Geologic Field Trips in Nebraska and Adjacent Parts of Kansas and South Dakota

Parts of the 29th Annual Meetings of the North-Central and South-Central Sections, Geological Society of America

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Robert F. Diffendal, Jr., Chair
Charles A. Flowerday, Editor

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April 1995

Cover photo: Sandstone with siltstone supporting pedestal, White River Group (Eocene-Oligocene), Toadstool Park, Sioux County, Nebraska. Due to erosion, this rock no longer sits atop its pedestal. Photo by R.F. Diffendal, Jr., CSD.
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Preface and Acknowledgments

The Conservation and Survey Division of the University of Nebraska-Lincoln (UNL) welcomes the opportunity to co-sponsor the 29th annual meetings of the North-Central and South-Central Sections of the Geological Society of America. Other co-sponsors are the UNL Department of Geology, the University of Nebraska State Museum, the Department of Geography and Geology at the University of Nebraska at Omaha, the Nebraska Geological Society, the Omaha office of Woodward-Clyde Consultants, and the Department of Geology at Kansas State University.

Acknowledgments and thanks go to the organizations just mentioned and the people who follow: Robert F. Diffendal, Jr., North-Central Section chair; James B. Swinehart, North-Central Section vice-chair; Philip L. Kehler, South-Central Section chair; Page C. Twiss, South-Central Section vice-chair; Roger K. Pabian, field trip coordinator. Thanks also go to Dee Ebbeka and Ann Mack, who did the drafting and paste up.

In addition, it should be noted that all manuscripts contained herein were peer-reviewed by specialists outside the author's organization. A special thanks is extended to these reviewers, who performed an important duty not always possible with guidebooks.

Two field trip guides will be available separately. They are Hydrostratigraphic Control of Contaminant Occurrence and Transport, Offutt Air Force Base, Nebraska, by Bob Goodwin, Denny Jorgenson and Terry Thonen of Woodward-Clyde Consultants, Omaha, and Ashfall Fossil Beds, by Michael R. Voorhies of the NU State Museum.

Thanks also go, of course, to the authors, who made timely submissions of manuscripts, complied with formatting and house-style requests and responded to peer reviews constructively and in good faith. It is the hope of the Conservation and Survey Division that these field guides will be of value to the trip participants and to those who may want to investigate the geology contained herein at some later date.

Charles A. Flowerday
Editor
Conservation and Survey Division
Late Pennsylvanian and Early Permian Biostratigraphy and Paleoecology in Richardson and Pawnee Counties, Nebraska

Field Trip No. 1

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Introduction

The purpose of this trip is to familiarize you with the latest Pennsylvanian and earliest Permian rocks that are exposed in extreme southeastern Nebraska. You will see eight exposures of these rocks and will have ample opportunity to collect lithologic samples, as well as samples for both macro- and micro-fossils. The stops have been selected to show you examples of several different environments that existed in southeastern Nebraska in the late Paleozoic. These include subaerial deposits with paleosols, nearshore and offshore marine clastic and carbonate sequences.

Each stop is covered in detail in the handouts that have been furnished to the trip participants. Subsequent readers will be able to find this information in the several references that are listed at the end of the text. All of the stops will be in Richardson and Pawnee counties (fig. 1).

Late Pennsylvanian and Early Permian rocks in the Midcontinent have been studied, especially in terms of cyclic sedimentation and in southeastern Nebraska, by students working under T. M. Stout, including Avers (1968), Bernasek (1967), Dishman (1969), McCrone (1955), Russell (1969), and Snyder (1968). R. C. Moore (1931, 1932, 1936) wrote several papers on rocks of similar ages in Kansas and Stout (1974, 1978) wrote several papers dealing especially with the Nebraska sections.

Heckel and Baesemann's (1975) and Heckel's (1977) papers on cyclic sedimentation in the Missourian of Kansas and Nebraska have been particularly useful. Their model fits only the lower part of cyclothsems of the Wabaunsee and Admire groups, however; these complex cyclothsems have probably been affected by Gondwanan glaciation (Veever's and Powell, 1987). The Wabaunsee and Admire cyclothsems in Nebraska have been discussed by Pabian and Diffendal (1991); in Wabaunsee and Admire sediments, regressive limestone facies either fail to develop or are flooded out by clastics. In the trip area, cyclothsems return to a more normal sequence that includes better developed regressive limestones, a sequence that disappeared after deposition of the Howard Limestone.

In the summer of 1992, Boardman (with Pabian and Diffendal) sampled many of the units listed by Pabian and Diffendal (1991) for conodonts. In addition to the above samples, Pabian, in 1994, has sampled additional units examined in the 1991 publication. Boardman has processed these samples for conodonts and his preliminary findings are shown with the faunal distributions that accompany each of the sections described herein. Legends for fossils and lithologies are shown in figure 2.

Stop 1 (fig. 3). This stop shows the earliest of the non-Missourian/Shawnee cyclothsems that have poorly developed regressive facies. It has been described by Pabian and Diffendal (1989, 1991).

The White Cloud Shale (units 1-5) is gray and contains some iron oxide in its lower part. Above the lower shale is a limestone that is about 2-ft (0.6-m) thick and contains fusulinids, brachiopods, and crinoids, all of which are heavily coated with algae. This bed appears to be only locally developed, and it has been observed in a roadcut about 1.3 mi north-northeast of here. The fossils are not algal-coated at the latter site. Up to about 20 ft (6 m) of the underlying shale are exposed in the roadcut, and the lower parts are more micaceous and sandier than the upper. Concretions containing plant remains have been recovered from this unit. South, toward DuBois, the White Cloud also tends to be
sandier, and Condra (1927) showed channel sands in the White Cloud southeast of Rulo, about 40 mi from here (see Pabian and Diffendal, 1991, figs. 33n, 33o). There are three shale beds ranging from gray and green in the lower to brown in the upper two. There are calcareous and iron-oxide concretions in the upper beds. Boardman has suggested that unit 2, stop 1, this trip (=unit 2, stop 1, Pabian and Diffendal, 1991) is actually the Happy Hollow Limestone. This unit has yielded fusulinids, brachiopods, and crinoid stems, most of which are algal coated. This unit also contains a *Streptognathodus* biofacies. Unit no. 6, called Happy Hollow Limestone by Pabian and Diffendal (1991), is up to 2-ft (0.6-m) thick and is crumbly, weathered to dark yellow-orange; it has yielded no fossils here.

The Cedar Vale Shale (units 7, 8) is about 7-ft (2.1-m) thick, gray in its lower part and black, crumblly to fissile in its uppermost foot. The black facies contains abundant ostracodes (*Holinella*) and a few pectinoid bivalves (*Dunbarella*). Above is the Rulo Limestone, a dense, dark gray, fossiliferous unit that weathers to yellow or brownish yellow; we have interpreted this bed as the transgressive limestone inasmuch as it contains a *Streptognathodus* biofacies. We suggest that the regressive sequence was overwhelmed by clastics, preventing development of a regressive limestone. The lower part of the Silver Lake Shale (unit 10) is gray, clayey, and contains pyrite, marcasite, and limonite, and is about 15-ft (4.6-m) thick. This is followed by about 5 ft (1.5 m) of siltstone that contains some plant remains in concretions. About 2 ft (0.6 m) of clayey shale is overlain by about a foot of coal smut (unit 13), followed by about another foot of shale.

The Burlingame Limestone (units 15-17) contains a lower and an upper limestone separated by about 2 ft (0.6 m) of shale. The limestones are dense, medium-crystalline, and gray, weathering to yellow-orange—the lower contains a few brachiopods, whereas the upper one contains brachiopods, clams, snails, and rare conularids. The Soldier Creek Shale contains some bryozoans, brachiopods, snails, and echnoderms, many of which are large, ornate forms, suggesting this may represent a regressive unit. The Wakarusa Limestone (unit 19) is deeply weathered, but we have not established if the weathering took place in the Paleozoic or Pleistocene, as it is overlain by glacial till.

**Stop 2** (fig. 4). The rocks here are a strong contrast to those seen at stop 1 inasmuch as the cyclic sequence here is much more similar to cycloths seen in the Missourian and early Virgilian (Shawnee Group). The lower sequence contains somewhat more clastic material than the Missourian or Shawnee cycloths (cf. Heckel and Baesemann, 1975, and Heckel, 1977).

The basal sandstone (unit 1) is micaceous, and ripple marks and cross beds can be observed in this unit if it is not covered with alluvium. The sandstone is overlain by about 2 ft (0.6 m) of siltstone, and about a foot of Nodaway Coal (unit 3) has been observed here. Immediately above the Nodaway Coal is a thin bed of calcareous concretions (top of unit 3) that contain pyritized and sphaleritized fossils, including brachiopods, clams, snails, goniatites, and bactritoids. We have interpreted this unit to be the transgressive limestone. Unit 4 contains *Streptognathodus* and is considered to be the lower part of a core shale. The overlying units (5, 6) have a very thin black shale that thickens to about 2 ft (0.6 m) over a very short distance. The black shale has produced goniatites, including one mature specimen, as well as the cranium of a fish (Martin, 1972); *Streptognathodus* is moderately abundant. The upper part of the shale is gray and contains brachiopods, bryozoans, and a few trilobites and crinoids. It is immediately overlain by the Howard Limestone, which contains fusulinids, bryozoans, brachiopods, clams, snails, nautiloids, and a few crinoids.

A few *Streptognathodus* were recovered from the top of the Severly Shale (unit 6) and the base of the Church Limestone (unit 7), whereas *Adetogna-
Abbreviations:

Ad = Adetognathodus  
St = Streptognathodus  
PO₄⁻³ = Phosphate 
........... = Alternate Sea Level Curve

Fig. 2. Legend of characters and abbreviations shown along measured sections.
thodus is abundant at the top of the Church Limestone (unit 8) and moderately abundant in the Utopia Limestone (unit 10). A Streptognathodus-Adetognathodus biofacies in the Winzeler Shale (unit 9) suggests a short transgressive pulsation.

The erosional surface at the top of the Utopia Limestone is probably Pleistocene.

Stop 3 (fig. 5). The cut created during the construction of the emergency spillway at Iron Horse Lake Dam is probably the finest exposure of Auburn, Emporia, and Willard formations to be observed in Nebraska. It was the intent of the project engineer, Howard McNiff, to keep as much of the geology intact as possible in this area. McNiff’s efforts have provided geology with an excellent outdoor laboratory. Huscher and Pabian (1989) subsequently described this section.

During and shortly after construction of the spillway, the lower part of the Auburn Shale (fig. 5, unit 1) was exposed, but this is largely overgrown or slumped over now. There were pyrite or marcasite concretions and some plant fossils in this unit, suggesting some of the Auburn was continental. The lower part of the Reading Limestone (units 2-7)
contains alternating limestones and shales, with only Adetognathodus being found in units 2-9; the shales become less prominent in the upper Reading (units 8-10). The upper Reading is quite fossiliferous, with brachiopods and crinoids being common. *Streptognathodus* has been found at the top of the Reading (unit 10). The Harveyville Shale (unit 11) has yielded an immature molluscan fauna, including clams, snails, and goniatites, as well as *Streptognathodus* being common at the base and middle and becoming abundant near the top. The lower part of the Elmont Limestone appears to be the regressive facies of a cyclothem; it contains brachiopods, crinoids, and snails, and some *Streptognathodus*. Unit 12 of the Elmont is a cross-bedded coquinitid limestone, suggesting very shallow conditions. Units 13 and 14 in the Elmont Limestone are very important, as the lower bed is a shale and the upper is a sandy shale with root mottling, suggesting an abbreviated regressive sequence and subaerial exposure. The upper Elmont (units 14, 15) may not be correlative with the upper Elmont at its type locality.

Thus, the new cycle in the upper Elmont, shown by the deposition of a transgressive limestone (unit 15), has almost no nearshore shale developed in the underlying unit 14, but the transgressive limestone is hard, dense and contains brachiopods, snails, crinoids, and a few shark teeth. *Streptognathodus* is abundant at the top of unit 15 and less common at the base of the Willard Shale (unit 16), suggesting a condensed section. The lower part of the Willard (unit 16) contains an immature molluscan fauna. A few mature clams have been found about 4 ft (1.2 m) above the base of the Willard Shale. The Willard is as much as 30-ft (9.1-m) thick locally and becomes sandier toward the top.

*Stop 4* (fig. 6). Burchett and Arrigo (1978) have discussed the structural geology of this area, and some of the complex structure of this region is readily observed between stops 4 and 5, where the Bennett Shale is near the 1,200-ft (365-m) contour near the southwestern corner of section 15 and the 1,100-ft (335-m) contour near the southeastern corner of.
Fig. 6. Measured section of Council Grove sediments exposed in roadcut on Four Mile Hill, Richardson County, stop 4 (cont.).

the section. Further, Burchett and Arrigo (1978, pl. 1) show the top of the Tarkio Limestone at 900 ft (274 m) in the southwestern corner and close to 800 ft (243 m) at the southeastern corner of sec. 15, T. 1 N., R. 13 E. The section exposed along Four Mile Creek and the road cut through the adjacent escarpment includes about 150 ft (45.7 m) of early Permian sediments.

The Roca Shale (units 1-10) is the outside shale of the first of at least three cyclothems exposed here.

It is overlain by the dense Sallyards Limestone (unit 12) and the Legion Shale (units 13-15), which are thought to represent the transgressive facies of the cycle; however, only a single platform *Streptognathodus* has been recovered at the top of unit 12. The upper units of the Legion Shale may represent a paleosol. Pabian and Diffendal (1991) suggested that the Burr Limestone (units 16-20) may represent the regressive facies; however, rare *Streptognathodus* from the top of unit 18 may suggest this is actually...
a transgressive limestone. The Salem Point Shale (units 21-23) may be an eolian deposit, and Joeckel (in Pabian and Diffendal, 1989) has demonstrated the presence of calcareous concretions in the unit. Near the top of the Salem Point is a foot-thick, thinly bedded sandstone that is bioturbated and represents the earliest marine incursions of the following cyclothem.

The lowest limestone in the Neva (unit 24) represents the transgressive unit of the cycle, and it contains brachiopods, mollusks, and a few trilobites; it has rare Streptognathodus near the base and common Streptognathodus near the top. Streptognathodus is abundant in the base of unit 25, suggesting this is an offshore shale. It is overlain by a dark brown to black, crumbly to somewhat fissile shale that contains inarticulate brachiopods and, in some areas, abundant shark teeth. Russell (1969) has called this unit a phosphorite and has traced it to the Manhattan, Kansas, area. Most of the regressive Neva facies have been quarried out of this area or are entirely covered by vegetation and removed overburden from the economic operations.

The Eskridge Shale (units 29-43) represents a long, emergent period with only a couple of thin marine limestones (units 33, 38). The upper part of unit 37 contains some fusulinids and snails, but it is root-mottled immediately below the limestone (unit 38). Unit 38 is made up almost entirely of spirorbid worm tests, and it has yielded some fish remains, including xenacanthids, suggesting freshwater deposits. Units 39-43 of the Eskridge contain numerous concretions, calcite geodes and some chert, suggesting caliche development here. About 3 ft (0.9 m) of the Cottonwood Limestone are exposed at the top of the section, and it contains numerous fusulinid molds.

Stop 5 (fig. 7). This stop shows the latest Admire and earliest Council Grove sediments. The West Branch-Hamlin shales are exposed at the lower part of the ditch (fig. 7, unit 2). This is a nearshore sequence of silts and shales that is followed by deposition of the Americus Limestone (units 3-5), which is a transgressive sequence containing brachiopods and conodonts. The lower part of the Hughes Creek Shale is dark gray, and it contains an immature molluscan fauna, including clams, snails, nautiloids and goniatites, as well as brachiopods and a few shark teeth (unit 6). The Hughes Creek becomes considerably more calcareous toward the top. There is an Adetognathodus-Streptognathodus conodont assemblage in unit 8 (fig. 7) and a Streptognathodus-dominant conodont assemblage at the top of unit 10 (fig. 7), suggesting separate pulses of deepening water. The upper Hughes Creek also contains large brachiopods, as well as bryozoans, trilobites, and crinoids; it had been regarded as a regressive sequence. However, the highest exposed bed (unit 14, stop 5) contains Streptognathodus, glauconite, and phosphate, suggesting deepening. Holterhoff and Pabian (1990) have discussed this fauna and suggested that it developed in regional depressions that formed as a result of subsidence along a downdropped fault block along an active Nemaha Ridge. They erroneously assigned these units to the overlying Red Eagle Formation.

The ammonoids in the Hughes Creek Shale are similar to those in the Bursum Formation near Tula-
Fig. 7. Measured section of Hamlin and Foraker formations exposed in roadcut near Four Mile Creek, Richardson County, stop 5.

rosa, New Mexico, reported by Furnish and Glenister (1971).

Stop 6 (fig. 8). Pabian and Diffendal (1989, fig. 33e) showed about 75 ft (22.8 m) of the latest Pennsylvanian-earliest Permian sediments exposed in this long roadcut. Since then, "highway beautification" has obliterated beyond recognition about the lower third of this exposure. A proposed Pennsylvanian-Permian contact was not buried here, and is now the only such contact exposed in this area. This roadcut provides the only exposure of the Onaga Formation in this area, although the entire Onaga and overlying Falls City formations were completely buried by highway beautification at an outcrop about 3 mi north of here.

The upper part of the Dry Shale was exposed here, and it was made up of red beds with calcareous concretions; the lower part of the Dry, about 5 mi west, is marine and contains an immature mol-

Fig. 8. Measured section of Root, Wood Siding, Onaga, and lower Falls City formations exposed on cut on Nebraska Highway 105, Richardson County, stop 6 (cont.).

luscan fauna with clams, snails, nautiloids and goniatites. The overlying Grandhaven Limestone (unit 2) contains brachiopods and mollusks; excellent examples of razor clams that were in vertical burrows were once seen here. The overlying Friedrich Shale (units 3-6) contains red beds and is most likely a continental or nearshore sequence that is overlain by
the Jim Creek Limestone. The lowest bed of the Jim Creek (unit 7) contains large productid brachiopods, myalinid bivalves, some bryozoans, and crinoid remains; it is probably a nearshore sequence. The upper Jim Creek (unit 9) is separated from the lower by about a foot of shale; it is dark gray and dense, and the lower part of the French Creek Shale (unit 10) contains an immature molluscan fauna with bivalves predominating and only a few goniatites. We have interpreted this as the transgressive facies of the cycle. The sequence then appears to have been flooded out by clastics; there is an underclay and coal (units 12, 13), followed by a shale and thin sandstone (unit 15). The overlying shale (unit 16) contains a coal bed in its middle.

The Wood Siding Formation (units 17-23) contains three limestones, the Nebraska City, Gray Horse, and Brownville, in ascending order, that are separated by shales. The intervening Plumb and Pony Creek shales contain red beds, suggesting subaerial erosion, whereas the Nebraska City and Gray Horse limestones contain immature mollusks, suggesting they were transgressive units.

The top of the Brownville Limestone has been considered the top of the Pennsylvanian in this area (Mudge and Yochelson, 1962); this correlation is based largely on fusulinids. We do not regard this to be a boundary section, however. There is currently much outstanding conodont data now being or having been recently collected, and these data will likely indicate where a boundary section should be located in the Midcontinent.

The Onaga Formation (units 24-28) consists mostly of shales here. There is a thin bed of concretions (unit 24) that we think is the Aspinwall Limestone. The thinning of the Aspinwall from its type locality about 40 mi east-northeast from here may be due to the proximity of this section to the Nemaha Ridge.

Stop 7 (fig. 9). This is the only exposure of the Five Point Limestone that is easily accessible in southeastern Nebraska. No unit in this section has yielded conodonts. The limestone near the top of this section has yielded a few bone fragments, suggesting this unit may be a freshwater deposit.

Stop 8 (fig. 10). Joeckel (1989, 1991) described paleosols in the Eskridge Shale from this site. The paleosol (fig. 10, units 3, 4) is at least 9.8-ft (3-m) thick here. It is underlain by mudstones and a limestone that contains molluskan and plant remains, suggesting nearshore conditions. The lower part of the paleosol is a red bed showing blocky weathering and containing carbonate sheets, and the upper 5 ft (1.5 m) is a gray mudstone with carbonate sheets. The land surface gave way to encroaching marine environments represented by the Cottonwood Limestone. The Cottonwood here contains abundant marine invertebrate fossils, including a few trilobites and a mature ammonoid. The lower part of unit 6 contains no conodonts, but upward, Sweetognathus and rare Streptognathodus have been found, and moderate concentrations of Streptognathodus have been found near its top. The Cottonwood contains several beds of chert nodules.

This is the only known spot where displace-
Fig. 9. Measured section of Five Point Limestone, Stine Shale, and Houchen Creek exposed on cut on Nebraska Highway 8, Richardson County, stop 7.

Fig. 10. Measured section of upper Eskridge Shale and Cottonwood Limestone exposed in borrow pit near Humboldt, Richardson County, stop 8.

Acknowledgments

Robert F. Diffendal, Jr., assisted in some of the field work done for this guide and reviewed earlier copies of the manuscript. Perry Wigley also reviewed the manuscript. Charles Flowerday edited the text and provided useful comments.

Road Log

<table>
<thead>
<tr>
<th>Mileage</th>
<th>(Mileage between directions in bold.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>Junction of Nebraska highways 4 and 65 (N-4 and N-65; Nebraska highways designated &quot;N-&quot;) at the southeastern edge of Table Rock, near Taylor Branch. (0.3)</td>
</tr>
<tr>
<td>0.30</td>
<td>Near foot of overpass, turn right; proceed about 100 ft to &quot;T&quot; intersection; turn left (east). (0.2)</td>
</tr>
<tr>
<td>0.50</td>
<td>Cross Burlington Northern railroad tracks. CAUTION! (0.2)</td>
</tr>
<tr>
<td>0.70</td>
<td>Cross Burlington Northern railroad tracks. CAUTION! Turn left at intersection and follow road that goes parallel to the railroad tracks. (0.8)</td>
</tr>
</tbody>
</table>
Note outcrops of Scranton Formation to your right. (0.5)

Stop 1. This is located on the large hill on the northwestern corner of the intersection. Note that the railroad tracks now head toward Humboldt and no longer run parallel to the trip road. (1.5)

"T" intersection—continue straight. (0.5)

Turn right (west) (0.2)

Abandoned road. (1.0)

Turn left (south) (1.5)

Junction of N-50 and county road. Turn left (east). Exercise extreme caution! Sight distance to west very short. Continue on paved N-50 toward DuBois. (4.9)

Junction of N-50 and N-8. Continue straight. (0.5)

Junction of N-50 and county road. Turn left (east). (0.55)

Stop 2. Cross bridge across creek. Park. Walk south along creek to outcrops. Turn around; return to N-50. (0.65)

Cross N-50; continue straight (west). Note exposures of Auburn and Emporia formations. (2.60)

Stop 3. Entrance to Iron Horse Lake Recreational Area. Note earthen dam to the right (northeast). Turn right (north) and head toward parking area. The outcrop must be reached by walking across the earthen dam. (0.3)

Lunch Break at Picnic Facilities. Restroom facilities and water available here. After lunch, return to county road.

County Road; turn left (east). (2.6)

Junction of N-50 and county road; turn left (north). (0.5)

Junction of N-50 and N-8; turn right (east). (2.9)

Dry Shale-Dover Limestone outcrop on left (alternate stop). (2.3)

Junction of N-8, N-105, and county road. Turn right (south) on county road. (1.0)

Intersection of county roads; turn left (east). (1.0)

Stop 4. Park in designated parking area. Return to county road; turn left (west); continue to intersection. (1.0)

Junction of county roads. Turn right (north). (0.3)

Stop 5. Continue northward. (0.7)

Junction of county road and N-8 and N-105; continue northward. (0.4)

Stop 6. Continue northward. (7.2)

Alternate stop*. Turn left (west); continue 1 mile; turn left (south); continue for 0.6 mi. Return to N-105.

Alternate stop*. Continue northward.
*Mileage between directions not included.

Enter Humboldt. Continue northward. (1.0)

Junction of N-105 and N-4. Turn right (east). (1.0)

Stop 7. Continue eastward. (0.5)

Intersection with county road; turn left (north). (0.1)


Drive carefully!

References


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Late Quaternary Fluvial and Eolian Sediments: Loup River Basin and the Nebraska Sand Hills

Field Trip No. 2

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Day 1

Introduction to Lower Loup River Basin Stops

On the first day of the trip, we will visit a dramatic exposure of Pliocene and Quaternary sediments, and we will see exposures of five out of six late Pleistocene to late Holocene alluvial fills in the Loup River basin (fig. 1). Stop 1 is an exposure created during construction of the Fullerton Canal through a hill 3 mi east of Elba, Nebraska (fig. 2). Stop 2 is Cooper’s Canyon in the North Loup Valley, which is the type locality for the Elba Valley Fill and Elba Terrace in the Loup River basin (Brice, 1964). At stop 3 in the lower South Loup River valley, an eroded remnant of a late Wisconsinan valley fill is exposed. At stops 4 and 5 in the upper South Loup River valley, we will see late Holocene alluvium. Figure 3 is a generalized cross section of the South Loup River valley showing the stratigraphic relationships among the six fills and the various terraces. Figure 4 shows the actual morphology of the South Loup River valley at selected cross sections. Given the complexity of alluvial events that emerged during May and Holen’s (1985) and May’s (1986) work in the valley, they first assigned local names to terraces until the morpho-stratigraphic relationships at various study localities could be resolved with careful mapping and radiocarbon dating. Table 1 lists some of the names introduced for equivalent terraces, and table 2 shows how individual alluvial fills have been designated in various publications.

Stop 1. The Elba Cut, Fullerton Canal. A dramatic exposure of Pliocene and Quaternary sediments (fig. 2) was revealed in 1991 when the Fullerton Canal was cut through the divide between the North Loup River and Cedar Creek (fig. 1). This exposure features a volcanic ash deposit, paleochannels, and a sequence of paleosols (fig. 2). Located 3 mi east of Elba, Nebraska, the cut is about 1,000-ft (305-m) long and about 65-ft (19.8-m) high from the canal bottom to the top of the divide. Managed by the Twin Loups Irrigation and Reclamation Districts, the Fullerton Canal is one of six irrigation canals of the North Loup Division, Bureau of Reclamation, U.S. Department of Interior, Pick-Sloan Missouri Basin Program.

Stop 2. Cooper’s Canyon. Cooper’s Canyon is a steep tributary to the lower North Loup River (fig. 1) that exposes the Elba Valley Fill beneath the Elba Terrace (Brice, 1964). Miller and Scott (1955) initially described and named the soils in the canyon wall. Once radiocarbon ages were determined on snail shells at the site (10,850 yr BP), it became clear that the alluvium was deposited in the very late Pleistocene and Holocene (Miller and Scott, 1961). Brice
(1964) also dated snail shells at the contact between the basal sandy alluvium and the overlying fine-grained alluvium (10,500 yr BP) (fig. 5). May (1990) returned to Cooper's Canyon to describe and date the soils that were initially named by Miller and Scott (1955). The results of this effort are shown in figure 6.

**Stop 3. Zwiener Cutbank.** The Zwiener cutbank exposes a fill in the South Loup River valley that Schreurs (1956) called the Todd Valley Formation, based on its stratigraphic position and similarity to the stratigraphy in Todd Valley in eastern Nebraska. May (in preparation) has recently demonstrated that at least some of the sandy fill in Todd Valley is a part of the Gilman Canyon Formation (dating locally to about 21,000 yr BP), so use of the term Todd Valley Formation in the Loup River basin is presently problematic. Where the Todd Valley Formation is not eroded, it is capped by Peoria Loess; this loess-mantled surface is the Pleasanton Terrace (figs. 3 and 4) (May, 1989a). At the Zwiener cutbank locality, the loess and much of the Todd Valley Formation have been eroded (fig. 7). Downstream of Pleasanton, Nebraska, the Todd Valley Formation is exposed in 98-ft (30-m) high bluffs, and locally the alluvial sand is overlain by a low-relief eolian sand sheet (fig. 7). A branch of *Abies balsamea* (balsam fir) recovered at the Zwiener locality from 4.9 ft (1.5 m) above the modern South Loup River in the Todd Valley Formation has an uncorrected radiocarbon age of 14,030±190 and a Δδ13C-corrected age of 14,080±190 yr BP (fig. 7) (May, 1989a). A sample of *Abies* (fir) bark that was recovered at another exposure of the Todd Valley Formation east of Pleasanton, Nebraska, (Staabs cutbank site) from 19.6 ft (6 m) above the river was in a 14-in. (36-cm)
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*Table 1. Names for equivalent terraces in the Loup River basin.*

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*Table 2. Designations for equivalent Holocene alluvial fills in the South Loup River valley.*

thick gray silty sand that has a corrected radiocarbon age of 14,630±3990 yr BP (fig. 7) (May, unpublished data).

**Stop 4. Pressy Park Cutbank.** The Pressy Park cutbank (fig. 1) is a rapidly eroding exposure of the late Holocene fills (I, II, and III) in the South Loup River valley (May, 1986, 1989b, 1992). Locally, they unconformably overlie a basal remnant of early-to-late Holocene fill IV (fig. 8). The three late Holocene fills were originally not identified by Brice (1964) in his pioneering work in the basin (table 2). Fill III was identified and first dated at this locality (May and Holen, 1985; May 1986). It has now been recognized and radiocarbon dated both upstream and downstream of this locality (May, 1992). Fill II has also been identified and radiocarbon dated upstream at the Chesley locality. Fill I is ubiquitous in the upper part of the valley and has been dated at several localities (May, 1992).

**Stop 5. Chesley Cutbank.** Several sections along the cutbank have been studied during the past decade (May and Holen, 1985; May, 1986, 1989b, 1992). A total of six radiocarbon ages have been determined on humates and bone collagen from these sections (May, 1992, table 1) (figs. 9 and 10). A chronology of late Holocene landscape evolution in the upper South Loup River valley thus has emerged. Valley filling waned about 4,960 yr BP. By 3,100 yr BP, the valley was deeply incised (to present river level). Channel migration and channel avulsions must have occurred before and after 2,300 yr BP and produced fill II (May, 1992). Then the rate of valley-bottom aggradation slowed between about 1,800 and 1,050 yr BP (estimating corrections for uncorrected radiocarbon ages of 1,660 and 930 yr BP; see May, 1992). The water table in the upper South Loup River valley must have been relatively high during this interval of very slow aggradation. Burial of most of the valley floor (then a low terrace) by fill I occurred shortly after 1,300 yr BP. Further burial of the floodplain occurred after about 1,000 yr BP. Deep incision has occurred during the last 1,000 yr and created the Low Elba Terrace and numerous unpaired cut terraces.

**Day 2**

**Introduction to the Sand Hills Stops**

The Nebraska Sand Hills provide compelling evidence of Holocene climate change near the center of the North American continent. The Sand Hills cover about 19,000 mi² (50,000 km²) of the central Great Plains (fig. 11) and constitute the largest sand sea in the western hemisphere (Smith, 1965; Ahlbrandt and Fryberger, 1980; Swinehart, 1990). The grass-stabilized colian bedforms are up to 426-ft (130-m) high and have been modified only slightly by pedogenic and fluvial processes. Large, active
Fig. 2. The Elba cut, Fullerton Canal, and table of lithologic units (continued on facing page). The Elba cut displays deposits ranging in age from Pliocene to Holocene. The units shown in the diagram are represented chronologically in the table. Key points are related to the table by circled numbers, and discussion is as follows: 1) The Brady Soil probably is not present unless represented in the modern soil in places along the cut; 2) The Loveland Soil may be equivalent to the Sangamon Soil of Illinois, but accurate identification of this or the several other soils in this part of the section is not possible at many, or most, sites in Nebraska without age-dating techniques; 3) Walnut Creek? soil may meet the concept of the Yarmouth Soil, but many paleosols can occur in the Pleistocene deposits; 4) Pre-Illinoian Pleistocene deposits appear to be a two-fold unit across most of the cut, so provisional names from Reed and Dressen (1965) were applied. The volcanic ash does not contain biotite so it probably is not from the Bishop Tuff (0.7 Ma; the tuffs described herein and their dates are from Izett, 1981). Since the ash is at the base of the lower unit, it may be the ash from the Mesa Falls Tuff (1.27 Ma), rather than the ash from the Lava Creek B Tuff (0.61 Ma); 5) The Fullerton Soil would have been considered the Afton Soil 30 years ago, but it is surely older than the Afton at its type locality. The interpretation of paleosols for stratigraphic purposes appears to be of limited value in going from the Midcontinent to the plains. The Gilman Canyon geosols probably represent the soils most likely to be of value in regional correlations; 6) The Fullerton Formation occurs throughout central and south-central Nebraska and extends eastward into the glaciated region of the state. To the west, north, and northeast, several gravel sequences occupy a stratigraphic position that probably is equivalent to the middle and lower parts of the formation. Several paleosols of unknown extent and magnitude occur in the Fullerton. A volcanic ash bed, probably located in the upper part of the formation, was dated at about 2.3 Ma (Boellstorff, 1978) at the Arcadia Canal Site. This ash may correlate with the Huckleberry Ridge Tuff (2.01 Ma). The Fullerton originally was conceived as representing the periglacial equivalent of the earliest glacial advance into what is now Nebraska, and that is probably the case for at least the upper part of the formation. There is no definitive evidence to show that the brown silt of the Fullerton or the equivalent gravels are older than 3.5 Ma.

