41st Annual North-Central Meeting
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Geological Society of America

FIELD TRIP 2: Fluvial-Estuarine Deposition in the Mid-Cretaceous Dakota Formation, Kansas and Nebraska

Field Trip Leaders:

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with a contribution by:

Darren R. Gröcke, McMaster University, Hamilton, Ontario

April 10, 2007

Kansas Geological Survey
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Cover photo—Field trip participants examining Cretaceous fluvial-estuarine mudrocks of the Kiowa-Skull Creek marine cycle exposed along cutbank exposures of the Solomon River near Salina, Kansas. Photo by Fred J. Anderson, North Dakota Geological Survey.

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Road Log

Mileage	Description
0.0	Depart Kansas Geological Survey, Lawrence; proceed N on Iowa Street
3.0	Kansas Turnpike/I-70 entrance ramp; proceed W on KT/I-70
21.0	I-70 exit 197
36.0	I-70 exit 364B
45.0	I-70 exit 343
52.0	I-70 rest stop
91.0	Pass Junction City, Kansas
94.0	I-70 rest stop
121.0	I-70 exit 266
127.0	Low buttes underlain by Dakota Formation to SW
136.0	I-70 exit 252; turn R (N) on Road 143 and proceed N
137.0	Cross Saline River
142.0	North Pole Mound, a butte underlain by Dakota Formation to R (E)
143.0	Pass Aspen Road
145.0	Turn R on Coronado Road, proceed on Coronado Road
146.0	Turn L on N 180th Road, proceed on N 180th Road
147.0	Turn R on gravel drive to Romm–Quiver residence, 298 N 180th Road.

STOP 1. Estuarine mudrocks of the Late Albian Kiowa–Skull Creek marine cycle exposed along the Solomon River near Salina, Kansas.

One of the major themes of this field trip will be to note the regional pattern of Late Albian fluvial-estuarine facies in the basal Cretaceous sections in northern Kansas, eastern Nebraska, and western Iowa (Witzke and Ludvigson, 1998; Brenner et al., 2000; Joeckel et al., 2005). Throughout this area, these facies preserve the landward record of a major mid-Cretaceous eustatic flooding of the North American craton, for the first time connecting the Boreal and Tethyan realms of the Cretaceous foreland basin system as a continuous north-south Western Interior Seaway. The rocks in question preserve the sedimentary record of extensive estuaries along the eastern cratonic margin of the basin, with longitudinal dimensions of up to 400 km, ranging from Salina, Kansas, to around Des Moines, Iowa.

Following the original definition of the Longford Member of the Kiowa Formation of Franks (1979), Hamilton (1994) showed the northward facies transition between marine shales of the Kiowa Formation into the fluvial-estuarine facies of the Longford Member as occurring just to the south of Salina, Kansas, as shown in fig. 1. The cutbank exposures along the Solomon River at this stop were described by Hamilton (1989, p. 154), who noted the presence of pyritic carbonaceous mudstones interbedded with laminated to ripple-laminated siltstones and very fine grained sandstones, with ichnologic features identified as *Planolites*, *Skolithos*, and *Diplocraterion* (fig. 2). These strata generally preserve primary sedimentary structures, although burrowing fabrics are prominently represented. Fig. 3a shows a photomosaic panorama of one of the cutbank exposures, with Joeckel for scale to the upper left. Fig. 3b shows a macrophoto of *Diplocraterion* from the upper part of the uppermost fine-grained sandstone in the Kiowa Formation (fig. 2).

Our visit to this site today is on the private property of the Romm family, and we are grateful for this opportunity to visit some truly exceptional exposures of these strata.

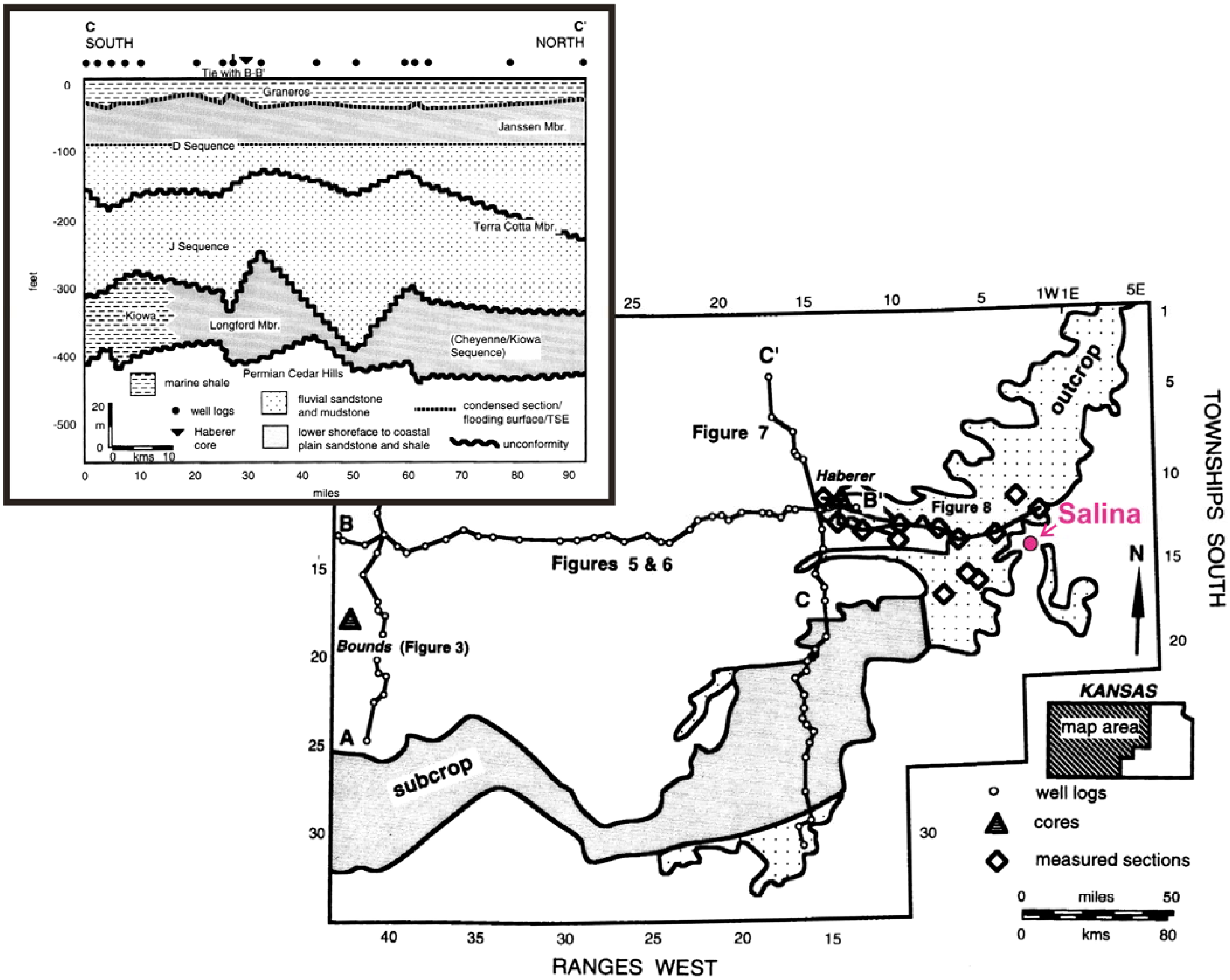

Figure 1. Outcrop and subcrop map of Albian–Cenomanian stratigraphic units in Kansas, with locations of stratigraphic cross sections B-B’ and C-C’. STOP 1 is the measured section located immediately to the NNE of Salina. Stratigraphic cross section C-C’ shows the lateral facies transition from Kiowa marine shales to the fluvial-estuarine Longford Member from south to north. Modified from graphics presented in Hamilton (1994).

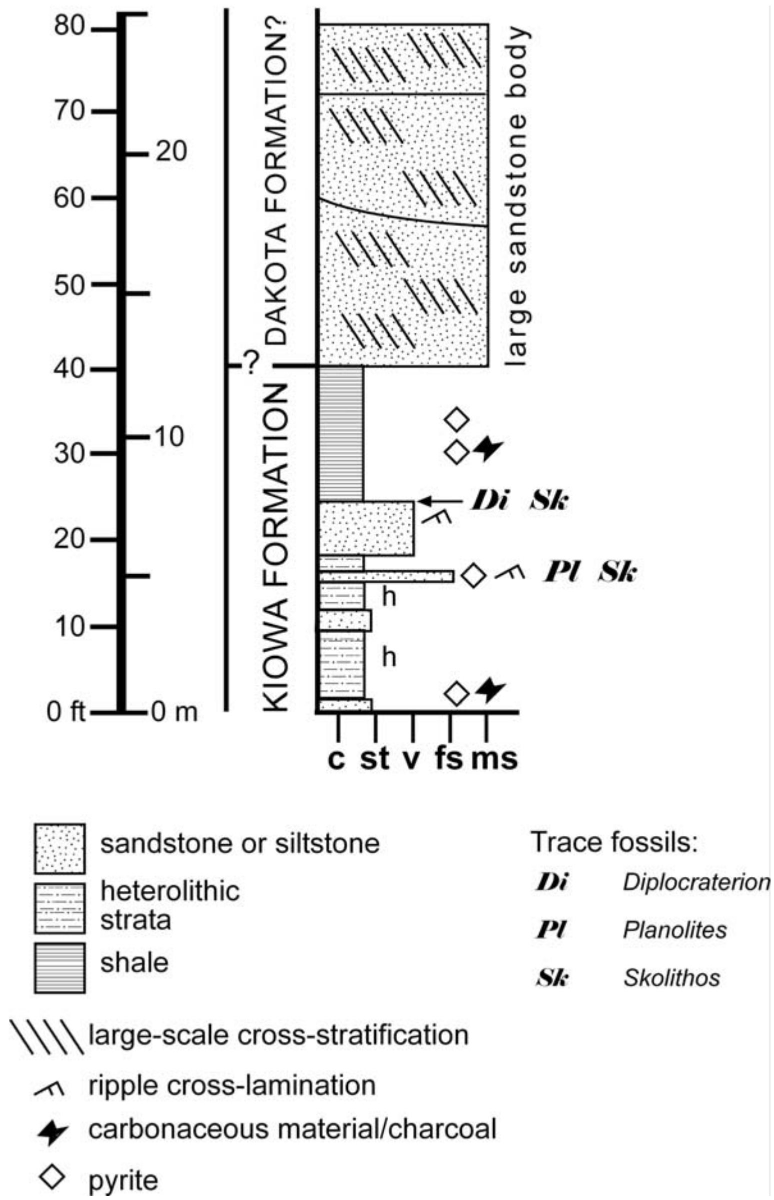

Figure 2. Graphic log of the Longford Member of the Kiowa Formation, overlain by fluvial sandstones, possibly of the Dakota Formation. Modified from a graphic in Hamilton (1989).

Figure 3a.

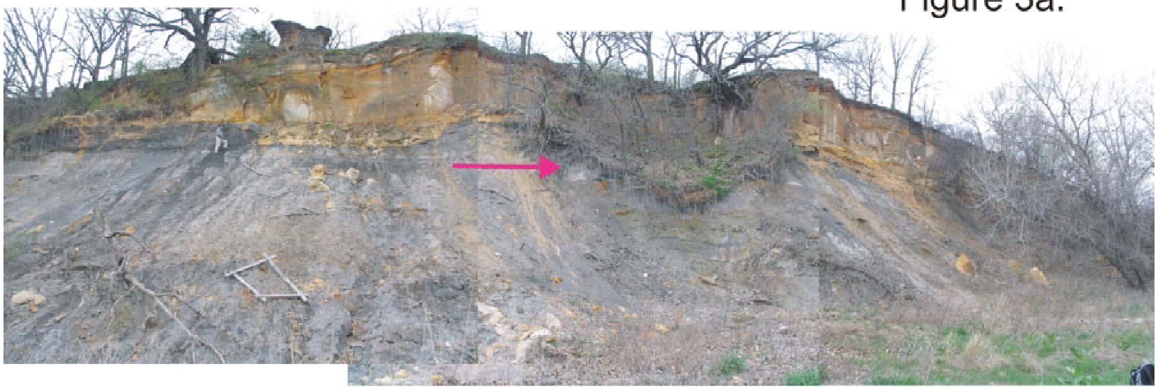

Figure 3b.

