KANSAS GEOLOGICAL SURVEY
OPEN-FILE REPORT 94-15

Road Log and Field Guide to
Dakota Aquifer Strata in Central Kansas

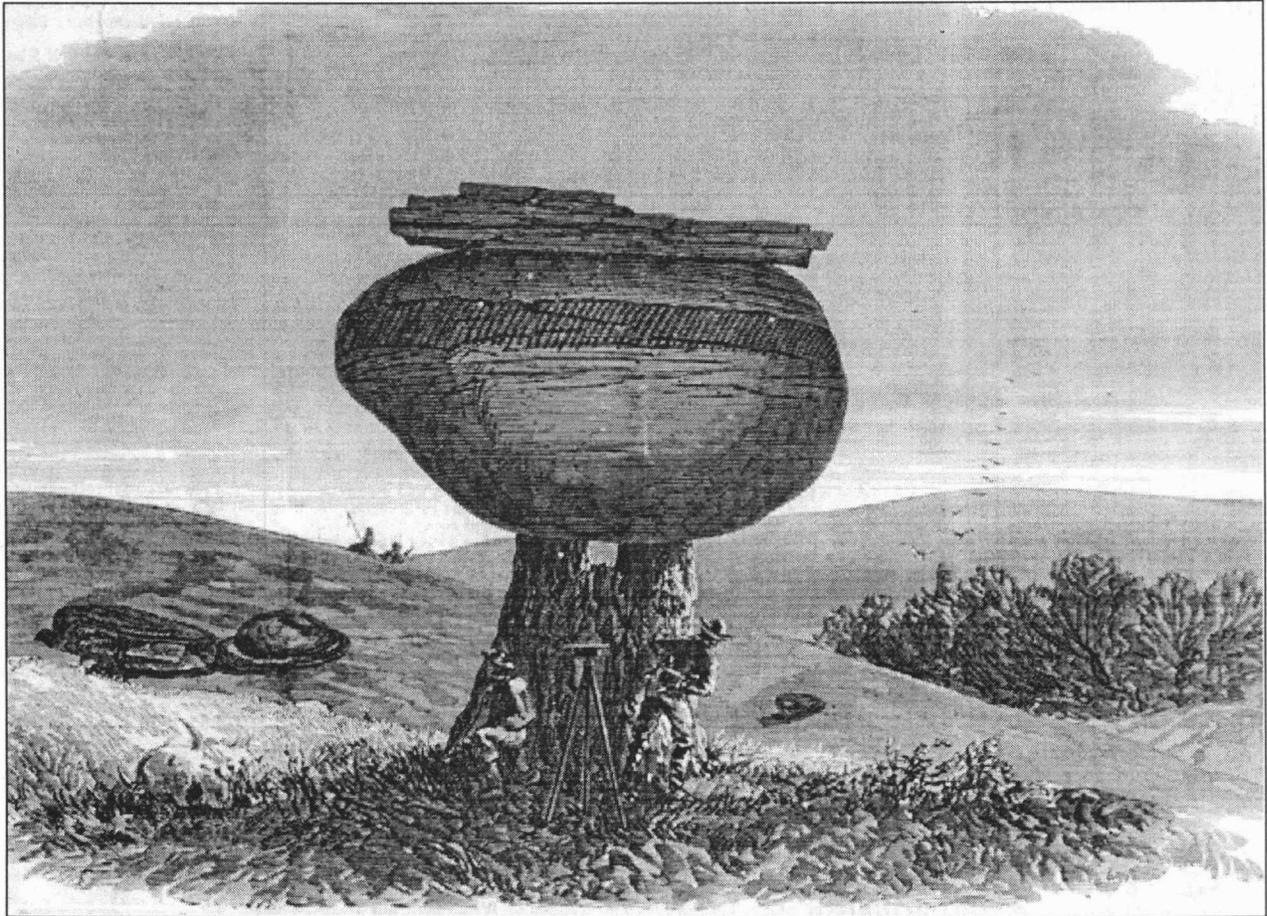compiled by

Howard R. Feldman

Disclaimer

KANSAS GEOLOGICAL SURVEY
1930 Constant Avenue
University of Kansas
Lawrence, KS 66047

Road log and field guide to
Dakota Aquifer strata
in central Kansas

Road log and field guide to

Pulpit Rock on Alum Creek, Kansas Pacific Railroad, Harper's Weekly, June 15, 1867

Kansas Geological Survey
**Open-file Report 94–15**

April 11, 1994

Presented in conjunction with
the Water and Energy Resources
of the Dakota Aquifer Workshop and Clinic

Compiled by Howard R. Feldman

"Despite expressed qualifications and warnings, the geologist is prone to fix his eye on resistant beds in a published columnar section. For this reason no channel sandstone is described in the following generalized section of the Dakota Formation. Any one desirous of doing so may insert a lenticular sandstone in any portion of the section and be reasonably assured that such a sandstone occurs at that stratigraphic position somewhere in the area of the outcrop."

From Plummer and Romary (1942, p. 328).
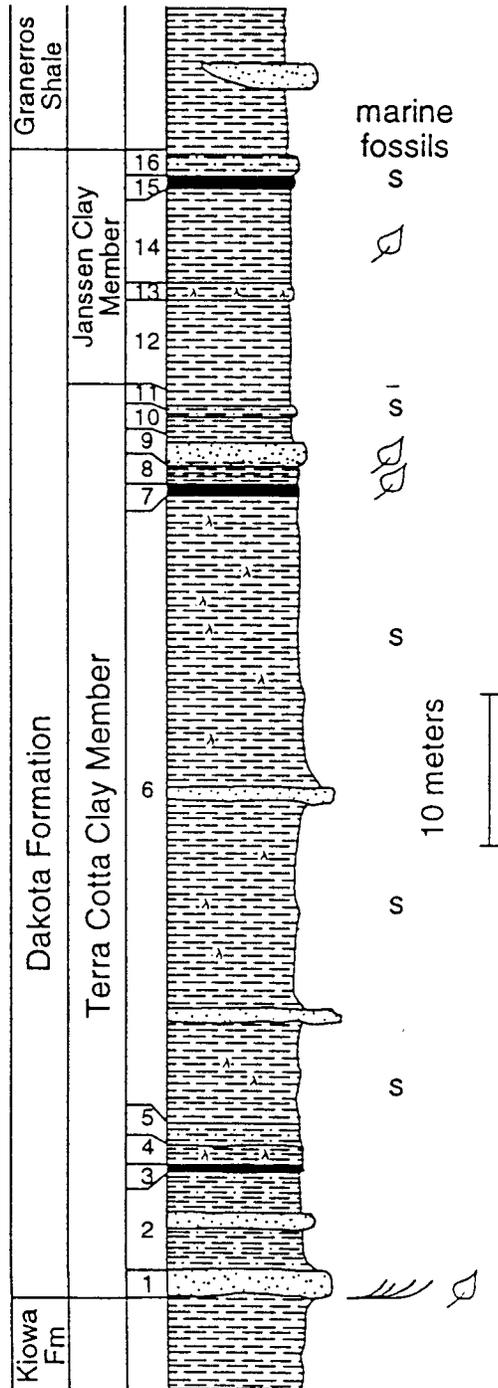
Generalized section of Dakota Formation based on description in Plummer and Romary (1942). Unit numbers refer to their description.

Table of Contents

INTRODUCTION
by Howard R. Feldman, Kansas Geological Survey

Field trip objectives

In this field trip we will observe the Cretaceous Cheyenne, Kiowa, Dakota, and lower Graneros formations that record the stepwise marine flooding of the Western Interior basin, forming the last great continental seaway in North America (Figs. 1, 2, 3). During Early through early Middle Cretaceous time, transgression occurred from the north and south, culminating with the formation of the Cretaceous Western Interior sea. Deciphering the history of this marine inundation is not simple, however, because these units encompass a stratigraphically complex mosaic of marine and terrestrial facies. The problems of stratigraphic correlation are compounded by the lack of fossils in many of the units and the paucity of stratigraphic markers. However, these rocks have been intensively studied, resulting in stratigraphic models that relate facies patterns to sea level changes.

The Dakota and related formations are being studied as a potential (and current) water source, as the Tertiary High Plains aquifer is depleted to the point where it will no longer be an economic source of water (Macfarlane *et al.*, 1990). In order to understand how best to manage and protect the Dakota aquifer (which includes the Cheyenne, Kiowa, and Dakota formations), hydrogeologic models are being developed that depend on accurate stratigraphic models (Macfarlane *et al.*, in review). The goal of the Dakota Aquifer Program at the Kansas Geological Survey is to develop a better understanding of the hydrogeology of the aquifer. This involves determining the stratigraphic architecture of sandstone bodies at the scale of meters to tens of meter in a few small areas (tens of km wide) (Fig. 5), and mapping the distribution of unconformity-bounded sequences throughout western and central Kansas.

This field trip provides an introduction to some of the wide range of facies that occur within the outcrop of the formations that comprise the Dakota aquifer in Rice and Ellsworth Counties, Kansas. The stops are organized in stratigraphic order, starting with the Permian-Cretaceous boundary and ending with the Dakota/Graneros transition. The objective is to display as wide a range of facies as possible and to provide evidence of some of the stratigraphic relationships that are important for interpreting the depositional history of these rocks.

The field trip area also has a colorful and unique history associated with the long occupation of the area by Native Americans and colonization by the Europeans. Interesting historical notes are presented in the road log that relate to localities along the field trip route.

Stratigraphic overview

Field trip participants will observe the Cheyenne,

Kiowa, Dakota, and Graneros formations, which comprise the Dakota aquifer in Kansas (Fig. 1). Together these units belong to two basinwide transgressive/regressive cyclothems: the Kiowa-Skull Creek cycle, which includes the Cheyenne and Kiowa formations, and the Dakota-Greenhorn cycle which includes the Dakota, Graneros and overlying marine units up to the base of the Niobrara Limestone (Kauffman, 1984). The upper cyclothem has been divided into two unconformity-bounded sequences by Weimer (1984) and Hamilton (1989). The following description of stratigraphic units is summarized largely from discussions in Franks (1975) and Hamilton (1989).

Cheyenne Sandstone: The Cheyenne Sandstone was named for exposures of the lowest Cretaceous sandstone at Cheyenne rock in Kiowa County, Kansas (Cragin, 1889). In the type area the Cheyenne Sandstone consists of fine- to medium-grained, cross-bedded sandstone with lenses of shale and conglomerate (Latta, 1946) and rests unconformably on Permian rocks (Latta, 1946). However, the Cheyenne rests on the Jurassic Morrison Formation in western and north central Kansas (Merriam, 1957) (Fig. 1). The Cheyenne Sandstone is variable in thickness, ranging up to 28.7 m (94 ft) on outcrop and 79.2 m (260 ft) in the subsurface (Merriam, 1957), and tends to thicken into paleotopographic lows (Latta, 1946; Merriam, 1957). The Cheyenne Sandstone does not outcrop in the field trip area; instead marine and coastal facies of the Kiowa Formation rest directly on Permian beds. At Stop 1 the basal Cretaceous unconformity is marked by a thin conglomerate which may be the stratigraphic equivalent of the Cheyenne.

Kiowa Formation: The Kiowa Formation was named for exposures of marine shale, sandstone and limestone near Belvidere, Kiowa County, Kansas (Cragin, 1895, Plummer and Romary, 1942). Merriam (1957) recognized a maximum thickness of the Kiowa Formation of approximately 115.8 m (380 ft), however, in the field trip area the Kiowa is typically 30.5 to 45.7 m (100 to 150 ft) thick (Fent, 1950; Hamilton, 1989). The Kiowa in this area consists predominantly of fossiliferous dark gray shale and burrowed, cross-bedded sandstone that were deposited in marine shelf environments (Scott, 1967). Minor thin (generally under 20 cm), fossiliferous limestones occur within the shale. The sandstone beds commonly contain abundant plant fossils and were deposited in nearshore to coastal environments. The basal Kiowa contact is erosional where the Cheyenne is absent, but in the type area of the Cheyenne and Kiowa formations in Kiowa County, Kansas, the contact has been described as both abrupt but conformable (Latta, 1946) and unconformable (Franks, 1975). In the type area the Champion shell bed commonly overlies the contact (Latta, 1946).

In north-central Kansas, white siltstones, lenticular sandstones, and red-mottled siltstones and mudstones in the base of the Kiowa Formation are included in the Longford

1

A

SW

TYPE KIOWA &
CHEYENNE

Field trip
area

KANSAS NEBRASKA

GRANEROS SHALE

NE

JANSSEN CLAY MEMBER

CENOZOIC DEPOSITS

TERRA COTTA CLAY MEMBER

DAKOTA FM.

DAKOTA FM.

?

PERMIAN ROCKS

PERMIAN ROCKS

LONGFORD MEMBER

KIOWA FM.

CHEYENNE SS.

B

Field trip
area

NW

SE

"X" bentonite

GRANEROS SHALE

CENOZOIC DEPOSITS

HUNTSMAN
SHALE

DAKOTA FM.

KIOWA FORMATION

CHEYENNE SANDSTONE

?

JURASSIC ROCKS

PERMIAN ROCKS

0	50 Mi
0	80 Km

30 ⌐100
METERS   FEET
0 ⌐ 0

Figure 1. Stratigraphic relationships among units that comprise the Dakota aquifer. A. Cross section along the Dakota aquifer outcrop belt showing the field trip area. Correlations are based on the model of Franks (1979). Uppermost Kiowa sandstone facies are place above the basal Dakota Formation unconformity by Hamilton (1989). Modified from Franks (1979). B. Preliminary schematic cross section from the northwestern corner of Kansas to the field trip area based on data from Merriam (1957) and Hamilton (1989) and applying Hamilton's stratigraphic model. The considerable local variation in thicknesses and facies is not shown. Datum is the "X" bentonite.

WEST
seaward

EAST
landward

Graneros

D

Hiatus and sediment bypass

95 m.y.

CS

Hunts.

J

Hiatus and sediment bypass

97 m.y.

Kiowa

CS

Longford

Cheyenne

Hiatus and sediment bypass

100 m.y.

