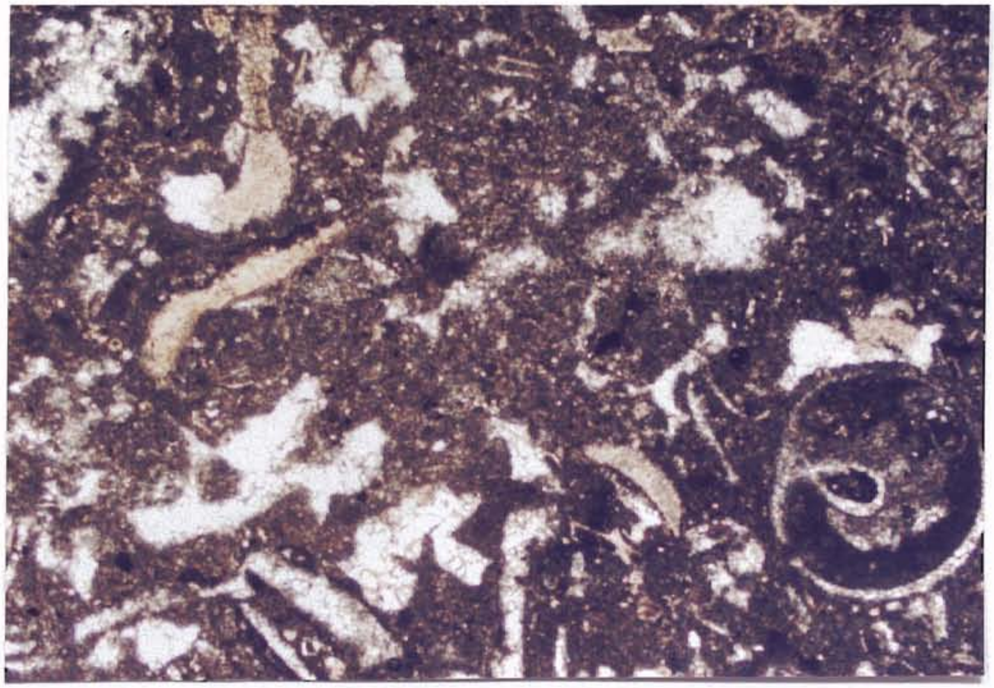
Photo 124 SK-7 Eiss Limestone
Taken at Cowley County road 7, west of Cedar Vale, Cowley County, Kansas. The Eiss Limestone is flagy and nodular limestone.

Photo 125 SK-7 Hooser Shale
Taken at Cowley County road 7, west of Cedar Vale, Cowley County, Kansas. The Hooser Shale is light olive to light olive brown, blocky to crumbly mudstones.

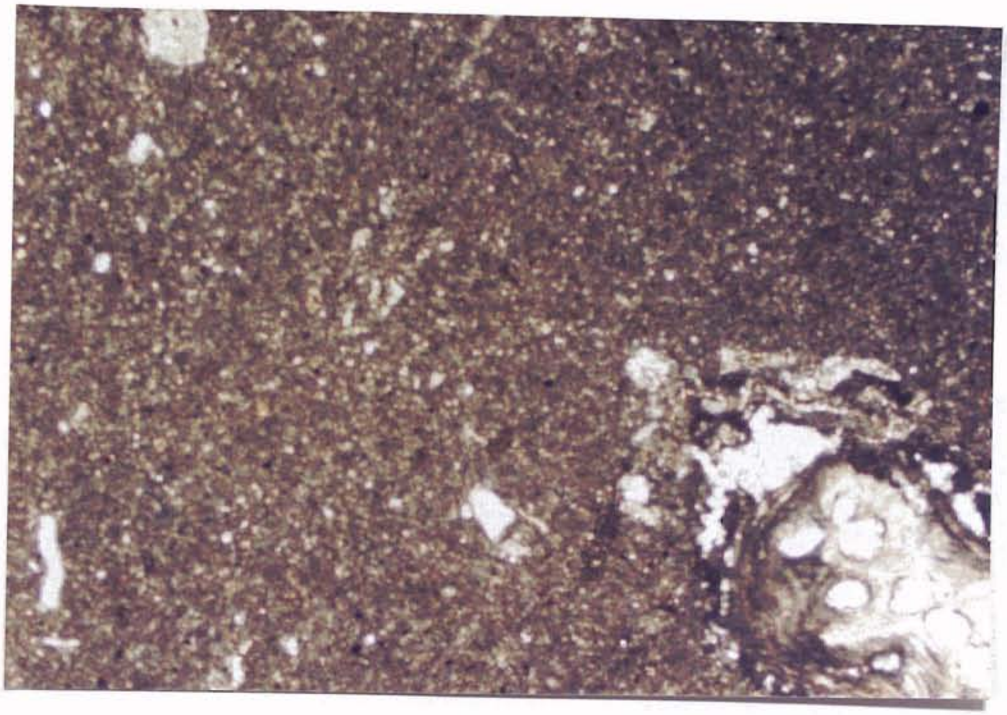
Photo 126 SK-7 Middleburg Limestone
Taken at Cowley County road 7, west of Cedar Vale, Cowley County, Kansas. The Middleburg Limestone is flagy or thin-bedded limestone.



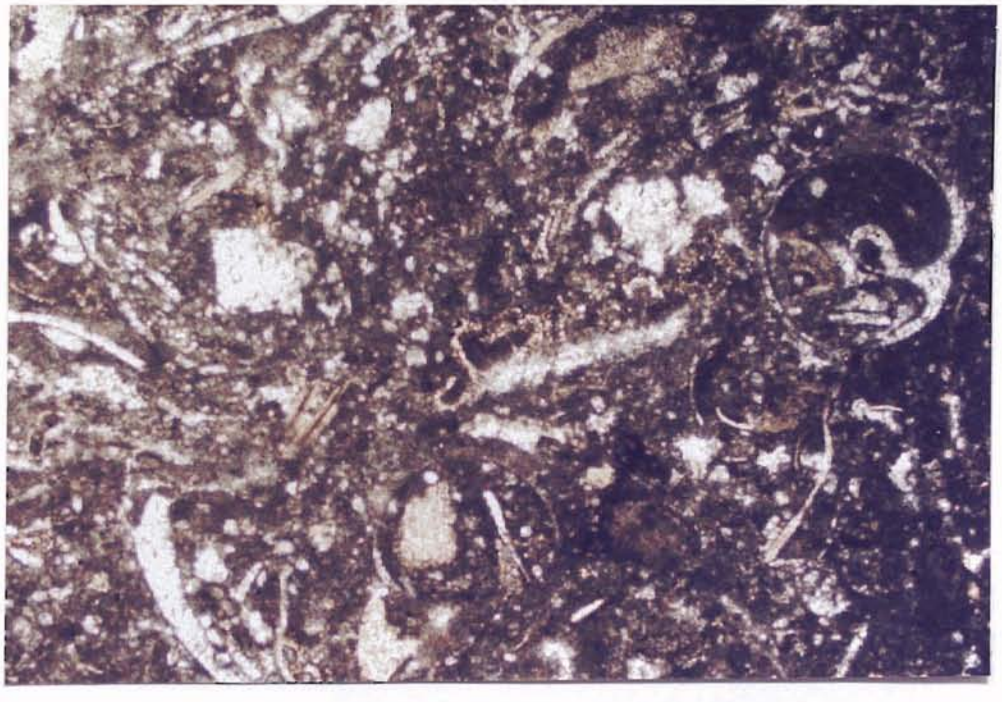
Photograph 127, SK-7, Eiss Limestone Member, Unit: 1
wackestone, bryozoan, algae, micrite.



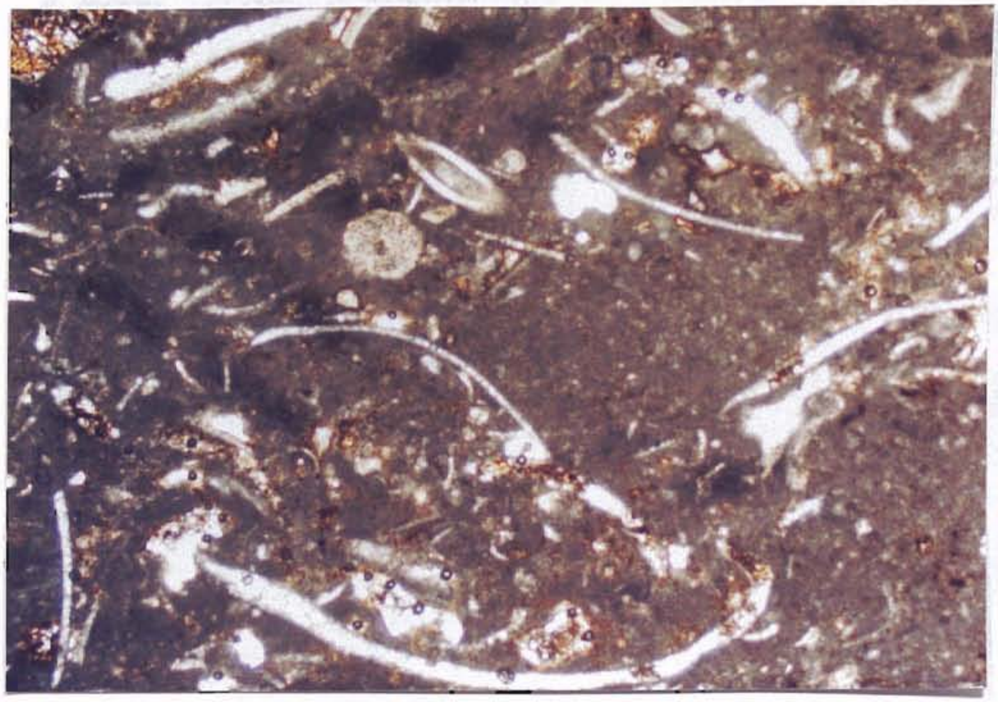
Photograph 128, SK-7, Eiss Limestone Member, Unit: 5
wackestone, gastropod, echinoderm, bioclast, micrite.



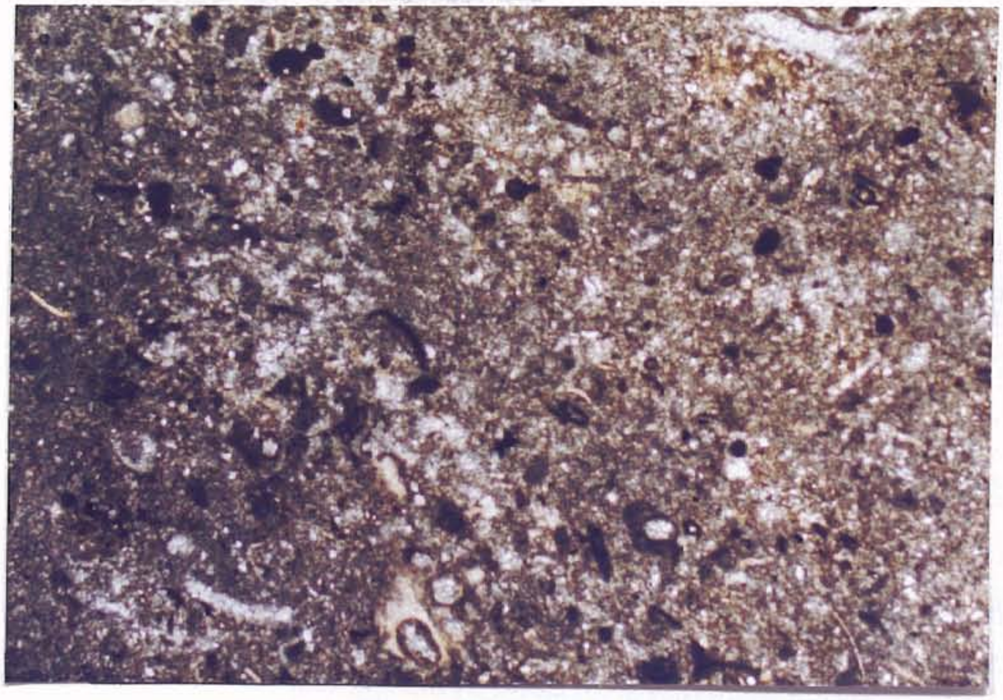
Photograph 129, SK-7, Eiss Limestone Member, Unit: 7
mudstone, bryozoan, micrite.



Photograph 130, SK-7, Eiss Limeston, Unit: 9
packstone, gastropod, echinoderm, bioclast, micrite.

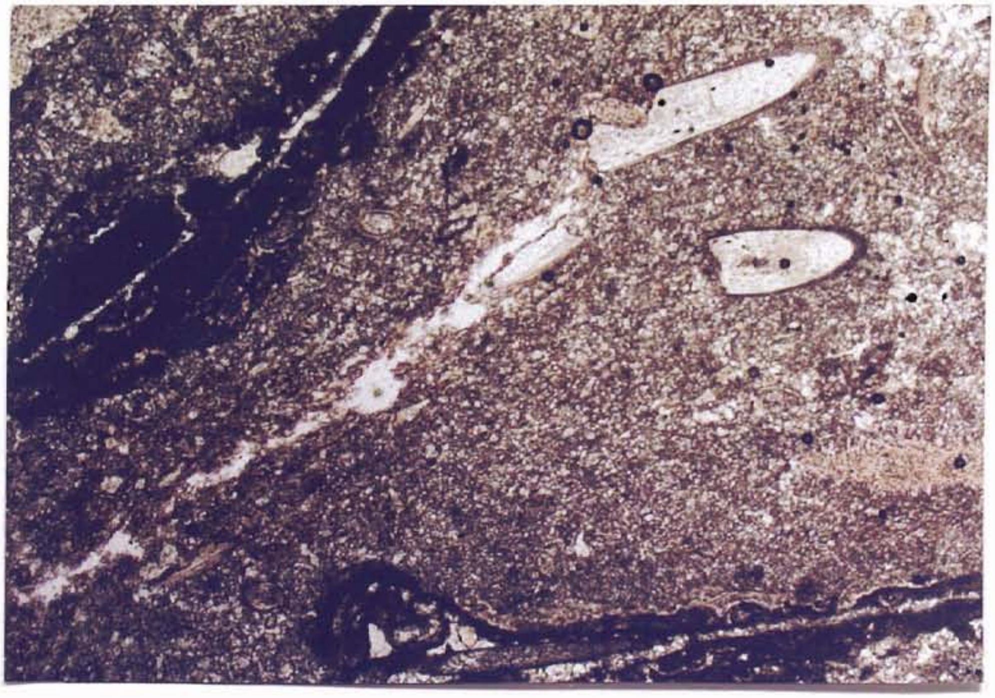


Photograph 131, SK-7, Eiss Limestone Member, Unit: 10
wackestone, brachiopod, echinoderm, ostracode, micrite.

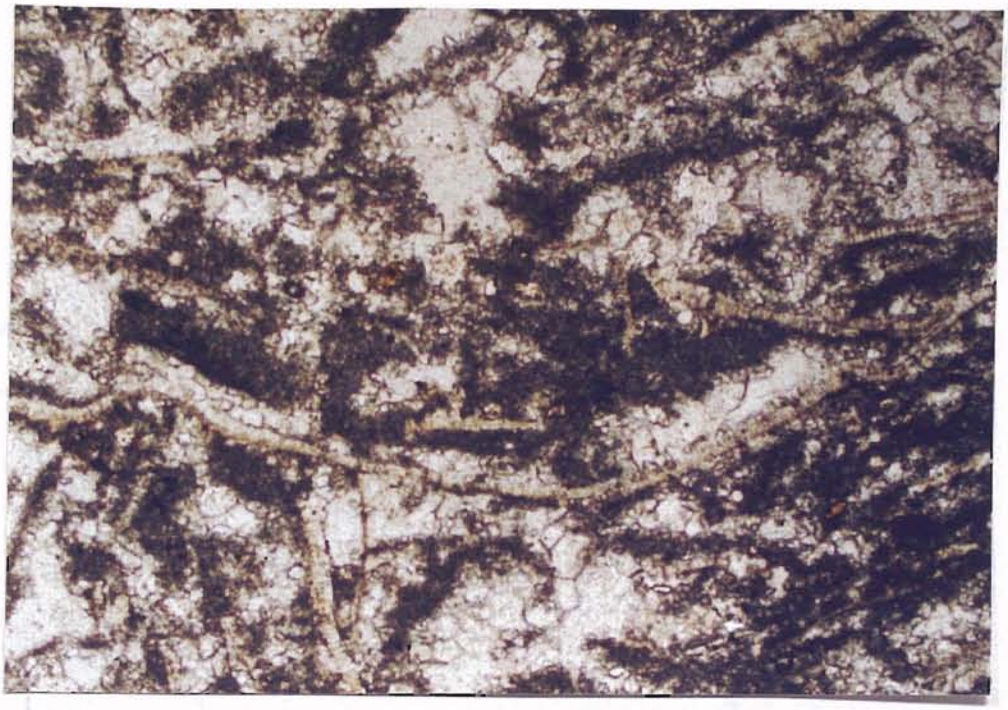


Photograph 132, SK-7, Middleburg Limestone Member, Unit: 16
Mustone, bryozoan, algae, micrite..

Photograph 133, SK-7, Middleburg Limestone Member, Unit: 17
packstone, brachiopod, gastropod, echinoderm, micrite.



Photograph 134, SK-7, Middleburg Limestone Member, Unit: 20
wackestone, trilobite, oncoid, echinoderm, micrite.



Photograph 135, SK-7, Middleburg Limestone Member, Unit: 24
wackestone, bioclast, algae, micrite.

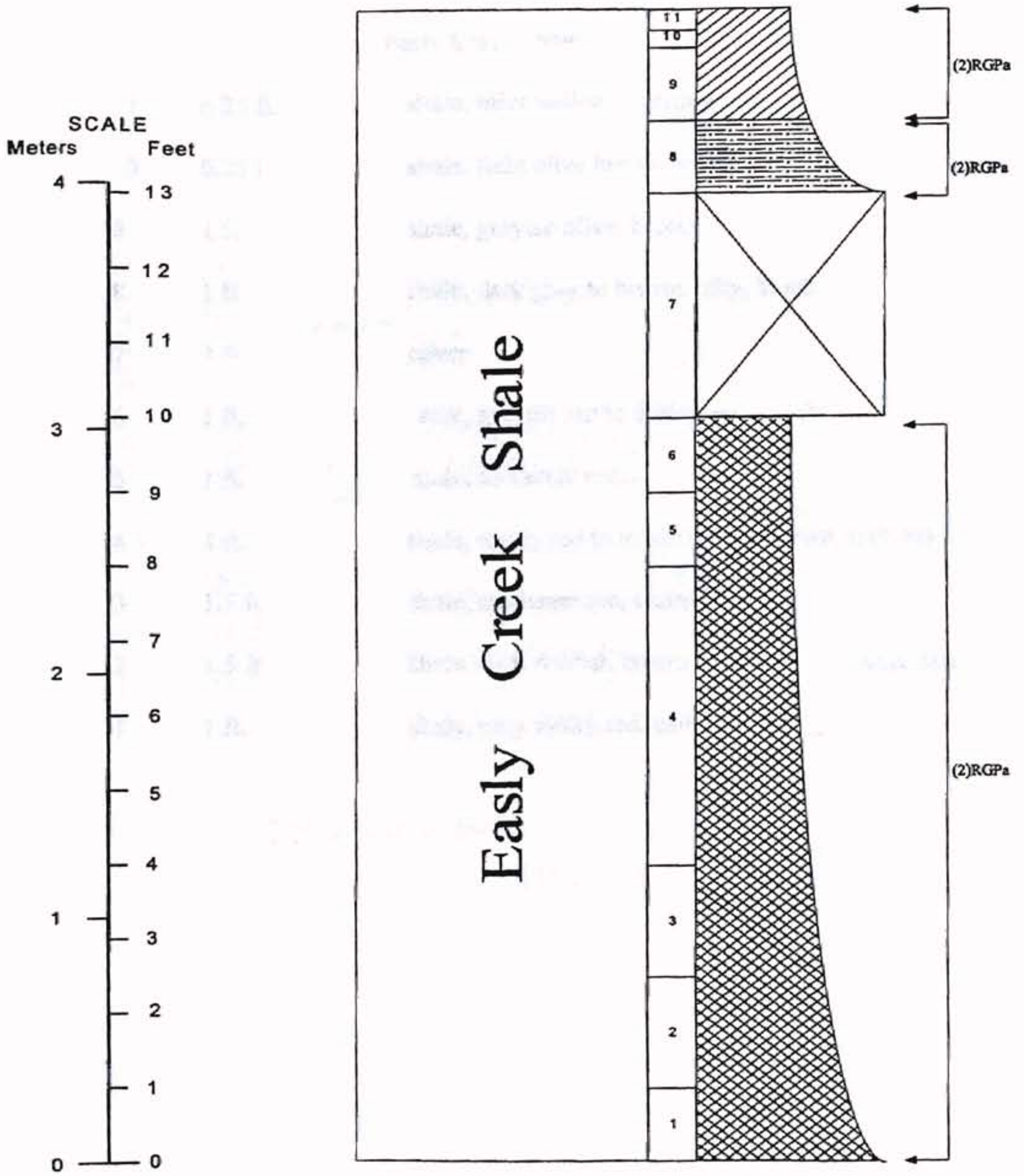


Figure 60. Measured Section SK 7, Easly Creek Shale.

State: Kansas   County: Cowley County

Locality Description:
Stream bank cut immediately east of Cowley County Road 7 near Hooser Kansas.
NW/4, NW/4, Section 36, T33S, R7S, R7E, Cowley County, Kansas.

UNIT DESCRIPTION

Easly Creek Shale

11	o.25 ft.	shale, olive yellow, crumbly
10	0.25 ft.	shale, light olive brown, blocky
9	1 ft.	shale, grayish olive, blocky
8	1 ft.	shale, dark gray to brown, silty, blocky
7	3 ft.	cover
6	1 ft.	shale, grayish red to dusky red, crumbly
5	1 ft.	shale, moderate red, crumbly
4	4 ft.	shale, dusky red to moderate red brown, crumbly
3	1.5 ft.	shale, moderate red, crumbly
2	1.5 ft.	shale, dark reddish brown to dark red, caliche,. crumbly,
1	1 ft.	shale, very dusky red, caliche, crumbly

Photo 136 SK-7 Easly Creek Shale
Taken at Cowley County road 7, west of Cedar Vale, Cowley County, Kansas. The lower Easly Creek Shale is red shale above limestone ledge (Middleburg Limestone).