Figure 3. Field photographs of STOP 1. **a.** Photomosaic panorama looking southwest at the cutbank exposure along the south bluff line of the Solomon River valley. Note geologist Joeckel for scale to the upper left. Sandstone bed labeled by red arrow contains prominent burrow fabrics. **b.** Macro-photograph of probable *Diplocraterion* burrow from the position of the red arrow in fig 3a. Penny for scale.

References

Brenner, R. L., Ludvigson, G. A., Witzke, B. J., Zawistoski, A. N., Kvale, E. P., Ravn, R. L., and Joeckel, R. M, 2000, Late Albian Kiowa–Skull Creek marine transgression, lower Dakota Formation, eastern margin of Western Interior Seaway, U.S.A.: Journal of Sedimentary Research, v. 70, section B, no. 4, p. 868–878.

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Formation (Cretaceous, Albian), eastern Nebraska, USA; *in,* Fluvial Sedimentology VII, M. D. Blum, S. Marriott, and S. Leclair, eds.: Blackwell Publishing, Oxford, International Association of Sedimentologists, Special Publication No. 35, p. 453–480.
Witzke, B. J., and Ludvigson, G. A., 1998, Cretaceous bedrock geology in the Springbrook area; *in,* The Natural History of Springbrook State Recreation Area, Guthrie County, Iowa, R. R. Anderson and B. J. Bunker, eds.: Geological Society of Iowa, Guidebook 66, p. 13–19. (http://www.igsb.uiowa.edu/gsipubs/pdf/GB66.pdf)

147.0	Return to vans and proceed on N 180th Road and Coronado Road
149.0	Intersection of Coronado Road and N 170th Road; turn and proceed N on N 170th Road
150.0	Cross Solomon River
151.0	Turn R (E) on K-18 and proceed E on K-18
152.0	Cross RR tracks in Bennington, Kansas
157.0	Cross N 230th Road
159.0	Sign for Niles, Kansas (to S)
164.0	Cross Dickinson County, Kansas, county line
166.0	Turn L (N) from K-18 onto Camp Road (becomes Cherokee Road to N); proceed N on Camp Road
170.0	Sign for Manchester, Kansas
173.0	Cross Clay County, Kansas, county line
175.0	Intersection with Road 829 into Longford, Kansas; proceed N on Cherokee Road
176.0	Intersection with Road 422; proceed N on Cherokee Road
177.0–178.0	**STOP 2**

STOP 2. The Type Longford Member of the Upper Albian Kiowa Formation, Longford, Kansas.

Franks (1979), in an historically important contribution, designated these roadcut exposures along what is now Cherokee Road to the north of the town of Longford as the type section of the Longford Member of the Kiowa Formation (fig. 4). Franks proposed that these Cretaceous strata, unconformably resting on Permian units, correlate to the marine shales of the Kiowa Formation. The Kiowa Formation contains the Upper Albian index fossil *Inoceramus comancheanus* (Scott, 1970), indicating an age ranging from 102.8 Ma to about 101 Ma (Kauffman et al., 1993).

Franks—Paralic to Fluvial Record of an Early Cretaceous Marine Transgression 51

APPENDIX B

DESCRIPTIONS OF MEASURED SECTIONS

1. Type section for Longford Member, Kiowa Formation, measured from creek bottom about 0.25 mile south cen. W line sec. 9, T.10S., R.1E. (about 200 ft south of bridge) to top of roadcut about 0.15 mile north SW cor. sec. 9, T.10S., R1E., Clay County, Kansas. Measured by Paul C. Franks.

Longford Member, Kiowa Formation:	Thickness (feet)	(meters)
Top of hill.		
19. Siltstone, very light brownish-gray; weathers pinkish gray to pale yellowish orange. Thin wavy laminae and even laminae weathering to sets 0.1 to 0.5 ft thick. Contains sparse mica flakes; sparse limonitic stain; sparse pyrite nodules. Abundant concretionary masses of calcite cement as much as 5 ft thick and 10 ft long near top; concretions stand out in relief and hold abundant disseminated pyrite. Abundant carbon as flecks and films. Grades sharply into next below ...... Exposed,	8.8	2.67
18. Siltstone, light-gray to light brownish-gray; weathers very pale orange to grayish orange. Indistinct thin wavy and thin even laminae; abundant carbon flecks, films, and fragments on bedding surfaces; sparse mica flakes; carbonized wood commonly replaced by pyrite; argillaceous. Grades into next below	3.7	1.13
17. Siltstone, pale grayish-orange. Bedding largely masked by limonitic stain; chalky texture, but hard and weathers to form prominent ledge. Irregularly distributed calcite cement; basal bed 0.1 to 0.2 ft thick and cemented by calcite stands out in relief	4.5	1.37
16. Siltstone, very light gray; sparse grayish-orange "limonite" stain along bedding surfaces; weathers yellowish gray to very pale orange. Thin indistinct wavy laminae; weathers to beds 0.1 to 1. ft thick. Hard, but does not stand out in relief. Sparse interstitial clay. Scour-fill contact with next below	3.1	0.95
15. Shale, medium-gray to medium light-gray; sparse limonitic stain; weathers very light gray to yellowish gray. Kaolinitic but contains some smectite. Thin-laminated to laminated; poor fissility; silty. Thickens southward into carbonaceous, silty mudstone. Grades sharply into next below	0.7	0.21
14. Siltstone, light-gray; weathers yellowish gray. Bedding indistinct; abundant interstitial clay, sparse mica flakes ...... Exposed,	2.9	0.88
Covered interval	7.9	2.40
13. Siltstone, light-gray to very light gray; weathers very light gray to yellowish orange and yellowish gray. Thin-laminated and ripple laminated; bedding inclined 5 or 6° north. Variable amounts of interstitial clay; where interstitial clay is abundant, contains contorted pods of less argillaceous siltstone measuring 1 cm thick and up to 3 cm long. Carbon as leaf and stem imprints on bedding planes locally abundant; local calcareous cement forms discoidal concretions as much as 0.2 ft thick; concretions contain scattered pyrite nodules	14.5	4.40
12. Sandstone and siltstone, light-gray to very light gray; abundant yellowish-orange limonitic stain. Very fine grained to silt-sized; friable; sparse interstitial clay; sparse grains of pink quartzite and flakes of mica. No obvious bedding. Grades sharply into next below	1.3	0.40
11. Sandstone, very light gray; mainly weathered dark yellowish orange to light brown and dusky brown; abundant limonitic and manganese-oxide stain. Fine- to coarse-grained; mainly medium-grained; thin-bedded to wavy laminated; contains sparse medium gray mudstone seams and pellets; sparse interstitial clay; abundant pyrite nodules; friable. Scour-fill contact with next below	4.0	1.22
10. Mudstone, light-gray with brownish overtones grading down to light brownish-gray. Dominantly kaolinitic but contains some smectite and sparse chloritic or vermiculitic mixed-layer clay. Abundant limonitic stain on fracture surfaces in siltiest parts; conchoidal fracture in upper parts; blocky fracture in lower parts. Sparse light-gray siltstone laminae near base. Bedding mainly indistinct. Grades into next below	4.6	1.40
9. Mudstone, very light gray to light yellowish-gray; abundant purplish-red to moderate reddish-brown mottles. Dominantly kaolinitic but contains sparse illite, smectite, and chloritic or vermiculitic mixed-layer clay. Plastic; blocky fracture. Grades sharply into next below	4.8	1.46
8. Siltstone, light-gray to very light gray with brown overtones. Bedding not obvious; locally calcareous; carbon fragments towards base; abundant limonitic stain. Grades into next below	1.7	0.52
7. Mudstone, light-gray with brown overtones and moderate reddish-brown to reddish-brown mottles. Largely kaolinitic but contains smectite and perhaps mixed-layer vermiculite-smectite. Less silty toward base; abundant carbon fragments in basal 1 to 2 ft. Grades sharply into next below	11.1	3.36
6. Lignitic shale, pale brown. Thin wavy laminae; abundant carbon as flecks, films, and carbonized wood fragments; abundant jarosite stain. Grades laterally into mudstone containing isolated fragments of carbonized wood. Grades sharply into next below	0.5	0.15
5. Siltstone grading down to mudstone. Light-gray grading down to light-gray with reddish-brown mottles. Clay fraction composed mainly of smectite and illite. Abundant grayish-yellow to yellowish-orange limonitic stain in upper 1 ft. Blocky to conchoidal fracture	12.2	3.71
4. Mudstone, light-gray grading down to light brownish-gray. Clay fraction composed mainly of illite and smectite but contains sparse kaolinite and perhaps chlorite or vermiculite. Very silty towards base; bedding indistinct; blocky fracture; abundant carbon in basal 3 ft as flecks, films, fragments, and imprints of stems and leaves; abundant jarosite stain on randomly oriented fractures	8.8	2.67
3. Mudstone, medium-gray with brown overtones and sparse moderate-red mottles; abundant "limonite" and jarosite stain along fracture surfaces. Clay fraction composed almost completely of smectite but contains sparse illite and vermiculite or chlorite. Nonplastic, blocky fracture; sparse carbon flecks, films, and imprints of plant debris. Base Longford Member, Kiowa Formation ..	3.0	0.91
Total thickness Longford Member, Kiowa Formation, measured	98.1	29.91
Unconformity.		
Wellington Formation:		
2. Mudstone, reddish-brown. Thin-laminated to laminated but poor fissility; blocky fracture. Clay fraction composed mainly of illite but contains appreciable smectite and chlorite. Scattered laminae bleached yellowish-gray in top 0.5 ft. Abundant limonitic or hematitic cement in top 0.5 ft. Grades sharply into next below	3.4	1.03
1. Mudstone, light-gray to moderate greenish-gray; weathers dusky yellow. Thin-laminated but poor fissility; blocky fracture. Clay fraction composed mainly of illite but contains appreciable smectite and chlorite. Base covered ...... Exposed,	1.5	0.46
Total thickness Wellington Formation measured	4.9	1.49

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Note: The Permian-Cretaceous contact and the base of the Longford Member, Kiowa Formation, also are exposed in a gully near cen. W ½ NW ¼ sec. 16, T.10S., R.1E. where the Permian-Cretaceous contact is about 18 ft higher than in the section described above. The contact corresponds approximately to the middle of unit 5. The topmost Permian mudstone is intensely weathered and variegated. It contains abundant kaolinite, illite, and smectite as well as minor amounts of chloritic or vermiculitic mixed-layer clay, and is overlain by a carbonaceous mudstone and lignitic sequence as well as by gray mudstone showing abundant red mottles similar to material described under unit 7 above. Sparse chert and quartzite pebbles weather out of the basal carbonaceous Longford mudstone.

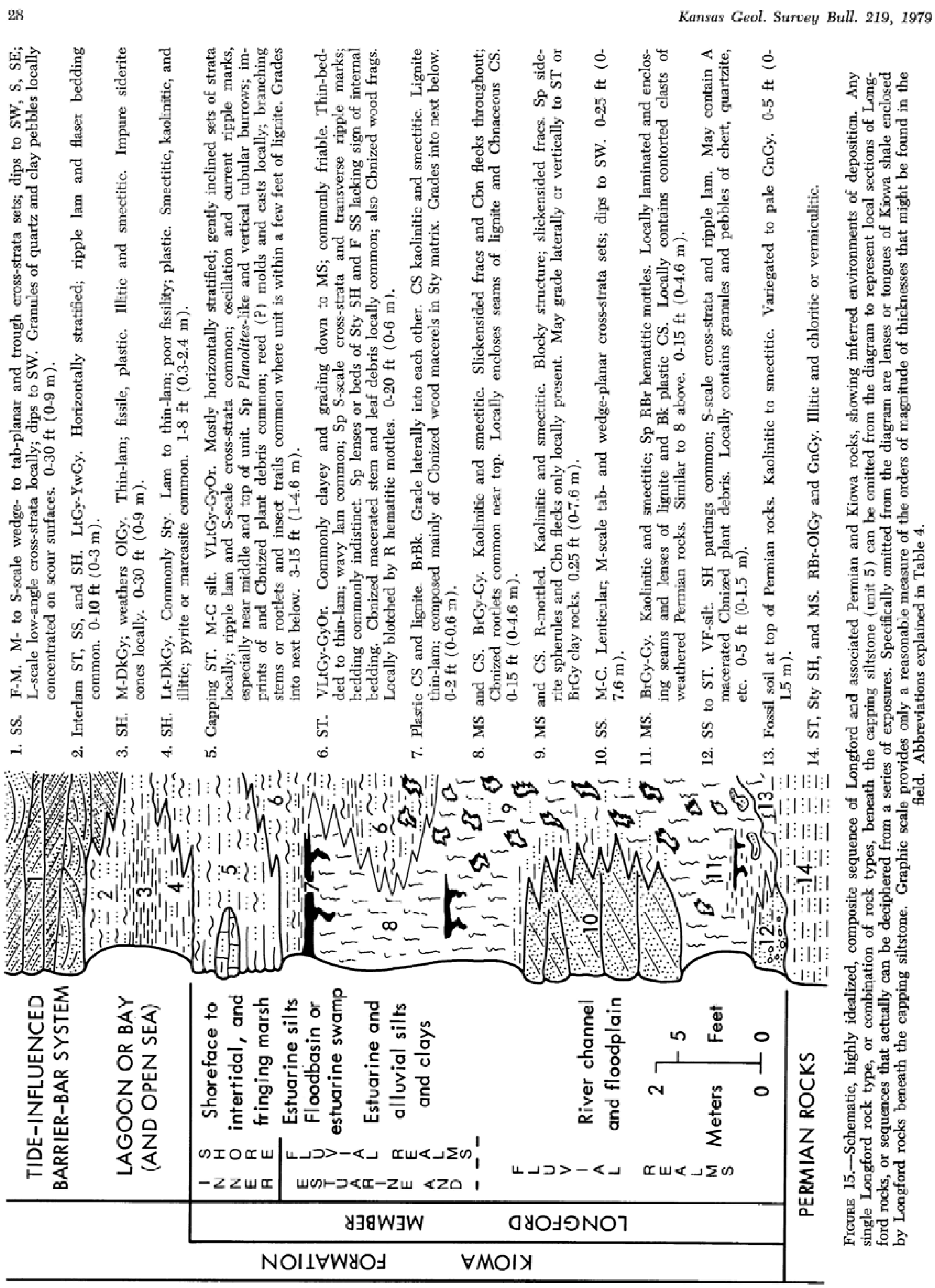
Figure 4. Copy of the described type section of the Longford Member by Franks (1979).