Time

Distance

marine shale

lower shoreface to coastal plain sandstone and shale

fluvial sandstone and mudstone

strata removed during period of formation of overlying and younger unconformity

nondeposition in marine condensed section

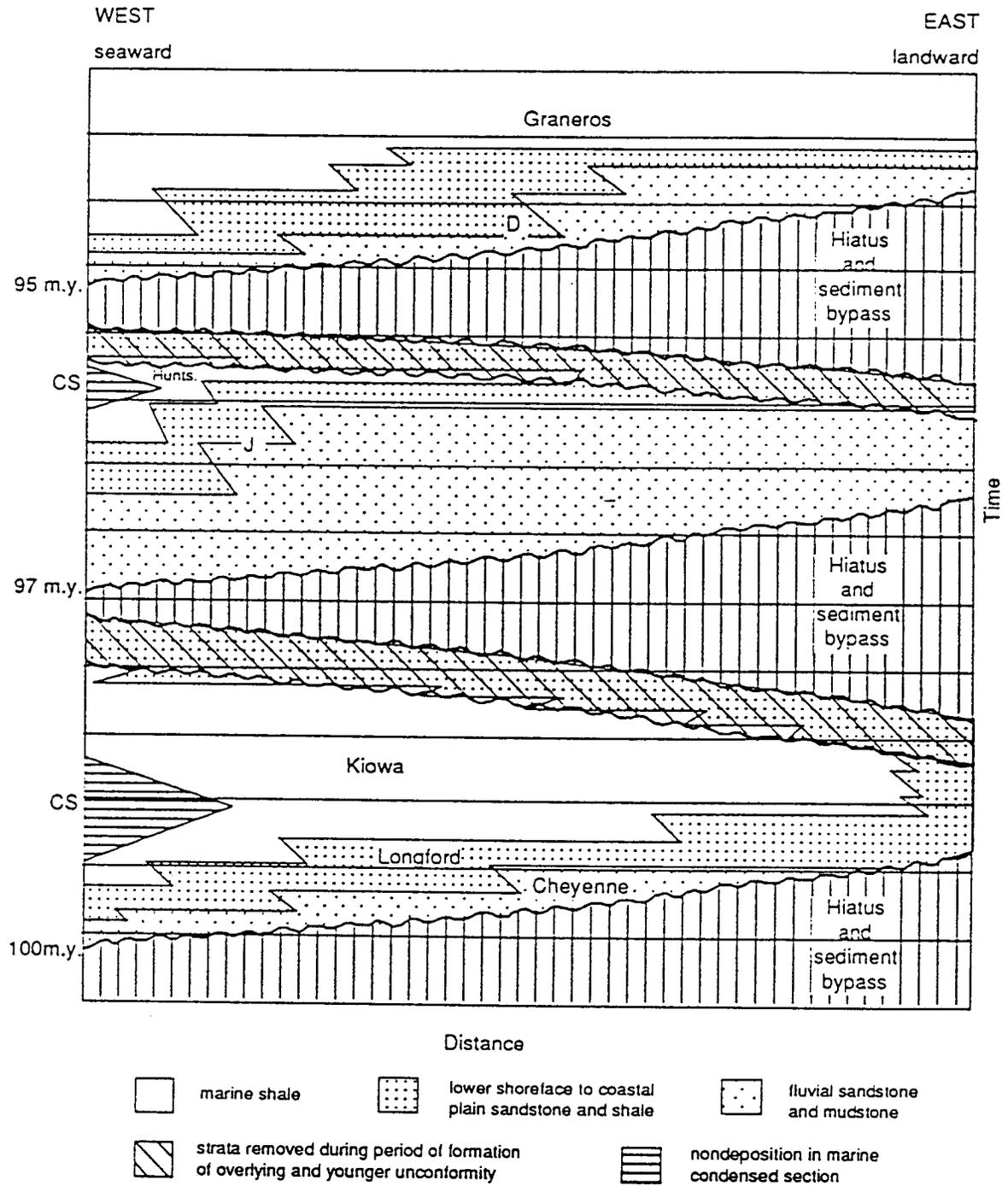Figure 2. Diagramatic east-west section showing time (not thickness) relationships of Early and early Late Cretacous rocks in Kansas. The three sequences that comprise the Dakota aquifer are the Cheyenne-Kiowa sequence, the J sequence (lower Dakota Formation), and the D sequence (upper Dakota Formation, Graneros Shale, and Greenhorn Limestone, and Carlile Shale). Sequence boundary dates from Weimer (1984). From Hamilton (1989).

Figure 3. Paleogeographic reconstruction representing central Kansas and adjacent areas during deposition of the upper part of the Dakota Formation and lower part of the Graneros Shale (from Hattin, 1967, p. 587).

Figure 4. Index map of Kansas showing outcrop belts of Cheyenne Sandstone (Kc), Kiowa Formation (Kk), and Dakota Formation (Kd). Hachures indicate outcrop area of Longford Member of the Kiowa Formation. El, Ellsworth County; Ri, Rice County. Modified from Franks (1975).
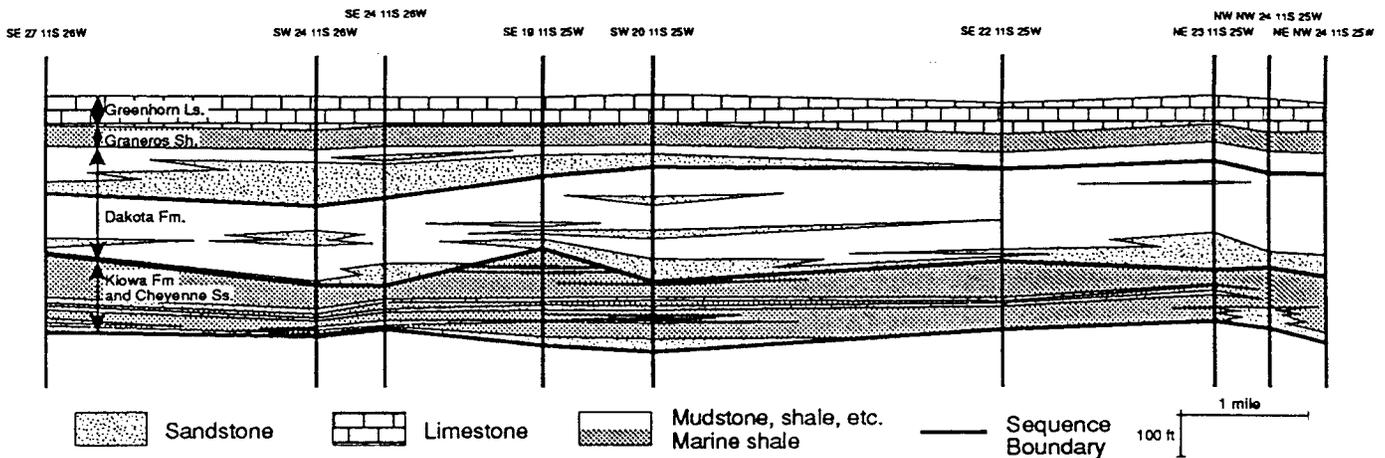
4

Figure 5. Structure cross section of Dakota aquifer in northeast Gove and northwest Trego counties, Kansas, based on interpretation of oil well wireline logs.

Member (Franks, 1975, 1979, 1980). The type area for the Longford Member is near Longford in Clay County where the Cheyenne Sandstone is absent and Longford deposits rest directly on Permian rocks. The Longford Member is thickest in paleovalleys eroded into Permian rocks where fluvial and estuarine facies are preserved, and is interpreted to have been deposited in protected lagoons landward of barrier bars (Franks, 1979, 1980). Longford Member deposits are overlain by marine Kiowa shale or Dakota sandstone.

Dakota Formation: The type area of the Dakota Formation is near Dakota City in northeastern Nebraska (Meek and Hayden, 1861). The Dakota Formation in Kansas consists mostly of nonmarine claystone, siltstone, and sandstone that occurs between the Kiowa Formation below and Graneros Shale above. The basal Dakota Formation boundary is erosional and separates the underlying marine to deltaic deposits of the Kiowa Formation from terrestrial facies of the Dakota Formation, although the exact nature of the boundary is under some dispute (Fig. 1, and see below). Fluvial through coastal facies of the uppermost Dakota Formation grade upward and laterally into widespread marine deposits of the Graneros Shale (Hattin, 1965; Franks, 1966; Siemers, 1976). In Ellsworth County, Kansas, the Dakota Formation is approximately 58 to 76 m (190 to 250 ft) thick (Bayne et al., 1971).

Plummer and Romary (1942) divided the Dakota Formation into the Terra Cotta Clay Member and the Janssen Clay Member (Fig. 1). The type sections for both are in Ellsworth County, Kansas. The lower Terra Cotta Clay Member is characterized by red-mottled gray to greenish-gray clay and siltstone which comprise the lower two thirds of the formation (Plummer and Romary, 1942). The upper Janssen Clay Member is characterized by dark-gray siltstone and clay with lignite and lignitic sandstone (Bayne et al., 1971), however, there is considerable variation in both

members, and for this reason Bayne et al. (1971) did not map the contact in Ellsworth County. Thick sandstone bodies occur throughout the Dakota, but are more common in the Terra Cotta Clay Member, with the Rocktown channel sandstone being a notable exception (Bayne et al., 1971)

Graneros Shale: The lower Graneros Shale is composed of dark-gray silty shale with irregularly interlaminated silt and fine sand and thin-bedded sandstones, starved ripples, and bone and shell lags (Hattin and Siemers, 1987). The Graneros/Dakota transition is gradational in the field trip area, as upper Dakota terrestrial to coastal facies grade upwards to more laterally continuous marine facies.

Sequence stratigraphy

Rocks that comprise the Dakota aquifer are best understood within the framework of sequence stratigraphy (Hamilton, 1989; Coleman and Turbek, 1992). The goal of sequence stratigraphy is to provide a high-resolution chronostratigraphic framework for correlation (Van Wagoner et al. 1990). The application of sequence-stratigraphic concepts can result in improved correlation of rock units that can lead to increased understanding of the geometries and continuity of aquifers and aquitards. Within the Dakota aquifer, different stratigraphic models have been proposed that have direct implications for how sandstone aquifers are connected and geometrically arranged. Well logs and cores provide information about the sequence of lithologies at point locations, but correlation among these points is largely influenced by the stratigraphic model being employed.

Various definitions have been proposed for sequences, but the definition used herein is that a sequence is a relatively conformable succession of strata that is bounded by unconformities and their correlative conformities (Mitchum,

1977; Van Wagoner *et al.*, 1990; Van Wagoner *et al.*, 1988). Sequence boundaries form in response to relative falls in sea level (Van Wagoner *et al.*, 1990) and are commonly associated with incised valleys, especially on exposed continental shelf settings where fluvial deposits rest erosionally on older marine deposits of the previous sequence. Basinwide correlation of sequence boundaries and the synchroneity of sequence boundaries among basins is generally interpreted to indicate that sea level falls are eustatic rather than due to local control (i.e. tectonic affects). Once the sea level history is understood, facies relationships can be predicted in areas with poor control (i.e. in which that are few well logs).

Sequence stratigraphic concepts are somewhat difficult to apply to cratonic deposits, because the model was developed for passive continental margins where slopes are relatively high and continental facies can be traced basinward into marine facies over relatively short distances. The Dakota aquifer in the eastern side of the Western Interior basin consists largely of continental deposits that cannot be correlated easily into marine deposits. A sequence-stratigraphic framework was developed for similarly aged deposits on the western side of the basin, where intertonguing of marine and continental rocks and deeply incised sequence boundaries provided key stratigraphic markers (Weimer and Land, 1972). The correlations of sequences on the western edge of the basin were subsequently extended throughout the basin and into Kansas (Weimer, 1984), and then to the Texas Gulf Coast with the addition of biostratigraphic control (Scott *et al.*, in press). Hamilton (1989) provided detailed correlations of the sequences in Kansas, tying the outcrop belt to a key core in western Kansas, which has also been a key core for biostratigraphic dating of Early Cretaceous sequence boundaries (Scott *et al.*, in press; Scott *et al.*, 1993).

Following the model of Hamilton (1989) and Coleman and Turbek (1992), the units that make up the Dakota aquifer are divided into three sequences, the Cheyenne-Kiowa Sequence, the J sequence, and the D sequence (Figs. 1, 2). The Cheyenne/Kiowa sequence extends from the base of the Cheyenne Sandstone to the top of the Kiowa Formation. The Cheyenne Sandstone was deposited in fluvial and coastal plain environments prior to transgression of the sea into Kansas. The sharp contact between the Cheyenne and Kiowa formations is a transgressive surface of erosion that formed by shoreface erosion during the eastward migration of the shore line (Macfarlane et al., in review). The overlying Kiowa Formation records widespread marine flooding of the Western Interior basin. The maximum extent of the Kiowa sea is not known due to post-Kiowa erosion, but Franks (1979) suggested that the distribution of nearshore facies in the Longford Member indicates that the present day eastward limit of the Kiowa Formation approximates maximum extent of the transgression.

The J sequence extends from base of the Dakota Formation to the mid-Dakota sequence boundary (Figs. 1, 2).

In the field trip area the base of this sequence is at the bottom of fluvial sandstones that occupy channels or valleys eroded into the marine Kiowa Formation during sea level lowstand. Although these same sandstones were interpreted as marine offshore bars by Franks (1979), the field guide uses the stratigraphic nomenclature of Hamilton (1989). Evidence for the sandstones being deposited by streams within incised valleys rather than barrier bars includes their concave-up erosional bases, the abundance of clay pebbles, and the lack of bioturbation. In addition subsurface correlation supports a sharp erosional contact at the base of the Dakota Formation that separates the thin, continuous, marine sandstone of the Kiowa Shale from thick, discontinuous sandstone above the contact (Macfarlane *et al.*, in review) (Fig. 5). Cores of the J sequence from western Kansas (Greeley and Cheyenne counties) reveal stacked, landward-stepping progradational units (Hamilton, 1989). The lowest units in the sequence are composed of fluvial facies and upper units contain marine shoreface facies. The basal Dakota unconformity is correlated in central Colorado with the base of the J sandstone (Weimer, 1984), and in the Denver basin this sequence culminates upwards with the marine Huntsman Shale, which is present only locally in northwestern Kansas. In central Kansas (the field trip area) there are no marine facies in the lower and middle Dakota making the mid-Dakota sequence boundary is difficult at best to identify (see below).

The D sequence extends from the mid-Dakota sequence boundary to the unconformity at the base of the Carlile Shale (Hamilton, 1989). The mid-Dakota unconformity has been correlated with the unconformity at the base of the D sandstone in central Colorado by Weimer (1984) and Hamilton (1989). Cores from western Kansas reveal that the lower D sequence is composed of landward-stepping progradational events that are overlain by a transgressive surface of erosion at the base of the Graneros Shale (Hamilton, 1989). In western Kansas the basal D sequence is composed of marine coastal facies. In central Kansas the Dakota Formation is composed of fluvial and overbank facies except for the uppermost beds near the Dakota/Graneros transition. In this area Hamilton (1989) placed the basal D sequence boundary at the sharp transition from meandering river deposits below the contact to braided river deposits above the contact. Commonly associated with the braided river deposits are granules of chert and quartz that may indicate a lowering of base level (Hamilton, 1989).

