STRATIGRAPHY AND PARASEQUENCE ANALYSIS OF DAKOTA FORMATION-GRANEROS SHALE TRANSITION (UPPER CRETACEOUS), CENTRAL KANSAS

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Kansas Geological Survey
Open-file Report 94-57

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Submitted to the faculty of the University Graduate School
in partial fulfillment of the requirements
for the degree
Master of Science
in the Department of Geological Sciences
October, 1994

Accepted by the faculty of the Department of Geological Sciences, Indiana University, in partial fulfillment of the requirements for the degree of Master of Science, October, 1994.

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ABSTRACT

In central Kansas upward stratigraphic transition from nonmarine and marginal marine Dakota Formation to offshore Graneros Shale was produced during eastward transgression of the Cretaceous Western Interior Sea. This transition was analyzed in eight stratigraphic sections situated in the Hodgeman/Ford and Russell/Ellsworth county areas. There, sandstone, mudrocks, and interbedded sandstone-and-shale intervals are principal lithologies in the upper Dakota and Graneros interval. In most of the studied sections, the lower units are typically composed of sandstone and mudstone, whereas the upper units are mostly shale and interbedded sandstone-shale.

Strata of the Dakota-Graneros transition comprise units that were deposited in environments ranging from nonmarine fluvial to open-marine shelf including floodplain, secondary fluvial channel, coal swamp, lagoonal and open-marine environments. Correlation of measured sections is problematic owing to great lateral variability of sedimentary facies, which reflects deposition in a complex clastic shoreline setting. In these sections bentonite beds are the most useful datums for chronologic correlation.

Previous workers imply that transgression of the Western Interior Sea occurred in response to uniform rise of relative sea level. However, minor sea level fluctuations led to episodic progradation along the siliciclastic shoreline in the study area and locally produced as many as four lithologically repetitive bundles of strata that are interpreted as parasequences. Each of these parasequences contains a shallowing-upward bundle of strata that is truncated by a marine flooding surface. The best-developed parasequences in the study area are characterized by an upward succession that includes marine sandstone, lagoonal silty to carbonaceous shale, and coastal lignite. This kind of succession compares well with models of parasequences developed in tidally dominated settings. Parasequences recorded in this study indicate the complex nature of transgression in the Western Interior Seaway and may prove helpful in studies of modern sea level fluctuations.

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INTRODUCTION

Hattin (1965, 1967) and Seimers (1971) studied the upper part of the Dakota Formation and Graneros Shale as part of a broad program aimed at determining stratigraphy, depositional environments, faunal assemblages, and paleogeography of upper Cretaceous strata in central and western Kansas (Fig 1). These formations were laid down during the transgressive part of a depositional cycle, the maximum transgressive peak of which is marked by Greenhorn Limestone. This unconformity-bounded stratigraphic interval, referred to by Hattin (1964) as the Greenhorn cyclothem and by Hamilton (1994) as the D Sequence, is termed Greenhorn Sequence in this investigation (Fig. 2). Although the overall transgressive nature of the upper Dakota-Graneros interval has been documented (Hattin, 1968), the specific nature of depositional episodes that occurred as the Western Interior Sea moved eastward in central Kansas is not well understood. The stratigraphic interval containing (ascending) the nonmarine to marginal marine Dakota Formation and the marine Graneros Shale is transitional, and study of this portion of the Greenhorn Sequence is key to interpreting the manner in which sediments accumulated along the transgressive eastern margin of the Western Interior Sea during Cenomanian time.

Increased usage of sequence stratigraphic concepts since their introduction by P.R. Vail, R.M. Mitchum, J.B. Sangree and S. Thompson III of Exxon (in Payton, 1977) has led to their application outside the passive-margin shelf setting, including the Cretaceous Western Interior sedimentary basin. The Dakota-Graneros interval, which is a part of the well-defined Greenhorn Sequence, locally contains repetitive depositional successions that are interpreted as parasequences. Presence of such parasequences reflects shoreline fluctuations which were caused by episodes of westward shoreline progradation that punctuated overall eastward movement of the shoreline owing to generally transgressive nature of the sea. VanWagoner and others (1990) demonstrate the possibility of defining these smaller scale phenomena in both outcrops and well cores. In my study, sequence

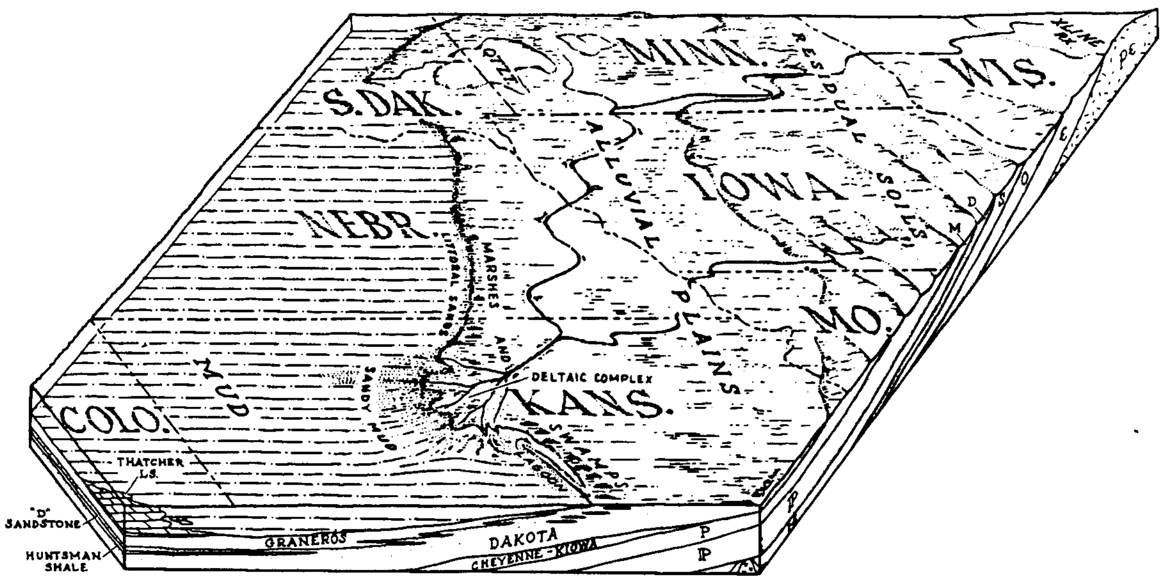


Figure 1 Paleogeographic reconstruction of Kansas during Cenomanian time (from Hattin, 1967).

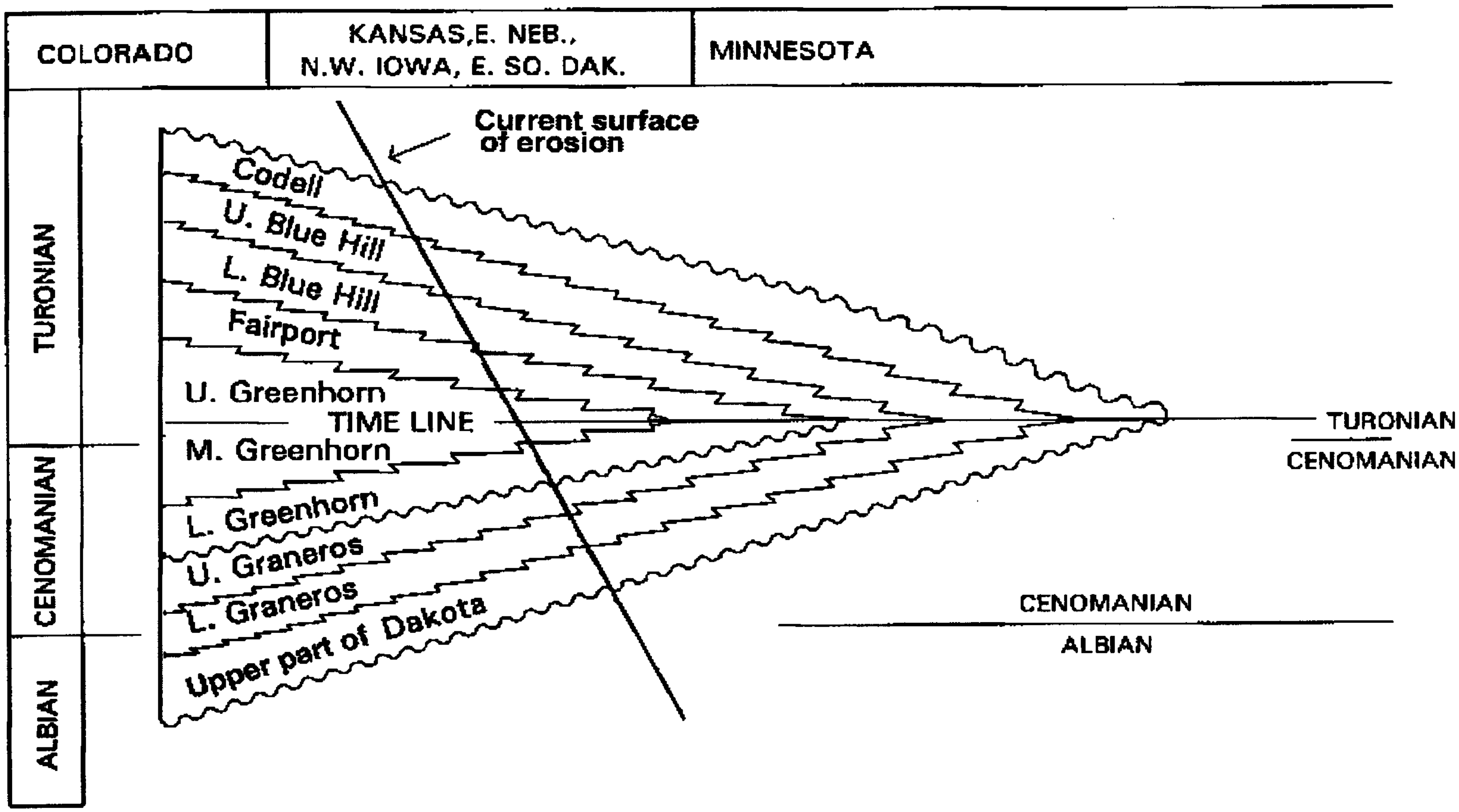


Figure 2. Greenhorn Sequence with basal unconformity at bottom of upper part of the Dakota Formation. Great vertical exaggeration accounts for the steepness of the line labeled "current surface of erosion" (modified from Hattin, 1986 and unpublished data).

stratigraphic concepts have been utilized in an attempt to identify parasequences that were deposited within the Dakota-Graneros transition in central Kansas. Isochronous bentonite seams were of particular value in the identification of parasequences that can be defined in the study interval locally.

Purpose

The goals of this project are (1) to describe strata within the upper part of the Dakota Formation and Graneros Shale in central Kansas, some of which have never been described previously, (2) to interpret the sequence of depositional events and environments that produced the studied stratigraphic units, (3) to analyze the upper Dakota-lower Graneros transition in the light of sequence stratigraphic concepts, and (4) to reconstruct the paleogeography of the study area within the context of a complex sedimentary system associated with the margin of a transgressing sea. These goals will facilitate understanding of sedimentary processes that occurred along the eastern shoreline of the Western Interior Sea during deposition of the Dakota Formation and Graneros Shale.

Location of Study Area

In central Kansas the outcrop of the Dakota Formation and Graneros Shale occurs mainly within the Dissected High Plains physiographic province (Schoewe, 1949; Fig. 3), and trends northeastwardly from Ford County in south-central Kansas through Lincoln County and into Washington County on the Nebraska border of north-central Kansas (Fig. 4). The best exposures occur along major east-flowing rivers and their tributaries. Except for epeirogenic uplift, tectonic activity has not significantly affected the Cretaceous strata of Kansas; structural dip is consistently less than one degree throughout most of the state (Merriam, 1957). Three sections along the Smoky Hill River in Russell and Ellsworth Counties, and four sections along Sawlog Creek in Ford and Hodgeman Counties were

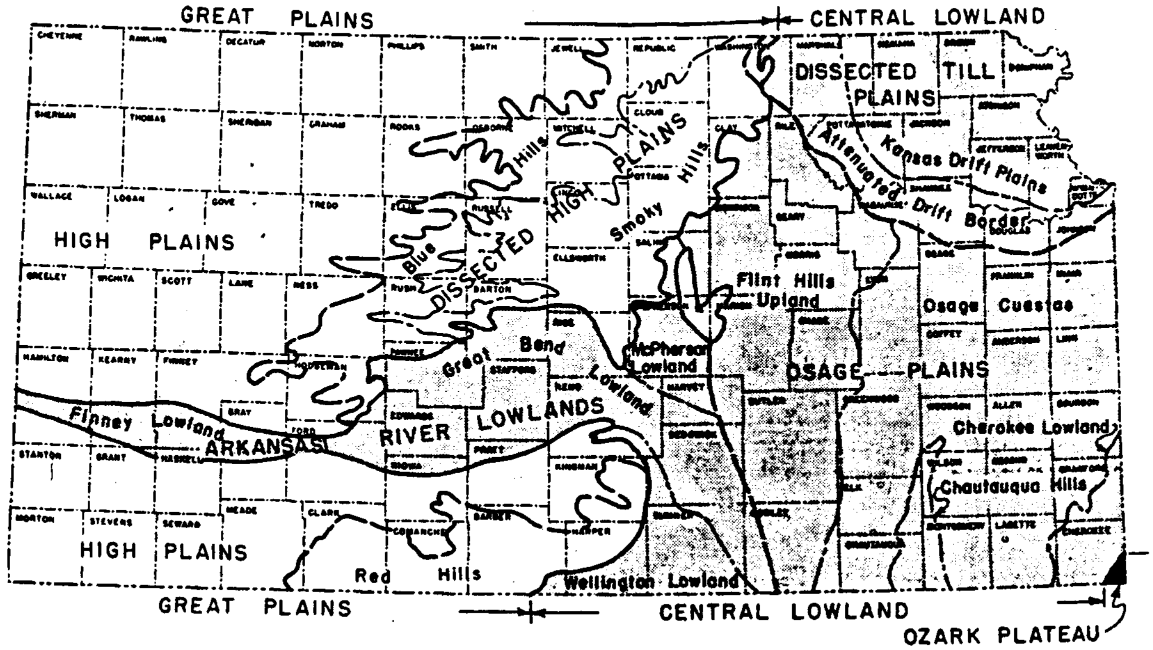
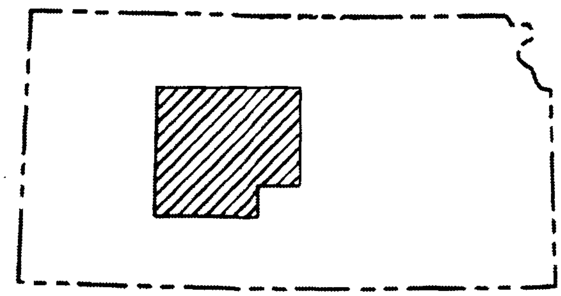


Figure 3. Physiographic map of Kansas (from Schoewe, 1949).

measured during the course of this study (Fig. 4, Appendix A). No measurable sections of the Dakota-Graneros transition could be located in Pawnee, Barton, or Rush counties, which are situated between the two study areas. Initially, I planned to study the Dakota-Graneros transitional interval in these counties but extensive field reconnaissance was unsuccessful in locating measurable stratigraphic sections.