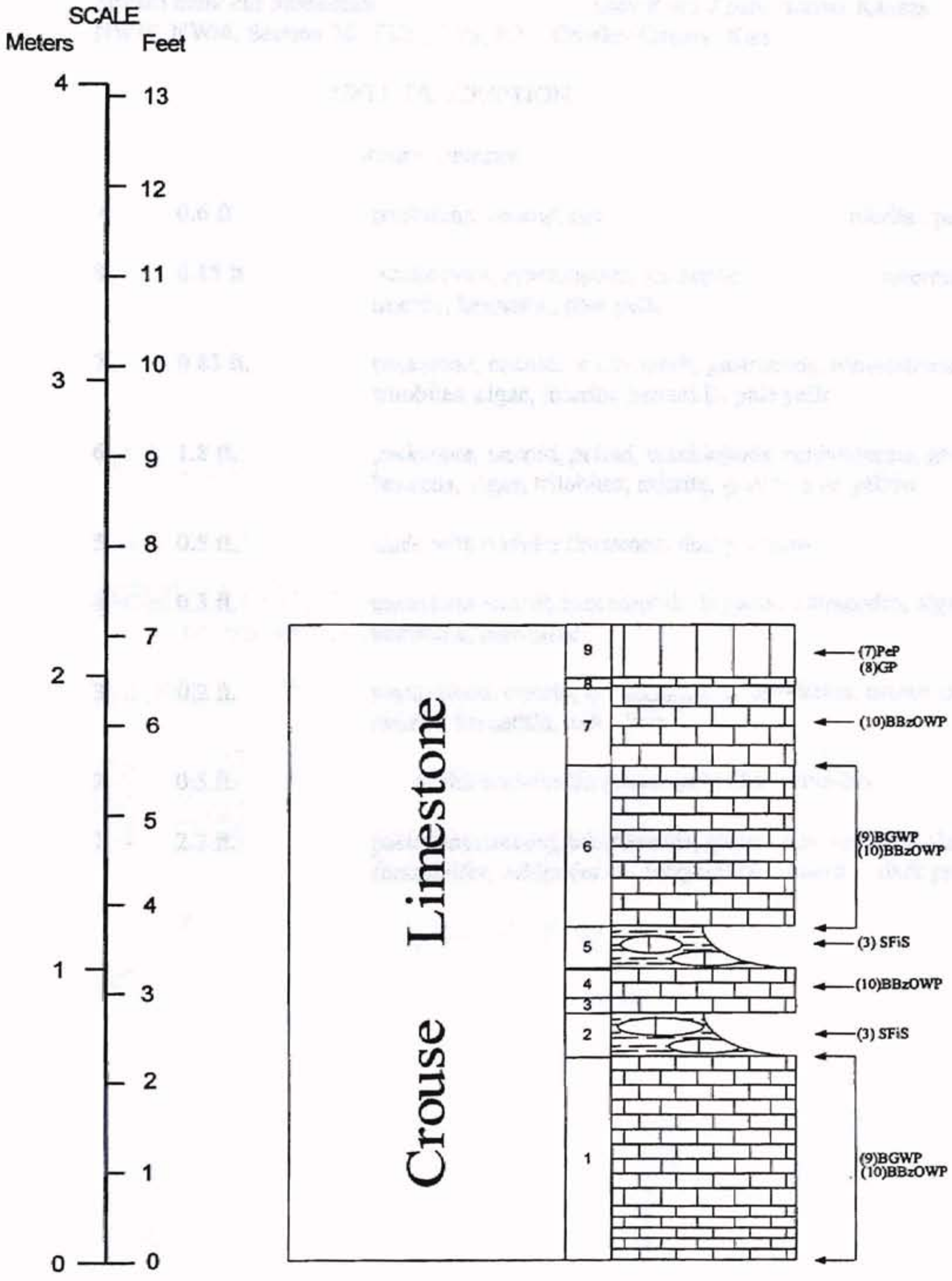


Figure 61. Measured Section SK 7, Crouse Limestone.

State: Kansas County: Cowley County

Locality Description:
Stream bank cut immediately east of Cowley County Road 7 near Hooser Kansas.
NW/4, NW/4, Section 36, T33S, R7S, R7E, Cowley County, Kansas.

UNIT DESCRIPTION

Crouse Limestone

9	0.6 ft.	packstone, oncoid, peloid, gastropods, algae, micrite., pale yellow
8	0.15 ft.	wackestone, brachiopods, gastropods, coral, echinoderms, algae, micrite, hematitic, pale yellow
7	0.85 ft.	packstone, oncoid, brachiopods, gastropods, echinoderms, trilobites, algae, micrite, hematitic, pale yellow
6	1.8 ft.	packstone, oncoid, peloid, brachiopods, echinoderms, gastropods, bryozoa, algae, trilobites, micrite, gray or pale yellow
5	0.5 ft.	shale with nodular limestone, dusky yellow
4	0.3 ft.	packstone oncoid, brachiopods, bryozoa, ostracodes, algae, micrite, hematitic, pale olive
3	0.2 ft.	wackestone, oncoid, brachiopods, echinoderms, ostracodes, algae, micrite, hematitic, pale olive
2	0.5 ft.	shale with nodular limestone, pale olive, crumbly
1	2.2 ft.	packstone, oncoid, brachiopods, gastropods, bryozoa, algae, foraminifer, echinoderms, recrystallized micrite, dark gray to gray

Photo 137 SK-7 Crouse Limestone
Taken at Cowley County road 7, west of Cedar Vale, Cowley County, Kansas. The middle part of the Crouse Limestone is very thin to medium bedded limestones with wheathering vugs.

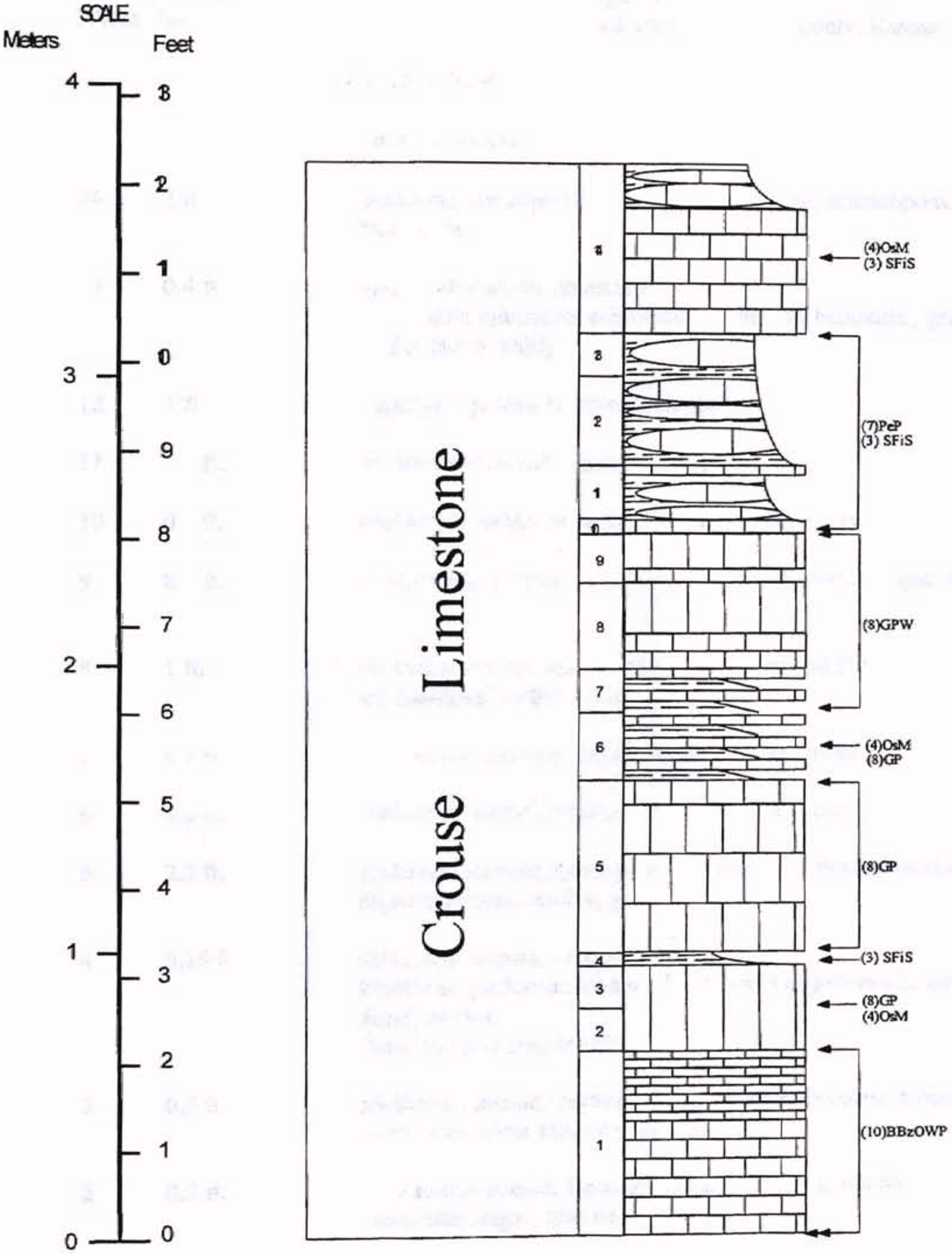


Figure 62. Measured Section SK 166, Crouse Limestone.

State: Kansas County: Cowley County

Locality Description:
Roadcut on north side of west bound lane of US Highway 166.
NW/4, Section 30, T32S, R8E, Dexter NE 7.5' Quadrangle, Cowley County, Kansas.

UNIT DESCRIPTION

Crouse Limestone

14	2 ft.	mudstone, gastropods, bryozoa, echinoderms, brachiopods, algae, micrite, reddish gray
13	0.4 ft.	shale with nodular limestone, Limestone: mudstone, echinoderms, micrite, hematitic , gray Shale: red, crumbly
12	1 ft.	packstone, peloid, micrite, dark gray
11	0.6 ft.	wackestone, peloid, algae, micrite, gray
10	0.2 ft.	packstone, peloid, ostracodes, algae, micrite, gray
9	0.6 ft.	wackestone, gastropods, foraminifer, echinoderms, algae, micrite, gray
8	1 ft.	packstone oncoid, gastropods, foraminifer, ostracodes, echinoderms, micrite, gray
7	0.5 ft.	wackestone, gastropods, echinoderms, ostracodes, micrite, gray
6	0.8 ft.	packstone, peloid, echinoderms, ostracodes, gray
5	2.2 ft.	packstone, oncoid, gastropods, foraminifer, bryozoa, echinoderms, algae, trilobites, micrite, gray
4	0.15 ft.	shale with nodular limestone limestone: packstone, oncoid, brachiopods, gastropods, foraminifer, algae, micrite, shale: reddish gray crumbly
3	0.5 ft.	packstone, oncoid, gastropods, foraminifer, bryozoa, trilobites, ostracodes, algae micrite dark gray
2	0.5 ft.	wackestone oncoid, foraminifer, echinoderms, trilobites, ostracodes, algae, micrite reddish gray
1	2.1 ft.	wackestone, oncoid, brachiopods, gastropods, foraminifer, bryozoa, echinoderms, trilobites, ostracodes, algae, micrite, reddish gray to gray

Photo 138 SK-166 Crouse Limestone
Taken along Highway 166 west of Cedar Vale, Cowley County, Kansas. Hammer sets on the basal Crouse Limestone, below is the Easly Creek Shale.

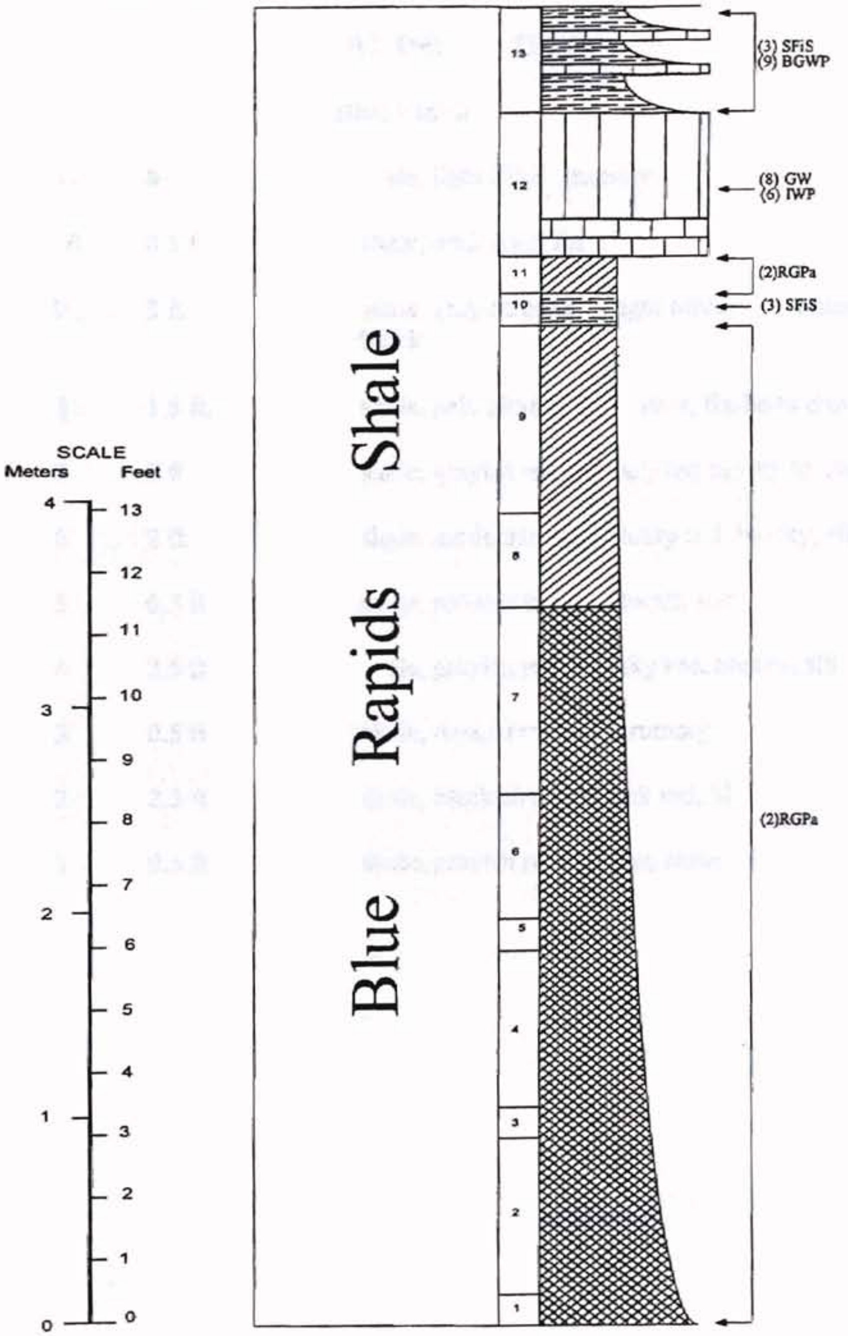


Figure 63. Measured Section SK 166-2, Blue Rapids Shale.

State: Kansas County: Cowley County

Locality Description:
Roadcut on north side of west bound lane of US Highway 166.
NW/4, Section 30, T32S, R8E, Dexter NE 7.5' Quadrangle, Cowley County, Kansas.

UNIT DESCRIPTION

Blue Rapids shale

11	0.6 ft.	shale, light olive, crumbly
10	0.5 ft.	shale, dark gray, fissile
9	3 ft.	shale, grayish olive to light olive gray, crumbly to fissile and blocky
8	1.5 ft.	shale, pale olive to light olive, fissile to crumbly
7	3 ft.	shale, grayish red to dusky red blocky to crumbly and fissile
6	2 ft.	shale, moderate red to dusky red, blocky, silty
5	0.5 ft.	shale, reddish brown, blocky, silty
4	2.5 ft.	shale, grayish red to dusky red, blocky, silty
3	0.5 ft.	shale, dusky red, silty, crumbly
2	2.5 ft.	shale, blackish red to dark red, blocky, silty
1	0.5 ft.	shale, grayish red, caliche, crumbly

Photo 139 SK-166 Blue Rapids Shale
Taken along Highway 166 west of Cedar Vale, Cowley County, Kansas. The Blue Rapids Shale is crumbly or blocky mudstones below the Funston Limestone (the upper limestone ledge in photo).

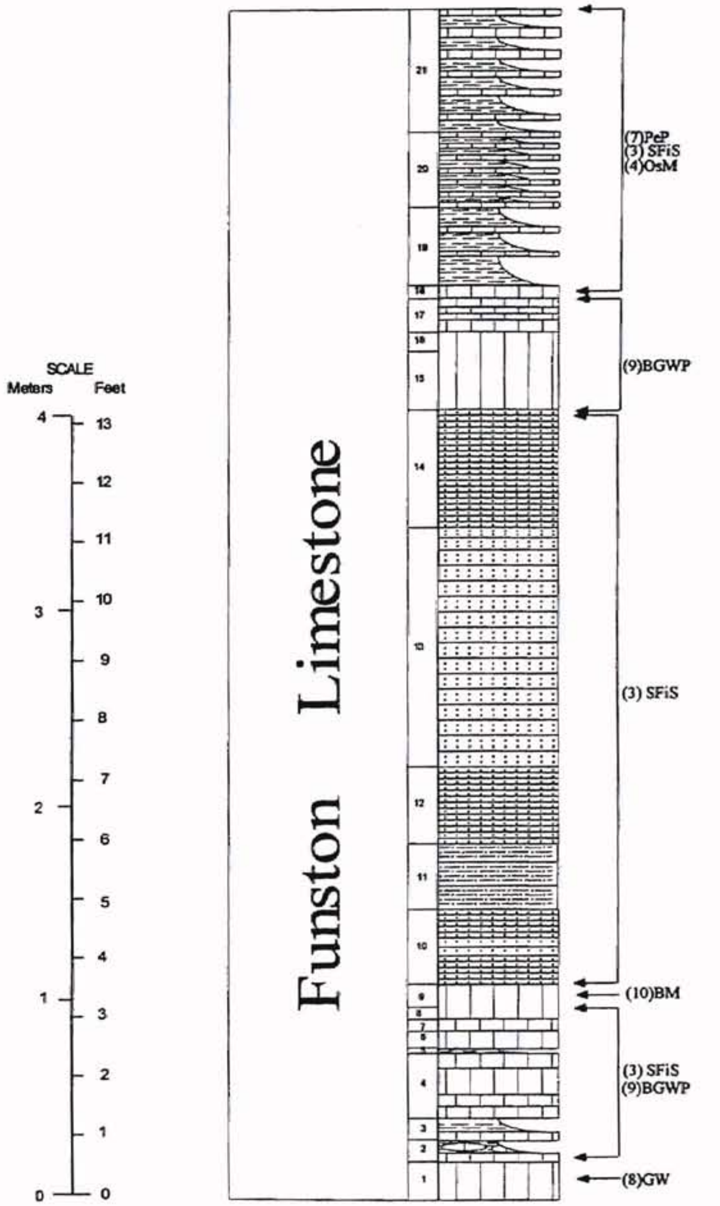


Figure 64. Measured Section SK 166-2&3, Funston Limestone.

State: Kansas County: Cowley County

Locality Description:
Lower part of Funston- Roadcut on north side of west bound lane of US Highway 166.
NW/4, Section 30, T32S, R8E, Dexter NE 7.5' Quadrangle, Cowley County, Kansas.
Upper part of Funston-Roadcut on US Highway 166
C/N2, Section 12, T34S, R6E, Dexter SW 7.5' Quadrangle, Cowley County, Kansas

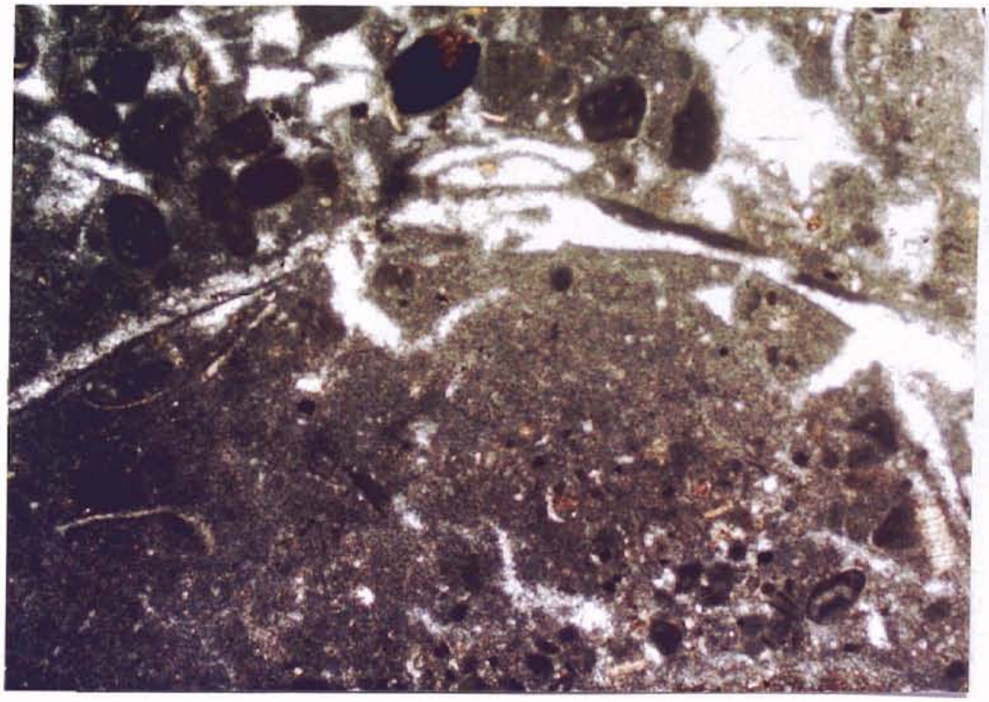
UNIT DESCRIPTION

Funston Limestone

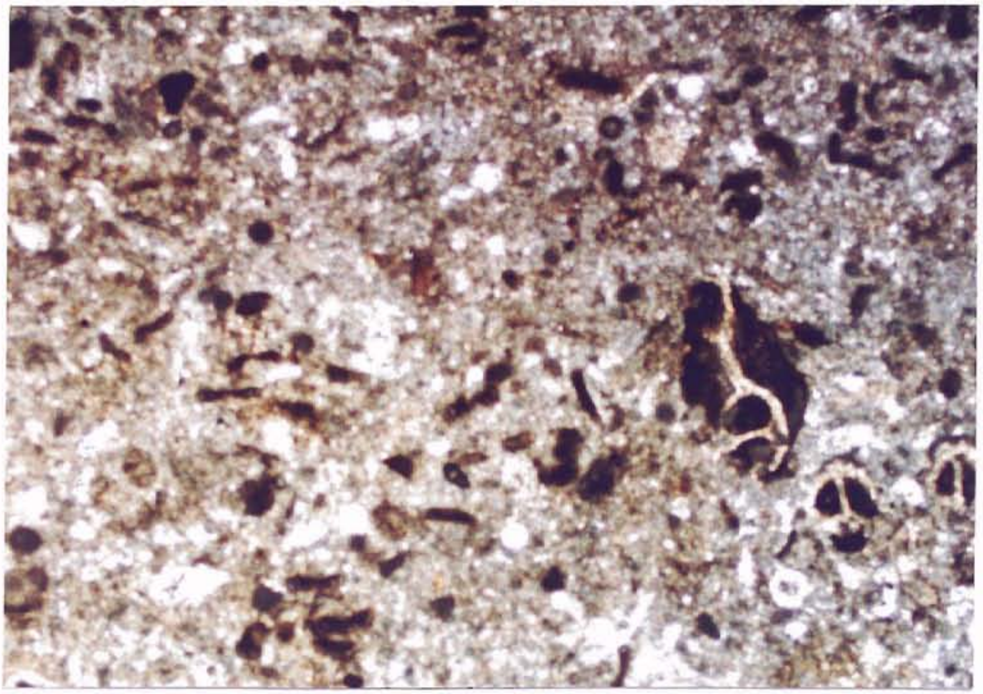
23	2.1 ft.	limestone interbeded with shale limestone: mudstone, peloid, micrite shale: reddish gray, crumbly
22	1.2 ft.	limestone interbeded with shale limestone(bottom): wackestone, peloid, ostracodes, algae, micrite, hematitic, gray limestone (top): mudstone, ostracodes, micrite, hematitic, reddish gray shale: red crumbly
21	1.3 ft.	shale interbeded with 2 limestone shale: grayish red fissile limestone (bottom): wackestone, peloid, intraclasts, ostracodes, micrite, gray limestone (top): mudstone, boring, micrite, gray
20	0.2 ft.	mudstone, peloid, trilobites, micrite, yellowish gray
19	0.6 ft.	wackestone, oncoid, brachiopods, bryozoa, bivalve, trilobites, ostracodes, micrite, algae, hematitic, silica, reddish gray to greenish gray
18	0.3 ft.	wackestone, oncoid, brachiopods, bivalve, bryozoa, algae, micrite, reddish gray
17	1 ft.	packstone, oncoid, brachiopods, gastropods, trilobites, algae, micrite, reddish brown
16	2 ft.	sandstone,very fine grain, olive brown
15	4 ft.	sandstone interbeded with shale,very fine grain, olive brown
14	1.3 ft.	sandstone,very fine grain, dark orange
13	1.1 ft.	sandy siltstone, dark olive
12	1.3 ft.	sandstone,very fine grain, greenish gray to dark olive
11	0.35 ft.	mudstone, brachiopods, micrite, gray
10	0.2 ft.	wackestone, brachiopods, bryozoa, ostracodes, micrite, gray