Franks (1979) made a number of prescient observations on the rock succession in the Longford Member (fig. 5). He presented macromorphologic and micromorphologic observations on the mudrock facies in the Longford Member, lines of evidence that are now confidently recognized as arguing for the development of ancient pedogenic processes during the aggradation of a succession of nonmarine paleosols. He also recognized that fluviatile siltstone-shale facies in the Longford Member contained subtle sedimentologic evidence for tidal modulation and proposed that the unit accumulated in an estuarine paleoenvironment. The sedimentologic observations and interpretations of Franks (1979) were prescient in that they anticipated what have since become mainstream sedimentary approaches to interpreting fluvial-estuarine facies.

One flaw in the synthesis of Franks (1979) on the Longford Member was his proposal that the unit is confined to a small area of northern Kansas, where he interpreted the Longford to have been erosionally truncated and beveled northward by overlying units of the Dakota Formation. In truth, the facies associations of the Longford Member are duplicated many times in the regional Albian–Cenomanian succession, and the proposed unconformity in northern Kansas has not been supported by paleontologic or other lines of time-stratigraphic evidence. Temporal and paleoenvironmental correlates to the fluvial-estuarine Longford Member are now widely recognized to the north and east of Kansas in Nebraska (Brenner et al., 2000; Joeckel et al., 2005) and Iowa (Witzke and Ludvigson, 1998; Brenner et al., 2000). In point of fact, we are now standing at the singular place where a regionally extensive sheet of Upper Albian fluvial-estuarine deposits on the eastern margin of the Western Interior Seaway was first recognized. These deposits accumulated during the Albian Kiowa–Skull Creek marine transgression, as landward-stepping fluvial depositional systems were ponded by rising sea level.

The hard-cemented siltstone bed exposed below our field-trip stop staging area is probably bed 13 in the measured section of Franks (1979; fig. 4). In thin section view, the cemented siltstone preserves a high intergranular volume (~ 40 %) filled by a poikilotopic calcite cement (fig. 6). As noted by Phillips et al. (2007), this relationship suggests that calcite cementation was an authigenic process that preceded the compactive collapse of pore space under burial conditions. This indicates that the rock is an excellent candidate for exploring the stable-isotope paleohydrology of the Kiowa estuarine system in northern Kansas.

From this point, we are driving northward to an outstanding field area of extensive Cretaceous exposures along the Rose Creek escarpment in Jefferson County, Nebraska. Just to the north of the Kansas–Nebraska border along Highway 15, the escarpment is capped by pelagic chalks of the Turonian Greenhorn Limestone (fig. 7; we extend our sincere appreciation to our colleague Brian Witzke for his permission to include this previously unpublished graphic). Fluvial-estuarine facies of the Kiowa–Skull Creek marine cycle are well exposed in Jefferson County, Nebraska (see section CJ near the bottom of fig. 7) but are challenging to reach by off-road access. We will visit two sections in Jefferson County, the world-famous Rose Creek Pit (fig. 7), straddling the D_2 sequence boundary (Brenner et al., 2000) between the latest Albian Muddy Sequence and the base of the Cenomanian Greenhorn Sequence, and the Starr Pit (fig. 7), which exposes fluvial-estuarine cycles (parasequences) within the Muddy Cycle. A lateral correlate to a hard-cemented parasequence boundary preserving ornithopod dinosaur footprints in Jefferson County is exposed at the Starr Pit (Phillips et al., 2007), and we will examine this rock.



1. SS. F-M. M- to S-scale wedge- to tab-planar and trough cross-strata sets; dips to SW, S, SE; L-scale low-angle cross-strata locally; dips to SW. Granules of quartz and clay pebbles locally concentrated on scour surfaces. 0-30 ft (0-9 m).

2. Interlam ST, SS, and SH. LtGy-YwGy. Horizontally stratified; ripple lam and flaser bedding common. 0-10 ft (0-3 m).

3. SH. M-DkGy; weathers OlGy. Thin-lam; fissile, plastic. Illitic and smectitic. Impure siderite cones locally. 0-30 ft (0-9 m).

4. SH. Lt-DkGy. Commonly Sty. Lam to thin-lam; poor fissility; plastic. Smectitic, kaolinitic, and illitic; pyrite or marcasite common. 1-8 ft (0.3-2.4 m).

5. Capping ST. M-C silt. VLtGy-GyOr. Mostly horizontally stratified; gently inclined sets of strata locally; ripple lam and S-scale cross-strata common; oscillation and current ripple marks, especially near middle and top of unit. Sp *Planolites*-like and vertical tubular burrows; imprints of and Cbnized plant debris common; reed (?) molds and casts locally; branching stems or rootlets and insect trails common where unit is within a few feet of lignite. Grades into next below. 3-15 ft (1-4.6 m).

6. ST. VLtGy-GyOr. Commonly clayey and grading down to MS; commonly friable. Thin-bedded to thin-lam; wavy lam common; Sp S-scale cross-strata and transverse ripple marks; bedding commonly indistinct. Sp lenses or beds of Sty SH and F SS lacking sign of internal bedding. Cbnized macerated stem and leaf debris locally common; also Cbnized wood frags. Locally blotched by R hematitic mottles. 0-20 ft (0-6 m).

7. Plastic CS and lignite. BrBk. Grade laterally into each other. CS kaolinitic and smectitic. Lignite thin-lam; composed mainly of Cbnized wood macerels in Sty matrix. Grades into next below. 0-2 ft (0-0.6 m).

8. MS and CS. BrGy-Gy. Kaolinitic and smectitic. Slickensided fracs and Cbn flecks throughout; Cbnized rootlets common near top. Locally encloses seams of lignite and Cbnaceous CS. 0-15 ft (0-4.6 m).

9. MS and CS. R-mottled. Kaolinitic and smectitic. Blocky structure; slickensided fracs. Sp siderite spherules and Cbn flecks only locally present. May grade laterally or vertically to ST or BrGy clay rocks. 0.25 ft (0-7.6 m).

10. SS. M-C. Lenticular; M-scale tab- and wedge-planar cross-strata sets; dips to SW. 0-25 ft (0-7.6 m).

11. MS. BrGy-Gy. Kaolinitic and smectitic; Sp RBr hematitic mottles. Locally laminated and enclosing seams and lenses of lignite and Bk plastic CS. Locally contains contorted clasts of weathered Permian rocks. Similar to 8 above. 0-15 ft (0-4.6 m).

12. SS to ST. VF-silt. SH partings common; S-scale cross-strata and ripple lam. May contain A macerated Cbnized plant debris. Locally contains granules and pebbles of chert, quartzite, etc. 0-5 ft (0-1.5 m).

13. Fossil soil at top of Permian rocks. Kaolinitic to smectitic. Variegated to pale GnGy. 0-5 ft (0-1.5 m).

14. ST, Sty SH, and MS. RBr-OlGy and GnGy. Illitic and chloritic or vermiculitic.

FIGURE 15.—Schematic, highly idealized, composite sequence of Longford and associated Permian and Kiowa rocks, showing inferred environments of deposition. Any single Longford rock type, or combination of rock types, beneath the capping siltstone (unit 5) can be omitted from the diagram to represent local sections of Longford rocks, or sequences that actually can be deciphered from a series of exposures. Specifically omitted from the diagram are lenses or tongues of Kiowa shale enclosed by Longford rocks beneath the capping siltstone. Graphic scale provides only a reasonable measure of the orders of magnitude of thicknesses that might be found in the field. Abbreviations explained in Table 4.

Figure 5. Copy of a schematic illustration of the type Longford Member from Franks (1979).

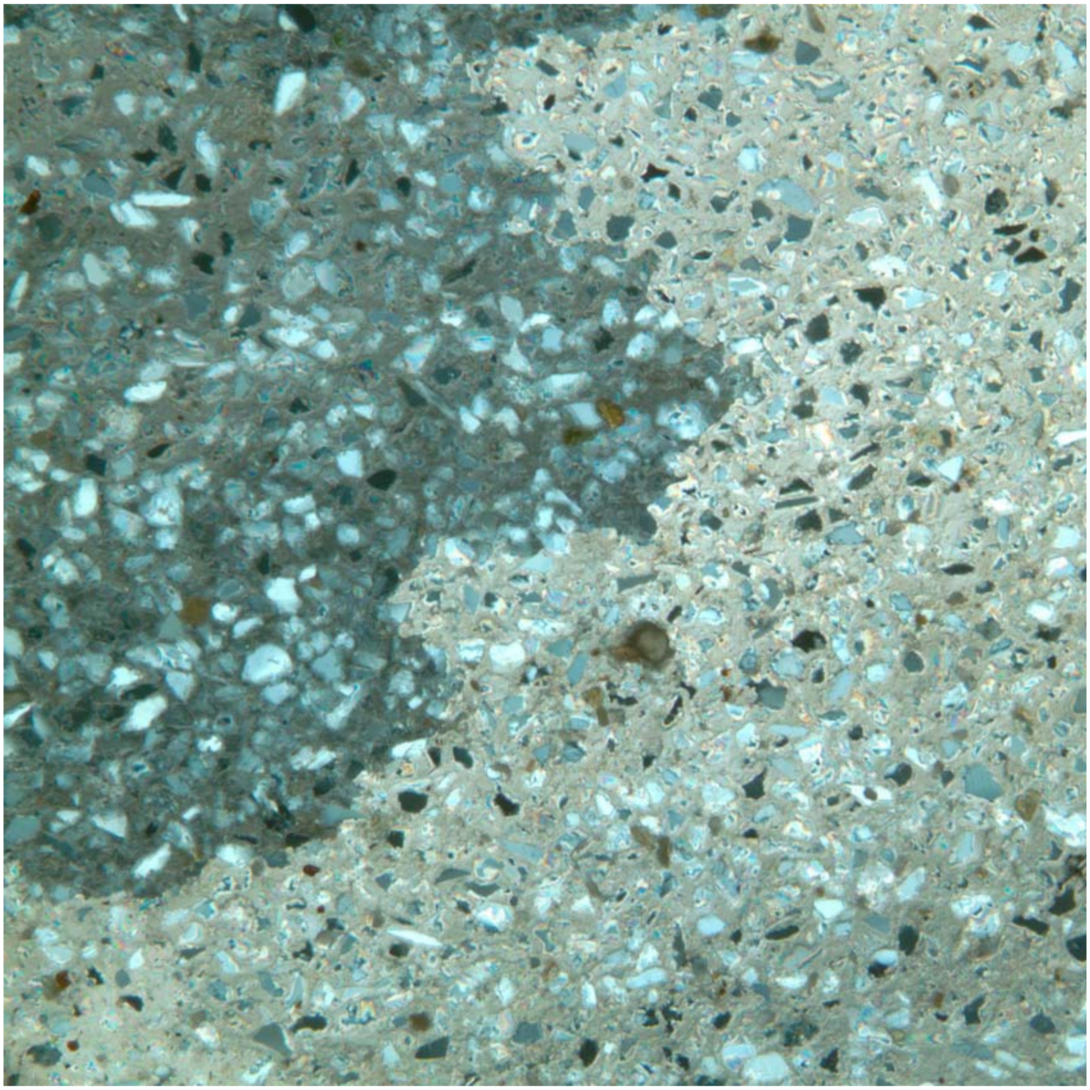


Figure 6. Thin-section photomicrograph of calcite-cemented siltstone bed from the Longford Member at its type section, probably from bed 13 in fig. 4. Intergranular pores in the siltstone are filled by a poikilotopic spar with optically continuous domains several millimeters in diameter. The micrograph shows the irregular boundary between two optical domains, with the domain to the upper left in extinction. Note that the calcite spar occludes about 40% intergranular volume, suggesting cementation by syndepositional authigenesis. Cross-polarized light, field of view is 1.25 mm.