Regional Stratigraphic Framework

Cretaceous rocks deposited on the eastern margin of the Western Interior Basin are part of a large eastward-thinning wedge of sediments that can be recognized in a several state area extending from Minnesota south to Kansas (Shurr, et al., 1994). This basin formed as a result of thrust-induced crustal loading associated with the Sevier orogenic event in Nevada and Utah that caused crustal subsidence in the region extending from eastern Utah to Kansas. The area was inundated with seawater that



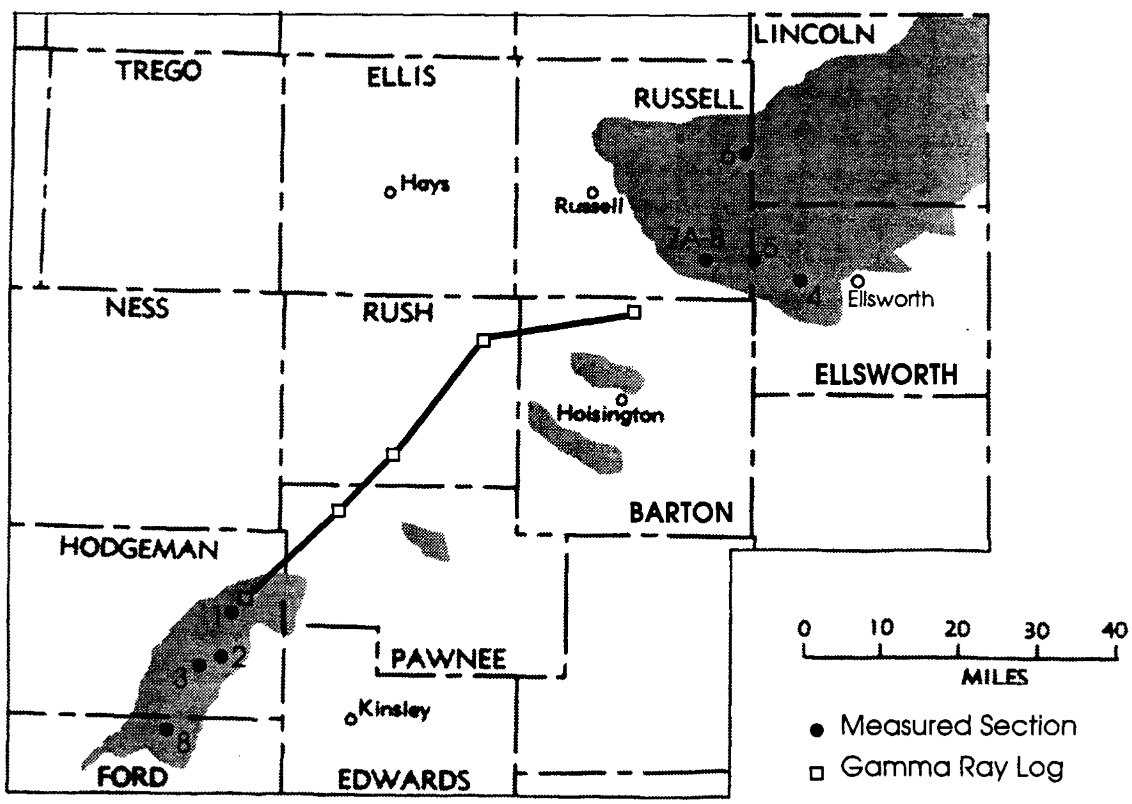


Figure 4. Map showing localities in central Kansas at which stratigraphic sections were measured. Shaded areas indicate outcrop pattern of Dakota-Graneros transition. Gamma Ray Log cross section shown in Figure 18 (modified from Hattin, 1965; Kansas Geological Survey, 1991).

during most of Late Cretaceous time connected the Gulf of Mexico and Arctic Ocean (Fig. 5). Sediments derived from the Sevier orogenic belt filled the western portion of the basin whereas sediments on the eastern margin were derived from source rocks that lay mostly to the east of the basin. During the transgression of the Western Interior Sea the eastern shoreline of the basin migrated eastwardly, leading to deposition in Kansas of stratigraphic units that reflect progressive increase in water depth. Maximum transgression resulted in deposition of the Greenhorn Limestone. Units that comprise the Greenhorn Sequence include the upper part of the Dakota Formation (also known as the Janssen Clay Member), Graneros Shale, Greenhorn Limestone, Fairport Chalk Member, Blue Hill Shale, and Codell Sandstone which is the topmost unit . My study focuses on the upper Dakota-Graneros transition, which was deposited during the

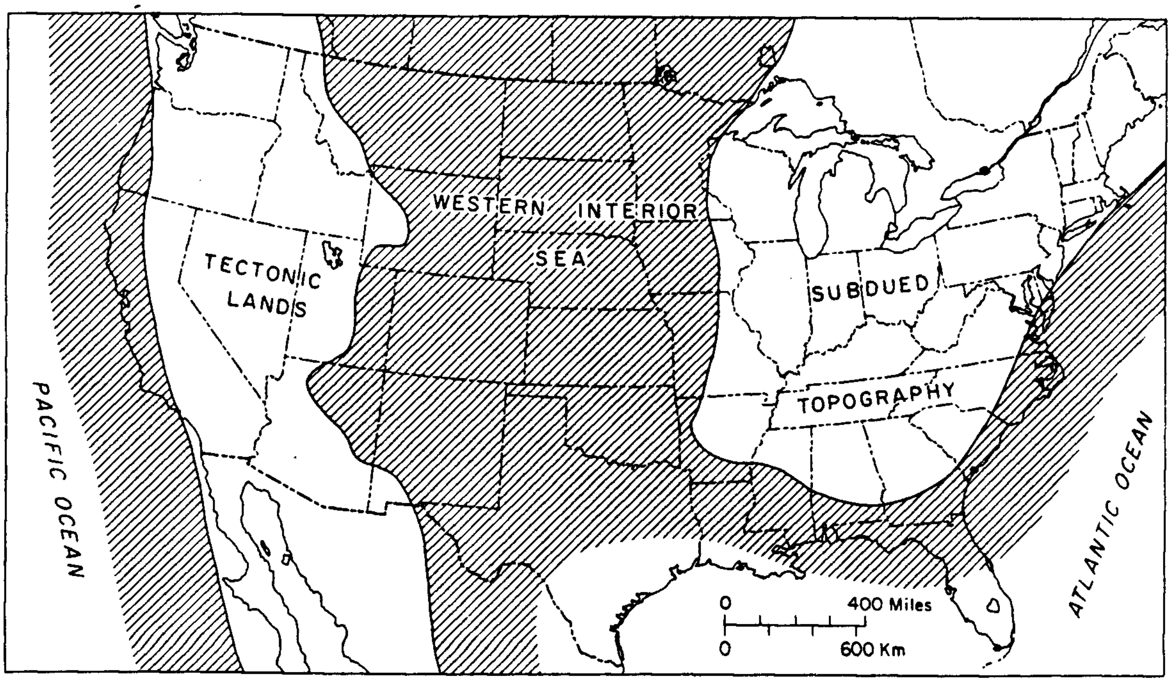


Figure 5. Paleogeographic map of North America during maximum transgression of the Greenhorn cycle of deposition (Hattin and Siemers, 1987; modified from Williams and Stelck, 1975).

transgressive portion of the depositional cycle. The Janssen Clay Member of the Dakota, first described by Plummer and Romary (1942), comprises the upper one third of the formation and consists of gray to dark gray shale, lignite, and fine-grained sandstone (Franks, 1975) that formed in nonmarine to marginal marine environments. The overlying Graneros Shale consists of medium- to dark-gray mostly noncalcareous silty marine shales that contain numerous thin sandstone beds and lenses in the lower half and local coquinoidal limestone lenses near the top (Hattin, 1965).

Previous Work

Meek and Hayden (1862) described the "Dakota group" in its type locality in Dakota County, Nebraska. Twenhofel (1924) later referred to this interval as the "Dakota formation" and Plummer and Romary (1942) divided the Dakota of Kansas into a lower Terra Cotta Clay Member and upper Janssen Clay Member. Some concern has been raised over the usage of the term "Dakota" for rocks on the western edge of the Western Interior Basin owing to differences in source area (Franks, 1975; Witzke and Ludvigson, 1994) and for rocks in the Kansas outcrop belt, some of which lie hundreds of miles from the type locality (Franks, 1975). Other important studies of the Dakota Formation in Kansas include those of Rubey and Bass (1925), who described the Dakota in Russell County; Schoewe (1952) who reported on the Dakota lignites; and Franks (1966) who studied the stratigraphy of the Dakota and Kiowa Formations in central Kansas. Paleoenvironmental interpretations of the upper part of the Dakota in Russell and surrounding counties by Siemers (1971), and the application of sequence stratigraphic methodology to the Dakota aquifer by Hamilton (1989) are additional important studies that include the Dakota-Graneros transition.

The earliest detailed description of the Graneros Shale is that of Logan (1897), whose "Bituminous Shale Horizon" was later correlated with the Graneros Shale of Colorado (Logan, 1899). Darton (1904) first applied the name Graneros to rocks in

Kansas. The description of the Graneros in Russell County (Rubey and Bass, 1925) is fairly detailed although Hattin (1965) describes the Graneros paleontology and stratigraphy much more completely. Boberg (1990) described and interpreted a rare occurrence of coquinoidal limestone lenses in the lower Graneros of southwestern Russell County, Kansas.

Methods of Investigation

Field Methods

Field work was conducted primarily during the summer of 1993, with supplemental work carried out during the spring and summer of 1994. Eight stratigraphic sections, each including the upper Dakota-Graneros transition, were measured in two widely separated study areas (Fig. 6). Sections were located by reference to published work, suggestions of D.E. Hattin, and utilization of topographic maps in conjunction with field reconnaissance. Each section was measured using a steel tape and hand level, with lithostratigraphic units being differentiated on basis of lithology, bedding, color, or degree of cementation. Color was determined with the aid of a rock color chart (Goddard, et al., 1948). Whenever possible, units were measured to within a tenth of a foot, with thicknesses later being converted to metric units. Poorly exposed intervals were trenched with a ax-mattock, or measured as covered section. Lithologic samples were collected from every measured unit and representative fossils were collected from each fossiliferous unit. Special attention was given to measurement and description of bentonite seams, which were used as datums. For sections in Russell and Ellsworth counties the "X" bentonite was utilized as a datum because of its great thickness (23-30 cm) and ease of recognition. In Ford and Hodgeman counties the "X" bentonite is not present, but a thin persistent bentonite that occurs in all sections there was used as an alternate datum.

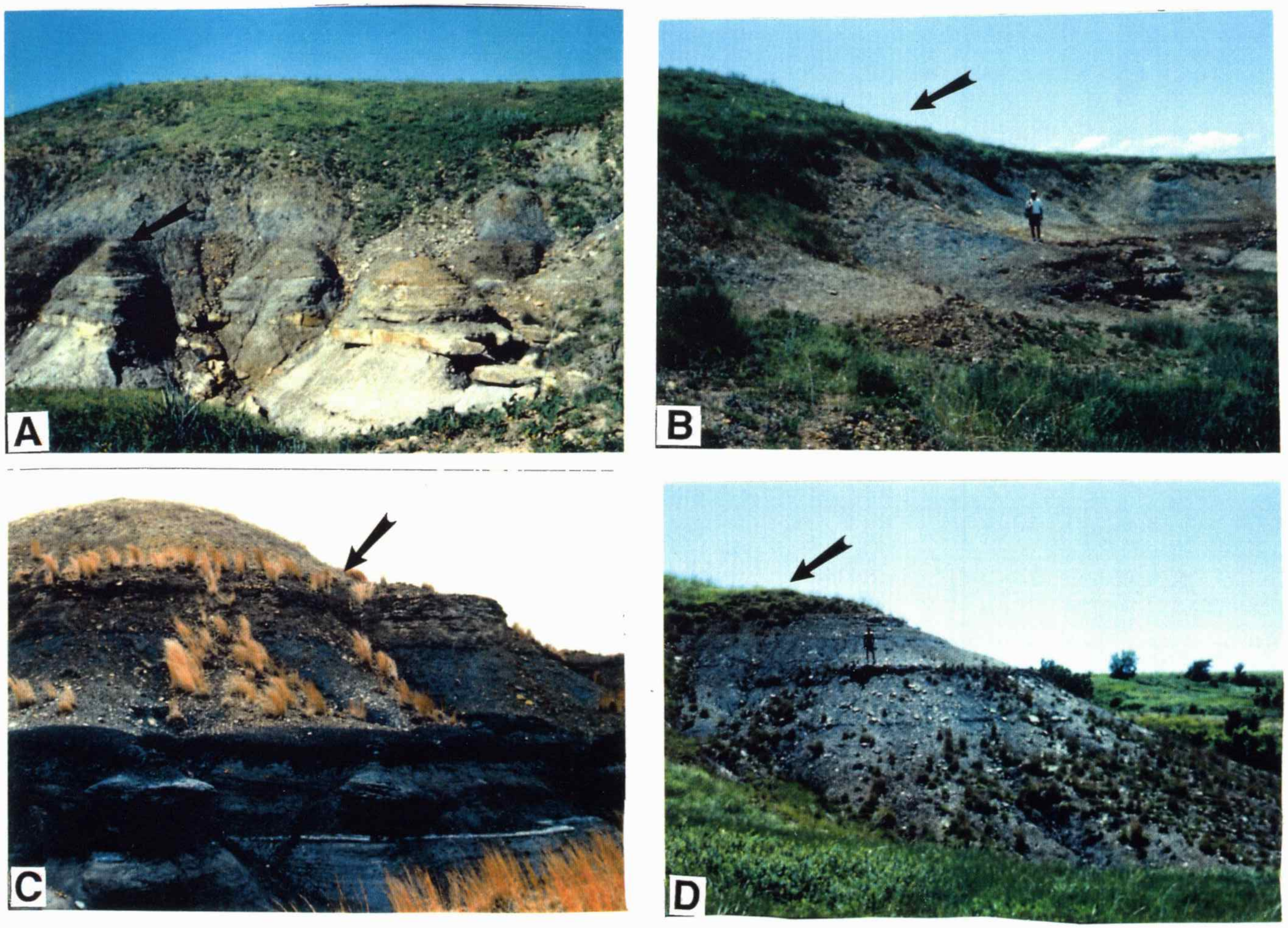


Figure 6. Localities of measured sections of Dakota-Graneros strata. A. Locality 1, B. Locality 3, C. Locality 4, D. Locality 5. Arrow indicates Dakota-Graneros contact.

Laboratory Methods

Thin Section Analysis- Thin sections were made of sandstone samples from Locality 1 (Dakota Formation) and Locality 8 (Graneros Shale) (Fig. 4). Point counts were conducted to determine lithologic differences that might aid in physical correlation of units. Sandstones were too uniform (i.e. almost entirely quartz) to use petrology as a means for correlation of sand bodies and therefore petrographic analysis of sandstones from other localities was not conducted. Epoxy impregnation was necessary due to the friable nature of the sandstones. A petrographic microscope was utilized for point counting, and 300 grains were counted per slide. During thin section preparation the type and composition of fossil fragments and voids was also noted for later use in interpretation of paleoenvironments.

X-ray Diffractometry- Bentonite and shale samples were analyzed by means of X-ray diffraction techniques to determine bulk clay mineralogy. Oriented slides were made of the two micron particle size and scanned in the range from three to fifty degrees 2 Θ. Clay-mineral data from bentonite samples were useful in my attempts to effect correlation between measured stratigraphic sections.

Micropaleontology- Shale samples were disaggregated by soaking in kerosene and boiling in water. Samples were then washed through sieves of 0, 1, 2, and 3 phi sizes to determine the presence of microfossils, which are primarily Foraminifera.

ACKNOWLEDGMENTS

I am indebted to Dr. Donald E. Hattin for serving as my advisor, helping me select this project, and providing insight into various methods of approaching the problem. Drs. Lee J. Suttner and J. Robert Dodd provided valuable comments on my research and the resulting thesis. Lou Bucklin assisted with preparation of thin sections for petrographic analysis. Dr. Colin Harvey and Jason McCuistion instructed me in procedures for preparation of oriented clay slides for X-ray diffraction analysis. Dr. N. Gary Lane helped with shale-preparation procedures in conjunction with micropaleontological analysis. I am grateful to Drs. P. Allen Macfarlane and Howard Feldman of the Kansas Geological Survey for allowing me access to core and well-log data in addition to providing me with additional opportunities to conduct field work and present my research. Special thanks go to my field assistants, Steve Maximuk and Matt Noriega, for tolerating many Kansas thunderstorms and "carrying the load". The Soil Conservation Service offices in Ford, Hodgeman, Ellsworth, and Russell counties furnished information to assist in locating stratigraphic sections. I am grateful for access to exposed sections that was granted by owners of land on which I worked. Mary Iverson furnished valuable information in conjunction with preparation of the thesis and Barbara Hill assisted with her photographic expertise in preparation of several figures. John Cooper Gibson was helpful in utilizing computer graphics to modify figures. I would like to thank all of my friends and family who kept me motivated and had faith in my ability to complete this project.

Financial support for field work was furnished by the Indiana University Department of Geological Sciences and the Kansas Geological Survey.

STRATIGRAPHY AND SEDIMENTARY PETROLOGY

Upper Part of Dakota Formation

General Characteristics

Plummer and Romary (1942) divided the Dakota Formation of central Kansas into lower and upper members (Terra Cotta Clay Member and Janssen Clay Member) with the upper member comprising 9 to 24 m of beds lying directly under the Graneros Shale. In the study area I measured as much as 13 m of Dakota strata (Appendix A), all of which lie within the upper member. Typical lithologies include light gray nonmarine mudstone, lignite, noncalcareous sandstone, gray shales which may or may not be silty, and intervals of interbedded sandstone-shale. Along the outcrop belt, prominent lithologies within the upper Dakota are sandstone, interbedded sandstone-shale, or mudrocks as shown by statistical analysis (Table 1). Sandstone comprises no more than 30 percent of any single section whereas interbedded sandstone-shale units commonly constitute a larger percentage of a given section.

Locality	Sandstone	Interbedded Sandstone- Shale	Mudrocks
1	16	38	46
2	0	83	16
3	26	40	33
4	27	17	55
5	9	45	42
6	30	52	17
7A	5	68	27
7B	3	40	56
8	29	22	49
Averages	**16.11**	**45.00**	**37.89**

Table 1. Percentage of prominent lithologies in upper part of Dakota strata.

Sandstone

Every measured section except that at Locality 2 contains at least one sandstone unit. On average, each section contains only 16 percent sandstone, making that lithology least abundant of the major rock types (Table 1). Even so, sandstones are usually the most conspicuous lithology in a given exposure owing to their light color and greater resistance to erosion. Thin sections were cut from samples from several sandstone units at Locality 1, and point counts (Table 2) indicate that each sandstone unit is a mature quartz arenite, with mica and chert present in minor amounts (Fig. 7). Point counts were not conducted for Dakota sandstones at other localities since the all sandstones appeared to be composed predominantly of quartz grains. Therefore, thin section analysis did not aid in correlation of sandstone units between localities.

Unit	Poly Qtz	Mono Qtz	Mica	Chert	Rock Frag
12	5	91	3	2	0
2 (top)	2	93	4	0	1
2 (base)	3	95	2	1	0

Table 2. Point count data for sandstones at Locality 1. Numbers are percentages based on 300 points counted per slide and have been rounded.

Cleanly-washed sandstone-- Cleanly-washed sandstone is a nearly pure quartz arenite free of matrix in which coloration ranges from light gray to yellowish gray. Most of these sandstones are poorly cemented, and friable. Typically, these sandstones form ledges on shale-covered slopes, regardless of degree of cementation. Grain sizes range from very fine- to medium-grained sand, with fine sand being most common. Grains range from angular to rounded with subangular being most common. Sedimentary structures in these sandstones include ripple marks (symmetric, asymmetric, and interference), cross bedding, and indeterminate sole marks.