9	0.2 ft.	mudstone, brachiopods, bryozoa, trilobites ostracodes, micrite, yellowish gray
8	0.3 ft.	wackestone, mud pellet, brachiopods, bryozoa, echinoderms, trilobites, algae, micrite, yellowish gray
7	0.05 ft.	shale with nodular limestone, ght olive gray, crumbly
6	1.1 ft.	wackestone, brachiopods, bryozoa, coral, ostracodes, algae, micrite, hematitic, yellow olive gray to olive gray
5	0.4 ft.	shale and limestone limestone: mudstone, brachiopods, bryozoa, echinoderms, trilobites, algae, hematitic, yellowish shale: gray olive, crumbly
4	0.4 ft.	shale with nodular limestone and limestone limestone: wackestone, brachiopods, bryozoa, algae, micrite, yellowish brown shale : moderate olive brown shale, crumbly
3	0.65 ft.	wackestone, gastropods, ostracodes, algae, micrite, yellowish brown
2	1.3 ft.	shale interbedded with limestone limestone: wackestone, brachiopods, gastropods, ostracodes, inclast, algae, micrite, gray shale: moderate olive, brown, fissile
1	2.3 ft.	wackestone, mud pellet, gastropods, intraclasts, ostracodes, algae, micrite, gray

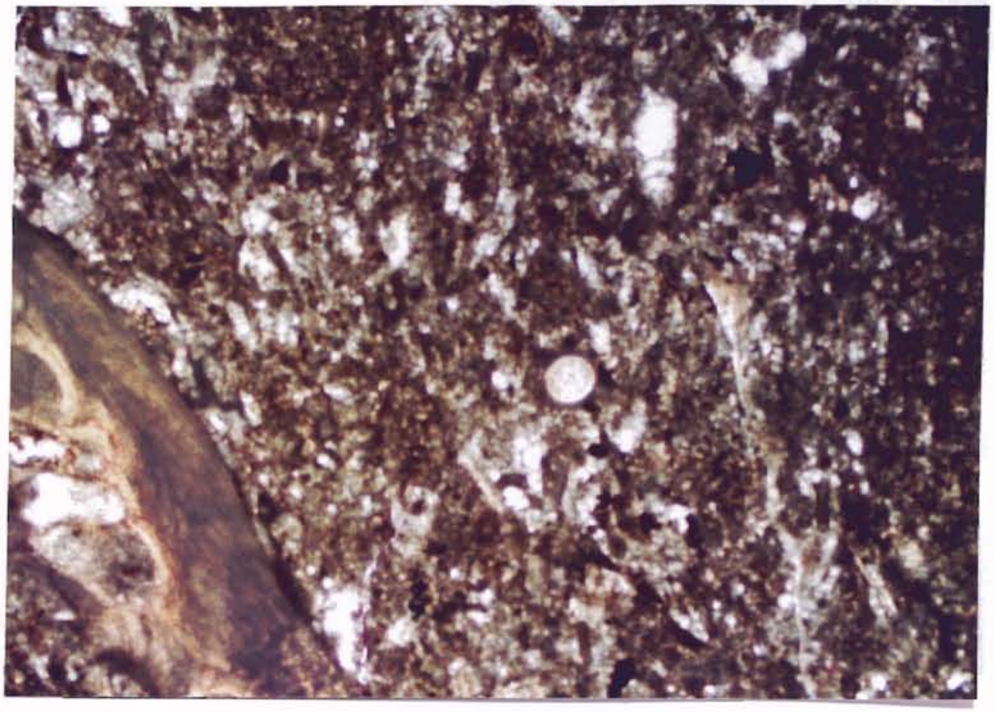
Photo 140 SK-166 Funston Limestone
Taken along Highway 166 west of Cedar Vale, Cowley County, Kansas. The lower Funston Limestone is thick to thin-bedded limestones.



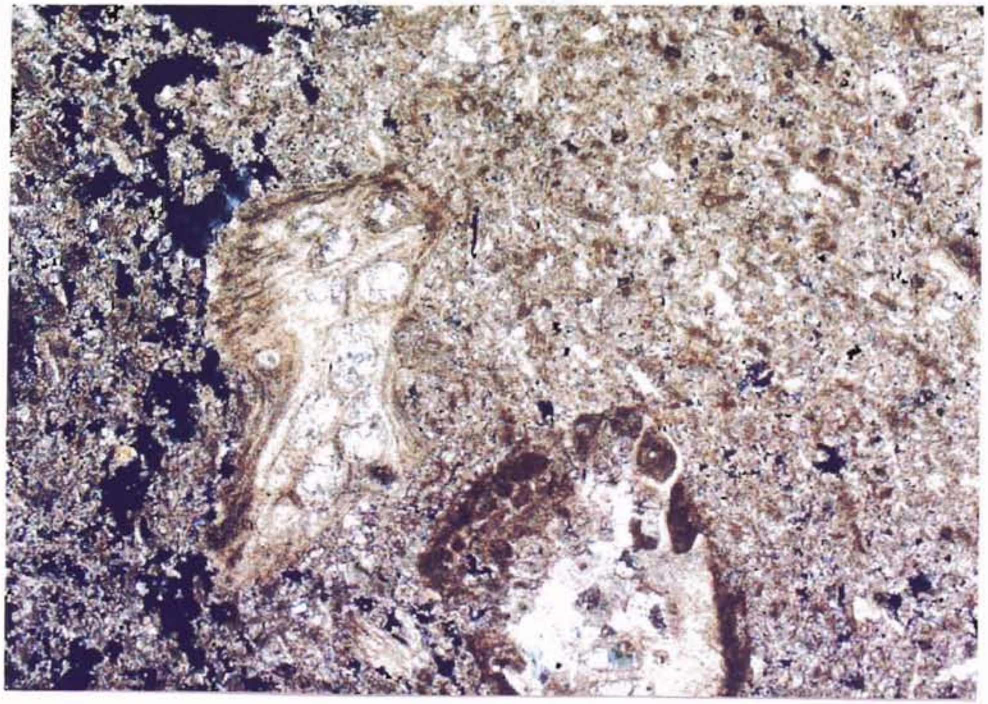
Photograph 141, SK-38, Funston Limestone, Unit: 1
wackestone, intraclast, bioclast, micrite.



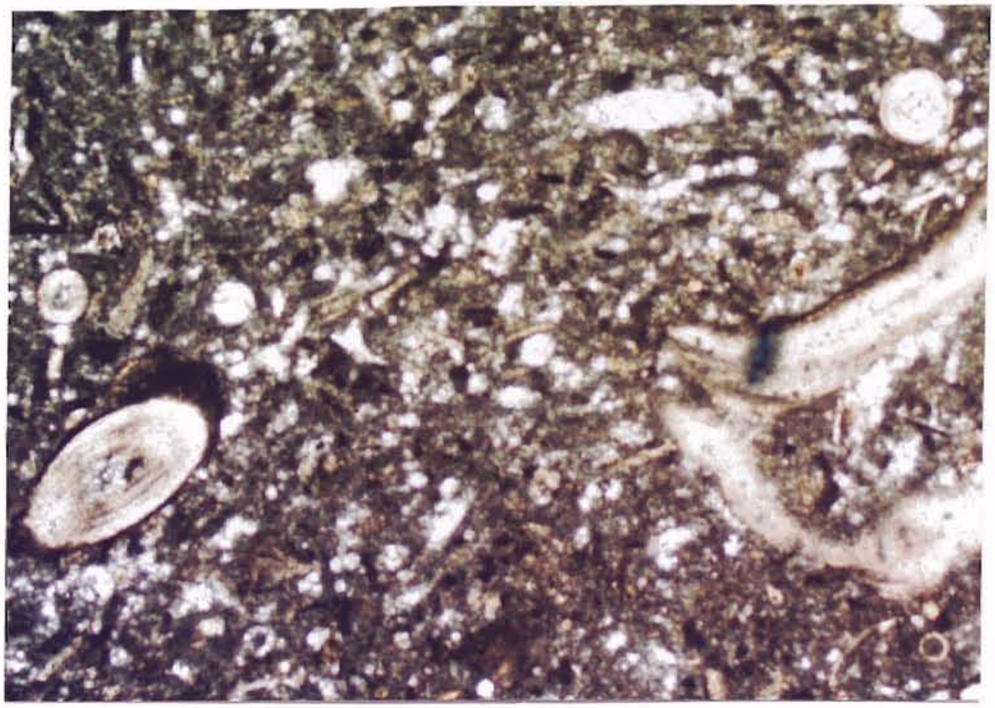
Photograph 142, SK-166, Funston Limestone, Unit: 3
wackestone, bryozoan, algae, micrite.



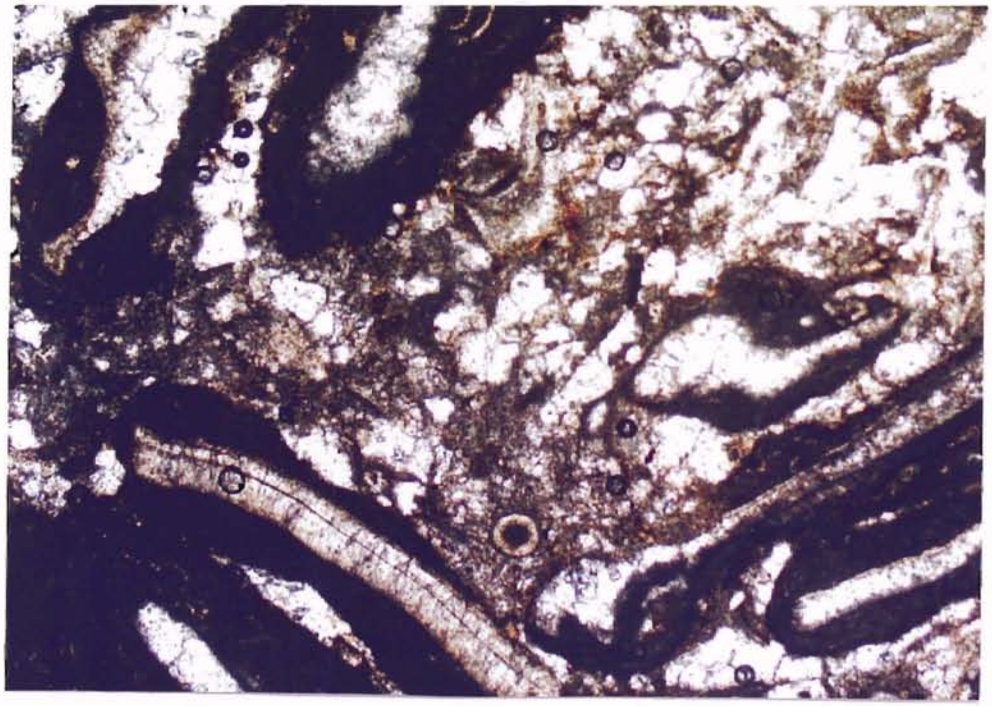
Photograph 143, SK-166, Funston Limestone, Unit: 4
wackestone, bryozoan, micrite.



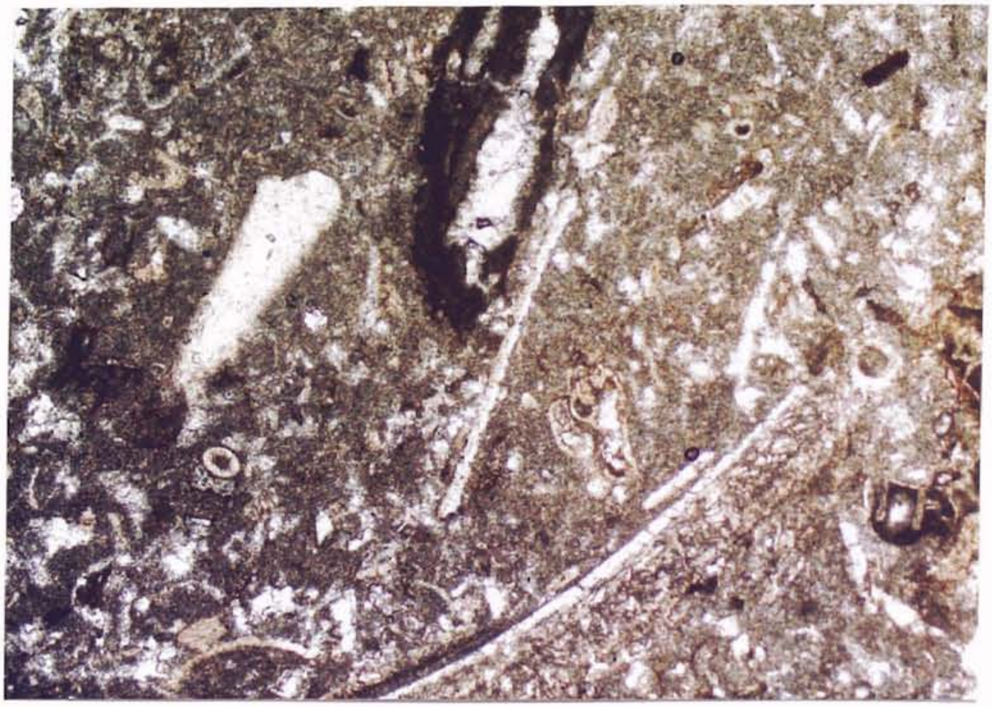
Photograph 144, SK-166, Funston Limestone, Unit: 17
wackestone, bryozoan, micrite,



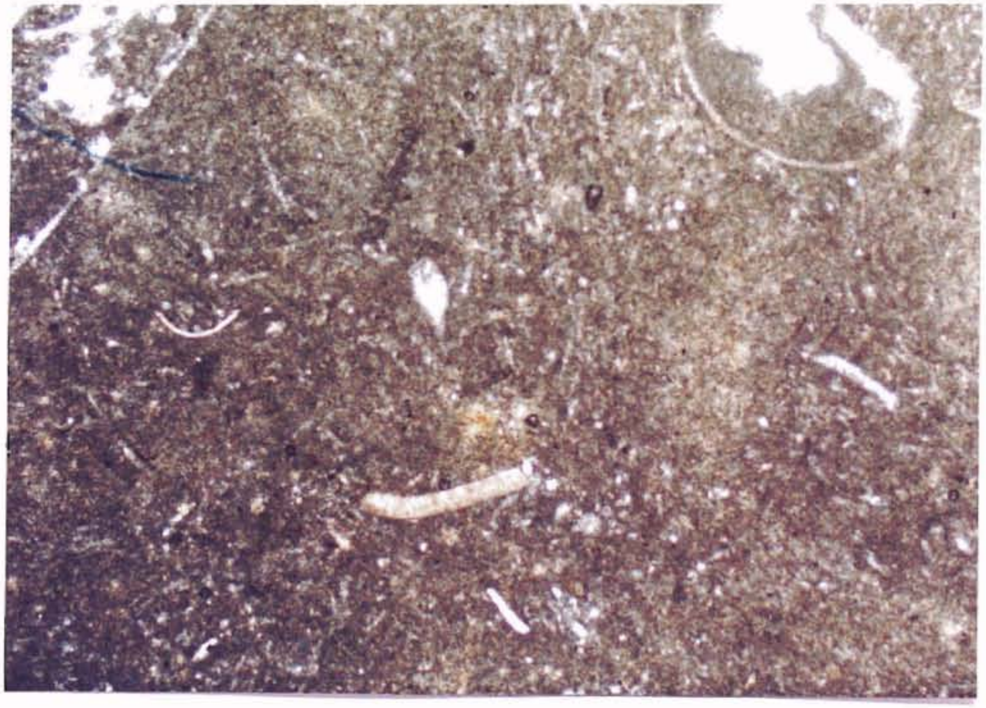
Photograph 145, SK-166, Funston Limestone, Unit: 10
wackestone, trilobite, micrite..



Photograph 146, SK-166, Funston Limestone, Unit: 17
packstone, oncoid, micrite.



Photograph 147, SK-166, Funston Limestone, Unit: 19
wackestone, oncoid, bryozoan, bioclast, micrite.



Photograph 148, SK-166, Funston Limestone, Unit: 22
mudstone, ostracode, bioclast, micrite.

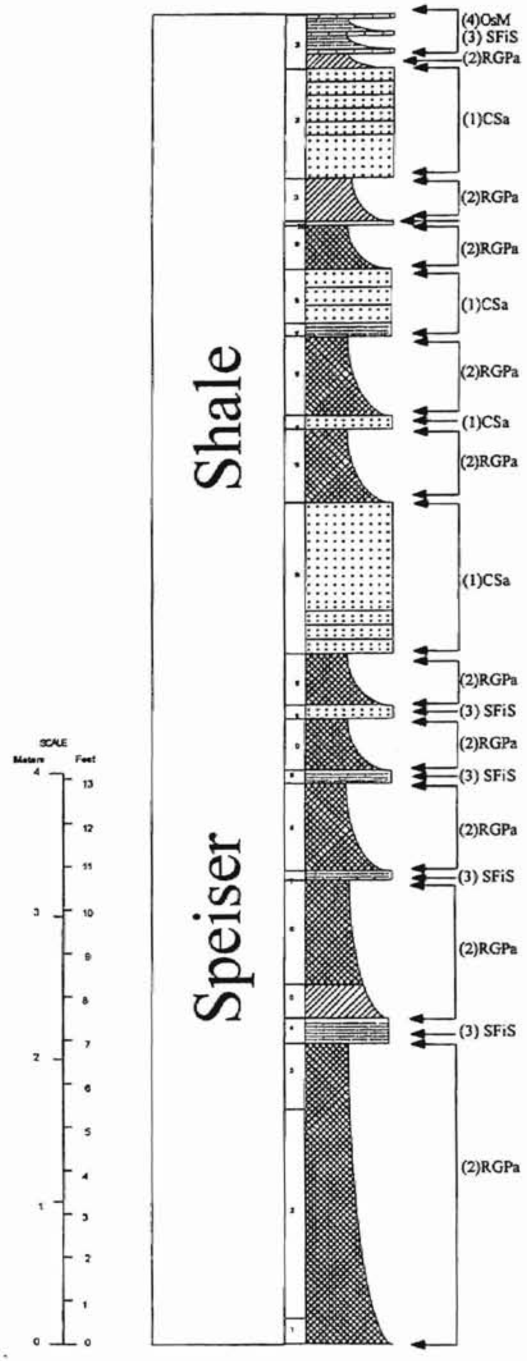


Figure 65. Measured Section SK 166-3, Speiser Shale.

State: Kansas County: Cowley County

Locality Description:
Roadcut on US Highway 166
C/N2, Section 12, T34S, R6E, Dexter SW 7.5' Quadrangle, Cowley County, Kansas

UNIT DESCRIPTION

Speiser Shale

23	1.3 ft.	limestone interbeded with shale limestone: very thin bed, light olive gray shale: greenish gray to grayish black, silty, crumbly
22	2.5 ft.	sandstone, very fine grain, cross bedding, light olive to pale yellow
21	1 ft.	shale, light olive to pale olive, silty, crumbly
20	0.2 ft.	sandstone, very fine grain, cross bedding, light olive
19	1 ft.	shale, dusky red, silty, crumbly, caliche
18	1.2 ft.	sandstone, very fine grain, cross bedding, pale yellowish gray to reddish gray
17	0.5 ft.	sandy siltstone, olive red
16	1.6 ft	shale, dusky red, silty, crumbly
15	0.3 ft.	sandstone, very fine grain, cross bedding, light olive
14	1.7 ft.	shale, dusky red to very dusky red, silty, crumbly
13	3.5 ft.	sandstone, very fine grain, cross bedding, light grayish red to reddish red
12	1.2 ft.	shale, dusky red, blocky, silty
11	0.3 ft.	sandstone, grayish red
10	1.2 ft.	shale, very dusky red, silty, blocky
9	0.3 ft.	sandy, siltstone, dark reddish brown
8	2 ft.	shale, dusky red, silty, blocky,
7	0.2 ft.	sandy siltstone, grayish red
6	2.5 ft. ft.	shale, very dusky red to dark reddish brown, silty, blocky to crumbly, caliche at top
5	0.75 ft.	shale, greenish black, silty, blocky
4	1.2 ft.	shale, grayish black, silty, blocky to crumbly

3	1.5 ft.	shale, dark grayish red, silty, blocky
2	4.8 ft.	shale, dusky red to very dark red, silty blocky
1	0.6 ft.	shale, very dusky red, silty, crumbly

Photo 149 SK-166 Speiser Shale

Taken along Highway 166 west of Cedar Vale, Cowley County, Kansas. The Speiser Shale at this locality contains silty red and green shale and channelized sandstone lense.

Sequence Stratigraphy

General Statement

The concept of stratigraphic sequence was first outlined by Sloss et al. (1949). Sequence was defined as "assemblages of strata and formations" bounding by prominent interregional unconformities. In the same year, Israelsky (1949) constructed an oscillation chart which shows an transgressive to regressive event based on analysis of the microfauna. In general, the concept of Israelsky's oscillation chart is related to Sloss ideal of the stratigraphic sequence based on the method of correlation. According to the concept of the stratigraphic sequence, Sloss (1963) subdivided the cratonic stratigraphic column from late Precambrian to present into six sequences bounded the major unconformities. However, this concept of stratigraphic sequence was not fully accepted at this time. Vail et al. (1977) reintroduced Sloss's ideas and used seismic data to designate the sequence stratigraphic model, as well as attempt to introduce sequence stratigraphy terminology. In addition, Vail et al. (1992) showed that high resolution biostratigraphy, well-logs and seismic profile are three fundamental components in sequence stratigraphic analysis. At this time, sequence stratigraphy had evolved from a theoretically controversial model into a practically accepted method and became widely accepted. Wagoner et al.(1988, 1990) proposed the hierarchy of sequence-stratigraphy units. Sarg (1988) applied the ideas of the sequence stratigraphy to the interpretation of carbonate platforms. Condensed Section, as a unit of sequence stratigraphy, was described more fully by Loutit (1988), and Shaffer (1990). The genetic stratigraphic sequence, flooding-surface bounded depositional unit, was introduced by Galloway (1989). Sequence

Stratigraphy of the Council Grove Group was interpreted more thoroughly by Boardman et al. (1995). They subdivided a third-order depositional sequence of the Council Grove Group into several fourth-order depositional sequences; such as Beattie, Lower Bader, Upper Bader, Crouse, and Funston Sequence in the upper Council Grove Group. Exxon-type sequences are disconformity-bounded, and in many instances, actually represent the Heckel cyclothem model. "Stratigraphic Sequence and cyclothem share a common trait (Rascoe, 1995)" that is central reason for their existence and that both of them are discussed in this paper. Genetic stratigraphic sequence, bounded by Maximum marine flooding surfaces, was introduced by Galloway (1989). The genetic stratigraphy are defined on the basis of feature formed during times of maximum regression. Galloway's stratigraphic sequence provides an useful method for interpretation of the terrigenous clastic basins.