The dunes of the Sand Hills overlie between 500 and 1,000 ft (150 and 300 m) of coarse late Cenozoic clastic deposits—the thickest part of the High Plains aquifer, a hydrogeologic unit that stretches from Texas to South Dakota. The aquifer is the principal source of water in one of the major agricultural areas of the United States. Owing to the high recharge rates of dune sand and the thickness of sand and gravel beneath the Sand Hills, 65 percent of the water stored in the aquifer is in Nebraska (Weeks and Gutentag, 1988). Unconsolidated Quaternary fluvial sands, eolian sand sheets and fluvial sand and gravel of the Broadwater Formation of Pliocene age (Swinehart and Diffendal, 1990) separate the Quaternary dune sand from underlying strata of the Ogallala Group of Miocene age in many places.

The local source of sand for the Sand Hills is Miocene through Pleistocene deposits by streams flowing eastward from the western plains and Rocky Mountains. Eolian bedforms comprise about 80 percent of the total sediment volume in the sand sea. Although the thickness of Quaternary eolian sand below most of the interdune surfaces rarely exceeds 33 ft (10 m), in the south-central and west-central areas, up to 66 ft (20 m) of sandy sediment is present.

The dune field has long been thought to have
formed during Pleistocene time (Smith, 1965). Recent workers (Ahlbrandt and others, 1983; Swinehart, 1990; Loope and others, in press), however, have argued that much of the sand, including that within some of the largest bedforms, was reworked during early-to-late Holocene time. Holocene eolian activity has been well documented in adjacent parts of the Great Plains: Colorado (Madole, 1994; Forman and others, 1992; Muhs, 1985), Wyoming (Gaylord, 1990), Kansas (Arbogast, 1994; Porter and others, 1994); and Texas (Holliday, 1989).

**Stop 6. Red Ranch.** Along the Middle Loup River just east of Seneca, there are good exposures of a flat-bedded eolian sand up to 66-ft (20-m) thick. It underlies the late Quaternary bedforms of the central Sand Hills (Myers, 1993; fig. 12). These deposits were previously interpreted (Maroney, 1978) as the upper part of a fining-up, gravelly fluvial deposit, equivalent to the Broadwater Formation. The beds can confidently be dated as Pliocene, probably between 2.5 and 2 million yr old, based on fossil mammals assigned to the middle Blancan North American Land Mammal Age (M. Voorhies, 1994, personal communication). They are probably coeval at least in part, to the Fullerton Formation observed at stop 1. The Pliocene sediments are
Fig. 3. Generalized cross section of the South Loup River valley, showing the morpho-stratigraphic relationships among six fills.

Fig. 4. Morphology of South Loup River valley shown with cross sections. Numbers indicate distance (in kilometers) upvalley from confluence with Middle Loup River (modified from May, 1986, fig. 3.1).
somewhat finer and more poorly sorted than the dune sand of the Sand Hills (fig. 13) but were probably a major source of sand for the dune field.

Paleocurrent data (fig. 14) indicate winds were predominantly from the north with little indication of the southerly component present today. These wind directions are comparable to those recorded in the overlying Nebraska Sand Hills eolian sediments (Ahlbrandt and Fryberger, 1980) and are approximately perpendicular to the east-northeast paleocurrents reported by Maroney (1978) from the underlying fluvial sand and gravel of the Broadwater Formation.

The eolian sediments can be divided into two basic facies (fig. 15): 1) a well-sorted fine-to-medium sand facies that is dominated by horizontal to low-angle wind-ripple strata and with local granule ripples; and 2) a silty fine sand (loess?) facies usually associated with abundant biogenic traces. These traces, which include rodent burrows, root molds, and tracks, frequently mark the position of diastems. Tracks, typically seen in vertical cross-section, range up to 21.7 in. (55 cm) in diameter. Mammal burrows range up to 6 in. (15 cm) in diameter with most between 1.6 in. and 3.9 in. (4 and 10 cm). Calcareous rhizoliths occur mostly as broken tubes. High-angle eolian crossbeds occur locally, but rarely exceed a thickness of 5 ft (1.5 m).

Eolian sediments dominate our measured sections at most localities and are interbedded with thin (ephemeral?) stream deposits and diatomaceous lake beds up to 6.6-ft (2-m) thick (Maroney, 1978).

The recognition of a thick eolian sand sheet requires a major change in the paleogeographic and paleoclimatic interpretation of the Pliocene of this portion of the Great Plains.

There are up to 46 ft (14 m) of late Holocene dune sand overlying the Pliocene sand-sheet strata. D. Muhs (1994, personal communication) reported radiocarbon dates on bison bones found in a paleosol and dune sand (fig. 15). S. Stokes (1993, personal communication) determined a preliminary optically stimulated luminescence (OSL) date of about 3,000 yr BP from eolian sand 3.3 ft (1 m) above the contact with the Pliocene strata.

Stop 7. Big Creek Fen—Vibracores. At Big Creek, in central Cherry County (fig. 1), an interdune fen contains a record of late Pleistocene? and Holocene climate changes. In the present sub-humid climate, dead plant matter accumulates under anoxic groundwater conditions in the fen to form peat. The groundwater level declines during extended drought conditions, allowing the surface peat to degrade to muck. If dune-stabilizing vegetation is reduced enough, widespread eolian activity can occur. Sand sheets and dunes can then move over the interdune valley, depositing sand on the peat. With the return of a wetter climate and a resulting water-table rise, peat can begin to accumulate above the sand layer, which remains as a record of eolian activity.

Two vibracores (VC93-5 and VC94-8) were obtained from Big Creek in 1993 and 1994. The red-brown peat beginning at 17.8 ft (5.4 m) in VC94-8 (fig. 16) possibly correlates with a similar peat unit.
in Jumbo Valley, about 165 ft (50 km) to the west (fig. 1), which has yielded radiocarbon dates of 10,790 and 12,260 yr BP (fig. 17). The red-brown peat at Jumbo Valley also contains as much as 72 percent spruce pollen, according to M. Bolick of the University of Nebraska State Museum (1994, personal communication). Radiocarbon dates from the Big Creek vibracores suggest at least one significant arid episode between 4,990 and 3,800 yrs BP and shortly after 960 yrs BP (fig. 16). Three hand-auger transects at Big Creek delimited the thickness and extent of the uppermost eolian sand (fig. 18). According to C. Markley, a Conservation and Survey soil scientist who first notified Swinehart about the shallow sand sheets in interdune peats, these are common in many interdunes. Sand sheets correlating with one of the latest Holocene dune sand reactivations have been mapped at three other fens in Cherry County by M. Ponte, a UNL graduate student. Small sand mounds up to 5.3-ft (1.6-m) high and 329-ft (100-m) long occur on the fen surface and represent small, degraded eolian bedforms active during the latest Holocene. These sand sheets interbedded in the peat appear too extensive to represent sand blown out onto the fen surface from a local blowout or off a sand-dune alluvial fan. Their formation would seem to require an extended drought with an attendant groundwater-level decline and loss of vegetation, so that sand could be transported out over the interdune.

**The Vibracorer.** The vibracorer uses a concrete vibrator to set up an oscillation in a 3-in. (7.6-cm) irrigation pipe. The base of the core tube liquifies the underlying sediment, and the core tube sinks into the ground under its own weight. All vibracoring systems require the water table to be at or near the surface. Details on techniques and equipment for land-based vibracoring are available in Thompson and others (1991).

**Stop 8. Old Growler Spring.** The many deep, sand-filled artesian or "boiling" springs (which only seem to boil due to the roiling suspended sediment welling up under pressure) comprise one of the many intriguing features of the Sand Hills. Guhman and Pederson (1992) described several boiling springs along the Dismal River, including one as deep as 151.3 ft (46 m). At stop 8 are two such boiling springs, Old Growler and Little Growler. Old Growler has created a 115-ft (35-m) high amphitheater, exposing strata of the Pliocene sand sheet de-
Fig. 8. Generalized profile of Pressy Park cutbank. Radiocarbon ages are for total soil/sediment humates. A sample of bone was collected from a depth of 2.4 m (in Fill III). The collagen age was 3,030±150 yr BP (modified from May, 1986, fig. 3.13).

posit we observed at stop 6. Sand Hills dune sand caps these exposures. These springs are relatively unstudied. J. Goeke of the Conservation and Survey Division measured Old Growler and found it a minimum of 22-ft (6.7-m) deep. According to Goeke, Old Growler may be deeper because he used a line with an 24-lb (11-kg) weight and may have only reached a “null point” where the weight was not able to descend because of the greater force of the upwelling sand-and-water mixture. Old Growler is about 23 ft (7 m) in diameter and has a throat about 10-ft (3-m) wide. Goeke measured a temperature of 57 degrees F (14 degrees C) and a conductivity of 142.8 mS/cm.

Road Log

Day 1

Mileage (Mileage between directions in bold.)

0.0 Lincoln. Go west on Interstate 80 (I-80). (87.8)
116.7 Cross Middle Loup River and continue north through St. Paul. (4.3)
121.0 Cross North Loup River. Confluence of North and Middle Loup rivers is 2.5 mi east. (0.3)
121.3 Turn left (west) onto gravel road (Alexander Ave.). (1.4)
122.7 Turn left (west) just before canal crossing (Alexander Ave.). (1.7)
124.4 Turn right (north). (1.5)
125.9 Turn right (north) on Liberty Rd. and take the right branch of the fork in the road. (0.6)
126.5 Stop 1: Fullerton Canal Cut.
   Turn right (west) at exit from canal access road onto gravel road. (2.0)
128.5 Cross North Loup River. (0.8)
129.3 Elba. (0.4)
129.7 Intersection with Nebraska Highway 11 (N-11; Nebraska highways designated by "N-#"). Turn left (east) onto N-11. (1.5)
131.2 Stop 2: Cooper's Canyon Cutbank.
   Turn left onto N-11. Watch for traffic! (3.5)
134.7 Intersection of N-11 and N-92. Continue straight ahead (south) on N-11. (6.9)
141.6 Intersection of N-11 and N-58 east at Dannebrog. Continue straight ahead (south) on N-11 and N-58. (5.0)
146.6 Intersection of N-11 south and N-58 west.
   Continue straight ahead (west) on N-58. (0.6)
147.2 Well-defined terraces on the right. We are about 1.5 mi east of confluence of the Middle and South Loup rivers. (4.8)
152.0 Turn left into Boelus. (0.6)
152.6 Cross Middle Loup River. (0.3)
152.9 Cross diversion canal for power plant. Turn right (west) onto 2nd Ave. (gravel road) at the substation. (0.9)
153.8 Turn left (south). (2.5)
156.3 Cross South Loup River. Gaging station is the only one operating today on the South Loup River. (0.6)
156.9 Cross railroad tracks. Road turns to right (west). (0.3)
157.2 Turn left (south). This is/ was the town of St. Michael. (1.5)
158.7 N-2. Turn right (west) onto N-2. (7.8)
166.5 Turn right (north) onto blacktop access road to Ravenna State Recreation Area. (0.9)

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**EXPLANATION**

- Soil
- Organic-rich stratum
- $^{14}$C humate sample

**Fig. 9. Stratigraphic sections along the Chesley cutbank**
(modified from May, 1992, fig. 3).

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**Fig. 10. Profile of Chesley cutbank where paleochannel fill is present**
(modified from May, 1986, fig. 3.18).
Fig. 11. Sand Hills with generalized dune types and distributions of thick late Wisconsin (Peoria) loess deposits.

Fig. 12. Minimum extent of Pliocene sand sheet sediments in central Nebraska (after Myers, 1993).
Fig. 13. Textural comparison of Pliocene sand sheet and Holocene dunes.

Fig. 14. Paleocurrent data from Pliocene eolian (from Myers, 1993) and fluvial deposits (from Maroney, 1978).
Fig. 15. Composite stratigraphic section at the Red Ranch locality (stop 6). Unpublished paired radiocarbon dates from D. Muhs and T. Stafford (personal communication); upper number is carboxyl CO$_2$ age of bone and lower number is collagen age of same bone. Preliminary optically stimulated luminescence (OSL) date from S. Stokes (personal communication) (modified from Myers, 1993).
Fig. 16. Location of Big Creek area and isopach map of "upper" sand sheet. Topography from Mayhew Lake USGS 7.5-minute quadrangle. Auger hole data collected by M. Ponte and J. Swinehart.
Fig. 17. North-south vibracore transect at Big Creek site (fig. 16). Radiocarbon ages in years before present (*AMS date).
Fig. 18. West-east transect of the fen in Jumbo Valley based on four vibracores. Radiocarbon ages in years before present (*AMS data). Pollen record from peat in VC93-16 analyzed by M. Bolick, University of Nebraska State Museum. Pollen record shows that between 12,000 and 9,000 years ago, the vegetation changed from spruce forest to prairie with no significant evidence of an intervening deciduous forest.

167.4 **Lunch Stop.**
Leave lunch stop heading south out of the recreation area. (1.0)
168.4 N-2. Turn right (west) on N-2. (0.9)
169.3 Intersection of N-2 and N-68 at Ravenna. Continue straight ahead (west) on N-2. (2.0)
171.3 Intersection with blacktop road to Poole. Turn left on blacktop. (2.0)
173.3 Intersection with road to Poole. Continue straight ahead (west). (6.0)
179.9 Intersection of blacktop and N-10. Turn left (south) onto N-10. (3.5)
182.8 Cross South Loup River at Pleasanton. Continue straight ahead. (1.5)
184.3 Turn right (west) onto gravel road. (4.0)
188.3 Intersection of gravel roads. Stop, then continue straight ahead. (0.6)
188.9 Turn right (north) into gravel driveway. Stop at west gate. Drive west from gate into pasture toward river. (0.7)
189.6 **Stop 3: Zwiener Cutbank.**
Return to gravel road. (0.7)
190.3 Turn right (west); climb hill; curve left (south). (0.4)
190.7 Turn right (west). (1.1)
191.8 Turn right (north) at “T” intersection. (0.2)
192.0 Turn left (west). (1.0)
193.0 Intersection of gravel roads. Stop, then turn left. (2.0)
195.0 Intersection of gravel roads. Turn right (west). (6.8)
201.8 N-40. Turn right (northeast) onto N-40. (2.3)
204.1 Intersection of N-40 and US-183 in Miller. Continue straight ahead (northwest) on N-40. (26.1)
230.2 Intersection of N-40 and N-21 at south edge of Oconto. Turn right (north) onto N-21. (5.1)
235.3 Cross South Loup River and turn left into Pressy Park. (0.7)
236.0 **Stop 4: Pressy Park Cutbank.**
Return to N-21. (0.7)
236.7 Turn right (south) onto N-21. (0.6)
237.3 Turn right (west) onto oiled gravel road. (8.7)
246.0 Turn left (west) onto blacktop road. (7.5)  
253.5 Stop sign just past water tower in Callaway. Turn right (north) onto blacktop road heading north out of town. (7.5)  
261.0 Outcrops of volcanic ash on right during next 0.8 mi. (3.8)  
264.8 Turn left onto gravel road. (1.1)  
265.9 Turn right into alfalfa field. (0.5)  
266.4 **Stop 5: Chesley Cutbank.**  
Return to blacktop road. (1.6)  
268.0 Turn left (west) onto blacktop road. (6.9)  
274.9 Intersection of blacktop road, N-92 and N-70. Turn left (west) and continue west through Arnold. (16.1)  
291.0 Intersection N-92, N-70, and US-83. Turn right (north) onto US-83. (5.2)  
296.2 Cross South Loup River. Headwaters are 12 mi west. (35.0)  
331.2 Intersection of US-83 and N-2 in Thedford.  

**Day 2**  

0.0 Leave Arrowhead Motel in Thedford and head west on N-2. (9.0)  
9.0 Cross Middle Loup River for the third time. Sand and gravel pits along river mine the Broadwater Formation equivalent (Pliocene). (7.0)  
16.0 Junction of N-2 and N-86A. Turn north to Seneca. (0.3)  
16.3 Turn east on north side of Burlington Railroad tracks. (0.6)  
16.9 Stop after crossing Middle Loup River. (0.9)  
**Stop 5: Red Ranch**  
17.8 Return to N-2 and turn west towards Mullen. (4.2)  
22.0 Kelso archaeological site to north, one of only a few published sites within the Sand Hills. Described by Kivett (1970) as a woodland complex (a riparian-based culture) site containing a paleosol dated at 1,150±200 yr BP and overlain by few meters of eolian sand. (7.1)  
29.1 Intersection of N-2 and N-97 in Mullen (population 750). Turn north on N-97, across railroad tracks; jog right, then left. (1.7)  
30.8 Descend into Middle Loup Valley and cross Middle Loup River. Exposures of Broadwater Formation equivalents just above river level overlain by Pliocene sand sheet unit containing a 6.6-ft (2-m) thick diatomite. (1.9)  
32.7 Hooker/Cherry county line. Gradually leave region of small, highly modified megabarchan dunes and enter area where barchanoid-ridge dunes (typically 5-mi [8-km] long and 215-ft [65-m] high) predominate. (17.5)  
50.2 Enter Big Creek Valley and fen. Turn west to Stichka ranch.  
**Stop 6: Big Creek Fen/Vibracore**  
Lunch  
Return to Mullen. (21.3)  
71.5 Intersection of N-2 and N-97 in Mullen. Continue south on N-97. (4.8)  
76.3 A typical complex barchanoid-ridge dune visible to northwest and northeast. It is about 2.5-mi (4-km) long and rises a maximum of 230 ft (70 m) above the adjacent interdune. Small linear dunes are superimposed on dunes in this area. (8.7)  
85.0 Enter Dismal River valley. Exposures of the Pliocene sand sheet unit and Holocene pre-dune fluvial sediments. At two sites within 3.7 mi (6 km) upstream, organic-rich units in the fluvial sediments yielded radiocarbon ages between 8,400 and 3,500 yrs BP (Ahlbrandt and others, 1983). The Dismal River valley appears to be younger than 3,500 years. (0.3)  
85.3 Cross Dismal River at junction of North and South forks. Almost all rivers and streams within the Sand Hills have exceptionally uniform flows derived almost entirely from groundwater seepage (Bentall, 1990). Just downstream is a "boiling" sand spring up to 145-ft (44-m) deep (Guhman and Pederson, 1992). (23.4)  
108.7 Intersection of N-97 and N-92 just west of Tryon. Head west on N-92. (18.5)  
127.2 Turnoff on asphalt road to Diamond Bar Lake near milepost 185. Turn south. (2.5)  
129.7 End of asphalt. Diamond Bar Ranch Rd. and Lake to west. (5.9)  
135.6 "T" intersection; turn west. (1.7)  
137.3 Turn south across cattle guard on gravel ranch road. Watch for loose sandy areas. (1.6)
Bear southeast--center-pivot irrigation to southwest. (2.1)
Descend into valley of West Birdwood Creek; cross creek and park on south side. Walk east along north side of creek.

**Stop 7: Old Growler Spring**
Return to "T" intersection. (3.7)

"T" intersection; turn east. (2.7)

Turn south. (2.0)

Turn east. (5.0)

Turn south onto asphalt road. (3.0)

Cross West Birdwood Creek. (11.9)

Leave the Sand Hills and cross the North Platte River. (1.7)

Cross railroad and canal. (1.8)

Intersection with N-30 at east edge of Sutherland. Turn west. (0.6)

Turn south on N-25 in Sutherland. (1.2)

Turn east onto 1-80 after crossing South Platte River. Return to Lincoln on 1-80. (243)

End of field trip.

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Quaternary and Engineering Geology of the Lincoln, Nebraska, Area

Field Trip No. 3

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Introduction

Lincoln, Nebraska, was established in 1867 as the state capital on the site of the village of Lancaster. It was picked as an alternative location to the two cities on the Missouri River that were competing for the government site, Omaha and Bellevue. Early in its history, most of the city developed on the east side of Salt Creek, but the community has grown eastward so that now it takes up the entire upland between Salt Creek and one of its major tributaries, Stevens Creek (fig. 1). The city has also spread west of Salt Creek and three of its tributaries, Haines Branch, Middle Creek, and Oak Creek.

The part of the community located on the floodplain of Salt Creek was affected by flooding frequently from the time the village of Lancaster was established (Otteson and others, 1966?). Channelization, which began early in this century, helped, but flooding was a common event, with property damage and occasional deaths, until nine flood-control reservoirs were completed on tributaries of Salt Creek in the 1960s.

Most of the city is situated on an upland that is underlain by loess, till, Pleistocene fluvial and lacustrine sediments, and a bedrock surface that had considerable relief before it was buried beneath the glacially derived materials. Bedrock of the Dakota Formation (Upper Cretaceous) crops out in several places in and near Lincoln where Salt Creek and its tributaries have removed the overlying sediments. The Dakota has served as the raw material for brick making, and the Yankee Hill Brick Company, on the southwestern edge of the city, has been in operation since the 1880s. Sandstone from the Dakota is generally poorly cemented, but in the late 1800s, it was quarried a few miles north of Lincoln for dimension stone. The main part of the wall in front of the restored courthouse, on "O" Street between 9th and 10th, shows how this rock unit has weathered in more than a century of exposure.

Where sandstone exposures are absent, the surface of bedrock may be as deep as 100 ft (30 m). Nearly all buildings in the city that exceed four floors in height are built on piling that extends to the rock surface, although one, the First National Bank building at 13th and O streets, was constructed on a thick "floating" mat of reinforced concrete.

An area that was buried at least twice by glacial ice, where drainage was northeastward toward the ice and where the landscape was blanketed by loess during the Wisconsanian glaciation, offers a wide range of Quaternary materials that must be considered in any construction. In addition, not all the tributaries of Salt Creek are controlled by reservoirs, and the expansion of residential and business developments on the slopes south of Lincoln has increased runoff into Beal Slough, causing frequent flooding during storms.

Prior to the Wisconsanian glaciation, a Yarmouth-Sangamon soil profile had formed on the surface of the pre-Illinoian till in eastern Nebraska. This soil profile, with its argillic B horizon, lies beneath the Peoria Loess, which veneers the surface. Erosion has thinned the loess away from the crests of the hills, so that the paleosol emerges on slopes. Where the loess is thicker, the buried paleosol serves as a layer of lower permeability, which results in a temporary perched water table during the spring and early summer months. Many basements that penetrate the basal part of the loess may become wet when the perched water table develops, although they are dry the remainder of the year.

The matrix of the uppermost pre-Illinoian till is a calcareous silty clay or clayey silt that is fractured by a polygonal joint pattern. The fractures are bounded by zones of oxidation and/or precipitation of limonite, the oldest and most distinctive of which are more than 3.9 in. (10 cm) wide on each side of the fracture. These may also contain sheets or nodules of secondary calcium carbonate that extend 9.8 to 13.1 ft (3 to 4 m) beneath the surface (Wayne, 1985). These fractures are clear evidence that the pre-Illinoian till body as a whole is significantly more permeable than is the unfractured till.

A second till is present beneath the surface, although it rarely becomes exposed. In the few
Fig. 1. Lincoln and vicinity, showing locations of stops.
places where it has been observed, it is dark gray, calcareous silty clay or clayey silt that contains scattered pebbles and cobbles. It resembles the till that was called "Nebraskan" by Shimek (1909) and is exposed at the base of the bluffs of the Platte River at Fremont, Nebraska (Wayne, 1987). A similar till rests on the bedrock surface at the limestone quarry at Crescent, Iowa.

In Nebraska, a Great Plains state, landsliding might be viewed as unimportant. Nevertheless, slumps and earthflows take place regularly, particularly in Quaternary sediments (Wayne, 1990). Many of the slumps and earthflows occur where slopes have been oversteepened for a road or railroad cut or for channelization of a stream. The basin of Salt Creek in and near Lincoln contains a loess-covered till that overlies lacustrine sediments that were deposited when the northeastward-flowing predecessor of Salt Creek was ponded by the advancing early to mid-Pleistocene glaciers. These lake sediments are particularly susceptible to landsliding.

Much of the University of Nebraska-Lincoln (UNL) downtown campus is built on a terrace that is underlain by silt and fine sand that was deposited during the late Wisconsinan glacial maximum. Excavations within the city's downtown commonly expose the buried Sangamon paleosol at a depth of 16 to 20 ft (5 to 6 m) beneath the surface of this terrace, which is 26- to 33-ft (8- to 10-m) higher than the present floodplain of Salt Creek.

This surface was deeply incised by streams that drained the region during the Wisconsinan glaciation, and a bed of soft gray silt that contains wood fragments and peaty material has been encountered at depths of 26 ft (8 m) and greater in test borings in some of the valley floors. These organic materials are young; radiocarbon dates place them in the range of 10,000 to 14,000 years old.

In Stevens Creek, a major tributary of Salt Creek just east of Lincoln, black clayey silt was encountered in test holes for a proposed damsite between 25 and 33 ft (7.6 and 10 m) beneath the floodplain surface. A radiocarbon date from the bottom of this organic-rich sediment is 9760±100 yrs BP (Beta 73244). Dates of wood fragments and of peat collected from samples of silt recovered from beneath the floodplain of a tributary of the Elkhorn River at a proposed damsite southeast of Norfolk are slightly older. They range in age from about 10,000 to 13,500 yrs BP.

These young lacustrine silt beds that contain organic matter are soft, and they have a low hydraulic conductivity, two features that have considerable significance in engineering geology studies. Their low strength is important in foundation investigations, and the low permeability indicates that fluid migration through the sediment would be very slow. That such sediments were encountered at relatively similar depths beneath the surface of the floodplains of both Stevens Creek and Butterfly Creek suggests that similar lake sediments may be present under many of the tributaries of the Platte River in eastern Nebraska. Their recognition provides an explanation for one of the anomalies encountered in test holes in some of the valleys of east-central Nebraska.

These dates indicate that the streams of east-central Nebraska have cut downward to a base level that was significantly lower than the present during late Wisconsinan time and again during the Holocene. Because Salt Creek and the Elkhorn River are tributaries of the Platte, which flows into the Missouri River, that trunk stream must also have cut its channel deeper at those times. The lower base level during the late Wisconsinan could have been caused by adjustment of the Mississippi-Missouri system to the lowering of sea level during the Wisconsinan glacial maximum. Later, when meltwater from the James River Lobe flowed down the Missouri River, the rising base level of this master stream resulted in aggradation and local ponding in tributaries.

**Stop 1. Road Cuts Along U.S. 77 North of Lincoln**. Exposures of the sediments that underlie the surface in eastern Nebraska are not common. A rolling topography, loess cover on the uplands, and thick alluvial fill in most valleys make natural exposures scarce, so most of the places to examine the Pleistocene sediments are cuts along highways, railroads, quarries, and, of course, landfills.

The upland is a dissected surface on pre-Illinoian till that was covered with a veneer of loess during the Wisconsinan glaciation. Post-Wisconsinan erosion has removed the loess from most slopes, so cuts through hills or ridges generally expose a lens-shaped cap of loess that overlies a weathered till surface. These materials are slowly permeable, so much of the precipitation during high rainfall events runs off, eroding the slopes and often exceeding channel capacity of streams.

Construction began in 1993 to make U.S. Highway 77 a four-lane road northward from Lincoln; the more southerly cuts have been grassed, but new ones are being made as construction moves northward. Most of the cuts expose till capped by Peoria Loess 6.6- to 9.8-ft (2- to 3-m) thick. A thin layer of dark gray silty clay that underlies the Peoria Loess in many of the exposures—the Gilman Canyon bed—rests on till, the upper part of which has been weathered. This weathered zone, the Sangamon paleosol, generally is a compact clay loam, with a B horizon that is strong brown (7.5YR 4/4), has a subangular blocky structure, and is 2.3- to 3.3-ft (0.7- to 1-m) thick. The unweathered till is grayish brown (2.5Y 5/2), calcareous clayey silt; large clasts are not
abundant, but cobbles and boulders of one lithology, light red Sioux Quartzite from southeastern South Dakota, are noticeable. Fractures extend downward into the till through the buried solum, are bordered by an oxidation zone 3.9-in. (10-cm) wide on each side, and commonly contain nodules or a sheet-like filling of secondary calcium carbonate. The secondary calcium carbonate disappears about 9.8 ft (3 m) beneath the paleosol and may have formed in desiccation cracks that remained open for very long periods during an earlier interglaciation, perhaps Yarmouth (Wayne, 1985).

Stop 2. Lincoln Landfill. After the landfill along Salt Creek that Lincoln had used since 1959 became nearly full, a search began for a new site. One was chosen along U.S. Highway 77 following a long selection process, and preparation began for its use in 1987-1988. The geologic materials at this site are dominated by till, and no potential aquifers were recorded within 100+ ft (30+ m) of the surface. The hydraulic conductivity of the till is low, although it is cut by a polygonal joint pattern like that observed in the road cuts. The site was built with an underdrain and a base liner made of recompacted till. Dumped refuse is compacted regularly and covered daily. Any leachate generated is recovered for proper disposal.

Stop 3. Oak Creek Earthflow, Lincoln, Nebraska. Oak Creek, a major tributary of Salt Creek, was channelized into a U-bend around the south end of the Lincoln airport in the late 1940s to accommodate a longer runway for large military aircraft. At the south end of the bend, the bank is about 65.5-ft (20-m) high where the new channel was cut through a spur of the upland. The cutbank was graded to 20 degrees and was stable from the time it was made until the spring of 1977, when it began to fail as a small slump near the top of the slope with a bulge above the base.

The base of the sloped embankment exposed a small outcrop of the Dakota Sandstone, but the remainder of the cut consists of Pleistocene sediments (fig. 2). Directly overlying the sandstone is 22.9 ft (7 m) of very dark gray smectitic clay that has a low shear strength and a high water content. Field-moisture content of a sample collected in fall 1989 was 32 percent by weight; organic material was 0.87 percent of the dry sample. During one of the early years of slide activity, a large block of very dark gray till was shoved to the surface in the middle of the slide. Similar till is present below the middle of the slope at the east side of the earthflow and underlies the black clay. Till about 19.6-ft (6-m) thick caps the section. Loess once covered the till here, but it has since been removed by excavation to provide fill for an additional runway.

In 1977, after an unusually wet spring, movement began as a small slump-earthflow. By the following year, a lobe had moved into the edge of the channel and a 16.4-ft (5-m) high main scarp had formed at the top of the bank. The upper surface of the slump block tilted slightly toward the main scarp, and a shallow pond formed on it. One cause of the earthflow probably was vibrations from sound waves from F-4 aircraft engines, which were tested in 1977 by the Air National Guard north of the high bank. Even though the testing ended within a year or two, flow has continued during all periods of high precipitation since. By 1990, the earthflow had become about 328-ft (100-m) long and 328-ft (100-m) wide. The sheet of material in the slide above the plane of failure varies from 3.9 ft (1.2 m) to 9.8 ft (3 m) in thickness. The volume of debris involved is about 706,000 ft³ (20,000 m³).

Movement is spasmodic; not all parts of the earthflow move at any particular time. By 1979 a small grove of popular trees had taken root and began to grow vigorously on the slump block below the main scarp. The trees grew there for a few years, but during the wet spring and early summer of 1985, after two previous wet years, the entire grove moved downslope 65.6 to 82 ft (20 to 25 m). Most of the trees continued to grow there for a few more years. By 1989, though, all but three of the trees had been tipped over and buried in the flowing debris. By 1994 the few remaining trees had moved downslope another 65.6 ft (20 m). The toe of the earthflow never has completely dammed the channel of Oak Creek.
Creek, but it has nearly done so at least twice.

The zone along which flowage seems to be most active is 8- to 12-in. (20- to 30-cm) thick and lies from 4.9 to 9.8 ft (1.5 m to 3 m) beneath the surface of the earthflow. During periods of movement, it is saturated and easily distinguishable from the undisturbed sediment beneath it in hand-auger holes. Water enters the earthflow by infiltration from the flat surface below the main scarp, but more importantly, through many transverse fractures on the surface of the flow.

Stop 4. Burlington-Northern Cuts West of Lincoln. The cuts along the Burlington-Northern Railroad at the U.S. Highway 6 overpass west of Lincoln have failed repeatedly during the 1970s and 1980s. The cuts have been made at a standard slope for unconsolidated sediments, about 20 degrees, which is stable much of the time, but vibration from passing trains and increased moisture during the spring has resulted in earthflows in the Quaternary sediments.

The base of both groups of cuts is in sandstone of the Dakota Formation, and the material that overlies it is olive-gray to dark gray silty clay. Ice overrode the area, and till is present near the top of the westernmost cut (fig. 3), but only a lag of cobbles remains beneath a veneer of loess on the cuts east of the overpass.

All cuts were reshaped in 1977-1978 when a second track was added along this line; twice since then, though, slope failures have tilted the power poles and debris has flowed into and blocked the drainage ditch along the railroad. The triggering factor for each failure must be the vibrations of train traffic, but the high moisture content and low wet strength of the clay-rich lacustrine sediments in the lower part of the exposures greatly reduce the stability of the material.

Most recently, in 1990, the north-facing slope between U.S. Highway 6 and the county road bridge began to slump toward the rail line. In 1993-1994 it was reshaped and benched to stop further movement. The south-facing slope shows the tumbled surface of slumps and earthflows, although it seems to have stabilized naturally.

Stop 5. Beal Slough at Salt Creek. Stream-bank exposures along Salt Creek through Wilderness Park in Lincoln, as well as some of the other streams of eastern Nebraska, show that several periods of cutting and filling have taken place during the Holocene. One of the more distinctive sediments is a black gyttja-like material that can be seen in the lower part of the banks and in the bed of the stream (fig. 4). This particular sediment is dark gray to black clayey silt, the bottom of which is 3.3 to 4.3 ft (1 to 1.3 m) beneath the bed of the creek. It rests on coarse sand. A radiocarbon date of material from the basal 1.9 in. (5 cm) of a core at this location is 5150±80 yr BP (Beta 52163). This date indicates that Salt Creek was flowing at a somewhat lower level than today. The lower base level may be related to the more humid conditions that accompanied the onset of Holocene glaciations in the mountains.

