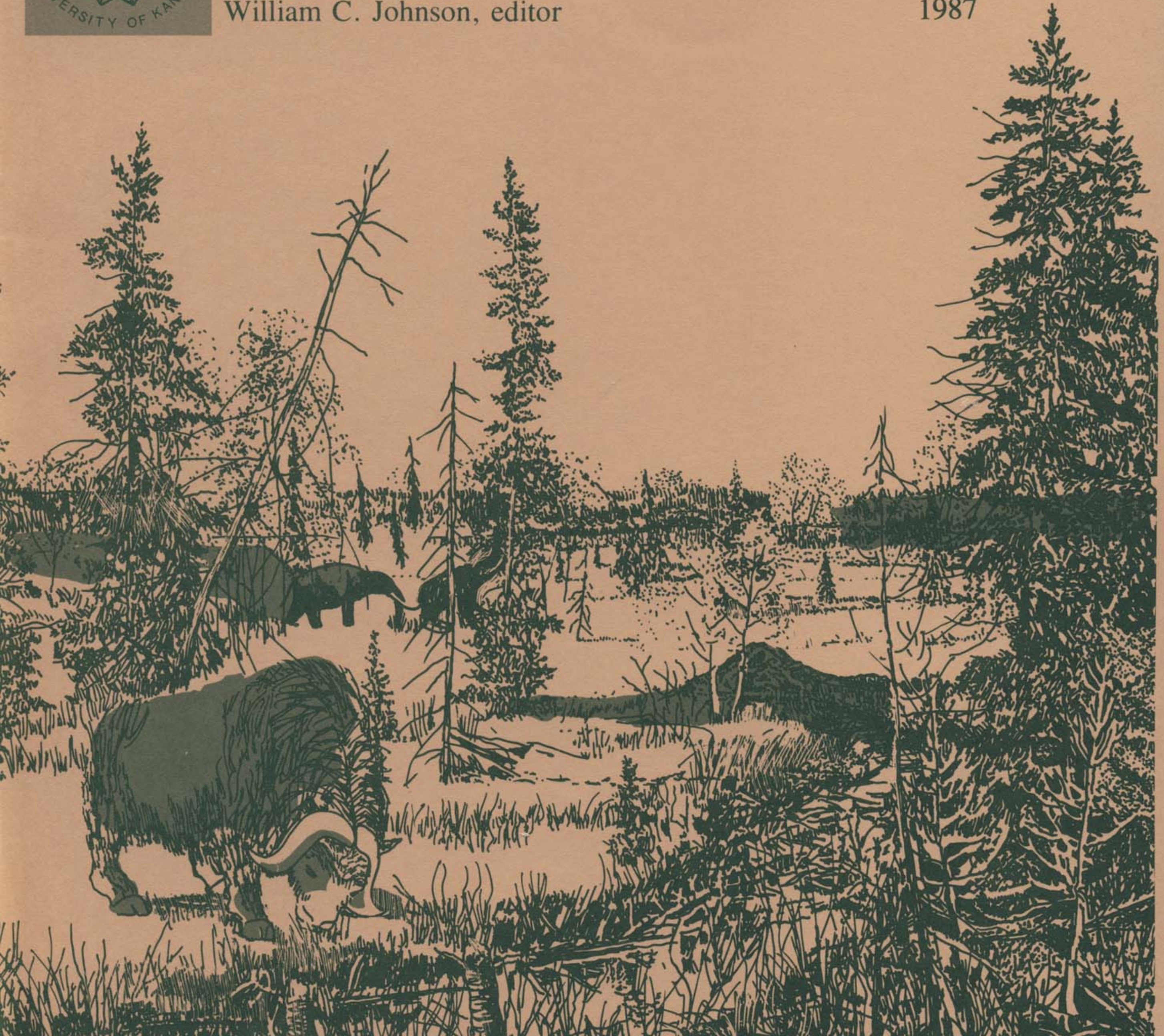
Kansas Geological Survey

Guidebook Series 5

Quaternary environments of Kansas

William C. Johnson, editor

1987



Former Meetings
Midwest Friends of the Pleistocene

	Year	Location	Leaders
1	1950	eastern Wisconsin	S. Judson
2	1951	southeastern Minnesota	H. E. Wright and R. V. Ruhe
3	1952	western Illinois and eastern Iowa	P. R. Shaffer and H. W. Scholtes
U	1952	southwestern Ohio	R. P. Goldthwait
U	1953	northeastern Wisconsin	F. T. Thwaites
U	1954	central Minnesota	A. E. Wright and A. F. Schneider
6	1955	southwestern Iowa	R. V. Ruhe
U	1956	northwestern lower Michigan	J. H. Zumberge et al.
8	1957	south-central Indiana	W. D. Thornburg and W. J. Wayne
9	1958	eastern North Dakota	W. Laird et al.
10	1959	western Wisconsin	R. F. Black
11	1960	eastern South Dakota	A. F. Agnew et al.
12	1961	eastern Alberta	C. Gravenor et al.
13	1962	western Ohio	R. P. Goldthwait
14	1963	western Illinois	J. C. Frye and H. B. Willman
15	1964	eastern Minnesota	H. E. Wright and E. J. Cushing
16	1965	northeastern Iowa	R. V. Ruhe et al.
17	1966	eastern Nebraska	E. C. Reed et al.
18	1967	south-central North Dakota	L. Clayton and T. F. Freers
19	1969	Cyprus Hills, Saskatchewan and Alberta	W. Kupsch
20	1971	Kansas–Missouri border	C. K. Bayne et al.
21	1972	east-central Illinois	W. H. Johnson et al.
22	1973	Lake Michigan basin	E. B. Evenson et al.
23	1975	western Missouri	W. H. Allen et al.
24	1976	Meade County, Kansas	C. K. Bayne et al.
25	1978	southwestern Indiana	R. V. Ruhe and C. G. Olsen
26	1979	central Illinois	L. R. Follmer et al.
27	1980	Yarmouth, Iowa	G. R. Hallberg et al.
30*	1981	northeastern lower Michigan	W. A. Burgis and D. F. Eschman
29	1982	Driftless area, Wisconsin	J. C. Knox et al.
30	1983	Wabash Valley, Indiana	N. K. Bleuer et al.
31	1984	western Wisconsin	R. W. Baker
32	1985	north-central Illinois	R. C. Berg et al.
33	1986	northeastern Kansas	W. C. Johnson et al.

U—unnumbered
*—misnumbered

Kansas Geological Survey

Guidebook Series 5

Quaternary environments of Kansas

William C. Johnson, editor

Midwest Friends of the Pleistocene

33rd Field Conference

August 1986

Wakefield Dort, Jr., William C. Johnson, and
Curtis J. Sorenson, leaders

Lawrence, Kansas

1987

Cover art, graphics, and layout by Jennifer Sims.

Preface

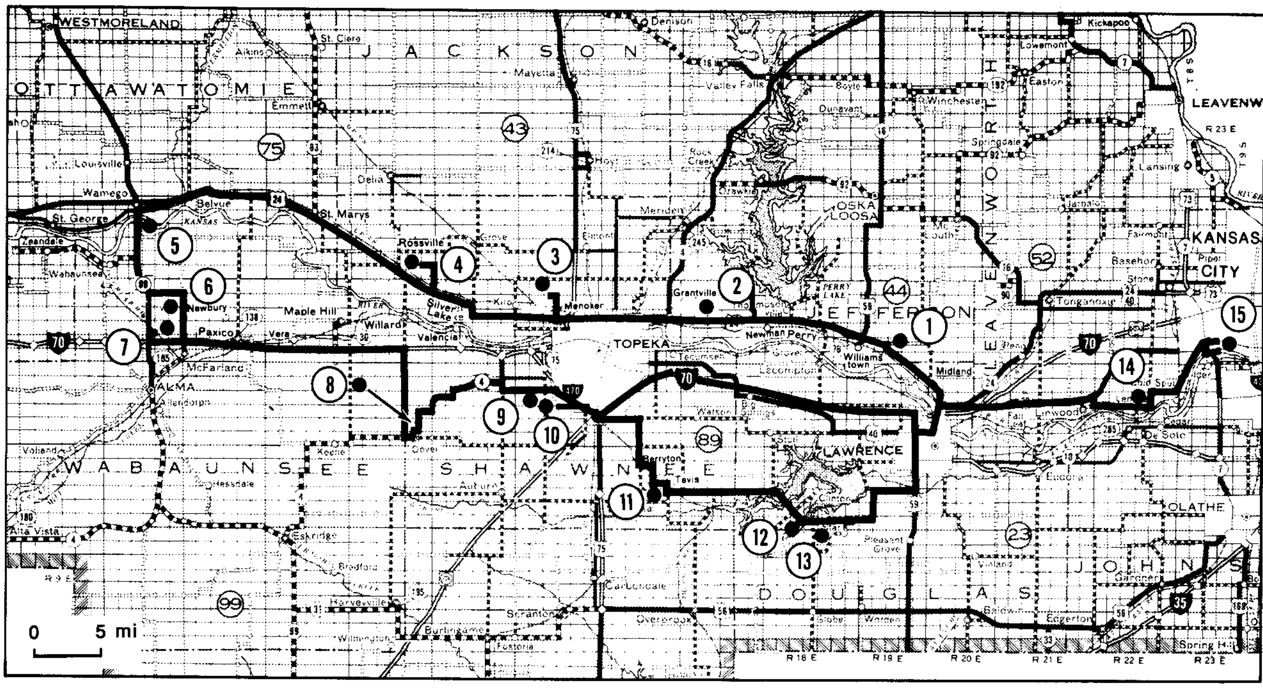
The Midwest Friends of the Pleistocene meeting has been held in Kansas only once before, 1976–Meade County (Kansas Geological Survey, Guidebook Series 1). Focus of the 1986 field conference is not upon upland faunal sequences of south-central Kansas, but rather on the glacial terminus area and late Pleistocene–Holocene alluvial fills of northeastern Kansas. The glacial-limit problem has not been seriously addressed in recent years, and alluvial stratigraphy has only begun to receive attention.

Part two, Contributed Papers, has a dual purpose: 1) to provide background information for the stops during the field conference, and 2) to present a collective statement of what is currently known of Kansas prehistory. The former is necessary to place the conference stops in a regional context. The majority of stop descriptions are brief statements, primarily because the localities have only recently been discovered or exposed to their present extent. In-depth staff and student research is underway at most localities and will come to fruit in the near future. Observations and interpretations offered by participants will thereby prove invaluable. Early work in Kansas, such as that by Frye, Leonard and Hibbard up through the 1950's, is being expanded upon and, in many instances, revised. The Dort and Jones volume *Pleistocene and Recent environments of the central Great Plains,* published in 1970 (University Press of Kansas), provided a summary of regional data to that point. We have, however, extended well beyond the 1970 statement and consequently perceive this volume, although not as comprehensive, as an update of the former. The data base is rapidly expanding, largely due to an increasingly interdisciplinary approach. Individuals involved are from several units of the University community: Departments of Geography, Geology, Botany, and Anthropology; the Museums of Natural History and Anthropology, and the Kansas Geological Survey.

The leaders of this field conference are indebted to the large number of colleagues and graduate students that assisted in the preparations for the meeting. Further, Sharon Geil (Geology) presents her graduate research results at Stop 14 and Professors Larry Martin (University of Kansas Museum of Natural History) and Richard Rogers (University of Nebraska) assist with Stop 15B. Field work and conferences such as this can not, of course, be conducted without the cooperation of landowners and, in many instances, local informants. It is therefore appropriate that the following be acknowledged for providing access to sites described herein: Mr. S. Smith (N. R. Hamm Quarries), Mr. W. Doyle (Menoken Quarry), Mrs. S. Mitchell (Silver Lake), Mr. T. Clevenger (Bank 4, Topeka), Mr. E. Dalaba (De Soto), the staff of Builder's Sand Plant No. 2, and Mr. R. Elder (City of Wamego Water Department). Further, our knowledge of and access to the Topeka glacial terminal area has been greatly enhanced by Mr. W. Boltz (Topeka). Financial support from the University of Kansas Office of Research Support facilitated the preparation of site exposures. Finally, the volume in its refined form would not have been possible without the dedication of Marla Adkins-Heljeson, editor, and Jennifer Sims, illustrator, both with the Kansas Geological Survey.

William C. Johnson
Department of Geology
University of Kansas
Lawrence, Kansas
February 1987

Contents



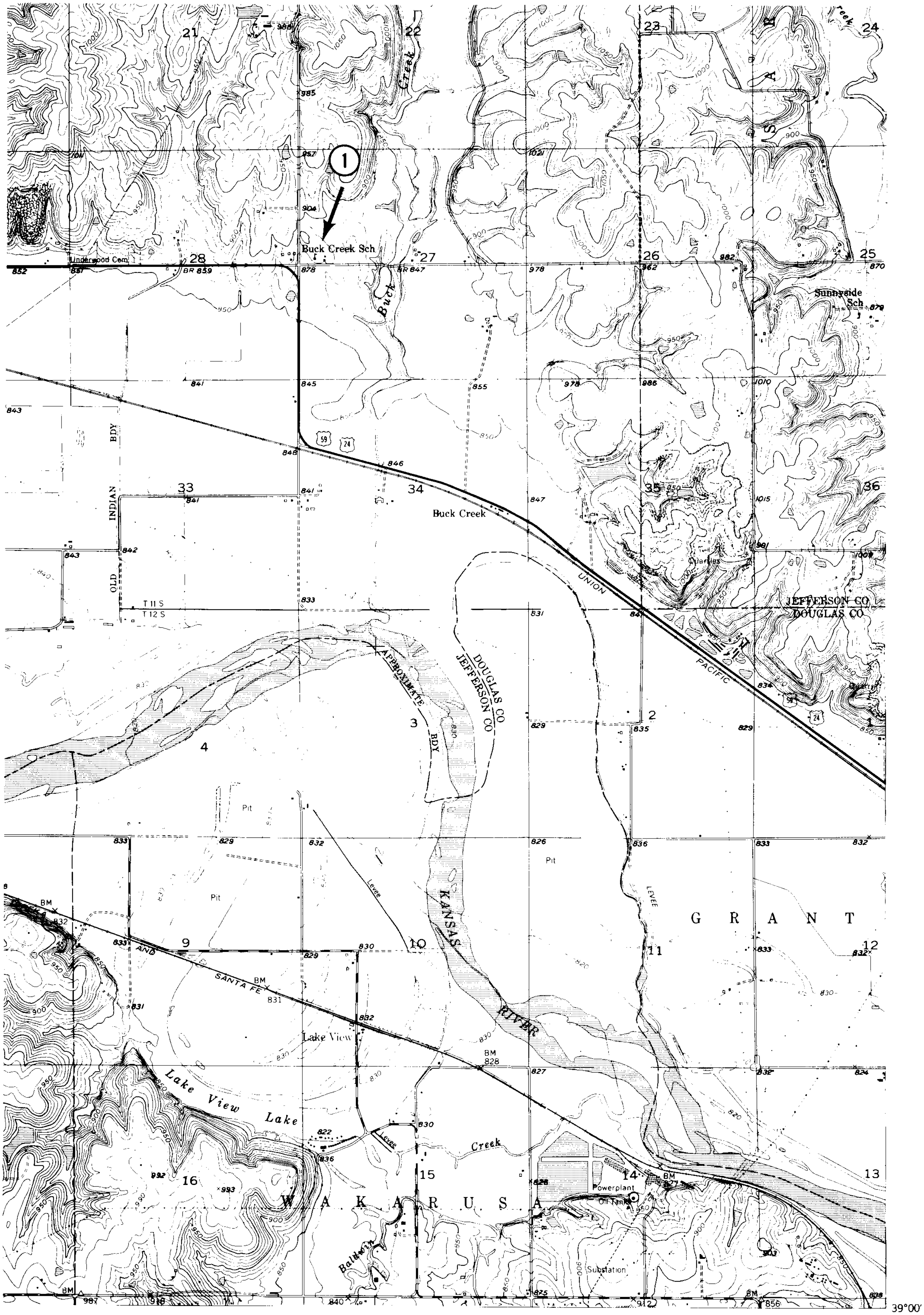
Field-trip map

Day 1, stops 1–13

Day 2, stops 14–15

Quaternary environments of Kansas

Road log



1
Buck Creek Sch
Underwood Cem
Buck Creek
Sunnyside Sch
OLD INDIAN BDY
T 11 S
T 12 S
UNION PACIFIC
JEFFERSON CO
DOUGLAS CO
APPROXIMATE BDY
Pit
Levee
KANSAS RIVER
G R A N T
SANTA FE
Lake View
Lake View Lake
Creek
W A K A R U S A
Powerplant
Oil Tanks
Substation
Quarries
39°00′
95°15′

Day one (Saturday, August 16, 1986)

miles

0.0 Intersection of 6th and Iowa streets in Lawrence, Kansas, at Master's Inn, conference headquarters. Proceed east on 6th Street (US-40, -59).

1.3 Turn north across the Kansas River.

3.2 Junction of US-59 and US-40.
Continue north and west on US-24, -59. (The Sunday trip will turn east here.)

4.9 Rise up low terrace scarp. (This will be discussed on Sunday.)

5.8 View ahead to right shows subdued alluvial fan profile. The highway is located on the Newman terrace, purportedly of late Pleistocene and Holocene age. Therefore, these minor fans must have formed in Holocene time.

7.3 Limestone quarry on right is in the Oread Limestone (Upper Pennsylvanian); fig. 1 presents the bedrock stratigraphy pertinent to the field-trip route.

9.5 Rise up scarp from Newman terrace to the Buck Creek terrace.

9.7 Straight ahead on gravel road.

9.8 Turn right (east) on gravel road to Buck Creek School.

9.9 **STOP 1**—Buck Creek School; NWSW sec. 27, T. 12 S., R. 19 E., Williamstown 7½-min quadrangle.

This first stop presents an excellent vantage point from which to consider an overview of the late Quaternary alluvial history of the lower Kansas River valley. The school site and directly north and east is the type locality for the Buck Creek terrace, named such by W. A. Carlson in 1951. Fig. 2 presents a schematic drawing of the terrace system for the lower Kansas River valley, as proposed in 1951. All four terraces and exposures of their fills will be visited during the course of the two-day field conference. For a detailed description of the terraces and associated soils types, see discussions by Dort and Sorenson et al., this volume. Also, Johnson and Martin, this volume, present an alluvial chronology of Holocene fills and place it in a regional context.