Carbonaceous sandstone-- At Locality 4, the lower quartz arenite units (Fig. 8) contain enough carbonized plant material to impart a dark gray coloration. Traced laterally, such sandstones can be correlated with lignite seams. Some other sandstones in the upper part of the Dakota Formation are also carbonaceous, but contain smaller

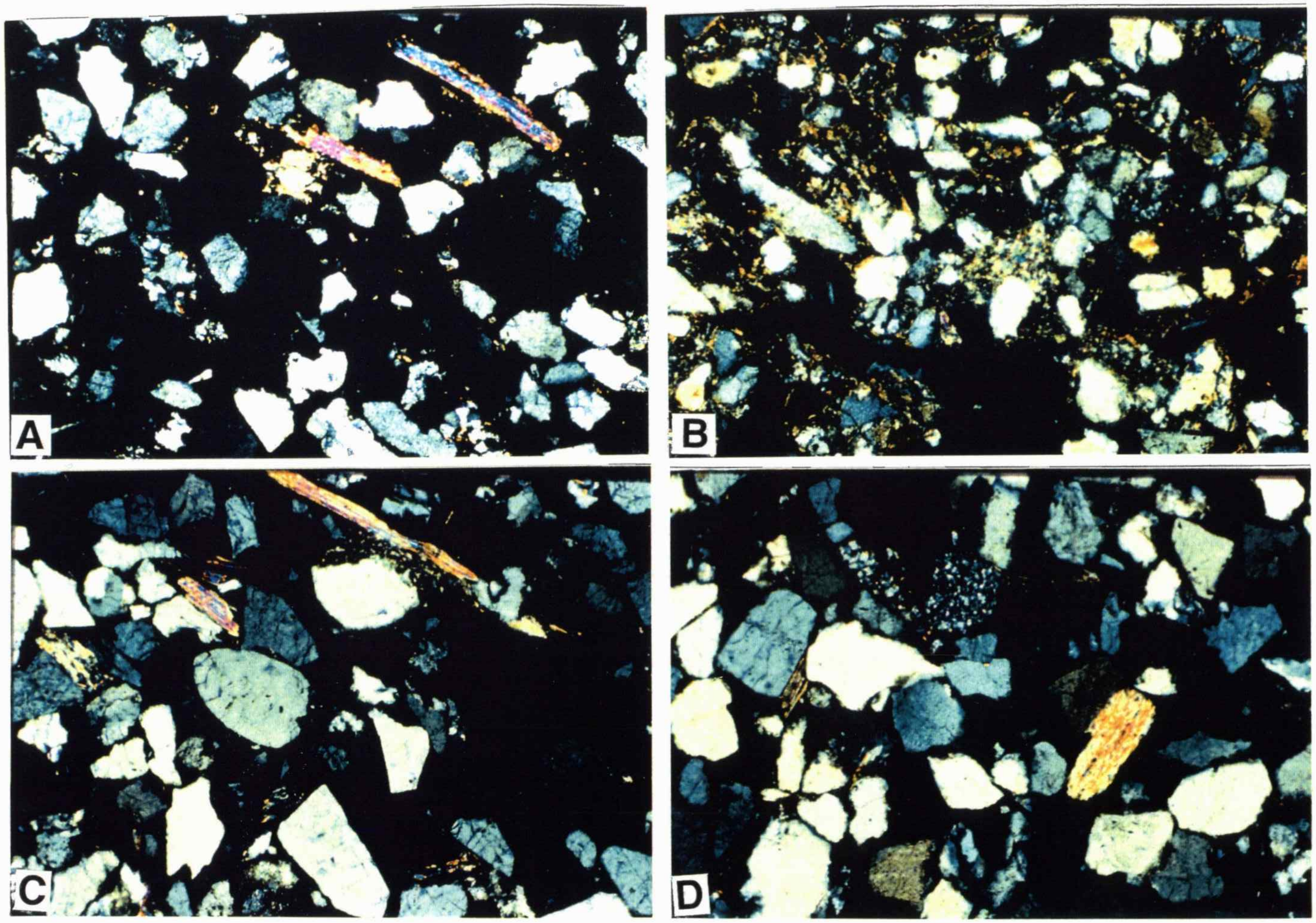


Figure 7. Photomicrographs of sandstones from upper Dakota strata at Locality 1 (X10). A. Quartz and mica from unit 2 (base), B. Quartz with pseudomatrix from unit 2 (top), C. Quartz and mica from unit 12, D. Quartz, mica, and chert from unit 12.

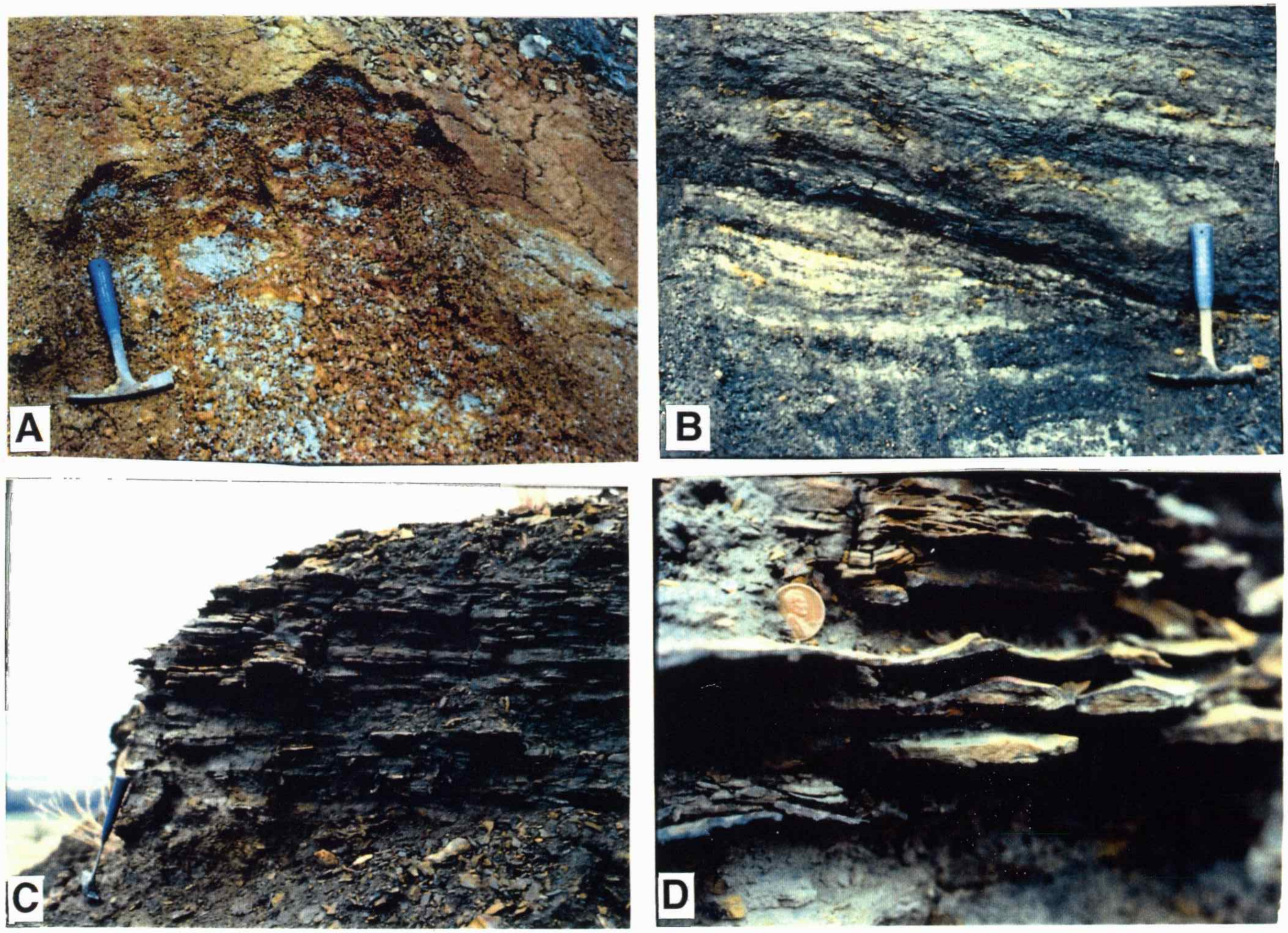


Figure 8. Sedimentary features from upper part of Dakota Formation at Locality 4. A. Mottled mudstone (units 1 and 2), B. Carbonaceous sandstone (units 3 and 5), C. Interbedded sandstone-shale (unit 7), D. Ripples in sandstone (unit 7).

proportions of carbonaceous material than those at Locality 4, and locally contain woody fragments as much as a centimeter in length. Other sandstones contain the carbonaceous material concentrated in laminations between thicker noncarbonacous layers. Erect molds of reed-like plant stems occur in some of the less carbonaceous units.

Hematite-cemented sandstone-- At Localities 3 and 4 the upper Dakota section contains hematite-cemented units which form prominent breaks in the sloping topography of the area. These sandstones are dusky red to dark yellowish red, are extremely resistant to erosion, and have a much higher density than other Dakota sandstones. Poorly preserved molds of the marine invertebrate *Laternula* sp. occur in a hematite-cemented sandstone that lies at the top of the Dakota Formation at Locality 4.

Fossiliferous marine sandstone-- The sections at Localities 5,6, and 7A-B include light gray to dark yellowish orange fine- to medium-grained sandstone that contains only minor amounts of silt and preserves several kinds of marine body and trace fossils. Fossils recorded in these sandstones include burrow structures (including *Arenicolites* at Locality 5) (Fig. 9) and molds of several marine macroinvertebrates, including *Corbicula?* sp., *Cymbophora* sp., *Exogyra levis* Stephenson, and *Geltena* sp. A few of the invertebrate shells are replaced by selenite crystals, but most shell material has been removed by dissolution.

Mudrocks

Mudrocks including both mudstones and shales, comprise an average of 39 percent of upper Dakota strata in the sections studied (Table 1). X-ray diffraction analysis showed kaolinite to be the primary clay mineral in these mudrocks. Carbonized plant fragments are the most common fossils within the upper Dakota mudrocks. In addition to numerous stems, roots, and woody fragments, a poorly preserved leaf and a large (approximately 20 centimeter) piece of wood were also recorded. The leaf and wood were insufficiently

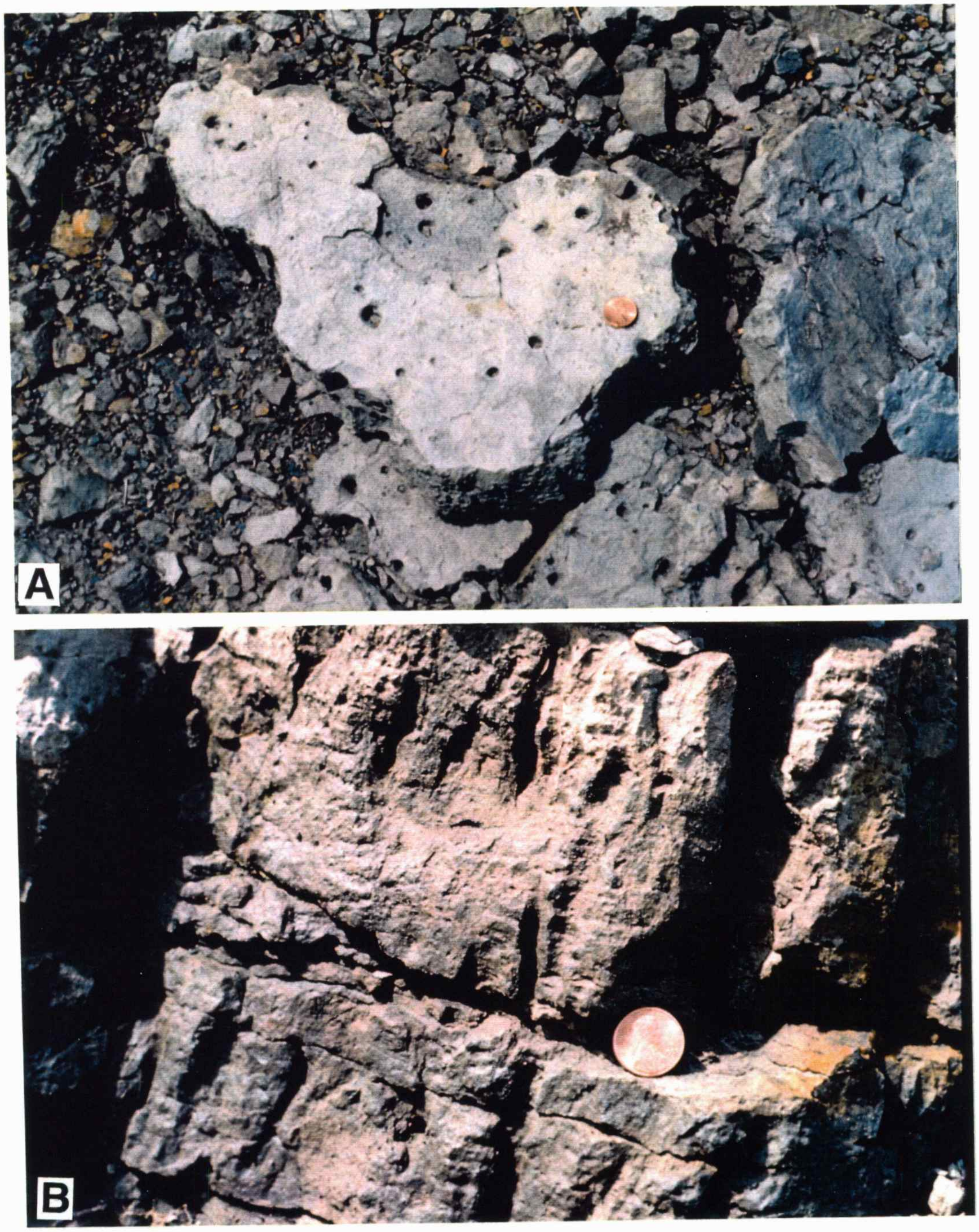


Figure 9. *Arenicolites* burrows within sandstone unit 5 at Locality 5. A. Top view of paired burrows, B. Side view of burrows.

complete for taxonomic identification. Burrow structures occur in shale at Locality 3, but these are too obscure to be identified.

Mudstone-- At several of the localities, light gray to medium gray mudstones lie near the base of the measured section. Coarser grained material within the clay ranges from abundant fine-grained sand to sparse silt, and sideritic spherules (less than 2 mm in diameter) of diagenetic origin (Scott, 1994) were discovered by sieving washed samples from Locality 4. Iron staining imparts a dark yellowish orange coloration to some of these mudstones.

Shale-- In the studied sections upper Dakota shales range in color from light to dark gray and typically are stained by jarosite, which is a product of weathering. Crystals of selenite as much as 10 cm in length occur in upper Dakota shale exposed at Locality 1 (Fig. 10), and smaller crystals occur in such shales at all other locations. Selenite originates by weathering of pyrite to form sulfates which, combined with meteoric water, forms sulfuric acid that dissolves calcareous material and results in the precipitation of calcium sulfate (Hattin, 1965). Weathering of pyrite is also responsible for the production of jarosite, a hydrated iron sulfate, and iron oxides that are the cement in upper Dakota sandstones. Sieve analysis of shales indicates that most upper Dakota shales contain at least minor amounts of quartz silt, which is present mainly as small aggregates of grains. A notable exception was recorded in unit 7A-3 in which silt is present in only trace amounts at the base but becomes progressively more abundant upward.

Carbonaceous shale-- Whereas many Dakota shales contain small amounts of carbonaceous plant material, in some shales the amount is quite large. At Locality 4, the lower portion of unit 6 (Fig. 11) is highly carbonaceous and grades laterally into lignite (Fig. 12). The carbonaceous shales at Locality 5 (Fig. 13) are vertically adjacent to lignite seams which occur in that section.

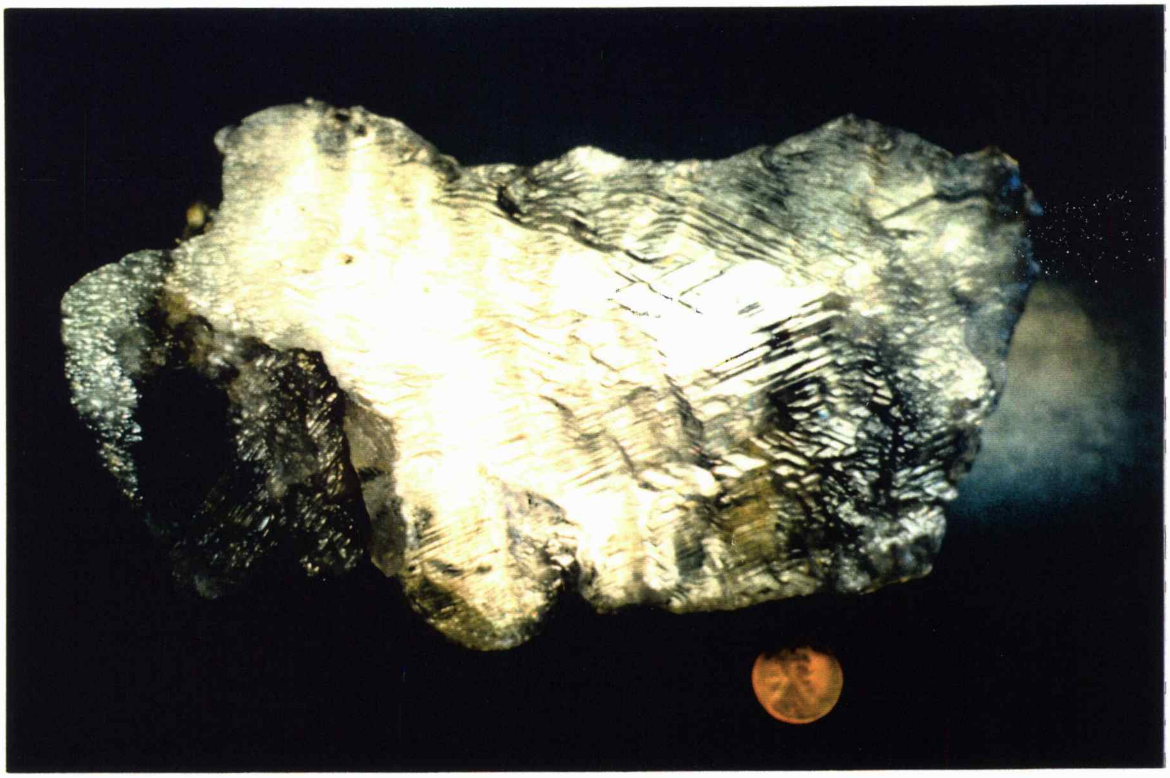


Figure 10. Large gypsum crystal from Dakota-Graneros transition at Locality 1.