The channel of Salt Creek meandered across the floodplain surface, and at this site a younger cut and fill has been exposed from time to time (fig. 4). Along this meander cut one can also see at the top a layer of "postsettlement alluvium" about 3.3-ft (1-m) thick, which lies on a Mollisol-like profile that had formed on the underlying floodplain sediments.

Stop 6. Beal Slough Culvert, Flooding History. Starting in the early part of this century, efforts to reduce regular flooding in Lincoln and accompanying damage began with the channelization of Salt Creek through the city. This procedure moved the water out faster but also increased the flood frequency downstream. Eventually, all of Salt Creek and its tributaries were channelized, from the upstream edge of the city to the junction of Salt Creek with the Platte River near Ashland. Flood damages continued, however, because runoff from the urbanizing upland continuously stressed the channel capacity during large storms and because development continued on the floodplain.

From 1960 to 1970, nine multipurpose reservoirs were built on Salt Creek and its tributaries for flood control and recreation. Reservoirs were built on all of the major tributaries upstream from Lincoln, and they have been effective in reducing flood damage in the city. At the time they were planned,
Fig. 4. Sediments exposed in the bank on the outside of a meander of Beal Slough, near the junction with Salt Creek in Wilderness Park, Lincoln.

however, Beal Slough drained a small basin that was completely rural and offered a very minor flood threat. At that time, and until 1977, Lincoln’s zoning did not restrict construction on floodplains. When the housing subdivision along the north side of Beal Slough and east of 40th Street was planned in the mid-1960s, the developer raised the land adjacent to the creek to the level of the low terrace to the north, and the three houses nearest to the creek were built partly on the fill. At that time the 40th Street bridge over Beal Slough had a single small opening, but it had been adequate to carry stormwater from the part of the basin upstream.

By 1970 commercial and residential land development had begun to cover the slopes on the south side of Beal Slough as far upstream as 56th Street. A severe storm in October 1973 caused the discharge of the stream to exceed the capacity of the opening beneath the 40th Street bridge, and water flowed over the street, coming within one foot of the floor of the house northeast of the bridge. During the next few years, urbanization continued on the slopes of the basin, and almost every year, at least one storm caused water to flow across the bridge.

When Nebraska Highway 2 was expanded to four lanes in 1983, the road bed of 40th Street was raised and the capacity of the bridge openings increased by about 300 percent. Nevertheless, at least three storms since that enlargement have dumped enough water into Beal Slough to cause water to flow across the top of the bridge (1984, 1986, 1989).

Although since 1977, Lincoln has had an ordinance that prevents construction of residences on floodplains, urbanization of the slopes continued, and stormwater reaches Beal Slough even more rapidly. During the mid-1980s, the commercial structures just east of 56th Street on the south side of state Highway 2 were damaged repeatedly by high water.

In 1993 the city began to require land developers to include storage basins to prevent stormwater from leaving the developed land faster than it would have prior to urban development. Although this requirement is still in its infancy, it surely will help prevent further flooding of this channel. After we leave this location, we will drive beside one of these new subdivisions.

**Stop 7. Schwark Quarry.** This quarry has been in continuous operation by the same owner since 1953 and is the only active quarry today in an area that supplied dimension stone for local construction during the 1860s. At least five of the homes still standing in or near Roca, Nebraska, were built with stone from one of the abandoned quarries nearby. The beds of limestone used for this purpose now serve as a source for stone used in landscaping and retaining walls. Some can be seen on the UNL downtown campus north of Love Library.

This quarry is difficult to operate because it includes much waste rock that is too shaly for any commercial use and because the overburden becomes too thick to remove economically as the opening is extended into the upland. Exposure of that overburden, though, has provided considerable information about the Quaternary deposits of the area. At this time (1994), the east part of the quarry is not being worked actively, and Mr. Schwarck has reopened the west side.

The east highwall of the quarry exposes the uppermost pre-Illinoian till of this part of Nebraska (fig. 5), which has a strongly developed Sangamon-Yarmouth paleosol with a strong brown (7.5YR 4/4) B horizon and well-developed subangular blocky ped structure. This buried paleosol is overlain by about 13.1 ft (4 m) of Peoria Loess. The calcareous silty clay till is extensively jointed; the fractures are filled with chalky calcium carbonate and bordered by 1.9-in. (5-cm) wide oxidized bands. The till rests on a noncalcareous bed of brown (10YR 5/5) clay, the lower part of which becomes silty clay.
change in grain size to silt is a zone of secondary calcium carbonate about 3.3-ft (1-m) thick. Beneath this zone the sediment consists of beds of pure silt that display climbing-ripple cross-bedding. A lens of a very boulder-rich diamicton underlies the silt beds and rests on the limestone.

In the early 1970s the active quarry was on the west side of the county road, and the highwall along the south side exposed a series of climbing-ripple-marked cross beds, each separated by a thin layer of clay (fig. 6). Stanley (1974) interpreted them to be varves produced as density flows into an ice-marginal lake. The silt layers, produced by summer meltwater, with their winter cap of clay, became progressively thinner upward, and the rhythmite character disappeared completely in the nearly massive clay beneath the till cap. He regarded the boulderly diamicton at the base to be an ice-marginal debris cone from the margin of the glacier that served as the dam for the lake into which the ripple-bedded silt came as a density flow. The overlying till represents a later readvance of the ice.

Waste rock has been dumped into some of the worked-out parts of this quarry, and the owner is reclaiming those areas for future use as farmland. Even though Nebraska never has adopted a reclamation requirement for mineral operations, some of the quarry and gravel-pit operators recognize the importance of reclaiming the land to avoid leaving only holes in the ground.

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**Road Log**

Mileage (Mileage between directions in bold.)

0.0 Start from Morrill Hall (State Museum) at 14th and Vine Sts. and drive eastward on Vine St. (1.0)
1.0 Turn north (left) on 27th St. (4.5)
5.5 Turn east (right) on U.S. Interstate 80 (I-80). (2.3)
7.8 Leave I-80 and turn north (left) on U.S. Highway 77 (US-77; U.S. highways designated by US-#). (6.2)
14.0 Stop along road at fresh road cut (distance measured to Davey Rd.).
   **Stop 1: Road Cuts Along US-77 (under construction).** Turn around and return southward. (5.0)
19.0 Bluff Rd.; turn east (left). (0.3)
19.3 Entrance to Lincoln Municipal Landfill.
   **Stop 2: Lincoln Municipal Landfill.** Turn west (left) on leaving landfill. (0.3)
19.6 Turn south (left) on US-77. (1.2)
20.8 Turn southwest (right) on I-80. (10.1)
30.9 Leave I-80 at Exit 395 and turn north (right). (0.7)
31.6 Turn east (right) on gravel road. (1.0)
32.6 Turn around and stop at end of road.
   **Stop 3: Oak Creek/Airport Earthflow.** Leave autos and walk along fencrow for about 0.25 mi; then
go along edge of woods to road and follow it upslope to top. Return to autos by the same route and
drive west. (1.0)
33.6 Turn south (left) on paved road. (1.0)
34.6 Turn west (right) at US-6. (1.5)
36.1 Emerald--reduced speed zone. (1.3)
37.4 Stop along road on top of hill just west of overpass. (0.7)
   **Stop 4: Burlington Railroad Cuts at US-6.** This stop consists of two parts. The cuts on the southwest
side of the overpass were stable in the fall of 1994, after having been repaired a short time earlier, but
the slump on the northwest side has not been repaired. After having examined these cuts, we will
return to the autos and drive 0.2 mi to the east, turn north (left) another 0.2 mi and look at a second
set of cuts that has been unstable.
38.1 Turn east (left) on US-6. (5.5)
43.6 Turn south (right) on US-77. (2.5)
46.1 Turn east (left) on Pioneers Blvd. (at traffic light). (0.6)
46.7 Cross Salt Creek and enter parking area for Wilderness Park. (0.8)
   **Stop 5: Beal Slough at Salt Creek.** Leave autos and follow path northeast to swinging bridge. This is
the channel of Beal Slough, which has been straightened upstream from Wilderness Park but returns
to a meandering stream here in the park. The change has resulted in severe bank erosion along the
meanders. (If water in creek is low, we will go down to it and look at materials; if it is running high,
we will discuss it from the top of the bank). Return to autos and drive eastward (left) on Pioneers
Blvd.
47.5 Turn southeast (right) on N-2 (Nebraska highways: N-#), then east past the state penitentiary. (2.3)
49.8 Turn north (left) on So. 40th St. and enter parking area. (1.5)
   **Stop 6: Beal Slough Culvert and Flooding History.** Return to intersection of So. 40th St. and N-2.
Cross N-2 and drive southward on 40th St., observing the extent of residential development on the
slopes that drain into Beal Slough.
51.3 Turn east (left) on Pine Lake Rd. to So. 56th St. The new development on the south side of the road
was started after the city began in 1993 to require catchment basins to reduce the rate of runoff from
urbanizing areas. (1.0)
52.3 Turn south (right) on 56th St.; except for a large commercial development at the southeastern corner of
N-2 and So. 56th St., the part of the basin of Beal Slough that lies east of 56th St. is still largely rural at
this time (1994). (3.0)
55.3 Turn west (right) at Saltillo Rd. (0.2)
55.5 Turn south (left). (1.6)
57.1 Drive into quarry entrance. (0.3)
57.4 **Stop 7: Schwarck Quarry.** Follow quarry road 0.26 mi to area of highwall at east side of operation.
(0.3)
57.7 Return to county road; turn north (right). (1.5)
59.3 Saltillo Rd.; turn west (right) at "T" intersection. (1.9)
61.1 Cross Salt Creek bridge at south end of Wilderness Park. (0.9)
62.0 14th St. road; turn north (right). (1.4)
63.4 Cross bridge over Salt Creek channel again. (4.0)
67.4 Turn northwest (left) on N-2 beside state penitentiary and continue northward on 10th St. (3.4)
70.8 Follow 10th St. into UNL campus, bending east (right) past stadium, along south side of railroad
tracks. (0.7)
71.5 Turn south (right) on 14th St. at traffic light. (0.3)
71.8 14th and Vine Sts.; Morrill Hall is one block ahead.

References Cited

The development of a program for the Salt-Wahoo watershed in Nebraska: University of Nebraska Agricultural Experiment Station, SB490, 54 p.
The White River Group Revisited: Vertebrate Trackways, Ecosystems, and Lithostratigraphic Revision, Redefinition, and Redescription

Field Trip No. 4

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Introduction

The White River Group represents the fluvial, eolian, and lacustrine accumulation of epiclastic and volcaniclastic sediments on the Great Plains during late Eocene to middle Oligocene time. Early studies of the White River Group were mostly concerned with collecting and documenting fossil vertebrates (Leidy, 1853; Meek and Hayden, 1857; Schultz and Stout, 1955; Schultz and Falkenbach, 1968). Subsequent research, in addition to vertebrate paleontology, has focused on stratigraphy, sedimentology, geochronology, magnetostratigraphy, and paleoclimatology (Swinehart and others, 1985; Tedford and others, 1985; Swisher and Prothero, 1990; Prothero and Berggren, 1992).

In recent years geologists and paleontologists working on Paleogene rocks and faunas have concluded that the current White River Group lithostratigraphy in Nebraska is inadequate. Work within each region has resulted in a proliferation of unit names and descriptive criteria, with little contribution toward understanding White River Group stratigraphy and sedimentation (fig. 1). Most established unit boundaries cannot be traced out of the type areas in Nebraska and South Dakota. Early attempts at correlation (Schultz and Stout, 1955) between Nebraska and South Dakota were based on assumptions we now recognize as invalid, and the Nebraska lithostratigraphy does not conform to the current North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983). Tedford and others (1985) attempted correlation for the upper part of the White River Group. However, no revision or redescription has successfully addressed these problems.

Recent lithostratigraphic correlations between the Big Badlands of South Dakota and the Toadstool Park area of northwestern Nebraska by Terry and LaGarry, and detailed geologic mapping of northwestern Nebraska by LaGarry and Armantrout have provided large amounts of previously unavailable data. Based on this new data, Terry and LaGarry (in preparation) have constructed a revised White River Group lithostratigraphy that will be formally introduced elsewhere. This stratigraphy (Terry and LaGarry, 1994) is based on the areal distribution and internal variation within the Eocene Chamberlain Pass and Chadron formations (South Dakota and Nebraska), the repositioning of stratigraphic boundaries within the Brule Formation (Nebraska), and the inclusion of a new formation and two new members within the White River Group (Nebraska). Also, our recent studies have provided new data regarding the depositional environments and paleoecology of the Orella Member of the Brule Formation in northwestern Nebraska (Wells, 1994; Wells and others, 1994), along with new data from a large number of associated trackways and invertebrate ichnofossils within the Toadstool Park Channel Complex (Nixon, 1991; Nixon and LaGarry-Guyon, 1993a, 1993b). The purposes of this field guide are threefold: 1) to introduce field trip participants to the revised White River Group lithostratigraphy; 2) to describe the
Fig. 1. History of White River Group stratigraphic nomenclature and correlations in South Dakota and Nebraska in comparison to the lithostratigraphy discussed in this field guide. Thickness of some units distorted to illustrate equivalency. Asterisks denote palyno zones.
depositional environments of the Orella Member; and 3) to briefly describe the Toadstool Park Trackway Site.

Geologic History
and Stratigraphic Nomenclature

South Dakota

Onset of the Laramide Orogeny, regional uplift, and the retreat of the Cretaceous Interior Seaway resulted in the deep weathering of subaerially exposed Cretaceous through Eocene strata from Colorado to North Dakota. This deeply weathered zone was called the Eocene Paleosol by Pettyjohn (1966). Within the Big Badlands of South Dakota this weathering profile modified the typically black or brown Pierre Shale to a bright yellow and lavender color. Retallack (1983) classified this zone as the Yellow Mounds Paleosol Series. The first phase of post-Yellow Mounds Paleosol fluvial activity is represented by the Chamberlain Pass Formation (Evans and Terry, 1994). The Chamberlain Pass Formation is composed of the reddish Interior Paleosol Series of Retallack (1983), sometimes described as a red band at the top of the "Eocene Paleosol," and isolated white channel sandstone deposits originally assigned to the Slim Buttes Formation by Clark and others (1967). With continued tectonic development of the Black Hills, drainages began dissecting the Chamberlain Pass Formation, the Yellow Mounds Paleosol, and the Pierre Shale. Deposition of the Chadron Formation subsequently filled these paleovalleys. Clark (1937, 1954) and Clark and others (1967) divided the Chadron Formation of South Dakota into the Ahearn, Crazy Johnson, and Peanut Peak members. These members were defined to differentiate fluvial and lacustrine deposits that filled a specific paleovalley, called the "Red River Valley" (Clark, 1954; Clark and others, 1967). In general, these strata represent a shift from deposition dominated by channel facies to deposition dominated by overbank facies during backfilling of the paleovalley. Once filled, deposition proceeded outside of the paleovalley. Outside of the "Red River Valley," the Chadron Formation consists of bluish or olive-gray mudstones that weather into rounded hummocks. Individual members are not recognized outside of the "Red River Valley." The top of the Chadron Formation in the Big Badlands is commonly marked by a limestone that appears to represent a period of geomorphic stability. Specific outcrops of these limestones (see Welzenbach and Evans, 1992) have been referred to as the "Bloom Basin limestone bed(s)." These limestones were in turn overlain by the silty claystones, clayey siltstones, and siltstones of the Scenic and Poleslide members of the Brule Formation.

Northwestern Nebraska

The most widely used classification of White River Group sediments in Nebraska (fig. 1) is that of Schultz and Stout (1955). They divided the White River Group into the Chadron and Brule formations at the "upper purplish-white layer," a locally persistent marker bed. The Chadron and Brule formations were likewise subdivided into members, and in turn the members into stages at other locally persistent marker beds. Schultz and Stout (1955) defined the stratigraphy in this way to better constrain the stratigraphic occurrence of fossil mammals collected from the White River Group in northwestern Nebraska. This use of locally persistent marker beds in locating the stratigraphic position of fossils is a common and accepted method. However, defining lithostratigraphic units based on event beds rather than lithology is in violation of the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983). Therefore, such use of event-bed boundaries should be discontinued in favor of a lithostratigraphic-based classification. Souders (1981) and Swinehart and others (1985), using extensive subsurface data, began this by following Darton's (1899) classification and restricting the Chadron Formation to the claystones, mudstones, and associated sandstones at the base of the White River Group. Pertinent details of Darton's (1899), Schultz and Stout's (1955), and Swinehart and others' (1985) classifications, along with proposed lithostratigraphic revisions, are discussed at length within the following field-trip stop descriptions.

Vertebrate Trackways and
White River Group Lithostratigraphy

The field-trip stops (fig. 2) are located within the Buffalo Gap (stop 1) and Oglala National grasslands (stops 2-4), which are administered and managed by the Nebraska National Forest (U.S. Department of Agriculture Forest Service), Chadron, Nebraska. Excavating any non-vertical surface is illegal without a Special Use Permit issued by the Nebraska National Forest. Collecting fossil vertebrates is also illegal on U.S. Forest Service lands without a Special Use Permit from the Nebraska National Forest. Currently the Oglala National Grassland is closed to permit-regulated collecting of fossil vertebrates pending completion of fossil-resource inventories by the University of Nebraska State Museum (LaGarry-Guyon, 1994). As is the case with any field trip, please be mindful of yourself and others when climbing steep slopes, especially when they are wet.

Stop 1. Oelrichs, South Dakota. Our first stop is at Limestone Butte, 1 mi (1.6 km) east of Oelrichs, South Dakota (fig. 2). As in the Big Badlands (fig.
Fig. 2. Location map of measured sections (numbered circles) visited during this field trip. Stop 1: Limestone Butte, 1 mi east of Oelrichs, South Dakota in the S1/2, SW1/4 sec. 16, T. 10 S., R. 8 E., Oelrichs 7.5-minute Quadrangle. Stop 2: east end of Sugarloaf Road, Dawes County, Nebraska in the S1/2 sec. 17, T. 34 N., R. 52 W., Wolf Butte 7.5-minute Quadrangle. Stop 3: 1 mi north and 3 mi west of Toadstool Park along the Montrose Road at "Orella Bridge," Sioux County, Nebraska, in the NE1/4, NE1/4 sec. 8, T. 33 N., R. 53 W., Roundtop 7.5-minute Quadrangle. Stop 4: Toadstool Park, Sioux County, Nebraska, in the NE1/4, NE1/4 sec. 8, T. 33 N., R. 53 W., Roundtop 7.5-minute Quadrangle.

3a), unaltered Pierre Shale that grades into an equivalent of the Yellow Mounds Paleosol Series is visible in several outcrops 0.5 mi (0.8 km) to the northwest. Closer at hand, the Yellow Mounds Paleosol Series equivalent and the channel sandstone facies of the Chamberlain Pass Formation are present (fig. 3b, 4a) at the base of the northern side of Limestone Butte. These deposits retain the characteristics originally described in the Big Badlands by Retallack (1983) and Evans and Terry (1994), respectively. For the following discussion, we continue to refer to exposures on the northern side of Limestone Butte (fig. 4a).

Above the channel sandstone facies of the Chamberlain Pass Formation is the Chadron Formation, consisting of a bluish gray and olive mudstone (fig. 3b, 4a). Although some question the utility of the Chadron’s various members, their respective geographic designations, and their type sections in South Dakota (Harksen and MacDonald, 1969), we suggest a name other than "undifferentiated Chadron" be used for the hummocky, bluish-gray Chadron sediments deposited outside Clark’s (1954) "Red River Valley." Rather than add to the proliferation of names, we provisionally suggest that Clark’s (1954) and Clark and others’ (1967) Peanut Peak Member be expanded to include these deposits. They are consistent in lithology with the Peanut Peak Member, and while the Ahearn and Crazy Johnson members are demonstrably confined to the "Red River Valley," deposits that we would classify as the Peanut Peak Member are not (Clark, 1954; Clark and
In this field guide we will refer to these bluish-gray and olive mudstones as the Peanut Peak Member of the Chadron Formation. Near the top of Peanut Peak Member at Limestone Butte is a prominent lenticular volcanic ash that, if datable, may constrain the minimum age of the Peanut Peak Member.

In the steep slopes above the Peanut Peak Member of the Chadron Formation are interbedded silty claystones and limestones (fig. 3b, 4a). The silty claystones show slight evidence of pedogenic modification, and appear to consist of repeated limestone/green silty claystone/red silty claystone packages. This repetition of beds is best exposed on the northwestern side of Limestone Butte. The limestones contain mudcracks, fossil plant remains, and mollusks, indicating probable lacustrine deposition. The green and red silty claystones do not occur in the Big Badlands area. Rather, the "Bloom Basin limestone bed" occupies this stratigraphic position to the northeast. The limestones at the base of each of the limestone/green silty claystone/red silty claystone sequences seen here may correlate to the "Bloom Basin limestone," or may represent localized floodplain lakes. If the former is correct, we are closer to what would have been the shoreline of the lake in which the "Bloom Basin limestone" was deposited, and equivalent beds further from the Big Badlands.
Fig. 4. Selected outcrops along field trip route: A) Stop 1, Limestone Butte, near Oelrichs, South Dakota: Is = limestone; L/GM/RM = sequences of limestone, green claystone, and red claystone; PPM = Peanut Peak Member of Chadron; CPF = Chamberlain Pass Formation; YM = Yellow Mounds Paleosol Series equivalent; B) Stop 4, view from Toadstool Park parking lot: Br = Brule Formation; Ch = Chadron Formation; UPW = "upper purplish-white layer" of Schultz and Stout (1955); C, D) Stop 4, Toadstool Park: TPC = Toadstool Park Channel Complex; OM = overbank facies mudstone; OS = overbank facies sandstone; Or = Orella Member; Wh = Whitney Member.
Badlands should contain fewer limestones and more non-lacustrine deposits. The correlation of these beds will be discussed at Toadstool Park (stop 4).

**Stop 2. Pete Smith Hill, Nebraska.** Our second stop is Pete Smith Hill, an escarpment along the south side of Sugarloaf Road west of Nebraska Highway 2/71 (figs. 2, 3c). About 0.75 mi (1.2 km) south of Pete Smith Hill, unaltered Pierre Shale crops out in ephemeral stream drainages. Visible at the base of Pete Smith Hill is slightly-altered Pierre Shale, above which are yellow and red mudstones and white sandstones. Schultz and Stout (1955) referred to these yellow and red beds as the "interior Paleosol Complex." These beds are composed of the equivalents of the Yellow Mounds Paleosol Series and Interior Paleosol Series of Retallack (1983). Likewise, the Interior Paleosol Series equivalent, just as in the Big Badlands and Oelrichs, South Dakota, represents the pedogenically modified distal over-bank facies of the Chamberlain Pass Formation. The white sandstone visible at the base of Pete Smith Hill is the channel sandstone facies of the Chamberlain Pass Formation (figs. 2). The beds above the Peanut Peak Member (Evans and Terry, 1994; Terry and Evans, 1994). Darton (1899) probably considered these sandstones to be part of the Chadron Formation in northwestern Nebraska. He described the "basal Chadron sands" at Adelia as being overlain by beds of a "bright dark-red color." Schultz and Stout (1955) referred to these beds as the "basal Chadron gravels," or Chadron A. Schultz and Stout (1955) correlated the Chadron A to Clark's (1954) Ahearn Member of the Chadron Formation in southwestern South Dakota (fig. 1). Ironically, the specific beds in southwestern South Dakota that Schultz and Stout (1955) refer to as Chadron A equivalents represent the channel sandstone facies of the Chamberlain Pass Formation rather than the Ahearn Member of the Chadron Formation. Schultz and Stout (1955) also suggested that the Chadron A (=Chamberlain Pass Formation) was equivalent to the Yoder Beds (Schlaikjer, 1935; Klim, 1987) of eastern-central Wyoming. We consider the Ahearn Member to be restricted to Clark's (1954) "Red River Valley," and, based on the available data, we reject any lithologic equivalency of these three units.

Above the Chamberlain Pass Formation (fig. 3c) are the same bluish-gray and olive hummocky mudstones that we assigned to the Peanut Peak Member of the Chadron Formation at Oelrichs, South Dakota (stop 1). These beds correspond to those Schultz and Stout (1955) assigned to the lower part of their Chadron B. The Chadron B, as defined by Schultz and Stout (1955), consists of mudstones between the "basal Chadron gravels" (Chadron A) and the "lower (=second) purplish-white layer." We reject event-bed boundaries such as the "lower purplish-white" in favor of boundaries that correspond to a change in lithology. The bluish-gray/olive beds above the Chamberlain Pass Formation have an abrupt contact with overlying thinly interbedded limestones and variegated mudstones. We suggest that the name Peanut Peak Member be applied to these bluish-gray/olive mudstones, as well as those that overtopped Clark's (1954) "Red River Valley." Schultz and Stout (1955) recognized this similarity but correlated the Chadron B to Clark's (1954) Crazy Johnson Member in South Dakota (fig. 1). We have rejected this correlation on the same grounds as the correlation of the Chadron A to the Ahearn Member. Namely, there are lithological differences, and the Crazy Johnson Member is areally restricted to the "Red River Valley" as intended by Clark (1954) and Clark and others (1967). Darton's (1899) original description of the Chadron Formation in Nebraska included only the lowermost 30-60 ft (10-20 m) of greenish-gray mudstones and sandstones. Likewise, Swinehart and others (1985) restricted the Chadron Formation to gray and greenish-gray bentonitic claystones, mudstones, and underlying coarse-grained sandstones and conglomerates. These mudrocks and claystones probably correspond to what we are calling the Peanut Peak Member.

The beds above the Peanut Peak Member (fig. 3c) at this locality include the remainder of Schultz and Stout's (1955) Chadron B. These interbedded limestones and variegated silty claystones are closely similar to those seen at Oelrichs, South Dakota (stop 1). Here, alternating green and red claystones grade laterally into olive, lavender, and yellow-green claystones. The limestones are thinner and more lenticular here than at Oelrichs. The lateral geometry of these beds and their contact with the underlying Peanut Peak Member can be observed in this outcrop. The contact apparently slopes into the escarpment, suggesting the beds above it were deposited in a shallow basin cut into the Peanut Peak Member. There is local dip of 3-5 degrees to the north, but the contact dips as much as 10 degrees to the north. Also, along the escarpment about a mile (1.6 km) west of Nebraska Highway 2/71, prominent lenticular limestones and volcanic ashes (the second and third "purplish-whites" of Schultz and Stout, 1955) give the appearance of having been deposited in a local basin cut into the Peanut Peak. It is our view that this sequence of beds above the Peanut Peak Member is the same depositional unit seen above the Peanut Peak Member at Oelrichs, South Dakota. The correlation of these beds will be discussed at Toadstool Park (stop 4).

**Stop 3. Orella Bridge, Nebraska.** Our third stop is at an outcrop 1 mi (1.6 km) north and 3 mi (4.8 km) west of Toadstool Park along the Montrose Road (figs. 2). The channel sandstone and overbank facies of the Chamberlain Pass Formation are visible.
southern of the bridge. Please be very cautious at this outcrop! The outcrop face is very unstable. Do not stand under the face of the outcrop. Rockfalls are frequent, especially during and after rain. Do not stand on the edge of the outcrop to look downward. At this locality the Chamberlain Pass Formation rests unconformably on unmodified to slightly pedogenically modified Pierre Shale (fig. 3d), rather than the Yellow Mounds Paleosol Series equivalent. This contact is commonly marked by a cobble lag. The channel facies is composed of coarse to fine-grained, trough-cross-bedded, multistoried sandstone bodies with basal lag deposits and occasional mud chips and clasts derived from bank failure. Occasional large, isolated slump blocks of bank material are present in the channel facies. Schultz and Stout (1955) described these slump blocks as pieces of the "Interior Zone" within the Chadron A, or "Yoder beds." The majority of outcrops of the Chamberlain Pass Formation channel sandstone facies are white, gray, or an olive-yellow color. The pronounced green color of the sandstone at this exposure may be the result of local diagenesis. Several zones of well-cemented sandstone retain a presumably pre-diagenesis white color.

The channel sandstone facies is interbedded and overlain by channel and overbank facies mudstones. The channel facies mudstone is preserved as a reddish-brown clay plug up to 13.1-ft (4-m) thick, probably formed by the isolation of a meander loop and subsequent development of an oxbow lake. The clay plug is overlain by 8.1-9.75 ft (2.5-3 m) of yellowish-olive, pedogenically modified proximal overbank mudstone. This mudstone contains a distinctive 1.5-ft (0.5-m) thick horizon of pea-sized iron oxide nodules. This paleosol is very similar in appearance and topographic position to the Weta Paleosol Series (Terry and Evans, 1994) within the Chamberlain Pass Formation of South Dakota. The Chamberlain Pass Formation is overlain by bluish-gray/olive deposits of the Peanut Peak Member of the Chadron Formation, which can be seen to the south. These beds in turn are overlain by siltier, cliff-forming rocks, which will be described in detail in the following discussion of Toadstool Park.

**Stop 4. Toadstool Park, Nebraska.** The fourth and longest stop is at Toadstool Park (figs. 2, 3e), where we will examine the type section of the proposed Big Cottonwood Creek Member (Chadron Formation), boundary changes within the Brule Formation, depositional environments within the Orella Member (Brule Formation), and the Toadstool Park Trackway Site. Please be advised that the preceding comments regarding the illegality of excavations and fossil collecting on the Oglala National Grassland apply to Toadstool Park as well. Please use caution when near cliffs within Toadstool Park, as the claystones are slippery and the sandstones very unstable when wet.

**Stratigraphic Revisions and Additions in the Toadstool Park Area**

Although the Yellow Mounds Paleosol Series equivalent and Chamberlain Pass Formation occur within the Big Cottonwood Creek drainage less than a mile from Toadstool Park, this stop focuses on the Chadron and Brule formations. As we turn off the Toadstool Road and drive toward the escarpment to the west, on our right just prior to the railroad tracks is an outcrop of the channel sandstone facies of the Chamberlain Pass Formation. This is one of the outcrops that Schultz and Stout (1955) correlated to the Yoder Beds (Schlaikjer, 1935; Kihm, 1987) of east-central Wyoming (see preceding discussions). After crossing the railroad tracks, there is a prominent butte north of the road, and an escarpment to the west. These outcrops will be the subject of the remainder of the field trip.

The outcrops north of the access road (fig. 3e) are composed of variegated green and red clayey siltstones, thin limestones, lenticular channel sandstones, and volcanic ashes. Visible at the base of the butte is a prominent white layer, the "third purplish-white layer." The next prominent white layer (about 25 ft [8 m] up) forms the upper boundary of Schultz and Stout’s (1955) Chadron B. This is the "lower (=second) purplish-white layer," which is followed by the "upper purplish-white layer" (up about 30 ft [10 m] more). The strata between the "upper and lower purplish-whites" comprised Schultz and Stout’s (1955) Chadron C (fig. 1). The "upper purplish-white layer" formed their contact between the Chadron and Brule formations. In Schultz and Stout’s (1955) classification, strata above the "upper purplish-white" and below the "lower nodular zone" (see following discussions) comprised the lowest subdivision of the Orella Member of the Brule Formation (fig. 1). Close examination reveals no lithologic difference between beds immediately above and below any of the various "purplish-whites." We consider the lithologic similarities of these beds to be more compelling than the convenience of the "purplish-whites" as stratigraphic boundaries. Dar- ton (1899) recognized these beds as a discrete lithologic unit, but included it within the Brule Clays. Skinner (1951, unpublished field notes) also recognized these beds as a discrete lithologic unit (his "Trunk Butte Member") but based his definition on a partial section exposed near Chadron, Nebraska. Therefore, we suggest that the strata above the Peanut Peak Member and below the "lower nodular zone" be included within a new member of the Chadron Formation. Notice also the similarity of...
These strata to those above the Peanut Peak Member of the Chadron Formation at Oelrichs (stop 1), South Dakota and Pete Smith Hill, Nebraska (stop 2). Using these and other measured sections, we have correlated this green and red silty claystone rock unit to Limestone Butte near Oelrichs, South Dakota.

These correlations (fig. 5) are the basis upon which Terry and LaGarry (in preparation) intend to reclassify the upper part of the Chadron B, the Chadron C, and the Orella A as a new member of the Chadron Formation in northwestern Nebraska (fig. 1). This new unit is provisionally named the Big Cottonwood Creek Member (Terry and LaGarry, 1994) for exposures along Big Cottonwood Creek, Nebraska, and the Toadstool Park escarpment (fig. 3e). The Big Cottonwood Creek Member is composed primarily of lenticular channel sandstones, overbank silty claystones, thin limestone interbeds, and the volcanic ashes, limestones, and gypsum layers that constitute the "purplish-white layers" of Schultz and Stout (1955). The Big Cottonwood Creek Member differs from the underlying Peanut Peak Member in that it is siltier, variegated in color, has a higher unaltered vitric volcaniclastic component, contains more limestone, and tends to form cliffs. The contact between these two units is either intertonguing or a local unconformity in areas where the Big Cottonwood Creek Member cuts into the Peanut Peak Member. The top of the Big Cottonwood Creek Member is not marked by the "upper purplish-white layer," where Schultz and Stout (1955) originally placed the contact between the Chadron and Brule formations. Instead the contact is recognized on the basis of the lithologic change from pedogenically modified green and red volcaniclastic silty claystones of the Big Cottonwood Creek Member to thinly interbedded and less pedogenically modified tan and brown volcaniclastic clayey siltstones and sandstones of the Orella Member of the Brule Formation. Swinehart and others (1985) apparently used this contact as the upper boundary of the oldest of three depositional sequences within the White River Group recognizable in the subsurface of western Nebraska. This oldest sequence consists of what they called Chadron Formation and included about the lower half of the Orella Member (fig. 1). This contact is intertonguing except where the channel sandstone facies of the overlying Orella Member cuts into the Big Cottonwood Creek Member (fig. 4b, 4c).