Merriam (1957) correlated the flooding surface at the base of the Huntsman Shale with the boundary between the Terra Cotta Clay and Janssen Clay members, but Hamilton (1989) correlates the boundary to a flooding surface within the D sequence, such that the D sequence contains the upper part of the Terra Cotta Clay Member and all of the Janssen Clay Member.
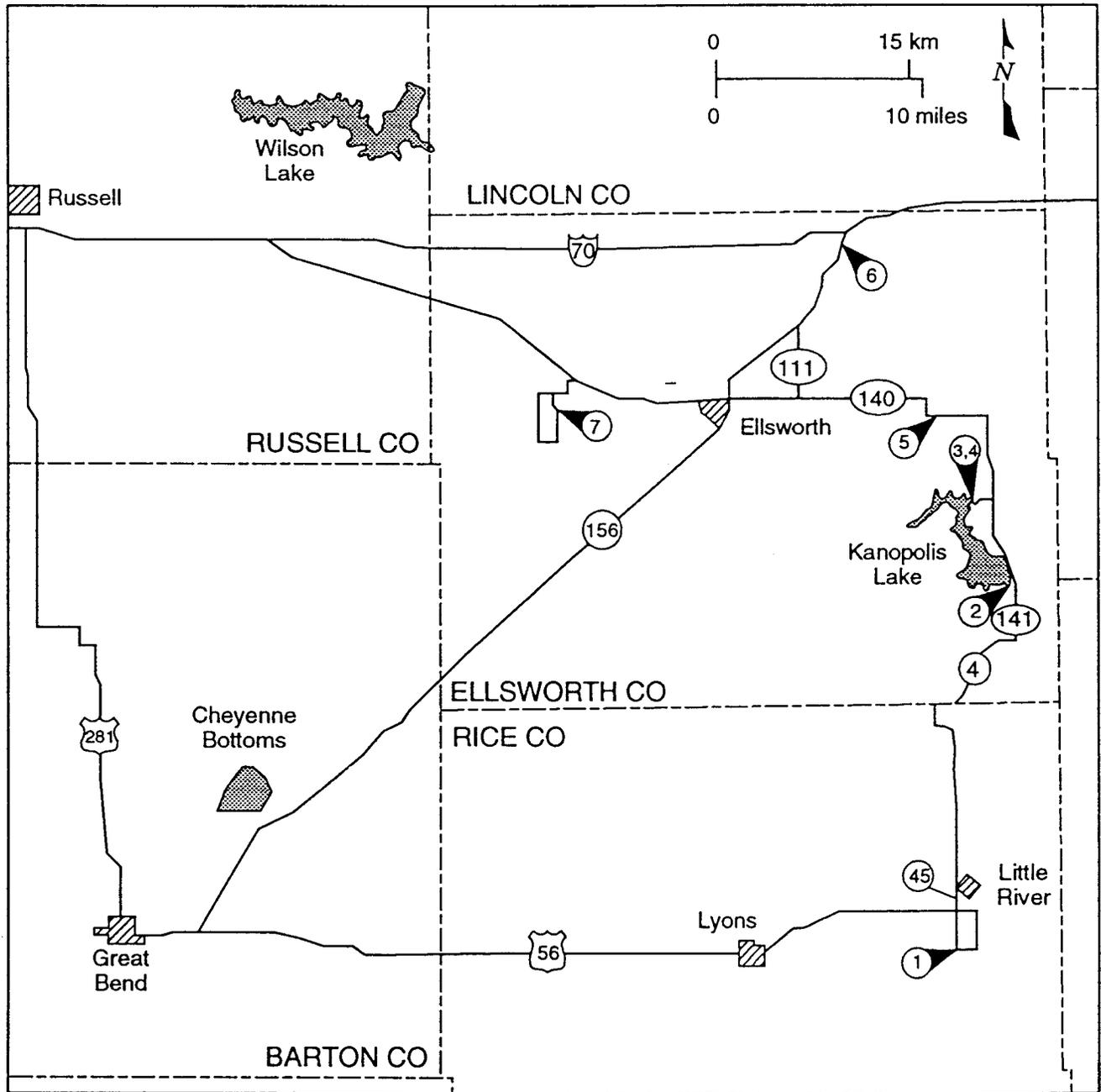
Acknowledgements

Figure 6. Map of field trip route showing stop localities (circled numbers) and major highways in the area.

ROAD LOG

by Rex Buchanan and Howard R. Feldman, Kansas
Geological Survey

See Fig. 6 for a map of the field trip route.

miles

0.0   Great Bend is named after the sweeping bow in the Arkansas River as it heads southeast toward Wichita and Oklahoma. Great Bend is the county seat of Barton County, the only Kansas county named after a woman, Civil War nurse Clara Barton. The county courthouse, completed in 1918 out of Bedford Limestone, is in the downtown business district, north of the highway.

The initial portion of this field trip is through the Arkansas River Lowlands physiographic province, in which alluvium, terrace deposits, and windblown sand are common. Just west of the town of Lyons, and for the remainder of the trip, the route is through rocks of Cretaceous age, mostly sandstones and shales, that have been eroded to form a rolling, upland topography known as the Smoky Hills. The hills' name comes from the smoky haze that often settles in the valleys; because of their rugged topography, much of the Smoky Hills remains in native pasture.

3.8   Walnut Creek.

This stream drains south into the Arkansas River (in Kansas, the river's name is pronounced ar-KAN-sas, not AR-kan-saw). For the first part of the trip, the river's course is visible south of the highway, marked by cottonwood trees along the river banks.

North of the highway is Fort Zarah Park, where Fort Zarah was established in 1864. For much of its route in Kansas, U.S. Highway 56 follows the approximate route of the old Santa Fe Trail, which ran from Independence, Missouri, to Santa Fe, New Mexico, in the mid-1800s. Fort Zarah, one of a string of forts built to protect travelers along the trail, was constructed of native sandstone, then abandoned in 1869. Perhaps the best-known fort along the Santa Fe Trail in Kansas is historic Fort Larned, which has been preserved and restored southwest of Great Bend near the town of Larned.

4.7   Intersection with Kansas Highway 156, which angles northeast to Interstate 70.

About six miles north of here is Cheyenne Bottoms Wildlife Refuge, a series of man-made ponds built in a natural depression and wetlands that attracts birds and other wildlife. The Bottoms now covers 19,000 acres and is on the flyway for many North American birds.

10.6   Ellinwood.

16.8   Rice County line.

19.9   North of the highway, wagon ruts from the Santa Fe Trail can be viewed. Today, ruts resemble terrace-like mounds of earth rather than simple tracks along the ground; ruts are also sometimes marked by the different vegetation that thrives in the disturbed ground. Because so much property in Kansas has been cultivated, recognizable ruts from the old trail are rare. In addition to these, Santa Fe Trail ruts are still visible near Dodge City, in the Cimarron National Grasslands of Morton County in far southwestern Kansas, and east of Baldwin City in Douglas County.

24.0   The town of Chase.

This small town is in the heart of the Chase-Silica oil field, which covers 40,000 acres in Rice, Barton, and Stafford counties. The Chase-Silica has produced more than 260 million barrels of oil since its discovery in 1930, making it second only to the El Dorado field in Butler County as the most prolific oil field in Kansas.

27.0   Cow Creek.

28.0   The concrete cross south of the highway is a monument to Father Juan de Padilla, who came to Kansas with Coronado in 1541. The Franciscan monk left Kansas, then returned in 1542 and was killed by natives, making him the first Christian martyr on land that now belongs to the U.S. Though there are monuments to Coronado and Padilla as far east as Herington, historians don't know how far the expedition penetrated into the state, though it is reasonable to assume that Coronado got at least as far as Rice County and encountered the native Quiviran Indians. The Rice County Historical Society museum in Lyons displays a number of Coronado relics, along with a mural painted by Protection native (and Lawrence resident) Stan Herd, who is also well-known for his field art.

31.1   The town of Lyons, the county seat of Rice County.

Rice County is named for Brigadier General Samuel A. Rice, who was killed at the Battle of Jenkin's Ferry in Arkansas in 1864. The county courthouse in the town square was constructed in 1911 from red brick with limestone trim.

Lyons is well-known for salt production from the Permian Hutchinson Salt Member of the Wellington Formation, which is about 1000 feet deep here and is, in places, 400 feet thick. A working salt mine still operates here and a local

9

inactive underground mine was considered in the 1960s by the Atomic Energy Commission as a possible site for the disposal of high-level radioactive waste. After concerns were raised about the mine's integrity, including possible oil wells that might have penetrated the salt, the plan was abandoned.

During the Christmas holidays, the water tower in Lyons is covered by strings of bright red lights and resembles a giant red bell floating in the night sky.

32.1   Intersection with Kansas Highway 14, which runs north to Ellsworth and south to Sterling.

38.8   About five miles to the north, a village of Wichita Indians lived along the headwaters of the Little Arkansas River from about 1500 to 1700; they may have been the same Indians encountered by Coronado. The spot has been studied by archaeologists from the Smithsonian Institution and the Kansas State Historical Society, some of whom believe that council circles in the village may have been located to line up with the sun during the summer solstice.

42.8   Kansas Highway 46, which runs north to the small town of Little River, named because of its proximity to the Little Arkansas River. South of here, the Santa Fe Trail forded the Little Arkansas River and, during the heyday of traffic on the trail, a small stone fort was constructed there out of local materials. That stone corral gave its name to the Permian Stone Corral Formation, which includes a layer of dolomite that is quarried locally for gravel.

43.8   Turn south (right) on gravel road (27th Street).

45.8   Turn east (right) at stop sign.

46.7   **STOP 1.**

46.8   Turn north (right) at stop sign.

48.9   Cross U.S. Highway 56, go north on K-46.

49.8   Leave K-46 and continue due north on blacktop along the west edge of Little River.

50.5   Stop sign.
The hill to the west is known locally as Clutter Hill, so-called because it was owned by relatives of the same Clutter family that was murdered by Richard Hickock and Perry Smith near the southwestern Kansas town of Holcomb in November, 1959. Six years later, Smith and

Hickock were hung for the crime. The episode was recorded by Truman Capote in his true-crime novel, *In Cold Blood*, which was made into a movie starring John Forsythe. At the base of Clutter Hill, a now-closed salt mine was dug into the Hutchinson salt in 1895.

51.4   Little Arkansas River.
The average annual precipitation in this area is about 25 inches, though yearly totals range drastically above and below that figure. The Little Arkansas River has long flooded this river bottom; today the local watershed district is building a series of small dams on tributaries of the Little Arkansas in an attempt to help control that flooding.

59.8   Intersection with Kansas Highway 4. Turn east (right).

60.8   Enter Ellsworth County.
 Ellsworth County was established in 1867 and named after Lieutenant Allen Ellsworth, who founded Fort Ellsworth along the Smoky Hill River in 1864. In this area K-4 follows closely the drainage divide between the Arkansas River drainage basin, to the south, and the Kansas River drainage basin, to the north. South of the highway, precipitation drains into headwaters of the Little Arkansas, joining the Arkansas River (known locally as the Big Arkansas) at Wichita. To the north of the highway, precipitation drains into the Smoky and eventually the Kansas River.

65.1   Kiowa Formation.

65.6   Turn north (left) on Kansas Highway 141.

67.5   Headquarters of the Post Rock Rural Water District.

68.5   **STOP 2.** Turn west (left) onto blacktop road at the south end of Kanopolis Dam.

68.7   Turn north (right) into Sumac campground and take the loop that returns to the blacktop.

69.4   Turn north (left) on K-141.
Construction on the dam for Kanopolis Lake began in 1940, was suspended during World War II, then completed in 1948, making Kanopolis the oldest dam and reservoir built by the Kansas City district of the U.S. Army Corps of Engineers. The dam is 15,810 feet long and impounds a lake with a surface area of about 3000 acres. The lake is named after the nearby town of Kanopolis.
The dam was built on the Smoky Hill River,

which has its headwaters in eastern Colorado and western Kansas (the Smoky is also dammed to form Cedar Bluff Reservoir in Trego County, about 90 miles west of here). Today the Smoky Hill exits Kanopolis Lake, runs past the towns of Marquette and Lindsborg, then turns to the north toward Salina, eventually joining the Republican River to form the Kansas. During the Pleistocene, however, the ancestral Smoky Hill continued flowing south from here, through the McPherson Channel, and joined the Arkansas River near Wichita. During the late Pleistocene, streams in the Kansas River basin to the north eroded headward, eventually capturing the Smoky Hill River in northern McPherson County.

72.0   Turn west (left) on Venango entrance to Kanopolis state park.

The small settlement of Venango was named after Venango County, Pennsylvania. The original townsite was located near what is today the swimming area in Kanopolis Lake at the north end of the dam.

72.8   Kanopolis State Park and Kansas Department of Wildlife and Park offices.

74.3   Turn left at T-intersection.

74.4   Turn right to Corral Group shelter house.

74.8   **STOP 3.**
Rest stop at shelter. Exposures by lake shore. Return to shelter for lunch.

75.2   Left at T-intersection to Horsethief Canyon.

76.4   **STOP 4.**
Horsethief Canyon is a box canyon formed by steep walls of Dakota Formation sandstone. Though the exact origin of the name is unknown, one version claims the canyon was named when several horse thieves were shot and buried here. From here, return to the blacktop road.

77.6   Turn southeast (left) to park office.

79.1   Park office.

80.0   Turn north (left) on K-141.
The hill to the northeast, capped by Dakota sandstone, is known as Buzzards Roost. The pastures in this area are mixed prairie, containing grasses that are common in the tallgrass prairie to the east and shortgrass prairie to the west, including big and little bluestem, sideoats grama, and blue

grama. Before white settlement, trees were generally found only along river bottoms. Joanna Stratton, in her 1981 book *Pioneer Women: Voices from the Kansas Frontier,* includes the following story: "Mr. Hilton, a pioneer, told his wife that he was going to the town of Little River for wood. She asked to go with him . . . She hadn't seen a tree for two years, and when they arrived at Little River, she put her arms around a tree and hugged it until she was hysterical."

82.0   The Oasis.

86.1   Turn west (left) onto sand road (Avenue K)

88.6   **STOP 5.**
At Mushroom Rocks State Park, a number of sandstone concretions have eroded out of Dakota Formation sandstone. The drawing on the cover of this guidebook is from an 1867 edition of *Harper's* magazine and is one of the earliest depictions of Pulpit Rock, located on the park's south edge. The earliest known photographs of Mushroom Rocks were taken in 1867 by Alexander Gardner, a famous Civil War photographer who took many portraits of Abraham Lincoln, including the final portrait of Lincoln before his assassination. In 1867 he was hired by the Union Pacific Railroad to document construction along its line, which at that time had been completed as far west as Hays. Gardner took many of the first photographs of noted geologic locations in the Dakota Formation, including the petroglyphs north of Horsethief Canyon and Palmer's Cave in the Dakota north of Carneiro. Comparison of the modern landscape with Gardner's photographs shows relatively little geologic change in the concretions here at Mushroom Rocks State Park, but shows substantial change in the vegetation, including a considerable increase in the number and variety of trees along Alum Creek and lusher prairie grass. After the stop, continue west on sand road.

89.1   Turn north (right) at T-intersection and cross the Union Pacific Railroad tracks.
This crossing is near the route of the old Smoky Hill Trail, which ran from Kansas City to the gold fields of Colorado in 1858 and, for much of its route, followed the course of the Smoky Hill River.

90.1   Turn west (left) on K-140.
This is the former U.S. Highway 40, one of the major highways across Kansas to Denver before the construction of Interstate 70.

90.7   Cross-bedded Dakota Formation sandstone.

93.5 Cross-bedded Dakota Formation sandstone.

94.9 20th Street.