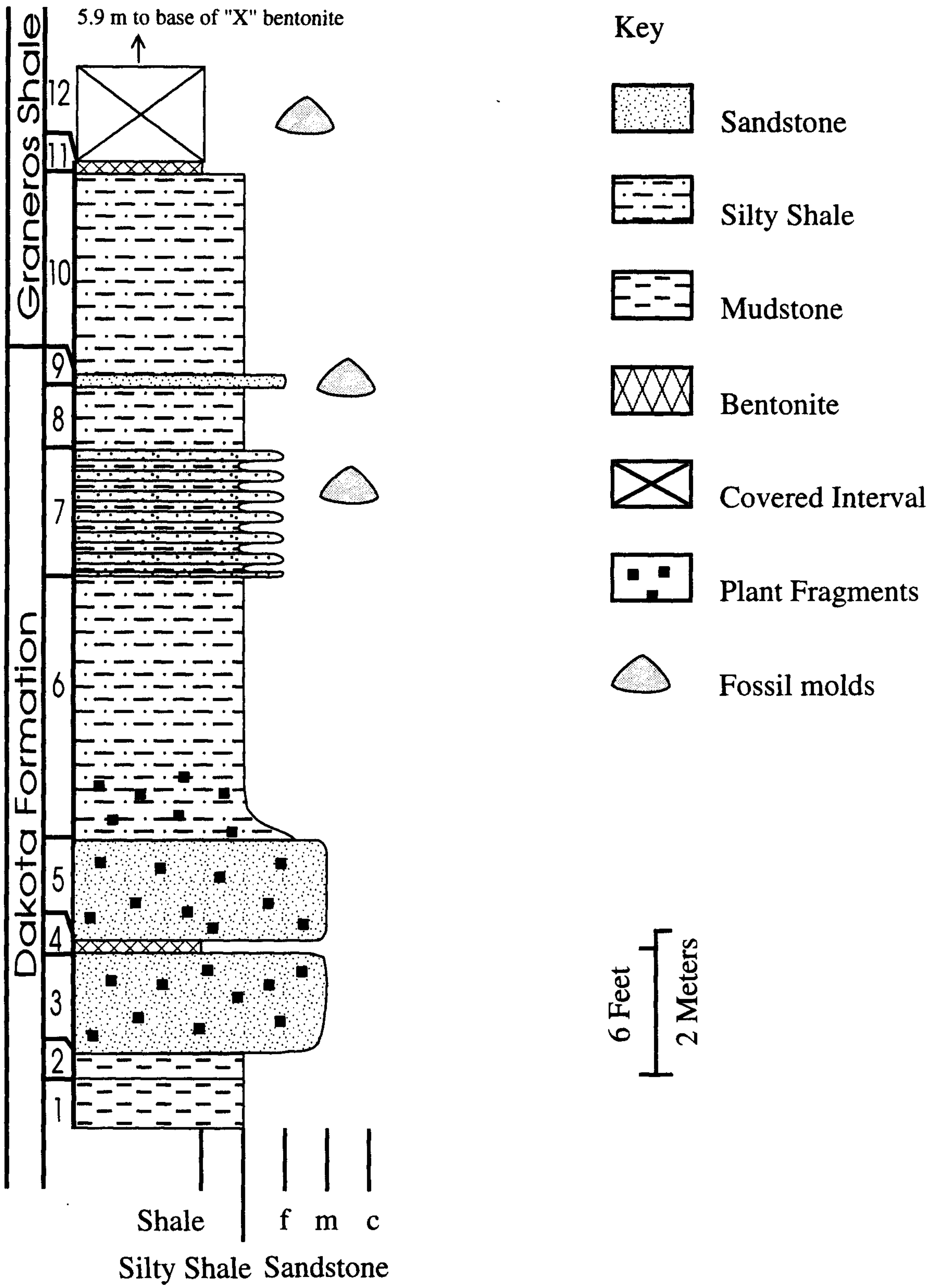


Figure 11. Graphic section of upper part of the Dakota Formation and Graneros Shale at Locality 4.

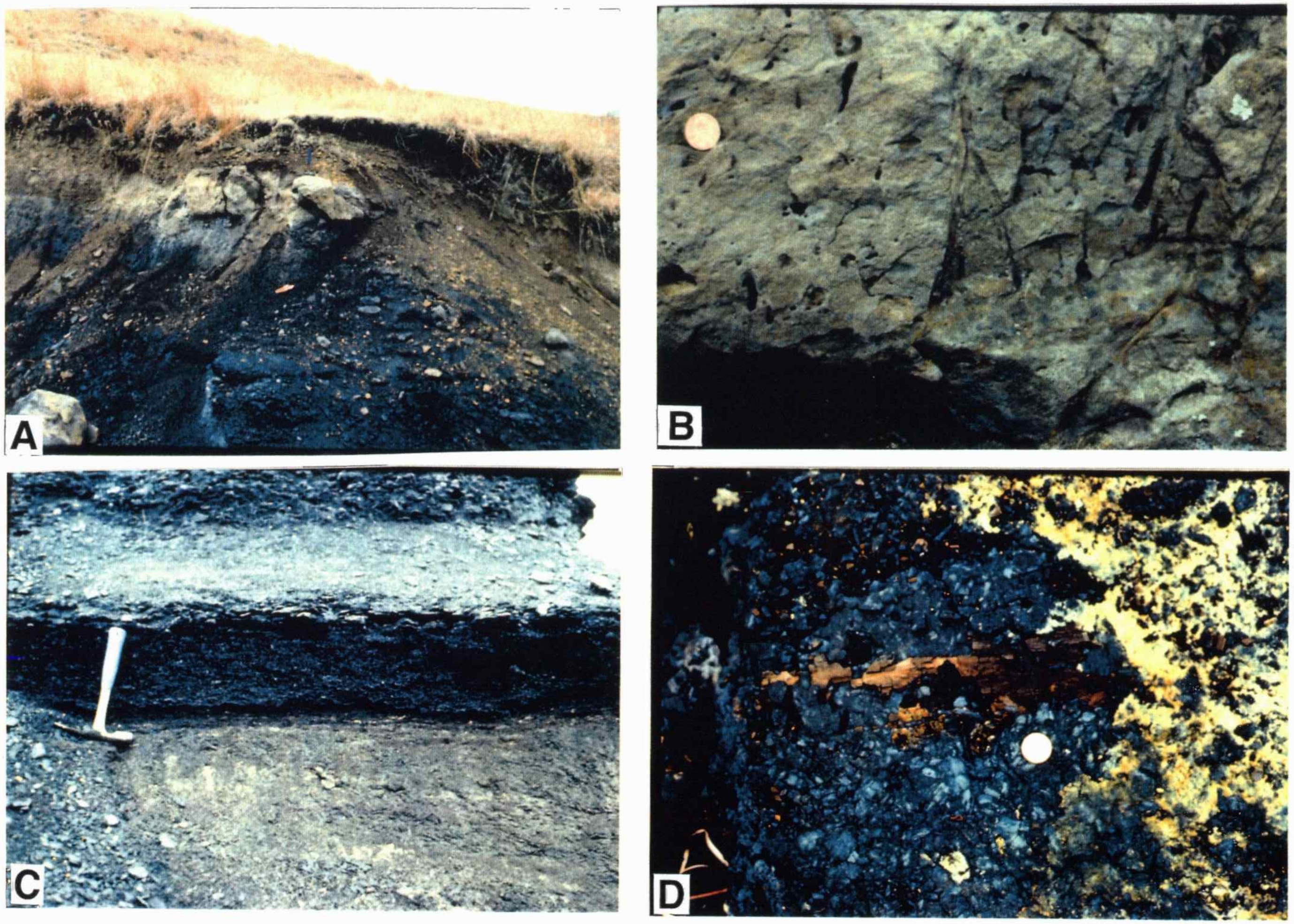


Figure 12. Features recorded within 100 meters from measured section at Locality 4. A. Sand body in shale unit 6, B. Erect molds of reed-like plant stems in sandstone shown in A, C. Lignite between units 5 and 6, D. Large piece of wood from shale unit 6, cent for scale.

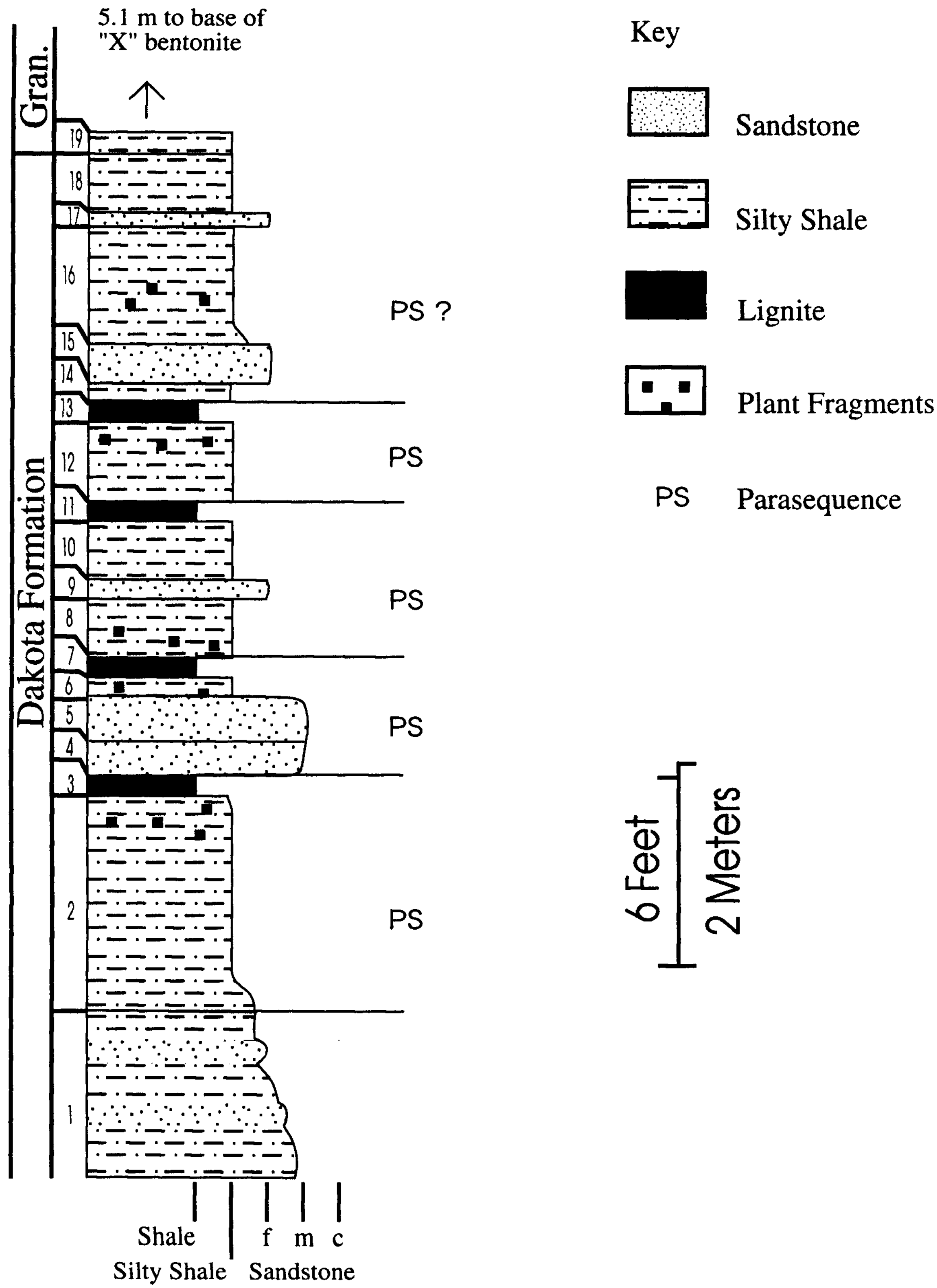


Figure 13. Graphic section of upper part of the Dakota Formation and Graneros Shale at Locality 5.

Sandstone bodies within shales-- In many shale units sandstone occurs as thin beds or laminations. These sandstones are normally composed of very fine- to fine-grained quartz sand, which is light in color except where stained by iron-bearing minerals. At Locality 4, shale unit 6 grades laterally in a distance of several hundred meters into several lenticular sandstone bodies, each of which is as much as meter in thickness (Fig. 12). Within a single exposure these large sandstone bodies are not common, whereas smaller sandstone bodies occur with a spacing of 100 m or more in several shale intervals..

Interbedded Sandstone-shale

Five of the sections that were measured for this study contain a larger percentage of interbedded sandstone-shale than either the sandstone or mudrock units (Table 1). These intervals comprise 2- to 5-cm thick alternations of thin to very thin sandstone and shale beds. Sandstone beds make these units fairly resistant to weathering although each shale bed forms a small reentrant. The sandstones are typically very light gray to yellowish gray and fine to medium grained. Almost every interbedded unit contains one or more thin sandstone beds that preserve current ripple marks (Fig. 12) and cross laminations, and some such sandstones preserve indeterminate sole marks. The marine fossils *Cymbophora* sp. and *Geltena* sp. occur as molds in many of these sandstone beds. In the interbedded units the shales range in color from medium to dark gray and are commonly silty. Some of the shale beds contain thin laminations of light gray fine-grained quartz sandstone. The interbedded sandstone-shale units typically contain small carbonized plant fragments throughout.

Lignite

At Locality 5 the upper part of the Dakota Formation contains several lignite layers that are scattered through the section. Other measured sections, such as that at Locality 4, contain very carbonaceous units that can be shown to grade laterally into lignite seams. Significant amounts of lignite exist in Ellsworth and Russell Counties and were mined during the latter part of the nineteenth century (Schoewe, 1952). Such deposits are laterally extensive only near Locality 4. Within the lignites are fragments of carbonized plant material that range in size from less than one to several centimeters. Lignite coloration ranges from brownish gray to black. Seimers (1971) recorded arenaceous foraminifers within Dakota lignites locally. Typically, carbonaceous shales or sandstones occur stratigraphically above or below these lignites.

Bentonite

At least two distinctive bentonite seams were recorded in the upper Dakota in the study area. These are 2 to 10 cm thick, with a common range of 3 to 5 cm (Fig. 14). Typical upper Dakota bentonites are soft and clayey with unweathered color ranging from white to bluish-gray. X-ray diffraction analysis shows that kaolinite is the principal clay mineral. In contrast, a bentonite seam that is preserved at Locality 4 (unit 4) is hard and brittle, has conchoidal fracture and contains carbonaceous plant fragments. Most of these thin bentonite seams cannot be traced between sections, and therefore do not aid in correlation attempts. A bentonite seam that occurs in my Hodgeman and Ford County sections appears to be present at all localities, and was used for correlation of sections in that area.

Graneros Shale

General Characteristics

In the study area the Graneros Shale has maximum thickness of 12.3 m in a composite section measured at Localities 32 and 40 of Hattin (1965) in Ellsworth County. The minimum thickness of Graneros strata (4.85 m) was measured at Locality 2 (Fig. 4). The southward decline of thickness is attributed to a pre-Greenhorn unconformity along which the uppermost portion of the Graneros Shale has been eroded (Hattin, 1965, 1968).

Figure 14. Bentonite seam in the upper part of the Dakota Formation at Locality 3.

At Localities 3, 6, and 7A covered intervals prevented measurement of the full Graneros section and at Locality 5 section measurement was complicated by severe slumping. In the sections that I studied shale is the predominant Graneros lithology, with thin calcareous sandstone beds scattered throughout.

The Dakota-Graneros contact is transitional, both units containing substantial amounts of shale and sandstone. In this study the boundary is chosen at the top of the uppermost noncalcareous sandstone (which is commonly hematite-cemented), clay ironstone zone or interbedded sandstone-shale unit. These units may display current ripple marks and cross laminations. The overlying shales of the Graneros contain marine invertebrates, foraminifers and silt content is lower than for the units within the upper part of the Dakota. These criteria are also factors in the variable thickness of the formations that is expressed by lateral changes in lithology over a relatively short geographic distance.

Shale

Shales of the Graneros possess many of the same physical properties as shales that occur in the upper part of the Dakota Formation. Graneros shales range in color from light to dark gray and typically exhibit yellow jarosite staining. Silt content normally is less than the shales in the upper Dakota and ranges from slightly to moderately silty. Thin quartzose sandstone and siltstone stringers occur in shales at Locality 1. Selenite crystals are present in most shales, the genesis of these being the same as for selenite in the upper part of the Dakota Fm. Selenite crystals range from the largest (as much as 30 cm in length) crystals at Locality 1 (Fig. 10) to thin, fracture-filling seams consisting of interlocking crystals at Locality 7A. I did not recover many macrofossils in these shales although Hattin (1965) recorded molds of bivalves, gastropods, and inarticulate brachiopods; and both Hattin (1965) and Eicher (1965) recorded significant numbers of Foraminifera from these shales. During my study selected shale samples were washed for microfossils but Foraminifera were recorded only in a sample from unit 10 at Locality 4, where several specimens of *Reophax* sp. were recovered.