All 7 1/2-min topographic-map areas shown in this road log have been photographically reduced to 85% of their original size.

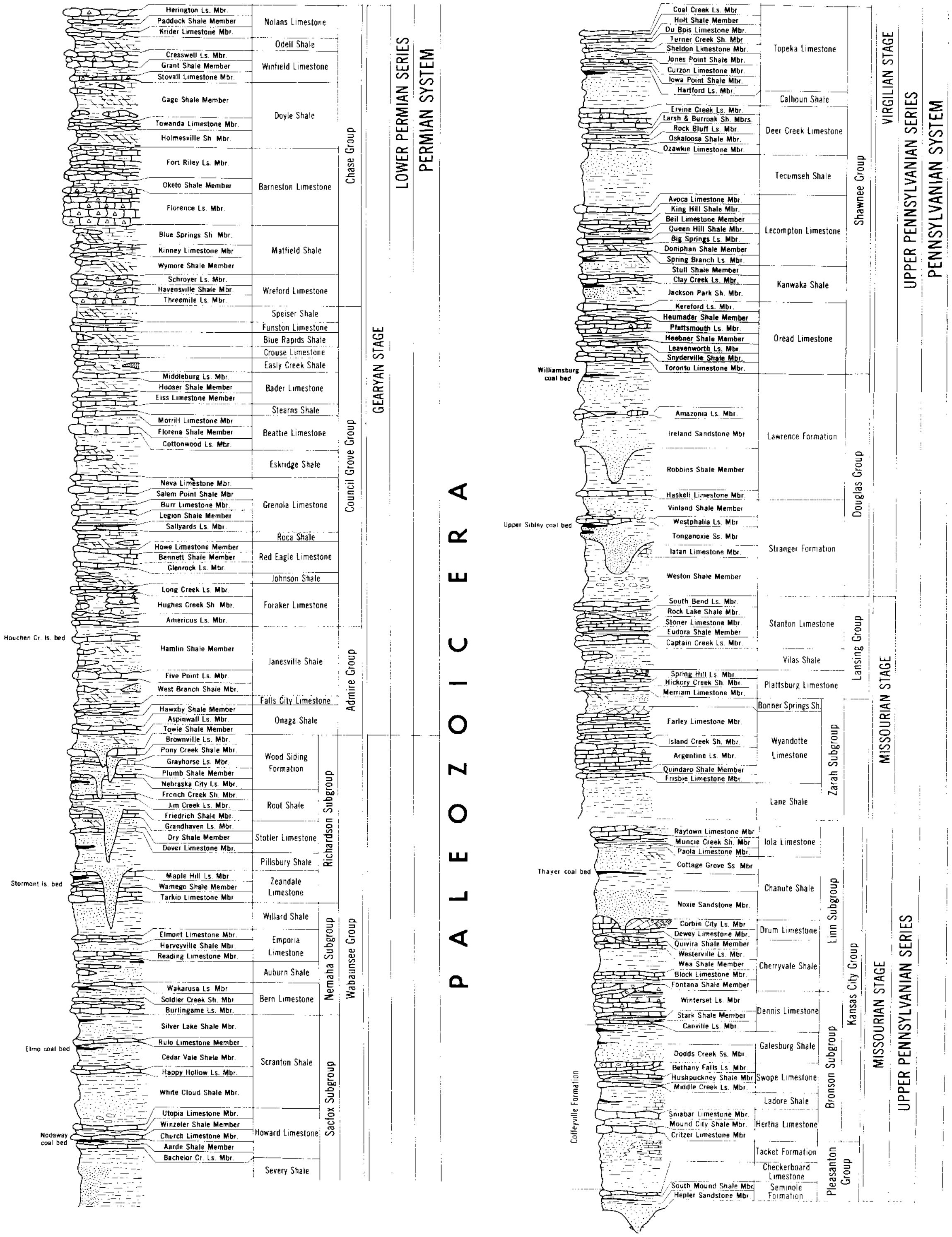


FIGURE 1—STRATIGRAPHIC COLUMN OF BEDROCK CROPPING OUT ALONG THE ROUTE OF THE FIELD TRIP (FROM ZELLER, 1968).

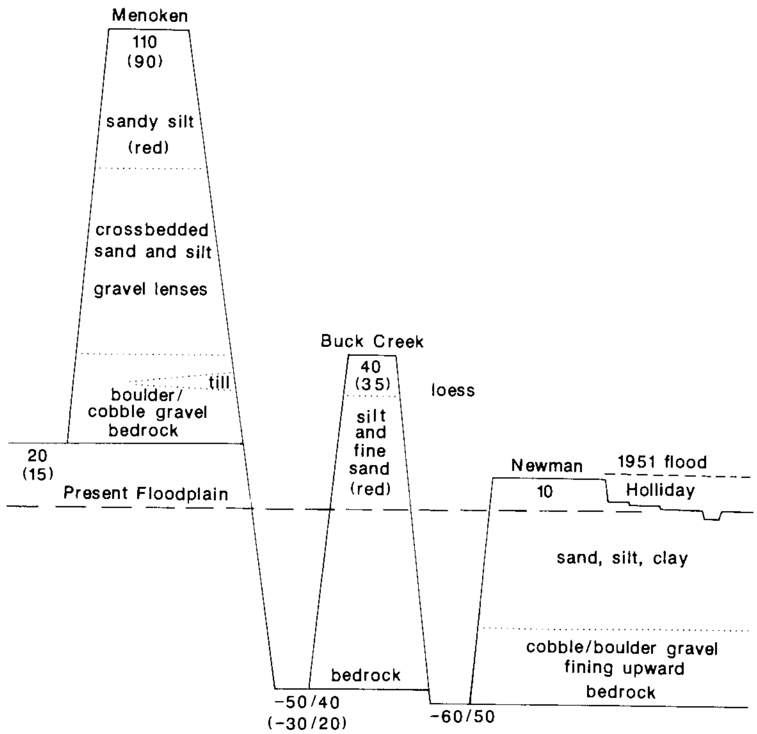
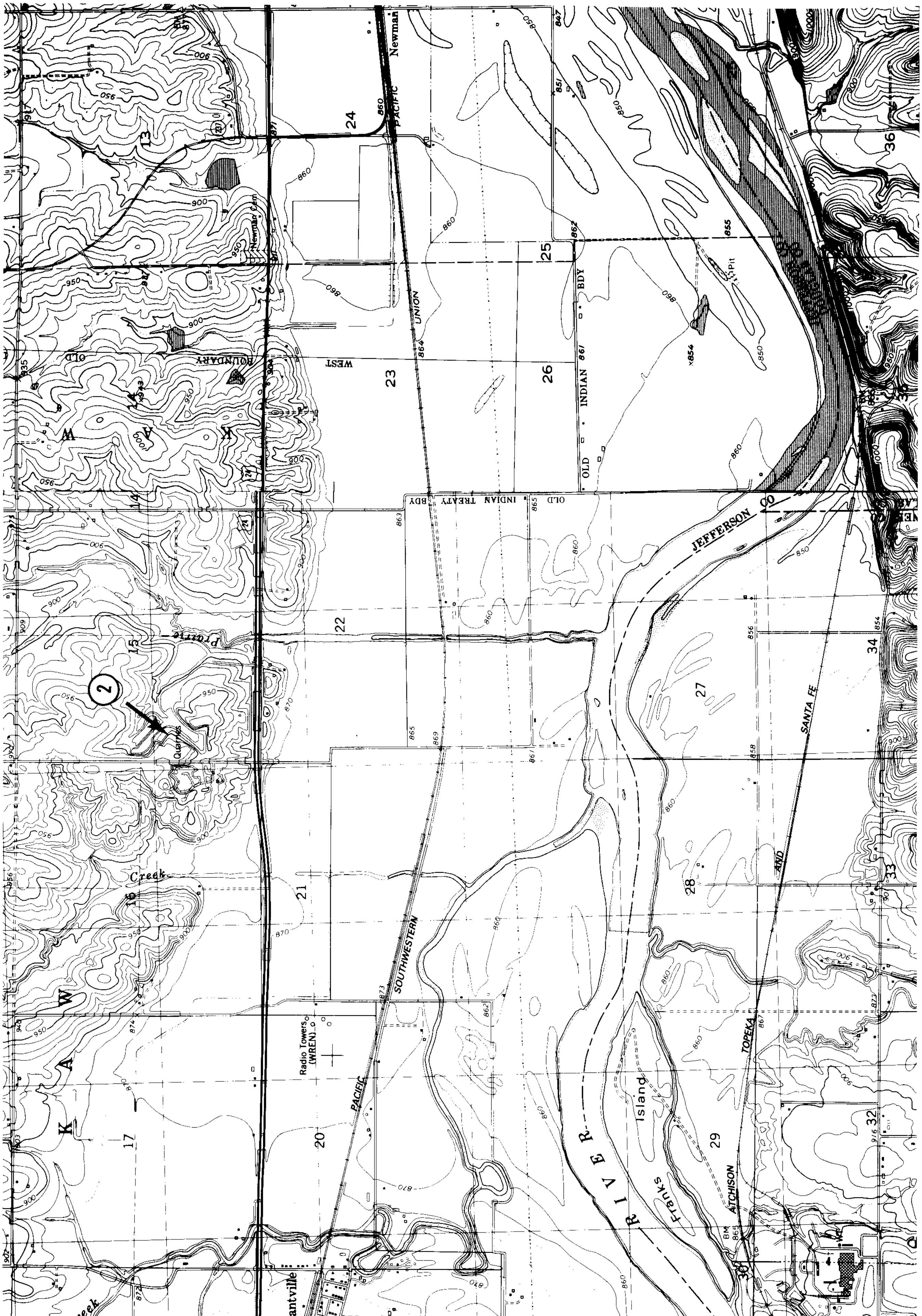


FIGURE 2--SCHEMATIC REPRESENTATION OF THE EROSIONAL/DEPOSITIONAL HISTORY OF THE KANSAS RIVER THROUGH PLEISTOCENE AND HOLOCENE TIME AS PROPOSED BY CARLSON (1952) AND DAVIS (1951) AND FOLLOWED BY SUBSEQUENT AUTHORS.


Newman
Newman Cem
PACIFIC
UNION
SOUTHWESTERN
Quarries
Prairie
Creek
Radio Towers (WREN)
Grantville
OLD INDIAN TREATY BDY
WEST BOUNDARY
JEFFERSON CO
RIVER
Franks
Island
ATCHISON
TOPEKA
AND
SANTA FE
2

10.1 Continue west on US–24, –59.
11.5 Limestone quarry to north, also in the Oread Limestone.
11.9 Continue west on US–24.
13.1 Continue on the Newman terrace surface. Less than a mile to the south is a low scarp separating the upper, smooth surface of the Newman terrace from the old channels and meander scars the Holliday terrace and floodplain.
15.0 Pass north of the town of Perry.
15.5 Cross Delaware River, impounded just to the north to form Lake Perry.
17.0 Perry Dam, built by the Corps of Engineers, is visible to the north.
19.4 Town of Newman to the south. This is the type locality for the Newman terrace, named jointly by S. N. Davis and W. A. Carlson in 1951.
22.4 Turn right (north) on gravel road.
22.6 **STOP 2**—Hamm quarry in the Deer Creek Limestone; NWSW sec. 15, T. 11 S., R. 17 E., Grantville 7½-min quadrangle.

This quarry is situated beneath an overburden of ''Menoken terrace'' deposits. The stratigraphy here is complex, but an idealized section would include glacial outwash or alluvium overlain by pre-Illinoian glacial till. The Morrill soil series has commonly formed in the till. In several exposures, the till is overlain by loess and a red soil (Gymer series) has formed in loess of probable Loveland or older age. In some, if not most, instances these soils have been truncated and often are buried beneath younger loess or colian sands in which the Sharpsburg or Shellabarger series are formed. Fig. 3 presents a regional representation of glacial limits for the four classical glaciations. See Dort, this volume, for a discussion of glaciation in Kansas.

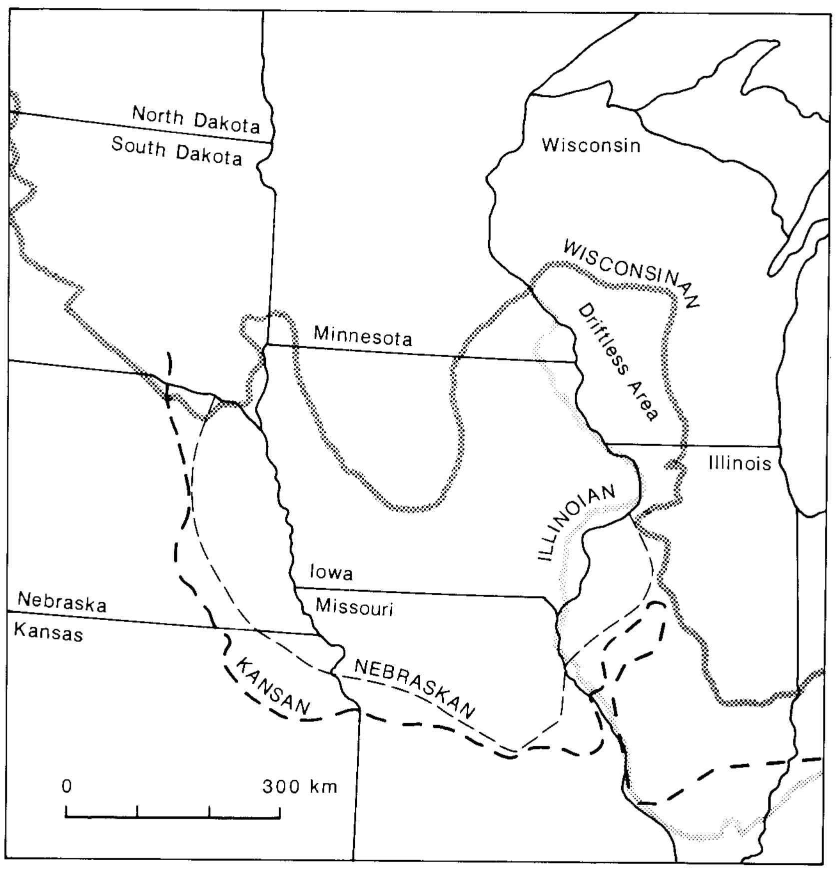
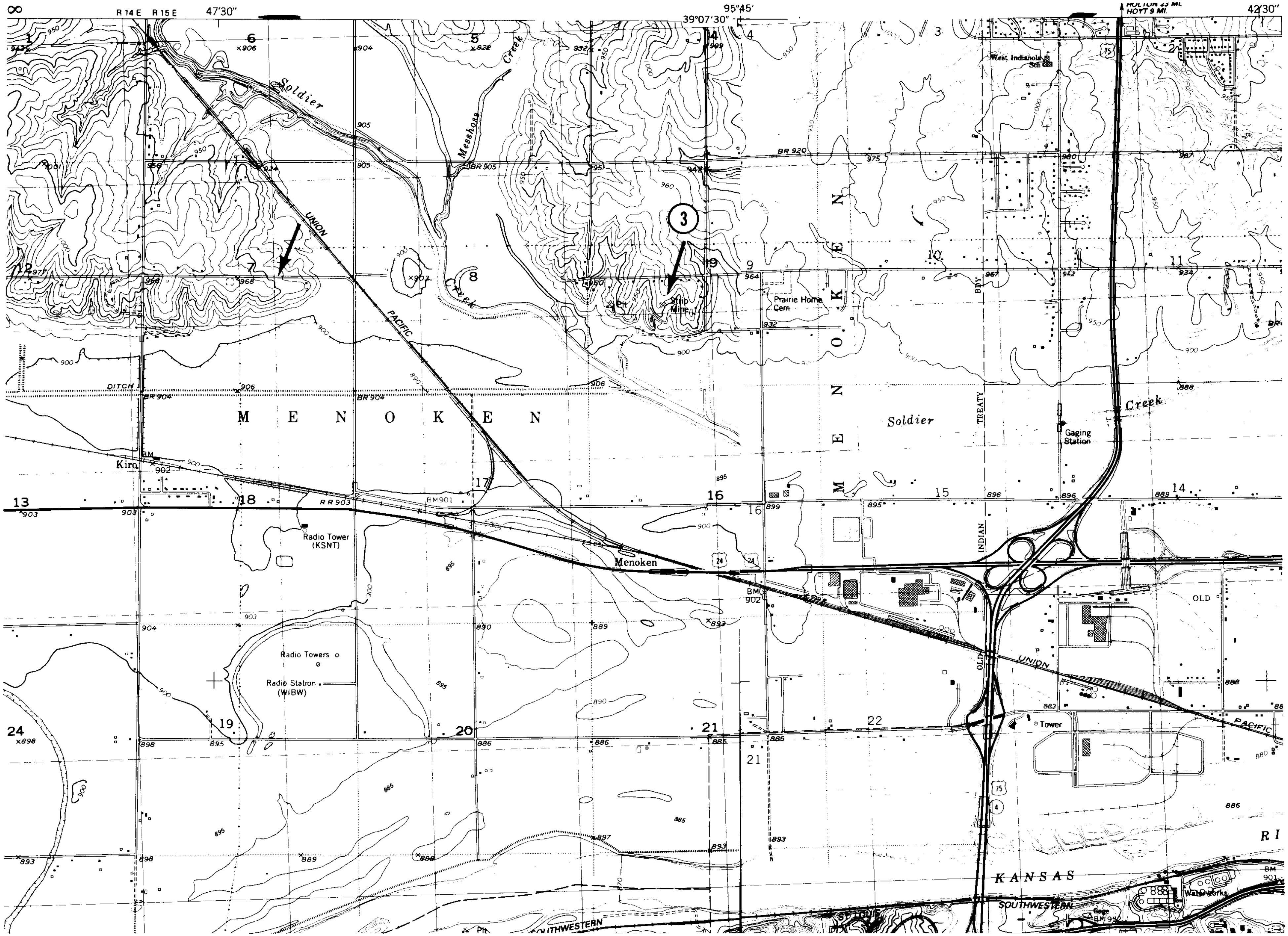


FIGURE 3--KNOWN OR INFERRED TERMINI OF THE FOUR CLASSICAL GLACIATIONS IN CENTRAL UNITED STATES (modified from Flint, 1971). Note the position of Kansas at the southwestern limit of pre-Illinoian ice sheets.