A detailed description of Israelsky's oscillation chart, Sloss's cratonic sequence, Exxon-type depositional sequence, and Galloway's genetic stratigraphy sequence is shown in this chapter.

Israelsky' Oscillation Chart

Oscillation Chart is constructed by Israelsky (1949) for time correlation based on transgressive-regressive events (Figure 66). Israelsky analyzed foraminiferal content of shaker samples ranging from 6,000 to 11,760 feet from a well in the Lirette field, Terrebonne Parish, Louisiana. "It is contended that the chart shows relative changes in depth of water at this geographic position during the deposition of the "Miocene" penetrated by the drill" (Israelsky, 1949, p. 92). The percentage of each species in each sample is used to determine the relative depth significance with plotting the percentage of each species group against "that of *Rotalia beccarii*, considered to be of brackish habitat, and then against *Uvigerina spp*., considered a typically deeper open water element" (Israelsky, 1949, p. 93). According to this method, the deepest point of deposition within the cycle in each column can be established, and by connecting these points together a time plane can be constructed. A time plane represents the time of maximum inundation by the sea, that is , the time at which water depth was great at any particular locality. The Israelsky Oscillation Chart illustrate how time-equivalent points on the cycle are related, resulting in a correlation from place to place based on transgressive-regressive events. Event correlation is based on the correlation of corresponding peaks of symmetric sedimentary cycles that are presumed to be synchronous. Correlation in this manner can be considered to be a part of sequence stratigraphy.

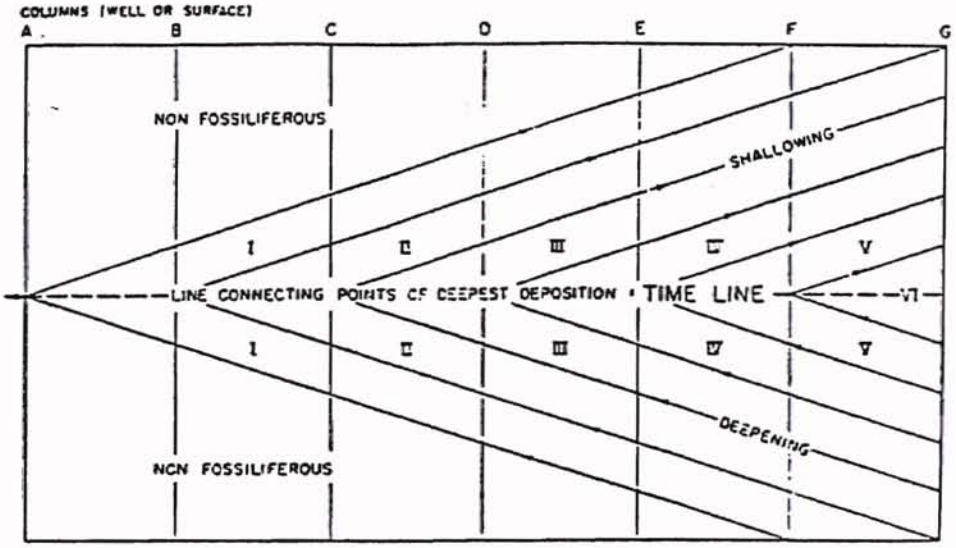


Figure 66 (from Israelsky 1949). Time correlation by position in a transgressive-regressive cycle. The line connecting points of deepest-water conditions is a time line.

Sloss' Cratonic Sequences

The term " Stratigraphic Sequence" was first proposed by Sloss et al. (1949) based on recognition of the four major rock-stratigraphic successions of the cratonic interior of North America from Cambrian through Jurassic (Figure 67). Sloss (1963) defined sequence as "rock stratigraphic units of higher rank than group, megagroup or supergroup, traceable over major areas of a continent and bounded by unconformities of interregional scope." He also reproposed other two stratigraphic sequences to include the Jurassic to Recent. The names of the sequences were derived by Sloss et al. (1949) and Sloss (1963) from North American Indian tribal names. A total of the six sequences was defined in cratonic interior of North America (Sloss, 1967); such as in ascending order Sauk, Tippecanoe, Kaskaskia, Absaroka, Zuni, and Tejas sequences. The initial recognition of the six cratonic sequences was based on careful lithostratigraphic and biostraigraphic correlation (Sloss, 1949, 1963). " Each sequence represents a major transgression and overlap, beginning at the cratonic margins and in the basins of greatest subsiding tendencies, gradually spreading to the more stable areas of the cratonic interior, and ultimately lapping up on the margins of the Canadian Shield" (Sloss, 1967, p. 95). These stratigraphic sequences are bounded by six major unconformites. The development of each unconformity was followed by a major transgression and onlap, beginning on the craton margins and extending into the major intracratonic basins and eventually onto the margins of the Canadian Shield. Sloss (1963) stated that the Sauk and Zuni sequences are characterized by slow transgression and rapid regression, whereas the Absaroka and Tejas

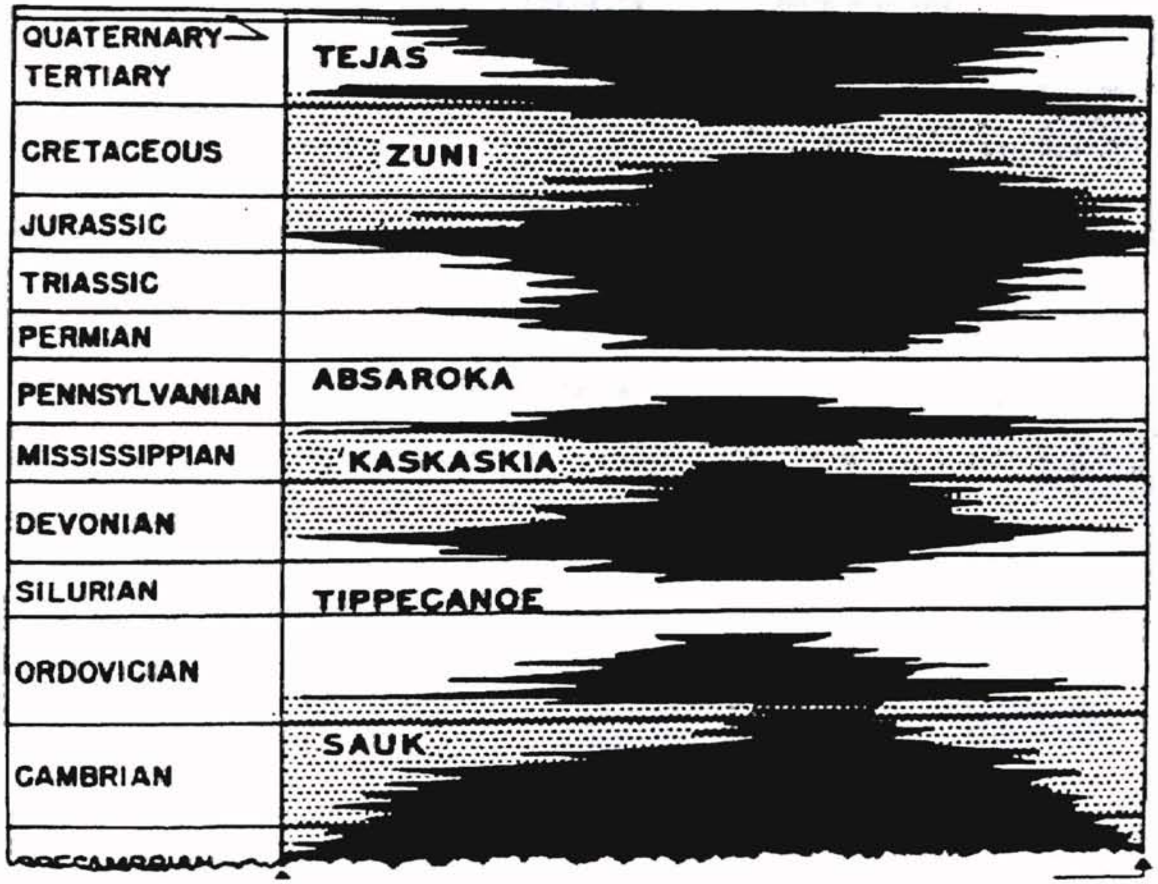


Figure 67 (from Sloss, 1963). Time-stratigraphic relationships of sequences in North American craton. Black areas represent nondepositional hiatuses; white and stippled areas represent deposition.

sequences, which were formed during times of marked cratonic mobility, show a rapid basal transgression and a long regressive phase. "The Tippecanoe sequence appears to represent an almost symmetrical cycle with maximum overlap near the middle of the time span involved" (Sloss, 1963, p. 109). Each of the six Sequence was also subdivided into several subsequence (chronological subdivisions) based on "the systems and periods of formal chronostratigraphy and geochronology as these are defined by biostratigraphic criteria" (Sloss, 1988, p. 3). A detailed Sloss' description of the six cratonic sequences of North America is listed in the following paragraphs.

Sauk Sequence ranges in age from latest Precambrian to early Ordovician. The sequence was named for exposures in Sauk county, Wisconsin. "The dominant features are the "zero" arc formed by the Canadian Shield and its a pendages and by the Transcontinental area. Above the basal sandstones in the margin basins the sequence is characterized by alternating shales and limestones, with relative thin regressive sands , culminating in this carbonate successions at the top... The cratonic interior areas are characterized by dolomitized carbonates above the basal sandstone" (Sloss, 1963, p. 96). This sequence was subdivided into the Sauk I (latest proterozoic to Early Cambrian), Sauk II (Middle and earliest Late Cambrian), and Sauk III (Mid-late Cambrian to Early Ordovician) third order sequences.

Tippecanoe sequence ranges in age from middle Ordovician to early Devonian. The sequence is named from Tippecanoe County, Indiana where numerous well-documented drill holes penetrate the entire succession. Tippecanoe character is the degree of overlap of the Transcontinental arch and the Canadian shield in the Dakotas and the Prairie provinces and in the Hudson bay area and the of nonpreservation on the

Sweetgrass arch. At Base of Tippecanoe sequence, the most typical and widespread lithology is pure quartz sandstone. Strata at the top of Tippecanoe is largely carbonate (Helderdergian strata) which are preserved only in the basins at the cratonic margins and in the more deeply subsiding interior basins. This sequence was subdivided into the Tippecanoe I (Middle and Late Ordovician) and Tippecanoe II (Early Silurian to Early Devonian) third order sequences.

Kaskaskia sequence ranges in age from Early Devonian to latest Mississippian. The sequence is named for the valley of the Kaskaskia River in south-central Illinois. The Kaskaskia sequence bears a record of at least two major tectonic and transgressive episodes. At base of Kaskaskia sequence, the basal units of the sequence are sandstone carbonate and cherty carbonate of late Early Devonian age in the basins it the cratonic margin and in the axial portions of certain of the interior basins. In other basinal sites the base of the sequence is commonly represented by Middle Devonian carbonates. At the top of the Kaskaskia sequence, carbonate of Early and Middle Mississipian age commonly form the preserved top of the sequence. A succession with numerous cyclical repetitions of sandstone appears to be in basins relatively close to the Canadian Shield and its appendages. This sequence was subdivided into the Kaskaskia I (Mid-Early Devonian) and Kaskaskia II (Latest Devonian to Late Mississippian) third order sequences.

Absaroka sequence ranges in age from Latest Mississipian to Early Jurassic. The sequence is named from the Absaroka Range in northwestern Wyoming and southern Montana. The complexity and rapid rates of change both in thickness and lithology of the Absaroka sequence provide a kind of unity to the succession which differentiate from the Kaskaskia sequence below and the Zuni Sequence above. Absaroka character is disappearance of the transcontinental arch as a controlling element in distribution, facies, and thickness of preserved sediment, and the abrupt appearance of numerous intracratonic positive elements and adjoining yoked basins in the Mid-continent and central and southern Rocky Mountain areas. Much of the cratonic interior bears a record of cyclic repetitions of marine and nonmarine deposition with increasing dominance of continental environments toward the northeast at base of the Absaroka sequence. The top of the Absaroka sequence is marked by a profound unconformity cut on Pennsylvanian strata. Early Permian strata are preserved along the axis of the Appalachian basin and in isolated basins of the Atlantic Coastal Plain and the Appalachian Piedmont and the Maritime Provinces. The final regressive phase of the Sequence is represented by nonmarine red beds and pure quartz sandstones. This sequence was subdivided into the Absaroka I (Latest Mississipian to Early Jurassic), Absaroka II (Middle Permian to Upper Permian), and Absaroka III (Triassic to Early Jurassic) third order sequences.

Zuni sequence ranges in age from Middle Jurassic to Middle Paleocene. The name is derived from the Zuni uplift on the Arizona-New Mexico border. The Zuni Sequence bears a record of at least two major tectonic and transgressive episodes. The pattern of Zuni sequence is characterized by alternations of dark shale, carbonates, and evaporites in the interior of the basin, interfingering updip with littoral sandstones and nonmarine deposits near the basin margin. The base of the Zuni Sequence is an easily recognized horizon typically marked by a basal sandstone bearing residual fragments of underlying rock units except on the Colorado Plateau and neighboring areas of preservation of Lower Jurassic regressive sandstones of the Absaroka sequence. At the top of the Zuni sequence, these strata mark the ultimate regressive elements of Zuni deposition and, almost everywhere, they rest with transitional and conformable contacts on the very similar nonmarine strata of youngest Cretaceous age. This sequence was subdivided into the Zuni I (latest Early Jurassic, Aalenian, to Early Cretaceous Berriasian), Zuni II (Early Cretaceous, Balanginian, to Late Cretaceous, early Cenomanian), and Zuni III (Late Cretaceous, late Cenomanian, to early Paleocene) third order sequences.

Tejas Sequence ranges in age from Early Miocene to Recent. The sequence is named from Texas, where there is a classic development of the great wedge of tertiary and Quaternary sediments filling the Gulf Coast Basin. Deposition was strongly controlled by a sharply differentiated tectonic framework developed during late Paleocene and subsequence time, dominated by numerous sharply defined positive and negative elements. The pattern of Tejas sequence is characterized as alternations of deltaic sands and down-dip marine shales, forming complex cyclical intertongues. Therefore, this Sequence is characterized by lacked carbonates and evaporites in the western and center Gulf region, these rock types are important in peninsular Florida.
This sequence was subdivided into the Tejas I (late Paleocene to middle Eocene) Tejas II/III (late Eocene to present) third order sequences.

Exxon-type Depositional Sequence

Though Sloss (1963) proposed the concept of the sequence as an unconformity-bounded stratigraphic unit, the Sloss theoretical ideal of the depositional sequence was not fully accepted by many geologists; due to the fact that the model of the depositional sequence was not practically constructed at that time. There was major breakthrough in sequence in sequence stratigraphy in the 1970's, when digitally record and processed multichannel seismic data, as seismic stratigraphy, was developed for basin analysis. Vail and others at the Exxon's Production Research Company first applied seismic stratigraphic analysis to interpret the depositional history of sedimentary basins from subsurface evidence, principally reflected seismic lines. Vail et al. (1977) constructed the practical model of depositional sequence called Exxon-type Sequence Model by analysis of seismic stratigraphy upon Sloss's concept and defined that "A depositional sequence is a stratigraphic unit composed of a relatively conformable succession of genetically related strata and bounded at its tope and base by unconformities or their correlative conformities"(1977b, p. 53). The terminology related to sequence stratigraphy was established by Van Wagoner et al. (1988) and later works, for example depositional system, systems tract, parasequence, and parasequence set. The fundamental concepts and terminology of the Exxon-type depositional sequence will be described and discussed as following:

Sequence Boundary

The Sequence boundaries can be unconformites of their correlative conformities. Van Wagoner et al. (1988) recognized two types of the sequences, type 1 and type 2 sequence boundaries (Figure 68).

Type 1 Sequnce Boundary

"A type 1 sequence boundaries is characterized by subaerial exposure and concurrent subaerial erosion associated with stream rejuvenation, a basinward shift of facies, a downward shift in coastal onlap, and onlap of overlying strata" (Van Wagoner et al., 1988 p. 41). The presence of subaerially exposed sediment is indicative of significant time of deposition (palesols with rooted zones or ped-structure).ccc Van Wagoner et al. (1988) explain that a type 1 sequence boundary forms when the rate of eustatic sea-level fall exceeds that rate of basin subsidence at the depositional-shoreline break, producing a relative fall in sea level at that position.

Type 2 sequence boundary

Type 2 sequence boundaries are characterized by "subaerial exposure and a downward shift in coastal onlap landward of the depositional-shoreline break" (Van Wagoner et al., 1988 p. 41); type 2 boundaries lack subaerial erosion associated with stream rejuvenation and a basinward shift in facies. Van Wagoner explained Because the rate of eustatic sea-level fall is less than the rate of basin subsidence at the depositional-shoreline break. Actually, there is no "relative fall in sea level at depositional-shoreline break" (Van Wagoner, 1988) for type 2 sequence boundary. As a consequence, basinward shift in coastal onlap above the unconformity can not be found.

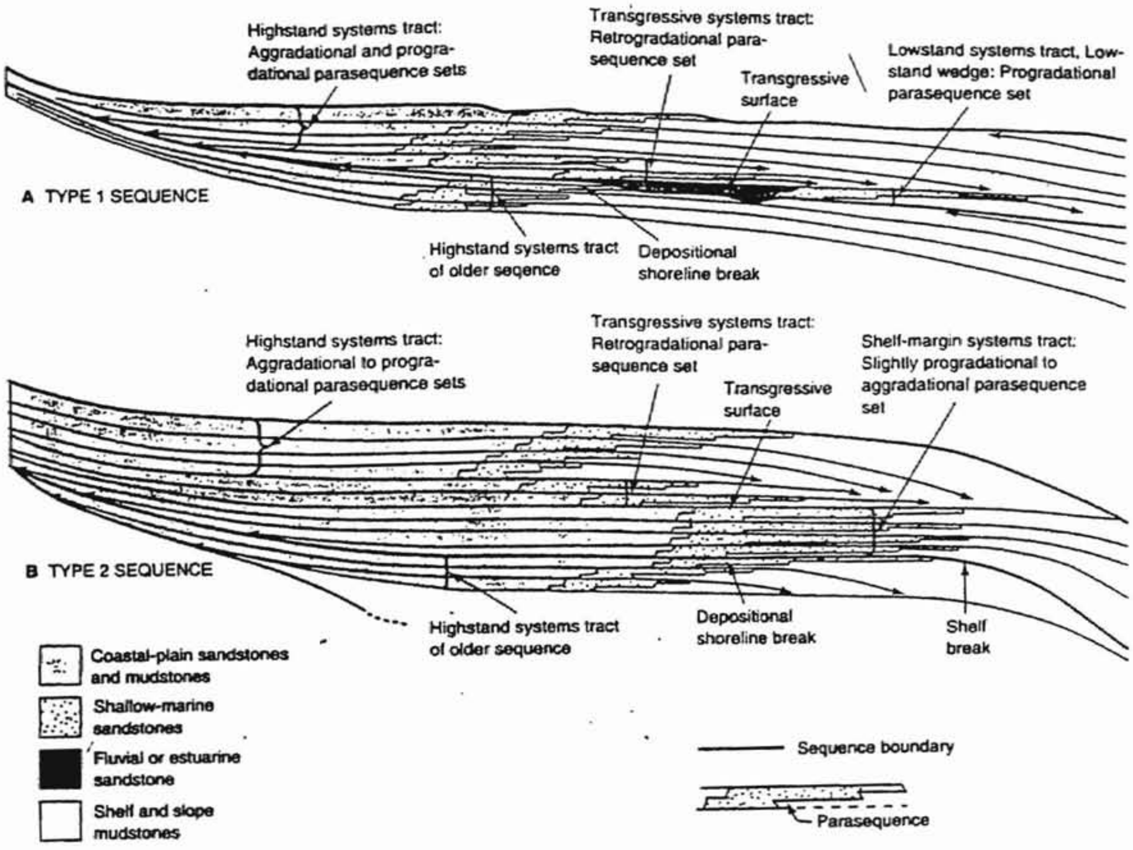


Figure 68 (modified by Boggs,1995 from Van Wagoner et al., 1990). Schematic illustration of systems tracts and parasequences in a type 1 (A) and a type 2 (B) sequence. The arrows show truncation of strata against some kind of bounding surface Time correlation by position in a transgressive-regressive cycle. The line connecting points of deepest-water conditions is a time line.

Depositional Systems tracts

"A depositional system is a three-dimestional assemblage of lithogacies (Fisher and McGowan, 1967). A systems tract is a linkage of contemporaneous depositional systems (Brown and fisher, 1977)" Van Wagoner et al. (1988). Each sequence can be subdivided by four system tracts: lowstand, transgressive, shelf-margin, highstand systems tracts (Figure 68).

Lowstand Systems Tract

Lowstand systems tract, commonly underlain by a type 1 sequence boundary, can form during a time of rapid eustatic sea-level fall or during late sea-level fall or early rise (Van Wagoner, 1988), associated with river system and causing the shelf to become subaerially exposed. During a relative fall in sea level, Stream incision and sediment bypass of the coastal plain are developed as well as sediment is transported into slope by sediment gravity flows and deposited as basin-floor submarine fans. Subsequently, the infilling of incised valleys, deltaic sediments may form and fill previously incised river valley during a relative rise in sea level. This sequence set is characterized by the prograding stacking pattern of individual sequences in the sets (Mitchum et al., 1990)."Deposition terminates when the rate of sediment supply cannot keep up with the combined rates of eustatic sea-level rise and basin subsidence" (Boggs, 1987, p. 518).

Highstand Systems Tract

Highstand system tracts, overlain by a type 1 sequence boundary or type 2 sequence boundary and underlain by the downlap surface, form during the late part of a sea-level rise, a sea-level standstill, and the early part of a sea-level fall (Van Wagoner, 1988). On the other hand, it is deposited after maximum transgression and before a sequence boundary, when the rate of creation of accommodation is less than the rate of sediment supply. This sequence set is characterized by the prograding stacking pattern of individual sequences in the set. (Mitchum et al., 1990). The late highstand systems tract is characterized by significant fluvial deposition. Highstand systems tracts are terminated by the unconformity produced by the next eustatic sea-level fall.

Transgressive Systems Tract

Transgressive systems tracts occur within the middle of either a type 1 or a type 2 sequence (Van Wagoner, 1988). It, deposited during a rapid eustatic sea-level rise, is bounded below by the transgressive surface at the top of the lowstand or shelf margin system tracts and above by the maximum flooding surface at the base of the highstand system tract. "This rapid rise floods the shelf, preventing rivers from incising. Under these conditions, little fluvial sediment is delivered to the shelf, and marine sediments build in a landward direction" (Boggs, 1987, p. 518). This sequence set is best recognized by the backstepping stacking pattern of individual sequences in the set (Mitchum et al, 1990) The maximum flooding surface represents the end of the transgressive systems tract.

Shelf Margin Systems Tracts

Shelf margin systems tract forms when the rate of eustatic sea-level fall is lower than that associated with the lowstand systems tract (Van Wagoner, 1988), associated with a type 2 sequence boundary. On the other hand, "relative sea-level may fall over the proximal area of highstand topsets, without falling at the offlap break" (Emery et al. 1996) during deposition of shelf-margin systems tracts. These systems tracts are bounded below by a type 2 sequence boundary and above by the first major flooding surface on the shelf. "Aggradation (vertical sediment accumulation) rather than progradation, takes place during deposition of shelf-margin systems tracts" (Boggs, 1987, p. 518). Deposition terminates when the first major flooding surface occurs.