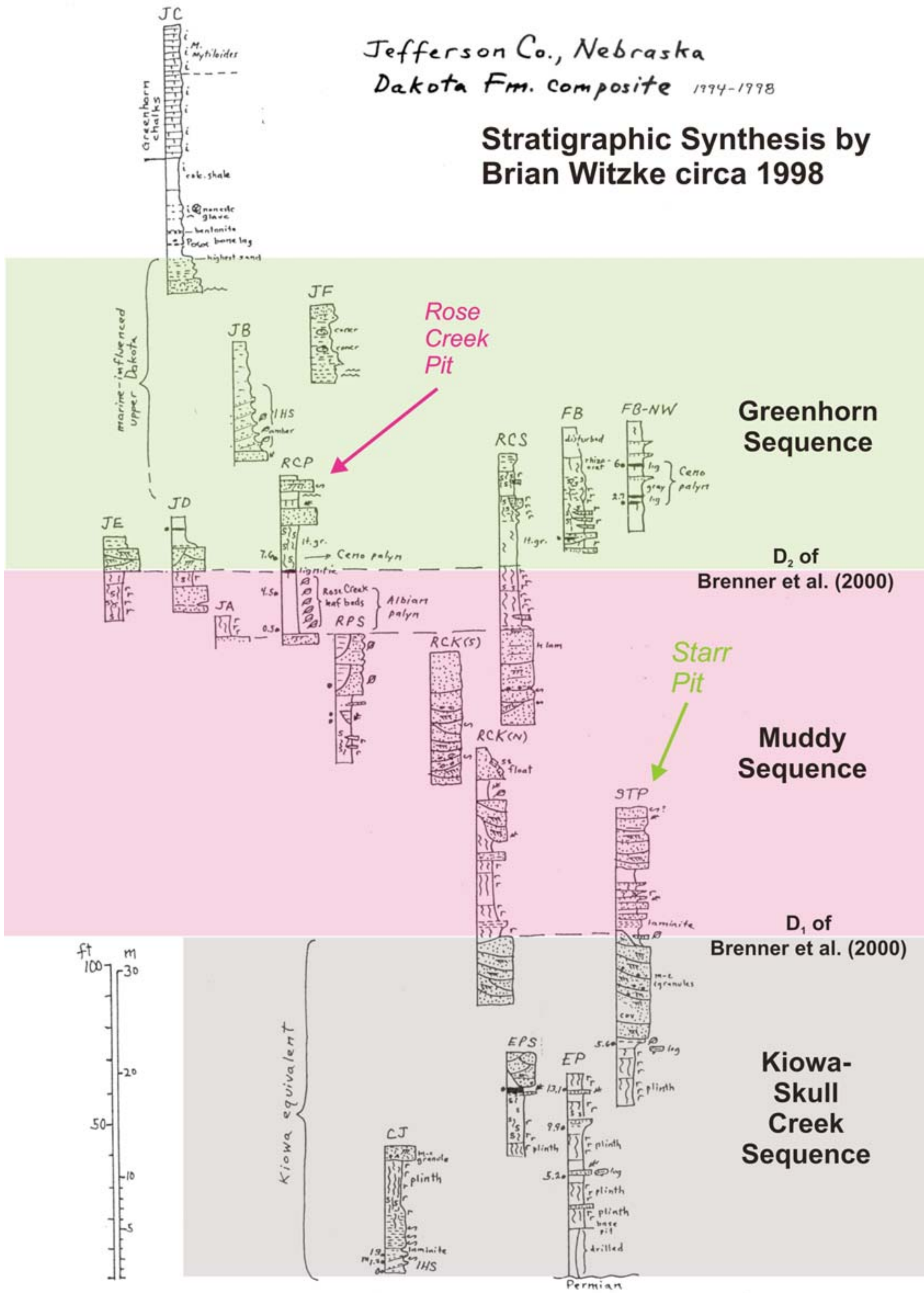


Figure 7. Composite stratigraphic section of the Cretaceous succession exposed along the Rose Creek escarpment in Jefferson County, Nebraska. This synthesis was compiled by Iowa Geological Survey geologist Brian Witzke in 1998, and has served as the foundation for a number of subsequent peer-reviewed published works.

Just to the south of the Rose Creek escarpment in northernmost Washington County, Kansas, the KGS #1 Gaydusek drillcore (see paper by Macfarlane elsewhere in this guidebook) preserves a complete record of the Cretaceous succession from the Greenhorn Limestone downward into underlying Permian strata (fig. 8). We invite you to compare the composite section from the Rose Creek escarpment (fig. 7) with the graphic log of the #1 Gaydusek core, and to comment on this comparison with us. Heterolithic strata from the 110-m to 140-m levels in the #1 Gaydusek drillcore (fig. 8) are probably tidally modulated fluvial-estuarine units that correlate to the Kiowa–Skull Creek Sequence, parceled into stacked parasequences of about 3–4 m in thickness.

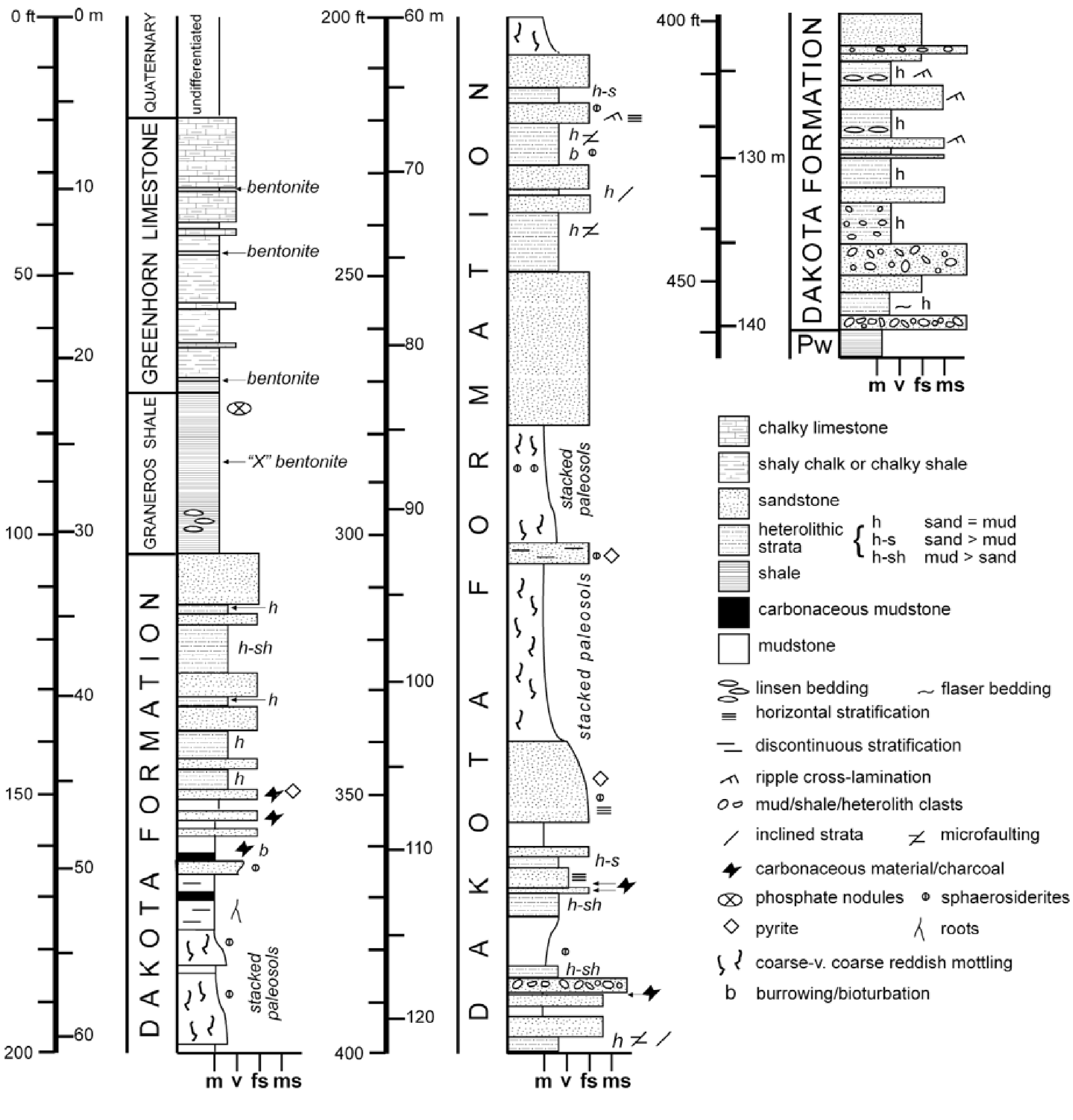


Figure 8. Graphic log of the KGS #1 Gaydusek drillcore in northern Washington County, Kansas. This core site is located just to the south of the Rose Creek escarpment.

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Brenner, R. L., Ludvigson, G. A., Witzke, B. J., Zawistoski, A. N., Kvale, E. P., Ravn, R. L., and Joeckel, R. M, 2000, Late Albian Kiowa–Skull Creek marine transgression, lower Dakota Formation, eastern margin of Western Interior Seaway, U.S.A.: Journal of Sedimentary Research, v. 70, section B, no. 4, p. 868–878.

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178.0	Return to vans and proceed N on Cherokee Road
178.5	Cross RR tracks
183.0	Turn R (E) from Cherokee Road onto 9th Road (Road 404) and proceed E
187.0	Large-scale cross stratified Dakota Formation sandstones in roadcut
187.5	Pass blue RWD #2 water tower
194.0	Turn L (N) from Road 404 onto Highway 15 and proceed N on Highway 15
203.0	Pass Deli-Stop in Clay Center, Kansas
235.0	Intersection of Highway 15 and Highway 36 at Washington, Kansas; turn L (W) and proceed W on Highway 15/36
241.0	Turn L (N) from Highway 15/36 and proceed N on Highway 15

255.0	Cross Kansas–Nebraska state line
256.0	Large, overgrown exposure of uppermost Dakota Formation, Graneros Shale (and "X"-bentonite), and Greenhorn Limestone
259.0	**STOP 3**

STOP 3. Rose Creek Pit, formerly mined by Endicott Clay Products (Endicott, Nebraska), south of Fairbury, Nebraska, on Highway 15.

The Rose Creek Pit, where low-chroma clays were once mined for specialty bricks, has long been recognized as a paleobotanical site of worldwide significance. It has yielded some of the oldest fossil flowers (Basinger and Dilcher, 1984; Upchurch and Dilcher, 1990). Well-preserved angiosperm cuticle is common at the site, and amber, wood, gymnosperm shoots, cones, and fossil ferns have also been found here and in the immediate vicinity.

Despite the discovery of important angiosperm fossils at the site over 35 years ago, the sequence-stratigraphic and geochronologic significance of Rose Creek Pit relative to global $\delta^{13}C$ chemostratigraphy has only recently been revealed. Together, the stratigraphic and paleobotanical attributes of the site give it particular importance.