R 14 E
R 15 E
47'30"
95°45'
39°07'30"
42'30"
HOLTON 23 MI.
HOYT 9 MI.
Soldier
Messhoss
Creek
West Indianola Sch
BR 920
BR 905
3
Strip Mine
Pit
Prairie Home Cem
BDY
TREATY
INDIAN
MENOKEN
Soldier
Creek
Gaging Station
UNION
PACIFIC
DITCH
BR 904
Kiro
RR 903
BM901
Menoken
BM 902
Radio Tower (KSNT)
Radio Towers
Radio Station (WIBW)
OLD
Tower
KANSAS
SOUTHWESTERN
Water Works

Return to US-24.

22.8 Continue west on US-24.

28.8 Cross Soldier Creek. Channelization by the U.S. Army Corps of Engineers has caused severe bank erosion and channel entrenchment at the upstream end.

29.7 Meier's gravel pit on left (south). Excavation uncovered numerous logs and stumps. Samples of *Platanus* sp. (sycamore) and *Quercus* sp. (white-oak group) stumps collected by W. C. Johnson and P. Kopsick were radiocarbon dated at 1,670 ± 55 (DIC–1760) and 2,620 ± 70 yrs B.P.(DIC–1761), respectively.

31.4 Abandoned meander to right (north) was cut off prior to earliest mapping in this area. It may be as old as 200 yrs.

33.4 Turn right (north) on Menoken Road.

33.9 Again cross channelized reach of Soldier Creek.

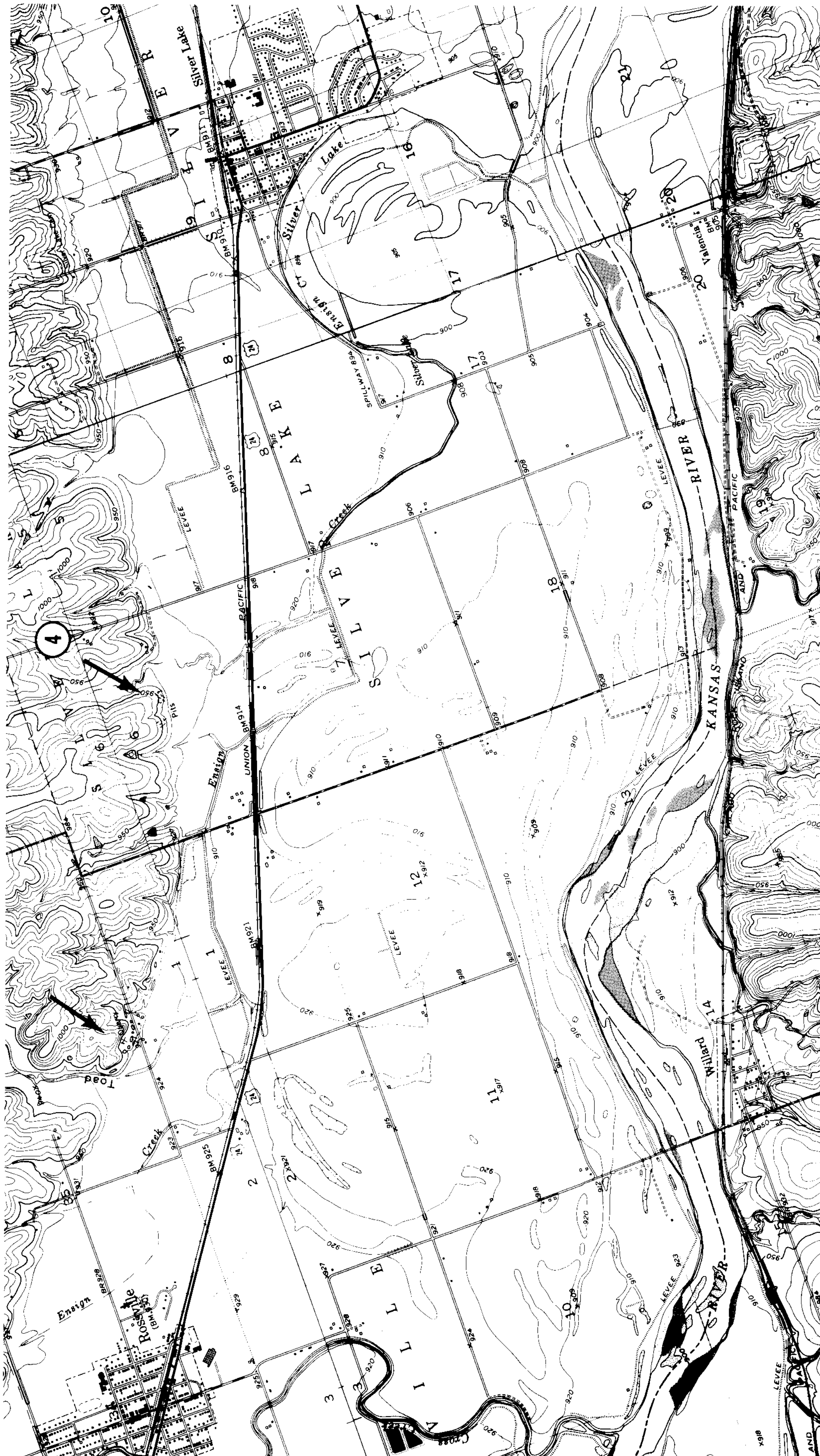
34.4 Turn left (west) on NW 33rd Street, a gravel road.

34.7 Continue west on private road.

34.9 Turn right (north) into Menoken (Doyle) gravel pit.

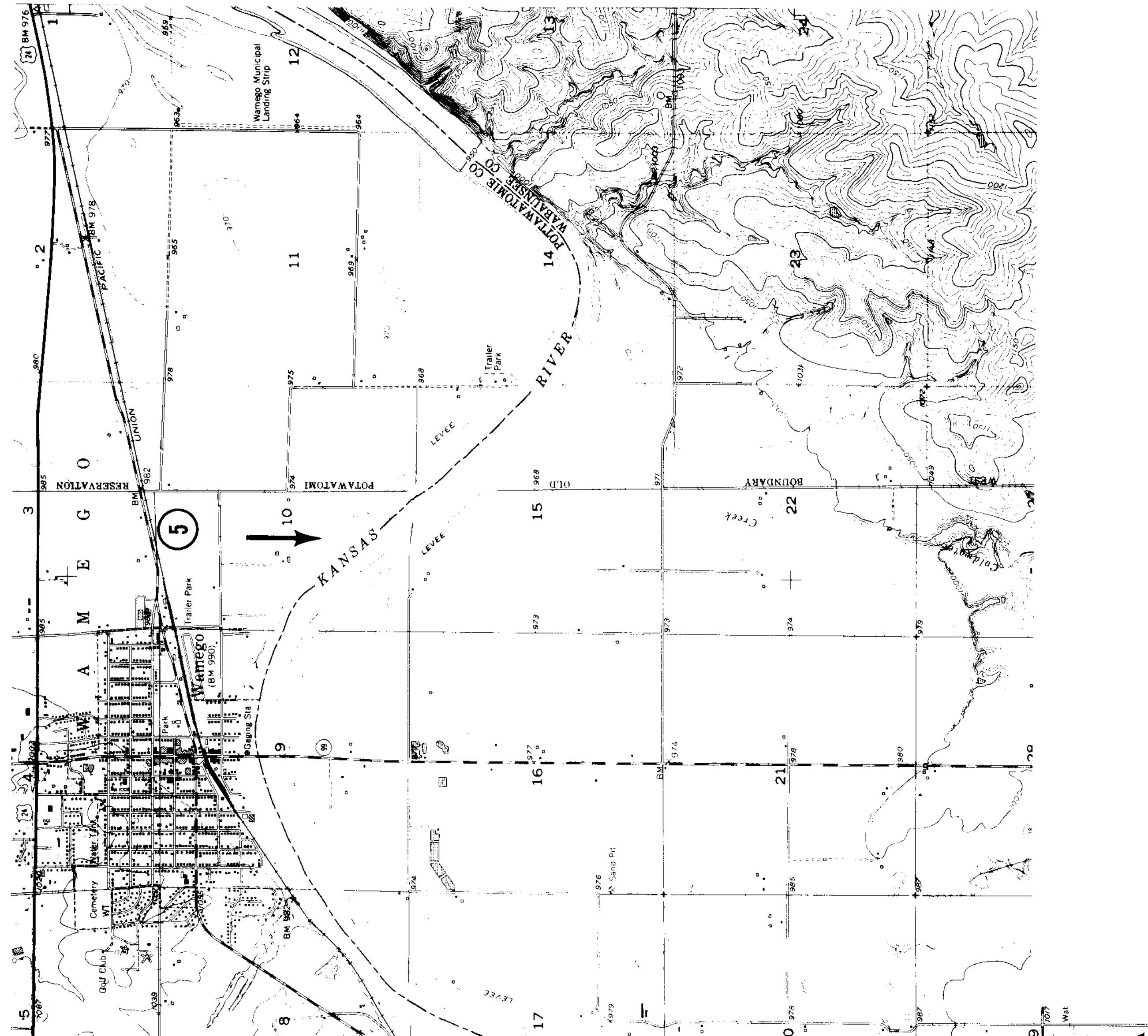
34.9 **STOP 3**—Menoken (Doyle) gravel pit; NESW sec. 9, T. 11 S., R. 15 E., Silver Lake 7½-min quadrangle.

This stop is the type locality for the "Menoken Terrace" complex that was named by S. N. Davis in 1951. The general stratigraphy here is similar to that at Stop 2. Major theses discussed at this stop include the possible glaciofluvial sources of the extensive gravel deposits here, the potential colluvial nature of the "loess," and sources of carbonates in some of the surface soils.


Silver Lake
Rossville
Willard
Valencia
KANSAS
RIVER
UNION PACIFIC
Ensign
Creek
LEVEE
SPILLWAY 894
SILVER LAKE
4

Return to US–24.
36.3 Continue west on US–24.
42.5 Silver Lake, the abandoned meander to left (west), was part of the channel of the Kansas River in 1873, but had been cut off by 1902.
43.2 Town of Silver Lake.
44.9 Turn right (north) on dirt road.
45.4 Turn left (west) on private drive.
45.9 **STOP 4**—Mitchell gravel pits; NWSE sec. 6, T. 11 S., R. 14 E., Willard 7½-min quadrangle.

The exposures at this stop are conspicuous by the near absence of till and the presence of a sharp, irregular buried surface separating "loess-colluvium" from underlying gravels. Irregularity of this surface seems to result from erosion. A well developed paleosol in the "loess-colluvium" is buried beneath sandy sediments. These sediments seem to be Holocene sands and are probably derived from floodplain deposits on the adjacent Newman surface.


Wamego
Wamego Municipal Landing Strip
Trailer Park
Golf Club
Cemetery
Park
Gaging Sta
Sand Pit
KANSAS RIVER
POTTAWATOMIE CO
WABAUNSEE CO
UNION PACIFIC
POTAWATOMI RESERVATION
OLD BOUNDARY
INDEFINITE BOUNDARY
LEVEE
SPOIL BANK
CHICAGO
ROCK ISLAND
Deep Creek

Return to US-24.
47.1 Continue west on US-24.
48.2 The abandoned meander to left (south) was cut off prior to the earliest mapping in this area. It is probably 300 yrs old. The feature occupies a local embayment of the floodplain into the Newman terrace.
49.1 A gravel pit is visible on the valley side to the right (north). It exposes material similar to that seen at Stop 4.
50.8 Town of Rossville.
56.7 The highway traverses another small embayment of floodplain into the Newman terrace.
58.5 Town of St. Marys.
58.7 The terrace scarp down to left (south) is between the Newman surface, on which the highway is located, and the floodplain. Although the river is now almost 2 mi (3 km) to the south, in 1902 it was only 1,500 ft (450 m) from the highway.
59.3 An old gravel pit is just visible on the valley side to right (north). It exposes a thin section of silt over gravel, similar to that at Stop 4.
61.3 Terrace scarp down to left (south) is between the Newman surface and the floodplain.
64.8 Town of Bellvue.
67.9 Cross the Vermillion River. Its confluence with the Kansas River is directly to the left (south).
69.2 Turn on Pottawotamie County road 72 to left, continue west.
71.6 Windmill Park. Note decorative use of Sioux quartzite erratics.
71.8 Town of Wamego. Turn left (south) onto Lincoln Avenue.
71.9 Turn left (east) on Valley Street.
72.4 Turn right (south) into Riverside Mobile Home Park.
72.6 **STOP 5**—River-bank exposure; SESW sec. 10, T. 10 S., R. 10 E., Wamego 7½-min quadrangle. The exposure is reached by walking approximately 900 ft (300 m) east (downstream).

Stop 5—Wamego River bank exposure

by *William C. Johnson*, University of Kansas, Lawrence, Kansas

This stop provides an opportunity to view one of the best exposures of adjacent Newman and Holliday terraces and fills on the Kansas River. It also presents an example of the influence of ancient stream deposits on contemporary channel stability.

ALLUVIAL SURFACES—Three alluvial terraces have been mapped within this reach of the valley (Beck, 1959; Fader, 1974; Bowman, 1985). They are, from oldest to youngest, Buck Creek, Newman, and Holliday terraces (fig. 4). Situated approximately 12 m (40 ft) above the floodplain, the Buck Creek terrace is well-represented through the reach on both sides of the valley. The river comes into contact with the Buck Creek fill, as mapped, at Wamego and upstream on the south side of the valley. This fill has been characterized as predominantly reddish-brown silt and clay, within which the Sangamon soil had developed (Dufford, 1958).

The Newman terrace, the most extensive terrace surface in the reach, is characteristically 3 m (10 ft) above the floodplain. Stratified silt, clay, and sand comprise Newman fill. Unaltered portions exhibit a distinct buff color. The Holliday terrace occupies an intermediate position between the Newman terrace and the lower, modern floodplain (McCrae, 1954). In contrast to the Buck Creek and Newman surfaces, the Holliday terrace exhibits numerous meander scars, point-bar scrolls, and other floodplain features. Underlying sediments are predominantly silts, gray in color. The floodplain, comprising most of the valley bottom in the reach, consists of sand fill with thin interstratified intervals of silt and clay (Bowman, 1985).

STRATIGRAPHY—This stop offers an excellent view of Newman and Holliday fill stratigraphy and of the contact with one another. Stratigraphy is exposed for a distance of approximately 800 m (2,640 ft) east from Wamego.

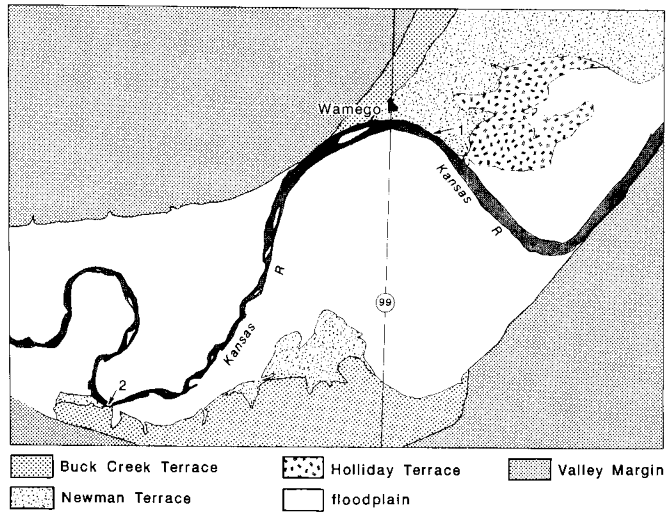


FIGURE 4--MAP OF ALLUVIAL SURFACES ADJACENT TO THE KANSAS RIVER IN THE VICINITY OF WAMEGO. The exposed contact of Newman and Holliday fill is noted by the arrow (from Bowman, 1985). Radiocarbon-dated localities indicated at points 1 and 2.

Bowman (1985) notes three stratigraphically distinct units within the Newman fill exposed. An upper unit (Tn–1) consists of buff-colored silt and lacks any apparent sedimentary structures. Thickness of this unit decreases eastward from 7.25 m (23.9 ft) to less than 1 m (3.3 ft) at the contact with Holliday fill. Alternating silt and clay strata comprise the next unit down (Tn–2), which becomes progressively coarser to the east, but pinches out well before the terrace-fill contact. The lowermost unit (Tn–3), consisting of trough-crossbedded sand and gravel, climbs from the lower .5 m (1.7 ft) eastward to the fill contact where it comprises the entire Newman fill sequence exposed.

Three paleosols are obvious within the Newman fill (fig. 5). Humates from the basal and middle paleosols have been radiocarbon dated to 7,250 ± 110 (DIC–2946) and 4,950 ± 120 yrs B.P. (DIC–3355), respectively. The paleosol extends for the entire length of the fill exposure and was dated 200 m (660 ft) upstream (fig. 4.1) of the contact with Holliday fill. This early Holocene age is consistent with radiocarbon dates obtained at the Bonner Springs exposure of Newman fill (Stop 15). A third radiocarbon assay was obtained on humates from a paleosol exposed in the first cutbank upstream (fig. 4.2). The date of 8,310 ± 120 yrs B.P. (DIC–3208) is Newman in age but occurs within fill below a surface mapped as the pre-Wisconsinan Buck Creek. Simple field observation indicates this is a case of mismapping or cartographic error.

Because of its near-horizontal orientation, the lowermost paleosol cuts through each of the stratigraphic units noted above and is thereby a time-stratigraphic marker (Bowman, 1985, p. 124). This fining-upward sequence, with its basal trough-crossbedded sand and structureless silt cap, probably represents vertical accretion beginning with point-bar deposition. At least three periods of relative floodplain stability occurred, however, permitting soil development.

Holliday fill presents a color and stratigraphic contrast with the adjacent Newman fill. The terrace fill, gray-brown in color, contains more silt and less clay than that of the adjacent Newman terrace. One paleosol is evident at the exposure but has not been radiocarbon dated due to humate contamination from abundant contemporary rootlets and the lack of charcoal or wood. Late Holocene radiocarbon dates have, however, been obtained on Holliday fill at the Bonner Springs exposure.

FIGURE 5—THREE PALEOSOLS (ARROWS) EVIDENT IN THE UPSTREAM END OF THE CUTBANK EXPOSURE OF NEWMAN FILL. A radiocarbon date of 7,250 ± 110 yrs B.P. (DIC–2946) has been obtained on the lowermost of the three paleosols, and 4,950 ± 120 yrs B.P. (DIC–3355) on the middle one. A paleosol exposed in the adjacent upstream bend has been dated at 8,310 ± 120 yrs B.P. (DIC–3208). All assays are from humates extracted from the upper 15 cm of the paleosols (photo by W. C. Johnson).