Condensed Section

The sediment described as the condensed section is deposited at the time of maximum transgression. The top of the transgressive system tract is commonly considered the condensed section; a facies consisting of thin marine beds of hemipelagic or pelagic sediments deposited at very slow rates. "Condensed sections are thin marine stratigraphic units consisting of pelagic to hemepelagic characterized by very low sedimentation rates. Condensed sections are associated commonly with apparent marine hiatuses and often occur as thin, but continuous (Loutit et al., 1988)." Abundant and diverse planktonic and benthic microfossil assemblage may present in condensed section. Those characteristics of condensed section have well presented in mid-continent black shale. The black shales are considered as condensed sections for the study of sequence stratigraphy. They can be predictable chronostratigraphic markers Loutit et al. (1988), because condensed sections are regionally most extensive at the time of maximum transgression. In addition, Loutit et al. stated that the condensed section is an excellent marker "for dating and correlating continental-margin sequences and reconstructing ancient depositional environment.

Parasequence Sets

Systems tracts are made up of smaller depositional units called Parasequence which is "a relatively conformable succession of genetically related beds or bedsets bounded marine-flooding surfaces and their correlative surfaces" (Van Wagoner, 1988, p. 39), "A main-flooding surface is a surface that separates younger from older strata, across which there is evidence of an abrupt increase in water depth" (Van Wagoner, 1988, p. 39). Parasequence sets, in turn, are composed of parasequences. Van wagoner defined that "parasequence set is a succession of genetically related parasequences which form a distinctive stacking pattern that is bounded....by major marine-flooding surfaces and their correlative surfaces" (Van Wagoner et al., 1988, p. 39). Three types of parasequence set stacking patterns are recognized based on the architecture of a vertical succession of parasequences; progradational, retrogradational, and aggradational parasequence sets (Figure 69).

Progradational Parasequence Set

Progradational parasequence set was formed when the rate of sediment supply exceeds the rate of accommodation formation development (Van Wagoner et al. 1990). In general ,it shows that the shoreline migrated toward the basin center. The thick prodelta and delta-front facies and steep prodelta slopes can be the important features in this progradational parasequence set (Galloway, 1989).

Retrogradational Parasequence Set

Retrogradational parasequence set is formed when the rate of sediment supply is less than the rate of accommodation development (Van Wagoner et al. 1990). It shows that the shoreline migration is toward landward direction. Intermittent sediment deposition commonly occurs across areas of the flooded depositional platform as well as

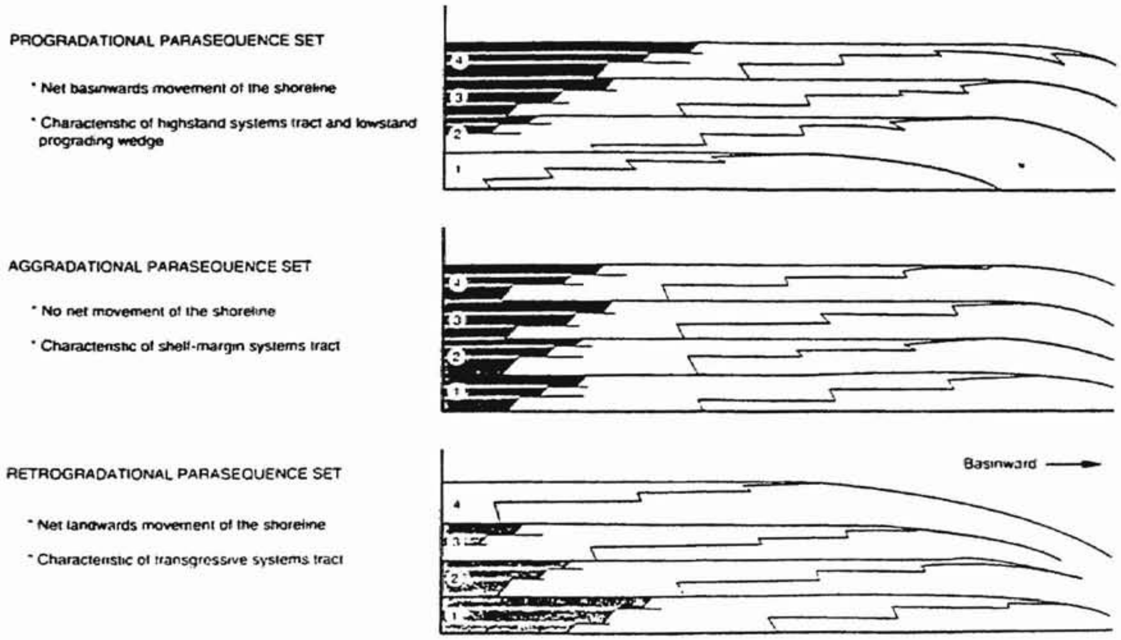


Figure 69 (modified by Emery 1996 from Van Wagoner et al, 1988). Parasequence sets.

terrigenous sedimentation rates are extremely low. Retrogradation is commonly reflected by the increasing importance of barrier bar/lagoon systems as coastal flooding occurs (Galloway, 1989).

Aggradational Parasequence Set

Aggradational parasequence set occurred when the rate of sediment supply is equal to the rate of accommodation formation (Van Wagoner et al. 1990). For example, "a keep-up carbonate systems tract displays a relatively rapid rate of accumulation and is able to keep up with relative rises in sea level" (Sarg, 1988, p. 163). It shows that there is no net movement of the shoreline.

Sea-level Analysis

Vail and others (1977) applied seismic data to construction of regional curves of relative changes of sea level, based on seismic reflection pattern. Seismic stratigraphic analysis is a method for interpreting the depositional history of sedimentary basins from subsurface evidence, principally reflection seismic lines. Seismic reflections result from acoustic-velocity-impedance contacts along bedding planes or unconformities and can be used stratigraphic markers; downlap, onlap, truncation, and toplap (Vail et al. 1977). These lapout patterns can be indicators of relative sea level changes According Vail et al., 1977a, b, the procedure, including three steps (Figure 70) , is described below:

First Step

The first step is that sequence boundaries (unconformities) have to be defined based on reflection termination. Reflection termination is the main criterion for use in

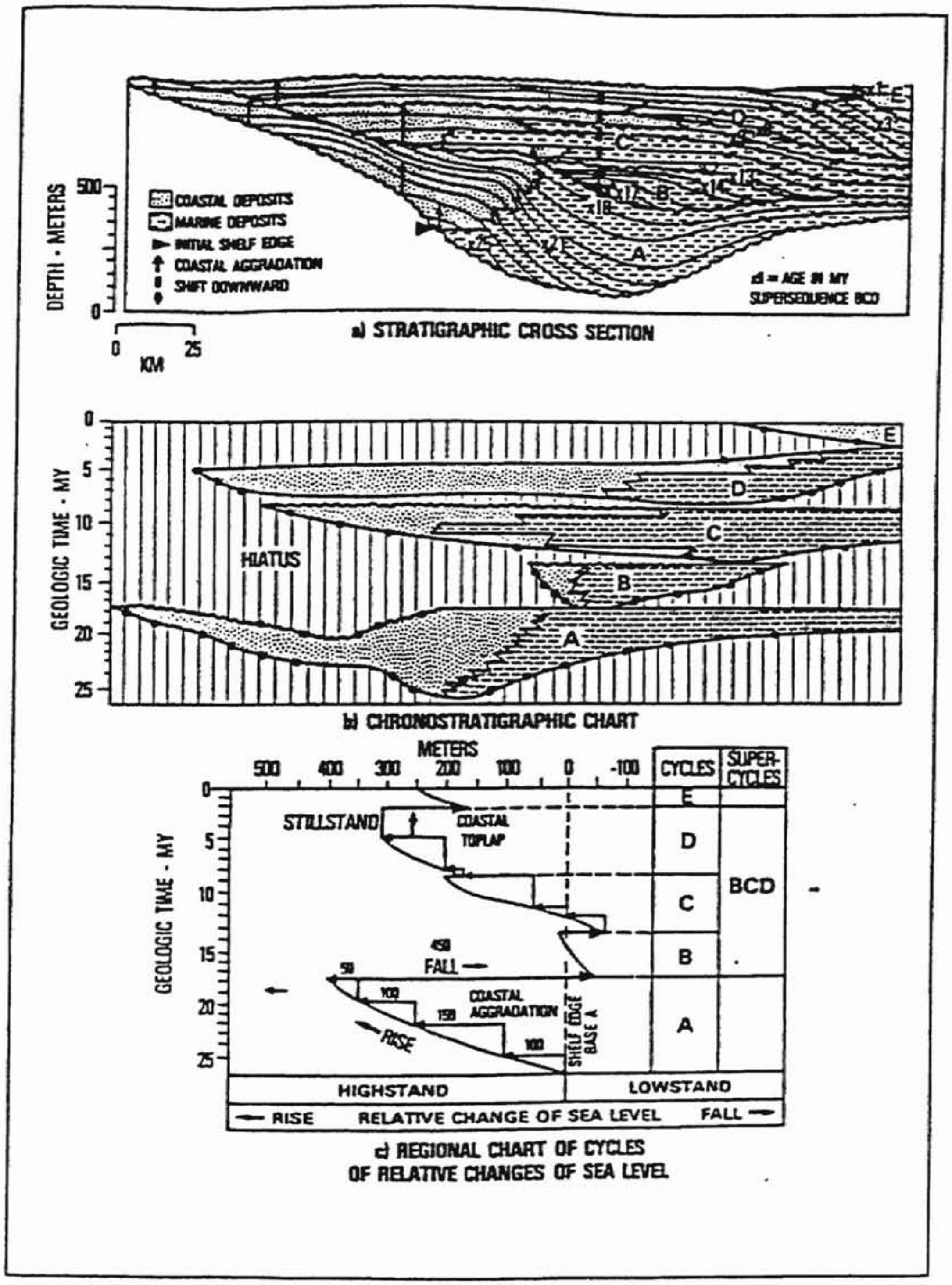


Figure 70 (Vail, et al., 1997b) Diagram illustrating the procedure used by Exxon geologists for constructing a regional chart of cycles of relative coastal onlap.

determining a sequence boundaries, because the types of reflection termination have been developed by concordance of discordance relation; such as concordance, erosional truncation, downlap, onlap, toplap,. Those types of reflection termination provide geological information about relations of strata to sequence boundaries. once sequence boundaries are determined, the ages of depositional sequence can be constructed.

Second Step

The second step is that a chronostratigraphic chart of the sequence can be constructed based on strata and unconformites surface which give time-stratigraphic information. Vail et al. explained that these surface are depositional surface, the seismic response to strata surfaces are assumed to be chronostratigraphic reflector. Seismic reflectors within each sequence indicate time markers which represent an equivalent age at everywhere, and they can cross lithologic boundaries. According to the ages of depositional sequence, Vail and others (1977) plot the stratigraphic information against geologic time to construct a chronostratigraphic chart.

Third Step

The final step is that a curve of relative rise and fall of sea level is constructed by using several lapout patterns within individual a sequence. According to Vail et al. (1977), indicators of relative sea level changes can be grouped into three basic lines of evidence: (1) Coastal onlap indicates a relative rise; (2) coastal toplap indicates stillstand; and (3) downward shift in coastal onlap indicates a relative (rapid) fall of sea level. Vail et al. (1977) pointed out that a measurement of sea level fall can be done by calculating the amount of downward shift as well as a measurement of subsequent sea level rise can be made by calculating the amount of coastal onlap. According their method of measuring sea level rise and fall, a regional chart of cycles of relative changes of sea level is constructed and composed for interpretation of transgressive-regressive history of all the basins studied.

Order of Sequence Cycles

The study of the depositional sequence considers several scales of cycles and uses a variety of information to characterize the subaerial unconformity-bounded depositional sequence (Vail et al., 1977). A hierarchy of sequence cycles has been developed based on an interval of geologic time during which a relative rise and fall of sea level occur (Figure 71). Vail et al.(1977) first defined three orders of magnitude in time duration from first order to third-order cycles. Later, Goldhammer et al. (1991) revised time durations of Vail et al.'s first, second, and third order cycles and added other two order-cycles; fourth and fifth-order cycles. A complete cycle hierarchy consists of five orders of magnitude from first to fifth-order cycles (Figure 72). Goldhammer et al. (1993) stated that "The sedimentary record has stratigraphic cycles of different orders, defined by duration. The amplitudes and rates of eustatic changes reflect the generating process, be it tectono-eustasy or glacio-eustasy. Third-order (1-10 m.y.), fourth-order (0.1-1 m.y.) and fifth-order (0.01-0.10 m.y.) eustatic cycles are of prime importance in stratigraphic packaging in shallow-marine carbonate platform deposits on the scale of both sequences and depositional cycles, because the cyclic rates of change are typically much greater than subsidence rates, and comparable with carbonate sedimentation rates. As a result, commonly the internal architecture of carbonate platform sequence contains a record of

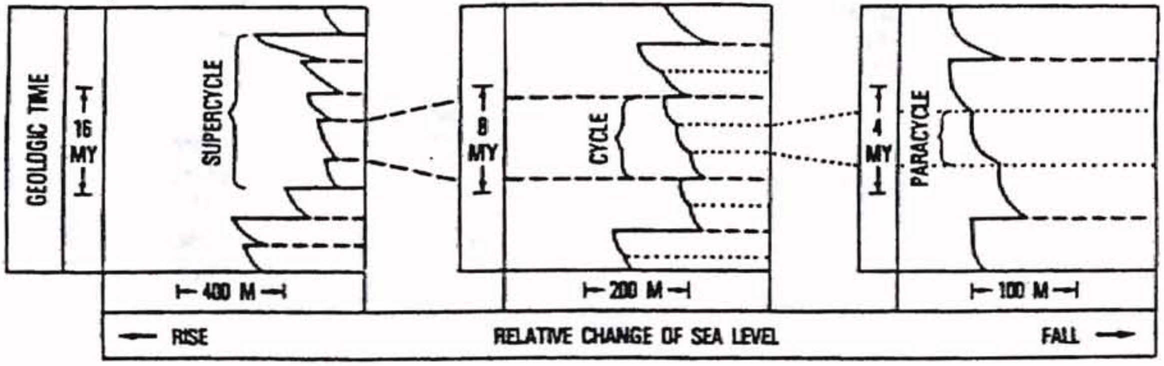


Figure 71 (from Vail, et al., 1977, Part 4). Charts of relative changes of sea level. Cycles consists of relative rises and falls of sea level, commonly containing several paracycles, which are smaller scale pulses of relative rises to stillstands. Several Cycles usually form a higher order cycles (supercycle) with pattern of successive rises betw3een major falls. Note asymmetry of gradual rises and abrupt falls at each scale

Sequence Stratigraphic Terminology	Eustatic Cycles (orders)	Duration (myr)	Amplitude (meters)	Rise/Fall Rates (cm/1000 yr)
	First	> 100		< 1
Supersequence	Second	10–100	50–100	1–3
Sequence	Third	1–10	50–100	1–10
Sequence, Cycle	Fourth	0.1–1	1–150	40–500
Parasequence, Cycle	Fifth	0.01–0.1	1–150	60–700

Figure 72 (from Goldhammer et al, 1991b). Orders of stratigraphic and eustatic cyclicity showing ranges of amplitudes and rates of sea level change.

superimposed orders of stratigraphic cyclicity" (Goldhammer et al., 1993, p. 327). Five orders of sequence cycles are described in the following paragraphs.

First Order Cycle

First order cycle is proposed by Vail et al. (1977). They believed that first order cycles last from 200 to 300 million years. Later, Goldhammer et al. (1991) changed time duration of first order cycles. They proposed that time duration of first order cycle is greater than 100 million years. These cycles represent a possible overall relationship to patterns of sea floor spreading rates and orogeny (Vail et. al., 1977, p. 94). They explained that global sea level rises during rifting and continental pull-apart because it reduces ocean-basin volume and global sea level falls when continents join together because ocean basin volume is maximized.

Second Order Cycle

Vail et al. (1977) proposed second order cycle. They believed that second order cycles have durations of 200 to 300 million years. Later, Goldhammer et al. (1991) changed time duration of second order cycles to a range of 10 to 100 million years. These cycles are equivalent to supersequence in sequence stratigraphic terminology (Goldhammer, et al., 1991). Second-order cycles are related to changes in rates of seafloor spreading (Vail et al., 1977).

Third Order Cycle

Third order cycles, proposed by Vail et al.(1977), have durations of 1 to 10 million years. Goldhammer et al. (1991) also agreed with time duration of Vail et al.'s third order cycle. These cycles are equivalent to sequence in sequence stratigraphic terminology (Goldhammer, et al., 1991). Vail et al. (1977) believed that "Glaciation and deglaciation are the only well understood causal mechanisms that occur at relatively rapid rates of third-order cycles. Rates of geotectonic mechanisms related to seafloor spreading are too slow" (Vail et al., 1977, p. 94), but Kauffman (1984) suggest that these cycles are associated with contemporaneous tectonism and volcanism in the Cordillera based on his correlatable third order cycles between North America and Europe.

Fourth and Fifth Order Cycles

Goldhammer (1991) proposed Fourth order cycles and fifth order cycles. They believed that fourth span periods of time ranging from 0.1 to 1 million years and fifth order cycles from about 0.01 to 0.1 million years. Fourth and fifth-order cycles are equivalent to sequence and parasequence in sequence stratigraphic terminology (Goldhammer, et al., 1991). Fourth and fifth-order cycles appear to be effected by changes in climates caused by cyclic changes in Earth's orbital parameter (Golbhammer et al., 1991). Goldhammer et al. (1991) believed "These orbital cycles, called Milankovich Cycles after the mathematician who calculated the climatic effects of the cycles...These cyclic changes in Earth's tilt and orbit cause cyclic variations in the intensity and seasonal distribution of incoming solar radiation. These variations in solar intensity, in turn, result in alternate accumulation and melting of continental ice sheets, producing cycles of falling and rising sea level" (Boggs, 1987, p. 557).

Galloway Genetic Sequence

Genetic Sequence model was defined by Galloway (1989) as depositional system bounded by maximum flooding surface upon Frazier (1974) genetic stratigraphic unit (Figure 73). On the other hand, maximum flooding surface is recognized as genetic stratigraphic sequence boundaries that record the relative clastic-sediment starvation of the shelf and slope during marine transgression. Frazier (1974) recognized "depositional episodes and depositional complexes as the principal genetic time and rock stratigraphic subdivisions of basin history and fill". He (1974) explained that "depositional episodes are ended by regional flooding events; their physical stratigraphic units provide a record of coastal outbuilding capped by transgressive facies and superjacent submarine unconformites or condensed sedimentary veneers".

In certain tectonic settings, concepts of genetic sequence stratigraphy are usefully applied to marginal marine basins where sand-rich progradational clastic wedges are separated by thinner, onlapping marine units. Galloway stated that "I built upon Frazier's model to provide an alternative sequence-stratigraphic paradign proven useful in analyzing prograding clastic basin fills" (p. 128). He explained why he used maximum flooding surface instead of unconformities surface for genetic sequence boundaries and compared with Exxon-type depositional sequence particularly for the following point. First "on seismic records, maximum flooding surface is recorded by coastal onlap followed by downlap" (Galloway, 1989, p. 138); downlap surfaces are best seen on seismic lines and or easy to identify on wireline logs. Second, "More important than ease of recognition, the surface of maximum flooding is a useful stratigraphic boundary. This

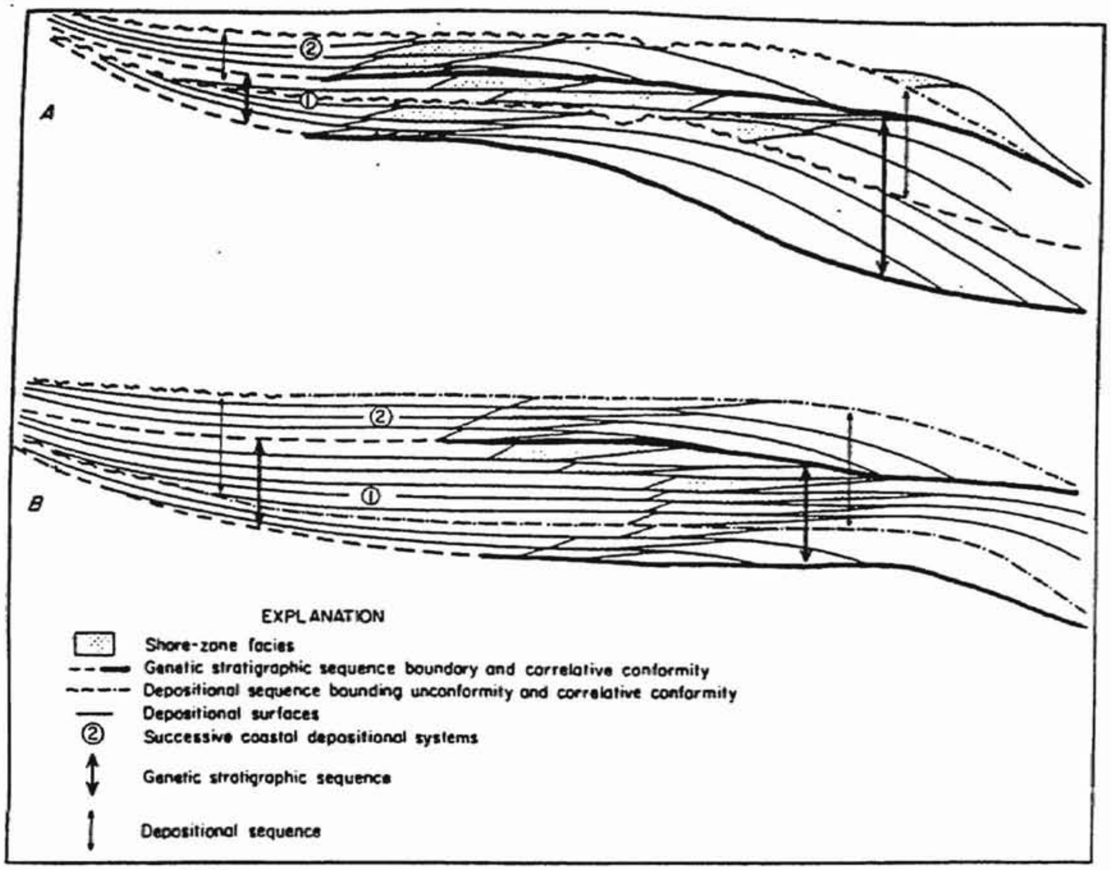


Figure 73 (from Galloway, 1989) "Comparison of boundaries for (A) Exxon type 1 and (B) Exxon type 2 depositional sequence with those of genetic stratigraphic sequence. (A) Exxon paradigm emphasizes subaerial unconformity and its equivalent stratal surface, which may be quite prominent where relative base level drops below progradational shelf edge. (B) In contrast, bounding unconformity is obscure and of limited extent in type 2 sequence where base level does not drop below platform margin, In both examples, downlapped hiatal surface created by transgression and flooding of coastal plain creates and easily correlated horizon that encapsulates prograded wedge of sandy coastal-plain, shore-zone, and marine-slope sediments".

surface is well developed across the middle of the facies tract where marine and nonmarine depositional systems interfinger". Third, "the fossil-rich condensed section deposited is useful in high-resolution chronostratigraphic correlation; interregional sequence correlation". Fourth, "ubiquitous widespread unconformities associated with abrupt sea level falls are problematical; more gradual eustatic change would not necessarily create widespread" (Galloway, 1989, p. 138). The maximum flooding surface and correlative facies of the shoreline of maximum transgression used as sequence boundaries commonly represent shelf-wide, regional transgressions and not local events. On the other hand, "genetic stratigraphic sequence boundaries.. have a geographic extent comparable to Exxon's type 1 depositional sequence boundaries which are difficult to trace into the deep marine section where pelagic drapes reflection relative highstand are widely used for sequence correlation" (1989, p. 139). "The greater extent and correlation potential of maximum flooding surfaces are most obvious where depositional sequences are bounded by type 2 unconformites. the subtle sequence-defining erosion surface may be found only along the innermost fringe of the basin fill...The potential for sequence definition by type 2 unconformites is further limited because the most landward area of basin fill is least likely to be preserved and the bounding unconformity is easily lost in a maze of fluvial channelization and local bypass surfaces. At worst , maximum flooding and transgressive surfaces are as extensive as type 1 sequence boundaries; at best, they have greater lateral extent and stratigraphic visibility than type 2 unconformities" (1989, p. 139). Fifth, "principal changes in the paleogeographic distribution of depositional systems and depocenters accompany transgression and flooding events. Major shifts in fluvial axes, deltaic depocenters, and interdeltaic shore-zone systems occur between genetic stratigraphic sequences. Regional mapping of depositional systems and interpreted paleogeography of the succession of major and minor Cenozoic episodes of the northwest Gulf basin shows that sequences defined by transgressions record deposition under conditions of source-area, tectonic and base-level stability. Vertical persistence of similar depositional elements within genetic sequences is a requirement for successful area delineation of depositional systems from regional lithofacies maps that incorporated hundreds to thousands of meters of sediment. In contrast, combing the lowstand and transgressive system tract with the overlying highstand system tract, as in the Exxon mode, randomly intermixes deltaic depocenters and interdeltaic systems within the same sequence" (1989, p. 140).