The Brule Formation is well exposed along the western escarpment, which contains the type sections of the Orella and Whitney members. Schultz and Stout (1955) defined the lower boundary of the Brule Formation (fig. 3e) at the "upper purplish-white layer." This prominent volcanic ash is visible in the escarpment from the Toadstool Park parking lot (fig. 4b). We redefine the lower boundary of the Brule at the lithologic change 29-33 ft (9-10 m) above the "upper purplish-white layer." The upper boundary of the Orella Member is visible about 0.5 mi (800 m) up the canyon that confines the Big Cottonwood Creek drainage beyond Toadstool Park. The top of the Orella Member was originally identified by Schultz and Stout (1955) as the "white layer." However, based upon a strictly lithostratigraphic interpretation, we propose to move the boundary 8 ft (2.5 m) lower to the top of Schultz and Stout's (1955) "bluish-green nodules." The "bluish-green nodules" (see following discussions) are the last occurrence of thinly interbedded and less pedogenically modified tan and brown volcaniclastic clayey siltstones, and sandstones (fig. 4d). Above the "bluish-green nodules" are the buff, massive, locally nodular volcaniclastic siltstones of the Whitney Member. This contact is intertonguing, as the "bluish-green nodules" are discontinuous and the Whitney lithofacies occasionally occurs at or below the "bluish-green" horizon. A more detailed discussion of Orella depositional environments follows below.

The remaining two members of the Brule Formation that we recognized will not be examined in detail. However, both the Whitney Member and the "brown siltstone" are visible along the escarpment to the north, and along the Big Cottonwood Creek canyon. The Whitney Member, which weathers into high, smooth slopes, was deposited by eolian processes (DeGraw, 1969; Swinehart and others, 1985). It contains infrequent lenticular sand bodies and channel sandstones. It also contains two prominent volcanic ashes, the lower and upper Whitney ashes (see Schultz and Stout, 1955). The top of the Whitney Member is marked by a sharp, undulating contact with cliff-forming volcaniclastic siltstones of the "brown siltstone" (see Swinehart and others, 1985). Swinehart (1994, personal communication) has proposed to name this unit the Roundtop Member of the Brule Formation. The "brown siltstone" is composed of massive to indistinctly bedded volcaniclastic siltstone and sandy siltstone. It contains the Nonpareil Ash Zone of Swinehart and others (1985) from which Swisher and Prothero (1990) obtained a date of about 30 Ma.

Depositional Environments of the Orella Member of the Brule Formation

For the remainder of the field trip, we will examine sedimentary structures within Toadstool Park. The "toadstools" that are the park's namesake are erosional remnants of the Toadstool Park Channel Complex (Schultz and Stout, 1955), supported by a pedestal of mudstone. The "toadstools" are most prominent along two faults that offset the channel by 22.9-32.8 ft (7-10 m) (down is to the north). The
features of the Toadstool Park Channel Complex (fig. 4c) discussed below are all visible from the visitor trail, which was originally designed to provide the best view of the "toadstools."

Schultz and Stout (1955) first recognized that the Toadstool Park Channel Complex was formed late in Orella deposition and downcut through the middle and lower Orella into the Chadron Formation (as defined herein and by Terry and LaGarry, 1994). Based on our preliminary observations and measurements, the Toadstool Park Channel Complex and its associated overbank deposits represent one of several episodes of fluvial downcutting and backfilling within the Orella Member (Wells and others, 1994). The Toadstool Park Channel Complex can be divided into two main facies: 1) a channel sandstone facies; and 2) an overbank sandstone and mudstone facies. Sedimentary structures within the channel sandstone facies include: 1) trough cross-bedding, planar tabular cross-bedding, and cross lamination; 2) upper flow-regime planar bedding and lamination; and 3) soft sediment deformation, including slumping, load casting, and sand volcanoes and dewatering veins. Trackways and pedogenic modification occur at multiple levels within the channel complex. The vertical and lateral arrangement of these structures indicates a mixed-load river system that was ephemeral or seasonal in nature (Wells, 1994; Wells and others 1994). Other important features include lateral-accretion surfaces, possibly forming off channel or point bars, and mudstone blocks and chips derived from bank failure. We have interpreted the river system as braided based upon comparisons to similar types and arrangements of sedimentary structures and facies in modern braided rivers (Bristow, 1993). These sediments appear to have been deposited very quickly, possibly by seasonal or episodic flash floods. Subsequent subaerial exposure provided an opportunity for organisms to leave tracks and trails and for pedogenic modification to take place.

The overbank facies (fig. 4c) is represented by packages of sheet sandstones and mudstones. Wells and others (1994) use the term "couplets" to describe these packages, which were probably produced by repeated flooding events (splay or avulsion) that eventually filled the previously cut paleovalley. Individual couplets thin towards paleovalley walls, forming wedges. Valley walls range from gentle 5-10 degree slopes to steep slopes approaching 36 degrees. Each "couplet" was modified by pedogenesis. Pedogenic modification is slight, showing only minor evidence of plants and very limited soil structure or horizonation. These soils would likely be
classified as "Entisols" (Soil Survey Staff, 1975). The few plant fossils that occur are chalcedony mineralizations within voids left over from the decay of former root systems and detrital vegetation within the channel and overbank deposits. These mineralizations occur in two sizes. The majority range in size from 0.04-0.6 in. (1-15 mm) in diameter. Individual "roots" of this size have been traced as far as 1.5 ft (0.5 m). Fewer fragments are 1.2-2 in. (3-5 cm) in diameter and up to 8-in. (20-cm) long. Both sizes are commonly oval in cross-section and branch or taper. They sometimes possess a rough surface texture similar to bark and occasionally occur as overlapping detrital fragments of stems, stalks, or branches (Goemann, 1994, personal communication).

Once the valley was filled, rivers appear to have been dominated by avulsion. This produced, in contrast to the areally restricted channel sandstones of the Toadstool Park Channel Complex, broad packages of interbedded sand sheets and mudstones (fig. 4c, 4d). These sheet sands form the various "nodular zones" of Schultz and Stout (1955). Vondra (1958) concluded that the nodular appearance of these zones was the result of fracturing and weathering, not evaporitic or pedogenic accumulation of minerals. Deposition of the Orella Member appears to have been the result of at least two separate and alternating periods of channelized flow and deposition during and after downcutting, and unconfined, avulsion-dominated flow and deposition following the filling of individual paleovalleys.

**Toadstool Park Trackway Site**
**(Toadstool Geologic Park Demonstration Area)**

One of the most exciting new developments at Toadstool Park has been the documentation of numerous vertebrate trackways and other ichnofossils. Trackways within the Toadstool Park Channel Complex were first reported by Nixon (1991). Subsequent to Nixon's discovery, the Nebraska National Forest contracted with the University of Nebraska State Museum for a comprehensive inventory of the Toadstool Park Trackway Site (see LaGarry-Guyon and others, 1993; LaGarry-Guyon, 1994). These inventories have documented numerous additional tracks and traces of invertebrate, avian, and mammalian origin. These inventories have also documented that the trackway-bearing slabs are fragile, and erosion by unrestricted foot traffic and bicycles, vandalism, and theft of fossils endangers the site. Please be conscious of what lies underfoot, and avoid walking on what might be trackway-bearing sandstone slabs. We have not included the exact locations of individual trackway slabs in order to prevent additional erosion and vandalism until protective measures are taken by the Nebraska National Forest.

Invertebrate trails and feeding structures are more common than vertebrate trackways and are present in both the channel and overbank sandstones (figs. 4c, 4d). Almost all of the vertebrate trackways have been observed on the uppermost surface of the Toadstool Park Channel Complex. We have identified 57 extensive trackways of 11 contemporary vertebrate species (including shorebirds, ducks, oreodonts, entelodonts, camels, rhinoceroses, and carnivores) along more than 0.6 mi (1 km) of paleostreambed (LaGarry-Guyon and others, 1993, LaGarry and others, 1994; Nixon and LaGarry-Guyon 1993a, 1993b). To date, we have assigned tracks to specific mammalian taxa, including Hyracodon, Subhyracodon (figs. 6a, 6b, 6c), and Poebrotherium, and have tentatively assigned tracks to Archeotherium, Mesohippus, oreodonts, and carnivores. The most spectacular mammalian trackways occur on a set of sandstone slabs that record, in sandy and muddy substrates, the mass movement of a large, cursorial rhinoceros, probably Subhyracodon (fig. 6c). These tracks were overprinted by tracks of individual Hyracodon. The Subhyracodon and Hyracodon trackways were then overprinted by entelodont and carnivore tracks. Once studied, the sequence and positions of the various tracks may reveal intra- and interspecies behaviors.

Close to the beginning of the Toadstool Park Trail are several large slabs showing surficial feeding trails of several different invertebrates, probably worms. Tracks of shorebirds (fig. 6d) and ducks are commonly associated with these invertebrate burrows. Between the shorebird tracks are regularly spaced holes that we have interpreted as bill probes. Ostensibly, the shorebirds were feeding on the burrowing worms. Duck tracks were also visible near the trail until 1993, when erosion destroyed the slab. Prior to its loss, this slab was cast in plaster by the University of Nebraska State Museum. A well-preserved slab containing duck tracks is accessible further along the trail. Ducks tracks are distinguishable from those of shorebirds because they usually show webbing between the toes, have a different gait, and lack the associated bill probes. Although not directly associated with trackways, fossilized duck eggs found near Toadstool Park may indicate that ducks nested within this environment.

**Summary and Discussion**

The inadequacy of the current formal stratigraphic classification of the White River Group can be addressed by data recovered during recent litho-
Fig. 6. Tracks and trackways from the upper surface of the Toadstool Park Channel Complex: A) Hyracodon track; B) Subhyracodon track with associated splash marks (?); C) trackway showing mass movement of Subhyracodon and isolated tracks of Hyracodon, entelodonts, and carnivores; and D) tracks of an unidentified bird.
stratigraphic correlations and mapping of the sur-
ficial geology of northwestern Nebraska (LaGarry
and Armantrout, 1994, unpublished data). Based
upon this data Terry and LaGarry (1994, and in
preparation) propose to introduce a revised, litho-
facies-based stratigraphy. Some might argue that
this stratigraphic revision is parochial and adds to
the proliferation of unit names (see comments by
Singler and Picard, 1980). However, the recogni-
tion of the same units in both Nebraska and South Dako-
ta promotes a regional view and reduces the number
of existing names. Our observations indicate that the
lithofacies-based units in this classification can be
extended into other regions. In addition, lithofacies-
based units and correlations conform to the North
American Stratigraphic Nomenclature, 1983. The
provisional revisions of Terry and LaGarry (1994)
were based upon outcrop data only. Formal revi-
sions (Terry and LaGarry, in preparation) will ad-
dress additional surface data and the subsurface
data and correlations of Souders (1981) and Swine-
hart and others (1985).

The stratigraphic revisions discussed in this
field guide are summarized as follows. In the view
of Terry and LaGarry (1994), no useful purpose
would be served in making major changes in the
established names and hierarchy. Therefore, the
basic stratigraphic nomenclature of Schultz and
Stout (1955) is retained with the following additions
and modifications. The White River Group has three
formations: 1) the Chamberlain Pass Formation;
2) the Chadron Formation, composed of the Peanut
Peak and Big Cottonwood Creek members; and
3) the Brule Formation, composed of the Orella,
Whitney, and "brown siltstone" members. The previ-
ous stratigraphy of Schultz and Stout (1955) is modi-
ified by: 1) dividing the "Interior Zone" into the Yel-
low Mounds Paleosol Series equivalent and the
overbank mudstone facies of the Chamberlain Pass
Formation; 2) extending the Chamberlain Pass Forma-
tion and the overlying Peanut Peak Member of
the Chadron Formation into Nebraska from South
Dakota; 3) redefining the beds assigned to the Chad-
ron A as the channel sandstone facies of the Cham-
berlain Pass Formation; 4) recognizing a new litho-
logic unit, the Big Cottonwood Creek Member, to
contain the remainder of the Chadron Formation in
Nebraska; 5) moving the contact of the Chadron and
Brule formations upward from the "upper purplish-
white layer" to the lithologic change from silty vol-
caniclastic claystones to interbedded clayey volcanic-
lastic siltstones and sandstones; and 6) moving the
contact of the Orella and Whitney members of the
Brule downward from the "white layer" to the litho-
logic change from interbedded clayey volcaniclastic
siltstones and sandstones to massive volcaniclastic
siltstones. Based on additional lithologic data, Terry
and LaGarry (in preparation) reject the presence of
the Ahearn Member of the Chadron Formation in
Nebraska, as previously suggested (Terry and La-
Garry, 1994). Also, based on our field investigations
and unpublished data contributed by Swinehart
(1994, personal communication), we recognize the
"brown siltstone" of Swinehart and others (1985)
to contain the distinctive siltstones above the Whitney
Member of the Brule Formation and below the Arik-
aree Group. This unit had previously been consid-
ered part of the Arikaree Group (Schultz and Stout,
1955), but recent treatments of the Arikaree Group
do not support this view (Swinehart and others,
1985; Tedford and others, 1985).

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Ashfall Fossil Beds

Field Trip No. 5

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(Available Separately)
Geology of the Ogallala/High Plains
Regional Aquifer System in Nebraska

Field Trip No. 6

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This guide is mostly figures with a reference section containing some of the pertinent literature on the Cenozoic geology we will see over the next four days. Copies of some of the cited works will be assembled in a packet and handed out on the morning of April 29th. We will make all 17 stops (fig. 1) if the weather is reasonably good and the roads are passable. On the first day, April 29, we will try to get to stops 1-5, the more distal parts of the Ogallala and younger deposits in Nebraska. On April 30, we will try to visit stops 6-9. Stops 10-15, in areas closer to the sediment sources of the Ogallala and some of the younger units, will be examined on May 1. Stops 16-17 will be made on our return trip to Lincoln.

April 29, 1995

Stop 1. Todd Valley. Our first stop will be north of North Bend, Nebraska, on the surface of the Todd Valley fill to see some of the Quaternary geomorphology of eastern Nebraska and to review some aspects of Quaternary stratigraphy in the eastern part of the state. From Lincoln to the Platte River valley, we have traveled across land underlain by glacial tills, loesses, and fluvial deposits of Quaternary age. A great deal about the early views on Pleistocene geology in eastern Nebraska is in Lugn (1935). More recently, Reed and Dreeszen (1965) attempted to classify and show the relationships between Pleistocene units in Nebraska (fig. 2). This classification was widely accepted until the work of Boellstorff (1978) began to show that the stratigraphy was even more complex in places than previously depicted. At present, I believe that this classification is still in a state of flux; several workers are trying to clarify the relationships between units and to better define the ages of those units. Between the work of Lugn and that of Reed and Dreeszen, Lueninghoener (1947) tried to work out the post-Kansas geologic history of the lower Platte River valley (fig. 3). We are standing on the Todd Valley terrace, noted in figure 2 as medial Pleistocene, and are looking south at the Platte Valley. The valley fill beneath the terrace surface and the Holocene alluvium beneath the Platte Valley are good aquifers and

Fig. 1. Map of Nebraska showing locations of stops on field trip no. 6.
### Fig. 2. Classification of the Pleistocene deposits of Nebraska (modified after Reed and Dreeszen, 1965, fig. 3).

### Fig. 3. Map of lower Platte Valley area. Approximate dimensions of block are 50 x 80 miles (after Lueninghoener, 1947, fig. 1).
have been developed for irrigation and municipal water supplies. As we go north, we will drive off of the fairly flat lands of the Todd Valley fill and up onto the better dissected lands underlain by eolian deposits and glacial tills that generally have more limited water resources. We will be traveling over these deposits for the most part until we reach the valley of the Elkhorn River near Norfolk, Nebraska, where we will once again be driving over Holocene alluvium.

From near Norfolk we will drive west across the glacial till border and begin to cross lands underlain by eolian sands, loesses and alluvium. The alluvium we will see from this point on ranges in age from late Pliocene to Holocene. For the most part, these deposits were laid down by the developing Platte River and its tributaries from late Pliocene to late Wisconsinan time (fig. 4). Most of the Ogallala/High Plains Aquifer System in Nebraska and most of the sites of greatest abundance of groundwater in Nebraska (fig. 5) occur in the areas where the Platte system or its ancestral drainages developed.

As we travel from U.S. Highway 20 north to Ashfall Fossil Beds State Historical Park (stop 2), we will encounter some of the stratigraphic units noted by Diffendal and Voorhies (1994) and shown in figure 6. Of the four Pliocene stratigraphic units recognized in parts of north-central Nebraska, only the Long Pine Formation is present in this area. The relationships of Pliocene and older Cenozoic units in north-central Nebraska and south-central South Dakota and those in western Nebraska are illustrated in figure 6. Swinehart and Diffendal (1990) have shown the general Pliocene and older stratigraphic units beneath the Nebraska Sand Hills area between north-central and western Nebraska.

**Stop 2. Ashfall Fossil Beds State Historical Park.** This is one of the truly extraordinary mammalian vertebrate fossil localities in North America. Mammal fossils have been known from this area at least as far back as the 1920s, but the site was first studied in 1971 by M. R. Voorhies, who found the first skull and later the rest of the skeleton of a baby rhino here. A test excavation, opened in 1977, revealed the intact skeletons of rhinos and three-toed horses. Much more faunal and some floral remains have been found here subsequently and described by Voorhies in a number of papers, particularly Voorhies (1985, 1990a). The fossils occur in a volcanic ash in the Caprock Member of the Ash Hollow Formation (fig. 7).

Land for the park was acquired in 1986, and the park was dedicated in 1991. Since then tens of thousands of visitors have come to see the fossils and the continuing excavation and study of these fossils by Voorhies and other paleontologists.

The formations exposed in the area (fig. 7) are part of the Ogallala/High Plains Aquifer System, which the U.S. Geological Survey has defined in a

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**Fig. 4. Postulated evolution of Platte River and related drainages (modified after Souders, Swinehart, and Dreeszen, 1990).**
number of publications as including almost all of the Cenozoic units named in figure 6. For an overview, see Gutentag and Weeks (1980), Weeks and Guten
tag (1981), and Weeks and others (1988). The various tributaries of Verdigre Creek in the area are perennial streams fed by springs coming from the Long Pine Formation and the Ogallala Group.

**Stop 3. Long Pine Formation.** Skinner and Hibbard (1972) described the units in this area and originally placed them in the early Pleistocene. The Keim, Long Pine, Duffy, and Pettijohn formations have subsequently been placed in the Pliocene and are equivalent in age to the Broadwater Formation of western Nebraska (fig. 6). The physical connection of these two named units was implied by Stanley in Stout and others (1971). The Keim, Duffy, and Pettijohn are local units, while the Long Pine is widespread (fig. 8). At this stop we will view the Long Pine Formation and part of the Keim Formation. From this point west, we will be passing through large areas covered by the Nebraska Sand Hills. This dune region has been studied extensively by J. B. Swinehart and colleagues. Results of those studies have been published in several papers, particularly Swinehart (1990).

**Stop 4. Valentine Formation.** This is a short stop to see some of the sands of the Valentine Formation and the Niobrara River valley. The geology of the area along and adjacent to the river has been described in detail most recently by Skinner and Johnson (1984) and by Voorhies (1990b).

**Stop 5. Valentine and Ash Hollow formations.** Skinner and Johnson (1984) subdivided these formations into a number of members, some of which can be seen exposed in roadcuts and natural exposures northeast of the city of Valentine, Nebraska (fig. 9). We will get a good view of these at this stop and also see the late-Pleistocene fluvial high terrace along the Niobrara River.

**April 30, 1995**

**Stop 6. Snake River Falls.** The geologic section exposed here (fig. 10) was illustrated and described by Skinner and Johnson. Part of the Caprock Formation of the Ash Hollow forms the resistant ledge over which the Snake River falls. From here to stop 7, we will be going mostly through the Sand Hills. We will see older units exposed only where bedrock highs come to the surface, where they have been cut through in a few roadcuts, or along river valleys.

**Stop 7. Box Butte Tablelands, Niobrara Valley, and Pine Ridge.** Swinehart and others (1985) have described the stratigraphy of this area in general and have placed in the Ogallala Group several units previously included by some workers in the Hemingford Group. We will stop at some of these older...
Correlation of stratigraphic units between north-central Nebraska/south-central South Dakota and western Nebraska (modified after Diffendal and Voorhies, 1994, and Swinehart and others, 1985).

Ogallala units exposed in roadcuts between Hay Springs and Alliance, Nebraska. The geology of this area has been discussed in a number of publications. For a more detailed overview than that given in Swinehart and others (1985), see Souders (1981) and Souders, Smith, and Swinehart (1980).

**Stop 8. Carhenge.** Considered folly by some, this piece of folk art by a local resident is intended to resemble the British stone circle, Stonehenge.

**Noteworthy but not a stop. Entering the North Platte Valley.** Swinehart and Diffendal have two geologic maps in press with the U.S. Geological Survey covering Morrill County (1:63,360) and the southern half of the Nebraska Panhandle (Scottsbluff; 1:250,000). In addition, Diffendal (1991) published the North Platte 1:250,000 map. Groundwater reports, including those by Smith and Souders (1975) and Souders (1981), have been prepared for most of the counties in the southern Panhandle.

**Stop 9. Duer Ranch.** Swinehart and Diffendal (1987) described this area (fig. 11) in detail. We will walk over parts of the area and see spectacular examples of Ogallala Group gully fills, Ash Hollow Formation sands and gravels filling channels and basal inner channels of the Broadwater Formation (=Long Pine).

**May 1, 1995**

**Stop 10. Multiple volcanic ash deposits in the Ash Hollow Formation south of Broadwater, Nebraska** (fig. 12). Diffendal (1984b) and Swinehart and others (1985) published maps showing the distribution of volcanic ash beds in the area. These ash beds and others found by Diffendal, Voorhies and others in the Ogallala across Nebraska and northwestern Kansas are currently the focus of studies by M. Perkins of the University of Utah, aided by Diffendal and Voorhies. Preliminary results indicate that ash chemistry may allow discrimination and correlation of ash deposits across the Great Plains and also of Ogallala ashes on the Great Plains with volcanic sources in Idaho and Nevada. The Ash Hollow Formation fills a paleovalley, the base of which is more than 150 feet below the lowest exposures here. Perennial springs issue from the lowest exposed Ash Hollow sands and gravels at several spots just east of this stop.

**Stop 11. Greenwood Canyon south of Bridgeport, Nebraska.** A general stratigraphic section of the rocks exposed in this area was published in Stout and others (1971). Subsequently, Diffendal (1984b) studied the area and, among other things, found multiple volcanic ash beds in the Ash Hollow Formation of the Ogallala Group (fig. 13). This stop is about 10 miles west of stop 10. We will look at some of these ash beds.

**Stop 12. Early Quaternary fluvial deposits of Pumpkin Creek valley.** If you look once again at figure 4, you will see that I have depicted a tributary to the North Platte River in the general position of Pumpkin Creek valley on the early Pleistocene maps, but have not shown it on the map of Pliocene drainages. This stop is at a gravel pit that yielded fossils of early Pleistocene mammals. It is one of several remnants of the topographically highest fluvial terrace in the valley. No older terraces are known from this valley. Today, Pumpkin Creek is an underfit stream, small even when rains are heavy. It is underfit, in part, because it has been pirated by other tributaries of the North Platte both eastward in Morrill County and in eastern Wyoming (fig. 14).
LONG PINE FORMATION
Unconsolidated coarse sand and gravel
many igneous and metamorphic pebbles
(contact not exposed)

CAP ROCK MEMBER
ASH HOLLOW FORMATION
Well-indurated sandstone, weathers
white, many siliceous tubules and much
disseminated volcanic ash
exposed thickness - 21 feet

DEVIL'S GULCH MEMBER
VALENTINE FORMATION
Semi-consolidated, poorly sorted silty, clayey
sand with numerous calcareous concretions
thickness - 30 feet

CROOKSTON BRIDGE MEMBER
VALENTINE FORMATION
Unconsolidated fine - to medium quartz sand,
mostly planar-bedded with some small-scale cross
bedding; root casts and insect? burrows present,
exposed thickness - 36 feet

Fig. 7. Geologic sections in the vicinity of Ashfall Fossil Beds State Historical Park (after Voorhies, 1985, fig. 2).

Fig. 8. S-N profile from Long Pine, Nebraska, northward (after Skinner and Hibbard, 1972, fig. 3; courtesy of the American Museum of Natural History).
Stop 13. Faden and Van Pelt ranches--Ash Hollow Formation valley fills. At Faden Ranch, the basal Ash Hollow Formation fills inner channels like those of the basal Broadwater Formation on Duer Ranch (stop 9). On the Van Pelt Ranch, we will look at part of one valley fill, tributary gully fills, opal beds, caliches and other interesting features. We will also see evidence of two Ash Hollow valley fills of different ages in this area (fig. 15). The Ogallala exposures on the Van Pelt and adjoining pastures were in part designated as separate formations younger than the Ash Hollow, called the Sidney Gravel and the Kimball Formation. This terminology has been abandoned, and all of the Ogallala rocks here have been placed in the Ash Hollow Formation by Diffendal (1985, 1990). Caliches and groundwater cements at this stop and stop 14 (fig. 16) have been studied and reported on by Gardener, Diffendal, and Williams (1992).

Stop 14. Exposures of the "typical Kimball" south of Kimball, Nebraska. This stop includes the supposed stratigraphically highest parts of the so-called Kimball Formation of the Ogallala.

Stop 15. Exposures of the "typical Sidney Gravel" near Sidney, Nebraska. We will look at compositional differences of this supposed unit, now included in an expanded Ash Hollow Formation (fig. 17).
May 2, 1995

**Stop 16. Ash Hollow.** Ash Hollow is the type area of the Ash Hollow Formation. Stout and others (1971) and Diffendal (1987) have described and diagrammed measured sections of the strata in this area. Diffendal's section (1987; fig. 18) shows that the formation in the subsurface thickens to the south. Multiple volcanic ash beds have been mapped in the Ash Hollow Formation in this area by Diffendal (1984b).

**Noteworthy but not a stop.** As we drive from here to Ogallala, observe the thick sequences of loess exposed in the canyons to the north of U.S. Highway 26. Some are up to 200-ft (66-m) thick. I will also point out sand and gravel deposits below the loess and on top of the Ash Hollow Formation that are part of the Broadwater Formation and were deposited by the ancestral South Platte River (fig. 4).

**Stop 17. Type area of the Ogallala Group.** This is the poorest type area of any we have seen. It has no exposed base and the top is erosional.

Return to Lincoln on I-80. End of trip.
Fig. 12. Map of part of Morrill County showing superposed ash lentils in Ash Hollow Formation (after Swinehart and others, 1985, fig. 18).

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Fig. 13. Map showing locations of volcanic ash lentils in the Ash Hollow Formation in the Greenwood Canyon area (after Diffendal, 1984b, fig. 7).
Fig. 14. Changes in course of Pumpkin Creek during the Quaternary in eastern Wyoming and western Nebraska (after Diffendal, 1984a, fig. 1).

Fig. 15. Distribution and age relationships of Ash Hollow Formation paleovalleys in part of Banner County, Nebraska (after Swinehart and others, 1985, fig. 17).


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Fig. 16. Stratigraphic sections and generalized N7W cross section from Kimball, Nebraska, to southern Banner County (after Gardner, Diffendal, and Williams, 1992, fig. 3).
Fig. 17. Ash Hollow Formation stratigraphy section east of Sidney, Nebraska (after Diffendal, 1990, fig. 7).
Fig. 18. Ash Hollow stratigraphy along Ash Hollow Creek, Garden County, Nebraska (after Diffendal, 1987, fig. 3).


Notes
Late Quaternary Landscape Evolution and Stratigraphy in Eastern Nebraska

Field Trip No. 7

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Introduction

Late Quaternary landscapes and stratigraphic units in eastern Nebraska are products of stream activity, loess deposition, local slope erosion and deposition, and soil formation. Large volumes of Holocene and late Pleistocene alluvium are stored in valley bottoms, and thick deposits of late Quaternary loess mantle the high alluvial terraces and uplands. Paleosols within the alluvial and eolian deposits mark episodes of landscape stability, while erosion surfaces and local slope sediments indicate former episodes of landscape instability.

Most previous studies of Nebraska’s late Quaternary record have focused on the western and central part of the state. We are just beginning to expand the data base for eastern Nebraska through interdisciplinary studies that have involved geologists, pedologists, paleontologists, and archaeologists. The purpose of this trip is to present the initial results of our investigations. We focus on the Holocene alluvial stratigraphy of large and small streams and demonstrate that there is a distinctive sequence of alluvial fills (the DeForest Formation) that can be traced from valley to valley across the region. We also examine late Quaternary loess deposits and associated paleosols and present new age determinations on the Gilman Canyon Formation and overlying Peoria Loess. Alluvial deposits beneath the loess mantle are examined at two localities, and paleoenvironmental interpretations are presented based on insect and plant macrofossils recovered from these late Pleistocene stream deposits.

Physiography and Geology

Much of eastern Nebraska is in Fenneman’s (1931) Glaciated Central Lowlands physiographic province. This region was glaciated several times during the early and middle Pleistocene (Boellstorff, 1978a). Drainage networks evolved and dissected the till plains during intervening interglacials, leaving behind a complex, discontinuous record of the early and middle Pleistocene.

Late Pleistocene Stratigraphy

The late Pleistocene stratigraphic framework of eastern Nebraska is based on Illinoian and Wisconsinan loesses. These deposits are regional in extent and thus provide "marker" units to which more localized fluvial and colluvial units can be stratigraphically related.

The interfluves and Pleistocene terraces in eastern Nebraska are mantled by late Quaternary loess. On the oldest surfaces, at least three stratigraphically superposed loesses are present: the loess of the Loveland Formation, Gilman Canyon Formation, and Peoria Loess. The Loveland loess is the most widespread pre-Wisconsinan loess in the Midwest. It has been described throughout the upper Midwest in the Missouri River, Mississippi River, and Ohio River basins (William and Frye, 1970; Reed and Dreeszen, 1965; Ruhe, 1969; Bettis, 1990). It has also been identified at several localities farther south adjacent to the Mississippi Valley in Arkansas and Mississippi (McCraw and Autin, 1989). The Loveland loess is typically a yellowish-brown or reddish-brown eolian silt that reddens toward the top of the unit. Regional stratigraphic relationships suggest that the Loveland loess in eastern Nebraska is Illinoian in age and that the Sangamon Soil developed in the upper part of the unit is buried by Wisconsinan deposits. Thermoluminescence dating at the Loveland paratype section in western Iowa indicates that the Loveland loess was deposited about 140 ka (Forman and others, 1992).

The Sangamon Soil is developed in the upper part of the Loveland loess in many areas of the
Midcontinent, including Illinois (Follmer, 1978), Indiana, Iowa (Bettis, 1990), Kansas (Frye and Leonard, 1952; Johnson and Zhaodong, 1993), and Nebraska (Johnson and others, 1990, 1993). This paleosol is usually well expressed, and its color ranges from a vivid to pale reddish-brown. The age of the loess into which the soil is developed, combined with radiocarbon ages from the base of the overlying Gilman Canyon Formation in Nebraska and Pissag Formation in Iowa, indicate that the period of pedogenesis could have extended from about 120 to 35 ka (isotope stages 5d to 3). This estimate is supported by unpublished U-series ages on pedogenic carbonate nodules associated with the Sangamon Soil in eastern Nebraska and western Iowa that indicate much of the nodule growth occurred during stage 5a between 60 and 90 ka (B. Szabo, personal communication, 1994). At some localities, the Sangamon Soil represents several soils welded together to form a “pedocomplex” that may represent formation over a longer time (Schultz and Tanner, 1957; Fredlund and others, 1985; Morrison, 1987).

The Gilman Canyon Formation was first described in south-central Nebraska (Reed and Dreeszen, 1965). This stratigraphic unit is at the base of the Wisconsinan loess and is in the stratigraphic position of the Pissag Formation in western Iowa (Bettis, 1990) and the Roxana silt of the upper Mississippi River basin (Follmer, 1983; Leigh and Knox, 1993). The loess facies of the Gilman Canyon Formation is a dark, noncalcareous, silt loam that has been modified by pedogenesis. Radiocarbon ages from the Gilman Canyon Formation range from about 35,000 at its base to 20,000 yr BP at the top (May and Souders, 1988; Johnson and others, 1990; Johnson and others, 1993; Johnson and Zhaodong, 1993). The Peoria Loess overlies the Gilman Canyon Formation and is typically calcareous, massive, light yellowish tan to buff-colored silt. In some areas, the loess exhibits primary eolian bedding that is indicative of rapid deposition. Radiocarbon ages from the Peoria Loess in Nebraska range from about 23,000 BP at its base to 13,000 yr BP near the top (table 1; Johnson and others, 1993).

**Holocene Alluvial Stratigraphy**

Deposits of fine-grained Holocene alluvium stored in river valleys of eastern Nebraska strongly resemble those of the DeForest Formation in western Iowa. This formation is a lithostratigraphic unit encompassing all Holocene alluvium in Iowa (Bettis, 1990). Recent studies recognized the DeForest Formation in southeastern Nebraska (Dillon, 1992), northwestern Missouri (Fosha and Mandel, 1991), and northeastern Kansas (Mandel and others, 1991; Mandel 1994a), and adopted Iowa’s lithostratigraphic nomenclature for Holocene alluvial deposits. This approach is reasonable since lithostratigraphic units do not terminate at political boundaries (Mandel and Bettis, 1992). Hence, we propose to include the Holocene alluvial deposits of eastern Nebraska in the DeForest Formation.