Although age, color, texture, and other stratigraphic differences exist between Newman and Holliday fills, x-ray diffraction data indicate the two have similar clay mineralogies. X-ray diffraction patterns of the whole-clay fraction from samples of both fills (fig. 6) indicate the clays are dominated by mixed-layer minerals containing notable concentrations of smectites. Kaolinite and illite are either extremely weathered or exist in very small concentrations. This mineralogy does contrast with the Newman and Holliday fills at the Bonner Springs exposure (see discussion Stop 15B).

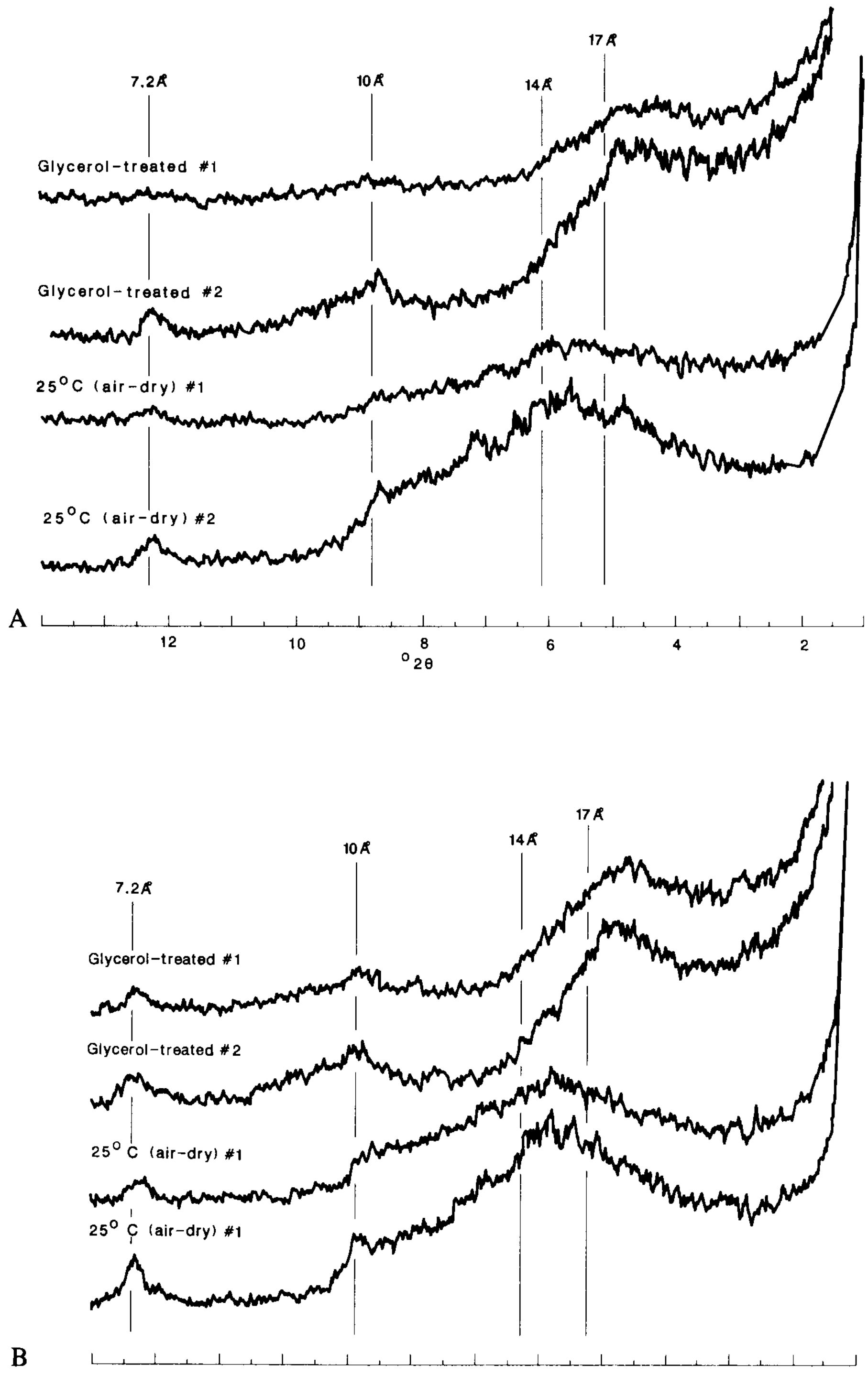


FIGURE 6—X-RAY DIFFRACTION PATTERNS OF THE WHOLE CLAY FRACTION (<2u) FROM THE WAMEGO RIVERBANK EXPOSURE. Clays are dominated by mixed-layer minerals that appear to contain significant concentrations of smectites, as supported by the expansion of the interlayer spacing to 17–18 Å (Newman fill) and 14–15 Å (Holliday fill) upon glycerol treatment. This is characteristic of the more pure forms of montmorillonite. Kaolinite and illite are extremely weathered or exist in extremely small concentrations. A, Holliday fill; B, Newman fill.

LATERAL-CHANNEL STABILITY—The valley reach in the vicinity of this stop provides an instructive example of control exerted by old alluvial fills on the degree of lateral-channel activity (Bowman, 1985). The upstream meander has been active historically, whereas the bend along which the Buck Creek, Newman, and Holliday fills are encountered has been relatively inactive (fig. 7). The active reach has undergone rapid meander growth since 1919, resulting in an anticipated cut-off of 156 hectares (390 acres) of agricultural land. Since about 1885, the bend near Wamego has maintained approximately the same position.

The active-channel meander has formed within the modern-floodplain alluvium, which is sandy and generally noncohesive. Fine, cohesive bank material encountered in the old alluvial fills of the stable meander are cohesive and therefore more resistant to erosion. The cohesive material permits the banks to withstand stream power induced by a channel slope (water-surface) that is somewhat greater than within the active reach (fig. 8). Further, the relatively steep valley slope has certainly contributed to the lateral activity of the upstream reach. Presumably the channel meandered until only suffficient slope remained to permit transport of sediment supplied to the channel.

Channel instability may be induced by the presence of valley fills that are out of equilibrium with the regimen of the contemporary channel (e.g., Grissenger and Murphy, 1983). In this situation, the deposits from precursors of the contemporary channel seem to be resulting in channel migration upstream.

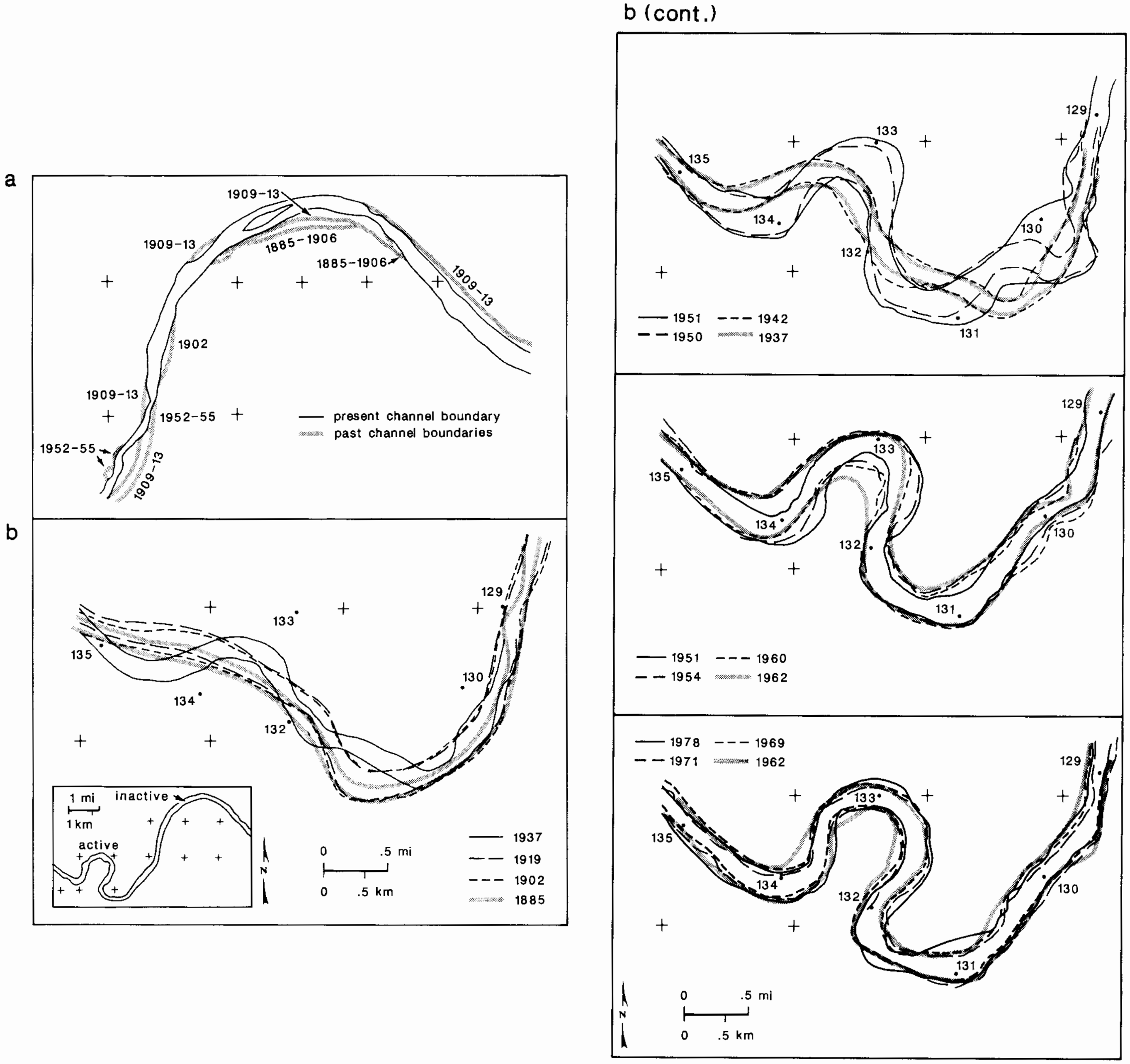


FIGURE 7—THE DISPARITY IN LATERAL MIGRATION BETWEEN TWO ADJACENT REACHES WITHIN THE VICINITY OF WAMEGO: a) the subtle changes in channel position since 1885 for the inactive (stable) reach. b) a sequence of four maps illustrating the large amount of lateral migration documented in the active (unstable) reach from 1885 to 1978 (from Dort, 1980).

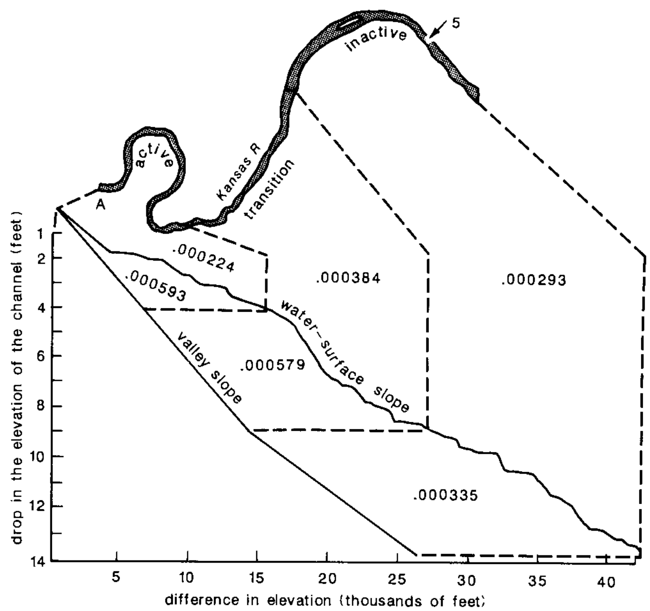
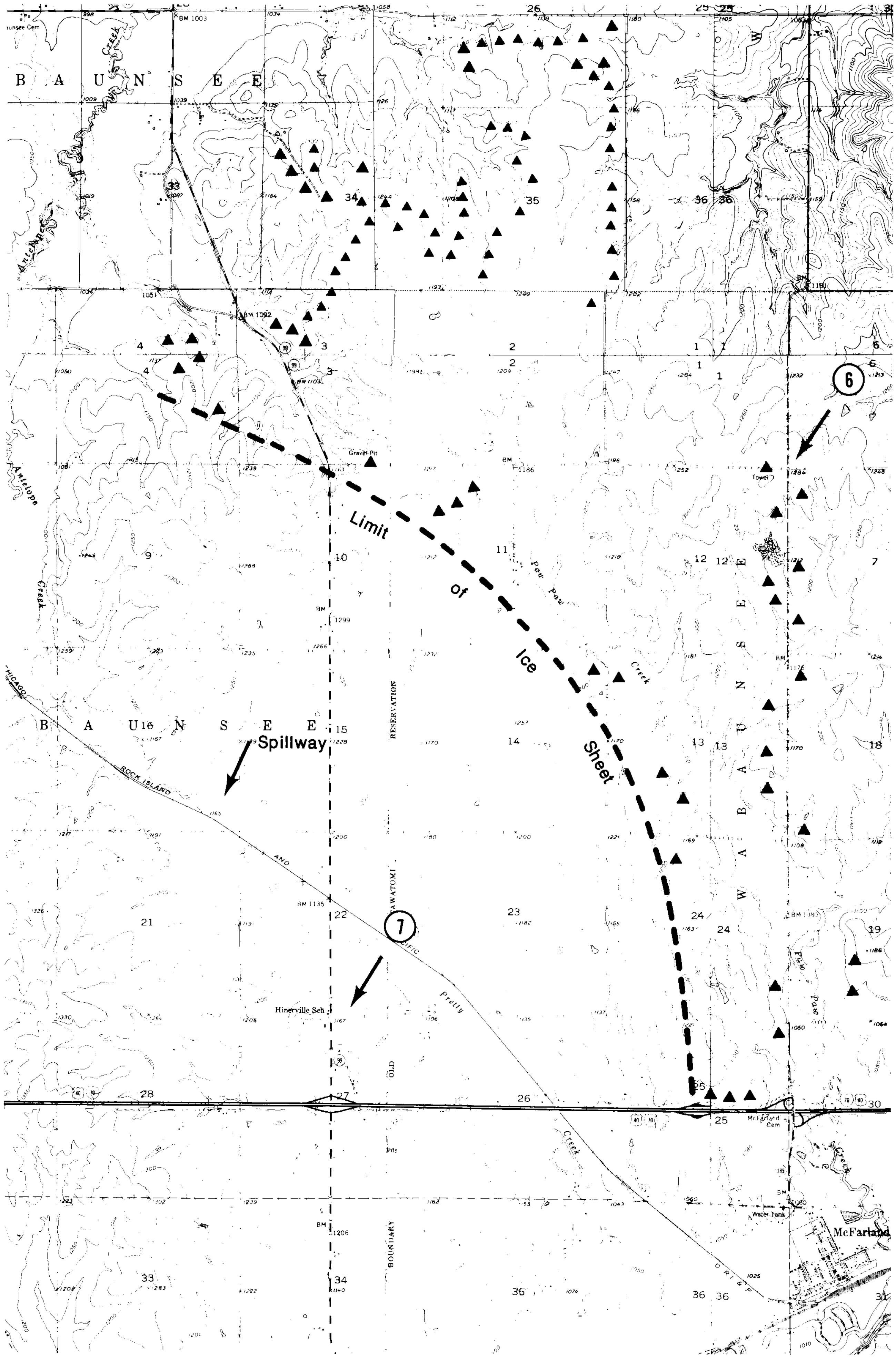


FIGURE 8--RELATIONSHIP BETWEEN WATER SURFACE AND VALLEY SLOPE FOR LATERALLY ACTIVE, INACTIVE, AND INTERMEDIATE REACHES OF THE KANSAS RIVER ABOVE AND IN THE VICINITY OF WAMEGO. Water-surface slope is presented as the drop in elevation divided by the length of channel (from Bowman, 1985).



Limit of Ice Sheet
Spillway
6
7
B A U N S E E
W A B A U N S E E
RESERVATION
POTTAWATOMI
OLD
BOUNDARY
Pretty Creek
Paw Paw Creek
Antelope Creek
Hinerville Sch
Gravel Pit
McFarland
Water Tank
McFarland Cem
Tower
CHICAGO ROCK ISLAND AND PACIFIC

Return to Lincoln Avenue (K–99).

74.0 Low terrace scarp to the right (west). This may be between the floodplain and one of the surfaces of the Holliday terrace complex.

76.3 Climb steep terrace scarp that separates the Buck Creek terrace above from a Newman or Holliday surface below.

77.6 Hill with limestone boulders to left (east).

78.5 Hill with limestone boulders to left (east).

78.8 This hill is veneered with quartzite boulders.

79.6 Turn left (east) on gravel road. Note limestone and shale bedrock.

80.3 Boulders on slopes ahead are Sioux quartzite.

80.9 Quartzite boulders on slopes ahead. Bedrock quarry to right (south). Quartzite boulders to left (north).

81.1 Quartzite boulders to left (north).

82.1 Turn right (south) on gravel road.

82.1 **STOP 6**—Hilltop microwave tower; NENE sec. 12, T. 11 S., R. 10 E., McFarland 7½-min quadrangle.

We are standing on an apparent terminal deposit left by a pre-Illinoian ice sheet. This locality and several others like it are striking because of the purity of the deposit which is composed of nearly 100% Sioux quartzite boulders. Concentration of these boulders on topographic highs has led to considerable speculation concerning the role of erosion in their distribution.

Continue south on gravel road.