Brenner et al. (2000) established sequence boundaries in the Dakota Formation using litho- and palynostratigraphic data from the Rose Creek Pit and from other exposures in Jefferson County, Nebraska, and northeastward across Nebraska and Iowa. These authors established the stratigraphic location of the Albian–Cenomanian boundary in the Dakota Formation at multiple sites on the eastern margin of the Western Interior Seaway, including Rose Creek Pit (see fig. 7). This work set the stage for the construction of a finely resolved plant-carbon $\delta^{13}C$ chemostratigraphy of the site through a 10–15-m stratigraphic section that includes the Albian–Cenomanian boundary (fig. 9; Gröcke et al., 2006). Late Albian strata at the site show a ~3‰ negative excursion in $\delta^{13}C$, but the overlying Cenomanian strata have background $\delta^{13}C$ values of -24‰ to -23‰ (fig. 10). The positive $\delta^{13}C$ excursion found at the Albian–Cenomanian boundary in more complete marine sedimentary records, however, is absent at Rose Creek Pit. This conspicuous absence suggests a depositional hiatus of some 0.5 m.y. at the site, an interval that can be readily associated with both a regional sequence boundary (D_2) identified by Brenner et al. (2000) and a major global regressive phase that occurred at the Albian–Cenomanian boundary.

Landowners Richard and Kitty DeBoer have graciously allowed us to continue our work at the site and to visit it today as part of our field trip.

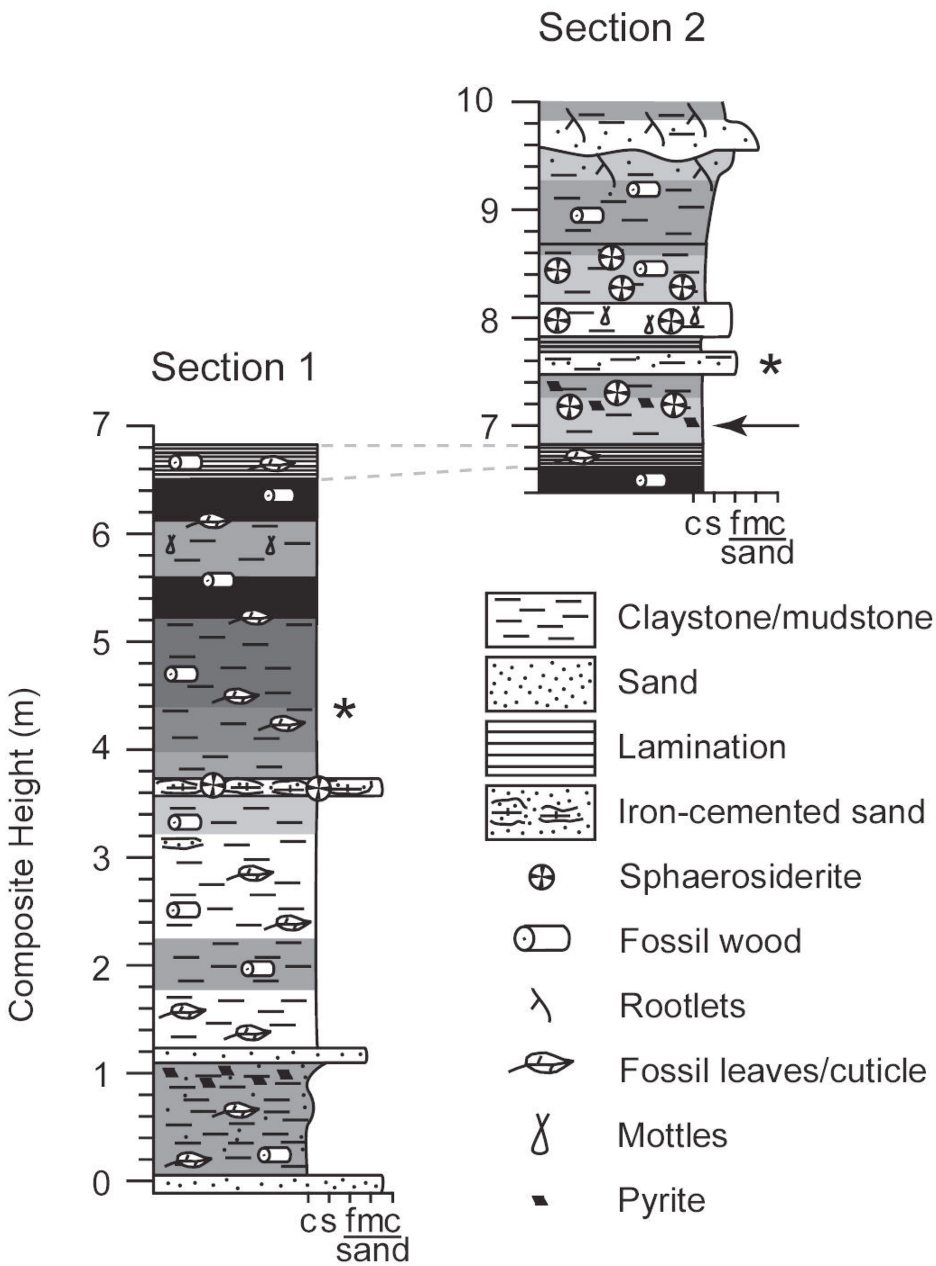

Figure 9. Graphic log of two overlapping stratigraphic sections from the Rose Creek Pit measured and sampled for organic carbon isotopes in 2002. Asterisks denote the positions of two productive palynostratigraphic samples taken in 1996. The lower sample produced the definitive Upper Albian spores *Disaltriangulisporites perplexus* and *Podocarpidites multesimus*, while the upper sample produced definitive Lower Cenomanian forms *Foveogleicheniidites confossus* and *Artiopollis indivisus* (identifications by R. L. Ravn). The arrow to the right of Section 2 identifies the position of the Albian–Cenomanian D_2 sequence boundary of Brenner et al. (2000), as identified by the carbon isotope profiling of Gröcke et al. (2006). Graphic reproduced from Gröcke et al. (2006).

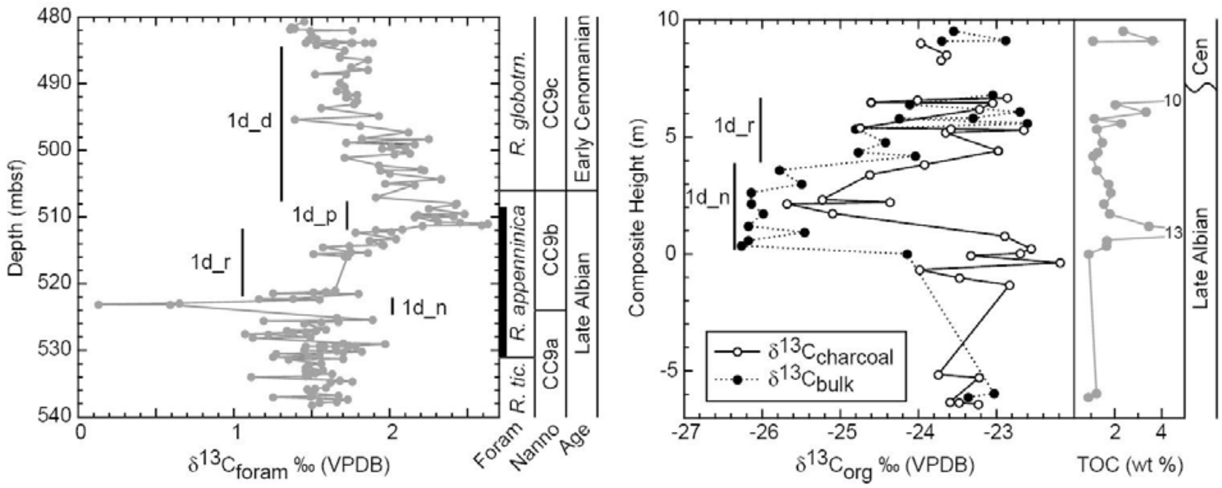

Figure 10. Carbon isotope profiles from the ODP Site 1052 at Blake Nose (left) and the Rose Creek Pit (right). Of special note in the Blake Nose record is the Late Albian abrupt negative $\delta^{13}C$ excursion segment (1d_n), followed upward by the 1d_r (rise), 1d_p (positive excursion), and 1d_d (decline). The missing 1d_p segment at the Rose Creek Pit section was used by Gröcke et al. (2006) to estimate the duration of the D_2 sequence boundary at this site. Graphic reproduced from Gröcke et al. (2006).

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259.0	Return to vans and proceed N on Highway 15
260.0	Cross Rose Creek
263.0	Cross Little Blue River
264.0	Intersection of Highway 15 and Highway 8 at southern edge of Fairbury, Nebraska; turn R (E on Highway 8) and proceed E

269.0 Endicott, Nebraska; Endicott Clay Products brick and tile plant and pit to S across Little Blue River

272.0 Turn L (N) on drive into Starr property; **STOP 4**

STOP 4. Sand pit on Starr property north of Highway 8 near Steele City, Nebraska.

The pit excavated in friable Dakota Formation sandstones at this site preserves approximately 25 m of strata dominated by fluvial-estuarine cross stratified fine sandstones. Work in the Lincoln–Omaha area, some 100 km to the northeast, has demonstrated the existence of numerous Albian–Cenomanian paleovalleys cut into Pennsylvanian strata and filled with similar fluvial-estuarine facies (Joeckel et al., 2005).

Laminated carbonaceous mudrocks here at the Starr site contain fossil leaves, plant debris, and palynomorphs. Brenner et al. (2000), relying on palynostratigraphy to establish a chronostratigraphic framework, identified their Late Albian-aged sequence boundary D_1 in the middle of the upper part of the section here, at the upper surface of a thick succession of cross stratified sandstones and below a package of thinly bedded sandstones and mudrocks (see fig. 7). Sequence boundary D_1 separates the Kiowa–Skull Creek depositional cycle below from the Muddy depositional cycle above across the eastern margin of the Western Interior basin. Coarsely mottled paleosols developed in mudstones appear at the base of the section at the Starr site and, indeed, such paleosols are common in the lower levels of the exposed Dakota Formation along the Little Blue Valley from Fairbury, Nebraska, southeastward to Steele City, Nebraska, and even into western Gage County to the east. These kaolinitic mottled paleosols are mined for brick and tile production at the Endicott Clay Products Pit south of the Little Blue River from the nearby town of Endicott, Nebraska.

At the Starr site, a sandstone bed some 4 m above the D_1 sequence boundary almost certainly correlates with a dinosaur-track-bearing sandstone at an undisclosed locality a few kilometers south (fig. 11): the tracks at that site constitute the first fully documented dinosaur fossils of any kind from Nebraska (Joeckel et al., 2004). The track-bearing sandstone shows high minus-cement porosity (>47%), low grain-to-grain contacts (~2.5), and a complex cement history dominated by phreatic calcite precipitation (Phillips et al., 2007). Using isotopic records from coeval paleosol sphaerosiderites as a proxy for the composition of ancient ground-water recharge on the coastal plain, it has been determined that the track-bed cements record an early stage of cement precipitation from mixed fresh and brackish ground waters during a higher stand of sea level and a later stage of freshwater cementation representing ground waters recharged in a much larger catchment area during a subsequent fall in relative sea level (Phillips et al., 2007).