The DeForest Formation consists of four members: Camp Creek, Roberts Creek, Gunder, and Corrington. The Camp Creek Member encompasses deposits formerly referred to as "postsettlement alluvium." This member usually consists of stratified, calcareous to noncalcareous, very dark gray to brown silt loam to clay loam, though some deposits may consist of coarser sediment. It is inset into or unconformably overlies the Gunder, Corrington, and Roberts Creek members, depending on the geomorphic setting and history of land use (Bettis, 1990). The thickness of the Camp Creek Member is extremely variable in eastern Nebraska, ranging from a few inches to over 20 ft (6 m). Surface soils developed in the Camp Creek Member are Entisols and thin Mollisols with organically enriched A horizons grading to stratified parent materials (C horizons). The Camp Creek Member includes sediment that accumulated after about 500 yr BP (Bettis, 1990).

The Roberts Creek Member consists of dark-colored, clayey, silty, and loamy alluvium. This member can overlie a wide variety of deposits, including the Gunder and Corrington members, coarse-grained older alluvium, loess, and glacial till (Bettis, 1990). Roberts Creek Member deposits usually occur beneath floodplains and low terraces (T-1) in large valleys. The Roberts Creek Member is separated from younger DeForest Formation deposits (Camp Creek Member) by either a fluvial erosion surface or an unconformity marked by a buried soil. Weakly developed buried soils with A-C or A-Bw profiles are common in the Roberts Creek Member, but they are rarely traceable from one valley to another. In eastern Nebraska, surface soils developed into the Roberts Creek Member are thick, dark-colored Mollisols. These soils are morphologically less well expressed and have darker colored B and C horizons than soils developed in the Gunder and Corrington members. In large valleys the Roberts Creek Member ranges in age from near 4,000 BP to 500 yr BP (Bettis, 1990).

The Gunder Member consists of oxidized, dominantly silty and loamy alluvium lacking a loess cover. Lower parts of this member may be reduced and/or coarse grained. Gunder Member deposits unconformably overlie coarse-grained and often organic-rich older alluvium, loess, glacial till, or bedrock (Bettis, 1990). Overlying younger members of the formation are separated from the Gunder Member by a fluvial erosion surface or an unconformity marked by a buried soil. Surface soils developed in the Gunder Member are thick Mollisols with
Table 1. Radiocarbon ages from solifluction deposits in the lower Peoria at the Maas Drive Section.

<table>
<thead>
<tr>
<th>Depth Above Base of the Peoria (in.)/[cm]</th>
<th>Material Assayed</th>
<th>Radiocarbon Age (yr BP)</th>
<th>Lab Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>(12.6)/[32]</td>
<td>Humins</td>
<td>&gt; 23,000</td>
<td>CAMS-10184</td>
</tr>
<tr>
<td>(12.6)/[32]</td>
<td>Humic acids</td>
<td>22,040+160</td>
<td>CAMS-10186</td>
</tr>
<tr>
<td>(14.2)/[36]</td>
<td>Humins</td>
<td>20,890+140</td>
<td>CAMS-10181</td>
</tr>
<tr>
<td>(14.2)/[36]</td>
<td>Humic acids</td>
<td>20,810+160</td>
<td>CAMS-10187</td>
</tr>
<tr>
<td>(15)/[38]</td>
<td>Humins</td>
<td>21,630+190</td>
<td>CAMS-10185</td>
</tr>
<tr>
<td>(15)/[38]</td>
<td>Humic acids</td>
<td>22,210+170</td>
<td>CAMS-10188</td>
</tr>
</tbody>
</table>

Brown or yellowish brown Bw, Bk, or Bt horizons. Buried soils have been documented within the Gunder Member, but they are not widely traceable. The Gunder Member ranges in age from about 10,500 yr BP at its base to about 3000 yr BP near its surface (Bettis, 1990).

Corrington Member deposits are restricted to alluvial fans and colluvial aprons along the margins of valley floors. The alluvial fans are located where small streams (first- through third-order) enter large valleys. The Corrington Member is the most internally variable unit of the DeForest Formation and consists of very dark brown to yellowish brown oxidized loam and clay loam with interbedded lenses of sand and gravel (Bettis, 1990). The unit is stratified and often contains multiple buried soils. Surface soils developed into this unit are thick Mollisols with argillic (Bt) or Btk horizons. The Corrington Member buries coarse-grained older alluvium, glacial till, loess, or bedrock, and can grade laterally into Gunder Member deposits. Radiocarbon ages indicate that most sediment composing the Corrington Member accumulated between about 9,000 and 2,500 yr BP (Bettis, 1990).

Descriptions of Stops

Most of the descriptions of stops on this field trip are brief, primarily because we have just started to collect data at the localities. Detailed studies are underway at most localities and will yield additional information in the near future.

In the first half of the field trip, we will examine Holocene alluvial deposits (DeForest Formation) in the valleys of Little Salt Creek (stop 1) and the Big Blue River (stops 2 and 3) (fig. 1). All members of the DeForest Formation, except the Corrington, will be inspected. We will also examine late Pleistocene loesses and alluvial deposits at stop 1. The second half of the trip will focus on late Pleistocene loess stratigraphy east of Lincoln (stops 4 and 5, respectively). Stop 4 will also provide opportunities to examine late Holocene alluvium and a Nebraska-phase archeological site. Radiocarbon ages presented in our descriptions are δ13C corrected.

Stop 1. Little Salt Creek. At this stop we will first examine the alluvial stratigraphy exposed in the incised channel of Little Salt Creek. We will look at three outcrops along a 0.6-mi (1-km) stretch of the entrenched channel. The exposed sequence of alluvial fills along this reach are representative of a moderate-sized valley (fourth-order) in eastern Nebraska. After discussing the Holocene alluvial stratigraphy, we will move to a higher position in the landscape and examine late Pleistocene loesses and alluvium exposed in a borrow pit operated by General Excavating of Lincoln.

Little Salt Creek has a drainage area of approximately 28 mi² (72 km²) and joins Salt Creek about 1.8 mi (3 km) south of stop 1 (fig. 1). Saline springs maintain flow in the lower reach of Little Salt Creek throughout the year, and salt marshes cover much of the valley floor in this area. Arbor Lake, a restored salt marsh, is on the east side of the gravel road opposite Little Salt Creek. Segments of the creek have been straightened, including the reach at stop 1.

Stop 1a. At this stop we will see the Camp Creek and Gunder members exposed in cutbanks on both sides of the creek. Camp Creek Member deposits form a thin mantle of overbank sediments above the Gunder Member. The Camp Creek Member is oxidized, brown silt loam, and shows little evidence of pedogenic alteration. The underlying Gunder Member is oxidized, brown to yellowish brown silt loam, and a thick Mollisol with A-Bw horizonation has developed in its upper part.

Stop 1b. At this stop we will see the Camp Creek, Roberts Creek, and Gunder members exposed in a cutbank on the west side of the channel (fig. 2). Note the color of the three units. The Camp Creek Member is the uppermost unit and consists of brown and pale brown, silty overbank deposits. The surface soil in the upper part of the Camp Creek Member has an A-C profile, and there is distinct planar bedding in the lower 15.7 in. (40 cm) of the unit. The Camp Creek Member mantles a dark gray flood drape that forms the Roberts Creek Member.

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Fig. 1. Locations of the field-trip stops in eastern Nebraska.
Fig. 2. Holocene alluvial deposits exposed in the west bank of Little Salt Creek at stop 1b.

A soil developed in the upper part of the flood drape is characterized by a thick A horizon above a laminated C horizon. The Roberts Creek Member is 21.6-in. (55-cm) thick and overlies the Gunder Member, which is the lowest exposed alluvial fill in the section. The Gunder Member consists of oxidized, brown to yellowish brown silt loam grading downward to loam. A soil with A-Bw horizonation is developed in the upper part of the Gunder Member. Note how this buried soil dips to the north. Stratified loam and fine sand in the lower 9.5 to 10.8 ft (2.9-3.3 m) of the section overlie reduced fine-grained alluvium with abundant plant macrofossils. Wood from this organic-rich zone yielded a radiocarbon age of 7,080±90 yr BP (Beta-75728). This age is consistent with others from the lower part of the Gunder Member in moderate-sized valleys of western Iowa (Bettis, 1990) and northeastern Kansas (Mandel and others, 1991).

Stop 1c. The Camp Creek Member is exposed in the west bank adjacent to the road that leads into a borrow pit operated by General Excavating of Lincoln. This unit is present as a narrow remnant along the modern entrenched channel and is inset into the Gunder Member. Note the stratification (planar) and the poorly developed soil (A-C profile) in the upper part of the unit. Also notice that the Camp Creek Member is composed of coarser alluvium compared to the Gunder and Roberts Creek members. A piece of barbed wire was found at a depth of about 9.8 ft (3 m) in this exposure of the Camp Creek Member, demonstrating the Historic age of the unit.

Stop 1d. Our first loess section is located in the borrow pit at the base of the western valley wall of Little Salt Creek. The landform here is a loess-mantled terrace. The purpose of this stop is to examine a Wisconsinan loess sequence at a locality distant from the Platte Valley source. Subsequent loess stops will be at a locality close to the Platte Valley and at another locality close to both the Platte and Missouri valleys.

At this locality the Wisconsinan loesses bury a morphologically well-expressed Sangamon Soil developed in an upward-fining alluvial fill sequence (Crete sand and gravel member of the Loveland Formation; Reed and Dreeszen, 1965). These fluvial deposits are presumably pre-Wisconsinan in age.

Two late Wisconsinan loesses are present: the loess of the Gilman Canyon Formation and the overlying Peoria Loess (fig. 3). The Gilman Canyon loess is noncalcareous and dominated by pedologic features of the Gilman Canyon pedocomplex, including common macro pores, platy to subangular blocky structure, iron and manganese oxide stains, and discontinuous clay films and silt patches (silans) in the lower part of the unit. These features are typical for this unit in south-central Nebraska and Kansas (Reed and Dreeszen, 1965; Feng and others, 1994). The unit’s brown to dark yellowish brown color is probably a product of soil organic-matter additions (melanization) during development of the pedocomplex. At this locality the pedocomplex is expressed as a 20-in. (51-cm) thick A-AB soil profile welded to the underlying Bt horizon of the Sangamon Soil. Sand content increases downward through the Gil-
man Canyon into the Sangamon Soil developed in sandy alluvium. Two radiocarbon ages on humates extracted from bulk samples of the Gilman Canyon bracket the age of the pedocomplex here between 28,280±590 yr BP (Tx-8213--upper 4 in. [10 cm] of the 3Btlb of the Sangamon Soil) and 23,460±380 yr BP (Tx-8212--upper 4 in. [10 cm] of the 2A1b of the Gilman Canyon).

The contact between the Gilman Canyon and the overlying Peoria Loess is clear with some evidence of a mixing zone in the lower 6 in. (15 cm) of the Peoria. Peoria Loess is 13-ft (4-m) thick at this locality. A modern surface soil with an A-ABBt-Btk (weak stage II carbonate morphology)-Bct profile is developed in the upper 3.3 ft (1 m) of the loess. Beneath the solum the loess is noncalcareous yellowish brown to light brown, jointed silt loam (jointed, oxidized and leached weathering zone--JOL) with thin discontinuous organo-clay and carbonate coatings on the joint faces. A weakly calcareous zone

Fig. 3. Stratigraphic sequence for the General Excavating section, stop 1d.
that contains common medium-sized hard carbonate nodules (mottled, oxidized, unleached with secondary carbonate weathering zone-MOU2) is present from 10 to 11.7 ft (3.05-3.56 m). Snail shells are present in the lower 15 in. (38 cm) of this zone. The lower 16.9 in. (43 cm) of the Peoria Loess is noncalcareous, streaked pale brown to grayish brown silt loam with common mottles and iron and manganese stains (mottled, oxidized and leached to oxidized and leached weathering zone-MOL-MDL).

**Stop 2. Big Blue River, T-1 Terrace, Site 25SW28.** At this stop we will again examine the Gunder, Roberts Creek, and Camp Creek members, note the consistent lithologic properties observed at the previous stop, and compare soils developed into the units. The Big Blue River has migrated laterally into the valley fill beneath the lowest alluvial terrace (T-1) at this locality, forming a steep cutbank on the south side of the channel. Figure 4 shows the sequence of alluvial fills exposed in the cutbank. The Camp Creek Member is the uppermost unit and is 15.7- to 23.6-in. (40- to 60-cm) thick. This unit consists of grayish brown (10YR 5/2, dry) to light brownish gray (10YR 6/2, dry) silty overbank deposits. The surface soil developed in the Camp Creek Member is a thin Entisol (A-C profile). Notice how bedding has imparted platy structure within the C horizon.

An abrupt boundary separates the Camp Creek Member from the underlying Roberts Creek Member. There is a thick, dark cumulic soil with an A-Bw profile developed at the top of the Roberts Creek Member. The 2Ab horizon is 25.6-in. (65-cm) thick and is dark grayish brown (10YR 4/2, dry) silt loam. Prehistoric cultural materials, including fire-cracked rocks and chert flakes, have been recovered from the upper 13.8 in. (35 cm) of the 2Ab horizon (Mandel, 1994b). The 2Bwb horizon is 15.7-in. (40-cm) thick and is dark grayish brown to grayish brown (10YR 4/2-5/2, dry) silt loam with very weak, fine, subangular-blocky structure. The 2C1 horizon consists of faintly laminated grayish brown (10YR 5/2, dry) silt loam with many small pieces of wood charcoal. The lower part of the Roberts Creek Member is characterized by distinct planar bedding. The individual beds consist of upward-fining couplets grading from silt loam at the base to dark-colored silty clay loam and silt clay in the upper part.

Two radiocarbon ages were obtained from the Roberts Creek Member at this section (Mandel, 1994b). The zone of charcoal in the 2C horizon was dated to 1,100±90 yr BP (Tx-7949), and humates from a thin A horizon developed at the top of a planar bed in the lower 19.7 in. (50 cm) of the unit yielded a radiocarbon age of 3,550±60 yr BP (Tx-7951). Hence, most of the alluvium comprising the Roberts Creek Member at 25SW28 accumulated between about 3,500 and 1,000 yr BP.

The Gunder Member is the lowest exposed alluvial fill in the section. Upper parts of the unit have been eroded by episodes of entrenchment that preceded aggradation of the Roberts Creek Member. The Gunder Member is brown to dark brown (10YR 5/3-4/3, dry) and has common yellowish brown (10YR 4/4, dry) mottles. A buried soil is present in the Gunder Member at the bottom of the section. When the water level is low in the Big Blue River, the upper 11.8 to 15.7 in. (30-40 cm) of this soil are exposed along the south bank. The buried soil is laterally continuous, dark-colored, and well developed. A radiocarbon age is pending on charcoal from the upper 7.9 in. (20 cm) of this soil.

**Stop 3. Big Blue River, T-2 Terrace, Jursa Cutbank.** At this stop we will examine valley fill beneath the second terrace (T-2) of the Big Blue River near the confluence of this stream with the West Fork Big Blue River (fig. 1). The surface of the T-2 terrace is about 6.6 ft (2 m) higher than the T-1 terrace examined at stop 2. These two geomorphic surfaces are separated by a gently sloping scarp. A steep cutbank on the west side of the Blue River (Jursa property) provides an opportunity to view the stratigraphy of the T-2 fill.

The lowest exposed alluvial fill is about 13.1-ft (4-m) thick and rests unconformably on pre-Illinoian till (fig. 4). The lower part of this fill consists of stratified silt loam, loam, and fine sandy loam with a thin bed of fine sand and gravel. A dark brown paleosol developed in the upper part of this unit is mantled by a 3.3-ft (1-m) thick zone of sandy alluvium with redoximorphic features. Humates from the upper 4 in. (10 cm) of the buried paleosol yielded a radiocarbon age of 19,940±250 yr BP (Tx-7949). Based on its morphology and age, this alluvial fill appears to represents the alluvial facies of the Gilman Canyon Formation. Johnson and others (1990) noted that where the Gilman Canyon Formation is in an alluvial setting, the top of the unit is usually sandy, as is the case at stop 3.

A thick package of oxidized, silty sediment overlies the sandy zone of the Gilman Canyon Formation. The surface soil developed at the top of this unit is a thick, well-developed Mollisol with an A-Bt-Btk-Bck profile. Based on its lithologic properties and landscape position, we suspect that this unit is the Gunder Member and that it aggraded between about 10,500 and 4,000 yr BP. Although parts of this unit look much like loess, notice how the sediment becomes progressively sandier near channel deposits at the north end of the section. Hence, this appears to be a good example of different facies of the Gunder Member, that is, sandy channel and near-channel deposits versus silty distal floodplain deposits.

**Stop 4. Armbrust Creek, Sarpy County.** At this
stop we will examine two natural exposures along the south bank of a third-order stream that flows southward to the Platte River. Although it does not have a formal name, local residents call this stream Armbrust Creek. After inspecting a small section of late Holocene alluvium, we will examine a large section consisting of three loesses above two upward-finishing alluvial sequences. If time permits, we will also examine the floors of several Nebraska-phase earth lodges on the ridge above the large section of loess-mantled alluvium.

**Stop 4a.** At this locality late Holocene alluvium is exposed in a cutbank on the east side of Armbrust Creek. The stream has cut into valley fill beneath its...
Two stratigraphic units are visible in the section: the Camp Creek and Roberts Creek members (fig. 5). The Camp Creek Member underlies the modern floodplain and is draped over the T-1 terrace. This unit consists mostly of stratified brown and dark brown (10YR 5/3-4/3, dry) silt loam with laminae of pale brown (10YR 6/3, dry) silt loam. A thin channel lag marks the base of the Camp Creek Member. Bedding in the upper part of the unit has been disturbed but not obliterated through bioturbation, and the surface soil is a thin Entisol. Our initial impression was that the Camp Creek Member is less than 100 yr old at this locality. A radiocarbon age confirmed our suspicion: wood recovered from the base of the unit dates to 50±60 yr B.P. (Beta-75227). The lateral contact with the Roberts Creek Member is abrupt but very irregular (fig. 5), and large masses of the Roberts Creek Member form bank debris that has been incorporated into the Camp Creek Member along that contact.

The Roberts Creek Member forms most of the valley fill exposed beneath the T-1 surface (fig. 5). The lower part of this unit consists of stratified silt loam, loam, and fine sand. The silty beds are very dark grayish brown to dark brown (10YR 3/2-4/3, dry), and the sandy beds are brown to yellowish brown (10YR 5/3-5/4, dry). A soil developed in the upper part of the Roberts Creek Member has a thick A-AC profile. The 2Ab horizon is 26.8-in. (68-cm) thick and is a very dark grayish brown (10YR 3/2, dry) silt loam. This soil is mantled by recent overbank deposits (Camp Creek Member) that form a veneer that is about 51-in. (1.3-m) thick.

**Stop 4b.** This locality, which we refer to as the Armbrust Creek Pleistocene section, has not been studied in detail, but some general observations about the loesses, sub-loess alluvial units, and buried soils point to some interesting correlation issues. The upper (inaccessible) several meters of the section consist of two Wisconsinan loess units: the Peoria Loess and underlying loess of the Gilman Canyon Formation (fig. 6). The Peoria Loess is about the same thickness here as it is in the Little Salt Creek valley (stop 1), despite the close proximity of the Platte Valley source. The Peoria/Gilman Canyon contact is more gradual than at stop 1, and a basal mixing zone is better developed. The loess of the Gilman Canyon Formation is modified throughout by the Gilman Canyon pedocomplex, but at this locality properties of the unit are significantly different than to the west. Macropores are not as abundant here, and the unit is not as dark colored, suggesting a lower organic-carbon content. Although the Gilman Canyon is over 3.3-ft (1-m) thick, there is no evidence of discrete buried soil surfaces within the unit. The Gilman Canyon's properties here are intermediate between those typical of the unit farther west and those typical of the loess facies of the Pisgah Formation to the east in the thick loess region of western Iowa.

The Gilman Canyon Formation buries the Sangamon Soil developed in the loess of the Loveland Formation, with a gradual mixing zone boundary between the two (fig. 6). The Loveland is modified by pedogenesis throughout its extent, though the soil’s morphology is not strongly expressed. The Sangamon is a little over 3.3 ft (1 m) in thickness.

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**Fig. 5.** Late Holocene alluvial deposits exposed in the east bank of Armbrust Creek at stop 4a.
Fig. 6. Stratigraphic sequence for the Armbrust Creek Pleistocene section, stop 4b.
and has a minimally expressed Bt horizon. Sand content increases downward in the Loveland Formation to its contact with a reddish brown buried paleosol developed in an upward-fining alluvial fill.

Reed and Dreeszen (1965) and Dreeszen (1970) identified three formations in eastern Nebraska consisting of pre-Wisconsinan loess and alluvium that are stratigraphically above pre-Illinoian deposits and soils. In order of decreasing age, these are the Grafton, Beaver Creek, and Loveland formations. These units were presumed to relate to periglacial conditions during Illinoian glacial advances that terminated to the east and northeast. The Grafton Formation was interpreted as the periglacial region equivalent of the Santee Till. These alluvial units, silts (loesses), and associated soils were correlated to loesses and soils in the classic Buzzard's Roost section in Lincoln County, Nebraska (Reed and Dreeszen, 1965). Schultz and Martin (1970) proposed further revision of these units and suggested that the Loveland Formation include, from oldest to youngest, the Grafton, Beaver Creek, and Gothenburg members. All of these units are loesses at the Buzzard's Roost section. Boellstorff's (1978a, b) work on the correlation of the glacial sequences in eastern Nebraska, southeastern South Dakota, and Iowa demonstrated that what had formerly been interpreted as an early Illinoian till in eastern Nebraska (Santee Till) was actually pre-Illinoian in age and is stratigraphically below the Peoria "O" volcanic ash bed. This raised questions regarding the age of the Grafton Formation (or member in the terminology of Schultz and Martin, 1970) and also questions the relationships between what has been called Grafton in eastern Nebraska and the Grafton at the Buzzard's Roost section where it lies stratigraphically above the Peoria "O" volcanic ash bed.

So, how does this mess of stratigraphic terminology pertain to the Armbrust Creek Pleistocene section? Beneath the Sangamon Soil developed in the loess of the Loveland Formation are two upward-fining alluvial fill sequences with associated paleosols. Using the scheme of Reed and Dreeszen (1965), these would be the Beaver Creek (upper) and Grafton (lower) formations. The landscape positions of these alluvial fills suggest that they are inset into the youngest glacial tills on the uplands (pre-Illinoian "A" tills of Hallberg, [1986]) and are therefore less than 500,000 years old. They are older than the loess of the Loveland Formation (140+20 ka at the paratype section in western Iowa [Forman and others, 1992]), which buries a reddish brown paleosol with a Bt horizon and stage II carbonate morphology developed in the upper alluvial fill. The relationship of these two sub-loess alluvial fills to the modern drainage is unknown. Though we have indicated these units with their formal names followed by question marks for ease of discussion in figure 6, we feel it would be best to forgo naming units such as these until their chronometric age is known or until physical correlation to well-documented units is demonstrated. The lowest fill contains abundant beds of transported but well-preserved gastropod shells. Beneath the gastropod-bearing zone near creek level is an organic-rich paleosol that contains pollen and abundant plant and insect fossils being analyzed at this time.

**Stop 4c.** Time permitting, we will take a brief look at the floors of several Nebraska-phase earth lodges on the ridge above the Armbrust Creek section. The Nebraska State Historical Society recently excavated two of the house floors and left their excavation units open for our inspection. The Nebraska phase dates to about 1,000-700 yr BP and is a common Late Prehistoric affiliation in eastern Nebraska, especially on uplands.

**Stop 5. Maas Drive Section, Bellevue, Nebraska.** The final stop of this trip is at an abandoned borrow pit cut into a narrow interfluve descending to a tributary of Papilion Creek in Bellevue, Nebraska. This locality is about 4.4 mi (7 km) north of the Platte Valley and 3.4 mi (5.5 km) east of the Missouri Valley (fig. 1). Lower parts of the section are slump covered but the exposed section contains two Wisconsinan loesses overlying a well-expressed buried paleosol developed in another loess (fig. 7).

The upper 28 ft (8.5 m) of the section consists of Peoria Loess and a basal silty slope sediment. The loess is typical of the Peoria—oxidized, calcareous, and jointed with a few gastropod shells in some zones. The lower 3.3 to 5 ft (1-1.5 m) of the Peoria is distinctly different from the loess above it. This basal zone is more mottled, contains streaks of deoxidized (light gray) silt and secondary accumulations of manganese oxide, exhibits coarse horizontal parting ("platy" structure), and has prominent wavy "streaks" of organic-rich (including charcoal) silt that are occasionally overturned into recumbent folds. These and similar deposits in the basal part of the Peoria in western Iowa have been interpreted as solifluction deposits (Bettis, 1994).

Radiocarbon ages (AMS) have been determined on humins (sediment) and humic acids (extracted from sediment) from three locations within the Peoria at the Maas Drive section (Bettis and Stafford, in preparation). These ages are presented in table 1. Note that the ages do not become progressively younger from the lowest sample to the highest one in the section. This discrepancy can be explained by considering the genesis of the basal part of the Peoria. The wavy topography of the organic-rich beds, the presence of overturned folds, and the discontinuous nature of individual beds all point to a depositional rather than an in-situ pedogenic origin for
Fig. 7. Stratigraphic sequence for the Maas Drive section, stop 5.
these features. If the sediment in this basal zone was deposited by solifluction on the footslope and toeslope position of the late Wisconsinan landscape, then the organic-rich sediment must have been derived from A horizons of surface soils upslope. If this is the case, the radiocarbon ages of the organic-rich beds do not correspond precisely to the time of their deposition but rather to the age (mean residence time) of carbon in the soil horizon being eroded upslope.

The contact between the Peoria and the loess of the Gilman Canyon Formation is abrupt and wavy across the section. Abrupt contacts in loess-loess sections are the exception rather than the rule in the Midcontinent. In this case, the abrupt contact probably reflects rapid burial of the surface soil developed in the Gilman Canyon Formation by solifluction deposits. This would inhibit bioturbation and development of a mixing zone.

The loess of the Gilman Canyon Formation varies from 19.6 in. to 3.3 ft (50 cm-1 m) in thickness across the section. Characteristics of the Gilman Canyon Formation here are very similar to those of thick loess facies of the Fisgah Formation in western Iowa. The unit is modified throughout by a soil that lacks the strong biofabric common to the Gilman Canyon pedocomplex to the west. For the sake of discussion, we have called this buried paleosol the Farmdale Soil—the soil stratigraphic unit in this position across the Missouri Valley in Iowa. Charcoal collected 3.9 in. (10 cm) below the top of the Farmdale Soil in this section yielded an AMS radiocarbon age of 25,340 ± 260 yr BP (CAMS-10190). This is consistent with other radiocarbon ages from the upper part of the Farmdale Soil in Iowa and Illinois (Bettis, 1990) and with the ages from the Gilman Canyon pedocomplex at the Little Salt Creek locality (stop 1d).

The Gilman Canyon Formation has a gradual boundary (mixing zone) with the underlying Sangamon Soil developed in Loveland loess. The Sangamon Soil developed in loess here is as morphologically well expressed as has been recorded in the area. The soil has a thick A-Bt profile with thick, continuous clay films, strong structure, and strong rubification. Unmodified Loveland loess is not exposed in the section. At the north end of the section, the Loveland loess rests directly on Pennsylvanian rock. Elsewhere, the base of the Loveland is not exposed.

Summary

As we have seen on this field trip, several lithologically distinct alluvial fills comprise the DeForest Formation in eastern Nebraska. Morphological differences between members of the formation are attributed to several factors, including changes in sediment source, aggradation rates, water-table levels, and bioclimatic conditions. Stratigraphic, geomorphic, and chronologic relationships of the fills are predictable and provide insights into the long-term behavior of streams in eastern Nebraska.

A sequence of three late Pleistocene loesses can be traced across eastern Nebraska: the Loveland, Gilman Canyon, and Peoria. The upper part of the oldest loess, the Loveland, is modified by pedogenesis (Sangamon Soil), but the morphology of the soil varies from weakly expressed in bluff-line exposures strongly expressed on the broad interfluvies. Properties of the pedocomplex developed in the Gilman Canyon Formation vary systematically from west to east across the region. Also, physical and chemical properties of the lower part of the Peoria Loess suggest that the landscape was strongly affected by mass-wasting processes (solifluction) in a periglacial environment during the early part of the Peoria's depositional history.

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Hydrostratigraphic Control
of Contaminant Occurrence and Transport
Offutt Air Force Base, Nebraska

Field Trip No. 8

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(Available Separately)
Permian Strata in the Manhattan, Kansas, Area:
Implications for Climatic and Eustatic Controls

Field Trip No. 9

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Overview

Biostratigraphy
The exposure at Tuttle Creek (stop 4) is unique from a biostratigraphic viewpoint. There has been extensive debate regarding placement of the Pennsylvanian-Permian boundary (see Moore, 1940) in the Kansas section. Recent work (Baars and others, 1994) has suggested a boundary placement at the base of the Neva Limestone (fig. 1); however, this boundary has not been agreed to by the Working Group on the Pennsylvanian-Permian Boundary of the International Commission on Stratigraphy. The International Commission is considering three positions for boundary placement (see horizontal arrows on fig. 1). From lowest to highest, the boundaries are: 1) within the Americus Limestone Member of the Foraker Limestone; 2) at or near the top of the Glenrock Limestone Member of the Red Eagle Formation; and 3) within the Burr Limestone Member of the Grenola Formation. The two highest positions are exposed at stop 4 (fig. 2), and the lowest position is exposed nearby. Thus, this important systemic boundary will be available near Manhattan, Kansas.

Climatostratigraphy
There are significant differences between the Permian and the underlying Pennsylvanian in terms of the major controls. The Permo-Pennsylvanian of the Midcontinent contains a number of repetitive depositional sequences ("cyclothems") commonly viewed as the product of depth-controlled lithofacies formed during cyclical glacio-eustatic flux (see Heckel, 1986). However, basinal paleoclimate exerts a high degree of control on siliciclastic influx, which in turn affects the proclivity of carbonate deposition. Tectonics, climate, and eustacy, are completely interwoven and had significant effects on lithofacies. Analyses of lithofacies distributions indicates a prominent shift, during the Permo-Pennsylvanian, from wetter to drier climates.

The "drying trend" is largely controlled by paleolatitude because Kansas shifted from a near-equatorial position in the middle-upper Pennsylvanian to approximately 15 to 20 degrees north during the Permian. Movement through the latitudinally controlled climatic belts resulted in a concomitant shift from equatorial everwet to wet seasonal (monsoonal) and ultimately to dry seasonal paleoclimates. The paleosols viewed during this trip are generally indicative of highly seasonal climates (Joeckel, 1991; Miller and others, 1992).

Average global sea level also underwent a gradual reduction, and the extent of the highstand epicontinental seaways was significantly less during the Permian compared to the underlying Pennsylvanian. Some of the effects of climate and sedimentation during the Midcontinental Permo-Pennsylvanian have been discussed by Archer and West (1993), Archer and others (1994), Miller and West (1993), Miller (1994), and Schutter and Heckel (1985).

Cycle Patterns
In the study area, cyclothem boundaries are not defined as they are for Pennsylvanian cycles of eastern Kansas (Heckel, 1986). The lower boundary of the Permian cycles described herein is placed at the base of the stratigraphically lowest marine limestones that occur above a paleosol-bearing interval. Commonly, these fossiliferous marine limestones directly overlie and can partially truncate the uppermost paleosol. Cyclothem boundaries, as defined herein, are always surfaces of inferred deepening and dislocation of depositional facies. The boundaries commonly appear to be erosive, although little to no relief is evident on an outcrop scale. The cyclothem-bounding surfaces are thus equivalent to the transgressive surfaces of erosion defined by Van Wagoner and others (1988). Compared to Pennsylvanian cyclothem terminology, the base of a Permian...
Fig. 1. A) Stratigraphy of the Council Grove and lower Chase groups with vertical arrows showing intervals covered by field trip stops. Horizontal arrows mark three suggested placements of the Pennsylvanian-Permian boundary. B) Key to lithologic and pedogenic features utilized in the detailed stratigraphic section.
Fig. 2. Map of the Manhattan and Junction City area showing locations of four field trip stops.

Paleosols

Stacked paleosol profiles comprise a substantial part of the variegated mudstones of the Permian strata (Joeckel, 1991). Flooding surfaces, consisting of lags of intraclasts, fish bones, ostracodes, and shelly debris, commonly subdivide these units. These subdivisions form units that are laterally traceable for tens of miles or more (Miller and others, 1992; McCahon and Miller, 1993). Variations in paleosols within laterally correlated cycles have been found to be small relative to differences among vertically stacked paleosol profiles at a single locality. In addition, the vertical succession of paleosol types observed within individual cycles is consistent among various localities. In general, paleosol successions include from lowest to highest: 1) calcic clay-rich profiles containing carbonate nodules and rhizocretions to 2) profiles with pseudoanticlines and other features of vertic paleosols.

Certain enigmatic features of the lower calcic paleosols indicate polygenetic profiles. Carbonate nodules and rhizocretions are concentrated in the upper parts of the profiles and overlie argillic horizons with well-developed clay cutans. This pattern is the reverse of what is expected in a typical calcic soil, where carbonate precipitation occurs below the zone of seasonal leaching and clay illuviation (Birke-
land, 1984; Marriot and Wright, 1993). Climates wet enough to translocate clay downward through a profile would also leach soluble salts from the upper horizon. Thus, it is inferred that these paleosols developed initially under humid to subhumid conditions. The subsequent precipitation and preservation of carbonate occurred under semi-arid conditions later during pedogenesis, when rates of evapotranspiration greatly exceeded mean annual precipitation (Boul and others, 1980; Mack, 1992).