Calcareous Sandstone

Calcareous sandstones occur within the Graneros section measured at Localities 1, 2, 4, and 7A. Sandstones in the Graneros are resistant and are readily observed in the field except at Locality 4, where sandstone occurs only as float within a large covered interval. Color ranges from yellowish gray to yellowish orange, and limonite staining is far less common than in sandstones of the upper Dakota. Fine- to medium-grained quartz sand is the major constituent of these calcareous sandstones, with calcite as the cement. Fossils include plant fragments, molds of *Aphrodina lamarensis* (Shumard) and shells of *Ostrea* sp. At Locality 7A (Fig. 15) calcareous sandstone grades laterally into a sandy, fossiliferous limestone over a distance of less than 100 m. This unit may be correlative with the coquinoidal limestone lenses of southwestern Russell County that were reported by Hattin (1965) and Boberg (1990). The slope between the sandstone and limestone is covered, so the exact nature of this transition is unknown.

Bentonite

The thickest bentonite within the Graneros Shale is the "X" bentonite, which lies near the top of the formation in Russell and Ellsworth Counties but is truncated by the pre-Greenhorn unconformity in Hodgeman and Ford Counties. Coloration is similar to bentonites that occur in the upper Dakota, with white to bluish gray being the most common for unweathered samples. X-ray diffraction analysis shows kaolinite and montmorillonite to be the principal clay minerals. This bentonite, which can be recognized throughout the Great Plains and across much of the Rocky Mountain region, apparently corresponds to the Soap Creek bentonite of Wyoming and Montana (Hattin, 1965). Thickness ranges from 23 to 28 cm, and this is by far the thickest bentonite seam in the entire upper Cretaceous of Kansas (Hattin, 1965). Because of its thickness and ease of recognition I have used the "X" bentonite in correlation of sections in Russell and Ellsworth Counties.

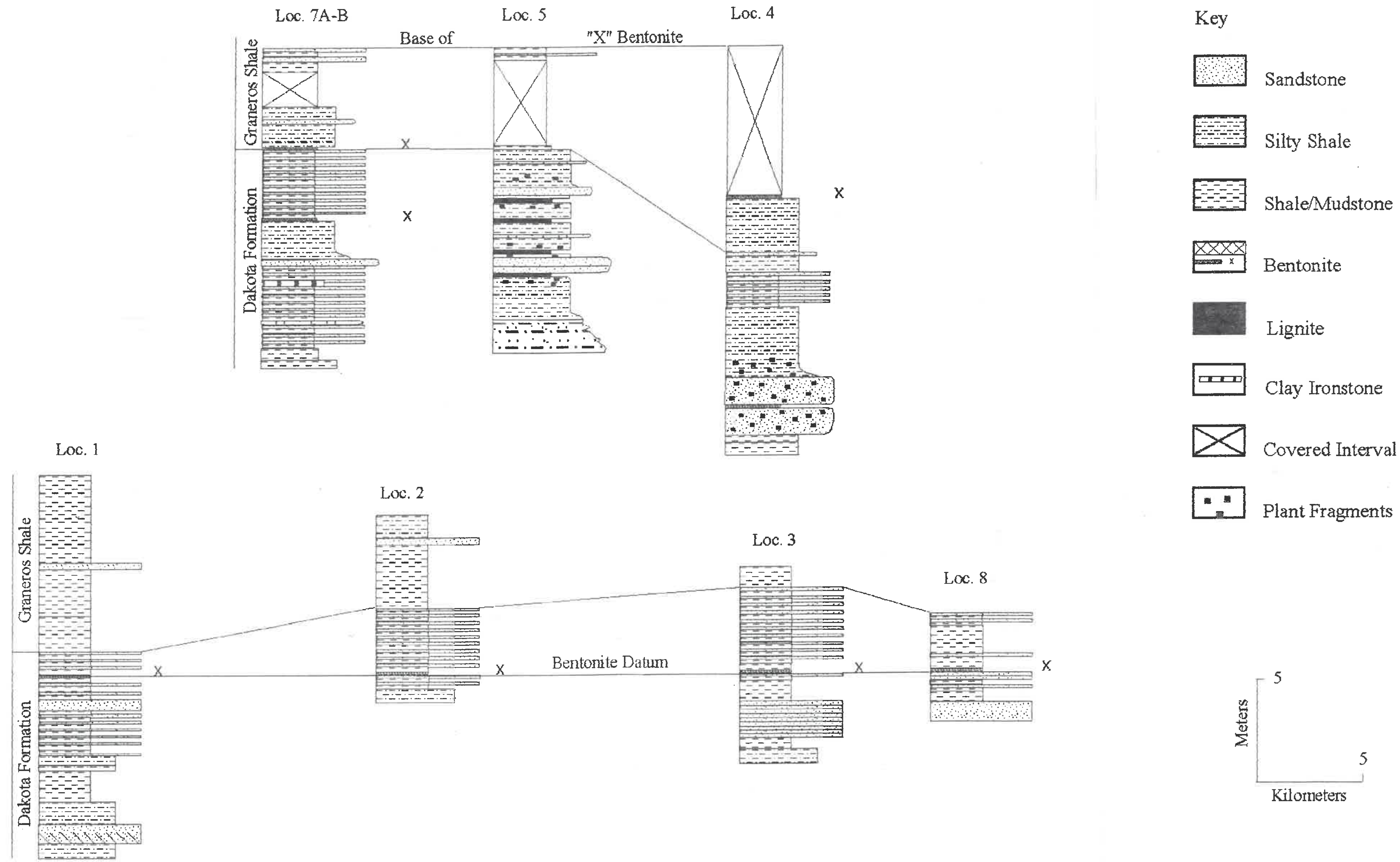


Figure 15. Diagrams showing correlation between measured sections in the Hodgeman/Ford and Ellsworth/Russell county areas.

PALEOENVIRONMENTAL INTERPRETATION

Depositional Environments

Hattin (1965) and Siemers (1971) identified depositional units in the Dakota-Graneros transition as part of a large deltaic complex that was constructed during eastward transgression of the Western Interior Sea during Cenomanian time. The lowest units are fluvial and marginal marine coal swamp sediments, strata of the uppermost Dakota are marginal marine sediments, and the Graneros sediments were deposited in an open marine environment. Whereas the overall transition of nonmarine to marine environments is not disputed, the sequence of depositional environments in which the strata in the study area formed differ from the standard constructional delta model owing to the geographic limitations on size of a delta and also the migratory nature of a delta complex. Strata studied in this research project formed mostly in a tidally dominated marginal marine complex with possible barrier islands and probable brackish water lagoons rather than in a constructive deltaic setting. Locality 4 (Fig. 11) contains the most complete section for demonstrating the transgressional succession of environments in the study area and is utilized as the key section for demonstrating an upward transition from nonmarine to marine sediments. Other studied sections are interpreted in relation to the key section, which seems best to fit existing models of linear siliciclastic shorelines (Reineck and Singh, 1980; Reinson, 1992)

Nonmarine Environment

At the base of the key section, units 1 and 2 are mottled mudstones that are slightly carbonaceous in unit 2 and are similar to the variegated claystones of Seimers (1971). The red and orange mottles and gray mudstone matrix are similar to those described by Mack and James (1993) and indicate alternating oxidizing and reducing conditions. These lower mudstones are analogous to flood plain deposits shown in the shoreline model depicted in Figure 16 and suggest fluvial overbank deposits such as those described by Siemers (1971) and Franks (1975). Presence of siderite spherules in unit 2 indicates soil formation (Franks, 1975; Witzke, 1983; Scott, 1994) thus lending support for a nonmarine interpretation. Mottled mudstones of units 1 and 2 are overlain by richly carbonaceous sandstones of units 3 and 5, which pass laterally in a distance as little as 100 m into lignite seams. The lignite and carbonaceous sandstones are deposits of a coastal swamp and adjacent fluvial/swamp transition, respectively. The carbonaceous sandstones consist of alternations of light gray sand and carbonaceous sand (Fig. 8). A bentonite seam (unit 4), which lies between units 3 and 5, was deposited as a volcanic ash that is truncated locally by a shallow channel in unit 5 that is interpreted as the result of fluvial floodwater flow (Fig. 8). Units 3 and 5 suggest episodes of higher fluvial input, apparently with minor channeling, coupled with episodes of greater input of organic material from adjacent swamps.

Nonmarine strata also are developed at Locality 1 (Appendix A) where sandstones and mudstones occur in the lower portion of the section. In this section the lowest unit consists of silty mudstone that coarsens upward into a sandstone unit that is cross bedded and resistant near the bottom and becomes finer-grained and has a muddy matrix near the top. Silty mudstones that lie above the sandstone contain carbonaceous plant material. The combination of mudstone-sandstone-mudstone units with carbonaceous material suggest overbank deposits with a fluvially derived sandstone between. This interpretation is similar to that of Witzke and others (1983) for sandstone within mudstone intervals in the upper part of the Dakota Formation.

Lenticular sand bodies containing erect molds of reed-like plant stems have been found at Locality 2 and near Locality 4 (Fig. 12) . These occur within shale intervals and also are interpreted as either nonmarine or marginal marine sandstones. Insufficient data are available to determine whether these plants grew in fresh or brackish water. At locality 7B, the basal part of the exposed Dakota interval comprises a silty mudstone unit

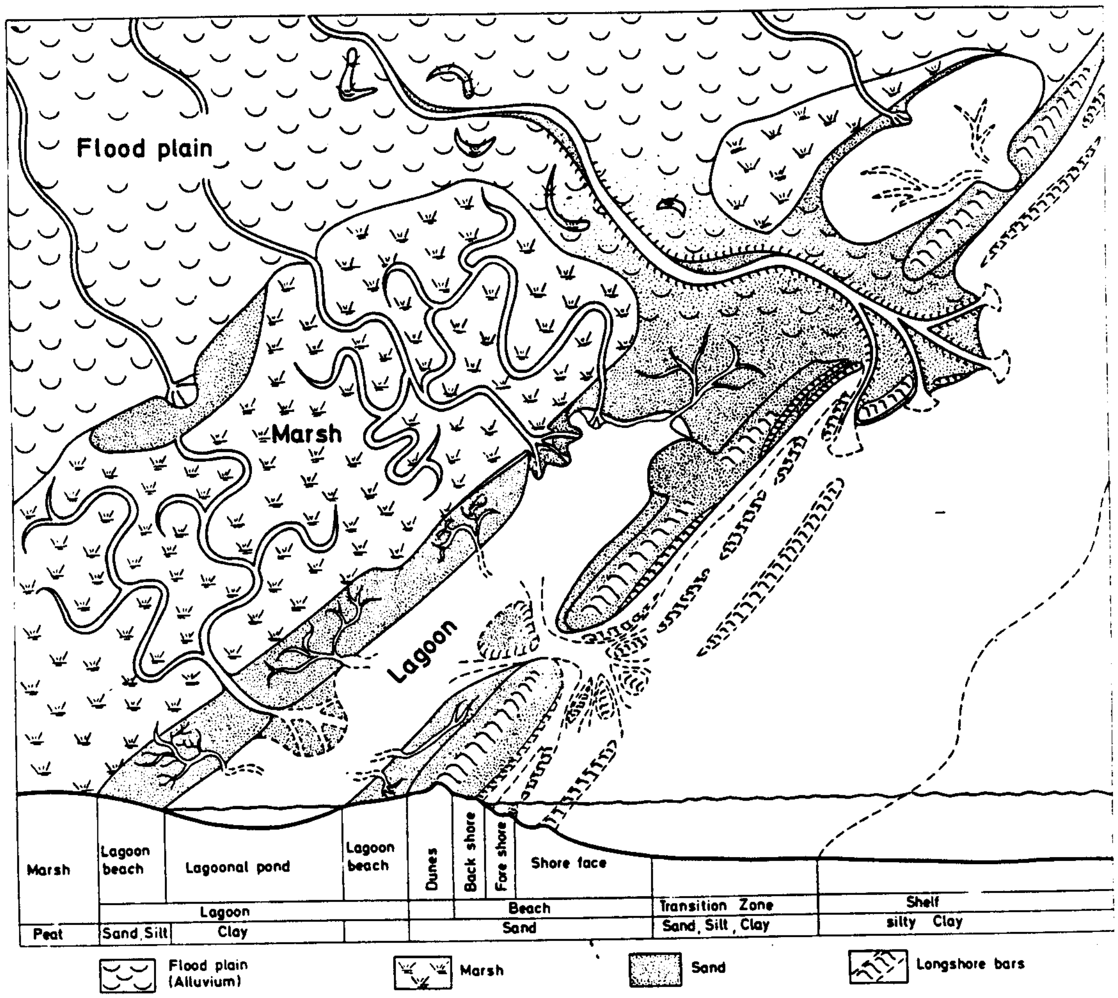


Figure 16. Paleogeographic reconstruction of a hypothetical Cretaceous shoreline showing the relationship of deltaic and linear clastic depositional environments (after Reineck, 1971; modified from Masters, 1965).

formation on a flood plain, as at Locality 4, and the amount of sand within the mudstones is a function of proximity to fluvial channels. Sand percentage increases with proximity to channels on the flood plain.

Marginal Marine Environment

In the key section, carbonaceous sandstone comprising unit 5 is overlain by medium gray shale (unit 6), which is silty and carbonaceous at its base and less silty and nearly devoid of carbonaceous material in the upper part (Fig. 8). Lack of sandstone beds within this shale indicates the unit was deposited in quiet water, low-energy conditions. Unit 6 is interpreted as the deposit of a shore lagoon that was bordered by coastal swamps that became progressively more remote as the open marine shoreline encroached on this area. These shales are similar to lagoonal deposits shown by Reinson (1992) in models of tide-dominated shorelines. As the shoreline moved eastward the amount of carbonaceous material reaching this portion of the lagoon decreased steadily.

In the section at Locality 4 unit 7 is key to the interpretation of stratigraphically upward transition to open-marine conditions. This unit, which is a thin-bedded alternating succession of cleanly washed cross-laminated sandstones and medium gray silty shales, contains molds of the marine pelecypods *Geltina* sp. and *Cymbophora* sp. as well as pebble- and cobble-sized siderite nodules and ripple marks (Fig. 8). According to Hattin (1967) *Geltena* and *Cymbophora* (family Mactridae) inhabited waters of normal to near normal salinity. Siderite nodules, commonly called clay ironstone concretions, within the upper part of the Dakota Formation have been interpreted by Siemers (1971) as indicative of marginal to partly open marine lagoons. The combination of lithology, marine fauna, siderite nodules and current-induced sedimentary structures indicates a tidally influenced portion of a shore lagoon, possibly close to a tidal inlet.

Unit 7 is overlain by non-carbonaceous shale (unit 8) similar to that in unit 6 and was apparently deposited under the same conditions. Although the shale yielded no marine invertebrate fossils or foraminifers, unit 8 is bracketed by sandstone units that contain unquestioned marine invertebrate fossils. Apparently, the shale reflects re-establishment of a shore lagoon. Of especial interest are several thin sand stringers that lie within the shale. These may have been deposited during storms from a combination of lagoonal sediment reworking and transport of sand into the lagoon from an inlet.

Unit 8 is overlain by a thin brittle hematite-cemented sandstone bed (unit 9), which has no identifiable bedding and has an irregular upper surface that contains a fish scale, molds of oysters, and *Laternula* sp. Based upon fossil evidence, nonstratified nature of the sandstone, and position beneath an open-marine shale interval, unit 9 is interpreted as a marine sand which was either part of the sediment from a longshore bar or reworked sediments from a transgressive ravinement surface. Because the overlying section is dominated by slope-forming, flaky weathering gray shale characteristic of the Graneros, and because the high iron-oxide content of the sandstone in unit 9 is a characteristic feature of Dakota sandstones, the top of unit 9 is taken as the top of the Dakota Formation.

Marine Environment

Unit 10 of the key section (Fig. 11) comprises the lower portion of the Graneros Shale, which has been interpreted as an open-marine deposit of less-than-normal salinity. These shales were washed for microfossils and specimens of the foraminifer *Reophax* sp. were discovered. Both Hattin (1965) and Eicher (1965) have found large numbers and a fairly wide variety of Foraminifera throughout the Graneros Shale. Their work shows a shift from benthic arenaceous species in lower Graneros strata to planktonic forms in the upper part of the formation. Although no longer well exposed in the Black Wolf roadcut section (Locality 40 of Hattin, 1965), the lower part of the Graneros elsewhere in Ellsworth and Russell counties contains numerous lenses and thin beds of sandstone and, at most locations, a thin-bedded mid-Graneros sandstone body that contains oscillation ripple marks and many clam molds and oyster shells. These Graneros sandstones are deposits of a storm-influenced shelf (Retallack and Dilcher, 1981; Boberg, 1990). At Locality 4, float blocks of the mid-Graneros sandstone body contain molds of *Aphrodina lamarensis* (Shumard). In southwestern Russell County the same interval locally contains coquinoidal limestone that preserves evidence of a major storm that induced sea-floor scour, winnowed fines, and concentrated large numbers of marine invertebrate shells (Boberg, 1990). A lateral transition from sandstone to limestone is evident at Locality 7A, where the topmost sandstone (unit 8) laterally grades into coquinoidal limestone.

Correlation With Other Sections in Study

Locality 4 is the key section that best demonstrates upward transition from nonmarine to open marine environments. Sections measured in Hodgeman and Ford counties at Localities 1, 2, 3, and 8 (Fig. J, Appendix A) have characteristics similar to the key section. The basal portions of these sections are silty mudstones and shales that contain carbonaceous plant fragments and sandstone layers ranging from thin beds to laminations. These mudrocks are similar to the lower units in the key section and are therefore interpreted as being deposited in nonmarine overbank and marginal marine lagoonal environments. Interbedded sandstone-shale units are present in other sections throughout the study area and contain the same kinds of sedimentary structures (current ripple marks, cross laminated sands, and sole marks) as in the key section. Accordingly, such interbedded sandstone-shale units are also interpreted as tidally influenced marginal marine deposits.

At Locality 1, sandstone (unit 12) as much as 41 cm thick occurs within an interbedded sandstone-shale unit and may indicate current reworking of sediment and removal of clay particles. The top portion of this sandstone contains large trough structures which reinforces the localized current interpretation. Shale (unit 16) occurs above the interbedded units and contains less silt than the strata below. Hattin (1965) recorded several species of Foraminifera from these shales. The overall coloration of the upper shales in this section is darker than the lower shales (Fig. 6). Based on this evidence, the Dakota-Graneros contact is placed at the base of these shales. This section contains calcareous sandstones (unit 18) in which molds of the marine bivalve *Aphrodina lamarensis* (Shumard) were recorded.