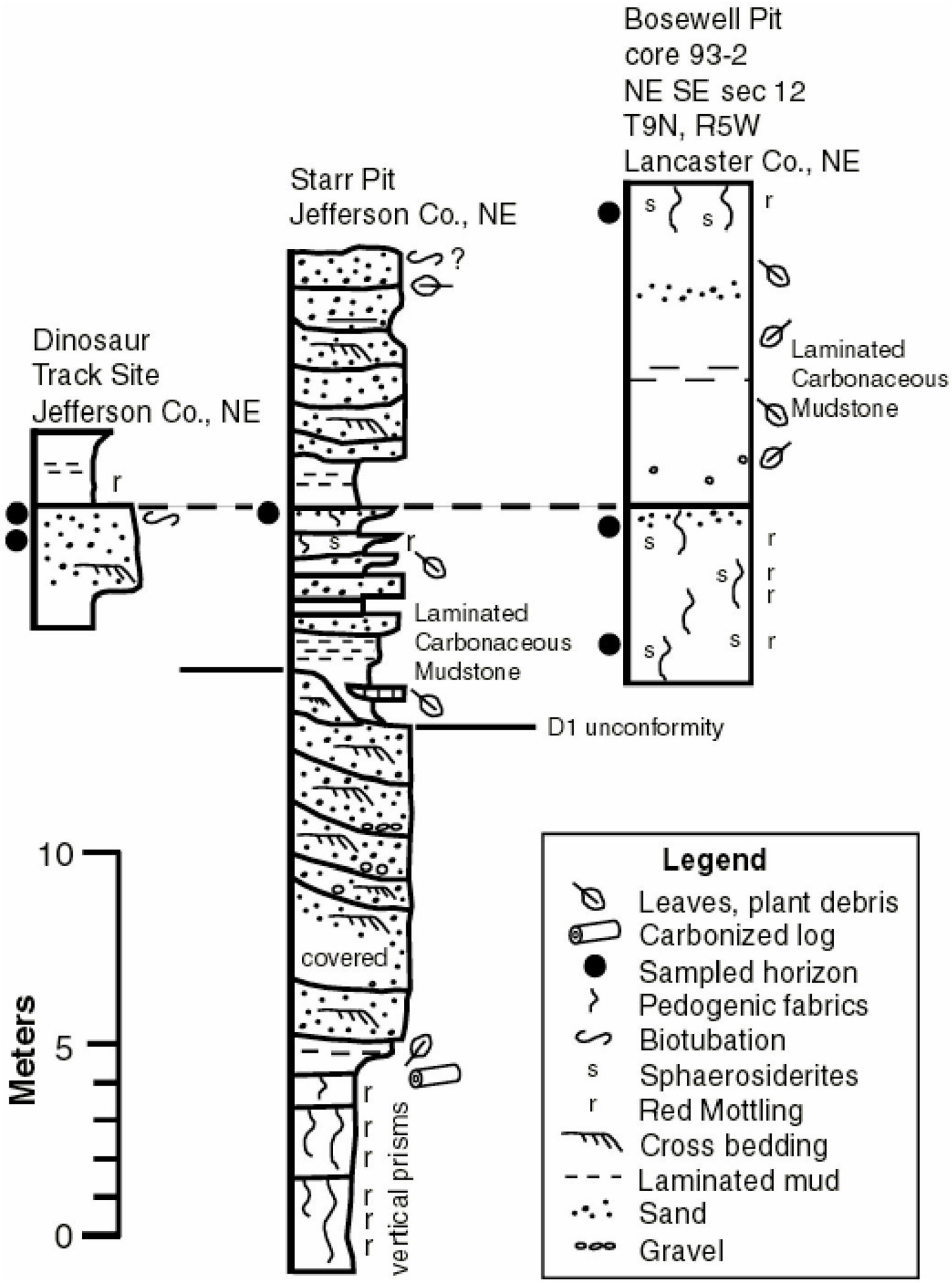

Figure 11. Graphic logs of stratigraphic sections from sites in Jefferson County and Lancaster County, Nebraska. All are contained within the Muddy Sequence of the Dakota Formation. The bold solid line adjacent to the Starr Pit section shows the D_1 Sequence boundary between the Kiowa–Skull Creek and Muddy Sequences, as proposed by Brenner et al. (2000). Features of special note are the sedimentary evidence for tidal modulation in the estuarine heterolithic strata and laminated carbonaceous mudstones above the D_1 unconformity, and the carbonate-cemented sandstone bed about 4 m above the D_1 surface that correlates to the dinosaur track bed of Joeckel et al. (2004). Graphic reproduced from Phillips et al. (2007).

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272.0	Return to vans and continue E on Highway 8.
275.0	Turn to Steele City, Nebraska; continue on Highway 8
287.0	Odell, Nebraska
290.0	Intersection of Highway 8 and Highway 112; continue E on Highway 8
294.0	Intersection of Highways 8 and 77; turn R (S) on Highway 77 and proceed S
309.0	Intersection of Highways 77 and 36; turn R (E) and proceed into Marysville, Kansas; dinner at Wagon Wheel restaurant by order, then return to vans and proceed E
314.0	Home City, Kansas
338.0	BP station in Seneca, Kansas
356.0	Intersection of Highways 77 and 75; turn R (S) onto Highway 75 and proceed S
382.0	Holton, Kansas
436.0	Topeka, Kansas; turn toward I-70
441.0	Kansas Turnpike/I-70 Toll Plaza; enter Kansas Turnpike/I-70 and proceed E

459.0 Kansas Turnpike/I-70 exit 202 (East Lawrence); exit and continue through McDonald Street S onto Iowa Street

463.0 Arrive at Kansas Geological Survey.
END OF TRIP

SUPPLEMENTAL PAPERS

Information Needs to Better Understand the Resource Potential of the Dakota Aquifer System

by
P. Allen Macfarlane
Kansas Geological Survey, University of Kansas, 1930 Constant Avenue, Lawrence, KS 66047-3724

Continuing interest in the natural-resources potential or sustainability of the Dakota aquifer arises primarily out of the water- and energy-resources needs and issues of the region (Russell, 1928; Jorgensen and Signor, 1981; Helgeson et al., 1993; Neuzil, 2002). Widespread use of the Dakota aquifer for water supply has been ongoing since before the turn of the 20th century in parts of the Great Plains (Darton, 1905). Russell (1928) expressed concern for the sustainability of the Dakota considering its heavy use for water supply. Since the late 1970's, interest has been expressed in using Dakota water resources to supplement or replace declining supplies in the High Plains aquifer (Keene and Bayne, 1977; Helgeson et al., 1982; Macfarlane, 1988). Concerns have also been raised about the impact of oil-brine disposal in shallow, saltwater-bearing aquifers on water quality in the overlying Dakota aquifer (Macfarlane, 1988). Garbarini and Veal (1968) discussed the potential for liquid-waste disposal in the subsurface of the Denver basin in eastern Colorado.

Energy resources of the Dakota have also been of interest since exploration began in the Denver and other intermontane basins in the late 1940's (Martin, 1965). The geologic and hydrodynamic control on hydrocarbon-reservoir distribution is unknown or poorly understood at many locations (see for example, Russell, 1961). Spurred on by the need to conserve nonrenewable sources of energy, regional and statewide studies (e.g., Sorey and Reed, 1984; Gosnold, 1984; Stavnes and Steeples, 1982) have been conducted to characterize the low-temperature geothermal resources of the Dakota aquifer. Guenther and Sharpe (1984) reported on a feasibility study to use geothermal resources from the Dakota aquifer to heat three building complexes in Scottsbluff, Nebraska.

To address these needs and issues requires a thorough understanding of the geologic framework, flow systems, and ground-water geochemistry of the Dakota aquifer, including its confining layers and interactions with other aquifers. In the early 1900's, hydrogeology as a field of study was in its infancy when Darton (1905) reported on his reconnaissance of the ground-water resources off the Great Plains region. With further exploration and scientific investigation of the aquifer, regional hydrogeology of the Dakota is now better understood conceptually. However, the extreme aquifer framework heterogeneity presents considerable challenges to the development of quantitative models that can be used for prediction of aquifer behavior under development with reasonable levels of confidence in the results. Thus, the Dakota continues to interest hydrogeologists as a research topic.

The Kansas Dakota Aquifer Program

In the late 1980s, State and local agencies recognized the localized depletion of the High Plains (Ogallala) aquifer and stream-aquifer systems in western and central Kansas and the need to identify other sources that might replenish available supplies. Little was known about either the quantity or the quality of ground water or the impact of regional or local development on the Dakota that could be used to guide regional or local planning. There were also concerns related to contamination by human activity, such as the potential hazards of disposing oil brine in shallow zones beneath the Dakota in central Kansas and the protection of usable ground-water resources in the Dakota from surface contamination by downward movement along the boreholes of improperly constructed wells. Kansas has had oil-well surface casing and cementing standards for protecting shallow fresh ground water since the 1960's.

In response, the Kansas Geological Survey began an eight-year research program into the hydrogeology and water quality of the Dakota in 1988. The goals of the program were to assess the water-resources potential of the Dakota aquifer and to assist the agencies in the development of appropriate management plans and policies. This program was unique because it was designed for proactive rather than reactive water-resources management of a regional aquifer system. The broad objectives of the program were to (1) characterize the geologic framework of the Dakota aquifer; (2) define the ground-water-flow system within the aquifer to identify sources of recharge, discharge, flow path, and areas of interaction with other aquifer systems; (3) assess the water quality of the Dakota aquifer; and (4) assess the impact of current and future development in the Dakota and interacting aquifer systems, including the impact of oil-field-brine disposal in the underlying Permian on the Dakota aquifer in the areas of aquifer interaction.

The study area investigated in the Dakota Aquifer Program includes the extent of the Dakota aquifer in Kansas and the adjacent areas of eastern Colorado (fig. 1). Eastern Colorado was included to establish regional continuity and a context for the portion of the aquifer in Kansas. During the course of the program, cores were collected from test holes to better understand the regional geologic framework of the Dakota. From this work, the stratigraphic units that form the aquifer were correlated with other units in eastern Colorado to the west and in southeastern Nebraska and western Iowa to the east. An analysis of the regional flow systems suggested an important recharge area for the Kansas Dakota aquifer in southeastern Colorado. This hypothesis was later supported using geochemical and tracer data developed in cooperation with the Lawrence Livermore National Laboratory, Livermore, California. A common interest in defining usable and freshwater zones in the Dakota aquifer in eastern Colorado and southwestern Kansas led to a cooperative effort between the Kansas Geological Survey and the Colorado Division of Water Resources to map water quality in the Dakota aquifer.

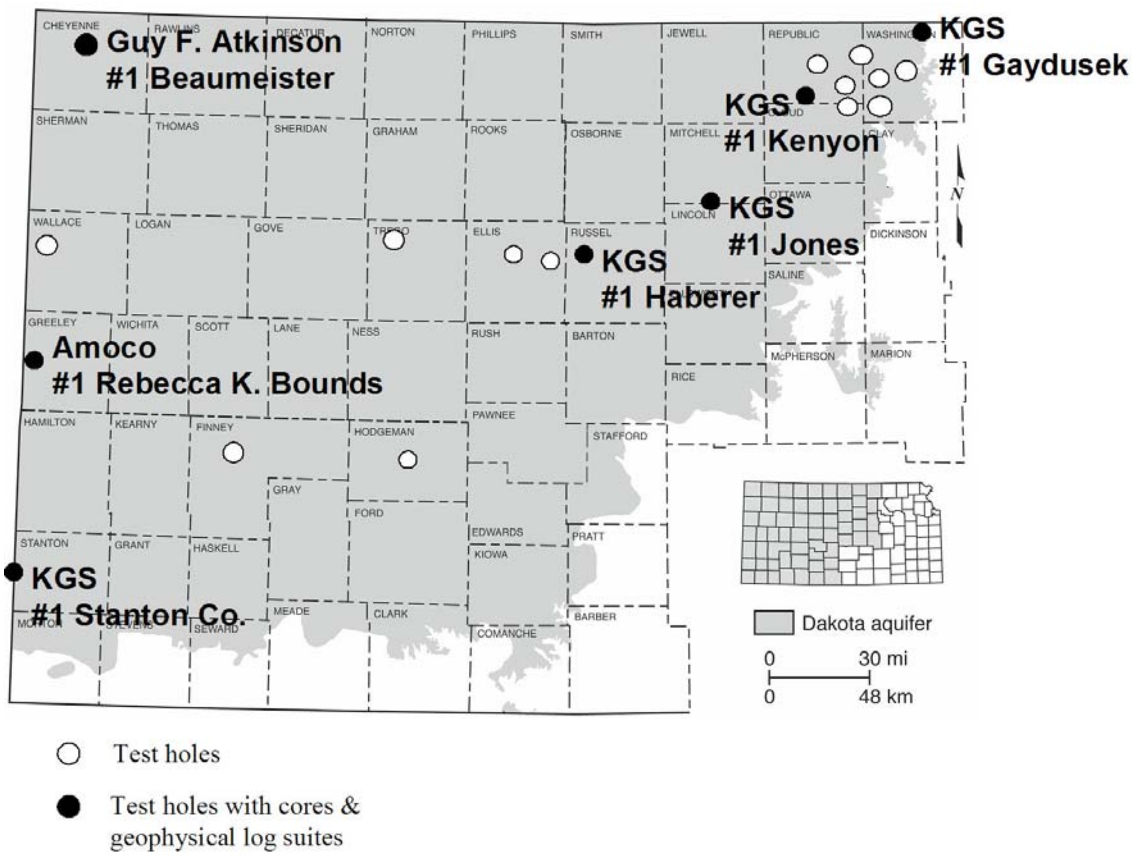

Figure 1. Location of the test holes with and without cores drilled during the KGS Dakota Aquifer Program. The Guy F. Atkinson #1 Beaumeister test hole was drilled earlier in the 1950's for hydrocarbons.