Pseudoanticlines and pedogenic slickensides of the vertic paleosols were produced by shrinking and expansion of clay-rich soils in response to wetting and drying in a markedly seasonal or monsoonal climate (Kraus and Aslan, 1993; Driese and others, 1992). The uniform green-to-yellowish color of the profiles suggests saturation of the soil during part of the year, and the lack of horizonation is consistent with the extensive turbation characteristic of Vertisols (Birkeland, 1984). Relatively high organic content (~1-2 percent) and presence of disseminated charcoal also reflect high rates of soil turbulence and an extended dry season. In the calcic soils, the abundant carbonate nodules that occur within the upper parts of some vertic soil profiles (such as the Roca Shale, fig. 6) suggest a trend toward drier conditions during later-phase soil development.

Stop 1. Emergency Spillway at Milford Reservoir--Introduction. The stratigraphic overview of this site is presented in figure 3. The U.S. Army Corps of Engineers supervises this site, and collection of in-situ geological samples is by permit only. Sampling related to research efforts are encouraged, and the field trip leaders are authorized to direct such activities. The area west of Kansas Spur 244 is designated "No Trespassing" because it is an impact zone for small-arms fire. For personal safety, previous arrangements must be made with the Geary County Gun Club before proceeding west of K-244.

The floodwaters of 1993 quickly stripped off the overlying fill and loosened in the center of this open spillway, washed out the roadway, which was subsequently rebuilt, and eroded the Permian bedrock. This erosion exposed a paleokarst topography with many sinkholes and east-trending solution channels that extend throughout the entire 72 ft (22 m) of limestone.

Blue Springs Shale Member of Matfield Shale. Only the upper 15 ft (4.57 m) of Blue Springs shale is exposed in the waterfall at the east. Close examination of the red and green mudstone and siltstone and greenish gray carbonate mudstone reveals several stacked sequences of paleosols. Blocky pedds, gleyed and limonite root traces, some polygons, curved fracture surfaces, manganese dendrites and coatings, and some carbonate-rich nodules occur. The upper part contains some coarse silt that may be wind-derived. The upper contact is a pale yellowish brown, ostracode packstone. Marine fossils are rare, but myalinid bivalves occur near the top.

Florence Limestone Member, Barneston Limestone. Orientation and origin of the 50 beds and horizons of chert within the 31.33 ft (9.55 m) of the Florence limestone can be examined in all dimensions. The horizontal pattern of the chert resembles a complex system of burrows somewhat similar to *Thalassinoides*. Several vertical channels join two or more of the horizontal chert beds, indicating multi-storied development. The chert seems to occur only in fine-grained carbonate mudstone. About 6.5 ft (2 m) above the base of the Florence are some monaxial sponge spicules in many dark gray cores of the chert nodules. A few silicified rosettes of gypsum occur in some chert bands.

At about 23 ft (7 m) above the base are two beds of botryoidal, or mammillar romanenchite (complex hydrated barium manganese oxide), that fills spaces between raised chert masses. The romanenchite forms several thin crusts in silicified rock that developed in the depressions between, and in some places, under the chert. Cross sections of the intergrowth of romanenchite and microquartz reveal a "wood-grained" structure that consists of thin black layers within the lighter chert. Both masses contain silicified skeletal debris similar to the same unsilicified types that occur in the adjacent carbonate mudstone and wackestone.

Biotic diversity of the Florence is high. Brachiopods, fusulinids, fenestrate, ramose, and encrusting bryozoans, crinoids, echinoids, ostracodes, bivalves, gastropods, sponge spicules, and lophophyllid corals occur throughout. The density and diversity of skeletal debris seem to increase upward and occur equally in the chert as silicified remains and in the carbonate mudstone and wackestone. The trace fossil *Rhizocorallium* occurs at the upper contact and continues into the overlying Oketo shale.

Oketo Shale Member, Florence Limestone. The Oketo Shale Member is 5.2-ft (1.58-m) thick and consists of clayey and silty, calcitic carbonate mudstone and wackestone that weathers more like a shale or mudstone. The lower boundary with the Florence limestone is sharp. The lower half contains only a few crinoids and thin-shelled brachiopods. The marine biota becomes more abundant and diverse upward and consists of brachiopods, fenestrate and ramose bryozoans, crinoids, and *Aviculopinna* (some in vertical position). *Rhizocorallium* is especially abundant on bedding planes in the upper part, and some *Thalassinoides*-like burrow systems occur in a few beds.

Fort Riley Limestone Member, Florence Limestone. The Fort Riley limestone is 37.4-ft (11.41-m)
Fig. 3. Stratigraphic section for rocks exposed by erosion during the flood of 1993 in the Milford Lake spillway (stop 1). A detailed description of this section can be found in Miller and Twiss (1994). Arrows mark flooding surfaces that bound meter-scale cycles.
thick and records a general marine regression. The biological diversity and abundance decreases upward, and the quantity of evaporites increases. The lower Fort Riley is a calcite wackestone that contains echinoids, crinoids, thin-shelled brachiopods, and *Aviculopecten*. Near the base is the thick (4.6 ft [1.4 m]), bioturbated "rimrock," a key bed that is mappable throughout the region. The base of the "rimrock" is marked by many *Rhizocorallium* burrows. The Fort Riley changes upward into a thin-bedded, light gray to pale brown calcitic and dolomitic carbonate mudstone that contains molds of possible gypsum rosettes and vugs that may have been halite inclusions. Many thin beds contain dense accumulations of internal molds of bivalves on the upper surfaces. Near the top the beds are thin-bedded, undulatory, dolomitic mudstone with many pin-point vugs and probable molds of gypsum rosettes. Other than some possible burrows, the upper unit is non-fossiliferous.

**Holmesville Shale Member, Doyle Shale.** Only the lower 8.72 ft (2.66 m) of the Holmesville Shale Member occurs in the spillway. The calcareous mudstone contains many calcite-filled polygonal fractures and tepee structures; boxwork structure is common and is suggestive of evaporite precipitation and dissolution.

**Pleistocene Loess.** Light yellowish brown, loess-filled sinkholes and solution channels penetrate the Permian rocks. Near the waterfall in the east end of the spillway, the loess has covered a pre-Pleistocene hill of Florence limestone. The waterfall is probably formed on the original valley wall of the Republican River before the loess filled in the old valley.

**Stop 2. Scenic Drive Roadcuts: Crouse, Funston, and Wreford Formations--Introduction.** The following information is a brief summary of extensive work by Miller and West (1993) on the stratigraphic exposures at this stop (fig. 4). These roadcuts were created during the construction of the road during 1990-1991; however, considerable degradation has subsequently occurred within the finer grained units. As defined by Elias (1937), six cyclothems occur in this interval; however, only four will be examined in detail (Crouse, Funston, Threemile, and Schroyer cycles). The latter three were grouped by Moore (1964) into a "megacyclothem."

**Easly Creek Shale.** This shale consists of a stacked series of paleosols. At the base, brecciated zones occur in outcrop that correspond to a 5.9-ft (1.8-m) thick interval of gypsum beds in the subsurface. Near the top, a 1.64-ft (50-cm) thick intraclastic limestone marks a cyclothem boundary as defined by Miller and West (1993). Thin limestones above contain abundant brachiopods, bryozoans, crinoids, algal-coated grains, and ostracodes. Fossiliferous shales near the top contain a low-diversity fauna of lingulids and pectinid bivalves.

**Crouse Limestone.** This limestone contains three widely traceable intervals (West, 1972). The lower unit consists of 4-in. (10-cm) thick wackestones to packstones, containing pyramidellid gastropods and bivalves that are separated by thin shale partings. The middle Crouse unit is a calcareous, silty mudstone containing carbonate-filled fractures and an evaporite-related brecciation(?). The upper unit is a thin-bedded, horizontally laminated dolomircite containing ostracode pavements. The Crouse appears to represent a shallowing-upward sequence formed within shallow subtidal to supratidal settings (West and Twiss, 1988).

**Blue Rapids Shale.** Overlying the Crouse are variegated mudstones of the overlying Blue Rapids Shale. The Blue Rapids is divisible, similar to the Eskridge Shale at stop 2, into units that are delineated by "flooding surface." Four such units can be recognized within the Blue Rapids at this locality. The characteristic upward trend from calcite to vertic paleosols is well displayed.

**Funston Limestone.** Depending on definitions of a "cyclothem," the lower cycle boundary could be placed either within the underlying Blue Rapids (cycle of Heckel, 1977) or at the base of the Funston (Miller and West, 1993). The basal Funston is marked by a prominent flooding surface that consists of a 1.31-ft (40-cm) thick argillaceous packstone containing granule-size mudstone clasts and fragmented skeletal debris (pyramidellid gastropods, ostracodes, productid brachiopods, bryozoans, and crinoids). An overlying unfossiliferous mudstone exhibits horizontal lamination in the lower part and thin-walled, silica geodes. These geodes have a botryoidal or cauliflower-form surface and are probably replacements of primary gypsum nodules. Thin overlying limestones contain ostracodes and pyramidellid gastropods. Mudstones exhibit pedogenic slickensides suggestive of incipient soil development.

**Speiser Shale.** This unit is a variegated mudstone very similar to the Blue Rapids Shale. Four subdivisions of the Speiser, consisting of paleosols capped by flooding surfaces, can be observed. The flooding surface that truncates the upper vertic paleosol is defined by Miller and West (1993) as the base of the next cycle. The uppermost interval is more fossiliferous and contains articulated bivalves, ramose and fenestrate bryozoans, and crinoids.

**Threemile Limestone.** This unit is the lowest prominent chert-bearing limestone in the area. It contains four distinct units at this locality: 1) a wackestone to packstone containing irregular chert beds and productid and crinoid debris; 2) a fissile calcareous shale grading upward into a wackestone
Fig. 4. Stratigraphic section for rocks exposed along Scenic Drive (K-408) roadcut (stop 2). Arrows mark flooding surfaces that bound meter-scale cycles (modified from Miller and West, 1993).
containing brachiopods, crinoids, fenestrate and ramose bryozoans, ostracodes, and chert nodules; 3) a wackestone containing brachiopods, small bivalves, and crinoids that thickens to 24.6 ft (7.5 m) in central Kansas (Hattin, 1957); and 4) a highly cherty wackestone to packstone containing crinoids, bryozoans, brachiopods and trilobites.

**Havensville Shale.** This unit is notably different from the previously described shales. The lower contact is gradational, rather than abrupt, and evidence of subaerial exposure and pedogenesis does not occur at the base. At the base, the Havensville includes calcareous shales and mudstones that are poorly fossiliferous except for pectinid bivalves. "Boxwork" fabric, which probably relates to subaerial drying and/or evaporite dissolution, overlies the poorly fossiliferous shales. An overlying wackestone contains abundant ostracodes, chonetid brachiopods, and is rooted at the top. The rooted zone is overlain by another "boxwork" zone, which in turn is capped by an argillaceous wackestone containing brachiopod debris, ramose and fenestrate bryozoans, crinoids, and ostracodes. As defined by Miller and West (1993), this limestone marks the next cyclothem. An overlying calcareous mudstone contains silica bands and nodules and cauliflower-shaped, quartz-filled geodes.

**Schroyer Limestone.** This unit is another highly cherty limestone and can be divided into four units: 1) a micrite containing ellipsoidal chert concretions and small, solution (?) voids; 2) a shale grading into a massive, chert-bearing wackestone containing articulated productids and *Composita*, ostracodes, crinoids, and bryozoans; 3) a fossiliferous calcareous mudstone that becomes rubbly and nodular at the top; and 4) a wackestone to packstone with abundant solution (?) voids and moldic porosity.

**Stop 3. Anderson Avenue Roadcuts (Near Intersection with Scenic Drive): Eskridge Shale and Beattie Formation--Introduction.** This site exhibits stacked paleosol profiles of the Eskridge Shale, as well as the facies sequence of the Beattie Formation (fig. 5). The Beattie, which consists of the Cottonwood limestone, Florena shale, and Morrill limestone, is one of the most complete cyclothems in the area (Elias, 1937).

**Eskridge Shale.** Four stratigraphic intervals occur within the Eskridge Shale that can be traced to the Nebraska border (Joeckel, 1991). The lowest interval is a red and green variegated mudstone with well-developed pedogenic structures, which include angular blocky peds, root traces, and dense, amalgamated carbonate rhizocreations. The rhizocretion layers resemble columnar peds and are stacked in units of a few decimeters in thickness.

The next interval consists of light gray calcareous mudstone and is marked by a thin, basal lag of ostracodes and gastropods. Above the lag are thin limestones containing myalinids, pectinids, and *Derbyia* brachiopods. An argillaceous packstone, interpreted as a condensed unit, forms the top of the second unit and contains ostracodes, skeletal debris, and fish bones.

The third interval, which consists of variegated red and green mudstones, exhibits well-developed angular blocky peds and brecciated fabrics. The upper boundary of these paleosols is truncated by an intraclastic limestone consisting of granule- to cobble-sized mudstone clasts, pyramidellid gastropods, and productid spines and shell fragments.

The fourth unit consists of poorly fossiliferous
shale (except for Derbyia and productid pavements) and the upper surface is extensively rooted. A grayish green paleosol containing angular blocky ped and possible pseudomorphs underlies a condensed phosphatic bed that directly underlies the Cottonwood limestone. The condensed unit contains mudstone clasts, phosphate nodules, bone fragments, and calcareous skeletal debris.

**Beattie Limestone.** The three members are exposed at this stop and consist of (in ascending order) the Cottonwood limestone, Florena shale, and Morrill limestone. The Cottonwood consists of a lower massive bioclastic packstone to wackestone containing fragments of brachiopods, bryozoans, and crinoids. Skeletal debris-filled burrows occur within this unit that are similar to "tubular tempestites" described by Wanless and others (1988). The upper part is a fusulinid packstone containing chert nodules near the top. Similar fusulinid packstones have been described as storm deposits (Ball, 1971) or as transgressive lags (Archer and others, 1994).

The Florena contains dense shell pavements of Derbyia and Neochonetes and would occupy a "core-shale" position in Heckel's (1977) "Kansas-type" cyclothem. The overlying Morrill includes lower argillaceous wackestone containing brachiopods, crinoids, and echinoid spines. The base of the Morrill commonly has a well-developed boxwork structure suggesting subaerial exposure (Twiss, 1988; Imbrie and others, 1964). An overlying gray fossiliferous shale contains pavements of Derbyia. The upper Morrill consists of cherty and vuggy limestones and calcareous mudstones.

**Stop 4. Emergency Spillway at Tuttle Creek Reservoir: Johnson Shale, Red Eagle Limestone, Roca Shale, and Grenola Limestone—Effects of Flooding.** This site is under the jurisdiction of the U.S. Army Corps of Engineers and collection of in-situ geological samples is by permit only. Before the summer of 1993, the spillway was a grassy flat that directly underlies the Cottonwood limestone. The condensed unit contains mudstone clasts, phosphate nodules, bone fragments, and calcareous skeletal debris.

**Stratigraphy.** A generalized section of strata exposed is shown in figure 6. During the trip, some discussion will be presented on the cycloths composed of the Johnson Shale, Red Eagle Limestone, and Roca Shale, which in some regards share similarities with Missourian sequences in eastern Kansas. The following stratigraphic overview is adapted from Miller (1994) and West (1994). The overall section exposed within the original excavations and by the 1993 erosion consists of nearly the entire Council Grove Group.

**Structural Geology.** The principal structural feature that influenced spillway erosion was the joints. In the Manhattan region, there is a general northeastern-southwestern and northwestern-southeastern orientation of joints (Chelikowsky, 1972). In addition, there is the Spillway Fault System, the orientation of which was influenced by the joint systems. Since joints are zones of weakness, the joints were preferentially eroded during floodwater release. At a number of locations south of the concrete apron of the spillway, significant upstream (northward) retreat of the limestone-capped escarpments occurred along one or more joints as joint-bounded blocks were ripped away by the force of the water.

The Spillway Fault System is exposed in the northeastern wall of the spillway (north of the gates); no part of the fault system lies beneath the dam nor the gates of the spillway. The Spillway Fault, with vertical displacement of about 23 ft (7 m), was studied carefully during the design of the Tuttle Creek Dam and was deemed to pose no significant threat to the dam or spillway. No evidence suggests that the fault has been active in geologically recent time. For example, during a 10-year period (1977-1987) of monitoring of microseismic activity by the Kansas Geological Survey, none of the microseismic events, which averaged about one per month, was associated with the Spillway Fault System (D. Steeple, personal communication).

**Foraker Limestone.** Unit is exposed at the base of the eroded section of the spillway. Portions of the Hughes Creek Shale Member and the entire, overlying Long Creek Limestone Member are exposed. The Hughes Creek includes several limestone beds that are abundantly fossiliferous. Common forms include productids, crinoids, cheonitids, fenestrate bryozoans, gastropods, crinoids, and some beds contain very abundant fusulinids. Several large slabs of limestone were overturned during the flooding and large, *Thalassinoides*-type trace-fossil networks can be seen. A dark shale within the interval principally contains inarticulate and articulate brachiopods.

The Long Creek limestone contains laminated dolomitic limestones and zones of replaced sulfate nodules. Fossils consist principally of a molluscan assemblage. An interval of desiccation cracks occurs in the middle of the unit. There are current and
Fig. 6. Stratigraphic section for rocks exposed by erosion during the flood of 1993 in the Tuttle Creek Lake spillway (stop 4). Detailed descriptions of this exposure can be found in Miller (1994) and West (1994). Arrows mark flooding surfaces that bound meter-scale cycles.
oscillatory ripples and crinkled surfaces (algal-mat controlled?) on some bedding surfaces. The limestone apparently formed within sabkha-like conditions.

**Johnson Shale.** This extensively eroded unit contains gray to yellowish gray shales and argillaceous limestones. Regionally, the lower part contains thin gypsum beds. Carbonate breccias and intraclasts and several paleosols occur within this unit. A paleosol with very well-developed columnar ped horizons is present and suggests pedogenesis under saline conditions.

**Red Eagle Limestone.** This formation consists of three members, in ascending order: the Glenrock Limestone Member, the Bennett Shale Member, and the Howe Limestone Member. The Glenrock is particularly interesting at the spillway because it consists nearly entirely of rounded and algal-coated grains and intraclasts ranging from 0.1-0.4 in. (2-10 mm) in diameter. The intraclasts show a variety of coloration, suggesting multiple origins. Fossils include gastropods, brachiopods, crinoids, bivalves, and bryozoans. Fusulinids are particularly common in the upper few centimeters. Dark, shale-filled burrows occur at the top of the unit.

The overlying Bennett shale is an olive-black shale. The shale is finely laminated at the base and is generally unfossiliferous except for horizons of abundant orbuloid brachiopods. Calcified shark cartilage and the jaw of a shell-crushing shark have been collected at this site. Upper parts of the shale are gradational with the overlying limestone and are lighter in color because of the bioturbational incorporation of overlying carbonate-rich sediment. Chondritid- and planolitid-type bioturbation predominates. In southern Kansas, this stratigraphic interval is predominately a light gray limestone that contains echinoderms, corals, and brachiopods.

The Howe limestone is a laterally persistent unit and consists of wackestones to packstones that contain fusulinids, brachiopods, bryozoans, and bivalves. The upper part consists of ostracode and coated-grain skeletal sand. The top of the unit is delineated by stromatolites that are extensively exposed at the east and west sides of the spillway. On the west side, ponded water commonly partially covers the stromatolites, which produces a good "Shark Bay" analogy.

**Roca Shale.** This extensively eroded unit consists of olive-gray to brown laminated shales at the base. A very prominent zone of mudcracks occurs below the transitional to reddish colorations. The variegated upper part of the Roca contains three stacked paleosol profiles. The locality provides an exceptional opportunity to view characteristic structures of calcic and vertic paleosols (detailed descriptions in Miller, 1994).

**Grenola Limestone.** This unit consists of three members, the Salyards Limestone Member, the Legion Shale Member, and the Burr Limestone Member. The Salyards limestone contains a molluscan assemblage and *Aviculohipina* is especially common. The unit is highly bioturbated and chondritid burrows and *Thalassinoides* networks are common. A lag of algal-coated shells and *Aviculohipina* and *Aviculopecten* occurs at the top of the unit.

The Legion Shale consists of olive-gray to dark gray calcareous shales and mudstones. The mudcracks are overlain by a thin, columnar ped horizon. The lower part of the unit has mudcracks filled with lighter gray mudstone. This mudcracked interval has extensively weathered since the floodwater erosion, and the mudcracks, which formed prominent polygonal networks, are now largely obscured. The upper part of the unit contains intraclasts and *Thalassinoides* burrow networks.

The Burr limestone occurs directly underneath the concrete lip of the spillway. In the lower part, *Aviculohipina*, crinoids, brachiopods, myalinids, and high-spired gastropods are common in the upper part, as well as chondritid burrows and *Thalassinoides* networks. The upper part consists predominantly of carbonate mudstone that contains gastropods and dark-colored plant debris.

**Quaternary Deposits.** Three late Pleistocene loess units and two alluvial stratigraphic units are exposed along the lower east side of the Tuttle Creek spillway (fig. 7). The oldest unit, which directly overlies the Long Creek limestone, is fine-grained, gray alluvium. The alluvium is poorly bedded, calcareous, and contains gastropods and enough organic matter to give it the gray color. It was probably deposited in an ephemeral-stream floodplain environment. The contact at the base of the gray alluvium is abrupt, and there is no indication of significant weathering or soil formation in the underlying bedrock.

Stratigraphically overlying the gray alluvium is a yellowish brown loess unit (loess no. 1, fig. 7) about 5-ft (1.5-m) thick. In the southern part of the exposure, loess no. 1 rests directly on gravel that overlies the bedrock, and the gray alluvium is absent. If regional correlations of the overlying loess units are correct, loess no. 1 may be equivalent to the pre-Wisconsin Loveland loess or to some early Wisconsin unit (see Forman and others, 1992). Loess no. 1 is not strongly weathered, although there is some evidence of soil development, so it may not pre-date the Sangamon soil, and may in fact be of early Wisconsin age.

Overlying loess no. 1 is an organic-rich paleosol that is tentatively correlated with the Gilman Canyon Formation of middle Wisconsin age. The paleosol is about 4.26-ft (1.3-m) thick and is devel-
oped in loess. It appears to be strongly pedoturbated; soil morphological features such as structure and horizonation are well developed, and the dark color suggests an increase in organic matter over the loess units above and below. The Gilman Canyon loess has been dated between 35,000 and 24,000 years in Nebraska and Kansas (Johnson and others, 1990) and probably represents a period when the rate of eolian-dust accumulation was relatively low compared with the rate of organic-matter accumulation in the soil.

A sample of the Gilman Canyon (?) paleosol collected from the Tuttle Creek spillway has yielded a radiocarbon age of 36,510 years BP and therefore should probably be interpreted as greater than 36,500 years BP, rather than as a finite age because only a small amount of young-carbon contaminant would cause a very old sample to appear to have a finite age. Therefore, the paleosol at Tuttle Creek is either at the lower age limit of the Gilman Canyon Formation or is older than the Gilman Canyon. The Gilman Canyon (?) paleosol grades upward into an approximately 4-ft (1.2-m) thick loess interval that is transitional in color between the Gilman Canyon (?) and the overlying Peoria (?) and may be equivalent to a similar transition zone noted elsewhere in the region at the base of the Peoria (Johnson and others, 1990). The Peoria (?) Loess itself is about 10-ft (3-m) thick, yellowish brown, and is the parent material for the modern (late Holocene) soil. It probably represents a period of more rapid dust deposition than the Gilman Canyon (?). Radiocarbon ages for the Peoria in the midwestern United States range between 25,000 and 12,000 years old (Forman and others, 1992; Johnson and others, 1990).

Alluvium overlies an unconformity that cuts out the Peoria (?) Loess, Gilman Canyon (?) loess, and part of loess no. 1 (fig. 1). The alluvium is fine-grained and yellowish brown, similar to the nearby loess units, but it also contains lenses of sand and gravel and has distinct bedding, as compared with the massive loess. The unconformity and alluvial fill record one cycle of downcutting and aggradation along the ephemeral stream that formerly flowed through the valley now occupied by the spillway. The alluvium grades upward into massive silt that is either Peoria Loess or loess reworked during the Holocene. In other words, it is unclear whether the unconformity is late Pleistocene (mid-Peoria) or Holocene in age.

### Road Log

**Day 1**

<table>
<thead>
<tr>
<th>Mileage</th>
<th>(Mileage between directions in bold.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>Manhattan Days Inn Motel, 1501 Tuttle Creek Blvd. At intersection of Ehlers Rd. and Tuttle Creek Blvd., turn right and continue south. Bluemont Hill is on the right and the Johnson Shale and overlying Red Eagle Limestone are exposed along the roadcut. (1.5)</td>
</tr>
<tr>
<td>1.5</td>
<td>Former Manhattan Union Pacific Railroad Station on the right. Highway is now Kansas 18 (K-18; Kansas highways designated by K-#). (2.1)</td>
</tr>
<tr>
<td>3.6</td>
<td>Bridge over Wildcat Creek that joins the Kansas River to the south. (0.4)</td>
</tr>
<tr>
<td>4.0</td>
<td>Intersection with K-113, Seth Childs Rd. Continue on K-18. (0.3)</td>
</tr>
</tbody>
</table>
Neva Limestone Member of Grenola Limestone in roadcut. (0.2)
Cottonwood Limestone Member of Beattie Limestone on the right. (0.3)
Cottonwood Limestone on the right. (0.1)
Poorly exposed varicolored Eskridge Shale on the right. (0.2)
Neva Limestone capped by varicolored Eskridge Shale with Cottonwood Limestone at the top. (0.2)
Poorly exposed Burr Limestone and Salem Point Shale. (0.25)
Junction with County 418. Crossing floodplain of Kansas River. (0.25)
On the right is an old meander scar of the Kansas River. (0.7)
Junction with County 408 scenic drive. Continue on K-18. Present course of the Kansas River is left of K-18. In the late 19th and early 20th centuries, the Kansas River meandered to the right of K-18. (1.5)
Manhattan International Airport. (2.1)
K-18 continues to left. (0.4)
Crossing overpass. (0.9)
Intersection with Ogden road. (1.2)
Geary County Line and bridge over Kansas River. (2.4)
Climbing hill underlain by limestone and mudstone of the Chase Group. (0.4)
Turn right at Salina exit to enter I-70. (0.4)
Schroyer limestone, Matfield Shale, and Florence limestone. (0.6)
Marshall Field and Fort Riley on the right. Grant Ridge on the left is capped by Fort Riley Limestone Member of the Barneston Limestone. (2.2)
Franks Creek. (1.1)
Grant Ridge Hill is on the right. An excellent exposure, in ascending order, of Wymore Shale, Kinney Limestone, and Blue Springs shale, members of the Matfield Shale. The chert-bearing Florence limestone caps the exposure. (0.6)
Crossing Smoky Hill River, which joins the Republican River east of Junction City to become the Kansas River that joins the Missouri at Kansas City. (2.4)
Hill on the right is capped by Fort Riley Limestone Member of the Barneston Limestone. (0.9)
Exit right at Exit 295 to US-77. (0.3)
Stop sign. Turn right and continue north on US-77. (0.3)
Right roadcut contains the Florence limestone, Oketo shale, part of the Fort Riley limestone, all members of the Barneston Limestone of the Chase Group. (1.4)
Fort Riley limestone and top of underlying Oketo Shale at old quarry on the left. Continue north on US-77, passing underneath K-18. (1.7)
Descending hill through the Barneston Limestone. An excellent vertical cut that exposes the rocks that we will also observe in detail at stop 1. (0.7)
Turn left on K-57 and K-244 and continue west on K-57. (0.4)
Stay on K-57 on the right. (0.3)
Traveling over K-57, which was washed out by 1993 flood and destroyed much of the experimental plots of the Kansas State University Forestry Department. (0.6)
Florence Limestone Member of the Barneston Limestone on the right. (0.5)
Turn left and continue on K-244 spur to parking lot. (0.2)
Turn left into gravel parking lot.
Stop 1 (figs. 2, 3): Milford Reservoir Spillway: Upper Blue Springs Shale Member of Matfield Shale, Barneston Limestone, Lower Holmesville Shale Member of the Doyle Shale, capped by irregular thicknesses of late Pleistocene loess.
Turn right on K-244 spur and retrace route. (0.2)
Stop sign. Turn right on K-57. (0.2)
Looking east at the valley of the Republican River floodplain. (0.9)
K-57 joins K-244; continue east. (0.7)
Stop. Turn right and continue south on US-77. (0.8)
The Fort Riley limestone grades upward into the Holmesville Shale Member, which is capped by the Towanda Limestone Member, both belonging to the Doyle Shale. (1.5)
Underpass of K-18. Look south at the Fort Riley limestone on both sides of the road. (0.3)
On the left is the Towanda limestone in the old railroad cut. Move to the left lane so that we can turn left after the underpass and enter eastbound I-70. (1.8)
36.2 Turn left and enter eastbound I-70. (1.3)
37.5 Take Exit 296 for LUNCH STOP in Junction City. (0.3)
37.8 Stop. Turn left. (0.2)
38.0 Entrance to the Golden Arches. This will be the lunch stop. Country Kitchen is to the west; Subway is across the street; Quick Shop at the Texaco Station; and McDonald's. After lunch we will return to I-70 and continue east toward Manhattan. (0.3)
38.3 Turn left to enter eastbound I-70. (1.9)
40.2 Crossing Smoky Hill River. (1.2)
41.4 Crossing Franks Creek. (3.0)
44.4 Take Exit 303 on the right to Manhattan. (0.2)
44.6 Stop. Turn left and continue north on K-18. (2.7)
47.3 Riley County Line and crossing Kansas River. (1.3)
48.6 Entrance to Ogden, Kansas; continue on K-18. (0.9)
49.5 Keep to the right; cross Seven Mile Creek and enter K-18 east. (2.5)
52.0 Entrance to Manhattan International Airport. Continue on K-18. (1.0)
53.0 At Dick Edwards Used Cars, move to the left lane so that we can turn left on Riley County Road 408 "Scenic Drive." Slow down as you will have to cross westbound traffic. (0.4)
53.4 Take right fork and continue on Riley County 408. (0.9)
54.3 Begin climbing hill that is underlain by alluvial fill and loess. (0.4)
54.7 Beginning exposures of limestone and mudstone of the Council Grove Group. (0.1)
54.8 **Stop 2 (figs. 2, 4). Scenic Drive (County Road 408): Crouse, Funston, and Wreford formations. (0.3)**
55.1 Threemile Limestone Member of the Wreford Limestone on right. (0.1)
55.2 Schroyer Limestone Member of the Wreford Limestone on right at the top of the hill. The Threemile, Schroyer, and the Florence are the prominent chert-bearing units that form the "backbone" of the Flint Hills Physiographic Province. (0.9)
56.1 Crossing Wildcat Creek. (0.3)
56.4 Stop light. Turn right on Anderson Ave. (0.25)
56.6 Turn left into parking lot.
**Stop 3 (figs. 2, 5). Eskridge Shale and Beattie Limestone.** When leaving the parking lot, turn left and continue east on Anderson Ave. (3.4)
60.0 Traffic light. Intersection with Manhattan Ave. Anderson Ave. now changes to Bluemont St. Continue on east on Bluemont to Juliette Ave. (0.5)
60.5 Traffic light. Turn left on Juliette Ave. and continue north. (0.4)
60.9 Climbing Bluemont Hill passing through Grenola Limestone and meandering right on Ehlers Dr. (0.3)
61.2 Turn left into Days Inn parking lot. End of Day 1.

**Day 2**

0.0 Leave Days Inn parking lot via Ehlers Rd. Turn left on northbound lane of Tuttle Creek Blvd. (0.2)
0.2 Grenola Limestone on the left. (0.5)
0.7 Intersection of Allen Rd. Johnson Shale and Red Eagle Limestone on the left (west) side of the road. (0.7)
1.4 Roca Shale overlap by base of the Grenola Limestone on the left. (1.6)
3.0 Burr limestone, overlap by Salem Point shale and Neva limestone (members of the Grenola Limestone) on the left. (0.2)
3.2 Neva limestone on the west for the next 0.5 mi. (1.0)
4.2 Entrance to Administration Building of U.S. Army Corps of Engineers. (0.25)
4.45 Turn right on K-13. Cottonwood limestone is overlap by the Florena Shale in the quarry on the southwest corner of the intersection. (0.25)
4.7 Crouse Limestone at top of roadcut on left. The road traverses from the Cottonwood Limestone Member of the Beattie Limestone, Stearns Shale, Bader Limestone, and Easly Creek Shale. (0.1)
4.8 Parking area on west side of Tuttle Creek Dam. Easly Creek Shale on the bank of the lot, overlying the Middleburg Limestone Member of the Bader Limestone. Elevation of the top of the dam is 1,159 ft; conservation pool level is 1,075 ft. Below the dam is River Pond State Park, which was under water during the 1993 flood. (1.4)
6.2 Parking lot on east end of Tuttle Creek Dam. Spillway Fault System (Underwood and Polson, 1988) is on the east end of the spillway wall. (0.1)

6.3 Crossing spillway bridge and the 18 floodgates. To the left and top of the hill is the Speiser Shale, the uppermost unit of the Council Grove Group. (0.4)

6.7 Turn right on asphalt road going south. (0.4)

7.15 Turn right at entrance to Spillway Cycle Area. (0.05)

7.2 Turn left into first parking area.

Stop 4 (figs. 2, 6, 7): Emergency Spillway of Tuttle Creek Reservoir: Foraker Limestone, Johnson Shale, Red Eagle Limestone, Roca Shale, and Burr Limestone Member of Grenola Limestone.