82.4 Quartzite boulders to left and right.

82.6 Bedrock quarry to right (west). Outcrop to left (east).

84.2 Quartzite boulders to left (east). The creek to the right (west) is the approximate glacial boundary.

84.9 Quartzite boulders are restricted to the base of the slope to the right (west).

85.6 Turn right (west) on I–70.

86.1 The valley to the left (south) was occupied by a pro-glacial lake.

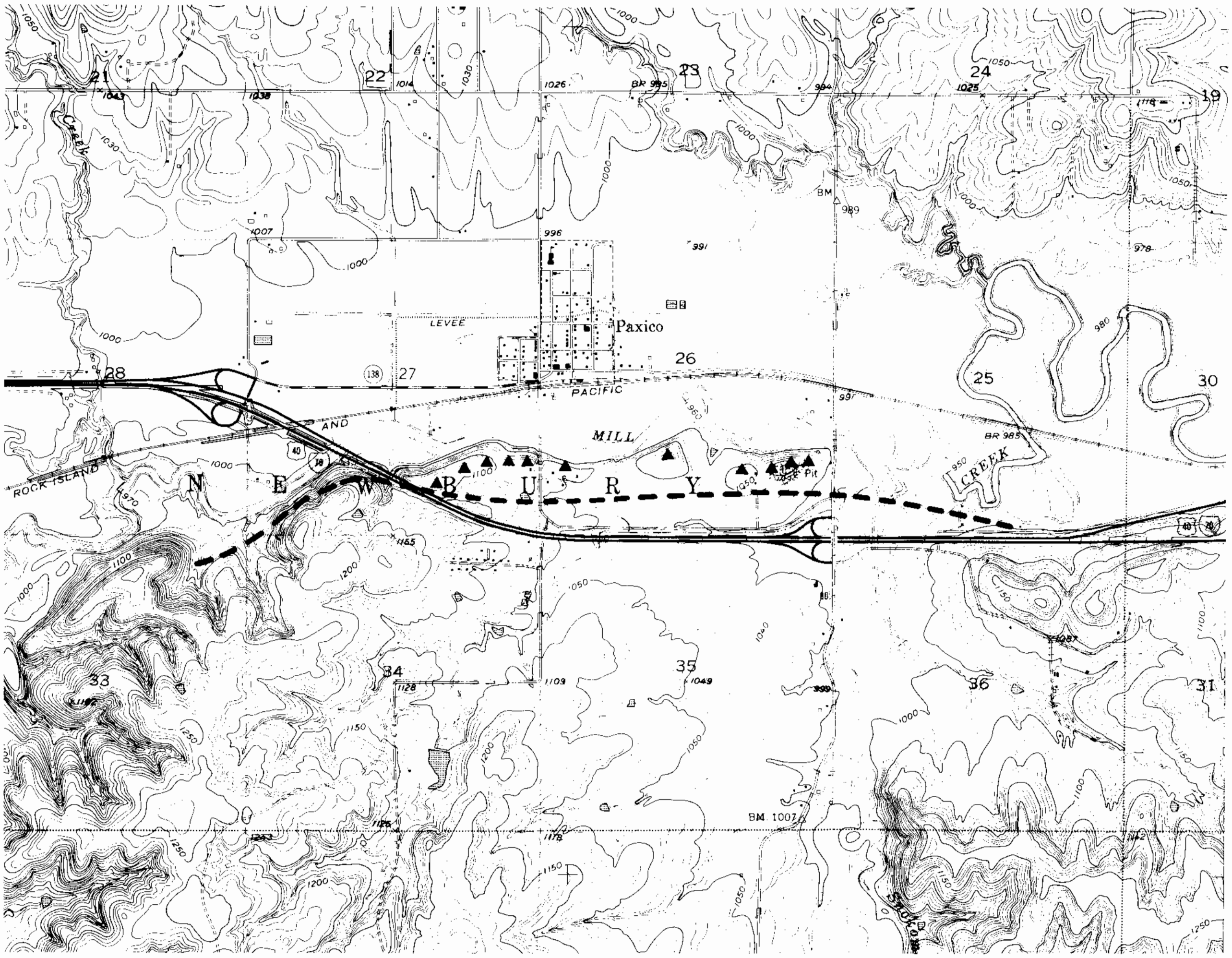
88.0 Exit to K–99 north.

88.2 Turn right (north) on K–99.

88.6 Turn right (east) on gravel road.

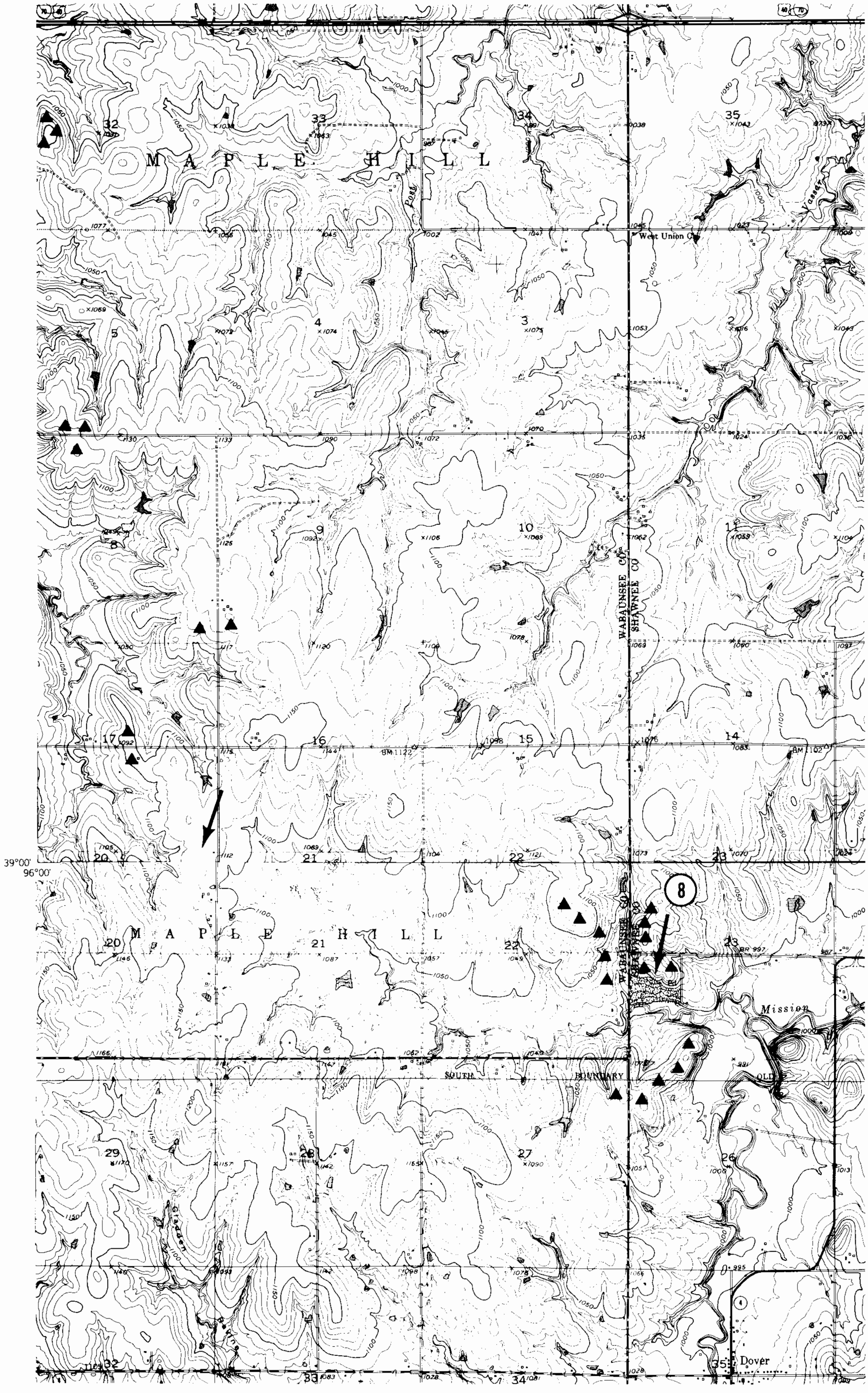
88.7 **STOP 7**—Roadside gravel pit; NWNE sec. 27, T. 11 S., R. 10 E., Alma 7½-min quadrangle.

This locality is more than 2 mi outside of the supposed limit of glaciation as indicated by the distribution of Sioux quartzite erratics, yet the gravel exposed here includes a scattering of quartzite cobbles. One possible explanation is that this deposit was left by a glacier advance earlier than that which spread the boulders to the northeast. Alternatively, it may be somehow related to the spillway 1 mi (1.6 km) to the northwest which controlled the overflow of a large pro-glacial lake in the Kansas River valley.



Paxico
N E W B U R Y
MILL
CREEK
PACIFIC
AND
ROCK ISLAND
LEVEE
Pit
BM 1007

Return to I–70.
89.4 Turn left (east) on I–70.
92.3 Erratics are present on the hills to the left (north), but not to the south.
95.3 Cross Mill Creek, the valley of which was occupied by a pro-glacial lake. The roadcut ahead coincides with the position of the glacier terminus.
95.7 Erratic boulders are present on the ridge to the left (north); none to the south (see topographic map on opposite page).
95.8 The gravel pit in the ridge to the left (north) exposes gravel underlying a till cap.
99.7 Crossing bed of small pro-glacial lake. Buffalo Mound ahead on left probably was unglaciated. The times of brush are controlled by outcrops of alternating limestone and shale.
102.9 Exit for rest stop.
103.3 **REST STOP.**


MAPLE HILL
West Union
WABAUNSEE CO
SHAWNEE CO
39°00'
96°00'
8
MAPLE HILL
Mission
SOUTH
BOUNDARY
Dover

Return to I–70.

103.6 Continue east on I–70. The glacial boundary crosses the highway and extends toward the southeast.

105.5 Numerous quartzite boulders are visible by the hilltop house to the right (south).

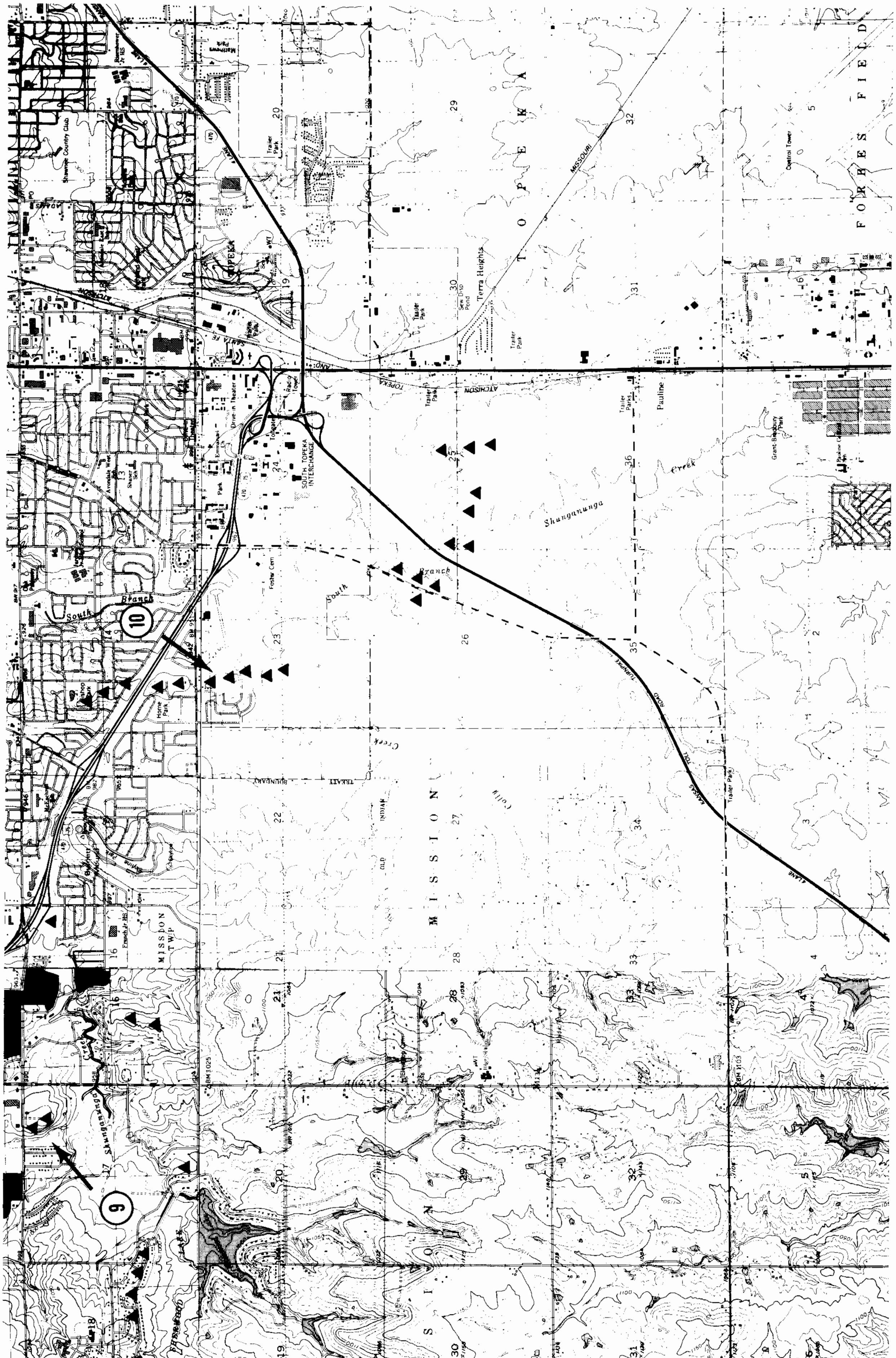
108.4 Leave I–70 at exit 346.

108.6 Turn right (south) on road to Dover.

113.0 Quartzite boulders are present on hills to the right and the left and ahead.

113.2 **STOP 8**—Dover quarry; NWSW sec. 23, T. 12 S., R. 13 E., Dover 7½-min quadrangle.

Exposed here is a combination of a concentrated upland boulder field, similar to that of Stop 6, and loess-colluvial soils like those of stops 1, 2, 3, and 4.

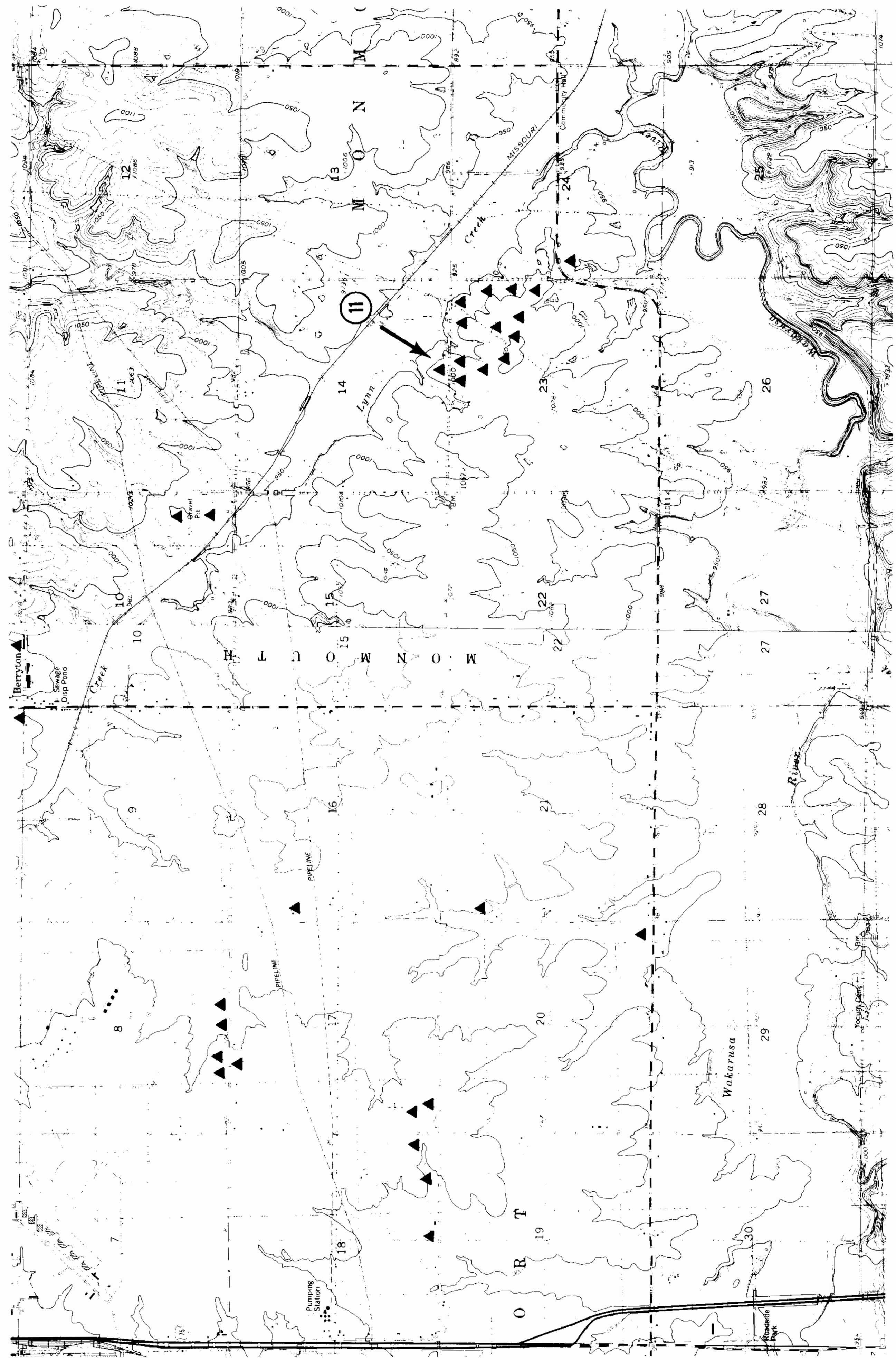

T O P E K A
M I S S I O N
F O R B E S F I E L D
Terra Heights
Pauline
SOUTH TOPEKA INTERCHANGE
Shunganunga
Creek
South Branch
MISSION TWP
Shawnee Country Club
9
10

Continue south.
113.6 Quartzite boulders are numerous on the ridge to the left (east); this is the glacier terminus.
115.1 Turn left (east) on K–4.
115.6 Town of Dover. Turn left (north) on K–4.
117.3 Quartzite boulders on hilltop. Continue on curvy K–4. Glacial boundary generally lies well north of the highway.
123.9 Quartzite boulders on hill to right (south). This is the approximate glacial boundary.
125.4 Stop sign. Turn right (south) onto Auburn Road.
125.9 Turn left (east) on 29th Street.
127.1 The development area nearby to the right (south) lies on till. The hills farther south are unglaciated.
127.4 Stop sign.
Continue east on 29th Street.
127.8 **STOP 9**—Baseball field exposure; NWNE sec. 17, T. 12 S., R. 15 E., Silver Lake 7½-min quadrangle.