Genetic sequence model can also be applied in the nonmarine setting. Another Example from the Gunnedah Basin of Australia is provided to support why Galloway genetic sequence model is so important by Hamilton et al. (1994). Hamilton et al. (1994) applied the concept of Galloway's genetic sequence to analysis of the nonmarine Gunnedah basin. "The Gunedah basin is a Permian-Triassic basin that, during the late Permian, occupied a foreland setting and was infilled by coal-bearing fluvial-lacustrine deposits". Hamilton (1994) explained that Nonmarine deposits dominate in Gunnedah Basin of Australia where marine flooding surfaces are absent, "different criteria for sequence recognition are necessary" (1994, p. 267). Hamilton et al. applied regionally extensive coal seams to be one type of sequence boundary. "Peat accumulation and preservation as coal can only occur in the absence of significant clastic deposition" (1994, p. 267) In the Gunnedah Basin, "coals are readily recognized and correlated by their unique seam signature, or profile, which is a function of the original peat-forming plants and the physical and chemical conditions imposed during peat swamp evolution" (1994, p. 267). "The numerous essentially isochronous events that occur throughout peat swamp evolution are recorded in the coal seam's characteristic profile, providing evidence of its time equivalence" (1994, p. 285). Hamilton et al. considered that these coal seams are analogous to the condensed sections of Galloway genetic sequence model in marine basin fills and have considerable utility in defining a basin's genetic stratigraphic framework. Hamilton (1990) explained why he applied the Galloway genetic sequence to Gunnedah basin instead of the Exxon-type sequence model. Hamilton stated that subaerial erosional unconformities as Exxon-type sequence boundaries may provide "one obvious type of bounding surface between stratigraphy packages, but many other, more subtle, conformable bounding surface are present, which allow subdivisions of terrestrial basin-fills in genetic units of common tectonic, climatic, and paleogeographic origin" (1990, p. a336). Coal seams of regional extent, as condensed section of the genetic sequence, "the product of prolific peat growth and preservation during periods of negligible clastic accumulation and can define times of relative stability between episodes of major reorganization in basin tectonics of climate" (Hamilton, 1990, p. a366).

Both of Exxon type sequence model and Galloway genetic sequence model may prove more useful for basin analysis in different tectonic settings. Authors conclude that Exxon type sequence model is useful in analyzing marine carbonate shelf basin fills, but the Galloway genetic sequence model is significant in interpreting marine prograding or nonmarine aggradating clastic basin fills.

Council Grove Group Sequence

General Statement

The third-order Council Grove Group Sequence in the Mid-Continent is part of the Absaroka I supersequence, Sloss's Absaroka Supersequence Set from northern Kansas through northern Oklahoma (Figure 74). The Council Grove Group Sequence, bounded above by the Chase Group Sequence and below by the Admire Group Sequence, is ranked as a sequence in sequence stratigraphic terminology based on Goldhammer's (1991b) classification stratigraphic sequence (Figure 72). The total thickness of this sequence is about 310 feet to 330 feet (94.4 meters to 100.5 meters). Boardman et al. (1993) divided the Council Grove Group depositional sequence into eight fourth-order sequences; the Foraker, Red Eagle, Grenola, Beattie, Lower Bader, Upper Bader, Crouse, and Funston Sequences, in ascending order. The Foraker and Red Eagle Sequences of the lower Council Group Depositional Sequence were investigated by Keairns (1995). Keairns found three marine condensed sections within the Foraker Sequence and two major and one minor marine condensed sections within Red Eagle Sequence. These condensed sections commonly are within dark gray to black shales in northern most localities and within carbonates in the southern sections. In general, they contain an abundance of phosphatic remains, glauconite, and an abundant offshore *Streptognathodus* conodont fauna. Keairns (1995) concluded that six transgressive - regressive cycles of sedimentation were found with the Foraker Sequence and two major transgressive-regressive cycles were found within the Red Eagle Sequence. The Council Grove Group

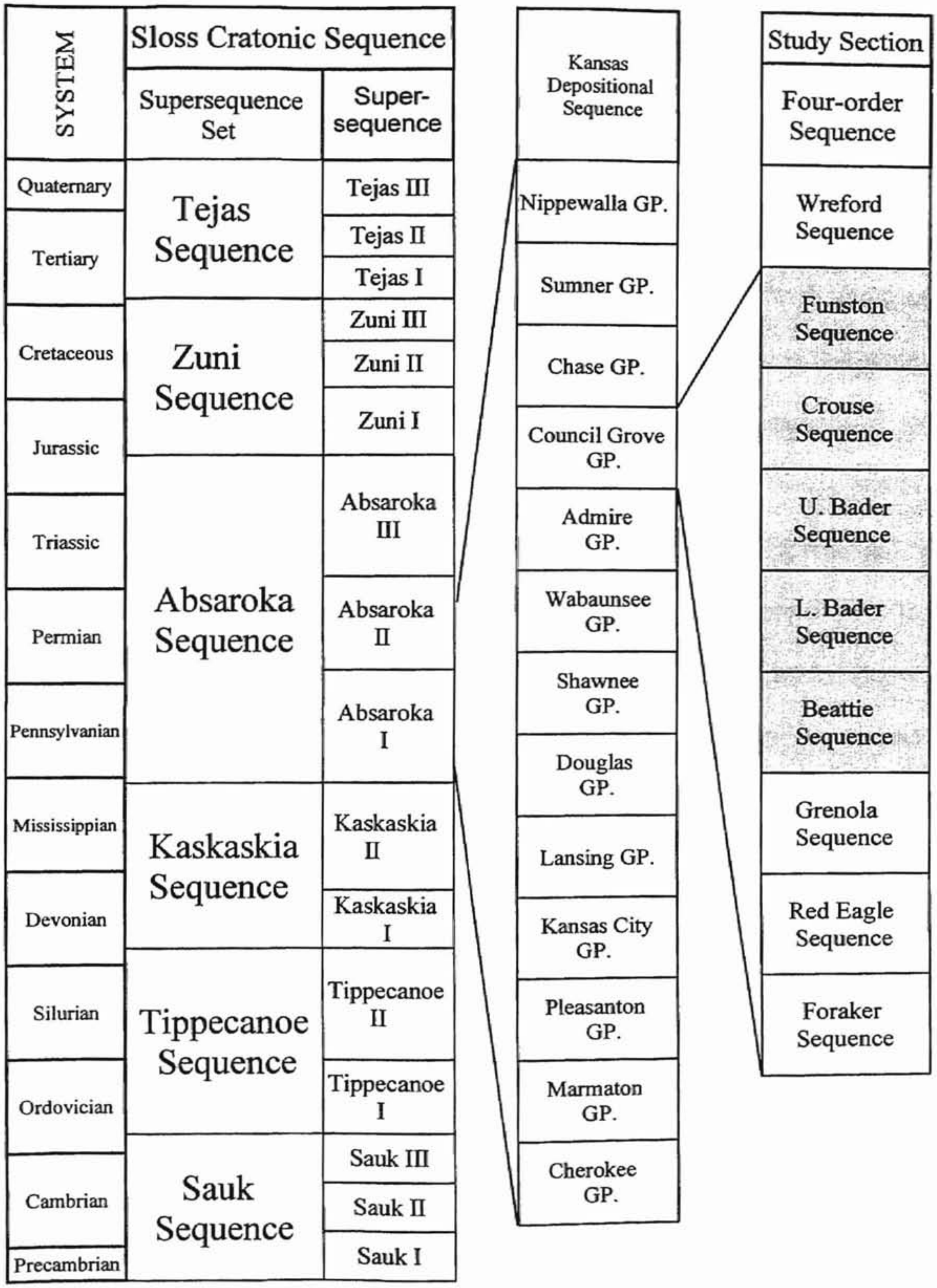


Figure 74 Sequence intervals of this study.

Sequence was also interpreted in greater detail by Puckette et al. (1995) from the Hugoton embayment and northern Oklahoma platform, including the Grenola Sequence of the lower Council Grove Group and Beattie, Bader, Crouse, and Funston Sequences of the upper Council Grove Group (Figure 26). Puckette et al. (1995) point out two distinct types of sequences within the Council Grove Group. They stated " The sequences in the lower part (Foraker through Crenola Formations) consist of (1) a basal transgressive surface, (2) a shallow marine limestone with a marine condensed section that represents the transgressive and highstand systems tracts, (3) shallow water carbonates with a weathered upper surface (exposure surface) that represents forced regression, and (4) red caliche-bearing, blocky claystones and siltstones (red beds) that may correspond to the lowstand systems tract of the Shelf margin. The sequences in the upper part (Beattie Limestone through Speiser Shale) are similar to those in the lower Council Grove, but lack the marine condensed section that represents a well defined highstand systems tract" (p. 269). Thin transgressive lag deposits, separating the limestones from the underlying nonmarine red beds, were recognized as the lower sequence boundaries of the Council Grove Group. A carbonate marine condensed section with glauconitic, skeletal phosphate, and abundant conodonts commonly represents maximum flooding surface within the sequence. "The upper surfaces of the regressive carbonate units and overlying nonmarine claystones and siltstones exhibit evidence of subaerial exposure...The succeeding claystone are red and contain nodular caliche" (Puckette, et al., 1995, p. 269). This paper concluded as follows; "(1) The Council Group is composed of repetitive cycles of shallow marine carbonates and siliciclastics and nonmarine red beds that document sea-level oscillations. (2) Depositional sequences in the Council Grove display a vertical facies succession (L-WP through RC) that documents flooding and deepening, followed by a general shallowing phase that culminated in subaerial exposure, karsting, and redbed deposition. A complete succession of these genetically related strata is considered a fourth-order depositional sequence. (3) The differences in the character of the fourth-order sequence reflect general trends in facies that help define sequence sets. The Council Grove consists of three sequence sets (transgressive, highstand, and regressive) that composed a third-order composite sequence." (p. 290). A detailed upper Council Grove Group Sequence from the Beattie Sequence through Funston Sequence will be also interpreted from the southern through northern Kansas late in this chapter.

Method of Determination and Recognition Boundaries and Systems Tracts From Facies Analysis

Sequence boundaries (transgressive surfaces), maximum flooding surface, and systems tracts can be determined from characteristics of the outcrop or analysis of thin sections. The five fourth-order sequences of the Upper Council Grove Group are equivalent to sequences according to Fritz and Medlock's five orders of stratigraphic cycles (1995). Van Wagoner et al.(1987) defined sequence as "bounded by unconformities and their correlative conformities". In addition, Van Wagoner (1988) defined stated that "a marine-flooding surface is a surface that separates younger from older strata, across which there is evidence of an abrupt increase in water depth". A marine-flooding surface is commonly equivalent to a transgressive surface of previous workers (Shelton et al. 1995). Fourth-order sequence boundaries defined as transgressive surfaces are commonly associated with subaerially exposed red or green shale, and incised valley fill with sandstone and transgressive lag.

In order to determine relative sea level and maximum flooding surface and to recognize sequence boundaries and system tracts, ten facies are designed from characteristics of the outcrop or analysis of thin section as the follows;

(1). Channelized sandstone facies (CSa): A well-sorted fine-grained sandstone with cross-bedding structure represents lens deposits in the outcrop.

(2). Red or green paleosol facies (RGPa): They are commonly represented as blocky or crumbly, red or green claystone that may be rich in calcium carbonate are referred to as caliche.

(3). Silty shale and Siltstone facies (SS): They are commonly represented as blocky or fissile shale with sparse fossils and are various in color.

(4). Peloid packstone facies (PeP): This is a pelletal sediment which shows considerable irregularity of "pellet" size

(5). Siliceous Chalcedony facies (SiCh): A fresh water diagenetic feature, silica replacement occurs within carbonate rock.

(6). Intraclast wackestone to packstone facies (IWP): Large, rounded grains with internal structure are clearly reworked sediments during first flooding transgressive event, and are commonly underlying red green paleosol.

(7). Ostracod mudstone facies (OsM): The thin-walled ostracod with the carapace is often found in the abundant amounts of mud matrix.

(8). Gastropod packstone facies (GP): Well-sorted gastropods are the dominant skeletal grains with abundant amounts of sparry cement.

(9). Gastropod-Brachiopod wackestone to packstone facies (GBWP): The majority of the skeletal grains are gastropods and brachiopods in a matrix.

(10). Brachiopod-bryozoan oncoid wackestone to packstone facies(BBzOWP): Brachiopod and bryozoan grains are coated by algae

(11). Brachiopod-bryozoan wackestone to packstone facies(BBZWP): Skeletal grains in matrix are dominated by brachiopods and bryozoan.

(12). fossiliferous shale facies (FoS): This facies consists of grayish, or brownish calcareous and fissile shale with abundant fossils. (only for Florena Shale)

(13). Fusulinid wackestone to packstone facies (FWP): Fusulinids are the majority of the skeletal grains in matrix.

Sequence Boundary

The transgressive surface at the sequence boundary was formed during the time between the maximum regression and the initial marine flooding event. This surface marks the change from regression to transgression. During maximum sea-level regression the paleoenvironment can include subaerial exposure, which is the favorable environment for the development of a mature soil profile (red and green paleosol facies), or incised valley fills (Channelized sandstone facies) on a semiarid to arid flood plain. The carbonates immediately began to be deposited above red or green paleosols. The transgressive lags and intraclasts can be commonly observed at the base of the carbonate formation. The transgressive lags and intraclasts, overlying the sequence boundary, were evidence of an abrupt increase in water depth, because they were deposited during the initial flooding event.

Underlying red and green paleosol facies and channelized sandstone facies

Red and green claystone as red and green paleosol facies, commonly deposited during maximum regression, have recently been described and recognized as paleosols from the stratigraphically repetitive sediments of Pennsylvanian-Permian of the Mid-Continent region, particularly by Joeckel (1985, 1991), Prather (1985), Schutter and Heckel (1985), Schultz (1988), Goebel et al. (1989), Joeckel (1989), and Ettensohn et al. (1988). Goebel states that "paleosols have potential for being excellent paleoenvironmental and paleoclimatic indicators.." (1989, p. 224). In addition, Paleosols are useful means for interpretation of the cyclothem boundary or sequence boundary, because the boundary represents maximum regression; "a mature soil profile developed in the upper shale during prolonged exposure on a semiarid to arid flood plain during maximum sea-level regression.." (Prather, 1984). Red and green paleosol facies are commonly represented as blocky or crumbly in internal structure. They may be rich in calcium carbonate as well, and are referred to as caliche. A detailed interpretation of the color of the paleosols has been done by many authors (e.g., Mcfadden, 1982; Mcfadden and Bull, 1988). Miller states that "The reddish color records oxidation under fairly well drained conditions, the underlying greenish gray horizons probably indicating the average position of the water table" (19? , A287). In addition, "secondary ferric-iron oxides have also accumulated in soils of arid and semiarid...the degree of reddening of the soils also correlates strongly with increases in soil iron-oxide content....the degree of reddening of soils is closely related to the relative amount of hematite present" (McFadden, 1988, p. 162). Paleosols rich in calcium carbonate are referred to as caliche; it is represented as a calcareous nodular interval within soil zones. "The caliches resulted from soil and ground-water conditions in a semi-arid climate characterized by seasonal rain and drought and an overall net moisture deficit" (Ettensohn, 1988, p. 49). The source of the calcium may have been calcareous dust blown from the top of carbonate rocks (Hubert, 1977). The Caliches are important indicators of paleosol development in Pennsylvanian-Permian of the Mid-Continent region. The characteristics of the caliche have been described by several authors (Ettensohn, 1988; Blodgett, 1988; Hubert, 1977; Wright, 1982; Mcpherson, 1979; Heckel, 1983 &1985; Schutter, 1983). A number of blocky mudstones provides substantial evidence of seasonal climatic conditions; "Blocky mudstones are particularly evident in those areas where there was little or no fluvial influence, and the subaerial environment.."(Heckel et al., 1985, p. 119). This is because "The swelling clays, under the influence of an alternately wet and dry climate, produce the blocky structure characteristic of the blocky mudstones..." (Heckel et al., p. 119). Therefore, paleosols may provide excellent markers for interpretation of the cyclothem or sequence boundary; the transgressive surface.

Channelized sandstone facies as incised valley fills indicate subaerial exposure with sandstone deposits. "Incised valleys form and fill in two phases. The first phase consists of erosion, sediment bypass through the eroded valleys, and deposition at the lowstand shoreline in response to a relative fall in sea level. The second phase consists of deposition within the valleys in response to a relative rise in sea level, generally during the late lowstand or transgressive systems tracts" (Van Wagoner et al. 1990, p. 31). In addition to the historical influence of sea-level history on the formation of incised valley fills, Archer et al. (1995) also considered that " climate may have had a profound influence. During wetter periods, rivers incised more deeply and developed extensive valley systems. During the drier periods, such as the Permian, valleys apparently did not develop at all". Fourth-order sequences are rather easily recognized by upward-coarsening. In general, these sandstone deposits lie directly below the sequence boundary. Incised valley fills can be rather easily recognized from the exposed outcrops.

Overlying transgressive lag and intraclast facies

The transgressive lag and intraclast facies can commonly be observed overlying a marine-flooding surface. They derive "from underlying strata by shoreface erosion during a marine transgression, and are concentrated as a discrete bed on top of the transgressed surface, commonly on the inner to outer shelf. The majority of marine-flooding surfaces observed...are marked by a sharp boundary free of concentrations of sedimentary particles" (Van Wagoner et al., 1990). The transgressive lags and intraclasts commonly observed at the base of the limestone formation from the exposed outcrops. They indicated the transgressive surface which represents a fourth-order sequence boundary.

Therefore, paleosols, incised valley fills, transgressive lag, and intraclast facies provide excellent markers for interpretation of the fourth-order sequence boundary.

Relative Sea level and Maximum Flooding Surface

The microfaunal content within the limestone can be observed from analysis of thin section. According to the Elias's Zonal distribution of benthnic organisms in shallow depths of Big Blue Sea (Figure 18), the fossil content can be a useful tool to construct the relative sea level curve of the Upper Council Grove Group. Elias (1937) interpreted the Late Paleozoic rocks of Kansas in terms of cyclic sedimentation and depth of deposition based on comparison of distribution of organisms in the cycles of the Big Blue with the benthonic zones of modern seas. Elias established several phases from deepest open marine to subaerially exposed environments: fusulinid phase, brachiopod phase, mixed phase, molluscan phase, lingula phase, green shale, and red shale phase, in ascending order. Several facies are designed for determination of the relative sea level based on Elias's Big Blue phases: (1). Channelized sandstone facies (CSa), (2). Red or green paleosol facies (RGPa), (3). Silty shale and Siltstone facies (SS), (4). Ostracod mudstone facies (OsM), (5). Siliceous Chalcedony facies (SiCh), (6). Intraclast wackestone to packstone facies (IWP), (7). Peloid packstone facies (PeP), (8). Gastropod packstone facies (GP), (9). Gastropod-Brachiopod wackestone to packstone facies (GBWP), (10). Brachiopod-bryozoan oncoid wackestone to packstone facies(BBzOWP), (11). Brachiopod-bryozoan wackestone to packstone facies(BBZWP), (12). fossiliferous shale facies (FoS), (13). Fusulinid wackestone to packstone facies (FWP). The maximum flooding surface, most extensive at the time of maximum regional transgression of the shoreline, is the interval of the changeover from transgressive to regressive phase within the sequence and boundary between transgressive system tract and highstand system tract. The maximum flooding surface of the fourth sequence in the upper Council Grove Group can be recognized by analysis of the facies. The basic models for that the idealized facies correspond to the relative sea-level fluctuation curve and transgressive-regressive phase are showing in Figure 75 and 76.

Systems Tracts

The Systems tracts of the upper Council Grove Group Sequence can be recognized from bio-facies and lithofacies analyses. The transgressive systems tracts consist of upward-deepening carbonate which is a gradual change in lithofacies and faunal content from intraclast-rich wackestone upward to skeletal and oncoid-rich wackestone. The maximum flooding surface commonly represents as early highstand systems tracts which commonly contain abundant bioclasts; fusulinid-rich wackestone to packstone or brachiopod and gastropod-rich wackestone to packstone. The late highstand systems tracts can be characterized by ostracod-rich wackestone to mudstone, peloid-rich wackestone to packstone, or siliceous rock of a fresh-water diagenesis event (chalcedony). The lowstand systems tract were developed during maximum regression, presenting subaerial exposure which is a favorable environment for palesols or silty shale, and siltstone, and incised valley sandstone deposits. The detailed facies relate to system tracts showing in Figure 76.