Field trip ends at this point.

References Cited


West, R. R., ed., 1972, Stratigraphy and depositional environments of the Crouse Limestone (Permian) in north-central Kansas: Kansas State University, Department of Geology, Guidebook for Geological Society of America, South-central section, Sixth annual meeting, 109 p.
West, R. R., ed., 1994, Contributions to the geology of the rocks exposed by the "flood of '93" at the Tuttle Creek Reservoir Spillway near Manhattan, Kansas: Kansas Geological Survey Open-File Report 94-36.
The Crow Creek Member, Pierre Shale (Upper Cretaceous) of Southeastern South Dakota and Northeastern Nebraska: Impact Tsunamite or Basal Transgressive Deposit?

Field Trip No. 10

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Abstract

The Crow Creek Member is one of several marl units recognized within the Upper Cretaceous Pierre Shale of eastern South Dakota and northeastern Nebraska. The member has been interpreted as a basal, transgressive unit of the Bearpaw Cycle, one of several Upper Cretaceous transgressive-regressive cycles. Recently, a significant discovery of impact shock-metamorphosed mineral grains in the Crow Creek was reported by Izett and others (1993) along with a new $^{40}$Ar/$^{39}$Ar age (73.8 Ma) for the Manson Impact Structure (northwestern Iowa, fig. 1) that suggested that the two were coeval. They interpreted the shocked grains in the Crow Creek as distal impact ejecta derived from the Manson Structure and further suggested that the member displays evidence of impact-induced tsunami sedimentation triggered by the Manson impact, a tsunami that may account for certain regional unconformities in the Western Interior Basin.

On this field trip we will visit several Crow Creek exposures in southeastern South Dakota and northeastern Nebraska (fig. 2). We will examine the rocks and discuss the characteristics of this unit and how they may be related to interpretations of its depositional history. We will end the trip at an exposure of Niobrara Formation chalk and compare this unit to the Crow Creek.

Physical Setting

The Upper Cretaceous Western Interior Basin is characterized by a coarse clastics-dominated western foreland margin, a central subsidence-prone trough, and an eastern gently inclined platform. Sediments on the eastern platform, the area of the present study, are typically dark-colored mudrocks, intermittent pelagic carbonates, and thin sandstones restricted to nearshore facies.

The basin has undergone several major transgressive-regressive cycles during the Upper Cretaceous, leaving a strong imprint on its eastern margin. This record is very different from the thick, clastics-dominated sequences along the tectonically active western margin. Low relief on the eastern platform forced shorelines and basin-margin facies to migrate across wide tracts (lowstand shorelines as far west as the central Dakotas, highstands to Wisconsin or beyond) in response to sea-level variations. The relative stability of the eastern cratonic platform allowed little subsidence. The adjacent low-relief terrestrial regions provided relatively small volumes of detritus. These factors contributed to a cyclic pattern of eastward-thinning sediment wedges, separated by eastward-expanding unconformities.

The Manson Impact Structure (MIS) lies about 125 mi (200 km) southeast of Yankton (fig. 1). Virtually all of the Upper Cretaceous rocks between the
Yankton area and the MIS have been removed by erosion. Likewise, rocks equivalent to the lower Pierre (Crow Creek Member) sequence have not been recognized in the MIS vicinity. Subsequent erosion may have removed the rocks, or the impact locality may have been on a terrestrial setting, outside the area of net sediment accumulation.

The sediments of southeastern South Dakota and adjacent areas were also strongly affected by the presence of the Sioux Ridge, a steep-sided erosional remnant of Proterozoic Sioux Quartzite (fig. 1). The Sioux Ridge is the topographically highest part of the Transcontinental Arch (Shurr, 1981). Narrow belts of basal sands, sandy mudstones and marls, and broad calc-rich facies flank the Sioux Ridge. The calcareous members of the Pierre Shale are particularly well developed in the Sioux Ridge area. Some, including the Crow Creek Member, occur only on or near the Sioux Ridge (fig. 1).

**Stratigraphy**

The Upper Cretaceous of the Yankton area is composed of the following units (in ascending order): Dakota Sandstone, Graneros Shale, Greenhorn Limestone, Carlile Shale, Niobrara Formation (marl), and Pierre Shale. Each formation contact is sharp and distinct except the Dakota-Graneros, which is gradational. Post-Cretaceous erosion has deeply incised the bedrock surface in the Yankton area; Pierre Shale, Niobrara Formation, and Carlile Shale each form the bedrock surface at various locations. Quaternary glacial and periglacial sediments mantle the Yankton area. These materials conceal the Upper Cretaceous rocks, except along a fairly continuous outcrop belt flanking the Missouri River and rare outcrops along valleys tributary to the Missouri.

The Pierre Shale (Campanian, lower Maastrichtian) is recognized through most of the central and eastern regions of the Cretaceous Western Interior Basin. Through most of the Pierre's areal extent, it is composed of hundreds of feet of monotonous dark shale. In the eastern South Dakota area, however, the formation thins to less than 650 ft (200 m) and can be differentiated into several members (fig. 3).

The Crow Creek Member normally varies in total thickness from 5 to 11 ft (1.5 to 3.2 m) (Bretz, 1979), but some thickened intervals have been measured to 20 ft (6 m) (Schultz, 1965). Like all Pierre strata, the Crow Creek is thicker in the western,
more distal shelf settings and thins paleo-shoreward (east). Two distinct lithologic units comprise the formation (fig 4). The lower red-brown to gray-brown silty, sandy, calcareous wackestone (basal clastic layer) generally ranges between 0.6 and 2 ft (18 and 66 cm) thick (Bretz, 1979) but is locally absent. The basal clastic layer generally becomes coarser eastward along the Missouri River outcrop belt. The upper tan to buff, sandy to silty marl is normally between 6.5 and 10 ft (2 and 3 m) in thickness and normally has a gradational contact with both the underlying basal clastic layer and the overlying DeGrey Member.

The basal clastic layer of the Crow Creek Member is far from a unique feature, other than containing MIS ejecta. The literature describing the eastern-margin Upper Cretaceous sediments shows that other calcareous units commonly contain clastic
intervals (Witzke and others, 1983). Sandy intervals are common in eastern margin marls, including the DeGrey Member of the Pierre Shale, (Schultz, 1965), Niobrara Formation, (Condra, 1908; Barari and others, 1981; Hammond, 1991; Hattin, 1975; Witzke and others, 1983), and Greenhorn Limestone (Witzke and others, 1983; Setterholm and others, 1987). The clastic components of these marls are interpreted to be derived from the adjacent eastern land mass (Witzke and others, 1983). A trend of decreasing clastic input upward through the Upper Cretaceous section is apparent; the basal clastic bed of the Crow Creek was the final relatively continuous sand in the area’s Upper Cretaceous marine sequence.

The Crow Creek Member conformably underlies the DeGrey Member, but is separated from subjacent sediments by a major unconformity. This unconformity is of regional extent, separating the underlying Clagett depositional cycle from the Bearpaw cycle. The unconformity’s irregular surface is incised into underlying sediments throughout the Missouri River valley’s Cretaceous outcrop belt, displaying channels up to 16.5 ft (5 m) deep at some locations.

The unconformity also bevels the underlying rock surface, capping progressively older units toward the east. The Gregory Member, greater than 165 ft (50 m) thick in the Pierre area, thins to the east and is truncated in the area west of Yankton. The Sharon Springs Member directly underlies the Crow Creek in the Yankton area. The former eastward extent of the Crow Creek Member is unknown due to pre-Neogene erosion. However, eastward extension of the trend of sub-Crow Creek erosion suggests that the Crow Creek Member would have directly overlie the Niobrara Formation a short distance east of Yankton. The sub-Crow Creek shales of the Pierre are absent at some localities in extreme northeastern South Dakota (South Dakota Geological Survey, unpublished data), and locally in the Mt. Vernon area (fig. 1), where the Crow Creek lies directly on the Niobrara Formation.

In the Yankton area, the Crow Creek-Sharon Springs contact is sharp and irregular with up to 0.2 ft (5 cm) of relief on individual outcrops. Plant debris, including probable angiosperm leaf impressions, is locally present at the contact (at Marindahl NW outcrop, stop 2). Abundant polished and abraded fish debris, phosphatic nodules, rare woody plant debris, and rip-ups of locally subjacent shale form a lag concentrate on the sub-Crow Creek surface and are locally reworked and incorporated into the basal Crow Creek clastics at several field trip stops.

**Petrology**

The Pierre Shale is typically dark gray to black, organic, bentonite-rich shale. The Crow Creek Member is lithologically quite different from the enclosing shales and forms a prominent light-colored band.

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Fig. 3. General northeast (Pierre, South Dakota) to southeast (Sioux City, Iowa) stratigraphic cross section of Upper Cretaceous units along the Missouri River. Datum is base of Crow Creek Member (cross-ruled interval). All units show general eastward thinning. Prominent regional unconformities separating major depositional cycles of the Western Interior Cretaceous are labeled. Approximate position of interval-bearing manganese carbonate concretions is outlined in the upper DeGrey Member (Mn-facies).
in otherwise dark lower Pierre Shale outcrops.

Basal Clastic Unit

The basal unit of the Crow Creek Formation consists of a wackestone fabric of silt-, sand-, and scattered granule-sized grains in a calcareous mudstone matrix. These wackestones in the Yankton area are poorly sorted, ungraded, and rich in quartz and feldspar grains (15 percent), detrital carbonate (14 percent), and phosphatic materials (>9 percent). All percentages are on a point-count volume basis. Shale clasts, primarily derived from the underlying Sharon Springs, make up more than 3 percent of the rock's volume. Fine-grained (<0.004 mm) matrix comprises more than 50 percent of the rock volume both in the Yankton area and in central South Dakota.

Detrital grains, particularly shock-metamorphosed quartz and feldspar, have been of particular interest. Quartz is the dominant grain type, generally occurring as subangular to subrounded silt and sand grains, with both polished and frosted surfaces. Rounded to spherical grains are also present. Most of the quartz is monocrystalline, but some polycrystalline grains occur, including chalcedony and chert.

Grain size ranges up to 3.7 mm, the coarsest grains occurring at the Lake Marindahl-Wakonda locations (stops, 1, 2, and 3).

A remarkably high percentage of the quartz and feldspar grains in the basal clastic layer exhibit shock-induced features. Over 22 percent of the Yankton-area quartz and feldspar grains display planar deformation features (PDFs); individual samples ranged from 10-30 percent. As a percentage of whole rock volume, shocked quartz and feldspar average 3.2 percent in the Yankton area. Many additional grains displayed unusual strained and mosaic extinction patterns under cross-polarized light. While not definitive for an impact-shock origin, such patterns suggest that even more of the quartz and feldspar grains may have been exposed to extreme pressure.

In samples from the area south of Chamberlain (about twice the distance from the impact site as Yankton; fig. 1), the shocked materials are much less abundant. About 6 percent of the quartz and feldspar grains contain PDFs; about 0.7 percent of the whole rock volume contained PDFs.

Detrital carbonate grains are about equally
abundant with the quartz-feldspar fraction in the basal unit (14 percent). Dolomite grains are the dominant detrital carbonate. The carbonate grains are typically angular to subrounded and show a similar size distribution to that seen in the quartz fraction, but clasts up to 0.2 in. (4.8 mm) occur at Lake Marindahl NW (stop 2). Limestone lithologies include pelletal, oolitic, and foraminiferal packstones to grainstones, skeletal wackestones to packstones (containing brachiopod, bryozoan, and crinoid debris), and glauconitic limestones. Larger dolomite grains are often a mosaic of silt-sized crystals. Micro-glide twinning is evident in the calcite cements and in some isolated calcite grains. Such micro-twinning suggests crystal strain associated with high pressures and may be analogous to PDFs seen in quartz. Some grains of internally fractured cataclasitic dolomite are also present.

Phosphatic material is common in the basal clastics. Small (mostly <1 mm) spherical to discoidal-shaped pellets or concretions with concentrically laminated rinds are commonly nucleated around bone or fish-scale fragments. Some concretions show soft-sediment deformation around adjacent grains or calcite-filled fractures.

Larger (0.2-3.15 in. [0.5-8 cm]) irregular- and cylindrical-shaped apatite concretions are conspicuous components at some Yankton-area localities. Some are nucleated around bone or tooth fragments. Identical concretions occur in upper Sharon Springs strata (Simpson, 1960) and locally in phosphatic lags developed at the top of the Sharon Springs Member. These concretions and most, if not all, of the abundant angular to subrounded bone fragments appear to be reworked from the underlying Sharon Springs Member and are concentrated as a lag along the basal unconformity of the Crow Creek Member.

Grains and larger clasts of gray noncalcareous shale in the basal clastic unit were derived from subjacent Sharon Springs sediments. Sand- and granule-sized grains are common. Clasts up to 0.78 in. (2 cm) are present at all Yankton area exposures, up to 4.3 in. (11 cm) (longest axis dimension) at the Marindahl outcrops in northeastern Yankton County. Many shale clasts show compactional deformation around adjacent grains. Scattered rounded clasts of pale-colored bentonite (to 0.4 in. [1 cm]) appear identical to lithologies in prominent bentonite seams of the underlying Sharon Springs Member.

Some sand-sized to rare pebble-sized well-indurated mudstone clasts are present that do not resemble any known lithologies from the lower Pierre. Some siltstone clasts contain quartz and feldspar grains that display PDFs, indicating a probable impact source.

Sedimentary structures are rare in the Crow Creek's basal clastics layer near Yankton. Some faint clay-rich laminae suggesting possible low-angle cross-stratification have been seen at Yankton Quarry (stop 4). Shale clasts contained in the unit are generally aligned, but some dip at low angles and may indicate minor imbrication. However, hummocky cross-stratification and small-scale cut-and-fill structures are common in the basal clastics layer in south central South Dakota (Bretz, 1979; Crandell, 1952).

Marl Unit
The Crow Creek marl unit also displays wackestone fabric, with silt- and sand-sized particles of quartz, detrital carbonate, foraminifera, shale clasts, and other grains floating in a highly calcareous claystone matrix. Several workers have observed a general upward increase in clay content (Schultz, 1965; Bretz, 1979).

The detrital content and clast size of the marl decreases upward, with the highest concentration of sand grains and shale clasts in the lower 0.2 to 0.5 ft (5-15 cm). The matrix volume clasts <0.004 mm increases from about 85 percent in the lower 2 ft (60 cm) of the marl to about 90 percent in the middle and upper marl (Yankton area). Largest quartz or carbonate grains decrease from coarse sand (1-2 mm, with some granules to 2.6 mm) to 0.5 mm or less in the middle and upper marl (Schultz, 1965; Bretz, 1979).

Although showing a general upward decrease in maximum grain size and coarse clastic abundance, the marl is poorly sorted with clay, silt, sand, and granules in a heterogeneous mix. Because of the poor sorting, the marl cannot be considered a graded unit in the strict sense of the term. Based on dominant detrital size modes, the basal portion is best termed sandy marl, but the bulk is silty marl.

Rounded chip-shaped clasts of gray shale comprise about 3-5 percent of the basal 0.2 to 0.5 ft (5-15 cm) in the Yankton-area marl unit but decrease in abundance and size upward and westward. Shale clasts in the lower 2 ft (60 cm) of the marl are primarily in the 0.4- to 2-in. (1- to 5-cm) range, but clasts of 0.4 to 1.2 in. (1 to 3 cm) are present. By contrast, lower strata in south-central South Dakota contain only scattered clasts of 1-3 mm, and upper marls seldom contain shale clasts larger than 3 mm. Shale clasts were almost certainly locally derived. Shale grains in the Yankton-area marls resemble the lithology of the underlying Sharon Springs Member. Shale grains further west resemble the subjacent Gregory Member.

Sedimentary structures are subtle in the marl unit. Crandell (1952) suggested that bedding and laminations are completely absent in the Crow Creek Member marl. However, we have identified faint horizontal laminations and have observed low-
angle dips on some shale clasts in the basal part of the marl. Bretz (1979) and Simpson (1960) have noted similar laminae. Simpson (1960) speculated that these laminations may be analogous to cyclic laminations within the Niobrara marls. Bretz (1979) noted localized burrowed sedimentary fabrics in the upper 0.3 to 1.3 ft (10 to 40 cm) of the marl unit, infilled by overlying DeGrey Member sediments.

Paleontology

Macrofossils

Macrofossils are not abundant in the Crow Creek Member, with few important specimens recovered to date (Bretz, 1979). Small fragments of inoceramids are common. Small (to 14 mm) ostracods, including some well-preserved complete valves, have been recovered in the Yankton area (Bretz, 1979; Witzke and others, in preparation). In addition, basal Crow Creek strata have produced calcite crinoid columnals, an ophiuroid ossicle (Bretz, 1979), siliceous monaxon sponge spicules, and elongate smooth-shelled ostracodes (Bretz, 1979). Ostracodes and sponge spicules also occur in the overlying marl. Pyritized and phosphatized burrows occupy the basal clastic layer, and the upper portion of the marl is locally burrowed.

The common occurrence of various benthic invertebrates in the Crow Creek Member, particularly its basal part, can be interpreted either as an indigenous fauna or as a transported assemblage. The fragmented nature of most of the material is consistent with some degree of current reworking, though preservation of small thin-shelled ostrid valves suggests that not all shell material was subjected to high-energy regimes or long-distance transport.

Foraminifera and Radiolaria

Several workers have assembled foraminifera lists for the Crow Creek Member. Bretz (1979) listed 29 genera of foraminifera from the Crow Creek, both pelagic and benthic forms. Some species were restricted to the Crow Creek among South Dakota rocks. Searight (1937, 1938) listed several foram species, both agglutinated and calcareous, that except for one long-ranging species, "do not occur in other beds of the South Dakota Cretaceous" (Searight, 1937, p. 58). Mendenhall (1954) also noted several Campanian species from the Crow Creek in northeastern Nebraska.

A change in foram and radiolaria assemblages occurs within the Crow Creek Member marl. Studies by K. M. Waage, summarized in Crandell (1952, 1958) note that both pelagic and benthic forams are present in the lower 2 to 5 ft (60 to 150 cm) of the marl unit, but the upper marl contains a fauna dominated by smaller pelagic forms. No radiolaria were found in the lower part of the marl but were present in the upper marl. Both pelagic forams and radiolaria continue upward into the overlying DeGrey strata, where radiolaria are more abundant.

Nannofossils

Carbonate nannofossils are abundant throughout the Crow Creek Member. This is especially true of the marlstone unit, where they comprise most of the carbonate material. Examination of samples from several stratigraphic sections reveals that two distinct nannofossil assemblages are present in the Crow Creek: a late Campanian assemblage assumed to be autochthonous, and a reworked assemblage of early Campanian age. The autochthonous assemblage provides the means to date precisely the age of Crow Creek deposition. The allochthonous (reworked) assemblage reflects the input of sedimentary carbonate from an eroding source area.

The Crow Creek can be dated precisely based on the presence of well-preserved nannofossil assemblages in the marlstone unit. These assemblages include common Reinhardtites levis; few Aspidolithus parcus constrictus and Tranolithus phacelosus; and rare Ceratolithoides aculeus, Prediscosphaera grandis, Quadratum trifidum, and Quadratum gothicum. Eiffelithus eximius, Quadratum sissinghi and Reinhardtites anthophorus (s.s.) are absent from this assemblage. This association of taxa is definitive of the Tranolithus phacelosus Zone (CC23) of Sissingh (1977) and Perch-Nielsen (1985). More specifically, the presence of Aspidolithus parcus constrictus indicates the lower subzone (CC23a) of Perch-Nielsen (1985). This subzone correlates to part of the late Campanian and is compatible with the Didymoceras stevensoni or D. nebrascense ammonite zonal assignment of Izett and Cobban (1994). Erba and others (in press) place this biostratigraphic interval in the mid- to late Campanian and assign an age of approximately 74.5 to 75.5 Ma. Given the uncertainties of the biogeochronologic correlation, this age date is compatible with the 74.2 +/-0.6 Ma for the Manson Impact Structure (Izett and Cobban, 1994).

The reworked assemblage is characterized by Aspidolithus parcus expansus, Calculites obscuris, Eiffelithus eximius, Marthasterites furcatus, Lithastrinus grillii, Reinhardtites anthophorus (early morphotype), and Seribiscutum primitivum. Although it is possible that there was more than one source-age for this material, the reworked assemblage is consistent with an assignment to the lower Aspidolithus parcus Zone (CC18a) of Sissingh (1977) and Perch-Nielsen (1985). Pelagic carbonates of this age occur in the upper Niobrara Formation from the eastern margin of the Western Interior Seaway (Watkins and Liu, in press). In addition, the reworked component contains several taxa (for example, Boletuvellum candens, 115
Biscutitan n.sp.) that are known in the Western Interior Basin only from the upper Niobrara of the eastern margin (Watkins and Liu, in press; Watkins, unpublished data). Specimens in the reworked assemblage are, almost universally, well preserved with little evidence of overgrowth or dissolution etching.

The abundance of reworked nannofossils is not uniform throughout the Crow Creek marlstone. This is indicated in figure 5. This figure shows the number of specimens of Eiffellithus eximius, Lithastrinus grillii, Mardhasterites furcatus, and Seribiscutitan primitivum in counts of 500 nannofossils at 0.3 ft (10 cm) intervals through the Crow Creek marlstones in Gregory Pumped Storage Core 18, Gregory Co., South Dakota (fig. 1). These four species all go extinct prior to the deposition of the Crow Creek Member and must be reworked from older strata. The highest abundance of these reworked species occurs in the lower part of the marlstone, where they attain abundances as high as 44 specimens per 500 count. The abundance of these reworked taxa diminishes upward, comprising about 10 specimens per 500 near the top of the marlstone.

This measure of reworking suggests greater influx of allochthonous material near the base of the marlstone with a waning influx as Crow Creek marlstone deposition progressed. However, because this measure depends on only a few species, it yields little information on the relative contributions of autochthonous and reworked components. In an effort to assess these relative contributions, the nannofossils were assigned to three groups and counted separately. One group consists of those species that are present in both assemblages. These are generally long-ranging species that exhibited no significant skeletal changes during the Campanian. This group comprises approximately 85 percent of the total nannofossils based on counts of 500 specimens. The second and third group are species believed to be derived exclusively from the autochthonous Crow Creek component and the reworked (Niobrara) component, respectively. The autochthonous assemblage includes taxa that are biostratigraphically restricted to the Crow Creek. The reworked group includes taxa that are biostratigraphically restricted to the early Campanian or older (for example, M. furcatus), as well as some taxa (for example, B. candens) that appear to be present only in the upper Niobrara of the eastern margin. The separation into the second and third group was checked by examining Crow Creek equivalent strata in the Miner County (South Dakota) and Sisseton (South Dakota) cores (fig. 1). In both of these cores, pelagic carbonates of Subzone CC23a are present but show no indications of reworking.

The results of this analysis (fig. 6) indicate a significant change in the intensity of reworking during deposition of the Crow Creek marlstones. Near the base of the marlstone, reworked components are more than 15 times more abundant than the autochthonous component. Toward the top of the marlstone, the reworked component drops to less than 5 times the autochthonous component. It must be noted that this is a relative measure of these components. The magnitude of the ratio depends not only on the amount of reworking but also on the original abundances of the chosen species in their respective assemblages. Despite this caveat, clearly the reworked nannofossil component decreases upward through the Crow Creek marlstones. Assuming that the production of nannofossils by living plankton was relatively constant throughout the Crow Creek deposition, the flux of reworked Niobrara nannofossils was highest during the initial stages of marlstone deposition and decreased with time.

**Discussion of Depositional Scenarios**

Izett and others, 1993

During a study of the Manson Impact Structure (MIS) of Iowa, Izett and others (1993) determined that the MIS did not occur at the Cretaceous-Tertiary boundary, as previously believed, but well before, about 73.8 Ma. Izett and others (1993) studied the region's stratigraphic record to select equivalent strata containing evidence of the impact, such as tsunami deposits, shocked mineral grains, and altered tektites. The Izett team concluded that the most likely rock would be the Crow Creek Member of the Pierre Shale, which is bracketed by radiomet-
ric-dated bentonites in the underlying Gregory Member (74.8 Ma, Baculites scotti zone) and overlying DeGrey Member (72.3 Ma, Baculites compressus zone). Izett and others sampled for and found shocked mineral grains in the basal clastic layer of the Crow Creek, which they speculate to be in the Exiteloceras jenneyi zone.

Izett and others (1993) suggest a number of phenomena that could be accounted for by an impact-generated tsunami. Among these are:

--The presence of the anomalous Crow Creek basal clastics and the fact that sand grains and shale rip-up clasts increase in size and abundance from west to east;
--The provenance of the lower Crow Creek sand has "puzzled geologists for 40 years" in an otherwise shale-dominated sequence;
--The "Crow Creek Member rests disconformably upon successively older beds of the Pierre Shale from northwest (Chamberlain) to southeast (Yankton) along the Missouri River toward the MIS";
--The puzzling absence of three ammonite zones above the zone of E. jenneyi at the Red Bird section in eastern Wyoming";
--"Regional unconformities above the zone of E. jenneyi and below the Teapot Dome Sandstone Member...and the Pine Ridge Sandstone of the Mesaverde Group in central Wyoming."

Steiner and Shoemaker, in preparation

Steiner and Shoemaker (in preparation) conducted a paleomagnetic study of the Crow Creek Member to "determine whether it has the same polarity of magnetization as the Manson impact melt rocks, therefore whether it could be a Manson tsunami deposit." They found the Crow Creek Member to be unusual in several ways: "it represents an abrupt lithologic change, is nowhere more than a few meters thick, and contains sand, unlike any other part of the Pierre Shale, the other members of which have hardly any silt-sized material."

Steiner and Shoemaker (in preparation) suggest that the entire Crow Creek is a tsunamiite deposit. They propose that the Crow Creek consists primarily of material scoured from exposed Niobrara Formation by a (Manson) impact-generated tsunami. They suggest that these scoured materials were suspended in the shallow marine water and carried westward by successive waves (seiche) and possibly distributed further after the tsunami or seiche dissipated.

Evidence cited includes:
--The first three points of Izett above;
--Current bedding (cross-bedding) near the base of the Crow Creek Member, rip-up clasts derived from the subjacent members of the Pierre scattered throughout the Crow Creek Member in exposures nearest the MIS;
--Distribution of sand grains throughout the Crow Creek in exposures nearest the MIS;
--Reported presence of abundant nannofossils reworked from the Niobrara Chalk in the Crow Creek Member (Shurr, 1990);
--Normal polarity (with a reversed overprint) of the entire Crow Creek Member, identical to those found within the MIS;
Paleomagnetic data suggest that the entire Crow Creek Member (and MIS) must have occurred entirely within 100,000-200,000 years of normal polarization during magnetostratigraphic Chron 32R (base of D. cheyennense zone) or during latest Chron 33N (D. stevensoni zone).

Witzke and others (1994, in preparation)

Witzke and others (1994, in preparation) suggest that normal sedimentary processes are sufficient to explain sedimentary structures and stratigraphic relationships displayed in the Crow Creek Member and adjacent rocks. They present several lines of evidence that argue against, but do not entirely preclude, the tsunami scenario:

--Eastward thinning of sediments and erosive bevelling of sediments at regional unconformities is common throughout the Upper Cretaceous stratigraphic section along the eastern margin of the Western Interior Basin (Witzke, 1983); no special explanation is required for this phenomenon;

--Occurrence of Crow Creek marls is also unremarkable. Several such marls exist in the Pierre (Mobridge, DeGrey, Gregory) in the region, and throughout the basin in older rocks (Niobrara, Greenhorn);

--Crow Creek Member basal clastics and their provenance are not unusual in the eastern margin context. Crow Creek basal clastics have several analogues in each of the older eustatic cycles in the Upper Cretaceous record; the Crow Creek clastics are the final widely continuous sand in Sioux Ridge area. The provenance for the Crow Creek sands is the adjacent eastern margin land mass, the same source of sands as other occurrences of eastern Upper Cretaceous sandy sediments;

--Above-cited evidence fits the pattern and timing of normal transgressive-regressive sequence (early Bearpaw cycle transgression);

--The tsunami models above invoke immense scouring of the sub-Crow Creek surface, then immediate (within days) burial of that surface by Crow Creek sediments; yet the sedimentary features at that surface show long-standing erosion or non-deposition (phosphate lag, phosphatized matrix, glauconite enrichment);

--Preservation of thin-shelled benthic mollusks is inconsistent with intense tsunami environment;

--Nannofossil data for Crow Creek is consistent with transgressive sequence: recognition of late Campanian nannofossil zone implies that some time was required to accumulate sufficient fossil debris and develop index species; change of nannofossil assemblage up through the Crow Creek marl stratigraphic section (figs. 5 and 6) counterindicates that the Crow Creek was formed during a single event, mixed and deposited within several hours;

--Radiolaria and foram assemblages change upward through Crow Creek Member marls and into the overlying DeGrey, counterindicating that the Crow Creek Member was formed during a single event, mixed and deposited within several hours;

--Tsunami propagation across a wide, shallow shelf is problematic; modern tsunamis are not known to traverse broad expanses of shallow water;

--Features associated with K-T boundary tsunami are absent (large-scale graded beds, complex interbedding, internal disconformities);

--Ejecta air-fall deposition is discordant with tsunami sedimentation.

Road Log

April 28, 1995

Mileage (Mileage between directions in bold.)

0.0 Nebraska Center, 33rd and Holdrege Sts., Lincoln, Nebraska. Depart Lincoln via Interstate 80 (I-80) east and then Interstate 29 (I-29) north to South Dakota Exit 25 (Vermillion-Yankton exit). (193)

193.0 Turn left from off-ramp and drive west on South Dakota Highway 50 (SD-50; South Dakota highways designated by SD-#). Take SD-50 bypass around Vermillion; continue on SD-50 to U.S. Highway 81 (US-81) in Yankton. (33)

226.0 Turn right onto US-81 (Broadway Street); drive to Broadway Inn (1210 Broadway, right side of street). Enter and check in. (1.8)

April 29, 1995

0.0 Broadway Inn, Yankton, South Dakota. Fifteenth St. borders the Broadway Inn on the north. Travel east on 15th to Ferdig Ave. Turn right at stop sign; then immediately turn left onto Whiting Dr. (stop sign, angles to left). Drive out of town; cross James River at 4 mi. Turn left at WNAX radio towers onto blacktop road. (4.5)

4.5 Drive north 6 mi; turn right (east) onto blacktop road. Drive 5.5 mi to "T" intersection. Turn left
(north) onto blacktop road. Drive 0.5 mi. Turn right onto gravel road. Drive 1.1 mi and stop near quarries in valley. (13.1)

Stop 1: Wakonda Lime Quarry.

17.6 Turn around in driveway and drive back 1.2 mi to "T" intersection. Turn right onto blacktop road. Drive 1.5 mi to end of blacktop road. Turn left onto intersecting blacktop road. Drive 3.5 mi. Turn right onto blacktop road. Drive 3 mi; turn right onto gravel road. Park along roadway. (9.2)

Stop 2: Marindahl NW Outcrops

26.8 Turn around at driveway, reassemble at intersection with blacktop road. Drive south (left) on blacktop road 2 mi, turn left onto gravel road and drive 1 mi to "T" intersection, turn right (south), drive 0.2 mi, turn left into Lake Marindahl public access area. Park in lake-access parking area. (3.2)

Stop 3: Marindahl Spillway (Lunch)

30.0 Drive south 0.8 mi from public access area to blacktop road; turn right. Drive west 3 mi to end of blacktop road. Turn left on blacktop road; drive south 2 mi to four-way stop; turn right onto intersecting blacktop road. Drive 4 mi west to "T" intersection. Turn left (south) onto US-81; drive 6 mi to intersection with SD-50 west. Turn right (west) onto SD-50, drive 1 mi (just past state highway shop); turn left (south) onto West City Limits Road. Drive 2.2 mi to SD-52 (second stop sign). Turn right (west) onto SD-52; drive 3 mi. Turn right (north) into driveway serving the old Yankton Quarry and the Dam Splash water park. Drive approximately 0.2 mi to Dam Splash parking lot and park. Outcrops are approximately 0.2 mi to the northwest, accessible by foot trail. (22.2)

Stop 4: Yankton Quarry

52.2 Return to SD-52 (0.2 mi). Turn right onto SD-52; drive 0.5 mi to Gavins Point Dam. Turn left (south) onto road along crest of dam; drive across dam and past powerhouse complex (1.8 mi) to intersection with Nebraska Highway 121 (N-121; Nebraska highways designated by N-#), 0.8 mi past powerhouse. Turn right onto N-121 west; follow curving road approximately 1.4 mi to entrance to Lewis and Clark State Recreation area. Turn right into park entrance and park near sign. (4.7)

Stop 5: Crofton Lakeview Golf Course

56.9 Turn right (west) onto N-121; drive 1 mi west. Turn right onto N-54C. Drive 1 mi; turn right onto left fork of gravel road; drive 0.6 mi down winding road to lakeside parking area. (2.6)

Stop 6: Deep Water Recreation Area

59.5 Return to Broadway Inn. Retrace route via gravel road and N-54C (2.6 mi). Turn left onto N-121 and drive 2.7 mi to stop sign. Turn right and follow N-121 for 3.6 mi to intersection with US-81. Turn left and follow US-81 north to the Broadway Inn, approximately 2.5 mi. (11.4)

References


Bretz, R. F., 1979, Stratigraphy, mineralogy, paleoecology and paleoecology of the Crow Creek Member, Pierre Shale (Late Cretaceous), south central South Dakota: Fort Hays State University, Master's Thesis, Hays, Kansas, 181 p.