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A Stratigraphic Test of the Terrestrial Carbon-isotope Record of the Latest Albian OAE from the Dakota Formation, Nebraska

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2. Conservation and Survey Division, School of Natural Resources, University of Nebraska-Lincoln, Lincoln, Nebraska 68588-0517, USA (rjoeckel@unlnotes.unl.edu)

Abstract

Recently, the Albian–Cenomanian boundary was identified in a terrestrial sequence at Rose Creek Pit (Gröcke et al. 2006) using carbon-isotope stratigraphy of bulk sedimentary organic matter and charcoal. However, within terrestrial sequences there are inherent difficulties associated with correlating from one section to another. In this study, we tested the stratigraphic reproduction of the negative carbon-isotope excursion in bulk sedimentary organic matter ($\delta^{13}C_{org}$) from a short core adjacent to the Rose Creek Pit and another from ~2.6 km from Rose Creek Pit. In each of these cores, a significant negative $\delta^{13}C_{org}$ excursion is recorded that is directly comparable to that produced from Rose Creek Pit and published in Gröcke et al. (2006). Although there are subtle differences in the absolute $\delta^{13}C_{org}$ value of bulk sedimentary carbon between the stratigraphic sections, this has not disguised the overall shape of the curve. Hence, high-resolution bulk sedimentary $\delta^{13}C_{org}$ records can be used to correlate not only global stratigraphies, but also locally complex stratigraphies in terrestrial environments.

Introduction

The ability with which to correlate marine and terrestrial stratigraphies has in the past proved problematic, or at least not very conducive to provide high-resolution comparisons. More recently, the use of carbon-isotope ratios ($\delta^{13}C$) from terrestrial organic matter has shown their ability in producing high-resolution stratigraphic correlations (e.g., Gröcke et al., 1999; Hesselbo et al., 2000, 2003; Hasegawa et al., 2003). Gröcke et al. (2006) reported a $\delta^{13}C$ curve for bulk terrestrial organic matter and charcoal from the quarry exposures at Rose Creek Pit and compared that to a high-resolution record produced from planktonic foraminifera (Wilson and Norris 2001). Previous palynology of the Rose Creek Pit suggested the section covered the Albian–Cenomanin interval and thus the latest Albian oceanic anoxic event (OAE) and its related isotopic perturbations. The terrestrial curve revealed the negative $\delta^{13}C$ excursion prior to the Albian/Cenomanian boundary, but did not record the subsequent positive $\delta^{13}C$ excursion. The Albian/Cenomanian boundary is concurrent with the D2 sequence boundary of Brenner et al. (2000). The D2 surface unconformably separates deposits of the underlying Upper Albian Muddy Cycle ("J" Sandstone) from the overlying Cenomanian–Turonian Greenhorn Cycle ("D" Sandstone) (Weimer, 1987). Gröcke et al. (2006) estimated based on the isotopic curve and using the timescale in Wilson and Norris (2001) the minimum duration of the D2 sequence boundary at Rose Creek Pit would be on the order of ~0.5 Myr.

The subtle depositional changes associated with terrestrial sequences inextricably are strewn with gaps and therefore, the carbon-isotope curve generated from Rose Creek Pit may not be reproducible from one section to another in the Dakota Formation. In order to test the reproducibility of this curve and its application, two separate cores were investigated: (1) a short core (~2.5 m) within several meters of the Rose Creek Pit quarry face – RC upper; and (2) a longer core (12 m) approximately 2.6 km SSW of RC upper –13A05. Neither of these cores was analyzed for palynology.

Geological Setting and Methodology

The Rose Creek Escarpment (Joeckel et al., 2005) of southern Jefferson and Thayer counties, Nebraska, exposes the classic midcontinent mid-Cretaceous succession of the Dakota Formation, Graneros Shale, and Greenhorn Limestone. These and other gently, westward-dipping (~2.0 m/km) Cretaceous strata cropping out across central to northern Kansas and into southernmost Nebraska produce conspicuous east-facing escarpments with relief exceeding 100 m. Escarpment topography disappears abruptly northward into southeastern and south-central Nebraska, where Cretaceous rocks are, for the most part, buried by thick Pliocene-Pleistocene loess, glacial till, and fluvial sediments. The Rose Creek Escarpment is, in essence, the northern limit of the Smoky Hills of Kansas (cf. Chapman et al., 2001), and it is one of the best field areas for the study of the midcontinent Cretaceous succession in the northern part of the eastern margin of the Western Interior basin.

As part of U.S. Geological Survey's STATEMAP cooperative geologic mapping project and associated research on Cretaceous bedrock geology and the regional mineral resources (particularly brick clays and limestone), the University of Nebraska-Lincoln Conservation and Survey Division drilled multiple shallow boreholes into the Greenhorn Limestone, Graneros Shale, and Dakota Formation on the Rose Creek Escarpment during 2004–2005 (fig. 1). These boreholes were drilled more-or-less along strike. One of these cores (13A05)

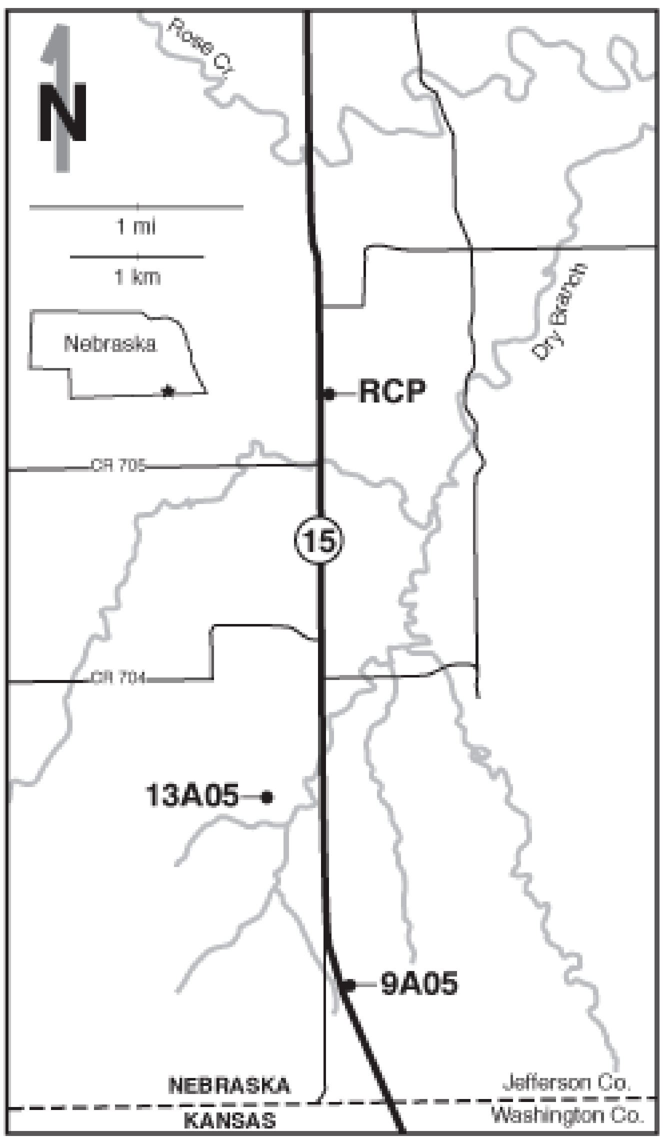

Figure 1. Geographic position of the three cores drilled in Jefferson County, Nebraska, as part of the involvement of the University of Nebraska–Lincoln Conservation and Survey Division in the U.S. Geological Survey's STATEMAP cooperative geologic mapping project. RCP = Rose Creek Pit. Core 9A05 will not be discussed in this study.

was drilled through the upper to middle part of the Dakota Formation in the SW NW NW sec. 26, T. 1 N., R. 2 E., at a new brick clay pit operated by Endicott Clay Products (Endicott, Nebraska). Core 13A05 (~ 12 m) penetrates cross-cutting tidally influenced fluvial-estuarine channel fills consisting largely of gray mudstones, dark lignitic mudstones, and sandstones (fig. 2 for stratigraphic key; fig. 3). This core reached red-mottled kaolinitic mudstones, more typical of lower Dakota Formation strata, at the bottom of the hole. The land-surface elevation of the borehole site is about 1,460 ft (445 m) MSL, or about 40 ft (12.2 m) below the "X"-bentonite marker bed in the Graneros Shale.

Another cored borehole (9A05), not discussed in this report, was drilled at a land-surface elevation of 1,540 ft (469.4 m) MSL about 2.2 km SSE (SW SW NE sec. 35, T. 1 N., R. 2 E.), and penetrated the Graneros Shale and uppermost Dakota Formation to a depth of some 60 ft (18.3 m) (fig. 1). The bottom of core 9A05 is slightly above the top of core 13A05.

A third, shorter core (RCP upper; fig. 1) was drilled approximately 2.6 km NNE of 13A05 into thin sandstones, lignitic mudstones, and gray mudstones in the highwall of the Rose Creek Pit (DeBoer property) in the SW NW SE sec. 14, T. 1 N., R. 2 E., at a land-surface elevation of approximately 1,440 ft (438.9 m) MSL (fig. 3). Cores RCP upper and 13A05, then, sample partially overlapping stratigraphic sections around the level of the Albian/Cenomanian boundary.

Bulk-sediment samples of ~1cc were ground to a fine powder and then chemically treated with 3 mol/L HCl. All carbon-isotope measurements were performed on a COSTECH Elemental Analyzer connected to a ThermoFinnigan DeltaPlus XP mass spectrometer. Carbon-isotope values are reported in the standard delta (δ) notation relative to VPDB with analytical precision of 0.1‰ on international and internal standards. Reproducibility on replicate bulk sediment samples was better than 0.3‰.

Results and Discussion

$\delta^{13}C_{org}$ analyses of bulk sediment were performed on the lower part of core 13A05 in order to capture the trend of the curve prior to the lignitic horizon (fig. 3). The $\delta^{13}C_{org}$ curve for core 13A05 shows a distinct trend from –25‰ to –24‰ in the lower part, followed by a rapid negative excursion of ~2.4‰ within the white sandy siltstone at ~9.8 m. $\delta^{13}C_{org}$ values remain relatively stable at ~ –26‰ to 8 m where they trend back towards an average value of ~ –24.5‰ (fig. 3). Within the Rose Creek Pit upper core, a similar $\delta^{13}C_{org}$ record is produced (fig. 4), with an offset in absolute values compared to core 13A05. $\delta^{13}C_{org}$ values at the base of the RCP upper core shift from ~24.4‰ to –23‰, and then rapidly to more negative values of ~ –25‰; which occurs within the middle of the lower lignitic horizon. From this point $\delta^{13}C_{org}$ values trend steadily to less negative values of ~ –22.3‰ before rapidly decreasing to ~ –25.4‰, after which the values fluctuate around –25.6‰ (fig. 4). The negative shift in the RCP upper core also occurs within a lithological unit (sandstone at ~1 m). This would suggest that the negative $\delta^{13}C_{org}$ excursion is not controlled by lithofacies, and in fact represents a significant shift in the isotopic value of the organic matter being inputted. What becomes apparent in these two datasets is the trend to less negative values that is interrupted by a rapid negative $\delta^{13}C_{org}$ excursion, a similar feature to that reported by Gröcke et al. (2006) for the Rose Creek Pit quarry.

Figure 5 depicts the carbon-isotope curves from core 13A05 and the RCP upper core compared to the original dataset produced in Gröcke et al. (2006) for the Rose Creek Pit quarry. All the $\delta^{13}C_{org}$ curves have been stratigraphic-tied to the Rose Creek Pit quarry data where the rapid negative shift is recorded. No stratigraphic heights have been adjusted as might be expected for changes in sedimentation rates—a definite possibility for these respective stratigraphic sections. The trend from negative $\delta^{13}C_{org}$ values to less negative values in the lower segments of core 13A05 and RCP upper are clearly evident. The only difference between these datasets is the absolute $\delta^{13}C_{org}$ value, which may in fact be related to different organic carbon inputs and/or preservation biases in organic matter between the two sites. This is unlike the study by Hesselbo et al. (2003) who reported a shift in $\delta^{13}C_{org}$ compared to $\delta^{13}C$ charcoal, in which they related this to the change in abundance of terrestrial versus marine organic matter. Although the Dakota Formation sediments in this region have intermittently been influenced by marine incursions, we suspect that these minor differences in $\delta^{13}C_{org}$ are not controlled by changes

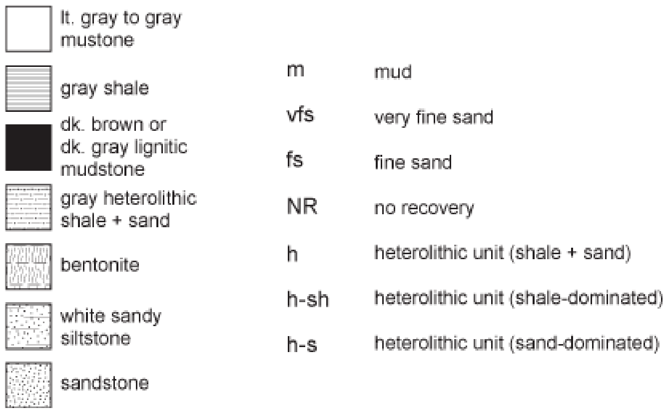

Figure 2. Key to the stratigraphic sections provided in figs. 3 and 4. lt. = light; dk. = dark.