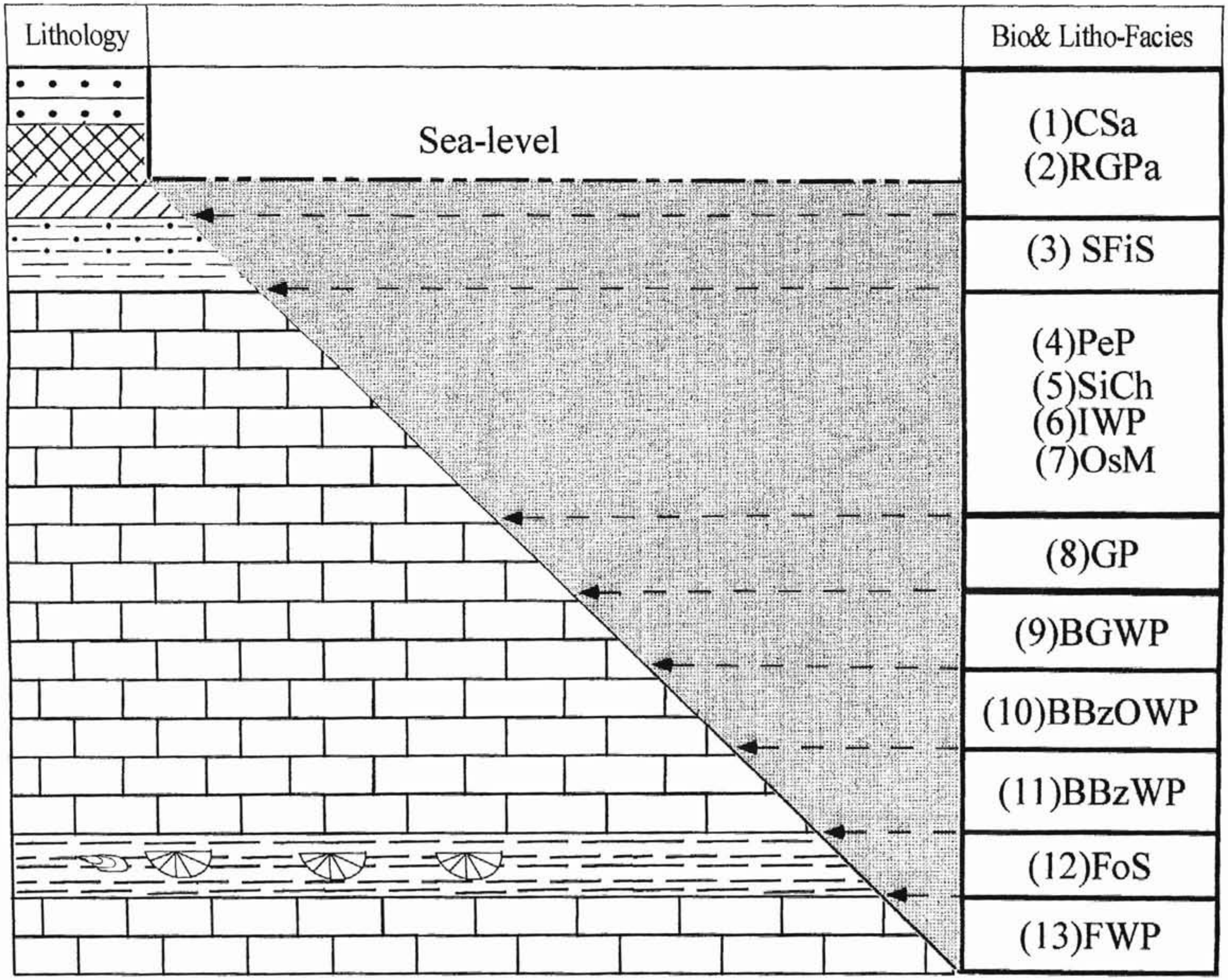


Figure 75 The bio and lithofacies related to relative water depth

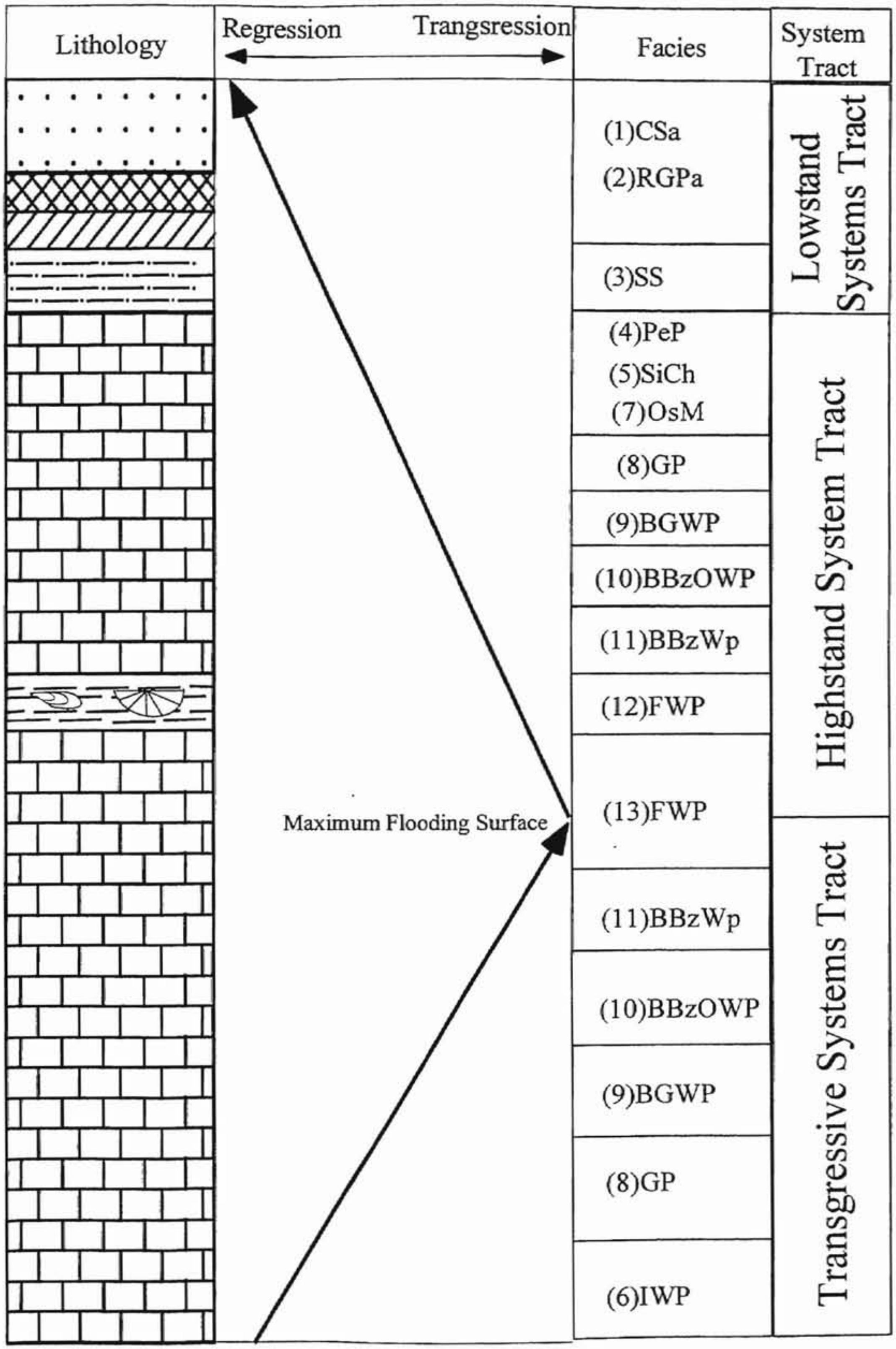


Figure 76 The bio and lithofacies related to Systems Tracts

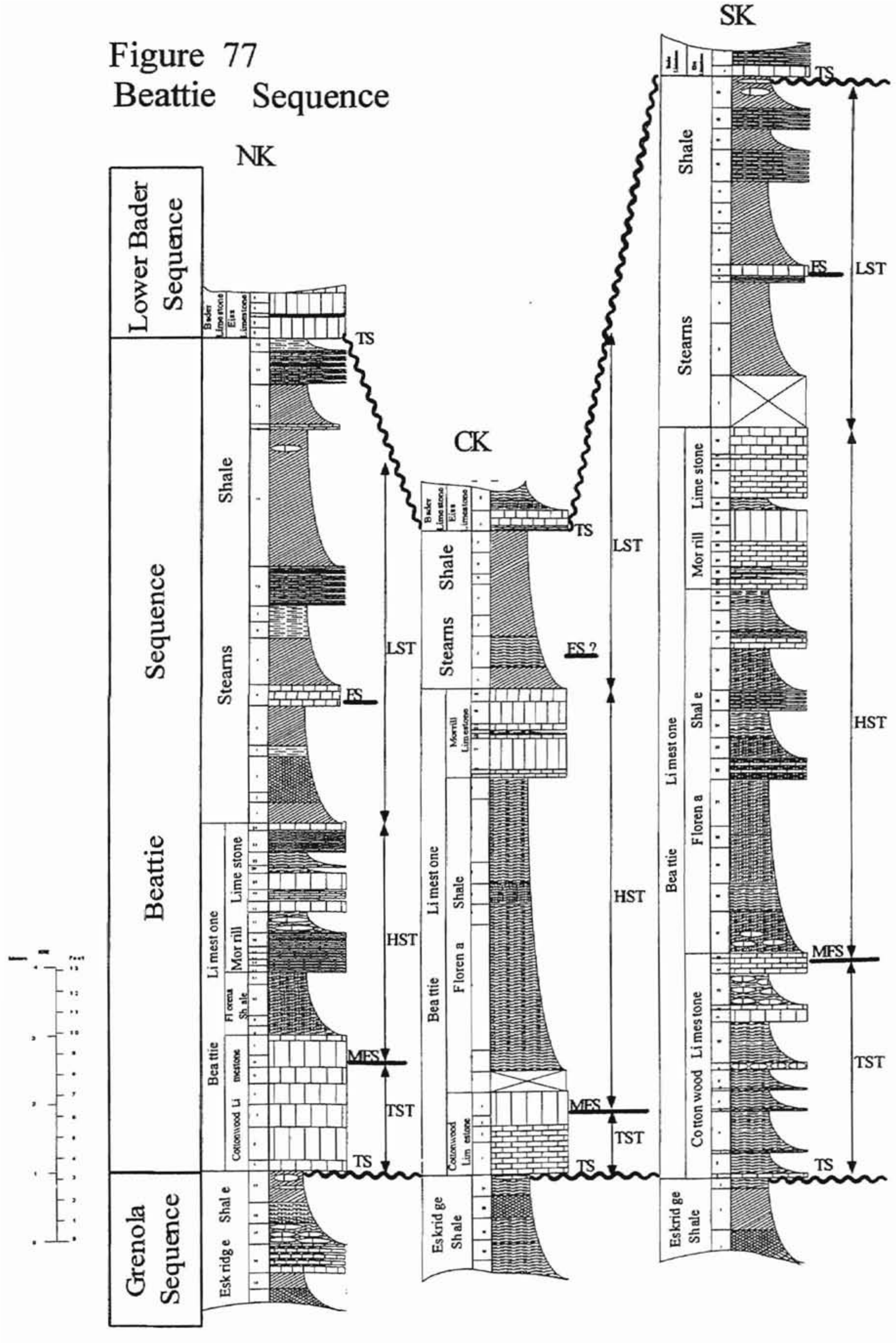
Interpretation of the Upper Council Grove Group Sequence From Analysis of the Outcrops

A total of five fourth-order sequences of the upper Council Grove Depositional Sequence have been studied and interpreted from the southern Kansas to northern Kansas exposed outcrops; in ascending order, Beattie, Lower Bader, Upper Bader, Crouse, and Funston Sequences.

Beattie Sequence

The fourth-order Beattie Sequence, underlain by the Grenola Sequence and overlain by the Lower Bader Sequence, is from the disconformable base of the Cottonwood Limestone Member to the top of the Stearns Shale (Figure 77). It consists of the Cottonwood Limestone, Forena Shale, Morrill Limestone, and Stearns Shale. The lower sequence boundary is a transgressive surface at the base of the Cottonwood Limestone. The red or green shale can be commonly observed below this lower sequence boundary (within the top of the Eskridge) and intraclasts can be found above this lower sequence boundary (within the base of the Cottonwood Limestone). This sequence contains one major maximum flooding surface (MFS) within the Cottonwood Limestone and one minor maximum flooding within the Stearns Shale (Nk unit 6, Ck, unit ?, and Sk unit 5). The MFS of the Beattie Sequence occurs within the deeper water Cottonwood Limestone Member, at approximately the top of the Cottonwood Limestone Member (Nk unit 6, Ck, unit 4, and Sk unit 15). The lithology of the maximum flooding within this sequence is limestone which commonly is wackestone or packstone with abundant

Figure 77
Beattie Sequence



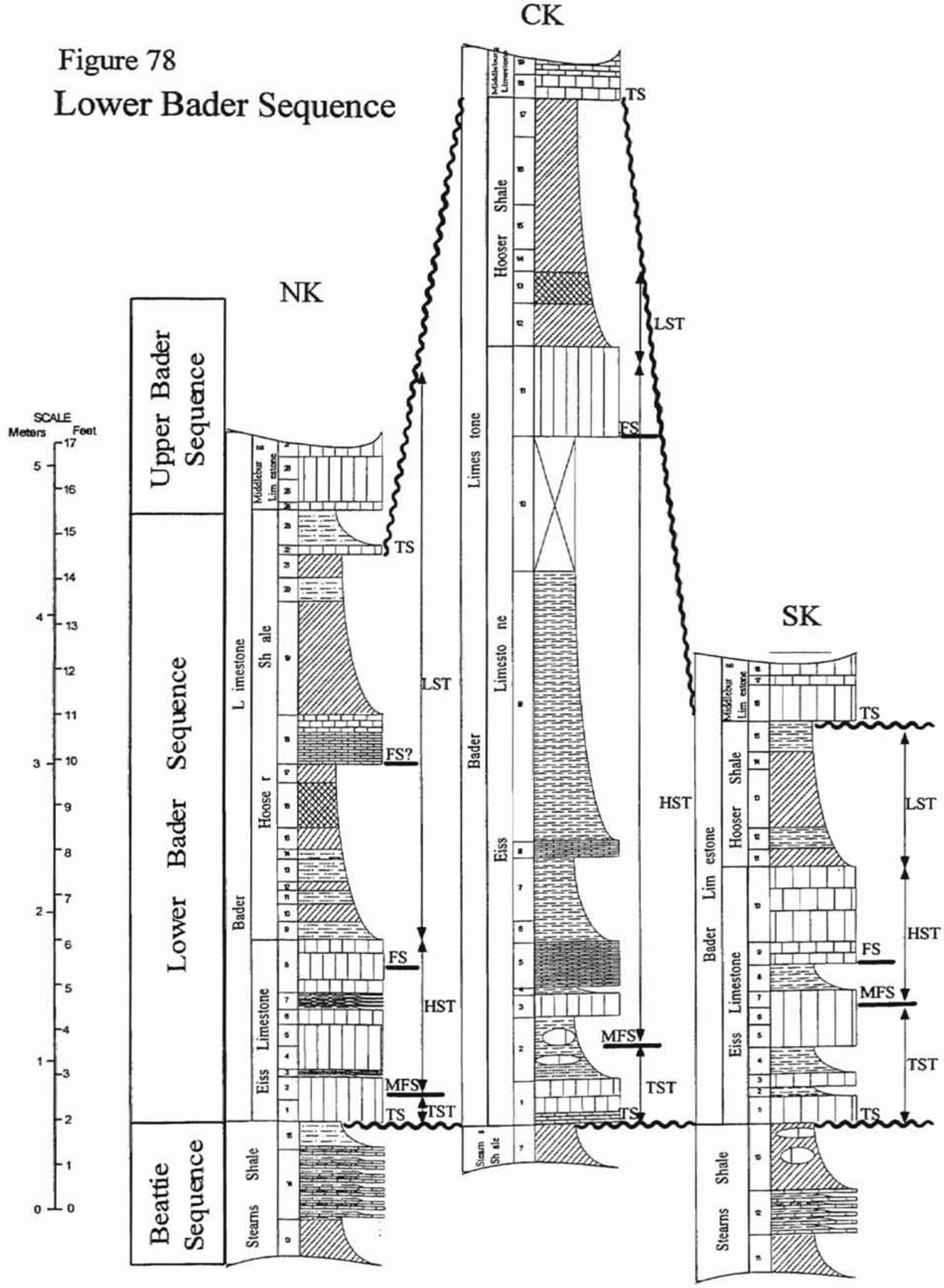
fusulinids ((13) FWP facies). In general, the Cottonwood Limestone forms the transgressive systems tract of the Beattie Sequence and contains an upward increase in microfaunal contents, especially fusulinids. The Florena Shale and Morrill Limestone are considered to be the highstand systems tract of this sequence which has upward-increasing restricted microfaunal content and peloids. The Stearns Shale in the upper part of this sequence, commonly red and green claystone ((2)RGPa facies), can be considered to be the lowstand systems tract which was formed during the maximum regression. The Beattie Sequence averages 41 feet (12.5 meters) in thickness. It thickens both north and south from Chase County where it is about 30 feet (9 meters) in thickness. A maximum thickness of about 52.5 feet (16 meters) was observed in Cowley County.

Lower Bader Sequence

The fourth-order Lower Bader Sequence, bounded below by the Beattie Sequence and above by the Upper Bader Sequence, extends from the disconformable base of the Eiss Limestone to the top of the Hooser Shale. This sequence includes both the Eiss Limestone and Hooser Shale (Figure 78). The Lower Boundary of the Bader Sequence is placed below the Eiss Limestone, a disconformable contact above which intraclasts and transgressive lags were deposited in the base of the Eiss Limestone and below which green shale (paleosol) was commonly found in the upper part of the Hooser Shale. The fourth-order Lower Bader Sequence contains three transgressive-regressive events of 5th order sequence. The two major and one minor flooding surface in this sequence were found within the Eiss Limestone and Hooser Shale (Nk unit# 2, 8, 18, Ck unit# 2, 11,?, and Sk unit# 7, 9, ?). The lithology of the two major flooding surfaces within this sequence is limestone, which commonly is wackestone or packstone with abundant gastropods and few brachiopods. The maximum flooding surface occurs in the lower part of the Eiss Limestone(Nk unit #2, Ck unit #2, and Sk unit #7), containing brachiopods, bryozoans, and echinoderms ((11)BBzWP). The Eiss Limestones of the Lower Bader Sequence is considered to be the transgressive to highstand systems tract. The Eiss Limestone is divided by the maximum flooding surface into the transgressive systems tracts in the lower part of the Eiss Formation and highstand systems tracts in the upper part of Eiss formation. The overlying Hooser shale of the upper part of this sequence, commonly red and green shale ((2)RGPa), can be considered to be the lowstand systems tract which was formed during the maximum regression. The Lower Bader Sequence averages 15.2 feet (4.6 meters) in thickness. Its maximum thickness is 23 feet (7 meters)

Figure 78

Lower Bader Sequence



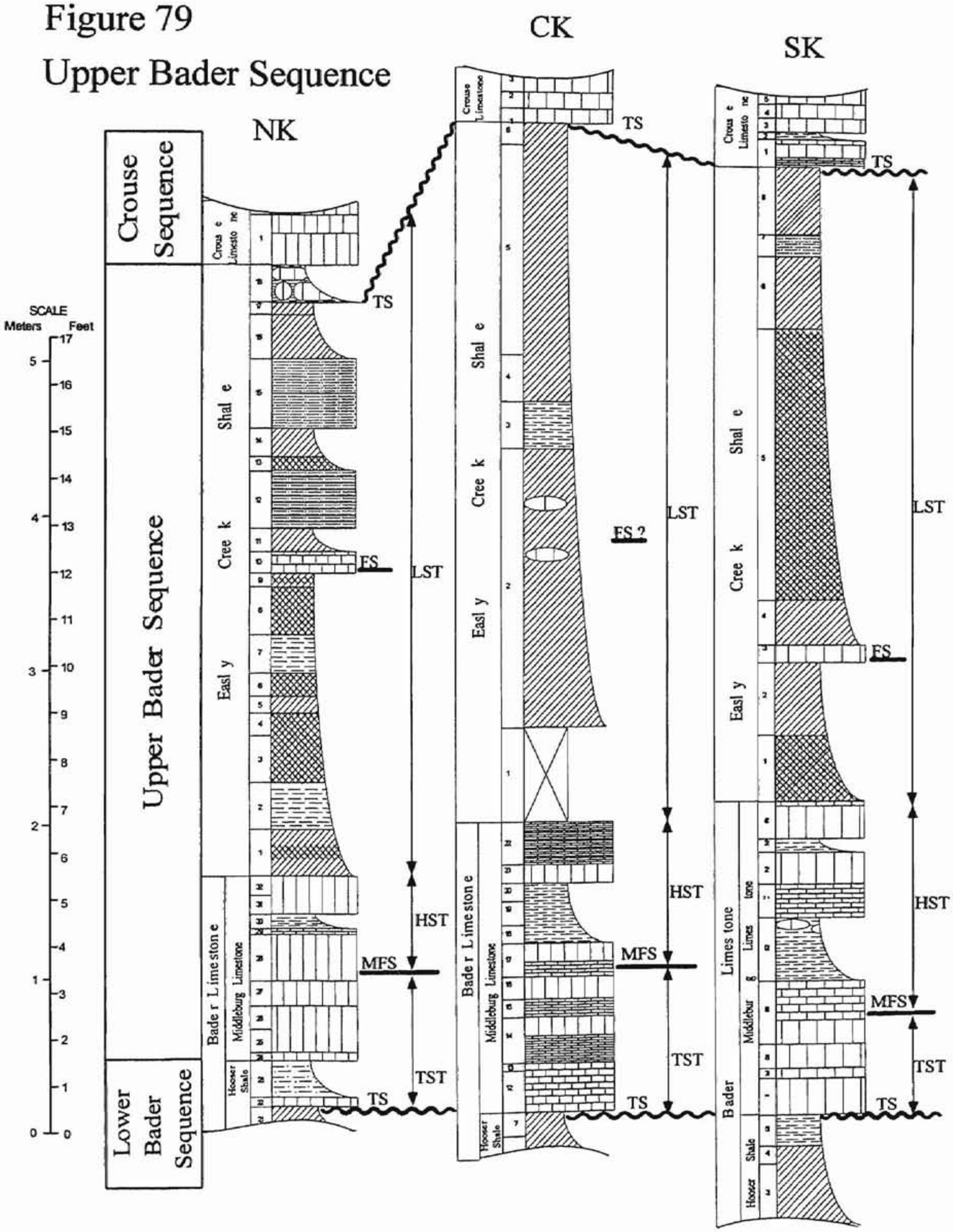
in Chase County, whereas a minimum thickness of 9 feet (2.7 meters) was measured in Cowley County. In general this Lower Bader Sequence thins both north and south from Chase County.

Upper Bader Sequence

The Upper Bader Sequence, underlain by the Lower Bader Sequence and overlain by the Crouse Sequence, extends from the disconformity at the base of the Middleburg Limestone (except in NK at the uppermost limestone of the Hooser Shale) to the top of the Easly Creek Shale (Figure 79). This sequence contains the Middleburg Limestone and Easly Creek Shale. The lower boundary of the Upper Bader Sequence occurs as a transgressive surface at the base of the Middleburg Limestone. The lower boundary is marked below by red or green shale of the Hooser Shale and above by abundant intraclasts within the base of the Middleburg Limestone. Two transgressive-regressive events of the sub-sequence are observed within the Upper Bader Sequence. One major and one minor marine flooding surface were found within the Middleburg Limestone and Easly Creek Shale. The major marine flooding surface within the Middleburg Limestone, consisting of wackestone or packstone with abundant gastropods ((8)GP facies), represent as a MFS of the Upper Bader Sequence (Nk unit 28, Ck unit 17, Sk unit 19). The Middleburg Limestones of the Upper Bader Sequence, separated by maximum flooding surface into the transgressive systems tract in the lower part of the Formation and highstand systems tract in the upper part of the Middleburg Limestone, is very thin to thick-bedded limestones. The lowstand system tract of this sequence is characterized with silty red and green shale ((2)RGPa facies) within the Easly Creek Shale which was deposited during the maximum regression. The Upper Bader Sequence averages about 19.7 feet (6 meters) in thickness, ranging from 17 to 19 feet (5 to 6.4 meters) and somewhat thins both north and south from Chase County Where it is about 21.3 feet (6.5 meters) in thickness.