The road to the south goes to the Kanopolis salt mine, the oldest continuously operating salt mine in Kansas. It produces salt from a 10-foot-thick section of the Hutchinson Salt Member of the Wellington Formation at a depth of about 850 feet.

96.2 Turn north (right) at intersection with Kansas Highway 111.

The town of Kanopolis is two miles south of here. Its name comes from the combination of the Greek word for city, "polis," and the first syllable of Kansas. Kanopolis was once promoted, because of its central location, for the capital of Kansas and several city lots--today the site of a town park--were reserved for the construction of a building. In spite of the efforts of the Populist Party in 1893, the capital remained in Topeka. The exact center of Kansas is actually located near the town of Bushton, a few miles southwest of here.

Kanopolis is also the site of Fort Harker, established in 1867 as a base for campaigns against Native American tribes in northwestern Kansas. A number of famous generals visited here, including Sheridan, Sherman, and Grant, and a Gardner photograph taken here in 1867 shows a dapper Wild Bill Hickock. Several of the buildings from Fort Harker survive, including the officers' quarters and the guardhouse, which is maintained as a museum by the Ellsworth County Historical Society.

100.0 Turn north (right) onto K-156.

104.3 **STOP 6.** After stop, continue north on K-156.

105.2 Turn around at gas station.

108.7 Greenhorn Limestone and Graneros Shale crop out to the west.

A thin but widespread limestone bed at the top of the Greenhorn Limestone is known locally as the "fencepost limestone" and was used not only for fenceposts, but for other construction by European settlers in this naturally treeless area. Many local schools, houses, bridges, barns, and churches are constructed from fencepost limestone; perhaps the best known is the Cathedral of the Plains in Victoria, east of Hays.

109.6 Greenhorn Limestone and Graneros Shale in roadcut.

110.4 Intersection with K-111. Continue on K-156 to Ellsworth.

115.4 Turn west (right) onto old highway 40 and continue through Ellsworth.

Ellsworth was known as a particularly rough cowtown in the 1860s. Among its notable residents was Wyatt Earp, who got his start as a law officer when he made two arrests here. Today, a new prison is located on the north edge of town along the highway.

123.5 Turn west (left) on dirt road (Avenue 1).

123.9 Dakota sandstone on the right.

124.2 Turn southwest (left).

124.3 Cross railroad tracks.

124.4 Smoky Hill River.

125.1 Turn west (right) at T-intersection.

125.6 Turn south (left).

126.8 **STOP 7.** Continue south after stop.

127.3 Merge left at yield sign.

128.2 Turn west (right).

128.9 Upper Dakota on both sides of the road.

129.5 Turn south (right) at the stop sign.

132.5 Turn east (right).

134.1 Turn south (left) at T-intersection.

134.3 Smoky Hill River.

134.4 Railroad tracks.

134.5 Turn left (west) at T-intersection in Black Wolf.

This town is named for the nearby creek, which may have been named after a local Native American.

134.9 Old Highway 40. Return to Great Bend.

Some of the information in this log came from R. C. Buchanan and J. R. McCauley, *Roadside Kansas: A Traveler's Guide to Its Geology and Landmarks* (University Press of Kansas, 1987).

12

STOP DESCRIPTIONS

by Howard R. Feldman, Kansas Geological Survey (except where noted)

STOP 1: Little River section: Basal Cretaceous unconformity

SW 1/4, SW 1/4, sec. 32, T. 20 S, R. 6 W, Rice County, Kansas. Outcrops on hillsides and along a creek 16 km (10 miles) east of Lyons and 4.8 km (3 miles) south of Little River. (Figs. 7, 8)

Earliest Cretaceous rocks in Kansas were deposited during the transgression following the regional sequence boundary dated at 100 my (Weimer, 1984; Hamilton, 1989). In south central Kansas these rocks comprise the Cheyenne Sandstone, which averages about 13.7 m (45 ft) thick (Latta, 1946). The Cheyenne sandstone was deposited in fluvial through coastal environments. Eastward, the Cheyenne thins to a feather edge against the basal Cretaceous unconformity. In Rice County the Cheyenne Sandstone is present only in the subsurface where it is composed predominantly of white to greenish gray siltstone with abundant beds of very fine-grained sandstone (Fent, 1950). Although no definite exposures of Cheyenne were mapped in Rice County by Fent (1950), he noted that sandstone and shale that from the matrix of a cobble zone at the base of the Cretaceous may be an outcrop expression of the Cheyenne. At Stop 1 the cobble zone is at or just above the basal Cretaceous unconformity. Do not confuse the Cretaceous cobble zone with cobbles that were reworked during the Pleistocene(?). The younger beds of cobbles are confined to channels eroded into the Cretaceous and Permian rocks, and include fossils, such as oysters, reworked from the Kiowa Formation.

Franks (1975) described basal cretaceous cobble beds from Clay, Rice and Barber counties and interpreted them as relics of an originally widespread mantle of gravel that blanketed the erosion surface prior to the early Cretaceous transgression. The composition of the pebbles from the basal Cretaceous (Table 1) suggests that most pebbles were derived from Paleozoic sedimentary and both Paleozoic and Precambrian metamorphic source rocks to the east and northeast. In addition, the dark chert pebbles may have been derived from source terrane to the west (Frank, 1975).

The source of pebbles and their well-rounded and polished surfaces suggest long distances of transport. The pebble lag and the overlying siltstones and sandstone record the transgression of the Cretaceous sea from west to east. Siltstones and sandstones overlying and interbedded with the pebbles probably were deposited in nearshore environments. The overlying gray shale contains shell beds and probably was deposited in a marine offshore shelf environment.

TABLE 1

Composition of pebbles in pebble zone at base of the Cretaceous System form a locality near Stop 1 (modified from Franks, 1975).

Lithology	SW 1/4 sec. 16 T. 20S, R. 6w, Rice County
Chert	62%
Quartzite	19%
Silica-cemented sandstone	2%
"Vein" or pegmatite quartz	20%
Silicified wood	2%
No. of pebbles counted	132

Sandstone		Large scale cross bedding		Iron sulfide concretions	
Siltstone		Low angle planer bedding		Phosphate concretions	o
Shale		Ripple scale cross bedding		plant fossils	
Shell bed		Burrows	⋎	Gastropods	g
Covered		cone-in-cone	⪼	Bivalves	b
Bentonite		clay pebbles	⊚	Shrimp	sh
Lignite or lignitic clay		Iron cement	Fe	Gypsum	gyp
Color mottling		Reed molds	rm	siderite	s
Conglomerate					

Figure 7. Keys to symbols used in graphic columns of measured sections.
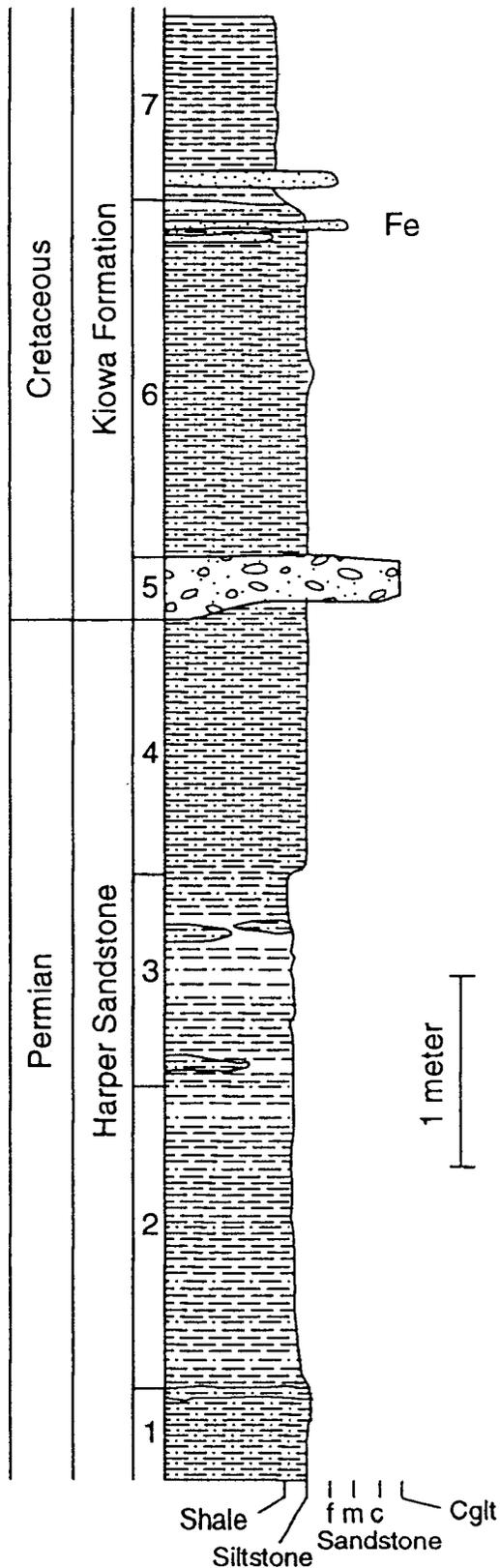
13

Figure 8. Graphic column of measured section at Stop 1.
This is a composite section based on several exposures
in this area.

Description of Units by Paul Franks.
This is a composite section based on exposures near Stop 1.
Kiowa Formation

7. Not measured, exposed on hillsides. Intensely
   weathered medium gray (N5) shale. Thin (3 cm thick),
   finely laminated sandstone 15 cm above base of shale.
   Shell beds in float up slope.

6. 128 to 186 cm. Poorly-cemented siltstone, very light
   gray (N8) to light yellowish gray (5Y 7/2) with local
   very pale reddish purple (5RP 7/2), pale pink (5RP
   8/2), pale yellow orange (10YR 6/2) stain. Unbedded
   with blocky fractures in lower part. Abundant pores
   less than or equal to 1 mm in diameter. Thinly bedded in
   upper 30 cm where dense. Calcite cement throughout.
   Abundant hematite nodules in upper 30 cm as well as
   seams of dark yellowish orange (10YR 6/6) limonitic
   very fine- to fine grained sandstone 1 cm thick.

5. 34 cm. Pebble zone. Well rounded pebbles from 1 cm
   to 10 cm in long dimension. Most are under 5 cm.
   Pebbles composed of chert, weathered chert, jasper,
   vein quartz, petrified wood, and rare productid
   brachiopod fragments. Matrix is very fine- to fine-
   grained friable sandstone, very light gray (N8) with pale
   yellow orange (10YR 8/6) to moderate reddish brown
   (10R 4/6) mottles. Upper contact nearly gradational.

Measured thickness of Kiowa Formation: 320 cm.

Permian Harper Sandstone

4. 140 cm. Mudstone, greenish gray (5GY 6/1) to light
   greenish gray (5GY 8/1), silty, thinly laminated, tends to
   have blocky fractures below the pebble zone. Locally
   stained dark yellowish orange (10YR 6/6) by limonite,
   particularly near gobs of dark ruby red (10R 4/6)
   mudstone like that below. Gobs most common towards
   base and commonly shaped like ink blots. Slope
   weathers mottled very light greenish gray (5GY 8/1) to
   grayish orange pink (10R 8/2) to moderate reddish
   brown (10R 4/6). Top of Permian.

3. 116 cm. Silty shale or thinly laminated mudstone. Dark
   reddish brown (10R 4/6). 9-cm-thick zone of pale olive
   (10Y 6/2) mudstone as thinly laminated irregularly-
   shaped lenses up to 1.5 m long and about 15 cm above
   base. Thinly laminated irregularly shaped lenses less
   than 15 cm thick and several meters long of greenish
   gray (5GY 6/1) to light greenish gray (5GY 8/1)
   interlaminated claystone and siltstone in a zone about 30
   cm below top of unit.

2. 167 cm. Silty shale or thinly-laminated silty claystone.
   Pale olive (10Y 6/2) with dark yellowish orange (10YR
   6/6) to light brown (5YR 5/6) limonite stains. Thinly
   laminated, but has shoe peg to blocky fractures.
   Irregular dark reddish brown (10R 3/6) 9-cm-thick zone
   15 cm above base. Gradational(?) upper contact.

1. 49 cm. Siltstone to mudstone, moderately greenish gray
   (5GY 5/1), faint laminations, blocky fractures, very
   silty. 3-cm-thick zone of dark brownish gray (5YR 3/1)
   irregular zone at top.

Measured thickness of Harper Sandstone: 472 cm.

14

STOP 2: Kanopolis Lake Dam: Kiowa Shale marine facies.
Center of NE 1/4, sec. 3, T. 17 S, R. 6 W, Ellsworth Co., Kansas. Exposure along shore of Kanopolis Lake, adjacent to Kanopolis Dam (Fig. 9).

Following Cheyenne deposition the Kiowa sea covered much of central and western Kansas. The maximum extent of Kiowa deposition is not know because of post-Kiowa erosion. The exposures at Stop 2 are show typical Kiowa facies that were deposited in open marine shelf to coastal environments. In this area the Cheyenne Sandstone is not present and gray shales of the Kiowa Formation rest directly on Permian rocks (Bayne *et al*, 1971). The base of the section of Kiowa Formation exposed here is approximately 6.3 m (22 ft) above the Cretaceous-Permian unconformity based on correlation of this exposure with sections formerly exposed 400 m (0.25 miles) to the east (Bayne *et al.*, 1971).

The purpose of this stop is to view unequivocal marine to coastal mudstone and sandstone facies. In subsequent stops we will be viewing sandstones that may either have been deposited in high energy marine (Kiowa) or fluvial (Dakota) environments. The measured section is based on the outcrop southwest of the dam tower and the same succession can be viewed along the cliff exposure northeast of the tower.

The exposure consists of a shallowing-upward succession of facies from open marine at the base to a possible beach deposit at the top. The gray shale at the base of the exposure contains an assemblage of marine, benthic molluscs (preserved as molds) including species of infaunal molluscs indicating that bottom waters were oxygenated (Scott, 1967). Shell beds probably formed from the winnowing of mud by storm-generated currents (Scott, 1967). Upward in the section, the proportion of sandstone increases, the abundance of marine fossils decreases, and the abundance of plant fossils increases. An increase in energy is indicated by the upward succession of facies from shale with starved ripples, to rippled thin sandstone beds with clay drapes, to amalgamated rippled sandstone beds, and finally thick, cross-bedded sandstones without clay drapes. The uppermost unit has characteristics of beach deposits such as low-angle to horizontal laminations, fine grain size, and very good sorting.