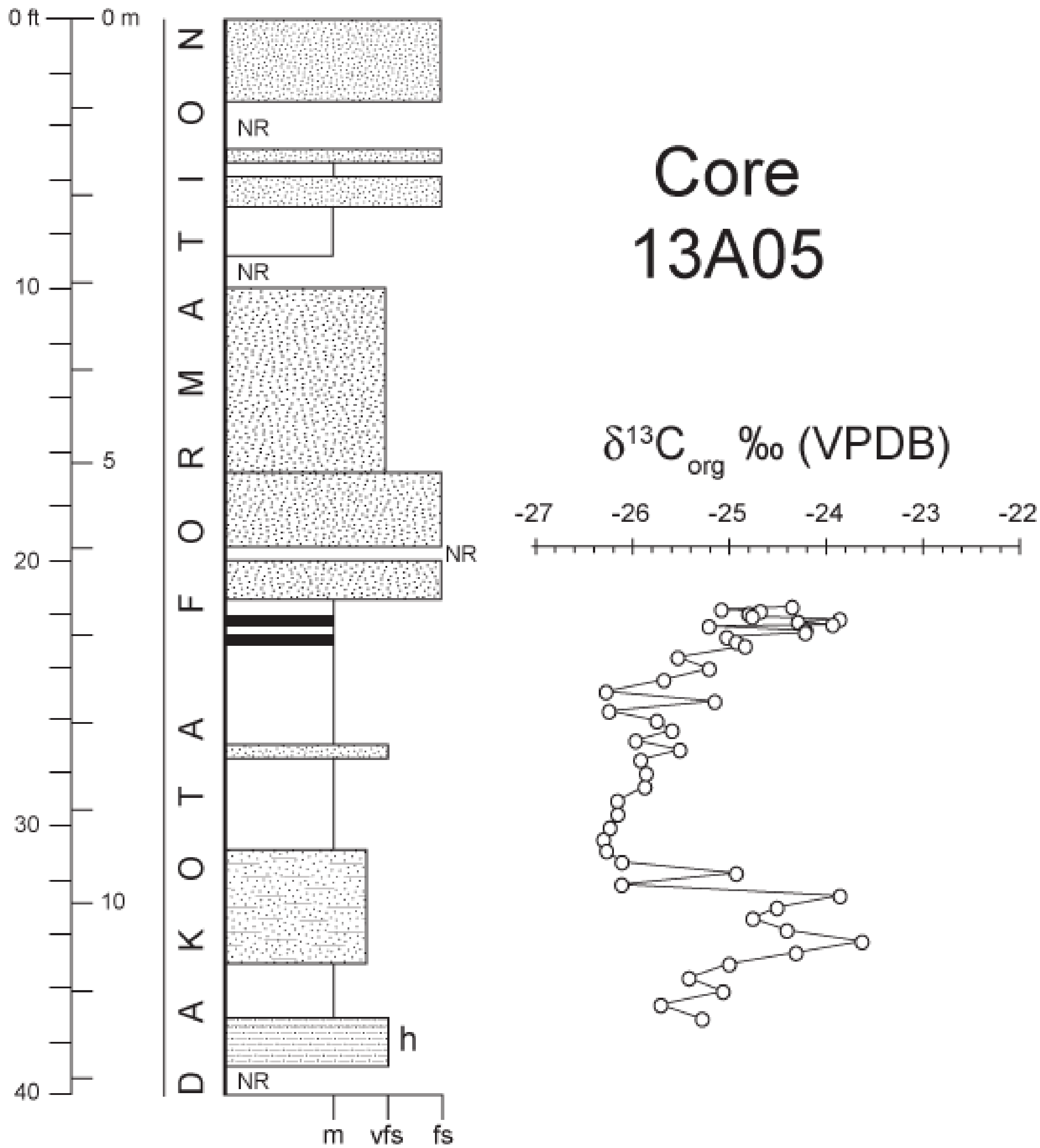

Figure 3. Stratigraphic section and $\delta^{13}C_{org}$ record of core 13A05 spanning the upper part of the Dakota Formation, Nebraska. The $\delta^{13}C_{org}$ curve was only produced for the lower segment of this core: see text for details. See fig. 2 for key.

in terrestrial versus marine organic matter in the bulk sediment. However, as noted in Gröcke et al. (2006), the delayed shift in $\delta^{13}C$ charcoal from the Rose Creek Pit may be influenced by a lack of sampling during the critical interval, because it is only one sample (at ~0.9 m; fig. 5) that does not support the negative $\delta^{13}C_{org}$ record. This sample (fig. 5, arrow) may also be a reworked fragment, a charcoal from older sediments, which is always a possibility when dealing with terrestrial sediments. Having said that, it is interesting to note that the trend back towards less negative $\delta^{13}C_{org}$ values in core 13A05 from ~2.3 m follows very nicely the charcoal record from the Rose Creek Pit quarry (fig. 5).

In conclusion, the construction of a bulk sedimentary $\delta^{13}C_{org}$ record from terrestrial sequences can be used to stratigraphically correlate sections. Although there will be inherent difficulties associated with this technique, it is recommended that high-resolution curves from multiple sections will resolve many of this issues. In addition, to avoid any biasing of the $\delta^{13}C_{org}$ record through preservation and input changes, future work should involve compound-specific analyses to confirm any significant shifts in $\delta^{13}C$ that may be associated with larger, global events, such as the oceanic anoxic event in the latest Albian.

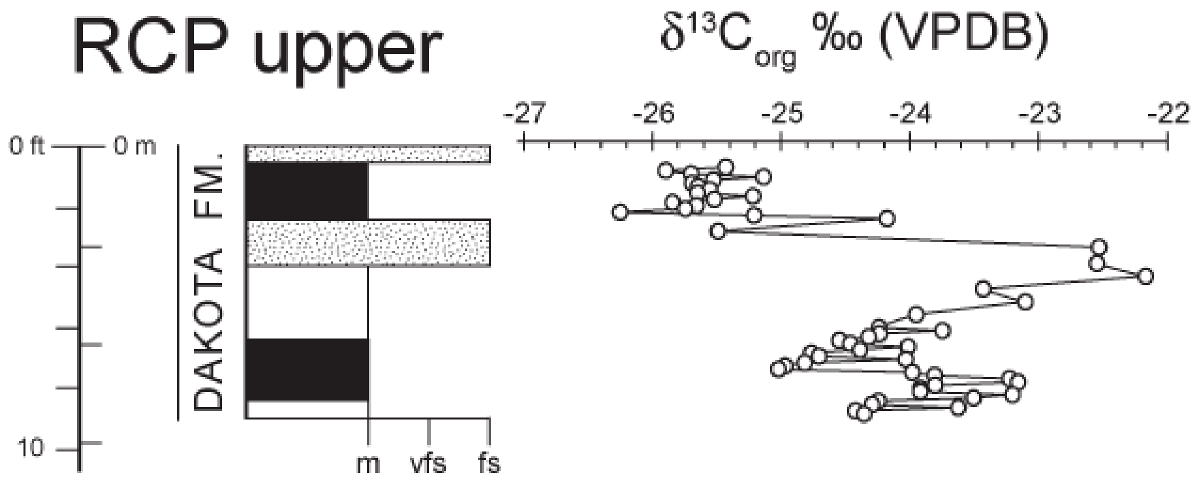

Figure 4. Stratigraphic section and $\delta^{13}C_{org}$ record of the Rose Creek Pit upper core spanning a brief segment of the upper part of the Dakota Formation, Nebraska. This core was taken close to the quarry wall and thus is directly comparable to the Rose Creek Pit quarry record produced in Gröcke et al. (2006). See fig. 2 for key.

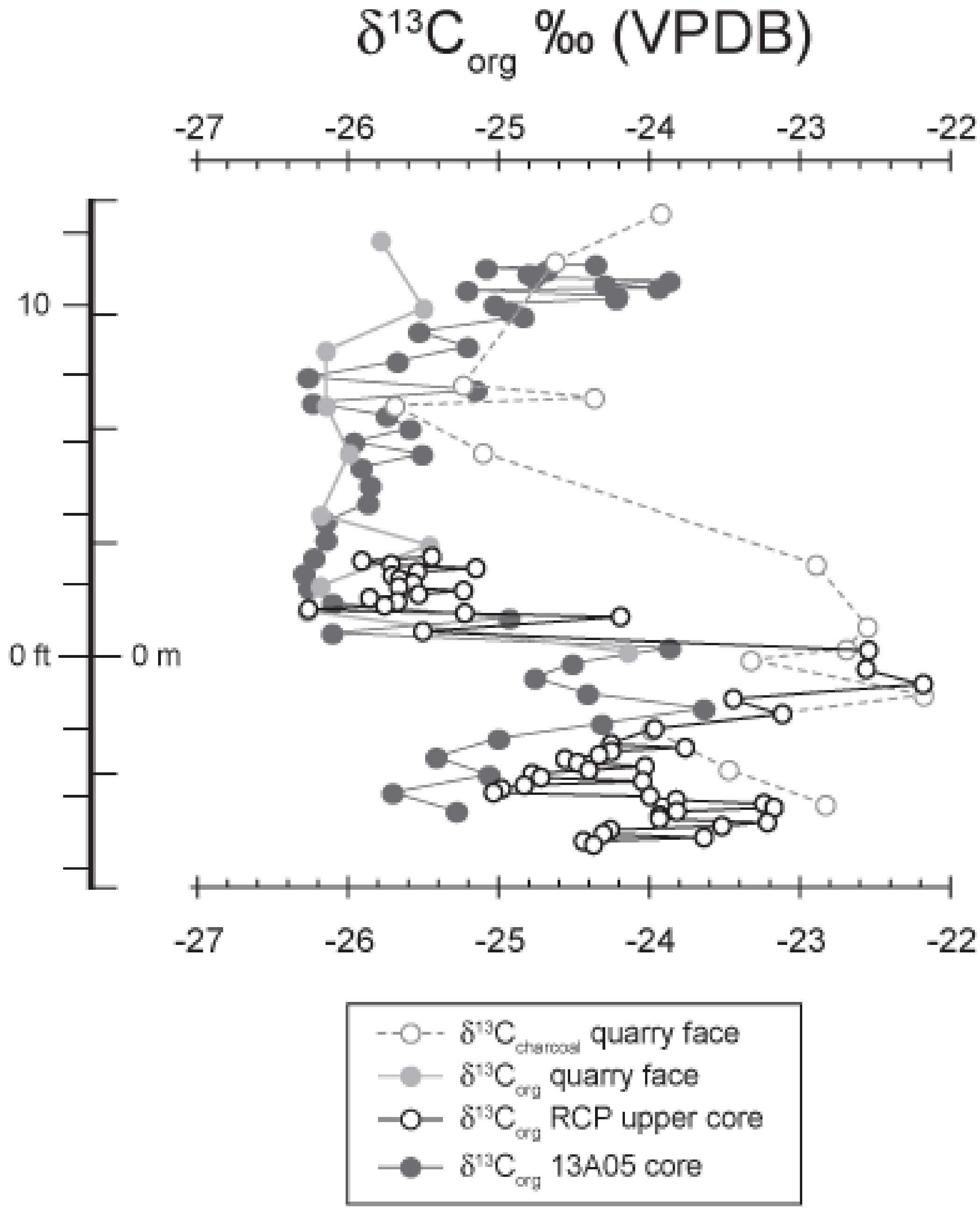

Figure 5. Stratigraphic comparison of the $\delta^{13}C_{org}$ records from the Rose Creek Pit quarry and the two cores, 13A05 and RCP upper. Included in this record is the $\delta^{13}C$ charcoal record from Gröcke et al. (2006). Each stratigraphic section has been fixed by the negative $\delta^{13}C_{org}$ excursion at 0 m.

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