Exposed here is a cobble-boulder gravel composed largely of limestone clasts, but containing a modest percentage of northern erratics, mainly greenstone and varieties of granite, some of which are thoroughly weathered and disintegrated. At the top is an intensely oxidized till in which the erratics are almost all Sioux quartzite. It is suggested that these two units represent two separate advances of the ice sheet.

Continue east on 29th Street.
128.9 Stop sign. Continue east.
129.4 Traffic signal. Continue east.
129.9 Turn right (south) on Fairlawn Drive.
130.0 Turn left onto I–470. Just to the west at this turn, Ed Marling's store lies on the glacial terminus. Till is exposed east of the store.
131.3 Roadcut through ridge, which is capped by till and is colloquially known as "The Terminal."
132.1 Leave I–470 at exit 5.
132.4 Turn left (north) on Burlingame Road.
132.7 Turn left (west) on 37th Street.
133.1 Turn left (south) on Wood Valley Drive; follow around to right.
133.4 Turn right (north) on Deer Trail Drive; follow around to left and uphill.
133.6 Top of hill.
133.6 **STOP 10**—Top of "The Terminal"; NENW sec. 23, T. 12 S., R. 15 E., Wakarusa 7½-min quadrangle.

This location is on the summit of what has been called colloquially the "Topeka Terminal." The ridge does mark the limit of ice advance, but it has a high bedrock core and so is not a true terminal moraine. An extensive network of deep excavations for sewers and water mains exposed thick, highly oxidized till, locally underlain by clean, well-sorted quartz sand. More than half of the boulder and cobble clasts are limestone; granitic types are moderately common, some intensely weathered; Sioux quartzite is relatively scarce. Although limonite "hollow stones" and masses of iron-oxide spongework are common, their significance has yet to be determined. The flat summit area seems to be a product of erosion (deflation?) to a resistant soil horizon.


M O N M O U T H
Herryton
Sewage Disp Pond
Gravel Pit
Lynn Creek
MISSOURI
Community Hall
PIPELINE
Pumping Station
Wakarusa
River
11

Retrace route and turn left onto I–470 eastbound.

134.1 Leave I–470 at exit 6 to US–75.

134.5 Turn south on US–75.

135.2 Turn left (east) on 45th Street.

137.2 Turn right (south) on California Avenue.

138.1 Forbes Field (airport) lies to the right.

138.2 Turn left (east) on 53rd Street.

139.3 Turn right (south) on Berryton Road.

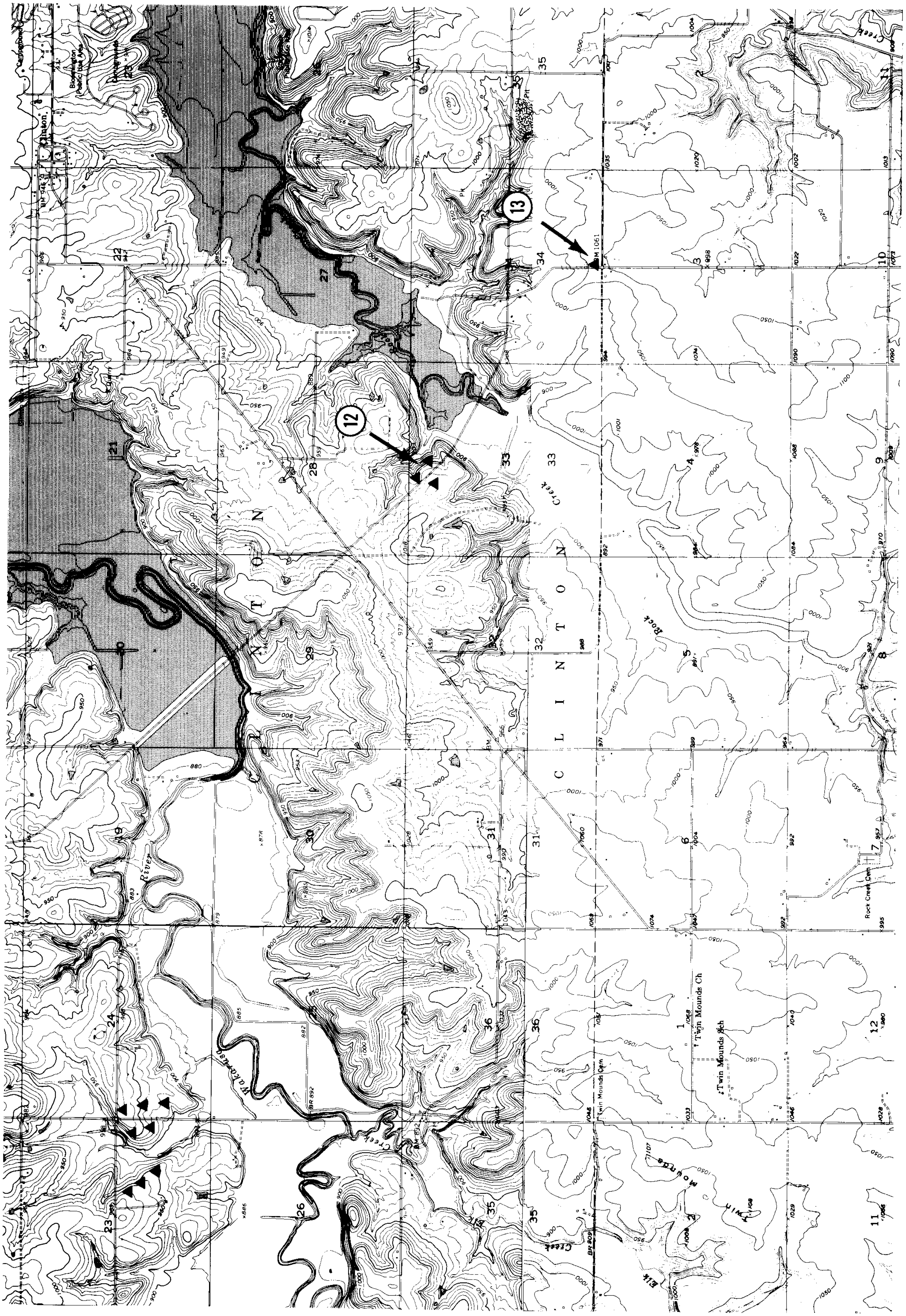
141.2 Turn left (east) on 69th Street.

142.3 Turn right (south) on Croco Road (gravel).

144.4 Turn left (east) on 45th Street. Areas of red soil mark patches of glacial sediments.

145.0 **STOP 11**—Ice-wedge patches in roadcut; SWSE sec. 14, T. 13 S., R. 16 E., Richland 7½-min quadrangle.

It is believed that this shallow cut exposes two sedimentary units of glacial origin. The lower one is basically a quartz sand with admixed clay and sparse erratics; the upper one is a till containing cobbles and small boulders of Sioux quartzite. Both are highly oxidized. Visible downslope to the east is a well-cemented limestone-pebble gravel with less than 1% northern erratics. Absolute-age relationships of these units are unknown.



12
13
C L I N T O N
Rock
Creek
Wakarusa
River
Twin Mounds Ch
Twin Mounds Sch
Twin Mounds Cem
Rock Creek Cem

Continue east.
145.4 Turn right (south) on Paulen Road.
146.0 Turn left (east) on 89th Street. Old gravel pit on left has been leveled for houses. Wakarusa Valley on right.
151.9 Boulder-covered hill to right front.
152.1 Turn left (north).
153.2 Turn right (east).
154.6 Turn right (south) on Douglas County road 458.
158.0 **STOP 12**—Two-till roadcut; NENW sec. 33, T. 13 S., R. 18 E., Clinton 7½-min quadrangle.

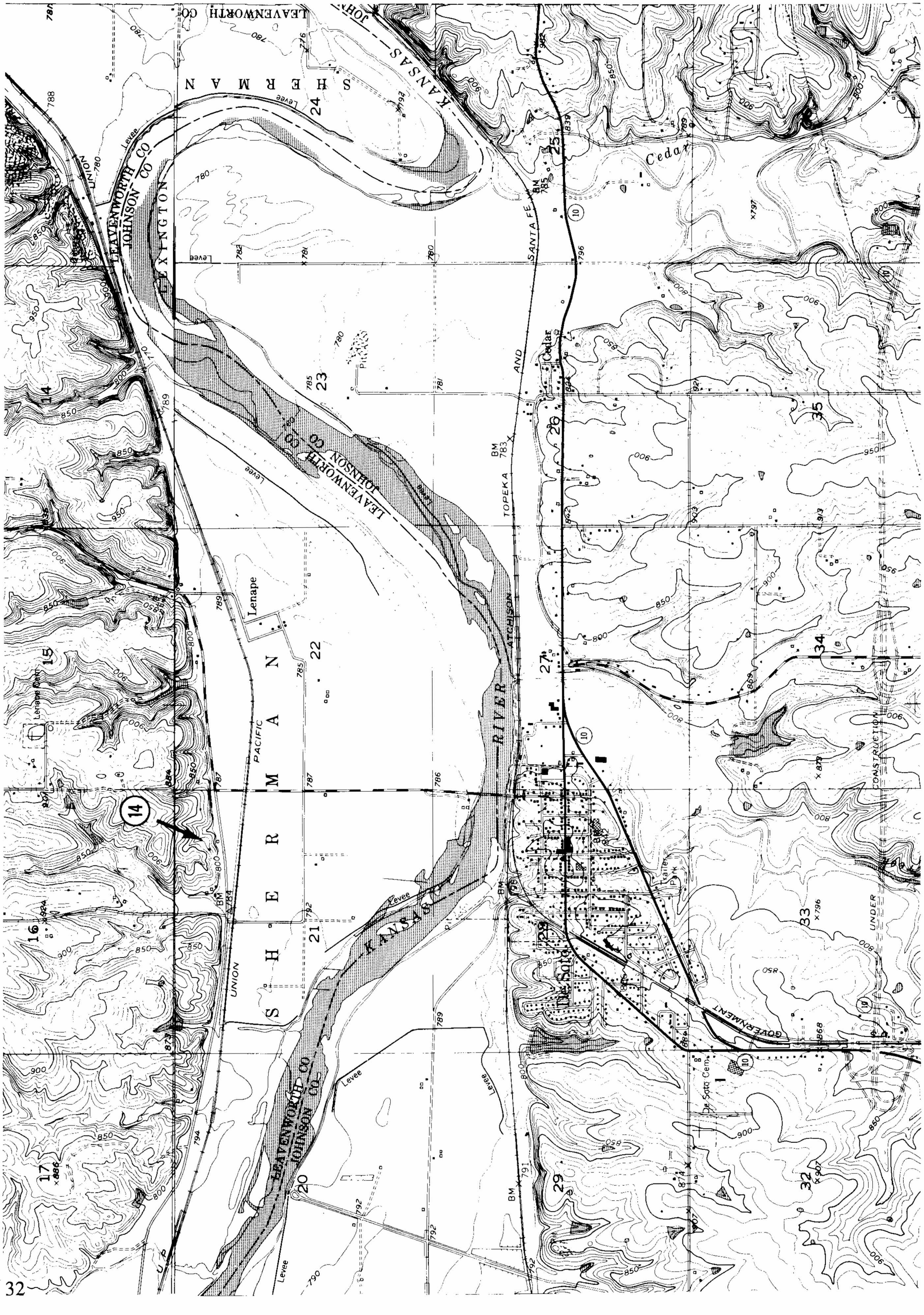
This long cut, situated very close to the glacial terminus, exposes till and glaciofluvial outwash above limestone bedrock. The presence of a paleosol between two units of glacial origin provides evidence of two advances of the ice sheet.

Continue east.
159.2 Turn right (south) on Douglas County road 1029.
159.7 **STOP 13**—Crestline till; SWSWSE sec. 34, T. 13 S., R. 18 E., Clinton 7½-min quadrangle.

Exposure of till, including Sioux quartzite erratics, at this road intersection proves that the ice front temporarily reached the crest of this divide.

Return to Douglas County road 458.
Continue east.
170.5 Turn left (north) on US-59 (Iowa Street).
175.2 Intersection of 6th and Iowa streets (return to meeting headquarters).

END OF DAY ONE.


SHERMAN
LEXINGTON
KANSAS
RIVER
LEAVENWORTH CO
JOHNSON CO
UNION PACIFIC
ATCHISON TOPEKA AND SANTA FE
Lenape
Cedar
De Soto
De Soto Cem.
GOVERNMENT
UNDER CONSTRUCTION
Levee
14

Day two (Sunday, August 17, 1986)

miles

0.0 Leave intersection of 6th and Iowa streets. Go east on 6th.
1.4 Turn north across Kansas River on US–40, –59.
3.3 Turn east on K–24.
3.4 The high-water level of the 1951 flood is marked on the concrete Tee Pee building to the right.
3.6 Rise from the floodplain/Holliday terrace complex onto the Newman terrace.
3.9 Cross the western end of an abandoned meander that cut into the edge of the Newman terrace. This channel was abandoned prior to the earliest mapping and may be 200–300 yrs old.
5.1 Cross the eastern end of the same abandoned meander.
5.6 Cross Mud Creek; it was channelized by the U.S. Army Corps of Engineers.
5.7 Turn east on K–32.
14.0 Town of Linwood.
14.6 Cross Stranger Creek.
15.4 Turn right on Leavenworth County road 26.
18.7 **STOP 14**—Volcanic-ash exposure; NENE sec. 21, T. 12 S., R. 22 E., DeSoto 7½-min quadrangle.

Stop 14—De Soto site

Significance and dating of a volcanic ash located within terrace fill north of De Soto, Kansas

by *Sharon A. Geil*, Department of Geology, University of Kansas, Lawrence, Kansas

The terraces along the lower Kansas River were mentioned in various reports during the mid-1930's and 40's, but were not named until the early 1950's (Davis, 1951; Carlson, 1952). At that time it was thought that one terrace had been formed during each of the last three of the four periods of continental glaciation of classical Pleistocene terminology. Davis and Carlson (1952) made detailed studies of those terraces between Lawrence and Topeka, Kansas. They stated that the Kansas River, as it exists today, formed during the Kansan glaciation as an ice-margin stream, though a precursor stream existed during the Nebraskan glaciation. The valley of the Kansas River was filled with up to 80 ft (24 m) of glacial outwash, forming the Menoken terrace surface. During the Illinoian glaciation, the valley was incised 50–60 ft (15–18 m) and then aggraded to 35 ft (11 m) above the modern floodplain level. The resulting surface, preserved only at the mouths of tributary streams, is known as the Buck Creek terrace. A cut-fill cycle which occurred during the Wisconsinan glaciation formed the Newman terrace. This terrace is still being aggraded by exceptionally severe floods (Holien, 1982). A fourth possible terrace, the Holliday terrace complex, was defined by McCrea (1954) and named by Dufford (1958). It is a complex of several small, scarped surfaces which Davis and Carlson (1952) included as irregularities on the modern floodplain surface.

Terraces are difficult geomorphic features to date since they technically consist of only a two-dimensional surface. The sediments within the underlying fill can usually only be assigned a relative age by using cross-cutting relationships. For example, the Buck Creek fill truncates Kansan glacial deposits and is capped by either a well-developed (Sangamon?) soil or discontinuous Peorian loess (Davis and Carlson, 1952). Thus it is assumed to be of Illinoian age.

The Buck Creek terrace generally is about 11 m (36 ft) above the floodplain. The Menoken terrace is usually 24–30 m (79–99 ft) above the floodplain, while the Newman terrace was covered during the 1951 flood. This suggests that the terrace at this locality is a remnant of the Buck Creek terrace. The upper surface is currently about 6 m (20 ft) above the level reached by the Kansas River during the 1951 flood, even though the field above this exposure has been bulldozed by the owners.