Description of units:
Kiowa Formation
9. 70 cm. Fine-grained, very well-sorted sandstone. Basal contact is scoured and some scours filled with trough cross-bedded sandstone. Rest of unit has low angle to horizontal laminations to thin bedding and few ripples.
8. 12 - 49 cm. Interbedded shale and sandstone. Red and gray shale with starved ripples and interbedded with rippled sandstone. Gradational lower contact.
7. 70 cm. Coarsening upward sequence. Shale and siltstone with abundant plant debris at base, grading

upward as proportion of sandstone increases. Starved ripples, lenticular bedding, and current ripples are common. Sharp lower contact.
6. 90 cm. Interbedded sandstone and siltstone. Mostly sandstone beds up to 20 cm thick; ripple-scale cross beds and lenticular bedding is common. Loose slabs probably from this unit contain symmetrical and asymmetrical ripples and burrows. Plant debris is abundant in some sandstone beds. Siltstone beds range up to 3 cm thick.
5. 49 cm. Sandstone with shale interbeds. Ripple-scale cross beds and clay drapes are common. Sandstone beds range up to 5 cm thick. Gradational lower contact.
4. 176 cm. Interbedded shale and sandstone. Proportion of sandstone increases upwards. Basal portion contains starved ripples and sand laminae, and upper portion contains lenticular bedding and sandstone beds up to 4 cm thick. Pyrite aggregates are abundant. Lower contact is gradational.
3. 76 cm. Gray shale containing fossil gastropods and bivalves. Pyrite aggregates are abundant, some are pyritized burrows. Basal contact gradational.
2. 81 cm. Interbedded shale and shell layers. Shale is same as in unit 1. Shell layers are discontinuous, up to 2 cm thick, have erosional bases, and show crude grading. Shell beds thicken upwards. Thick cone-in-cone beds (up to 32 cm thick) have shells at base and may be, in part, altered thick shell beds. Lower contact gradational.
1. 79 cm. Slightly silty gray shale with abundant fossils including gastropods, bivalves, and arthropods (shrimp). Phosphate and pyrite nodules are common. Shrimp occur both in phosphate concretions and as impressions on bedding surfaces.
Measured thickness of Kiowa Formation: 740 cm.

STOP 3: Corral Group Shelter: Basal Dakota Sequence Boundary?
Center of SE 1/4, NE 1/4, sec. 17, T. 16 S, R. 6 W, Ellsworth Co., Kansas. Outcrops along the shore of Lake Kanopolis, below the Corral Group Shelter (Fig. 10).

This outcrop exposes marine Kiowa Formation in the lower part and cross-bedded sandstone in the upper part. The facies of the Kiowa Formation here are similar to the interbedded shale and sandstone exposed in Stop 2. Shallow marine conditions are suggested by rippled and burrowed sandstone. The contact with the cross-bedded sandstone is sharp and erosional. The lowest meter of sandstone contains shale clasts and large blocks of lignitic sandstone. The sandstone lacks body fossils and burrows.

There is some controversy about the origin of the upper sandstone unit and this controversy involves how the Dakota/Kiowa transition is interpreted. In one view (Franks, 1979), all the rocks exposed here are within the upper Kiowa Formation. Franks (1975) and Bayne *et al.* (1971) interpret
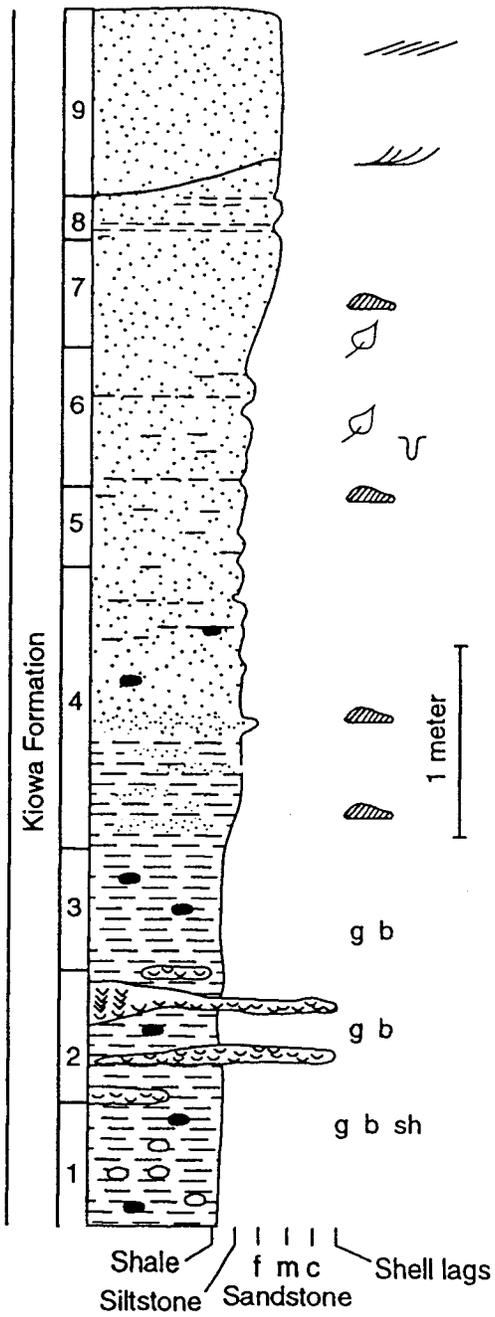
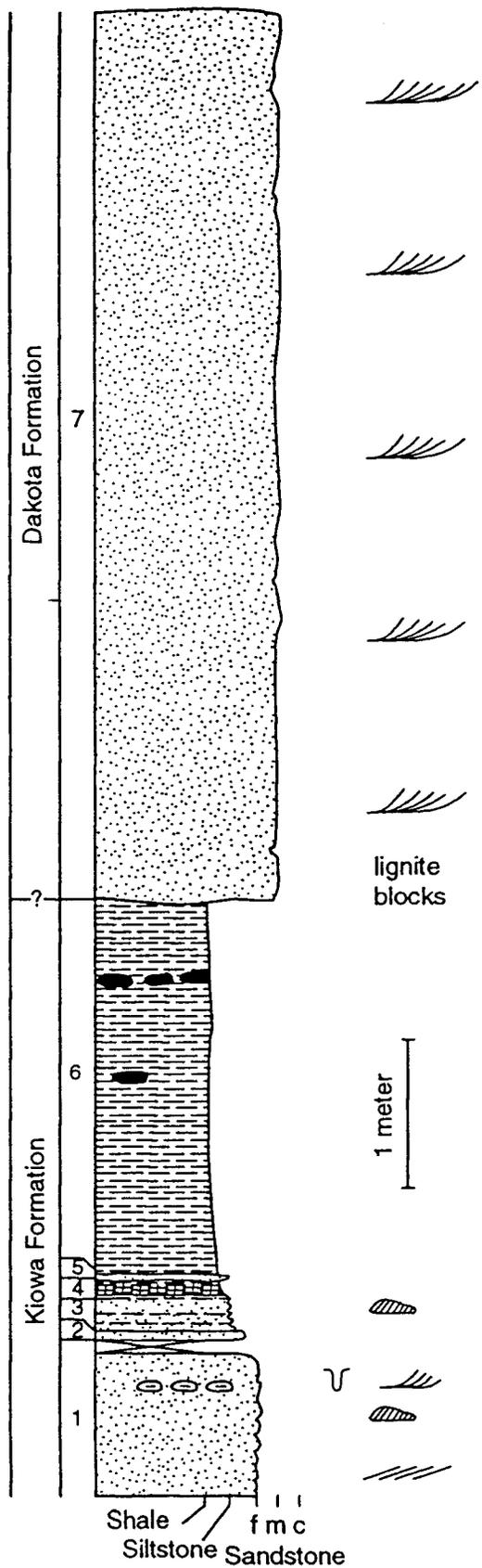Figure 9. Graphic column of measured section at Stop 2.

Figure 10. Graphic column of measured section at Stop 3.

these types of sandstone as large, lenticular bodies in the upper Kiowa. According to this view these sandstone bodies were deposited in offshore barrier bars during the marine regression just prior to Dakota deposition. Although the basal contact of the sandstone is here erosional, Franks (1975, 1966) noted that conformable upward transitions from marine Kiowa shale to thick cross-bedded sandstone occur.

An alternative is that the base of the cross-bedded sandstone exposed here is the basal Dakota sequence boundary and that this Dakota sandstone facies was deposited in fluvial environments (Hamilton, 1989). Hamilton (1989) interpreted the upper Kiowa barrier bar sandstones of Franks (1975, 1979) as fluvial channel deposits within the Dakota and adjacent mudstones as overbank deposits.

Field trip participants may wish to discuss the alternative models and decide whether the thick, cross-bedded sandstone exposed here is fluvial or marine. At Stop 4 we will view the entire thickness of this sandstone body, and at Stop 5 we will view the alternative basal Dakota contact (Franks, 1975, 1979).

Description of units. Stratigraphic nomenclature follows Harper (1989).

Dakota Formation
7. 6 m. Well sorted, poorly-cemented, medium-grained sandstone. Basal 1.5 m with large clasts of lignitic sandstone up to 280 cm long. Shale pebbles and weathered sulfide concretions in basal 50 cm. This unit is dominated by large scale trough cross beds up to 70 cm thick, mostly indicating southwesterly currents. Less common small scale troughs (8 to 15 cm thick). Erosional lower contact.
Measured thickness of Dakota Formation: 6 m.

Kiowa Formation
6. 183 cm. Dark gray silty shale, partly covered. No fossils observed. Large iron sulfide (marcasite) concretions up to 40 cm long by 10 cm thick. One layer of concretions 52 cm below top. Sharp lower contact.
5. 1-4 cm. Poorly-cemented, fine-grained sandstone. No bedding observed. Sharp, irregular lower contact.
4. 23 cm. Mudstone, hard, not bedded. Abundant wood pieces, some fusain, and abundant green grains (glauconite?). Grades upward to 2- to 5-cm-thick gray clay. Sharp lower contact.
3. 35 cm. Interlaminated mudstone and fine-grained sandstone. Sand laminae and starved ripples are common. Sharp lower contact.
2. 10 cm. Fine-grained sandstone. No bedding observed. covered, 20 cm.
1. 99 cm. Fine grained sandstone. Lowest 15 cm is very hard, dark reddish brown (10R 3/4), iron cemented. Bedding is difficult to observe, but includes low angle

planar and small scale cross-bedding. Upper 67 cm grayish orange (10YR 7/4), poorly cemented, well-sorted fine-grained sandstone with small scale trough and ripple-scale cross-bedding. Horizontal burrows are abundant on some weathered surfaces. Clay pebbles are common about 15 cm from the top. Uppermost 15 to 20 cm contain abundant ripples, small-scale cross beds, and vertical burrows.
Measured thickness of Kiowa Formation: 2.55 m.
Total measured thickness: 8.55 m.

STOP 4: Horsethief Canyon: Thick Dakota? sandstone.
NE 1/4 NE 1/4 NE 1/4 sec. 17, T. 16 S, R. 6 W, Ellsworth Co., Kansas. Outcrops along the shore of Lake Kanopolis, Horsethief Canyon area.

The purpose of this stop is to view an outcrop expression of a thick Dakota aquifer sandstone. This sandstone body has been interpreted as an offshore marine barrier bar of the upper Kiowa Formation (Franks, 1979, 1975; Bayne, 1971), and as a fluvial sandstone within the lower Dakota Formation (Hamilton, 1989). Either way it is characteristic in thickness and lateral extent of sandstone bodies that are common in the subsurface based on interpretation of wireline logs. Sandstone bodies such as this are major conduits of groundwater flow.

STOP 5: Mushroom Rock State Park: Alternative basal Dakota contact.
SE 1/4 sec. 19, T. 15 S., R. 6 W and NE 1/4 sec. 30 T. 15 S., R. 6 W, Ellsworth Co., Kansas. Sandstone mushrooms and spheres both north and south of the road, and small road cut on north side of road.

At this locality we view the basal Dakota contact according to Franks (1979, 1975) and Bayne et al. (1971). The contact is exposed in the road cut on the north side of the road where cross-bedded sandstone of the upper Kiowa Formation is truncated by gray siltstone with red mottles of the lowermost Dakota Formation. The sandstone exposed in the mushroom-shaped and spherical concretions are referred to the upper Kiowa in this model. Alternatively, Hamilton (1989) interpreted all of these exposures as Dakota Formation sandstone and siltstone. He postulated that the base of the mushroom "heads" may represent the unconformity at the base of the D sequence (Hamilton personal communication, 1994).

The mushroom shaped and spherical rocks exposed here offer an excellent opportunity to observe the geometries of cross bedding in the Dakota sandstone facies.

STOP 6: Elkhorn Creek section: Upper Dakota Formation, sandstone and mudstone facies.
Center of east line of SE 1/4, sec 8, T. 14 S, R. 7 W., Ellsworth Co., Kansas. Road cut on Kansas Highway 156, 1.5 km (1 mile) south of I-70. Section 3 of Hamilton (1989).

This road cut exposes a range of sandstone and mudstone facies from the middle to upper Dakota. The top of the exposure is approximately 7 to 10 m below the Dakota-Graneros contact based on projecting the contact (as mapped in Bayne *et al.*, 1971) from nearby hills to the east and west. There are two main purposes for viewing this exposure. The first purpose is to emphasize the importance of mudstone facies in the Dakota. Previous stops have focused on sandstone facies because mudstone outcrops tend to be covered by vegetation. Most of the Dakota Formation, however, is composed of clay-rich lithologies (Plummer and Romary, 1942). Clay is mined commercially in Ellsworth County, primarily near the town of Kanopolis where the clay is used for making bricks (see Grisafe, this volume). The second purpose for viewing this exposure is to observe a mudstone-filled channel that truncates a sandstone bed. Most models of Dakota stratigraphy emphasize sandstone-filled channels, however mudstone-filled channels are common. In addition to the exposure at Stop 6, channels filled with fine-grained facies in Ellsworth and Lincoln counties have been described by Hattin and Siemers (1987; stop 1, p. 33-35) and Hamilton (1989, sections 2 and 13).

These units exposed here were deposited in fluvial and overbank environments. The lowest unit of variegated mudstone (unit 1) is an overbank deposit, and displays paleosol features (Hamilton, 1989). Gray mudstone with red mottles is particularly common in the Dakota in this area.

Units 2 and 3 comprise a fining upward sequence from medium- and fine-grained sandstone with large scale trough cross-bedding to interbedded ripple cross bedded fine-grained sandstone and mudstones. The decrease in size of cross-beds upward in unit 2, the change upward from trough and planar cross-beds of unit 2 to ripple cross-bedding in unit 3, and the increase in mud interbeds are consistent with deposition in a fluvial point bar.

The point bar sequence (units 2 and 3) is truncated by a mud-filled channel. The base of the channel contains a shale pebble conglomerate that is thickest in the thalweg of the channel. The rest of the channel is filled with massive mudstone that contains abundant wood chips and a few discontinuous lignite beds that may be compressed logs. This may represent deposition in an abandoned channel. Alternatively, the lack of bedding and the random orientation of plant debris may indicate deposition by a debris flow. The zone of interbedded sandstone and laminated mudstone (unit 6) may represent a second, smaller channel fill incised into unit 5.