Locality 2 has less exposure of the Dakota-Graneros transition than the other sections although the transition is present. The lowest exposed unit is shale which contains silt, light gray sandstone beds which have erect molds of reed-like plant stems and carbonaceous plant fragments. This sandstone is similar to the sandstones occurring in strata at Locality 4, which are interpreted as lagoonal shales (Fig. 12). Based on this similarity, the shale unit with sandstone beds is interpreted as a nearshore lagoonal deposit. At Locality 2, topmost Dakota strata include interbedded shale and ripple-marked sandstone that is similar to unit 7 of the key section and is also interpreted as tidally dominated deposits of a marginal marine environment. Overlying Graneros strata consist of medium gray slightly silty shales and a calcareous sandstone (unit 6) which contains molds of *Aphrodina lamarensis* (Shumard). This sandstone is similar in character to sandstone float recorded in the covered interval (unit 12) in the key section (Locality 4). On the basis of predominantly shaly lithology and fossils, unit 6 is interpreted as an open marine deposit.

At Locality 3, lower strata (units 1-11) comprise an assemblage of silty mudstones, sandstones, and silty shales. Most of these units are slightly carbonaceous and some contain large plant fragments. By comparison of lithology and stratigraphic position with the section at Locality 4 and the work of Siemers (1971), these units are interpreted as nonmarine fluvial to marginal marine lagoonal deposits. Stratigraphically higher, the section consists of shale units that alternate with interbedded sandstone-shale units. This kind of lithologic assemblage is interpreted as lagoonal and tidally influenced deposits similar to those of units 6 through 8 in the key section (Fig. 11). Slightly more than one meter of the Graneros Shale is exposed at Locality 3, at which the formation is represented by light gray, slightly silty shale of the kind that has been shown by Hattin (1965) to be an open marine deposit laid down in water that had slightly less than normal salinity.

At several of the studied localities, sections differ stratigraphically from the succession exposed Locality 4, and are interpreted differently. At Locality 6 (Fig. 15) the Dakota Formation contains alternations of silty sandstone, shale, and sandstone. Some of the sandstones contain marine bivalves and suggest marine deposition, and the presence of clay ironstone concretions in some of the stratigraphically lower sandstone units reflects marginal marine lagoonal deposition (Seimers, 1971). Shale units contain well washed sandstone layers that range from thin beds to laminae, and possess an overall aspect similar to shale unit 8 at Locality 4 that I interpret as a lagoonal deposit. The lithologic and paleontologic evidence suggests that these strata were deposited during fluctuations of sea level. At Locality 6, the Dakota Formation is capped by interbedded sandstone-shale that contains ripple marked sandstone and resembles the tidally influenced deposits recorded in the key section (Fig. 8).

The sections at Localities 5, and 7A-B manifest very different character than other studied sections. At those two localities a distinct repetitive stratigraphic pattern is developed and suggests that shallower and deeper water facies appear to alternate throughout the section. Analysis of these sections reveals packages of strata that suggest upward shallowing, each package being truncated by a deeper water unit which, in turn, is succeeded by units that suggest deposition in progressively shallower water. This repetitive succession of shallowing upward bundles of strata suggests the presence of parasequences.

Evidence for Parasequence Stacking

Sequence Stratigraphic Context of Studied Interval

Work by Weimer (1984) on the Denver Basin subsurface and Front Range outcrop illustrates four sequences that occur in mid-Cretaceous strata of the Western Interior. The highest sequence, termed sequence 4, includes the upper portion of the Dakota Formation (called D Sandstone in Colorado) and Graneros Shale. The upper limit of this sequence is the unconformity at the top of the Codell Sandstone (Fig. 2), with strata of the Greenhorn Limestone being deposited during the time of maximum transgression (Hattin, 1964). The base of this sequence is marked by an unconformity dated at 95 Ma (Weimer, 1984), which places it within the Cenomanian Stage (Obradovich, 1993). Hamilton (1989, 1994) traced the four sequences of Weimer (1984) into the subsurface of western and central Kansas. His analysis of the fourth sequence in Kansas is limited to the Dakota-Graneros transition.

An east-west cross section (Fig. 17) shows these unconformities, which delineate three sequences that Hamilton (1994) recognizes in Kansas. The upper sequence, termed D Sequence, contains the upper part of the Dakota Formation, including the upper portion of the Terra Cotta Member and the Janssen Member, plus Graneros Shale. Use of the term "D Sequence" is somewhat problematic because it applies to the D Sandstone in Colorado, which is not a formal lithologic unit in Kansas. A more appropriate term would be "Greenhorn Sequence" because the Greenhorn Limestone is widely recognized throughout the Western Interior (Hattin, 1975) and formed during maximum transgression and relative highstand of the Western Interior Sea.

Another large-scale interpretation of the Kansas subsurface has been conducted by Feldman, Collins, and Doveton (pers. comm., 1994) using gamma ray measurements from well logs. The Graneros Shale thickens westwardly and onlaps eastwardly onto the Dakota Formation (Howard Feldman, pers. comm., 1994). Use of gamma ray measurements from Locality 6 has aided my attempts to correlate surface sections with

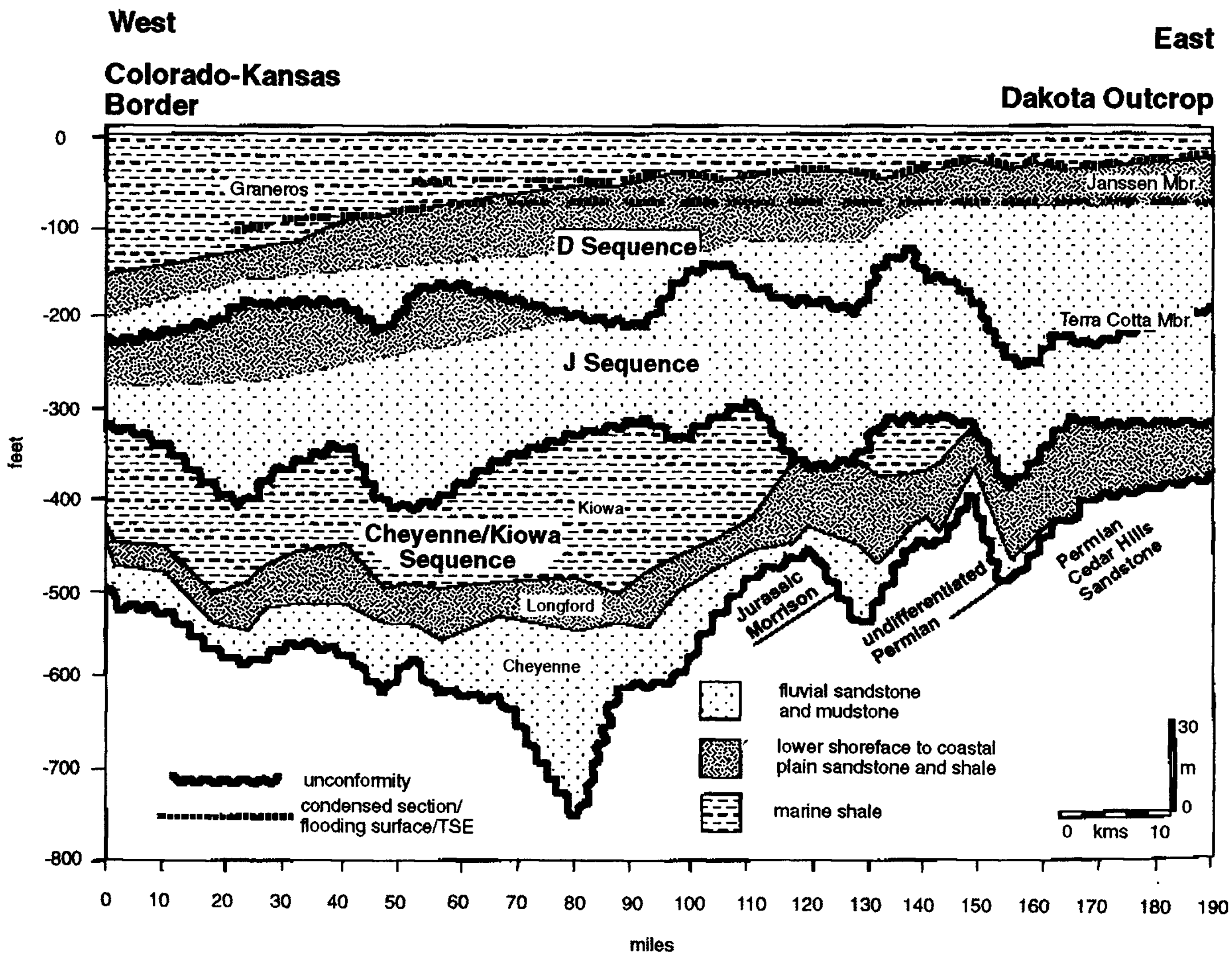


Figure 17. East-West cross section showing sequences in the Cretaceous of Kansas (modified from Hamilton, 1994).

subsurface sections in the Dakota-Graneros transition of central Kansas (Fig. 18).

Analysis of the upper part of the Dakota Formation and Graneros Shale shows that certain repetitive bundles of strata have the appearance of parasequences. According to Van Wagoner and others (1988), parasequences and parasequence sets are the fundamental building blocks of sequences. A parasequence is a relatively conformable succession of genetically related beds or bedsets bounded by marine flooding surfaces and their correlative surfaces (Van Wagoner, 1985). A typical parasequence consists of a shallowing upward succession of beds that is terminated at a sharp contact above which lie deeper water sediments (Fig. 19). These parasequences record changes in relative sea level, with apparent declines of sea level interrupted abruptly by apparent rises. Rapid accumulation of sediment, which outpaced sea level rise, is at least a partial factor in the formation of the shallowing upward sequence. Apparent sea level fluctuation alters the nature of a transgressive succession of sediments from apparent simple deepening upward recorded at Locality 4 to bundles of shallowing upward sediments (parasequences) in an overall deepening upward succession such as that preserved at Locality 5 (Fig. 13) and other localities. Water depth and sedimentation rate varied throughout deposition of each parasequence that can be recognized at Locality 5; however, a majority of the sediments were deposited in nonmarine to marginal marine environments and are properly assigned to the upper part of the Dakota Formation. In contrast, the base of the Graneros is defined by first occurrence of marine shale units that are not overlain by nonmarine or marginal marine deposits. The key section at Locality 4 demonstrates an apparently steady upward progression from nonmarine to marginal marine to marine strata without obvious parasequences but most of the other sections have much more complex stratigraphy, which I interpret as stacked parasequences within an overall transgressive setting.

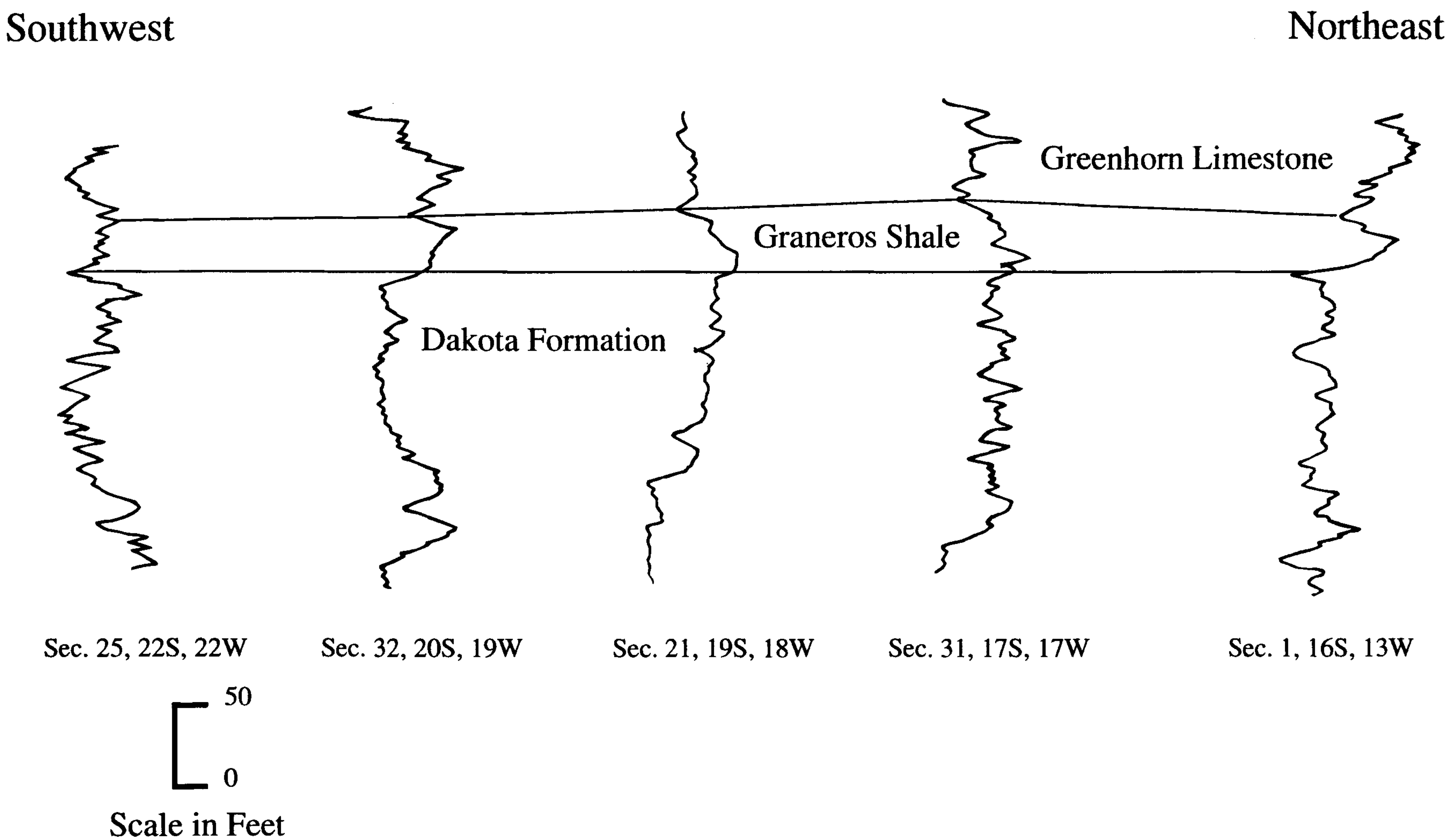


Figure 18. Cross section of gamma ray well logs between Hodgeman/Ford and Ellsworth/Russell County areas. Datum is Dakota-Graneros contact. Well locations are shown on Figure 5.

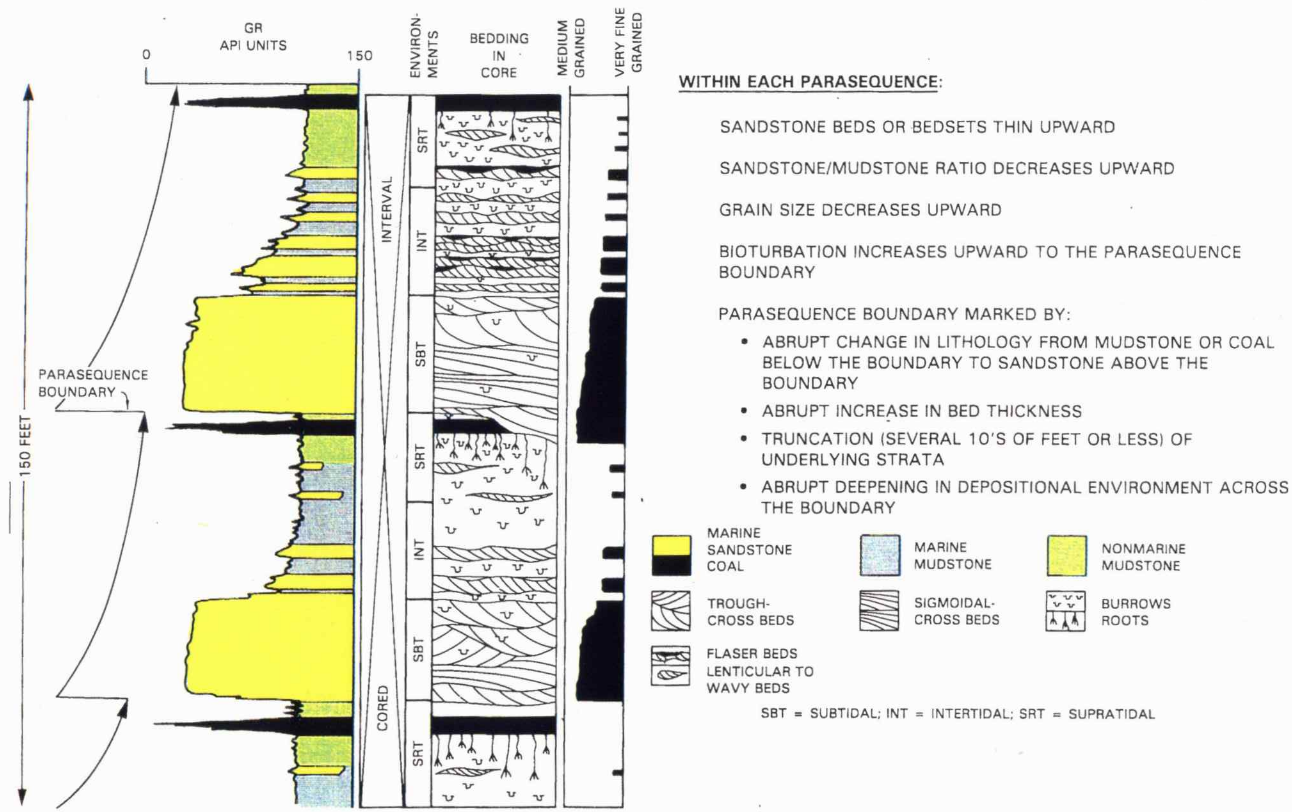


Figure 19. Model of parasequences in a tidally influenced environment that is used to interpret sections at localities 5 and 7A-B (Van Wagoner et al., 1990).