Figure 79

Upper Bader Sequence

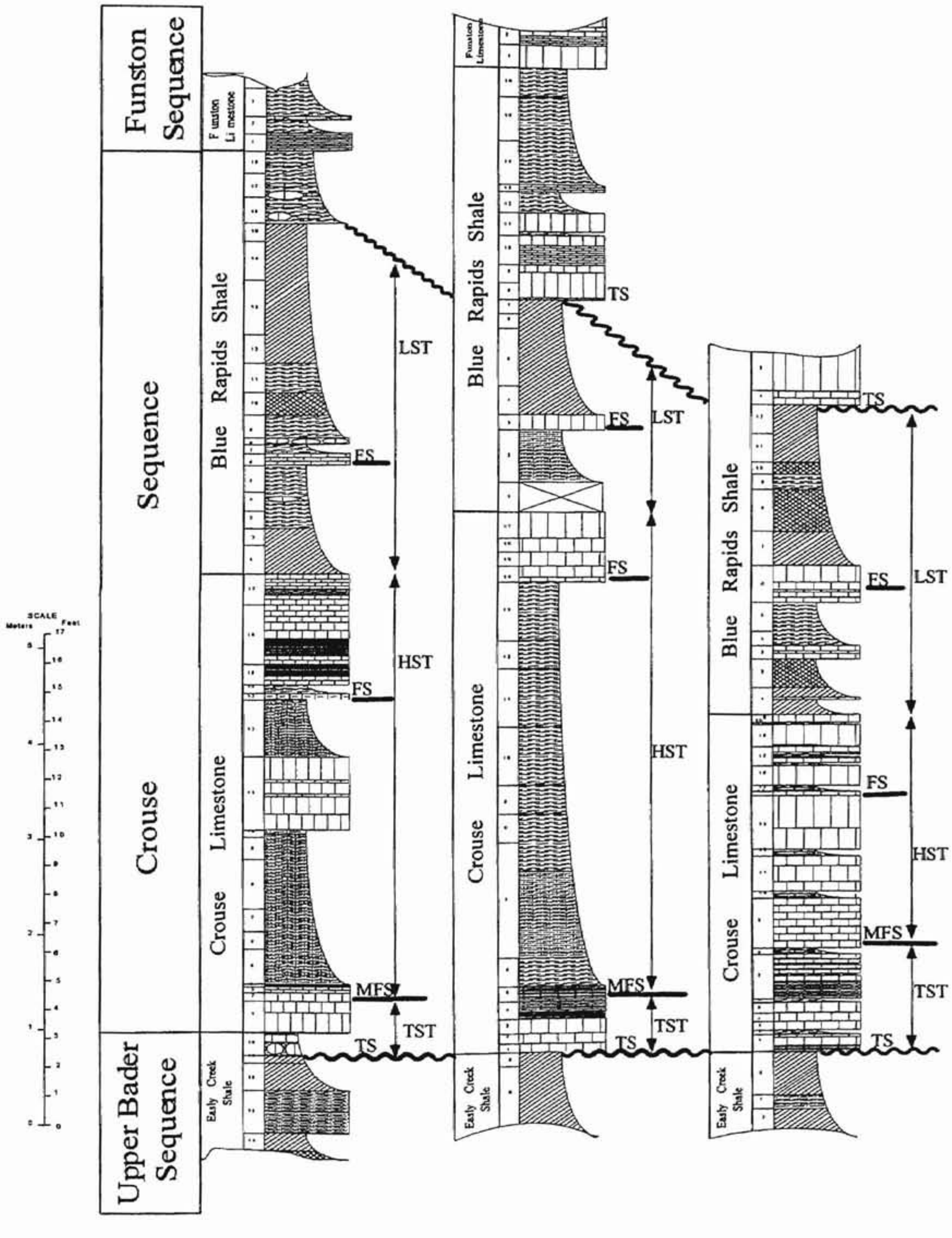


Crouse Sequence

The fourth-order Crouse Sequence, underlain by the Upper Bader Sequence and overlain by the Funston Sequence, is from the disconformable base of the Crouse Limestone Member to the upper limestone of the Blue Rapids Shale (Figure 80). It consists of the Crouse Limestone and Blue Rapids Shale. The transgressive surface occurs at the base of the Crouse Limestone, where it is the lower boundary of the Crouse Sequence. A paleosol forms below this boundary of the Crouse Sequence and is composed of red, green, or brown shales with some carbonate rock (within the tope of the Easly Creek Shale). Abundant intraclasts were deposited above this lower sequence boundary (within the base of the Crouse Limestone). The fourth order Crouse Sequence contains three transgressive-regressive events of the 5th order sequences. Two major marine flooding surfaces (Nk unit #2, 13, Ck unit #5, 14, and Sk unit #9,14) with abundant gastropods in the Crouse Limestone and one minor flooding surface (Nk unit #6, Ck unit 3, Sk unit 6) with some bioclasts in Blue Rapids Shale were found within the Crouse Sequence. The MFS of this sequence, a packstone with abundant gastropods and bioclast ((8)GP), occurs within the lower part of the deeper water Crouse Limestone (Nk unit 2, Ck unit 5, and Sk unit 9). It is a contact between transgressive and highstand systems tracts. The transgressive system tract of the Crouse Sequence was formed in the lower Crouse Limestone and the highstand system tract was formed in the upper Crouse Limestone. The upper lithologic unit (Easly Creek Shale) of the Crouse Sequence, consisting of olive gray and red shale ((2)RGPa) with some limestone beds, can be considered to be lowstand system tract, formed during the maximum regression and subaerial exposure. The Crouse Sequence averages about 26 feet (7.9 meters) in

Figure 80

Crouse Sequence

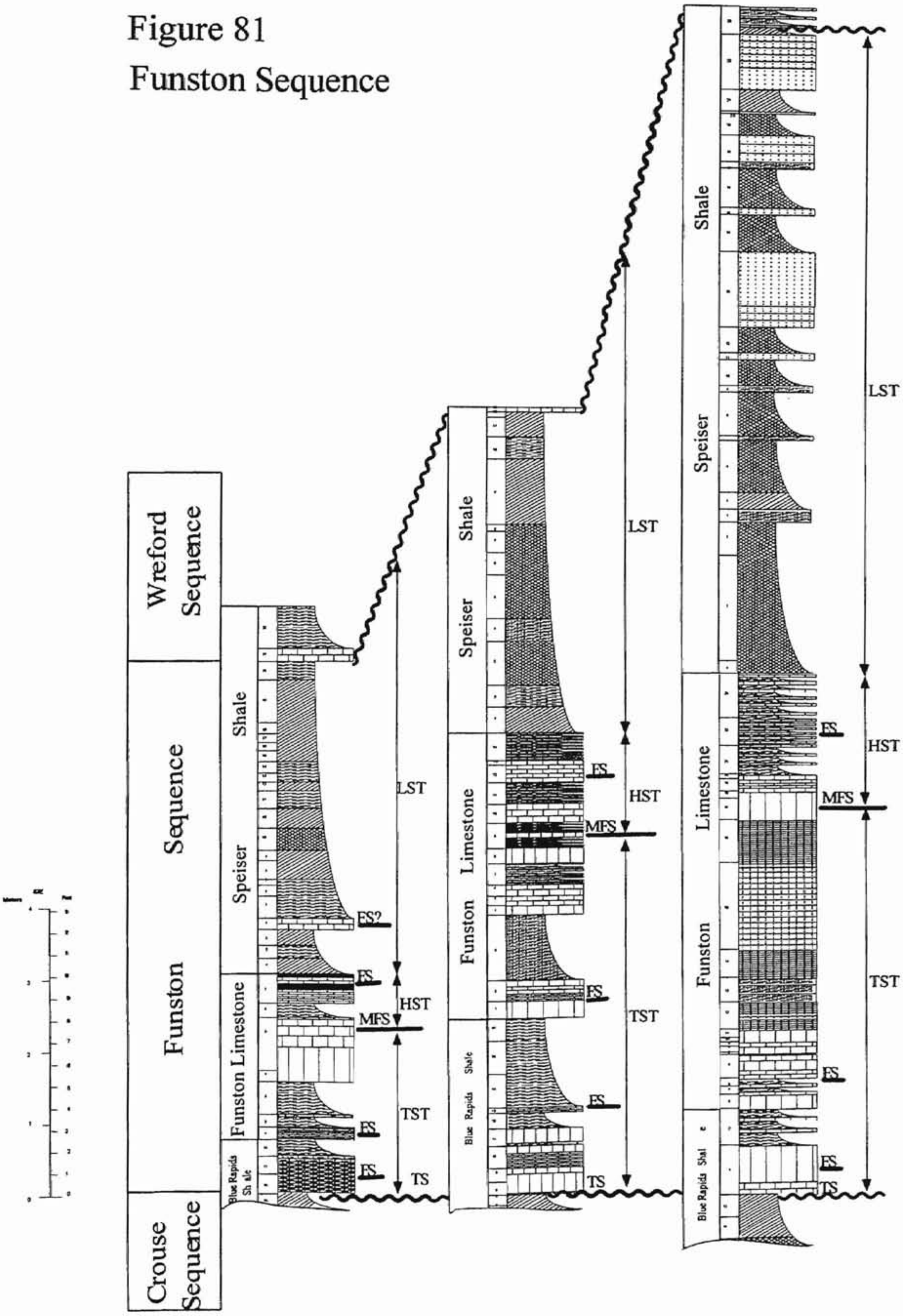


thickness, ranging from 22.7 feet (6.9 meters) in Cowley County to 29 feet (8.8 meters) Riley County and somewhat thins to north.

Funston Sequence

The Funston Sequence, consisting of the Funston Limestone and Speiser Shale, extends from the disconformable upper limestone of the Blue Rapids Shale to the top of the Speiser Shale (Figure 81). This sequence is bound below by the Crouse Sequence and Wreford Sequence. The lower boundary of the Crouse Sequence is at the upper limestone of the Blue Rapids Shale where the transgressive surface occurs. The olive brown and dark red shale with caliches in the Blue Rapids Shale can be observed below the transgressive surface. The base of the Funston Sequence commonly contains abundant intraclasts above the transgressive surface. The lithology of the Funston Sequence varies in different localities. This sequence commonly contains limestone in the lower part and a paleosol in the upper part. Incised valley fill ((1)CSa) with sandstone and siltstone ((3)SS) in the upper sequence can be observed at the south Kansas exposed outcrop. Four transgressive-regressive events of the subsequences are observed in this sequence. Three major marine flooding surfaces (Nk unit 1, 5, 7, Ck unit 2, 9, 12, Sk unit 1, 17, 22), commonly with oncoid, gastropod, bryozoan, and ostracod in the Funston Limestone and one minor flooding surface with few fossils in the Speiser Shale were found within the Funston Sequence. The MFS of this sequence, a packstone with few gastropods and bioclasts ((8)GP), occurs within the middle part of the deeper water Funston Limestone (Nk unit 5, Ck unit 9, and Sk unit 17). The lower Funston Limestone forms a transgressive system tract of the Funston Sequence and upper Funston Limestone forms a highstand system tract; separated by maximum flooding surface. The olive gray to red shale ((2)RGPa) and incised valley sandstone and siltstone ((1)CSa)of the Speiser Shale, formed during the maximum regression and subaerial exposure, are recognized as the

Figure 81
Funston Sequence



lowstand system tract of the Funston Sequence. The Funston averages 37 feet (11 meters) in thickness. In northern Kansas it is about 24 feet (7.3 meters) thick, thickening southward to as much as 53 feet (16 meters) in Cowley County.

The completely relative sea-level fluctuation curves of the Upper Council Grove Group from southern Kansas to northern Kansas, constructed from this study, are shown in Figure 82 through Figure 83.

Figure 82

NK Composite Section and Relative Sea-level Curve of the Upper Council Grove Group

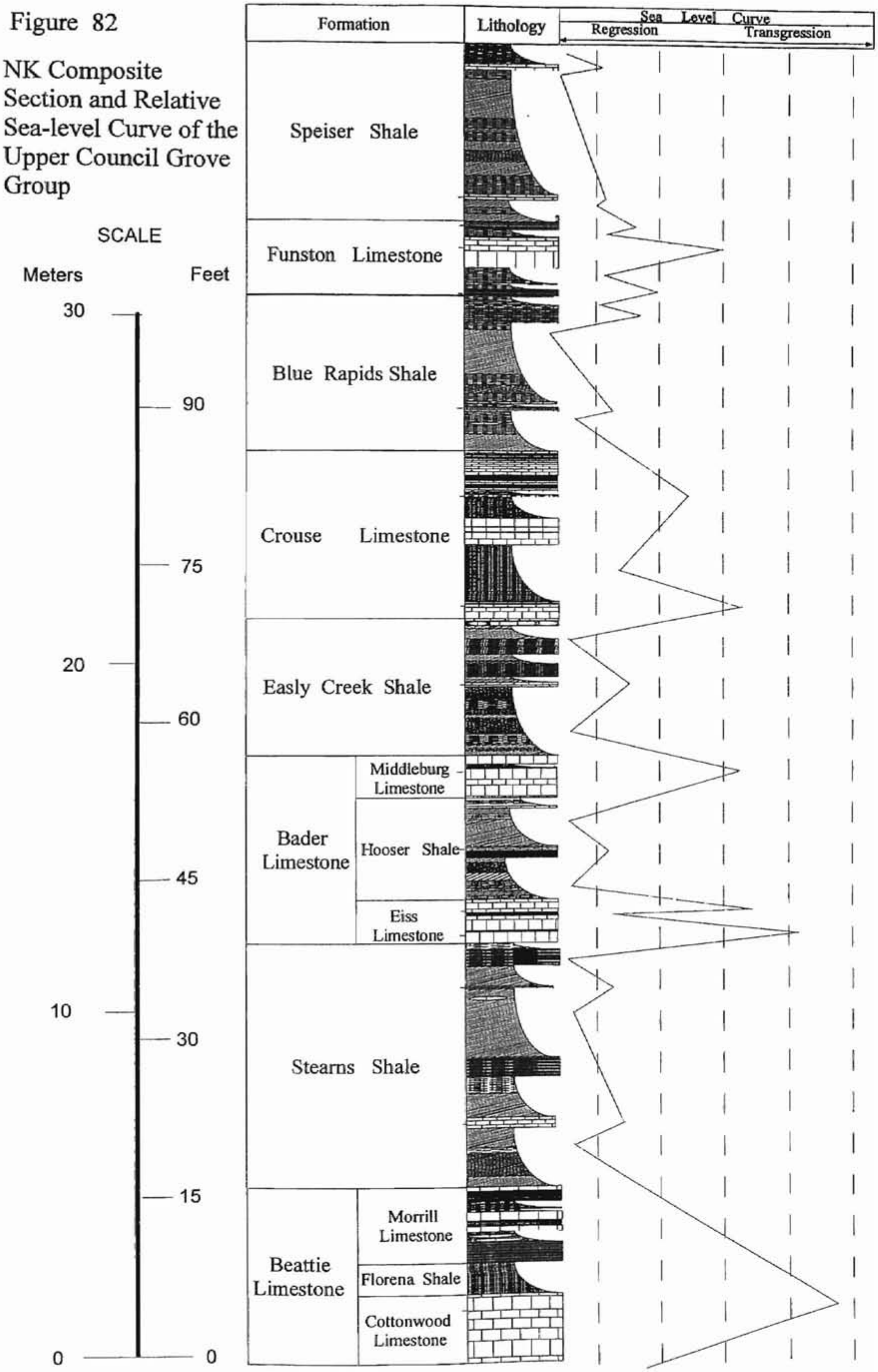


Figure 83

CK Composite Section and Relative Sea-level Curve of the Upper Council Grove Group

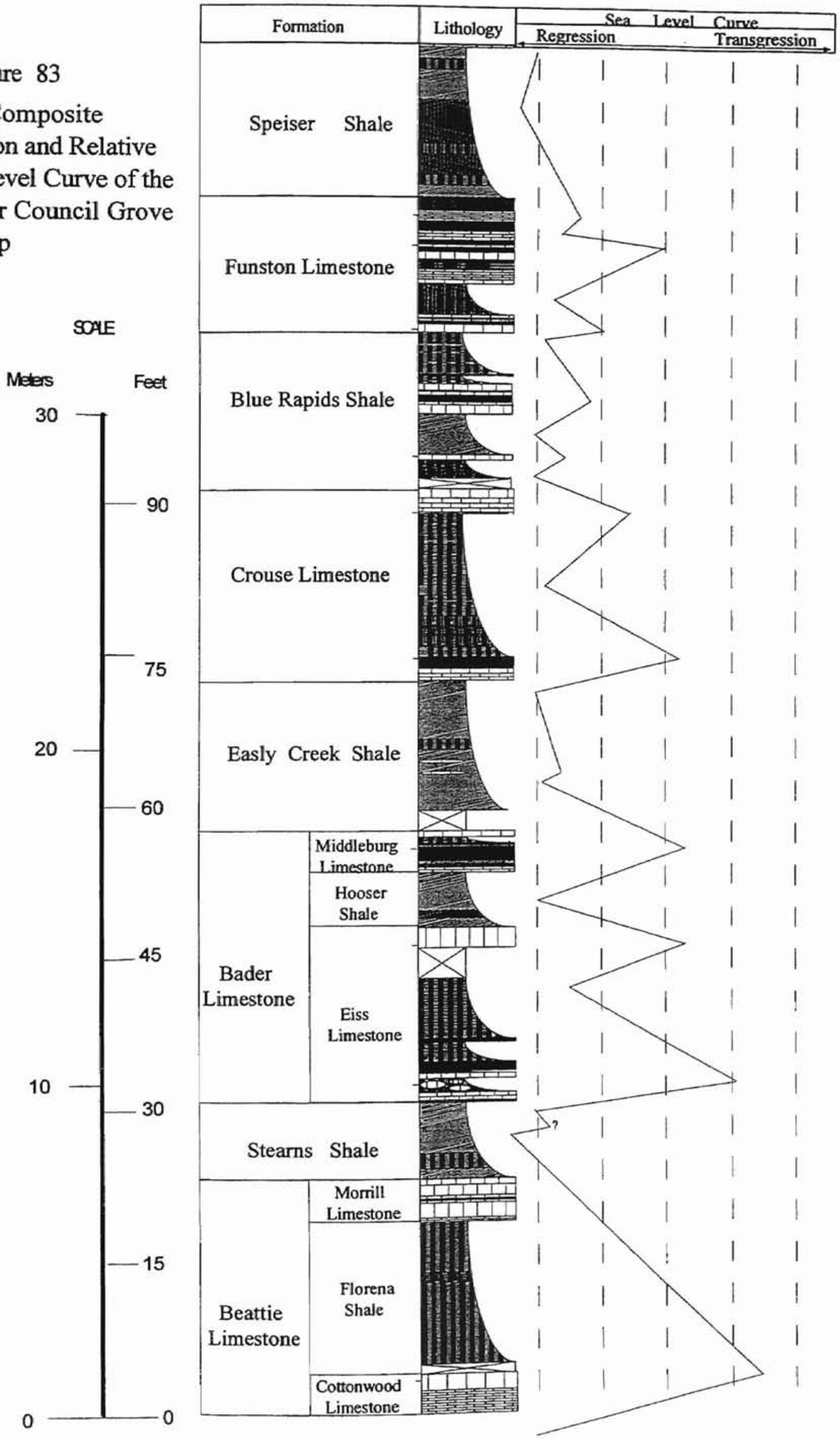
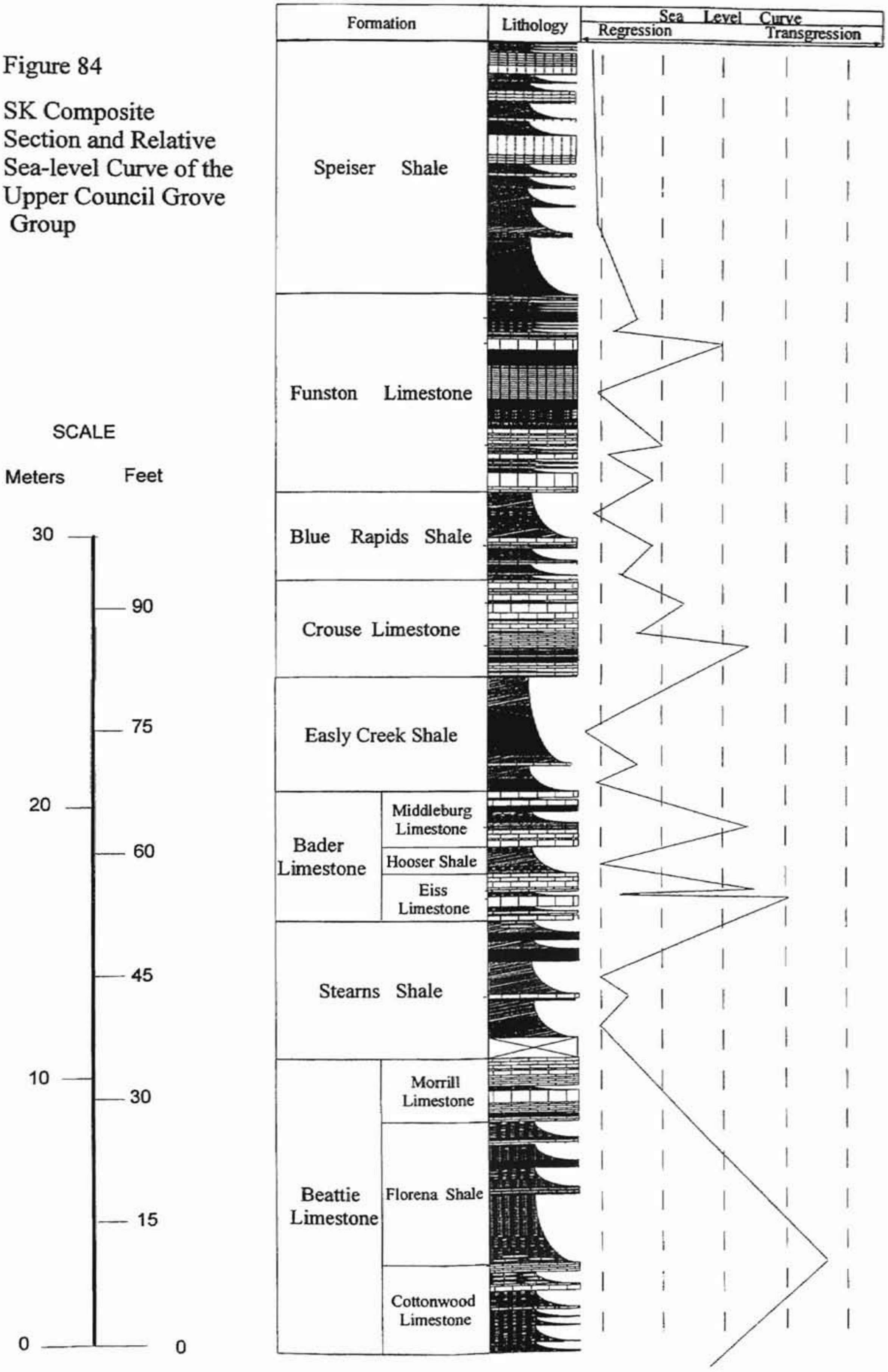


Figure 84

SK Composite Section and Relative Sea-level Curve of the Upper Council Grove Group



III

Conclusion

(1) Five cyclothemic-scale depositional sequences of the Upper Council Grove Group, as Forth-order sequence, are observed from study outcrop. They record sea-level oscillations during the Upper Council Grove Group time.

(2) The deepest maximum flooding surface of the Upper Council Grove Group occurs within the Beattie Sequence.

(3) The shallowest maximum flooding surface occurs within the Funston Sequence.

(4) The entire Council Grove Group Sea is shallowing toward to the top of the Council Grove Group.

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