Siemers (1987) interpreted the uppermost unit of trough cross-bedded sandstone as a fluvial channel deposit, however the unit is very similar to and in the same stratigraphic position as the flat-bedded sandstone of Hattin and Siemers (1987) that outcrops in central and eastern Russell County, approximately 24 km (15 miles) to the northwest. The flat-bedded sandstone facies in Russell County is an elongate, tabular sandstone body approximately 6 to 9 m (20 to 30 ft) thick. The facies contains burrows and a brackish water invertebrate fossil assemblage, and was interpreted as a deposit of a delta distributary and sand that was reworked during the Graneros transgression. No burrows were observed in unit 6, however, discontinuous mud-draped foresets are common in this unit, and are lacking from older sandstone. Mud drapes may indicate deposition in a tidally-influenced system.

Description of units: The following description is based partly on section 3 of Hamilton (1989).

6. 550 cm. Medium- to fine-grained sandstone with 10-cm- to 30-cm-thick sets of trough cross-beds. Shale pebbles are abundant in lowest 2 m as are discontinuous clay drapes on foresets. Uppermost 1 m contains wood chips, shale pebbles, and wavy laminations. Basal contact is erosional.

5. 240 cm. Interbedded sandstone and mudstone. Mudstone contains sand laminae, starved ripples and abundant plant debris. Sandstone beds are medium- to fine-grained, have scoured bases and range up to 55 cm thick. Sandstones are cross-bedded with ripple-scale cross-bedding and small-scale trough cross-beds. Plant fossils are abundant and range up to 33 cm long. The basal contact appears erosional and contains a shale-pebble conglomerate, but contact cannot be traced far due to modern slumping.

4. 0 - 640 cm. Shale and mudstone. Mudstone pebble conglomerate at base up to 22 cm thick. Poorly bedded to massive mudstone with abundant small (under 2 cm), randomly oriented plant chips, and a few larger discontinuous lignite beds that may be individual compressed logs. Abundant massive sandstone pods up to 12 cm thick, with abundant mudstone pebbles.

3. 330 cm. Interbedded fine sandstone and mudstone. Beds of fine sandstone very poorly cemented, up to 23 cm thick, dominantly ripple-scale cross-bedding. Laminated mudstone with starved ripples and sand laminae. Upper part of unit not bedded.

2. 0 - 380 cm. Medium-grained sandstone in basal 1 m to fine and medium-grained sandstone in upper 2.8 m. Basal meter consists of large scale (up to 25 cm thick) trough and planar tabular cross-bedding. Truncated sets are 5 to 10 cm thick. Upper 2.8 m consists of mostly tabular planar cross-beds with less common trough cross-beds. Thickness of cross-beds decreases upward from an average of 10 cm thick (maximum of 18 cm) in the basal half, and an average of under 5 cm thick for the upper half.

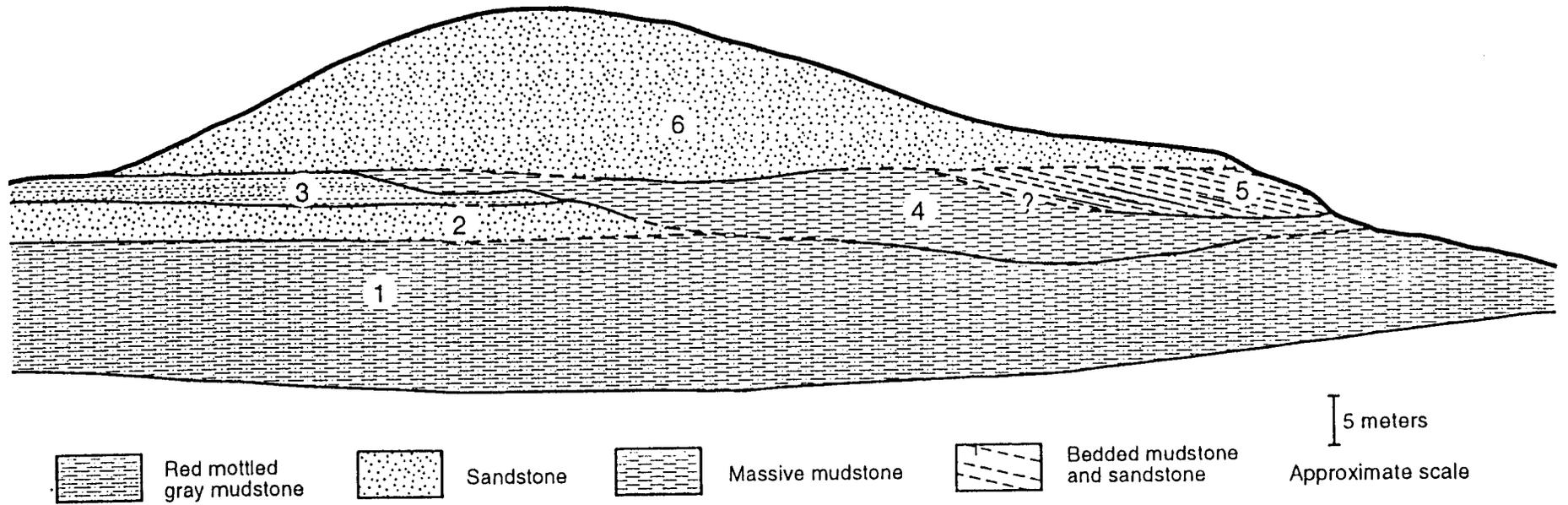1. 800 - 870 cm. Massive gray mudstone with red mottles. Measured thickness of Dakota Formation: 23.0 m. ·

18

Figure 11. Tracing of facies boundaries from a photograph of Stop 6. Scale is approximate and varies from one end of the sketch to the other.

STOP 7: Black Wolf section: Dakota/Graneros transition.
NW 1/4, SW 1/4, sec. 19, T 15 S, R 9 W, Ellsworth Co., Kansas.. Natural outcrops on hillsides 2.4 km (1.5 m) south of Black Wolf (Fig. 12).
Christopher A. Gellasch and Donald E. Hattin, Indiana University.

Introduction

The Dakota-Graneros transition in Ellsworth and Russell counties reflects complex changes of nearshore facies, even within short geographic distances. Stratigraphic studies by Rubey and Bass (1925), Hattin (1967), and Siemers (1971) outline the wide range of Dakota depositional environments (Fig. 3) that existed during eastward transgression of the Western Interior Sea during Late Cretaceous time. Reworked shoreline/shoreface, shore lagoon, coal swamp, and various deltaic and fluvial subenvironments have been identified within strata which comprise the transition. Work on paleobotany of the Dakota by Retallack and Dilcher (1981a,b) and by Farley and Dilcher (1986) also demonstrate environmental variability that embraces both non-marine and marine strata. Abrupt lateral changes of facies within the transitional interval greatly complicate attempts to achieve fine-scale lithostratigraphic correlation of closely spaced sections, although the use of bentonites has aided this effort. The 'X' bentonite, which lies near the top of the Graneros Shale throughout the study area, provides an isochronous datum that is an especially useful marker in stratigraphic study of the Dakota-Graneros transition. Bentonites that lie near the top of the Dakota Formation are impersistent, suggesting that local current scour in the marginal marine settings was a common phenomenon. This phenomenon is well displayed in the Black Wolf section, which is described below (Fig. 12).

Comparison with nearby sections

In order to determine the lateral extent of environments that produced the Black Wolf succession, attempts were made to correlate the this measured section with three other sections in the study area. The closest section is the Black Wolf section (Locality 40) of Hattin (1965), which was exposed within 100m of the field trip section. Dakota units shown by Hattin (1965) closely match units 6 through 9 of our section and the bentonite that caps the section of his Locality 40 is the same as our unit 11. Unfortunately, Hattin's measurements did not extend as low in the Dakota Formation as in the field trip section because he was primarily interested in the Graneros Shale. Further, in our section the Graneros is largely covered. One notable discrepancy between these two sections occurs near the base of the Graneros, below unit 11. Whereas Hattin (1965) describes a limonitized clay interval that contains several sandstone lenses at the base of the lower Graneros, the

equivalent interval of our section (unit 10) lacks these units, consisting instead of gray slightly silty shale. Some facies of the Dakota-Graneros transition are, therefore, traceable at least for short distances, whereas others cannot be traced as far as a hundred meters.

The Dakota-Graneros transitional section that is exposed south of Wilson, Kansas (NW 1/4, NE 1/4, sec. 6, T 15 S, R 10 W, Ellsworth Co.) is situated 6.75 miles from the section at Black Wolf. The two sections share several facies but the sequence of depositional events was not the same. In the Wilson section, the sandstone-dominated facies in the upper part of the Dakota occur stratigraphically higher in the section than at Black Wolf, and direct lithologic correlation with Black Wolf strata is not readily apparent. The topmost bed of the Dakota at Black Wolf is red, resistant, and contains oyster molds and Laternula sp., which is indicative of Dakota faunas. The equivalent bed at the top of the Dakota at Wilson is yellowish brown, and, according Hattin (1965), contains molds of Aphrodina?, which is normally associated with Graneros faunas.

An additional section, measured by Gellasch in the area south of Dorrance (NE 1/4, NE 1/4, sec. 12, T 15 S, R 12 W, Russell Co.), is situated 13.5 miles west of the Black Wolf section and 6.7 miles west of the Wilson section. There too, lithostratigraphic correlation with other sections is complicated by differences in the succession of lithofacies. Important differences between upper Dakota strata in the Black Wolf and Dorrance sections include lack of lignite layers at Dorrance and occurrence at Dorrance of two successions like that embraced by units 6 through 8 in the upper Dakota at Black Wolf. At Black Wolf, the upward succession consists of silty shale (unit 6) followed by interbedded sandstone and shale (unit 7), which grades upward into shale (unit 8) that contains scattered small sand lenses near the top of the Dakota. This same succession appears to occur twice in the Dorrance section. At Dorrance, however, the upper of the two successions lacks the abundant carbonized plant material found in the lower one.

Interpretation

Depositional environments represented by the facies developed in the Black Wolf section manifest an overall transgressive sequence. The basal portion of the section (units 1 and 2) contains mottled shales that become slightly carbonaceous in unit 2 and suggest fluvial overbank deposits such as those described by Siemers (1971) and Franks (1975). Mottled mudstones of units 1 and 2 are overlain by richly carbonaceous sandstones of units 3 and 5 that pass laterally in a distance as little as 100 meters into coal seams that were mined commercially in this area late in the 19th century (Schoewe, 1952). The lignite and carbonaceous sandstones are deposits of a coastal swamp and adjacent fluvial/swamp transition, respectively. A bentonite seam (unit 4) that lies between units 3 and 5 is truncated locally by

a shallow channel that we interpret as the product of fluvial floodwater flow.

Unit 5 is overlain by silty gray carbonaceous shale (unit 6) which becomes less silty and nearly devoid of carbonaceous material near the top. This unit is interpreted as the deposit of a shore lagoon that was bordered by coastal swamps and developed as a result of continued transgression of the marine shoreline across this area.

Unit 7 is key to our 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 gray silty shales, contains the marine pelecypods *Geltina* sp. and *Cymbophora* sp. as well as siderite nodules. We interpret this unit as the tidally influenced portion of a shore lagoon, possibly close to a tidal inlet.

Unit 7 is overlain by non carbonaceous shale (unit 8) that could reflect closing of a tidal inlet and re-establishment of quiet water lagoonal conditions, or first appearance of open-shelf muds.

Unit 8 is overlain by a thin hematite-cemented sandstone bed (unit 9), that contains molds of oysters, a marine clam (*Laternula* sp.), and erect reed? molds. 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 sandstone that comprises unit 9 is characteristic of the Dakota, we select the top of unit 9 as the top of the Dakota Formation. Unit 9 is a marine shoreline sand, and lower beds of the Graneros Shale (unit 10) are open-marine shelf deposits.

Although no longer well exposed in the Black Wolf roadcut section (Locality 40 of Hattin, 1965), the lower Graneros (units 10-12 of the field-trip section) throughout Ellsworth and Russell counties contains numerous sandstones stringers and, at most locations, a thin-bedded mid-Graneros sand body that contains oscillation ripples marks and large numbers of clam molds and oyster shells. These Graneros units are deposits of a storm-influenced shelf (Retallack and Dilcher, 1981a; Boberg, 1990), and are interpreted as a possible parasequence. Within the ripple marked mid-Graneros sand body, float blocks of which occur in the Black Wolf section, local coquinoidal limestone preserves evidence of a major episode of sea-floor scour (storm) that winnowed fines and concentrated large numbers of shells (Boberg, 1990).

Unit 13 is widely used as a datum for regional and interregional correlation (e.g. Merriman, 1957) and is the thickest bentonite seam in the Kansas Cretaceous (Hattin, 1965). This lithochronozone, 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). Extensive digging was required to expose this unit at the Black Wolf locality.

Summary

In the Black Wolf section, the vertical succession of strata records progressive change from nonmarine to marginal marine to open-marine depositional environments, with concomitant change from high to low content of carbonaceous plant debris and gradual appearance of marine fossils. The transition suggests a linear clastic shoreline rather than deltaic shoreline such as that documented farther north by Siemers (1971) in the area lying near Lake Wilson in Russell County. The transition compares more favorably with the upper Dakota succession that is exposed south of Wilson, Kansas, which also suggests upwards change from fluvial, marsh/swamp, and brackish water shore lagoon environments to a shoreline/shoreface sandstone unit with marine fossils that was designated the top bed of the Dakota by Hattin (1965).

Figure 12. Graphic column of measured section at Black Wolf locality, Stop 7.
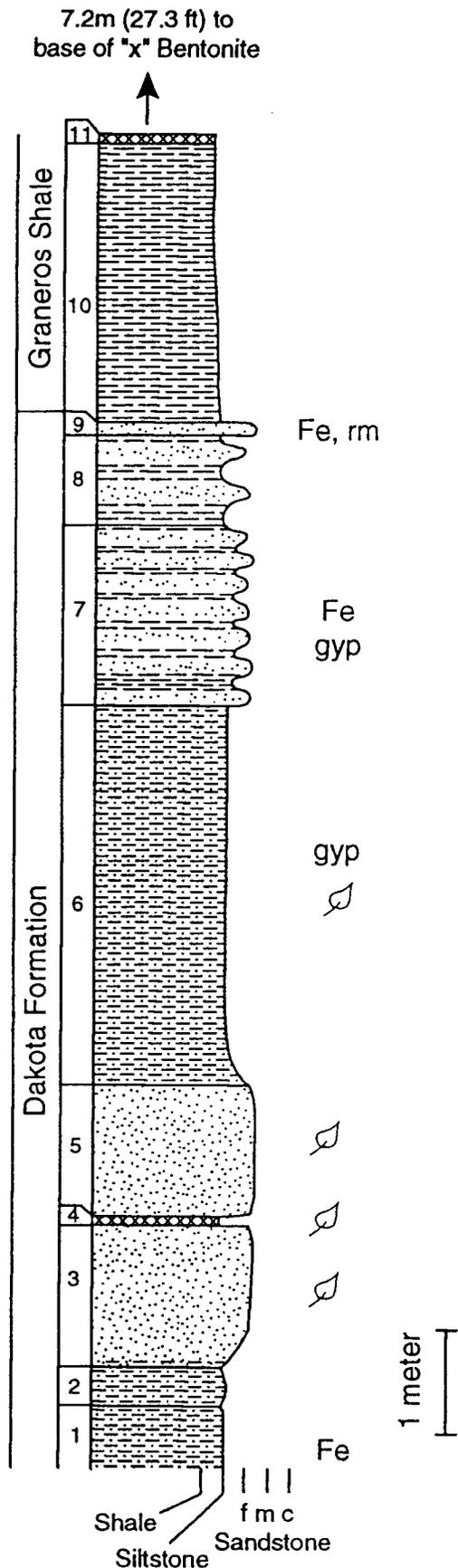
Description of units:

Graneros Shale

13. 27 cm. Bentonite, white, weathers yellow-orange owing to limonitic staining.
12. 722 cm. Covered interval; float contains yellowish gray sandstone with molds of *Aphrodina lamarensis*; medium gray shale also present in float.
11. 3 cm. Bentonite, white.
10. 290 cm. Shale, medium gray, becomes light gray near top, minor silt.