General Description of Parasequences

The best-developed example of parasequences that I encountered occurs in the section at Locality 5 (Fig. 13). Lignite intervals which contain terrestrial woody fragments are present in the section and are clear evidence of coal swamps. Such units lie near the tops of parasequences along a tidally dominated shoreline as shown in the model of Van Wagoner et al. (1990) (Fig. 19), and are interpreted thusly in the present study. Whereas determination of exact water depth and depositional environments for some sandstone-shale intervals are problematic owing to a paucity of fossils and sedimentary structures, the lignite units are accepted as deposits in environments that lay approximately at mean sea level. This interpretation is reinforced by occurrence of arenaceous foraminifers in lignite deposits of the upper Dakota a few miles north of the study area (Seimers, 1971). Further, Hattin (1965) has recorded arenaceous foraminifers in shales near the top of the upper Dakota in the study area. Such observations suggest that shales and lignites lying near the top of the Dakota were deposited in marginal marine environments. In the general sense, marginal marine shales that alternate with lignites deposited at or near mean sea level suggests at least small changes in relative water depth. This association of facies was enough to prompt further investigation into the existence of parasequences within the Dakota-Graneros transition along the central Kansas outcrop belt.

At Locality 5, each parasequence begins typically with cleanly-washed sandstones. In some of these sandstones Hattin (1965) has recorded molds of *Aphrodina lamarensis* (Shumard). Burrow structures and a paucity of plant fragments in these sandstones also are suggestive of marine deposition. These upper Dakota sandstones (Fig. 13) average 27 cm in thickness, with a range from 5 to 46 cm. Most such units are thinly bedded and similar to other sandstones in the section, with exception of iron stained intervals (most notably unit 17) which are more reddish instead of the typical light to medium gray colors.

Each of the marine sandstones is followed upward by a shale unit which is either silty or contains laminations of quartz sand or silt. Shale units range in thickness from 18 cm to 2.06 m, with an average of 72 cm. Some of these shales show a significant upward increase in the amount of carbonaceous plant fragments and others contain carbonaceous material throughout. Hattin (1965) has recorded foraminifers from these shales at his Locality 8, which is further evidence of marginal marine deposition. The coarse detrital component of these shales and presence of terrestrial organic matter indicates deposition near shore and suggests lagoonal conditions similar to those postulated for shale units 6 and 8 at Locality 4 (Fig. 11).

In each parasequence the shales are overlain by a lignite seam, which forms the top of the parasequence. These lignite seams range in thickness from 8 to 20 cm, averaging 15 cm. Organic materials that comprise the lignites are interpreted as deposits of coastal coal swamps that lay directly adjacent to lagoons in which the underlying shales were deposited (Fig. 16). Each lignite, such as unit 3 at Locality 5, has sharp upper contact with overlying strata that are indicative of deeper water. This abrupt increase of water depth suggests a marine flooding surface that divides one parasequence from the next. As much as 90% compaction rates (Skinner and Porter, 1989) may be experienced for lignites and one can therefore infer that these units represent a thickness of more than one meter of original organic matter. Even with a meter of organic matter, compaction of this material would be too much delayed to cause the abruptness or apparent amount of water deepening that marks the preserved marine flooding surfaces. Therefore, rises of sea level or larger scale subsidence led to the rapid change in water depth that appears to have occurred after deposition of each of the upper Dakota lignite-forming beds at Locality 5.

Parasequence Development

The exact nature of sea level fluctuations can be determined from a unit-by-unit examination of the section at Locality 5 (Fig. 13). Although the generalized example described above shows the basic succession that defines an upper Dakota parasequence in the study area, several variations may be observed within a particular parasequence.

Detailed analysis of each parasequence demonstrates that each shallowing upward sequence differs from the underlying and overlying packages of strata.

Parasequence 1-- Units 2 and 3 (Fig. 13) comprise this parasequence. No basal sandstone is present although the lower quarter of the silty shale (unit 2) is more resistant than the rest of the unit. Plant fragments are common at the top of this shale unit. Lignite (unit 3) at the top of the parasequence is the thinnest in the section (8 cm thick) and contains laminations of light gray silt. This parasequence is the most poorly developed of those described from Locality 5.

Parasequence 2-- The lower portion of the next parasequence consists of two thinly bedded sandstones (units 4 and 5) with burrow structures. The bottom bed in unit 5 is the thickest (10 cm) and contains well developed *Arenicolites* burrows. Above the sandstones is a shale interval (unit 6) which contains abundant plant fragments; this unit reflects shallowing upward. The overlying lignite seam (unit 7) does not indicate the top of this parasequence although it apparently formed at the lowest relative sea level. The parasequence is capped by silty shale (unit 8) which contains abundant plant material at its base and is interpreted to have been deposited in water that was just slightly deeper than at the time of lignite deposition. The marine flooding surface is at the top of this silty shale, which is considered to be the top of this parasequence. A slight relative rise in sea level or lateral shift in depositional environments may have resulted in the silty shale capping the parasequence.

Parasequence 3-- Unit 9 signifies a return to deeper water owing to marine flooding. This thin bedded sandstone unit is devoid of plant fragments and contains burrows and poorly preserved molds of marine bivalves. Silt-laminated shales of unit 10 are stained by limonite near the top and are capped by lignite (unit 11) that marks the top of the parasequence.

Parasequence 4-- This parasequence lacks a basal sandstone. The relatively thick basal unit is a silty shale (unit 12) that becomes more carbonaceous upward.

Relative sea level may not have dropped as much during deposition of this interval, as suggested by the lack of a basal burrowed sandstone. The silty shale becomes very carbonaceous at the contact with the overlying lignite (unit 13) and a slight rise in relative sea level or lateral shift in depositional environment is suggested by the overlying carbonaceous shale (unit 14), which caps the parasequence.

The remaining strata at Locality 5 cannot be clearly classified in a parasequence context. No lignites are present above unit 13 and the nature of sandstone and shale units above unit 13 changes from those found within the well-defined parasequences. Some of these higher intervals may indeed include parasequences but with current data such a determination would be tenuous at best.

Sections exposed at Localities 7A and 7B (Fig. 20) reveal less clearly defined parasequences. The lower, nonmarine mudstone units (A-G) are overlain by interbedded sandstones and shales of unit 1 that are lithologically similar to the intertidal deposits of unit 7 at Locality 4 (Fig. 11). The interbedded unit, which is interpreted as an intertidal deposit, is overlain by sandstone (unit 2) containing marine fossils including *Exogyra levis.* The sharp contact between intertidal and deeper marine units suggests termination of one parasequence and an abrupt deepening of water that heralded initiation of a second parasequence. The marine sandstone is overlain by shale (unit 3) that is clayey at the base and coarsens upward into silty shale and contains thin sandstone beds near the top. These shales reflect a shallowing upward, which is signified by upward increase in abundance of coarse detrital material. Bentonite seams of units 4 and 6 are interpreted as altered volcanic ash that fell in the marginal marine setting. The shale of unit 3 grades upward into interbedded sandstone-shale of unit 5, which contains cross-laminated and ripple-marked sandstones and is indicative of tidally influenced deposition. The overlying shale (unit 7) reflects deeper water open-marine deposition and is the basal unit of the Graneros Shale. Only one clearly developed parasequence appears to exist at this locality owing to the limited amount of exposure and the thickness of the parasequence.

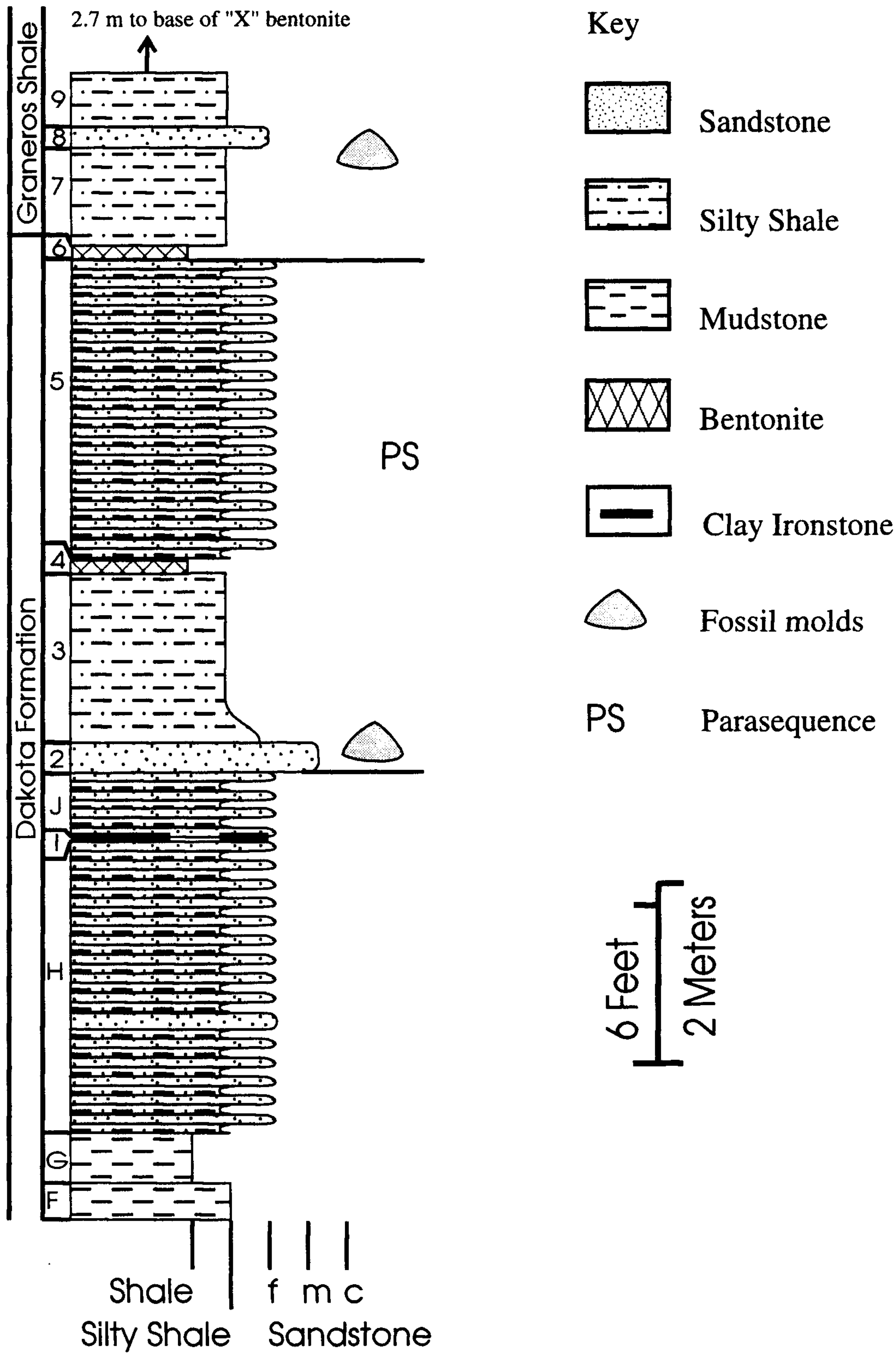


Figure 20. Composite graphic section of upper part of the Dakota Formation and Graneros Shale at Localities 7A-B.

Paleogeographic Implications

Regional Paleogeography

Paleogeographic reconstruction of Hattin (1967) shown in Figure 1 indicates the presence of a large deltaic complex with swamps, marshes, and shore lagoons along the shoreline. Siemers (1971) describes strata of the Dakota-Graneros transition as part of a large deltaic complex with many subenvironments that include nonmarine, brackish, and marine settings. Correlation of these subenvironments is problematic, even for closely spaced sections, owing to the limited extent of each specific depositional environment. Although the basic transition from nonmarine to marine strata determined in this study agrees with previous work, no compelling evidence for deltaic deposition was found within the study area. This may be in part owing to the limited geographic extent of the study area (Fig. 4), the small number of sections measured in relation to the work of Siemers (1971), and perhaps to location of study areas away from river mouths.

Based on the results of this research project, deposition of strata in my study area apparently took place adjacent to the deltaic complex along a tidally influenced siliciclastic shoreline containing lagoons that were bordered by coastal swamps and localized fluvial systems. The ubiquitous interbedded sandstone-shale units that contain ripple marks, cross laminations, and marine fossils are evidence of tidal influence along the Cretaceous shoreline in Kansas. Swamps were not as prevalent in the southern portion of the study area as is suggested by a dearth of lignite beds in the Hodgeman/Ford County sections. An example of the lateral association of the various environments described in the Dakota-Graneros transition is shown in Figure 16.

Impact of Sea Level Fluctuations on Paleogeography

The presence of parasequences at Localities 5 and 7A-B (Fig. 13 and 20) indicates that fluctuations in relative sea level took place during the transgression. This fluctuation caused several of the depositional environments to shift in a cyclic fashion and led to intertonguing of nonmarine and marine strata. As outlined previously, strata of the various subenvironments are difficult to correlate, and this complicates efforts to relate parasequences that occur in measured sections which are only a few miles apart. Bentonites have proved to be the best datums for correlating the measured sections in this study (Fig. 15) although the bentonite utilized for correlating sections in Hodgeman and Ford Counties left some uncertainty as to correlation potential. Attempts to correlate between the two study areas (Fig. 18) has met with limited success owing to the difference in detail obtained from surface sections and well logs. In order to better understand the precise nature of relative sea level changes along the Cretaceous shoreline of Kansas, more surface exposures of parasequences are required.

Work by Elder and others (1994) involves correlation of basinal carbonate cycles within the Greenhorn Limestone to nearshore siliciclastic parasequences along the western margin of the Western Interior Sea (Fig. 5). Those parasequences are situated near the top of the Dakota Formation and in overlying shales. Fluctuations of relative sea level have also been observed in the Coalville Member of the Frontier Formation in Utah (Ryer, 1977). These sediments were also deposited during transgression of the Western Interior Sea in Cenomanian time and represent coastal swamp, nearshore-marine, and offshore-marine environments. Evidence of parasequences on both edges of the Western Interior Sea lends support to the hypothesis of nonuniform rate of transgression during deposition of the Greenhorn Sequence. A complicating factor in the formation of western margin parasequences is the greater amount of tectonic activity in the Sevier orogenic belt compared to the more tectonically stable craton on the eastern side of the basin.

CONCLUSIONS

1. The upper part of the Dakota Formation and the Graneros Shale were deposited during the transgression of the Western Interior Sea in Cenomanian time. These strata formed during upward transition from nonmarine to marginal marine to open marine environments. The nonmarine units include mudstones and sandstones that are part of a meandering river system and flood plain. Marginal marine sediments include deposits of coal swamps, lagoons, and tidally influenced settings. Marine deposits were formed on the open shelf and were influenced by storms that produced fossiliferous sandstone layers within a generally shaly section.

2. During upper Dakota-lower Graneros deposition the study area was the scene of a tidally dominated siliciclastic marginal marine complex which was bordered by coastal swamps and floodplains. Interbedded sandstone-shale units are present in all measured sections and contain ripple marks, cross laminations, and marine fossils. These units are the principal deposits of the tidally influenced environments. Shore lagoons and deltas existed along this shoreline as evident from this and previous studies of the upper part of the Dakota Formation in central Kansas.

3. Strata representing the various subenvironments of upper Dakota-lower Graneros deposition are difficult to correlate over even short distances. This poses a significant problem in attempts to correlate parasequences between measured sections. The lack of exposure between the Russell/Ellsworth and Hodgeman/Ford County areas also complicates correlation attempts.

4. These transgressive strata are the basal units in a sequence that was marked during maximum transgression by deposition of sediments that formed the Greenhorn Limestone. In two of the studied sections this sequence, termed the Greenhorn Sequence, contains several parasequences. These parasequences are best defined in nonmarine to marginal marine upper Dakota strata that lie just below the contact with the Graneros Shale. The presence of parasequences indicates that transgression of the sea across

central Kansas was not uniform but was punctuated by several fluctuations of relative sea level.