The fill beneath this particular terrace remnant contains a volcanic ash for which an absolute date can be determined. Only two families of ash have been recorded within the eastern portions of Kansas and Nebraska (Boellstorff, 1976); these are the Bishop Ash from Long Valley, California, and the Pearlette family of ashes from Yellowstone, Wyoming. The ash within this terrace fill was inferred to be from Yellowstone on the basis of color, shard shape, and the absence of biotite phenocrysts. The Bishop Ash contains abundant biotite, is chalky white, and has pumiceous shards. The Pearlette ashes are silver-gray, contain no biotite phenocrysts, and have flat bubble-wall and bubble-junction-shaped shards (Izett et al., 1970). Incredibly, the three different voluminous ash falls from the Yellowstone area have three

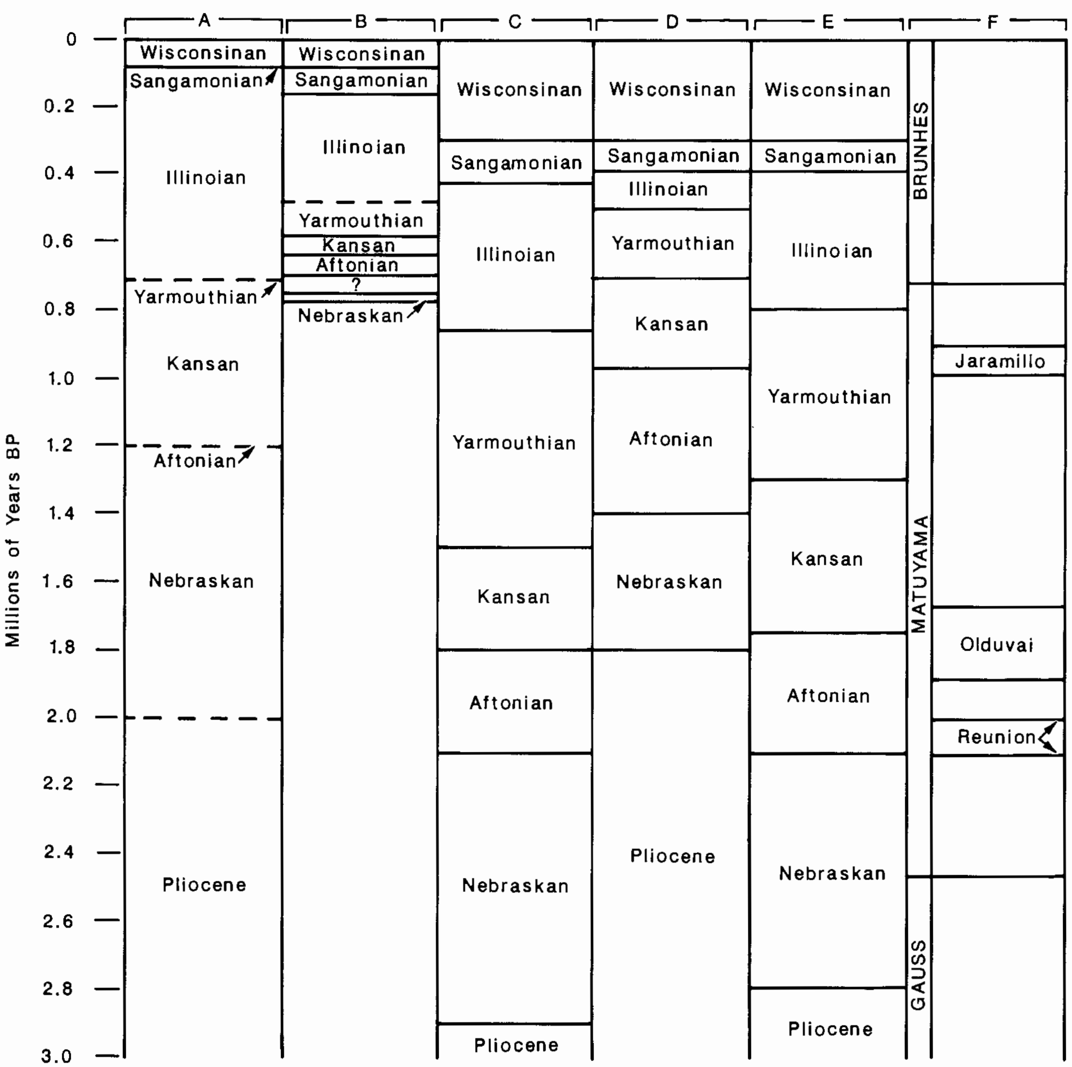


FIGURE 9—Comparison of recently published chronologies for the Pleistocene. A)—Boellstorf, 1976. Continental record, after Reed and Dreeszen (1965), based on reconciling data from Nebraska. B)—Dubé, 1985. Tentative Midcontinent record, based on best dates of type localities. C)—Dubé, 1985. Marine conceptual Midcontinent, based on correlation of paleotemperatures, eustatic cycles, and oxygen isotope stages in the Gulf of Mexico. D)—van Eysinga, 1978. Accepted as standard by the Geological Society of America. E)—Smith, 1985. Marine record, after Beard (1982), based on all available data from the Gulf of Mexico and Vrica, Italy. F)—Magnetic polarity, Mankinen and Dalrymple (1979).

different magnetic polarities (Reynolds, 1975); the Lava Creek B (Pearlette O) ash is normal, the Mesa Falls (Pearlette S) ash is reversed, and the Huckleberry Ridge (Pearlette B) ash is horizontal. Dr. Ken Kodama (personal communication, 1985) of LeHigh University determined that the magnetic polarity of this ash is normal, indicating that it is Lava Creek B ash. Mineralogically, the zircons within the Huckleberry Ridge ash are pink, while those of the Lava Creek B ash are clear. Euhedral, glass-sheathed zircons extracted from this ash are clear, thus supporting the paleomagnetic identification of Lava Creek B ash. A chemical analysis of the ash done by induction-coupled plasma atomic-absorption spectroscopy performed by Dr. P. H. Briggs at the Denver branch of the U. S. Geological Survey also is compatible with an identification of Lava Creek B ash (Dr. Glen Izett, personal communication, 1985).

I am in the process of fission-track dating the glass shards from this ash. Preliminary results using the population method of fission-track dating also are in agreement with an identity of Lava Creek B ash. Samples of ash were irradiated in the graphite section of the Georgia Institute of Technology research nuclear reactor. A fluence of approximately $5.40 \pm .25 \times 10^{14}$ n/cm^2 was determined for this run by averaging the results of glass standards from the National Bureau of Standards and Corning Glass Works. A total of 1,467 induced plus spontaneous tracks were counted for a density of 7.96×106 tracks/cm^2. The spontaneous-track density in this glass is quite low. Fifty tracks were counted to obtain a spontaneous-track density of 1.22×10^5 tracks/cm^2. These data suggest an age of $5.18 \pm .25 \times 10^5$ yrs. It is highly likely that this ash, as are most ashes in the Midcontinent, is annealed to some extent (Dr. Charles Naeser, personal communication, 1985). The accepted age for the Lava Creek B ash is 6.2×10^5 yrs (Izett and Wilcox, 1982).

The next problem is trying to fit this age within Pleistocene chronology. Depending on which time scale is chosen, the Lava Creek B ash was deposited during either the Yarmouthian or the Illinoian (fig. 9). Regardless of the choice, however, clearly the paleosol underlying the ash (figs. 10 and 11) is not of Sangamon age, as has been assumed for a well-developed paleosol found within other Buck Creek terrace fills.

FIGURE 10—Exposure of volcanic ash 2 mi (3km) north of De Soto (photo by S. Geil). The layer of white airfall ash, overlain by discolored, impure ash, is truncated to the right by a younger, filled gully. On the basis of chemical and physical properties, augmented by fission-track dating, this is the Lava Creek B ash and is 0.6 m.y. old. The land surface above this exposure has been identified as a remnant of the Buck Creek terrace.

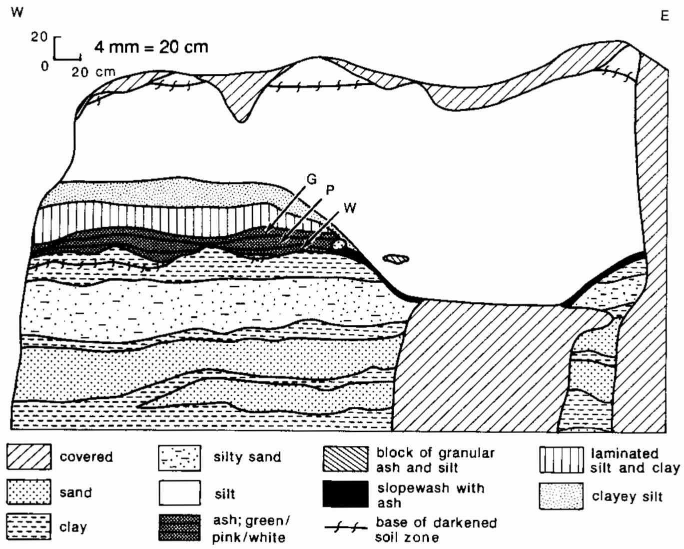


FIGURE 11--SCHEMATIC PROFILE OF VOLCANIC-ASH EXPOSURE NORTH OF DE SOTO, SWNENE SEC. 21, T. 12 S., R. 22 E., IN 1984.

An environmental reconstruction for the sediments within the terrace fill is complicated by lack of knowledge as to the proximity of a continental glacier. The lower alluvial sequence in which the paleosol is formed may have been deposited during any period of time between the late Kansan and early Illinoian. The alluvial character of these sediments is clearly shown by particle-size analysis (fig. 12). Within the paleosol, this character is somewhat damped, but still obvious. The ash is deposited directly on the eroded surface of the paleosol (where present) or on the uppermost alluvial clay unit. The contact is very sharp, but irregular. As can be seen from the particle-size graph, the white, airfall ash is coarser than the overlying salmon- and green-colored zones. Both the white ash and salmon zone consist of nearly pure glass. The green zone contains substantially more clay and is highly plastic. This material was probably derived from slopewash soon after the original ash fall. Wilcox (1965) has stated that ". . . environments favorable for preservation of a new ash mantle are those in which the normal sedimentation . . . was continuous. Among continental environments [in which] one would therefore expect to have most chance of finding ash beds . . . [are] lakes, bogs, depressions and valley bottoms." Indeed, the highly clay-enriched zone above the ash has been interpreted as lacustrine sedimentation by Ula Moody of Kilgore College in Texas (personal communication, 1985). The sediment in this zone breaks along horizontal partings and consists of silt and clay laminae of millimeter scale. Either concurrently or shortly thereafter, a channel was created running approximately parallel with the present terrace face. Occasional chunks of alluvial sediment can be seen within the lower portions of the loess fill within the channel. A fine trail of ash is visible lining both sides of the apparent channel in this cut; thus ash was being eroded out of the channel wall and was coating the bank. This is the main evidence for the direction in which the channel ran, since it is hard to imagine ash coating **both** the cut-bank and point-bar sides of a channel. A few cores taken from the upper surface substantiate the existence of an east-west channel. A thick loessal cover was then deposited over the entire area, filling the channel completely, during the Illinoian and/or Wisconsinan. A modern soil is developing within this loess.

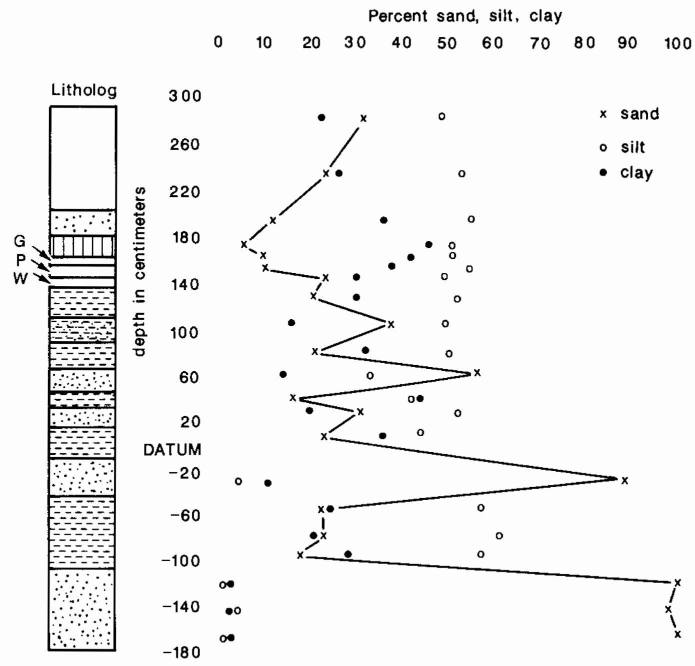


FIGURE 12—Variation of particle size with depth, De Soto ash exposure. The depths shown are representative and are not actual sample depths. Datum was chosen as the base of the profile shown in the preceding figure and the lithology uses the same symbols. Above datum, the numbers are averaged from several analyses; those below datum are from single analyses. The uppermost analysis is from the modern soil. The loess is quite variable, with clay and sand percentages each ranging from 20 to 30; this variability does not correlate with depth. Clay increases from the base of the loess to the ash. Note the sharp increase in particle size from the colored, secondary ash just above the 140-cm depth to the white, primary ash at the 140-cm depth. Below the ash, the alluvial character of the sediment is obvious, though pedogenic processes have somewhat dampened the size swings and increased the silt content of the sands above datum.

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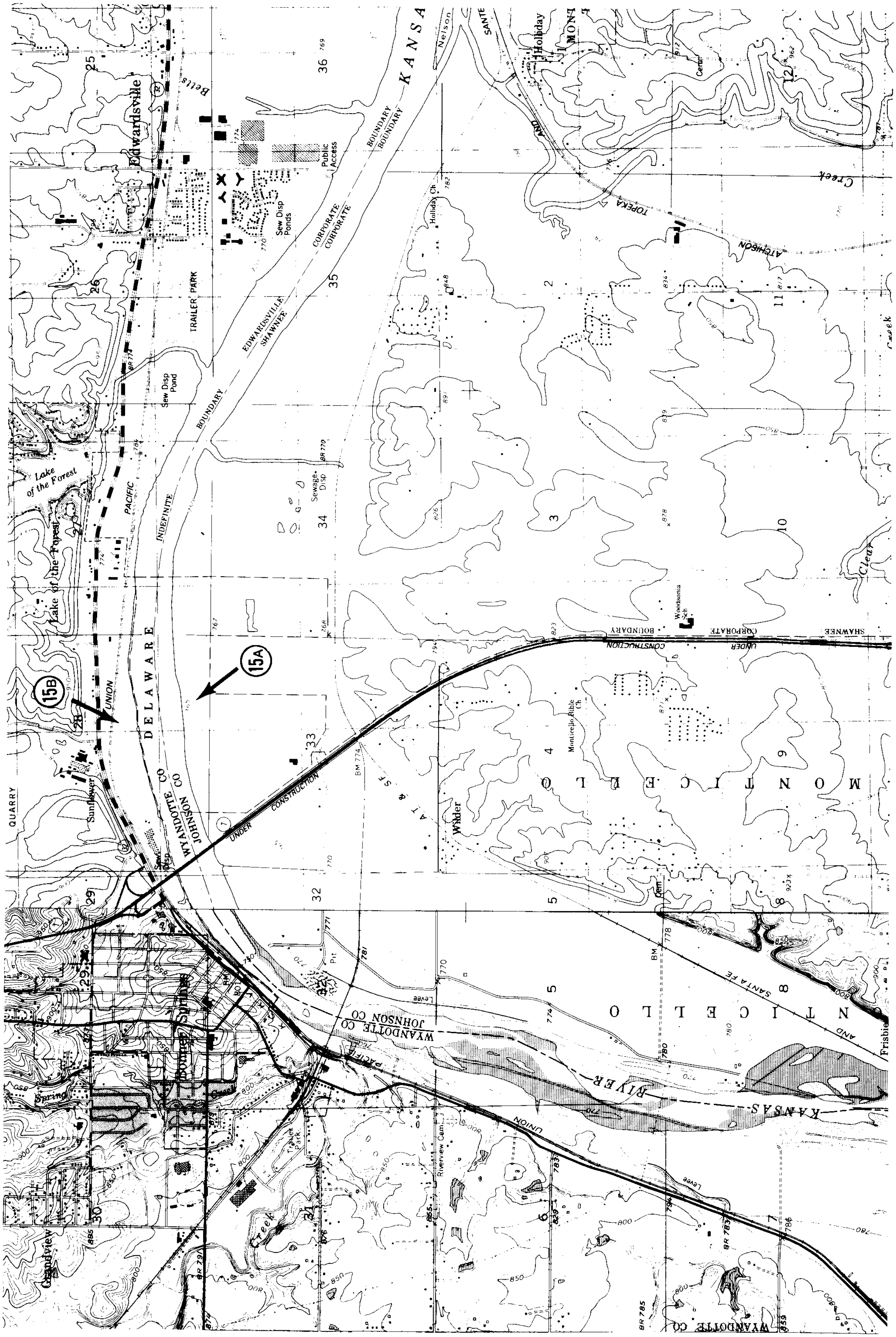


15A
15B
Edwardsville
Lake of the Forest
Sunflower
TRAILER PARK
Sew Disp Ponds
Public Access
DELAWARE
KANSAS
RIVER
WYANDOTTE CO
JOHNSON CO
EDWARDSVILLE SHAWNEE
CORPORATE BOUNDARY
INDEFINITE BOUNDARY
UNION PACIFIC
UNDER CONSTRUCTION
M O N T I C E L L O
Monticello Bible Ch.
Woodsonia Sch
Wilder
Holliday
ATCHISON TOPEKA AND SANTA FE
Riverview Cem
Trailer Park
Grandview
Frisbie
QUARRY

Continue east on Leavenworth County road 26.

19.8 The road leaves the river valley and climbs to the upland.

20.8 Turn right on Leavenworth County road 32.

22.8 Return to valley bottom. Turn right at T–junction: private road entering Loring quarries.

23.5 Gate to Southeastern Public Service Company Midcontinent Underground Storage Company, Bonner Springs Plant. Drift-shaft mining of limestone has created a system of large tunnels and chambers now used for controlled-environment storage. Return eastward.

24.3 Rejoin Leavenworth County road 32; continue east.

25.2 The two terrace levels visible here were mapped as the Buck Creek and Newman surfaces by A. E. Dufford (1958).

27.0 Cross Wolf Creek.

27.7 Town of Bonner Springs.

27.8 Join K–32; continue east.

28.2 Turn left (south) on K–7.

28.7 Cross the Kansas River.

29.4 Turn left (east) on 43rd Street.

30.0 Turn left (north) on private road to Builders Sand Company—Plant 2.

30.3 Max Brown sand pit on the right (east; fig. 13). Although now reclaimed by vegetation, the bottom of this pit (c. 13-m [43-ft] depth) when freshly excavated exposed several large logs (30–70-cm [12–28-inch] diameter) of *Quercus* sp. (white-oak group), one of which had been beaver-chewed prior to burial. A radiocarbon date of 2,395 ± 65 yrs B.P. (WIS–1030) was obtained on the outer 20 rings of a 40-cm (16-inch)-diameter specimen. Overlying sands are crossbedded and contain many clay balls and occasional modern bison bones.

FIGURE 13-A VIEW OF THE NOW-ABANDONED SAND PIT OPERATED BY MR. MAX BROWN UNTIL 1982. The pit, excavated in Holliday fill, exposed several large *Quercus* sp. (white-oak group) logs at a depth of approximately 13 m. One specimen yielded a radiocarbon date of 2,395 ± 65 yrs B.P. (WIS-1030; photo by W. C. Johnson).

30.5 Office and scale house—Builders Sand Company.

30.9 **STOP 15A**—River's edge; SWSE sec. 28, T. 11 S., R. 23 E., Edwardsville 7½-min quadrangle.

Stop 15A—Bonner Springs site

by *William C. Johnson*, University of Kansas, Lawrence, Kansas

In recent years the north (left) bank of the Kansas River immediately east of Bonner Springs and south of the Lone Star Cement Company has provided an interesting exposure of Newman terrace, Holliday terrace, and recent inset fill. This exposure in conjunction with that near Wamego (Stop 5), offers an impression of the similarities and dissimilarities existing within Newman and Holliday terrace fill as well as the varying complexity of the contact between the two. The exposure is best viewed from the opposite bank, i.e. here at the Builders Sand Company plant. Figure 14 depicts the distribution of alluvial surfaces in the Bonner Springs–Edwardsville reach.