Measured thickness of Graneros Shale 10.42 m.

Dakota Formation

9. 9 cm. Sandstone, dusky red, Fe-cemented, resistant, fine grained; contains clay-ironstone concretions. Fossils: erect reed? molds, fish scale, *Laternula* sp. mold, oyster mold.
8. 91 cm. 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 3 cm thick.
7. 183 cm. Sandstone and shale; sandstone yellowish gray, fine grained, resistant, contains clay ironstone concretions, oscillation and current ripple marks; unit interbedded and interlaminated with medium dark-gray silty shale that contains large (up to several inches) gypsum crystals. Fossils: molds of *Geltina* sp. and *Cymbophora* sp.
6. 381 cm. Shale, medium gray, silty, becomes darker and less silty near top; contains carbonized plant material near center; lower 91 cm weathers shaly.
5. 137 cm. 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.
4. 6 cm. Bentonite, light gray, hard, brittle, with conchoidal fracture, impersistent; contains sparse fragments of carbonized woody material.
3. 143 cm. 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.
2. 38 cm. Mudstone, light gray, pale yellowish orange, slightly carbonaceous.
1. 70 cm. Mudstone, dark yellowish orange to grayish red, silty, underlies light gray weathered slopes.

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

PRESERVATION OF PETROGLYPHS ON DAKOTA SANDSTONE

by David A. Grisafe, Geologic Investigations, Kansas Geological Survey

Introduction

Lacking pencil and paper and writing of the language, it seems safe to assume that the American Indian often used petroglyphs and pictographs to communicate significant events or history of the tribe or perhaps of the individual. In some cases, the glyphs may have indicated directions, e.g. an isolated arrow. Unfortunately, we do not know the meaning of most petroglyphs. Like pottery shards, spear points, etc., such Indian writing is an artifact of a past civilization. We respect such writing as a work of antiquity and hopefully preserve it so that future detailed studies may shed light on their significance and provide information of a past culture.

Petroglyphs are literally carvings on rocks while pictographs are paintings. Most sites that have received some degree of notoriety are located in the west, perhaps because they are relatively common in that portion of the country. However, Kansas does have its share of petroglyph sites and the majority of them are located in the central portion of the state, counties such as Ellsworth and Russell, where there are large exposures of the Dakota sandstone. Often the sandstone is quite soft and carving into the stone would be relatively easy.

Not surprisingly, many sites are located near a source of water and are often in protected areas such as a cliff, rock shelter or cave. Since there have been no systematic searches for sites in most areas, it seems likely that there may be other as yet undiscovered sites of rock art in central Kansas. Known sites may consist of only one or two glyphs while others may contain large numbers.

Vandalism is a continuing problem throughout our country. People spray paint, carve initials, burn fires near the glyphs, etc. and such action has certainly taken its toll. Even in relatively desolate areas such as Barrier Canyon in eastern Utah, graffiti has defaced some classic Barrier Canyon pictographs. Recently, the public has begun to awaken to this problem and in the case of the Barrier Canyon event, the guilty parties were prosecuted.

Kansas has its share of vandalism. People have gone so far as to collect petroglyphs by taking blocks of stone bearing petroglyphs out of a rock shelter site in Ellsworth County. In so doing, they not only took petroglyphs but also defaced the surrounding petroglyphs. One could argue such action is equivalent to cutting out a section of a Renoir masterpiece at the museum. Small wonder that private landowners, the National Park Service, the Bureau of Land Management or whoever has charge of such sites, are reluctant to tell people their location. In one respect, the American Indian is also guilty of defacing rock art as one generation or tribe might carve figures over the petroglyphs of previous dwellers at the site.

Not all graffiti is bad. Two sites come to mind, namely the carved names of Buffalo Bill Cody in red sandstone in Ellsworth County and the carved signature of the explorer John Clark (Lewis and Clark) on Pompeys Pillar National Historic Landmark along the Yellowstone River in Montana. In both cases, however, the names have not been carved into Indian petroglyphs; they stand alone. Also, early pioneers often carved their names and dates into stone, thus providing evidence as to the time the area was used.

Although many sites have been subjected to varying forms of vandalism, the most destructive force acting on all rock art is natural weathering. Rock art sites are gradually attacked by a variety of phenomena, including freeze-thaw, wet-dry and heat-cool cycling, wind and water erosion, biological growth, salts, atmospheric pollution, and mineral weathering. Naturally, the geographical location of a site (with regard to its climatic characteristics) and the degree of protection provided to the site play major roles in determining which agent or agents are most detrimental.

Despite the attempts to protect sites from vandalism, little work has been done in finding a suitable treatment to increase the durability of the stone itself. However, before treating any stone, it is necessary to understand the nature of the stone. For example, there is little point in treating a stone with a chemical solution if the stone has no absorption. Thus, it is important to understand certain basic mineralogical and physical characteristics of the stone and be able to evaluate the changes of such properties as a result of any type of treatment.

There are natural reservations to treating petroglyph sites since such art is irreplaceable. A treatment could produce more problems than cures. However, while debating the merits and durability of a treatment, nature continues to erode such art, and many sites cannot afford to wait much longer before destruction is complete. Greater emphasis has been placed on the chemical treatment of historical stone structures, particularly in Europe, than on treating petroglyphs. While not identical, there are similar problems and constraints in treating a building or a rock art site. Past experience with buildings provides useful guidelines for selecting a successful method for treating petroglyph sites. Some proposed methods of treatment border on the exotic. About 25 years ago, when epoxy cement became popular, it was proposed that holes be drilled behind petroglyphs and epoxy cement pressure-injected into the holes. Such a method has great potential to destroy rock art.

The primary objective of my research is to use a simple testing program to understand the nature of the stone both before and after treatment with a chemical solution and to show the effectiveness of silicic ethyl ester or ethyl silicate dissolved in the low-viscosity carrier methyl ethyl ketone and applied to a porous sandstone bearing petroglyphs to prolong the life of the petroglyphs.

.

Discussion of Requirements To Meet the Objective

Simple testing can be used to determine the basic properties of the stone. To examine the mineralogy, x-ray analysis or optical microscopy can be used, and to determine the porosity/permeability characteristics, capillary or immersion absorption and vapor or liquid transmission can be used. The latter physical characteristics can also be measured on treated stone. In addition, compressive strength measurements are often used to evaluate the effectiveness of a stone-strengthener treatment. Other methods to evaluate a treatment include freeze-thaw cycling and for stones that contain significant amounts of expandable clay minerals, wet-dry cycling. The important point to remember is that most of the physical property measurements do not require expensive instruments and can be done in almost any laboratory.

One may be misled into thinking that a waterproofing agent coating the surface of the rock art will be sufficient to stop deterioration caused by moisture. While this may help, it must be remembered that moisture is present throughout the stone. Fractures, joints, bedding planes, and the natural permeability of the stone all provide avenues for moisture to reach the rock art, including moisture from the ground moving upward and outward.

Many sites, particularly those on uncemented sandstones that are held together primarily by interlocking grains or sandstones that have undergone extensive weathering with little remaining cement, need to be treated with a cementing agent to bond the grains of the stone together before any waterproofing agent is applied. Such a cementing agent gives the stone additional strength that will enable it to better withstand the stresses caused by natural weathering phenomena. Requirements that must be met by any strengthening agent being considered for preserving a rock art site include:

a. Strengthening agent should penetrate stone to a sufficient depth to treat all of the zone of weathering.
b. Agent should increase strength and freeze-thaw resistance.
c. Stone should be able to breathe after treatment so that the stone can rid itself of moisture.
d. Treatment should not cause any color change.

Many attempts, using a variety of treatments, have been made to preserve stone on historical structures. Many of these probably have done more harm than good because of their failure to meet one or more of the above requirements, even when an increase in strength seems to have been attained.

To achieve the desired depth of penetration, the stone must have a certain amount of accessible porosity or permeability. However, one must also consider the properties of the treating agent. Depth of penetration will be enhanced by having the bonding agent be of a low molecular weight and completely dissolved in a low-molecular weight, low-viscosity hydrocarbon carrier. Such a system would be

expected to achieve greater penetration than an aqueous colloidal suspension such as an alkali silicate. In addition, the latter type of agent would be more prone to cause surface enrichment of the colloidal material, producing a lightening of the stone color due to the formation of a thin crust. Also, aqueous solutions often do not have neutral pH values, and in some cases, reaction with minerals in the stone and possible discoloration may occur. In contrast, organic systems, such as the one used in this study, possess neutral pH values.

Perhaps the most overlooked requirement in a strengthening agent is its effect on the permeability or vapor transmission of the stone. The agent must not completely seal the pore system of the stone, or problems will likely develop over time because of the excess moisture trapped behind the exterior of the stone. Such moisture can become rich in soluble salts that may crystallize during dry seasons just beneath the sealed pore zone. Then, a period of wet weather may cause rehydration of an anhydrous salt, and consequent volume expansion will occur. In colder climates, trapped moisture may lead to sanding and spalling. Remember that water begins to expand once the temperature drops below 4 °C, and additional expansion occurs if the moisture freezes. One needs only to recall the cracking, spalling, and potholes that appear in roads during the winter to realize how detrimental freezing can be. In summary, any treatment of rock art must allow the stone to breathe in order to minimize the destructive effects of excess moisture trapped in the rock.

Considering the stringent requirements for a safe and effective strengthening agent for use on rock art sites, the agent chosen for this study is based on ethyl silicate completely dissolved in the low-viscosity carrier/solvent methyl ethyl ketone. The low viscosity and low molecular weight of this solution enhance the depth of penetration for any stone, providing the stone has some degree of permeability. It is a colorless solution with a neutral pH value and would not be expected to cause any discoloration of the stone. In the United States, the sole supplier of this strengthening agent, known as Conservare OH, is the Process Solvent Company, located in Kansas City, KS.

The past experience of the author with this system in testing dimension stones from historically important buildings showed no discoloration of the stone, an increase in strength, and good depth of penetration; in addition, the system did not completely seal the pores. The mechanism involves a slow hydrolysis or reaction between the ethyl silicate and moisture in the stone to produce a silica-based cement. Strength measurements indicate the system is especially effective when applied to soft, porous sandstones and has led some researchers to believe a chemical bond is formed (-Si-O-Si-) between the hydrolysis-produced silica and the silica sand grain. Considering the above, the system seemed an ideal candidate to increase the durability of a rock art site where petroglyphs had been carved into a soft sandstone.

24

Some Experimental Results

To date, three sites have been treated with ethyl silicate to consolidate the relatively friable Dakota sandstone, all in the Kanopolis Lake area on land managed by the U.S. Army Corps of Engineers. All of the work has been funded by the Corps. In each case, sites were examined and in situ capillary absorption measurements were performed to obtain an idea of the permeability of the stone. Samples were collected at the sites and taken to the Engineering School at the University of Kansas where they were cored into 1.5" diameter cores, approximately 1.5"-1.75" high, for testing purposes.

Capillary absorption was measured by placing cores in a vertical position on a water-saturated sponge and measuring the weight gain as a function of time. The weight gain was also determined for cores that had been submerged in water for at least 24 hours.

Various treatments using the consolidating agent, Conservare OH, and in some cases a subsequent combination consolidant-waterproofing solution, Conservare H, were done by placing a thin layer of the desired chemical solution in a stainless steel pan and placing the cores, again in a vertical position, in the pan for the desired period of time. This method of treatment (capillary absorption) was chosen as being more representative of treating a site as opposed to immersion in the solution. A minimum of three weeks was allowed for curing before another treatment or testing was undertaken. After curing, core weights were obtained to determine the amount of chemical "solids" introduced into the stone. Treated and cured cores were then evaluated for their compressive strength and freeze-thaw resistance as well as their absorption characteristics.

Listed below in tabular form are the test results obtained from both untreated and variously treated cores from two of the three sites, Faris Cave and Red Rock Canyon (Tables 1, 2). The Faris Cave Site contains several petroglyphs carved onto a relatively "pure" sandstone (96% silica) while the Red Rock Canyon site contains the carved name of William F. Cody (Buffalo Bill) who was stationed at nearby Fort Harker. The latter stone contains several percent iron oxide. Both stones are relatively free of feldspar, clay minerals and carbonates. The third site is located along Alum Creek and the stone is virtually identical to that at Faris Cave, thus making detailed examination unnecessary.

Summary

The data presented in the tables are self-explanatory with respect to the effectiveness of the treatments. A single, two minute, capillary absorption treatment of OH doubled the compresive strength and sharply improved the freeze-thaw resistance. Subsequent treatments improved these properties still further. Even with multiple treatments, the stone retains some of its permeability, thus allowing it to rid itself of excess moisture.

Armed with the laboratory data, test panels at the sites were treated with the above mentioned chemical solutions, using an arbitrarily selected coverage rate of 10 ft/gal.. As expected, no discoloration occurred and in situ absorption measurements showed a pronounced reduction in the absorption of the stone. Afterwards, the petroglyph panels were treated in the same manner. In all cases, a low pressure sprayer was used with a fan tip spray nozzle to minimize washing any grains from the surface and to obtain a relatively even distribution of the chemical on the surface.

In closing, this method of preserving petroglyphs is new and has only been used to date on the Dakota sandstone in Kansas. It appears to be the first safe and adequate chemical method ever used but, since we are dealing with a new method of treating an object of antiquity, it will not be quickly accepted. The longevity of the treatment can only be determined by long-term monitoring of treated sites. At the present time, stone from two other sites (in Montana, and Saskatchewan, Canada) are being evaluated for this treatment.