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APPENDIX A
MEASURED SECTIONS

LOCALITY 1

Ravine on north side of east-west county road southeast of Hanston in SE 1/4, SW 1/4, sec. 24, T 22 S, R 22 W, Hodgeman Co., Kansas

Unit	
Graneros Shale	**Thickness, meters**
19. Shale, dark gray, stained by jarosite.	3.94
18. Sandstone, yellowish orange, fine grained, friable near top, well sorted, cemented by calcite. *Fossils:* molds of *Aphrodina lamarensis* (Shumard).	0.36
17. Shale, dark gray with jarosite staining, contains gypsum crystals as much as 30 cm in length.	2.37
16. Shale, dark gray, stained by jarosite, contains 1 mm thick stringers of white quartz sand.	1.75
Measured thickness of Graneros Shale:	**8.42 m**
Dakota Formation	
15. Sandstone and shale; sandstone yellowish gray, fine grained, resistant, contains current ripple marks; unit interbedded with shale, medium dark-gray, silty, contains large (>10 cm) gypsum crystals.	1.17
14. Bentonite, white, some Fe staining, resistant.	0.05
13. Sandstone and shale; sandstone yellowish gray, fine grained, resistant, contains current ripple marks; unit interbedded with shale, medium dark-gray, silty, contains large (>10 cm) gypsum crystals.	1.22
12. Sandstone, very light gray, weathers brown, fine to medium grained, friable, variable thickness with trough-like features at top.	0.15-0.41
11. Sandstone and shale; sandstone yellowish gray, fine grained, resistant, contains current ripple marks; unit interbedded with shale, medium dark-gray, silty, contains large (>10 cm) gypsum crystals. Amount of shale increases upward; sharp contact at top. Fossils: in shale, plant fragments.	1.42
10. Sandstone, yellowish gray, fine grained, well cemented, contains poorly developed interference ripples several cm high.	0.08
9. Shale, dark gray, becomes interbedded with yellowish gray sandstone near top.	0.30
8. Shale, dark gray, thin sandstone at top. *Fossils:* plant leaf.	0.15
7. Sandstone, light gray, fine grained, Fe staining.	0.05
6. Silty mudstone, medium light gray, contains plant fragments.	0.56
5. Silty mudstone, very light gray, weathers yellowish orange, resistant. *Fossils:* plant fragments..	0.33
4. Mudstone, light to medium dark gray, slightly silty, coarsens upward.	1.47

3. Silty mudstone, light gray, weathers into "popcorn" type slope.	1.14
2. Sandstone, light gray to yellowish orange, fine grained, resistant in lower 43 cm becoming muddy and poorly cemented near top, lower portion contains cross beds.	1.09
1. Silty mudstone, yellowish gray, coarsens upward to resistant sandstone.	0.71
Measured thickness of Dakota Fm.	**10.15 m**
Total thickness of measured section	**18.57 m**

LOCALITY 2

Stream cut along tributary of Sawlog Creek southeast of Jetmore in NE 1/4, SE 1/4, sec. 11, T 24 S, R 22 W, Hodgeman Co., Kansas

Unit **Graneros Shale**	**Thickness, meters**
7. Shale, medium gray, stained by jarosite.	1.12
6. Sandstone, dark grayish orange, thin bedded, calcite cement. *Fossils:* molds of *Aphrodina lamarensis* (Shumard).	0.38
5. Shale, medium gray, stained by jarosite.	3.35
Measured thickness of Graneros Shale:	**4.85 m**
Dakota Formation	
4. Sandstone and shale, sandstone dark yellowish orange, fine grained, contains current ripple marks; unit interbedded with shale, medium dark-gray, silty, stained by jarosite.	3.04
3. Bentonite, white, irregular surface, appears scoured.	0.07
2. Sandstone and shale, sandstone dark yellowish orange, fine grained, contains current ripple marks; unit interbedded with shale, medium dark-gray, silty, stained by jarosite.	0.89
1. Silty Shale, dark gray, contains two thin sandstone beds, very light gray, resistant. *Fossils:* erect molds of reed-like plant stems, plant fragments.	0.76
Measured thickness of Dakota Fm.	**4.76 m**
Total thickness of measured section	**9.61 m**

LOCALITY 3

Stream cut along tributary of Sawlog Creek at "Pointed Rock" in NW 1/4, sec. 18, T 24 S, R 22 W, Hodgeman Co., Kansas

Unit **Graneros Shale**	**Thickness, meters**
18. Shale, light gray, stained by jarosite.	1.04
Measured thickness of Graneros Shale:	**1.04 m**

Dakota Formation

17.	Sandstone and shale; sandstone, dark yellowish orange, resistant, contains current ripple marks; unit interbedded with shale, medium dark-gray, silty, stained by jarosite, contains gypsum crystals up to several cm in length.	3.78
16.	Shale, dark gray, becomes laminated with light gray sand near top.	0.25
15.	Bentonite, white.	0.05
14.	Sandstone and shale; sandstone, very light gray, friable, contains current ripple marks; unit interbedded with shale, medium dark-gray, silty, stained by jarosite, contains gypsum crystals up to several cm in length.	0.28
13.	Shale, dark gray, fissile, contains laminations of sand, stained by jarosite.	0.94
12.	Sandstone and shale; sandstone, very light gray, friable, current ripple marks; unit interbedded with shale, medium dark-gray, silty, stained by jarosite, contains gypsum crystals up to several cm in length.	0.10
11.	Shale, light to medium gray, silty, contains thin light gray sand stringers and two thin intervals of clay ironstone concetions, grayish red to yellowish orange, very resistant.	0.71
10.	Sandstone, dusky red, well cemented, very resistant, contains large ripple marks (10 cm high).	0.18
9.	Sandstone, light gray, thinly bedded, poorly to moderately cemented. *Fossils:* plant fragments.	0.41
8.	Sandstone, yellowish orange, massive, stained by limonite, contains possible burrow structures.	0.64
7.	Sandstone, yellowish orange, resistant bed, stained by limonite.	0.05
6.	Sandstone, light gray, thin to medium bedded, some calcite cement, with minor amounts of limonite staining. *Fossils:* plant fragments.	0.36
5.	Mudstone, medium gray, waxy appearance, silty, amount of silt increases upward. *Fossils:* abundant plant fragments, some as much as several cm in length.	0.66
4.	Silty mudstone, medium gray, contains possible burrow structures near lower contact. *Fossils:* plant material.	0.84
3.	Silty sandstone, dark yellowish orange to very pale orange, resistant.	0.05
2.	Silty Shale, light gray, fissile, contains minor amounts of silt.	0.10
1.	Silty sandstone, light gray, thin to medium bedded, with some limonite staining, pyrite.	1.07

Measured thickness of Dakota Fm.	**10.47 m**
Total thickness of measured section	**11.51 m**

LOCALITY 4

Ravines on west side of north-south county road sout of Black Wolf in NW 1/4, SW 1/4, sec. 19, T 15 S, R 9 W, Ellsworth Co., Kansas.

Unit **Graneros Shale**	**Thickness, meters**
13. Bentonite, white, weathers yellow-orange owing to limonitic staining.	0.27
12. Covered interval; float contains blocks of yellowish gray sandstone with molds of *Aphrodina lamarensis* (Shumard), medium gray shale also present in float.	7.22
11. Bentonite, white.	0.03
10. Shale, medium gray, becomes light gray near top, minor silt, *Fossils:* *Reophax* sp.	2.90
Measured thickness of Graneros Shale	**10.42 m**
Dakota Formation	
9. Sandstone, dusky red, Fe cemented, resistant, fine grained; contains clay-ironstone concretions. *Fossils:* fish scale, *Laternula* sp. (mold), oyster (mold).	0.09
8. Shale, medium dark gray, stained by jarosite and limonite, with several very thin lenses of white friable fine-grained sandstone; unit contains a small number of dark yellowish orange, resistant Fe-cemented sandstone beds, each less than 0.1 ft thick.	0.91
7. Sandstone and shale; sandstone yellowish gray, fine grained, resistant, contains clay ironstone concretions, oscillation and current ripple marks, and indeterminate sole markings; unit interbedded with shale, medium dark-gray, silty, contains large (up to several cm) gypsum crystals. *Fossils:* molds of *Geltena* sp. and *Cymbophora* sp.	1.83
6. Shale, medium gray, silty, becomes darker and less silty near top; contains abundant carbonized plant material at base; lower 3.0 ft. weathers dark gray and shaly.	3.81
5. Sandstone, medium gray (weathers dark gray), silty, carbonaceous, with large percentage of carbonized wood fragments; contains lenses of very thin grayish orange medium-grained sandstone that lacks woody material; entire unit fines upward into unit 6.	1.37
4. Bentonite, light gray, hard, brittle, with conchoidal fracture, impersistent; contains sparse fragments of carbonized woody material.	0.06
3. Sandstone, medium gray (weathers dark gray), silty, carbonaceous, with large percentage of carbonized wood fragments; contains lenses of very thin grayish orange, medium-grained sandstone that lacks woody material; lower part contains interbeds of shale like that in unit 2.	1.43
2. Mudstone, light gray, pale yellowish orange, slightly carbonaceous.	0.38
1. Mudstone, dark yellowish orange to grayish red, silty, underlies light gray weathered slopes, contains siderite spherules (less than 2mm).	0.70

Measured thickness of Dakota Fm.	**10.58 m**
Total thickness of measured section	**21.00 m**

LOCALITY 5

North facing bluff and adjacent slumped interval on east side of north-south paved road approximately 3 miles south of Wilson in NW 1/4, NE 1/4, sec. 6, T 15 S, R 10 W, Ellsworth Co., Kansas

Unit **Graneros Shale**	**Thickness, meters**
24. Sandstone and shale; sandstone yellowish orange, calcareous, resistant, interbedded with shale, medium gray; thin limestone lenses present throughout interval.	0.89
23. Bentonite, white, weathers dark yellowish orange, some portions resistant to weathering.	0.28
22. Sandstone and shale; sandstone yellowish orange, calcareous, thin bedded, resistant, interbedded with medium gray shale which contains minor amounts of silt.	0.61
21. Shale, light to medium gray, contains minor amounts of silt.	0.30
20. Covered interval, large slump of grass and shaly soil.	4.19
19. Shale, light to medium gray, contains yellowish orange sand stringers.	0.20
Measured thickness of Graneros Shale	**6.47 m**
Dakota Formation	
18. Silty shale, medium to dark gray; contains thin beds of sandstone, Fe-cemented, dark reddish brown, resistant. *Fossils:* plant material.	0.56
17. Sandstone, dark reddish brown, resistant, Fe cemented.	0.05
16. Silty shale, medium to dark gray; contains thin beds of sandstone, dark reddish brown, resistant, *Fossils:* plant material.	1.17
15, Sandstone, light gray, resistant, jarosite staining, contains gypsum at lower contact. *Fossils:* minor amounts of plant material.	0.36
14. Shale, grayish black, carbonaceous, weathers shaly, stained by jarosite.	0.18
13. Lignite, dusky yellowish brown, stained by jarosite.	0.20
12. Silty shale, medium dark gray, laminations of very light gray quartz sand. *Fossils:* abundant plant fragments at top of unit.	0.74
11. Lignite, dusky yellowish brown, stained by jarosite.	0.13
10. Shale, medium gray, laminations of silt, coarsens upward, Fe stains near top of unit.	0.64
9. Sandstone, very light gray, thin bedded, resistant, contains burrow structures.	0.10
8. Silty shale, medium gray, carbonaceous near base.	0.23
7. Lignite, black, some jarosite stains.	0.18

6. Shale, pale yellowish brown. *Fossils:* abundant plant fragments. 0.20
5. Sandstone, light gray, some Fe stains, beds thin upward. *Fossils:* plant fragments and *Arenicolites* burrows. 0.46
4. Sandstone, yellowish brown, thin bedded, contains burrow structures. 0.23
3. Lignite, grayish black. 0.08
2. Silty shale, light brownish gray, lower 60 cm are resistant. *Fossils:* plant fragments near top of unit. 2.06
1. Shale, medium light gray, becomes less silty upward, organic material more common near top, contains minor gypsum and jarosite; unit is interbedded with thin sandstone beds, Fe cemented, resistant, evenly spaced near bottom but irregular and widely spaced near top of unit. 6.10

Measured thickness of Dakota Fm. **13.67 m**
Total thickness of measured section **20.14 m**

LOCALITY 6
Cut on south side of spillway at Wilson Reservoir, in
SE 1/4, SE 1/4, sec. 36, T 15 S, R 11 W, Russell Co., Kansas

Unit
Graneros Shale **Thickness, meters**

14. Shale, medium gray, contains thin, Fe-cemented sandstone layers. 3.81

Measured thickness of Graneros Shale **3.81 m**

Dakota Formation

13. Sandstone and shale; sandstone dark yellowish orange, Fe cemented, slightly calcareous, thin bedded, contains current ripple marks interbedded with dark gray shale, fissile; small crystals of gypsum in float. 0.46
12. Bentonite, white, some Fe stains. 0.05
11. Sandstone and shale; sandstone dark yellowish orange, Fe cemented, slightly calcareous, thin bedded, contains current ripple marks interbedded with dark gray shale, fissile; small crystals of gypsum in float. 0.74
10. Sandstone, dark yellowish gray, friable. *Fossils:* molds of *Geltena* sp. 0.25
9. Shale, dark gray, stained by jarosite, contains gypsum crystals, thin sandstone (unit 9a) lies near base, dark yellowish gray, fine grained. 1.40
8. Sandstone, very light gray, thin bedded, resistant, base of unit contains shale-pebble lag. 0.71
7. Shale, medium gray, contains very thin sandstone lenses. 0.30
6. Silty sandstone, medium light gray, some Fe stains. 0.66
5. Bentonite, white. 0.03
4. Sandstone, pale yellowish brown, resistant, contains abundant small gypsum crystals, becomes shaly near top of unit. 0.36
3. Silty sandstone, medium light gray, contains sandstone lenses, less silty

than rest of unit, very thin, very light gray, some lenses contain Fe stains.

2.	Sandstone, moderate yellowish brown, contains gypsum and Fe-cemented concretions.	0.13
1.	Sandstone and shale; medium gray shale, very silty near base and becoming less silty near top of unit; contains several very thin to thin sandstone units, some of which are Fe stained.	4.04

Measured thickness of Dakota Fm. **9.99 m**

Total thickness of measured section **13.80 m**

LOCALITY 7A

Steep cutbank on east side of tributary to Smoky Hill River south of Dorrance in NE 1/4, NE 1/4, sec. 12, T 15 S, R 12 W, Russell Co., Kansas

Unit

Graneros Shale		**Thickness, meters**
13.	Bentonite, white, weathers dark yellowish orange.	0.23
12.	Sandstone and shale; sandstone, light gray, calcareous, with some Fe staining, some intervals contain cross lamination, unit interbedded with shale, medium gray, laminations of sandstone. *Fossils:* crushed shell of *Ostrea*? sp.	0.53
11.	Shale, medium dark gray, contains jarosite and gypsum.	0.58
10.	Covered interval.	1.60
9.	Shale, medium dark gray, contains jarosite and gypsum.	0.61
8.	Sandstone, dark yellowish gray, calcite cement, fossiliferous limestone lenses present throughout unit. *Fossils: Ostrea* sp.	0.23
7.	Shale, dark gray, abundant jarosite and gypsum, contains thin sandstone beds and laminations near bottom of unit, light gray, fine-grained.	1.07
6.	Bentonite, white.	0.03

Measured thickness of Graneros Shale **4.88 m**

Dakota Formation

5.	Sandstone and shale; sandstone, light gray, thin bedded, contains current ripples and cross laminations, sandstone becomes more prominent near top; unit interbedded with shale, medium dark gray, contains vertical fractures filled with gypsum.	3.30
4.	Bentonite, white.	0.03
3.	Shale, medium dark gray, very fissile, no silt near bottom, becomes silty and interbedded near top with sandstone, light gray, thin bedded.	1.83
2.	Sandstone, dark yellowish orange, heavily Fe stained, resistant, contains gypsum, heavily cemented areas contain numerous fossils. *Fossils: Exogyra levis* Stephenson, *Corbicula?* sp. (internal mold).	0.33

1. Sandstone and shale; sandstone, dark yellowish orange, Fe stained, thin bedded, contains gypsum, unit interbedded with shale, medium gray. *Fossils:* plant fragments. — 1.30

Measured thickness of Dakota Fm. **6.79 m**
Total thickness of measured section **11.67 m**

LOCALITY 7B
NW 1/4, NE 1/4, sec. 12, T 15 S, R 12 W
Steep cut on west side of stream
South of Dorrance, Russell Co., Kansas

Unit **Dakota Formation**	**Thickness, meters**
M. Bentonite, white, same as unit 4 in section 7A.	0.03
L. Shale, medium dark gray, very fissile, no silt near bottom, becomes silty and interbedded near top with sandstone, light gray, thin bedded.	2.06
K. Sandstone, dark yellowish orange, heavily Fe stained, resistant, contains gypsum crystals, heavily cemented areas contain numerous fossils. *Fossils: Exogyra levis* Stephenson, *Corbicula?* sp. (internal mold).	0.33
J. Sandstone and shale; sandstone, dark yellowish orange, Fe stained, thin bedded, gypsum, unit interbedded with shale, medium gray. *Fossils:* plant fragments.	0.69
I. Clay ironstone, yellowish brown.	0.03
H. Sandstone and shale; sandstone, dark yellowish orange, Fe stained, thin bedded, contains gypsum; unit interbedded with shale, medium gray, sandy. *Fossils:* plant fragments.	3.15
G. Mudstone, light gray, contains Fe nodules.	0.58
F. Silty mudstone, light gray, Fe stained, resistant to weathering.	0.30
E. Mudstone, medium gray. *Fossils:* plant fragments.	1.52
D. Silty mudstone, light gray, coarsens upward.	0.10
C. Sandy mudstone, light gray, contains 6 mm thick clay seam.	0.03
B. Sandy mudstone, medium light gray, carbonaceous.	0.13
A. Mudstone, light gray, becomes sandy near top of unit.	0.69

Total thickness of measured section **9.64 m**

LOCALITY 8
N 1/2, sec. 10, T 25 S, R 23 W
Northeast of Dodge City, Ford Co., Kansas

Unit	
Graneros Shale	**Thickness, meters**
11. Covered interval, medium gray shale in float.	
Dakota Formation	
10. Sandstone, yellowish orange, Fe stained.	0.13
9. Sandstone and shale; sandstone, grayish orange, thin bedded, contains current ripples, interbedded with shale, medium light gray, contains light gray sand laminations.	0.46
8. Shale, medium gray, contains very thin sandstone stringers, gypsum crystals as much as 10 cm in length.	1.40
7. Sandstone, yellowish orange, Fe stained, contains gypsum crystals.	0.13
6. Shale, medium gray, contains very thin sandstone stringers, contains gypsum crystals as much as 10 cm in length.	0.69
5. Bentonite, white.	0.05
4. Sandstone, light brown, Fe stained, thin bedded, unit pinches out within several meters towards southern portion of exposure.	0.28
3. Sandstone and shale; sandstone, grayish orange, fine-grained, thin bedded; interbedded with shale, medium light gray, stained by jarosite.	0.69
2. Shale, medium gray, contains two resistant beds of silt, units 2a and 2b, unit 2b is discontinuous, gypsum present.	0.48
1. Silty sandstone, light gray, possible burrow structures.	0.97
Total thickness of measured section	**5.28 m**

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