Upper Pennsylvanian Paleosols in the Platte and Missouri Valleys, Southeastern Nebraska

Field Trip No. 11

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Introduction

Several paleosols are preserved in Upper Pennsylvanian (Kansas City through Shawnee groups) cyclothems in southeastern Nebraska in association with laterally extensive marine units (fig. 1). The persistence of marine units throughout the Midcontinent has promoted the development of a sea-level curve (Heckel, 1986), which in turn provides a working interpretational framework for fine-tuning interpretations of basin history. Cyclothem paleosols are important in their most basic application as indicators of sea-level lowstand and the extent of subaerial exposure, but they are also valuable in interpreting regional paleoclimate, tectonism, and overall paleogeographic trends (fig. 2). This field trip guide is a summary and partial update of previous work, a sample of ongoing research, and a suggestion for future work; its interpretations are likely to change as more data become available and as the interpretational framework for paleosols at large expands. Details of regional geology and Midcontinent Pennsylvanian cyclothems can be read elsewhere (Burchett and Reed, 1967; Burchett, 1971; Heckel, 1980, 1986, 1991).

Stop 1. Upper Lawrence Formation and Snyderville Member Paleosols at Abandoned Quarry West of South Bend, Cass Co., Nebraska (SW 1/4 sec. 15, T. 12 N., R. 10 E.). The upper Lawrence Formation and the Snyderville Shale Member paleosols (Joeckel, 1993, 1994) lie within two successive cyclothems, yet they differ in several ways (fig. 3A, 4). Nonetheless, they are among the most prominent of several well-developed Missourian-Virgilian paleosols in the Midcontinent because they are readily traceable in well-separated outcrops and cores over about 90 mi (150 km) west-east and at least 160 mi (250 km) north-south (Joeckel, 1993, 1994).

The upper Lawrence paleosol is a dominantly high-chroma paleosol in outcrops in northeastern Kansas, southeastern Nebraska, southwestern Iowa, and northwestern Missouri. In Kansas and Missouri, additional paleosols are present, at least locally, lower in the southward-thickening Lawrence Formation. The upper Lawrence paleosol is thickest (deepest) and best developed shelfward (northward). South-north differences in solum thickness, horizonation, and degree of soil-structure development are compatible with increasing duration of subaerial exposure northward into Nebraska and Iowa, but eventually the entire Midcontinent shelf was drowned by the Toronto transgression. Sediments deposited atop the upper Lawrence paleosol in northeastern Kansas probably record estuarine-drowned valley systems with tide-influenced sedimentation.

The exposure of the upper Lawrence paleosol at this locality is particularly noteworthy. The profile is thick (86-94 in. [220-240 cm]) and the long exposure face reveals a succession of very well-preserved synformal-antiformal sets of very large slickensides (fig. 4), which are considered diagnostic of modern Vertisols. Eleven complete sets of slickensides (set wavelengths of 9.8-36 ft [3-11 m]) were once exposed over about 328 ft (100 m) of the main high wall in the quarry; most of these are still visible, but others have been covered by slumping since heavy rains in August 1993. The slickensides are very well preserved, down to the retention of minute (1 mm) grooves and ridges along their well-polished surfaces. Slickensides dip 25-45 degrees, and strike measurements indicate that the synformal ones are bowl-shaped in three dimensions. Other noteworthy features in the upper Lawrence paleosol at this locality are: 1) a well-exposed transition between the obviously stratified parent shales and the massive mudstone of the paleosol, which takes place within 3.9 in. (10 cm) or less; 2) filled soil cracks extending up to 39 in (100 cm) (and possibly more) downward from the top of the paleosol; 3) a concentration of dolomitic carbonate nodules at the base of the paleosol, apparently a water-table feature that may have been influenced during transgression by the mixing of marine and terrestrial waters; and 4) dolomitic carbonate "dikes" 2-4 in. (5-10 cm) long and up to 31.5-in. (80-cm) long, probably infillings
of large desiccation cracks, extending downward into the parent shales.

The Snyderville Shale Member shows two welded paleosols (the lower high chroma and the upper low chroma) in southeastern Nebraska, and what appears to be a single low-chroma paleosol elsewhere in the northern Midcontinent exposure belt. Clastic deposits directly above the Snyderville paleosol are more uniform than those above the upper Lawrence paleosol. Known outcrops of the Snyderville paleosol and overlying marine sediments do not show any north-south changes paralleling those visible in the upper Lawrence paleosol. This contrast with the upper Lawrence indicates a major change in paleogeography, probably in part related to the geomorphic control exerted by the underlying Toronto Limestone (versus the effects of the clastic sediments that underlie the upper Lawrence paleosol). The Snyderville paleosol does change west-east, however, across southeastern Nebraska and into the Forest City Basin in southwestern Iowa. This change is consistent with (but not absolutely diagnostic of) some form of structural control because it transects the Nemaha Uplift-Forest City Basin margin. In southeastern Nebraska (exemplified by this locality), a thick, complex profile appears in the Snyderville, recording up to four depositional events and two episodes of subaerial exposure and pedogenesis. The first pedogenic episode produced a high-chroma, well-structured soil on a well-drained landscape, with evidence for deep (> 78.7 in. [200 cm]) desiccation in the form of filled cracks and bow-shaped infillings in the paleosol. The second pedogenic episode produced a low-chroma, relatively poorly structured soil on a relatively poorly drained landscape like that apparently represented by the Snyderville in most of adjacent Iowa, Kansas, and Missouri. At this locality, the resulting two paleosols are separated by a thin, coarse siltstone to very fine sandstone that lacks diagnostic sedimentary structures or fossils and also bears some pedogenic overprint from the overlying paleosol.

The evolution of the Snyderville landscape was significantly different from that of the upper Lawrence landscape, although both occurred in the same region and during closely successive depositional cycles. Subtle tectonism on the Nemaha Uplift and Forest City Basin in Nebraska-Iowa may have produced the west-east differences in the Snyderville paleosol. Perhaps, in turn, the region was tectonically inactive during Lawrence time, and sea-level change controlled landscape development. Differences in paleosol color and morphology between the upper Lawrence and Snyderville also suggest drier or better drained conditions during upper Lawrence time and wetter or less well-drained conditions during later Snyderville time (or longer outside of Nebraska). Similar contrasts are apparent between wetter and drier Vertisols (Uderts and Usterts) that co-occur on some modern coastal plains, but the consistency of contrasting features in the paleosols indicates that the differences between them are due to climatic and/or region-wide geomorphic changes (products of tectonism, sedimentation patterns, and

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**Fig. 1. Generalized composite section (in part after Burdett, 1971), illustrating Upper Pennsylvanian strata discussed in field guide. Major paleosols and black shale units are indicated. Many thin units are not shown. Recorrelation follows work of P. H. Heckel (University of Iowa).**
Fig. 2. Map of localities. WWW: Exposure on Weeping Water Creek (SE 1/4 sec. 32, T. 11 N., R. 11 E., Cass Co., Nebraska); MMQ: Martin Marietta Quarry (NE 1/4 sec. 3, T. 10 N., R. 11 E., Cass Co., Nebraska) at Weeping Water; OF: Ost Limestone type section (SE 1/4 sec. 34, T. 10 N., R. 12 E., Cass Co., Nebraska); JP: Jones Point (NW 1/4 sec. 28, T. 10 N., R. 14 E., Cass Co., Nebraska); QHQ: Queen Hill Quarry (SW 1/4 sec. 9, T. 11 N., R. 14 E., Cass Co., Nebraska); BO: Burr Oak, Iowa (NW 1/4 sec. 15, T. 71 N., R. 43 W., Mills Co., Iowa); MV: well core near Malvern, Iowa (NW 1/4 sec. 5, T. 71 N., R. 41 W., Mills Co., Iowa); and BD: well core near Bedford, Iowa (SE 1/4 sec. 4, T. 67 N., R. 34 W., Taylor Co., Iowa). Other localities in immediate vicinity showing upper Lawrence Formation and Snyder-ville paleosols are: Mid-Am well, Lancaster Co., Nebraska (MA), abandoned quarry at Ashland, Nebraska (AQ), abandoned quarry west of South Bend, Nebraska (SB), and well cores from near Riverton, Iowa (RV), and Rockport (RP) and Wilcox (WX), Missouri (see Joeckel, 1993). Other abbreviations: AB (Appalachian Basin), AdB (Anadarko Basin), FCB (Forest City Basin, IA (Iowa), IB (Illinois Basin), KS (Kansas), MO (Missouri), NE (Nebraska), OK (Oklahoma). Louisville area includes Schramm Park, Nebraska Highway 31 road cuts, and Ash Grove Quarry. Paleogeography in part after Heckel (1980).

eustatic sea level). Higher or more seasonally consistent rainfall during Snyderville time, and/or the development of a poorly drained Snyderville coastal plain (possibly promoted by shallow Toronto bedrock) are hypotheses that explain the overall differences in paleosol features.

Stop 2. Rock Lake Member Paleosol at Schramm Park, Sarpy Co., Nebraska (SW 1/4 SE 1/4 sec. 12, T. 12 N., R. 10 E.). The Aridisol-like Rock Lake Member paleosol (Joeckel, 1989), down-section several cycles from the upper Lawrence Formation, will be examined at a forthcoming stop (fig. 3B). This stop introduces the paleosol and illustrates its lateral continuity in outcrops along the Platte River between Interstate 80 and Louisville, Nebraska. It is also a good opportunity to observe the upper part of the underlying Stoner Limestone Member, which in various localities shows different combinations of features compatible with an intertidal to supratidal marine depositional environment (fine lamination, teepee structures, mudcracks, birdseye, dolomite, etc.). Micritic carbonate nodules are concentrated in a subsoil horizon (Bk) of the Rock Lake paleosol. The depth to the top of this horizon varies, probably due mostly to transgressive erosion of the upper part of the paleosol. Erosion presumably took place within shallow ravinements. Other than depth to carbonate and overall thickness, lateral variability in Rock Lake paleosol horizotionation is relatively minor between the old Rock Lake Quarry (the type section for the member, a few miles west of Schramm Park) and Louisville. Major changes in soil characteristics are evident farther eastward, however, crossing the margin of the Forest City Basin.

Stop 3. Vilas Formation Paleosol on Nebraska Highway 31, Cass Co., Nebraska (N 1/2 SW 1/4 sec. 18, T. 12 N., R. 11 E.). The Vilas Formation paleosol, (fig. 1) the next paleosol down-section from the Rock Lake paleosol, is not well exposed in southeastern Nebraska. This road cut (fig. 5) is instructive because it seems to show toposequence (sequence of soils relative to topographic slope) or hydrosequence variation within the Vilas. Unfortunately, though, the outcrop is old and partially covered. At the east end of the cut, the Vilas paleosol profile is dominantly reddish brown (5YR 3/3), whereas at the west end it is dominantly gray to greenish gray (5Y 5/1, 6/1 and 5GY 6/1-7/1). The high-chroma profile weathers in a strongly blocky fashion and contains many pressure faces, but it lacks large, cross-cutting slickensides (as in the upper Lawrence paleosol) or any concentration of carbonate nodules (as in the Rock Lake paleosol). A karstic surface atop the underlying Plattsburg Limestone, with infillings of reddish brown mud, extends across the entire outcrop. A short distance eastward (toward Louisville) along Nebraska Highway 31 at the abandoned
Abandoned quarry near South Bend, Nebraska.

- Abandoned quarry near South Bend, Nebraska.
- Toronto Limestone Member:
  - SY 8/1 thinly bedded calcite; microsparitic
  - 230 cm: SY 7/1 massive mudstone, cmn v slipper shale
  - 230 cm: SY 7/1, 2.5YR 6/4, and 2.5YR 6/4 massive c mudstone (up to 3 total bands
deed, clear, smooth terr side
- 23-30 cm: SY 6/3 massive c mudstone
  - 28-29 cm: SY 6/3 massive c mudstone
  - SY 6/3 floaty bone band
  - SY 6/3 floaty bone band

Lawrence Shale Formation:
- SYR 3/4 sc mud shale; few dolomite "dikes"
- SYR 3/4 sc mud shale; few dolomite "dikes"
- SYR 3/4 sc mud shale; few dolomite "dikes"
- SYR 3/4 sc mud shale; few dolomite "dikes"

Oread Limestone Shale Member:
- SYR 3/4 sc mud shale; few dolomite "dikes"

Ash Grove Quarry at Louisville, Nebraska:
- SYR 8/1 calcite; locally fossiliferous
- SYR 8/1 mud shale; brachiopods
- SY 8/1 mudstone; mottled; nc: wx spheroid; clear wly terd
- SY 8/1 mudstone; mottled; nc: wx spheroid; clear wly terd
- SY 8/1 mudstone; mottled; nc: wx spheroid; clear wly terd
- SY 8/1 mudstone; mottled; nc: wx spheroid; clear wly terd

Fig. 3. A) Upper Lawrence and Snyderville paleosols near South Bend, Nebraska. Note complex profile in Snyderville Shale Member. B) Rock Lake Member paleosol at Ash Grove Quarry, Louisville, Nebraska.
Fig. 4. Slickenside sets and probable truncated microhighs at abandoned quarry near South Bend, Nebraska, beginning at south end of main highwall (A). Sections join A-B-C. Microhighs are indicated by slickenside peaks or "antiforms" and thinning of low-chroma horizon and thin marine shale.
Fig. 5. Variability of paleosol in Vilas Formation in southeastern Nebraska.
Meadow Quarry, the Vilas paleosol has large cross-cutting slickensides (fig. 5), suggesting a vertic variant of the non-vertic precursor soil seen at this locality. The Vilas paleosol appears in a well core from northeastern Lancaster County, Nebraska, and has also been identified in exposures near Winterset, Iowa (Heckel and Pope, 1992), nearly 120 mi (200 km) east-northeast. Note the exposure of the Stoner Limestone and the Rock Lake paleosol along the driveway upslope from this roadcut.

Stop 4. Lane Formation Paleosol, Rock Lake Member (Stanton Formation) Paleosol, and Lower Plattford Formation Paleosol at Ash Grove Cement Quarry, Louisville, Cass Co., Nebraska (secs. 12, 13, 14, T. 12 N., R. 11 E.). The main (deepest) part of this quarry is excavated into a thick limestone that has traditionally been called the Argentine Lime stone Member (Wyandotte Formation) by the Nebraska Geological Survey. Recorrelations by Heckel (University of Iowa) indicate that this limestone is actually the Raytown Limestone Member of the Iola Formation. In accordance with Heckel's recorrelations, the thin shale and limestone above the recorelated Raytown are the Quindaro Shale and (true) Argentine Limestone members, respectively. The upper 12-20 in. (30-50 cm) of the recorelated Argentine is an indurated, thinly laminated to thinly bedded calcilutite with light greenish gray (5GY 7/1) shale partings (or filled cracks) and local brecciation. The mudrock unit (~ 6.5 ft [2 m] thick) atop the recorelated Argentine is the Lane Shale Formation, which contains a low-chroma Vertisol-like paleosol (fig. 6A) about 67-69 in. (170-175 cm) thick, overlain by a 4-16 in. (10-40 cm) thick calcareous shale with brachiopods. The paleosol in the Lane Shale Formation (currently inaccessible) here has two or three color horizons: the lowermost is light gray to light greenish gray (5Y 7/1-5GY 7/1) and the upper horizon(s) is/are gray (5Y 5/1). There are large, well-polished and finely grooved, intersecting slickensides in the upper 40-60 in. (100-150 cm) of the paleosol. Slickensides truncate abruptly against the overlying shale in outcrop and are also prominent in well cores (Ash Grove Cement cores 87-5 and 87-8), verifying that they are original pedogenic features. Up-section, there is a paleosol in the Rock Lake Shale Member of the Stanton Formation (fig. 3B), which is underlain by a karstic surface atop the Stoner Limestone. This paleosol has been studied in detail (Joeckel, 1989), although some of the conclusions regarding its genesis are now being rethought. Where it is well-developed, it appears to be Aridisol-like, although it could also have affinities with drier modern Alfisols (for example, Ustalfs).

West of the Forest City Basin margin, the paleosol is consistently reddish brown (5YR 3/3), has a prominent subsoil carbonate horizon (Bkm and/or Bk), and has prominent clay-sheathed polished faces in a horizon (Bt) underneath the carbonate-rich horizon. Eastward, at the margin of the basin in easternmost Nebraska and into the basin in southwestern Iowa, the paleosol becomes markedly thinner, turns grayish to greenish, and shows little or no development of a carbonate horizon. In fact, the paleosol seems to disappear completely farther into the Forest City Basin, then reappear in the Winterset, Iowa, area, about 120 mi (200 km) east-northeast (Heckel and Pope, 1992). These changes are now most parsimoniously interpreted as toposequence variation, possibly controlled by subtle tectonism or differential compaction, across the Nemaha Uplift and Forest City Basin, although differential transgression (proposed in Joeckel, 1989) may still have played a role. West-east variation in the Rock Lake paleosol corresponds to similar variation in the Snyderville and Rakes Creek paleosols up-section.

A similar paleosol (lacking a carbonate horizon, however) is developed in the succeeding cyclothem, within the basal reddish brown mudstone of the Plattford Formation above the South Bend Limestone. This paleosol is very poorly exposed in this quarry and elsewhere, and it has not been studied at all. There is a karstic surface directly underneath the paleosol in the uppermost part of the South Bend Limestone, as might already be predicted from trends visible in other units.

Stop 5. Low-chroma Variant of Basal Rakes Creek Paleosol at Burr Oak, Mills Co., Iowa (NW 1/4 sec. 15, T. 71 N., R. 43 W.). Unfortunately, logistics dictate visiting this stop (fig. 7A) somewhat out of sequence. The exposure shows the low-chroma, presumably poorly drained version of the basal Rakes Creek paleosol so prominently exposed in the Weeping Water, Nebraska, area (see discussion for stop 7).

Stop 6. Paleosols and Exposure Surfaces (Atop Limestones) in the Swope Through Chanute Formations at City Wide Aggregates Quarry South of Richfield, Sarpy Co., Nebraska (NW 1/4 sec. 28, T. 13 N., R. 12 E.). This quarry exposes three prominent paleosols and two less prominent paleosols, as well as subaerial exposure surfaces atop limestones, in Kansas City Group strata (fig. 6B-D, 8). The correlation of the units exposed here with strata exposed in Kansas and Iowa has been disputed, and paleosol research on these units in Nebraska began only recently. The Nebraska Geological Survey (Conservation and Survey Division) has traditionally considered the succession here to be Dennis Formation (Winterset Limestone Member) through Lane Formation (Burchett and Reed, 1967; Burchett, 1971). Heckel (University of Iowa) and colleagues, however, consider it to be Swope Formation (Bethany Falls Limestone Member) through basal Iola Formation, a
Fig. 6. A) Lane Formation paleosol in main pit at Ash Grove Quarry, Louisville, Nebraska. B) Galesburg Formation paleosol at City Wide Quarry near Springfield, Nebraska. C) Nellie Bly Formation paleosol at City Wide Quarry near Springfield, Nebraska. D) Chanute Formation paleosol at City Wide Quarry near Springfield, Nebraska.
Fig. 7. Profiles of the basal Rakes Creek paleosol east of the western margin of the Forest City Basin (A) and on west of the Forest City Basin margin, on the Nemaha Uplift (B).
downward offset of one major cycle (Heckel and others, 1979; Heckel and Pope, 1992), which is accepted in this text. In Iowa, Heckel and Pope (1992) also interpreted paleosols in the same interval exposed at City Wide Quarry.

The section at City Wide consists of white to light gray, fine-grained, shallow-marine limestones and dark gray to gray to greenish gray mudstones and shales. High-chroma mudstones are conspicuously absent compared to overlying Lansing Group through Shawnee Group strata (beginning with the Vilas Formation) in the lower Platte Valley. This difference must be due to changes in paleogeography and/or paleoclimate that remain to be investigated.

The lowermost paleosol exposed at the quarry is in the Galesburg Shale (figs. 6B, 8, 9), which is underlain by an exposure surface on intertidal to supratidal calcilutite and local calcirudite (intrachastic limestone) of the upper Bethany Falls Limestone Member. This paleosol is developed exclusively in gray (N 6/0 or 5Y 6/1), weakly to strongly calcareous mudstone that contains common fine pyrite crystallites throughout and a few scattered marine invertebrate fossils. Soil structure is not apparent in thin sections, but there are a few vertical cracks (0.1-0.4 in. [0.3-1 cm] wide, extending downward up to 18 in. (45 cm) from the top of the paleosol) filled with black (~5Y 2.5/1) mud. Large, cross-cutting slickensides, dipping 20-50 degrees and spaced at vertical intervals of 0.8-4 in. (2-10 cm), extend throughout the profile (almost to the base of the unit), but they do not extend upward into the overlying shale. These slickensides are moderately polished and streaked with gray (5Y 5/1), but they are not finely grooved (several other Midcontinent paleosols do have finely-grooved slickensides). They intersect to form peaks (under microhighs) at interlying shale. These slickensides are moderately polishing synform or bowls (fig. 9). About 8-10 in. (20-25 cm) of microrelief is also visible atop the paleosol throughout the quarry. This microrelief is interpreted to be a relict feature from the original land surface (that is, gilgai; cf. Dudal and Eswaran, 1988; Wilding and others, 1990), and it appears to have influenced the deposition and/or compaction of overlying marine units, particularly the Canville Limestone, Stark Shale, and Winterset Limestone members.

There is a prominent, moderately cemented calcareous horizon between about 12 in. (30 cm) and 39 in. (100 cm) below the top of the paleosol along most of its exposure. In a now mined-out highwall, this horizon reached the upper surface of the paleosol in a few places (figs. 3A, 6), and even now in other parts of the quarry the horizon undulates or bulges slightly. These bulges are under microhighs in some cases, but they are not always fully coincident with slickenside intersections (peaks). Thrusting along slickensides appeared to have cut out or disrupted the calcareous horizon in at least two or three places (fig. 9C-E). Locally, the carbonate-rich horizon is not continuously cemented, but it still contains 15-30 percent carbonate nodules. Where it is cemented, however, the calcareous horizon is impregnated with micritic carbonate and contains many small, nearly pure or pure, typic or concentric, micritic carbonate nodules that are intergrown to form compound nodules up to 0.8 in. (2 cm) in diameter. Common equant spar-filled circumgranular cracks appear within the compound nodules.

The Galesburg paleosol is a Vertisol-like soil (cf. Dudal and Eswaran, 1988). The apparent lack of preserved soil structure and low-chroma color structure can be interpreted as indicators of aquatic conditions, in which case the calcareous horizon was probably a product of water-table fluctuation (cf. Sobecki and Wilding, 1983). Conceivably, early diagenetic or late pedogenic (syn-transgressive) modification of the paleosol could have disrupted or destroyed original soil structure, but this hypothesis is not parsimonious and also very difficult to test. The calcareous horizon may be derived in part from the modification of original marine carbonate-rich sediment, as it contains a few marine fossils (cf. West and others, 1988), but its fabric remains overwhelmingly pedogenic. The form of nodules within the horizon indicates periodic desiccation, as do filled cracks in the upper part of the paleosol (cf. Dudal and Eswaran, 1988). "Bulges" in the calcareous horizon are potentially analogous to calcareous diapirs (chimneys) resulting from pedoturbation in some modern Vertisols (for example, Wilding and others, 1990). There are broadly analogous, relatively well-drained Vertisols (Pellusterts) with low-chroma (gray) coloration, calcareous subsoil horizons, and gilgai microrelief on the Texas Coastal Plain today (for example, Neitsch and others, 1989). Similarly colored, but poorly drained Vertisols (Pelluderts) are present on the same landscapes (Neitsch and others 1989), yet these soils crack as little as half as deep (30 vs 60 in. [75 cm vs 150 cm]) as the Pellusterts. Thus, the apparent shallow cracking in the Galesburg paleosol may further support aquic conditions.

There is a cryptic paleosol within the upper part of the Cherryvale Formation. A gray (5Y 6/1) laminated calcilutite, 20-30 in. (50-80 cm) below the top of the Cherryvale shows evidence for subaerial exposure in the form of weak microkarst and an irregular upper contact. It is locally overlain by a thin (4-12 in. [11-30 cm]), greenish gray (5GY 6/1), strongly calcareous claystone with large slickensides. Elsewhere, though, this mudstone is absent and the weakly microkarstated limestone is overlain directly.
City Wide Aggregates quarry near Springfield, Nebraska

Fig. 8. Stratigraphic section of Kansas City Group strata at City Wide Quarry near Springfield, Sarpy Co., Nebraska.
Fig. 9. A-E) Panorama of now mined-out wall at City Wide Quarry, showing paleosol in Galesburg Formation (recorelated following Heckel and others, 1979 and Heckel and Pope, 1992; see also fig. 6B). Note variability in carbonate-impregnated horizon and apparent sets of very large slickensides. Carbonate-impregnated horizon "bulges" to upper surface. F-G) Close-ups of smaller "bulges" or "pods" in carbonate-impregnated horizon, which appear to have influenced or been associated with slickenside development.
by an intraclastic calcilutite. Apparently, part or all of a paleosol was removed by marine erosion during late Cherryvale time. The unit recorrelated as the Nellie Bly Shale contains a dark gray (N 4/0) and greenish gray to light greenish gray (5GY 6/1-7/1) calcareous siltstone interpreted as a paleosol (fig. 6C). The features of this unit are unusual, though, and it seems likely that at least some reinterpretation will eventually be necessary. Unusually prominent, mottle-like features (probably convoluted and broken sedimentary laminae) in the uppermost part of the siltstone are interpreted as the products of a post-transgression mixing zone created by liquefaction and/or burrowing in the overlying marine shale (probably the Quivira Shale Member) and the upper, then-waterlogged part of the paleosol. Thick, layered clay coatings appear along channels in the lower part of the siltstone, which has soil-like impregnative carbonate, and which grades downward into an impure carbonate unit of unknown origin. Heckel and Pope (1992) describe soil-compatible features and a thin coal from the Nellie Bly Shale in Iowa. Microscopic stringers of organic matter in the dark shale overlying the interpretive paleosol at City Wide may, in fact, be the remnants of a coal smut.

A thin but readily recognized Vertisol-like paleosol in the upper part of the Chanute Formation appears at the top of the section exposed in the quarry (figs. 3B, 5). Although it is now mostly yellowish in color due to the downward migration of a late Cenozoic weathering front, observations of unweathered zones indicate that the paleosol and its parent shale were originally light gray (5Y 7/1). The boundary between the paleosol and the underlying shales undulates with 12 in. (30 cm) of total relief. Synformal-antiformal sets (6.6-9.8 ft [2-3 m] wide) of large, cross-cutting slickensides (dipping 20-45 degrees) are as prominent in this paleosol as in the upper Lawrence paleosol up-section, but the Chanute paleosolom (< 43 in. [110 cm]) is only about half as thick. The Chanute soil, apparently very simple, could have formed relatively rapidly (within a few thousand years) on top of terrigenous muds deposited on a coastal plain or in a regressive shallow marine environment.

Stop 7. Well-drained Variant of Basal Rakes Creek Paleosol at Weeping Water, Cass Co., Nebraska (NE 1/4 sec. 4, T. 10 N., R. 11 E.). The basal paleosol of the Rakes Creek Member is thin (47-55 in. [120-140 cm]) but prominent in the Weeping Water Valley. In the same region, the underlying Ost Limestone, Kenosha Shale, and the upper part of the Avoca Limestone members are all intensely karstified. The depth from the upper surface of the basal Rakes Creek paleosol to the lowest occurrence of pervasive microkarst in the Avoca Limestone Member here is as much as 13 ft (4 m) (fig. 7B). The basal Rakes Creek paleosol and underlying microkarstic surface can be traced eastward to Burr Oak, Iowa, where the paleosol is much thinner and grayish to greenish, and where the underlying microkarst is weaker and restricted to the thinner Ost Limestone. The paleosol disappears a few tens of kilometers farther eastward into the Forest City Basin (fig. 2). Overall facies changes in the enclosing stratigraphic interval indicate a west-east topographic difference, previously interpreted as a product of syndepositional tectonism along the northeastern margin of the Nemaha Uplift (Condra and Reed, 1937, 1938; Fagerstrom and Burchett, 1972).

In the Weeping Water Valley, the basal Rakes Creek paleosol can be subdivided into three horizons. The upper horizon (~ 0-16 in. [0-40 cm]) is a gray (5Y 5/1-6/1) massive-weathering, noncalcareous, silty mudstone with a few stringers of light gray to pale yellow (5Y 7/2-7/3) very fine, silty sandstone (disrupted stratification, burrowing, and/ or filled cracks). This horizon has only weak and localized soil structure and exhibits moderately birefringent, weakly speckled to very weakly parallel striated birefringence fabrics. It includes a very few relict fragments of pedoturbated, clay-rich sedimentary laminae, and it has a smooth and gradual (~ 3 in. [7 cm]) lower boundary marked by distinct vermicular mottles. The middle horizon of the paleosol (~ 15-30 in. [40-70 cm]) is dusky red to dark red (2.5YR 3/2-4/2) with about 20-30 percent dark gray (N 4/0) mottles. It has weak to strong subangular blocky structure (peds ranging ~ 100x100-1500x4000 μm) and about 5 percent, small (0.08-1.2 in. [2-30 mm]) micritic to finely microsparitic carbonate nodules. The lowermost horizon (~ 30-50 in. [70-130 cm]) of the paleosol is dusky red to dark reddish brown (2.5YR 3/2-3/4) and has strong subangular blocky structure. There are abundant polished faces and about 15-20 percent, small (0.08-1.2 in. [2-30 mm]), equant, sharp-margined, micritic to finely microsparitic carbonate nodules. Some of these nodules are weathered fragments of the underlying Ost Limestone. There are a very few large (several centimeters long) recognizable fragments of the Ost Limestone in the lowermost part of this horizon.

The basal Rakes Creek paleosol becomes greenish gray or light greenish gray (5GY 6/1, 7/1) in the Missouri Valley, thinning from about 47 in. (120 cm) at Queen Hill Quarry on the Nebraska side to 18 in. (45 cm) near Burr Oak, Iowa. Farther eastward in the Forest City Basin (Iowa Geological Survey Bureau cores from near Riverton and Bedford, Iowa), the basal Rakes Creek paleosol is absent.

The basal Rakes Creek paleosol and underlying weathering marine sediments (locally there is a separate paleosol in the Kenosha Shale Member) indicates a substantial period of exposure and
water-table depression. During this exposure episode, clay illuviation (in the basal Rakes Creek paleosol) and carbonate dissolution (in the underlying Ost) were ongoing processes. Overall, the basal Rakes Creek paleosol is Alfisol-like rather than Vertisol-like.

Comparison of the Alfisol-like basal Rakes Creek paleosol to the Vertisol-like Snyderville Member and upper Lawrence Formation paleosols (Joeckel, 1993, 1994) reveals significant differences. The upper Lawrence and Snyderville paleosols have prominent slickensides, lack strongly blocky-weathering subsoil horizons or concentrations of carbonate nodules in the solum, and contain fewer illuvial clay coatings than the basal Rakes Creek paleosol. Also, the Toronto karst under the Snyderville paleosol is only one-half to one-third as deeply developed as the karst under the basal Rakes Creek paleosol.

Furthermore, the upper Lawrence paleosol hardly varies at all across the Forest City Basin. The Rakes Creek paleosol, however, varies strongly west-east, has a strongly blocky-weathering subsoil horizon with dispersed carbonate nodules and altered limestone fragments, has more illuvial clay coatings, and is locally underlain by relatively very deep karst.

The greater regional geographic variability in the Rakes Creek paleosol must be due to increased tectonic activity in Rakes Creek time relative to upper Lawrence-Snyderville time (which created more pronounced intrabasinal gradients) and/or a slower and/or less extensive post-Ost regression. The general morphological contrast between the Vertisol-like paleosols down-section and the Alfisol-like basal Rakes Creek paleosol cannot simply be a matter of landscape position from point to point within a given interval of pedogenesis, however. Instead, the transition from Vertisol-like soils (upper Lawrence and Snyderville paleosols) to more "Alfisol-like" paleosols (Rakes Creek) is hypothesized to have resulted from a trend from more seasonal to less seasonal rainfall and possibly a trend towards increased annual rainfall as well.

**Concluding Remarks**

This trip has offered a limited overview of Upper Pennsylvanian paleosols in southeastern Nebraska. Morphologically, these paleosols are varied, but in general they are restricted to Vertisol-like types and Alfisol-like to Aridisol-like types. The Vertisol-like paleosols would, no doubt, have qualified as Vertisols when they were extant soils. There is a great potential for using these and other paleosols in their stratigraphic context to reconstruct, on a relatively fine scale, Pennsylvanian climate trends in at least the northern part of the Midcontinent. Consistently, these paleosols also appear to record, with some detail, paleogeographic and paleoecologic trends in detail. A comprehensive analysis of these trends may eventually answer persistent questions about tectonism, sedimentation patterns, and the cycle-by-cycle effects of eustasy. In Nebraska and Iowa, many paleosols change laterally in a manner apparently consistent with the structural "grain" of the Nemaha Uplift and the Forest City Basin. The upper Lawrence paleosol, however, does not appear to change in this manner. Thus, there is at least some suggestion of changing patterns in tectonism, however subtle, as they affected sedimentation and pedogenesis. Ongoing research will provide a clearer picture of Pennsylvanian pedogenesis in the area and its implications.

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NOTE: Unconsolidated sediments of Recent and Pleistocene age cover the bedrock throughout much of the State and are not shown.