Table 1. Capillary and immersion absorption characteristics of treated and control cores

| Site and Treatment | Percent Weight Gain | | | |
| | Capillary Absorption | | Immersion | |
	1 min	1 hr	24 hr	24 hr
FARIS CAVE				
Untreated	15.8	15.8	15.8	16.1
1 OH	8.7	12.9	12.9	13.8
2 OH	2.7	10.1	10.2	11.0
3 OH	1.2	6.4	7.3	8.7
2 OH + 1 H	1.2	6.6	7.4	8.6
3 OH + 2 H	0.1	1.0	1.5	4.3
RED ROCK CANYON				
Untreated	16.4		16.5	16.8
1 OH	8.6	13.5	13.8	16.9
2 OH	2.7	10.6	10.9	13.6
2 OH + 1 H	0.0	0.1	0.7	3.1
2 OH + 2 H	0.0	0.1	0.6	2.6

Table 2. Compressive strength and freeze-thaw resistance

| Site and Treatment | Strength (in psi) | Percent weight loss after number of freeze-thaw cycles | | | |
		25	50	75	100
FARIS CAVE					
Untreated	1,080	76	100	-	-
1 OH	2,550	0.0	0.8	2.8	4.6
2 OH	3,050	0.0	0.1	0.8	1.3
3 OH	4,750	0.0	0.0	0.3	0.6
2 OH + 1 H	4,640	0.0	0.1	0.3	0.4
3 OH + 2 H	7,650	0.0	0.0	0.0	0.0
RED ROCK CANYON					
Untreated	850	13.0	96.2	-	-
1 OH	1,560	0.9	4.4	6.0	11.0
2 OH	2,940	1.2	3.0	3.6	4.3
2 OH + 1 H	3,860	0.6	0.7	0.8	0.8
2 OH + 2 H	4,240	0.5	0.6	0.7	0.6

DAKOTA CLAY DEPOSITS

by David A. Grisafe, Geologic Investigations, Kansas
Geological Survey

Although you will not be visiting any clay pits on the field trip, a word about the Dakota clays is included in the field book because of their importance as an industrial mineral. Here in Ellsworth County, the Acme Brick plant at Kanopolis operates several clay pits as sources for brick production. Dakota age clays are used in similar fashion by Cloud Ceramics (Concordia, Cloud County) and Kansas Brick & Tile (Hoisington, Barton County). Thus, three of the four brick plants operating in Kansas use Dakota clays as their raw material.

Perhaps the most consistent feature about Dakota clays is their inconsistency. Often the clay deposits thicken and thin, seemingly at random, and lens shaped deposits are common. In general, Dakota clay deposits should always be drilled to insure adequate reserves are present before opening a clay pit.

Variation is observed in their iron content and consequently, their ceramic properties. This variation does allow a brick producer to fabricate a large variety of colors, sometimes an advantage in the marketplace. That is one major reason why most brick producers operate more than a single pit. The producer can use the clay from one pit to produce one color of brick or a series of clays, each from a different pit, may be blended and used to produce the desired varieties of color. Considerable research is undertaken before such blends are finalized. Color is important but so is the workability (plasticity), firing temperature and thermal expansion, the latter especially important during the cooling cycle. Blending of clays from different pits often produces the desired workability and firing properties and eliminates the need for the producer to purchase more expensive chemical additives. Fortunately, many Dakota clays have good workability due to the fine particle sizes of both the clay minerals and quartz present and the ability of the clays to slake or disperse into minute particles when wet. Such deposits that also have a low iron content have led to the production of light colored brick. In some deposits, the iron level is so low that a white brick can be produced. By one estimate, approximately one-third of the Dakota clays fire to a white to light buff color. This is in marked contrast to the Pennsylvanian Age clays that seldom fire to a light color.

As a whole, the Dakota clays are the most kaolinitic clays in the state although many also contain significant amounts of illite. Few contain appreciable montmorillonite. By comparison, the Pennsylvanian Age clays that are used for ceramic raw materials tend to have more illite or montmorillonite associated with them. In general, then, the Dakota clays tend to be "purer" or basically composed of hydrated aluminum silicate. They possess less expandable clay minerals (consequently less drying shrinkage and

cracking during the production of brick or other ceramic objects) and are also more refractory.

Another general feature of Dakota clays is that they are generally not calcareous. This is also important to a ceramic manufacturer. The presence of calcium can lead to a narrowing of the maturing range (optimum firing temperature) or maturing temperature, thus requiring very close kiln temperature control to avoid the possibility of underfiring or overfiring brick or other ceramic products. Consider the consequences of slightly overfiring a kiln load of brick when the clay contains calcium so that a sufficient amount of liquid phase develops to "weld" the entire load. The Dakota clays generally have a much wider optimum firing range, thus making it easier to avoid problems associated with underfiring (high absorption, low strength) or overfiring (fusing or bloating).

Finally, the Dakota clays have been studied more than any other age group of clays in Kansas, largely due to the work of former K.G.S. staff members Norman Plummer, John Romary and later, Maynard Bauleke and William Hladik. The K.G.S. Bulletin 67, "Kansas Clay, Dakota Formation", by Plummer and Romary in 1947 provides excellent coverage of the topic. In addition, the chemical analyses and firing properties for most of the Dakota clays that have been sampled are in a computer database at the Survey.

PLANT FOSSILS OF THE DAKOTA FORMATION

By Frank Potter, Fort Hays University
and David L. Dilcher, University of Florida

The importance of the Dakota Formation is easily understood when you consider the abundant fossil plant material that is preserved there and the age of the Dakota Formation. The evolution of the flowering plants, Angiosperms, has evaded the paleontologist for decades. The earliest generally accepted traces of angiosperms have been found in lower Cretaceous rocks. Although the mid-Cretaceous age of the Dakota Formation in this area does not represent the earliest record of the flowering plants, the state of preservation and stage of rapid radiation makes the material valuable in our understanding of the plant division.

The most important contribution to our understanding of the early evolution and radiation of Angiosperms has been the diversity of flowers from the Dakota Formation of Kansas and Nebraska. The most complete of these early fossil flowers is from a locality in Nebraska. Radially symmetrical, the flower has five sepals, five petals, five stamens and five carpels. The stiff, broad sepals are joined at their base to form a robust shallow cup.

Another bisexual but very different flower is known from deposits in central Kansas. These flowers are large, solitary, and borne at the ends of stout, leafy shoots. At the base of the elongated floral axis are three large outer sepals, with six or nine radially arranged petals above them. Above the sepals and petals, numerous small elliptical scars mark the positions where stamens were attached. Up to 150 carpels, which matured into dry, boat-shaped seedpods, were spirally arranged on the reminder of the elongated flower stalk.

The best known and most widespread flower type is apparently a unisexual extremely small flower clustered into spheroidal heads. Up to thirty-six of these heads, each about one-quarter of an inch in diameter, are arranged at more or less regular intervals on a long, presumable pendulous axis.

Leaves are well represented in both the clay and sandstone facies of the Dakota Formation. The leaves are sometimes so well preserved that they can be removed intact from the clay and the epidermal cells are still preserved. One such leaf studied is most probably related to the Magnolia or Laurel families.

Fossil wood specimens are found in the Kiowa, Dakota and Greenhorn Formations. Most of the wood fragments from the Dakota are carbonized instead of premineralized. Limited studies indicate the wood is of gymnosperm or primitive angiosperm origin. The distribution pattern of the Dakota carbonized material and sediment grain sizes suggest deposition of the fragments after fires. The premineralized log material common in the Kiowa and Greenhorn Formations suggest rafting of logs into open water.

Conifers, ferns, and other plant groups are also represented. All of the mega- and microfossil material represented a time of explosive radiation, particularly of the flowering plants. This rapid diversification may prove very useful stratigraphically for telling us the age of the mid and upper Cretaceous.

REFERENCES

Coleman, J., and S. Turbek, 1992, Sequence stratigraphy of the Lower Cretaceous Dakota Aquifer framework in Kansas: AAPG Annual Convention Abstracts, p. 22.

Cragin, F. W., 1889, Geological notes on the region south of the Great Bend of the Arkansas: Bulletin Washburn College Laboratory of Natural History, v. 2, p. 33-37.

Cragin, F. W., 1895, A study of Belvidere Beds: American Geologist, v. 16, p. 357-386.

Bayne, C. K., P. C. Franks, and W. Ives, Jr., 1971, Geology and ground-water resources of Ellsworth County, central Kansas: Kansas Geological Survey Bulletin 201, 84 p.

Boberg, W. S., 1990, Paleontology, taphonomy, and sedimentology of unusual coquinoidal limestone lenses in the Graneros Shale of Western Kansas: M.S. Thesis, Indiana University, 97 p.

Farley, M. B., and D. L. Dilcher, 1986, Correlation between miospores and depositional environments of the Dakota Formation (Mid-Cretaceous) of north-central Kansas and adjacent Nebraska, U.S.A.: Palynology, v. 10, p. 117-133.

Fent, O. S., 1950, Geology and ground-water resources of Rice County, Kansas: Kansas Geological Survey Bulletin 85, 142 p.

Franks, P. C., 1966, Petrology and stratigraphy of the Kiowa and Dakota formations (basal Cretaceous), north-central Kansas: Ph.D. diss., University of Kansas, 312 p.

Franks, P. C., 1975, The transgressive-regressive sequence of the Cretaceous Cheyenne, Kiowa, and Dakota formations of Kansas, in, W. G. E. Caldwell, ed., The Cretaceous System in the Western Interior of Western North America: Geological Association of Canada, Special Paper 13, p. 469-521.

Franks, P. C., 1979, Paralic to fluvial record of an Early Cretaceous marine transgression -- Longford Member, Kiowa Formation, north central Kansas: Kansas Geological Survey Bulletin 219, 55 p.

Hamilton, V. J., 1989, Stratigraphic sequences and hydrostratigraphic units in Lower Cretaceous strata in Kansas: M.S. thesis, Colorado School of Mines, Golden, Colorado, 165 p.

Hattin, D. E., 1965, Stratigraphy of the Graneros Shale (Upper Cretaceous) in central Kansas: Kansas Geological Survey Bulletin 178, 83p.

Hattin, D. E., 1967, Stratigraphic and paleoecologic significance of macroinvertebrate fossils in the Dakota Formation (Upper Cretaceous) of Kansas; in, Essays in Paleontology and Stratigraphy, Raymond C. Moore Commemorative Volume: University of Kansas, Department of Geology, Special Publication 2, p. 570-589.

Hattin, D. E., and C. T. Siemers, 1987, Guidebook, Upper Cretaceous stratigraphy and depositional environments of western Kansas: Kansas Geological Survey Guidebook Series 3, 55 p.

Kauffman, E. G., 1984, Paleobiology and evolutionary response dynamic in the Cretaceous Western Interior seaway of North America: Geological Association of Canada Special Paper 27, p. 273-306.

Latta, B. F., 1946, Cretaceous stratigraphy of the Belvidere area, Kiowa County, Kansas: Kansas Geological Survey Bulletin 64, p. 217-260.

Latta, B. F., 1948, Geology and ground-water resources of Kiowa County, Kansas: Kansas Geological Survey Bulletin 65, 151 p.

Macfarlane, P. A., J. H. Doveten, H. R. Feldman, J. J. Butler, Jr., J. M. Combes, and D. R. Collins, in review, Aquifer/aquitard units of the Dakota aquifer system in Kansas: methods of delineation and sedimentary architecture effects on ground-water flow and flow properties: Journal of Sedimentary Research.

Macfarlane, P.A., D. O. Whittemore, M. A. Townsend, J. H. Doveton, V. J. Hamilton, W. G. Coyle III, A. Wade, G. L. Macpherson, and R. D. Black, 1990, The Dakota aquifer program: annual report, FY89: Kansas Geological Survey, Open-file Report 90-27, 302 p.

Meek, F. B., and F. V. Hayden, 1859, Remarks on the Lower Cretaceous beds of Kansas and Nebraska: Journal of Science, 2nd Series, v. 27, p. 219-227.

Merriam, D. F., 1957, Subsurface correlation and stratigraphic relation of rocks of Mesozoic age in Kansas: Kansas Geological Survey, Oil and Gas Investigation 14, 25 p.

Mitchum, R. M., 1977, Seismic stratigraphy and global changes of sea level, Part 1: Glossary of terms used in seismic stratigraphy, in C. E. Payton, ed., Seismic stratigrapy-applications to hydrocarbon exploration: American Association of Petroleum Geologists Memior 26, p. 205-212.

Plummer, N, and J. F. Romary, 1942, Stratigraphy of the pre-Greenhorn Cretaceous beds of Kansas: Kansas Geological Survey Bulletin, v. 41, p. 313-348.

Retallack, G., and Dilcher, D. L., 1981a, A coastal hypothesis for the dispersal and rise to dominance of flowering plants: Paleobotany, Paleoecology, and Evolution, v. 21, p. 27-77.

Retallack, G., 1981b, Early angiosperm reproduction: *Prisca Reynoldsii*, gen. et sp. nov. from Mid-Cretaceous coastal deposits in Kansas, U.S.A.: Palaeontographica, Abt. B, vol 179, p. 103-137.

Rubey, W. W., and Bass, N. W., 1925, The geology of Russell County, Kansas: Kansas Geological Survey, Bulletin 82, pt. 1, 36p.

Scott, R. W., 1967, Paleontology and paleoecology of the Kiowa Formation (Lower Cretaceous) in Kansas: Ph.D. diss., University of Kansas, 308 p.

Scott, R. W., P. C. Franks, J. A. Stein, J. A Bergen, and M. J. Evetts, 1994, Graphic correlation of synchronous Mid-Cretaceous depositional cycles: Western Interior and Gulf Coast, *in* J. Dolson, ed., Unconformity Related Hydrocarbon Exploration and Exploitation in Carbonate and Clastic Settings: Rocky Mountain Association Geologists Guidebook, in press.

Schoewe, W. H., 1952, Coal resources of the Cretaceous System (Dakota Formation) in central Kansas: Kansas Geological Survey, Bulletin 96, part 2, p. 69-156.

Siemers, C. T., 1971, Stratigraphy, paleoecology, and environmental analysis of upper part of Dakota Formation (Cretaceous), central Kansas: Ph.D. dissertation, Indiana University, 287p.

Siemers, C. T., 1976, Sedimentology of the Rocktown channel sandstone, upper part of Dakota Formation (Cretaceous), central Kansas: Journal of Sedimentary Petrology, vol. 46, p. 97-123.

Van Wagoner, J. C., H. W. Posamentier, R. M. Mitchum, P. R. Vail, J. F. Sarg, T. S. Loutit, and J. Hardenbol, 1988, An overview of sequence stratigraphy and key definitions, *in* C. W. Wilgus *et al.*, eds., Sea level changes: an integrated approach: Society of Economic Paleontologists and Mineralogists Special Publication 42, p. 39-45.

Van Wagoner, J. C.., R. M. Mitchum, K. M. Campion, and V. D. Rahmanian, 1990, Siliciclastic

sequence stratigraphy in well logs, cores, and outcrops: Concepts for high-resolution correlation of time and facies: AAPG Methods in Exploration Series, No. 7, 55 p.

Weimer, R. J., 1984, Relation of unconformities, tectonics, and sea-level changes, Cretaceous of Western Interior, U.S.A., *in* J. S. Schlee (ed.), Interregional unconformities adn hydrocarbon accumulation, American Association of Petroleum Geologists Memoir 36, p.7-36.

Weimer, R. J., and C. B. Land, Jr., 1972, Feild guide to Dakota Group (Cretaceous) stratigraphy, Golden-Morrison area: Mountain Geologist, vol. 9, p. 240-267.

—

30