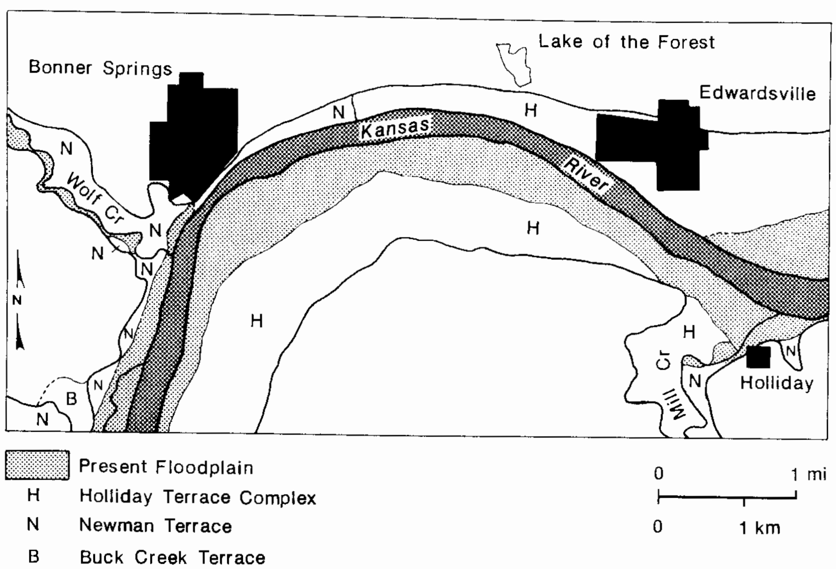


FIGURE 14—Map of alluvial surfaces in the Bonner Springs–Edwardsville vicinity. Stop 15 begins approximately 1 km (.6 mi) east of Bonner Springs (from Holien, 1982).

Return to K–7 and north across Kansas River bridge to K–32.
33.5 Turn east on K–32.
34.4 Turn right (south) on Swingster Road; bear right.
34.4 Turn left (south) onto gravel road.
34.5 **STOP 15B**—Bonner Springs exposure; NWSE sec. 28, T. 11 S., R. 23 E., Edwardsville 7½-min quadrangle.

END OF DAY TWO.

Stop 15B—Bonner Springs site

by *William C. Johnson*, University of Kansas, Lawrence, Kansas

CUT-BANK EXPOSURE—Paleosols are a major stratigraphic feature within the exposure (figs. 15, 16, and 17) and display temporal and spatial patterns throughout the east-central Plains (see Johnson and Martin, this volume). Within the Newman fill the well-developed, lowermost paleosol produced an early Holocene date of 10,430 ± 130 yrs B.P. (Beta–2931) from a humate sample taken 60 m (198 ft) west of the modern gully and 8.8 m (29 ft) below the surface. Logs from the water wells drilled immediately north of the exposure indicate that more than 15 m (50 ft) of alluvial sediments underlie this paleosol. A weakly developed soil approximately 2 m (7 ft) higher in the fill produced a radiocarbon date of 8,940 ± 90 yrs B.P. (DIC–3210) on humates as well. The lowermost paleosol in Holliday fill was sampled for radiocarbon dating 110 m (363 ft) east of the modern gully and 5.2 m (17 ft) below the

FIGURE 15—STRATIGRAPHY OF NEWMAN FILL. The lower dark zone in the foreground (arrow) is a well developed paleosol, radiocarbon dated at 10,430 ± 130 yrs B.P. (BETA–2931). Alternating silt and clay strata indicative of overbank flood events are visible approximately 4 m above the paleosol. Exposed sediments in the middle ground consist of Holliday fill overlain by recent flood and tributary deposits. One of the major fossil-producing gravel bars (Davis Bar) is partially submerged in the distance (photo by W. Dort, Jr.).

FIGURE 16—THE CONTACT BETWEEN NEWMAN FILL (LEFT) AND THE INSET HOLLIDAY FILL (RIGHT). The paleosol visible in the Holliday fill has been radiocarbon dated at a location approximately 100 m downstream (left) at 1,210 ± 50 yrs B.P. (DIC–3209; photo by W. Dort, Jr.).

surface, producing an assay of 4,290 ± 310 yrs B.P. (Beta–2159) on humates. The paleosol above the latter dated at 1,210 ± 50 yrs B.P. (DIC–3209), again from humates. Discharge from the Bonner Springs waste-treatment plant, completed within the last year, has expanded the modern gully dramatically, exposing the alternating silt and clay layers comprising the recent fill. The outer five rings of a *Salix* sp. (willow) log exposed at a depth of approximately 6 m (20 ft) within the gully (fig. 18) were radiocarbon dated at 110 ± 40 yrs B.P. (DIC–3255), verifying the relative youth of the cut and fill. This sediment is most likely derived from the Mission Creek drainage, the channel of which was diverted eastward along the north valley wall when the railroad and highway were constructed.

The major stratigraphic units exposed above low-flow stage within the Newman and Holliday fills were analyzed for their particle-size distribution via the hydrometer method. Both fills are dominated by the silt fraction (fig. 19). Those clays present occur primarily as medium-fine clays, i.e. coarse clays are the smaller fraction. Although silt-size material comprises the bulk of the fills, Newman fill contains more clay than the siltier, sandier Holliday fill. A similar relationship was noted at the Wamego exposure (Bowman, 1985).

An x-ray diffraction (xrd) analysis of the various fine-sediment fractions within the two fills produced interpretable differences in the whole-clay fraction (<2u). Clays of both fills are dominated by kaolinite and illite, with lesser amounts of mixed-layer (10–18Å) types (fig. 20). The diffraction patterns shown differ from the <5u fraction, which contains somewhat more of the mixed-layer species of clay. The similarity in clay composition between the fills is explained by the small time difference between the two, precluding significant alteration in the suite of clays via weathering. The source area is essentially the same. XRD patterns of the whole-clay fraction from the two fills exposed near Wamego (fig. 6) were similar to one another but different from this exposure: the clays are dominated by mixed-layer minerals, rather than kaolinite and illite. At this time the mineralogic differences in the whole-clay fraction between the fills here and at Wamego can not be resolved because the bedrock is too interbedded (limestone and shale) to initiate the differences observed. Further, the Pierre shales of the headwaters do not correlate with the fills near Wamego: the former is dominated by illite and the latter by montmorillonite.

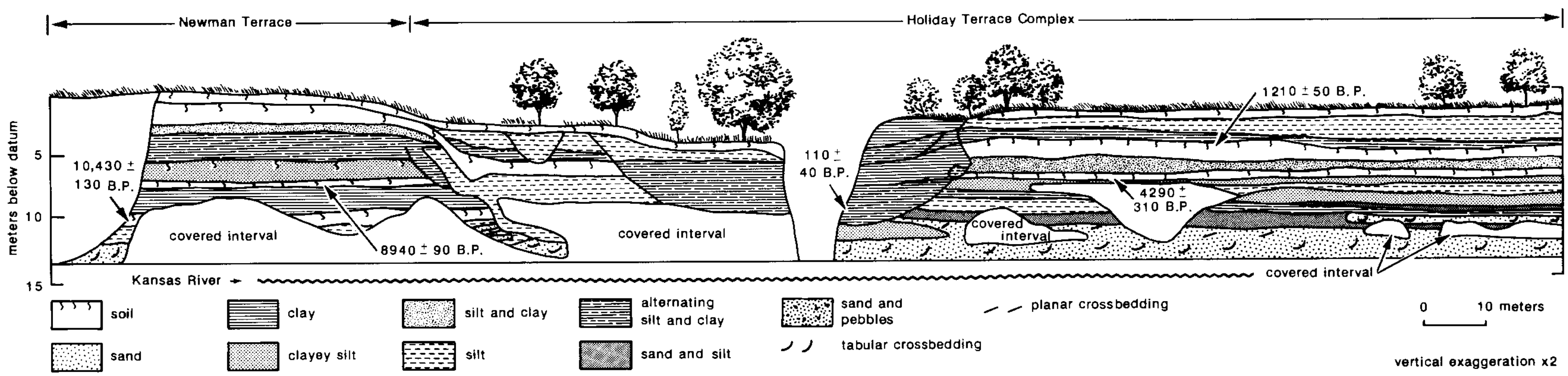


FIGURE 17—ALLUVIAL STRATIGRAPHY OF THE BONNER SPRINGS EXPOSURE. This left (north) bank exposure consists of three major units: Newman, Holliday, and intervening recent fill (modified from Holien, 1982).

FIGURE 18--RECENT (HISTORICAL) FILL EXPOSED IN A GULLY ONCE OCCUPIED BY MISSION CREEK AND NOW BY EFFLUENT FROM THE BONNER SPRINGS WASTE-WATER-TREATMENT PLANT. The 60-cm-diameter *Salix* sp. (willow) log (arrow) exposed has been radiocarbon dated at 110 ± 40 yrs B.P. (DIC-3255; photo by W. C. Johnson).

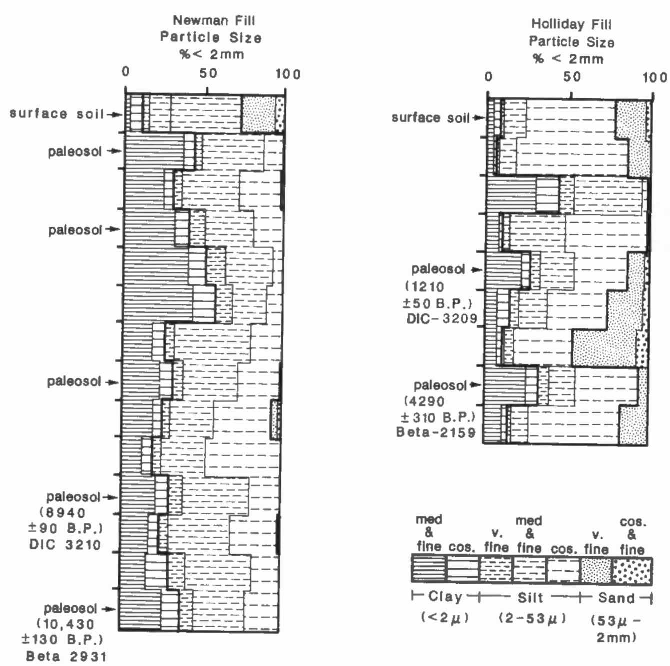
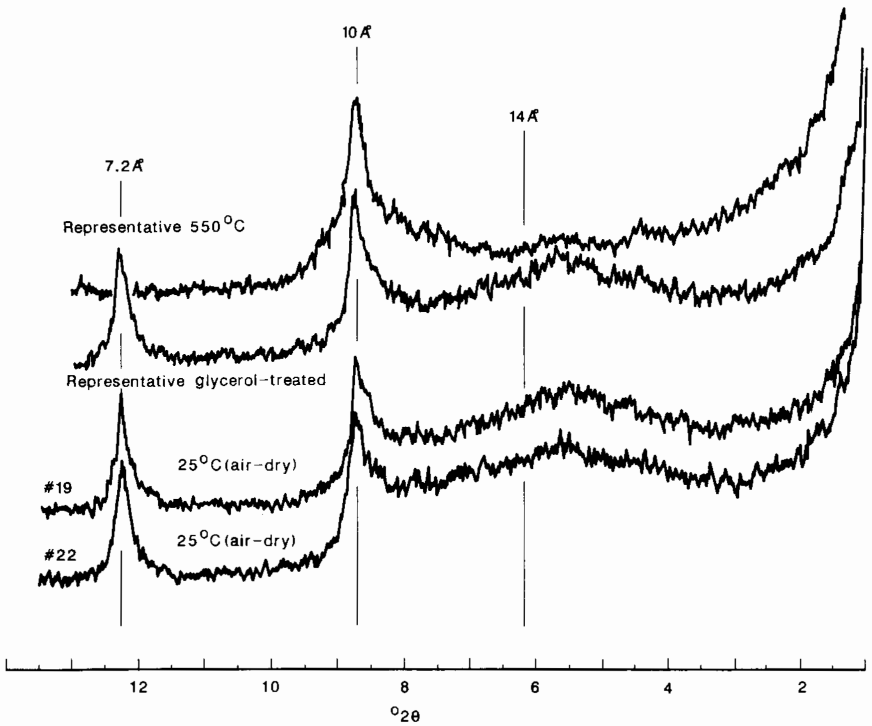


FIGURE 19—PARTICLE-SIZE DISTRIBUTION OF NEWMAN AND HOLLIDAY FILLS EXPOSED AT BONNER SPRINGS.



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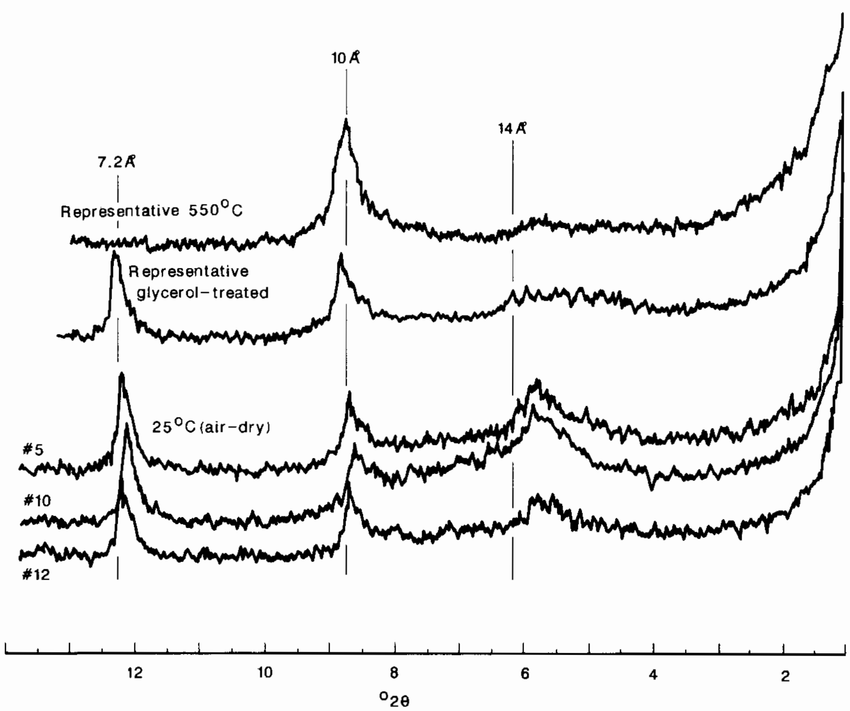

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FIGURE 20—X-RAY DIFFRACTION PATTERNS OF THE WHOLE CLAY FRACTION (<2u) FROM THE BONNER SPRINGS RIVERBANK EXPOSURE. Clays are dominated by illite and kaolinite, with lesser amounts of mixed-layer clays (10–18 Å). Compare with data from Stop 5 (fig. 6). A, Holliday fill; B, Newman fill.

The bottomland south of the exposure and river channel is composed entirely of modern floodplain and Holliday terrace. A scarp which varies from having a sharp to rather subtle relief separates the two surfaces. At the edge of the Holliday terrace is the abandoned Max Brown sand pit (mile 30.3). This date of 2,395 ± 65 yrs B.P. (WIS–1030) obtained on *Quercus* sp. stem material is consistent with the two dates obtained from Holliday fill in the exposure along the north (left) bank. However, note that the paleosol(s) present in the Holliday fill exposed on the opposite bank are not present in the Max Brown pit profile.

GRAVEL BARS—The composition of the gravel comprising the bars, from a sample of 3,600 clasts, is 61% limestone, 30% chert, 4% quartz, and 3% igneous and metamorphic rocks. The remaining lithologies represented are mudstone, sandstone, carbonate concretions, K-feldspar, Sioux quartzite, and black shale. Sources include locally exposed formations, the Ogallala Formation of west-central Kansas, and glacial deposits.

Little of the material eroded by the ancestral Kansas River before Kansan time is believed to be present in the Kansas River valley today. No alluvial deposits of this age are recognized in the area and material eroded during this initial stage of development of the Kansas River has been effectively "flushed out" of the system. Deposits of Kansan age represent a significant development in the Kansas River system. Parts of the Kansas River valley were eroded to their maximum depth during this time. Large quantities of glacial meltwater not only eroded deeply into the local bedrock, thereby incorporating it into the alluvium, but also reworked glacial till and outwash, incorporating them into the alluvial deposits. Runoff of glacial meltwater undoubtedly transported high-level chert gravel into the fluvial system. Due to a breach in the Flint Hills drainage divide by glacial meltwater, sediments derived from the Ogallala Formation were introduced into the lower Kansas River valley.

Coarse-grained material consisting of cobbles and boulders accumulated at the base of the alluvium as large volumes of water eroded the bottom of the bedrock valley and had the capacity to transport coarse gravel. As the discharge became less, the coarse-grained material was deposited and concentrated in the lower portion of the alluvial fill, some of it being sorted by the meltwater. Tributary streams deepened their valleys, eroding into local bedrock and transporting coarse gravel to the Kansas River. These streams drained the upland areas and high-level chert gravel and glacial deposits were eroded and eventually incorporated into the Kansas River alluvium.

After the retreat of the Kansan glacier, the Kansas River became the only mechanism of sufficient force to erode, transport, and rework gravel stratified within its alluvium. Discharge of the Kansas River is not believed to have been greatly increased in Illinoian time, but another period of degradation and increased fluvial activity is proposed for Wisconsinan time when more coarse gravel was probably introduced from the surrounding area into the river valley. The gravel within the channel became increasingly concentrated as a lag deposit while fine-grained material previously associated with it was in large part flushed from the system.

As the Kansas River migrated across its valley, previously deposited alluvium was eroded and introduced into the river channel. Coarse gravel present within the alluvium and often found in a stratified bed became concentrated as a lag deposit on the bottom of the active channel. High-flow events further acted to sort this coarse-grained material which is eventually buried due to channel migration and alluviation. The coarser-grained material is continually being reworked to a lower position in the valley alluvium during periods of degradation of the Kansas River. Thus the gravel on the channel bars is exposed for only a brief time before it is buried within the river alluvium, possibly to be exposed again at some later time because of ongoing stream activity.

Gravel bars in the Kansas River in the vicinity of the Bonner Springs site are producing a rich fauna of Pleistocene and Holocene mammals (fig. 21). Although very little has been found in situ, the Kansas River localities still provide our best information concerning the late Pleistocene and early Holocene fauna of eastern Kansas. Martin and others (1979) provided a review of the paleontological data from the Kansas River, although many significant specimens have been found since. Examples of three specimens from the Bonner Springs reach are shown in fig. 22. Presently, radiocarbon assays are pending on a *Cervalces* (stagmoose) antler and a human femur. All bones of apparent late Pleistocene and early Holocene age are notably permineralized. A remarkably complete sequence of projectile points, also from these gravel bars, contributes new information concerning the distribution of types of projectile points in Kansas (see Rogers and Brown and Logan, both this volume).

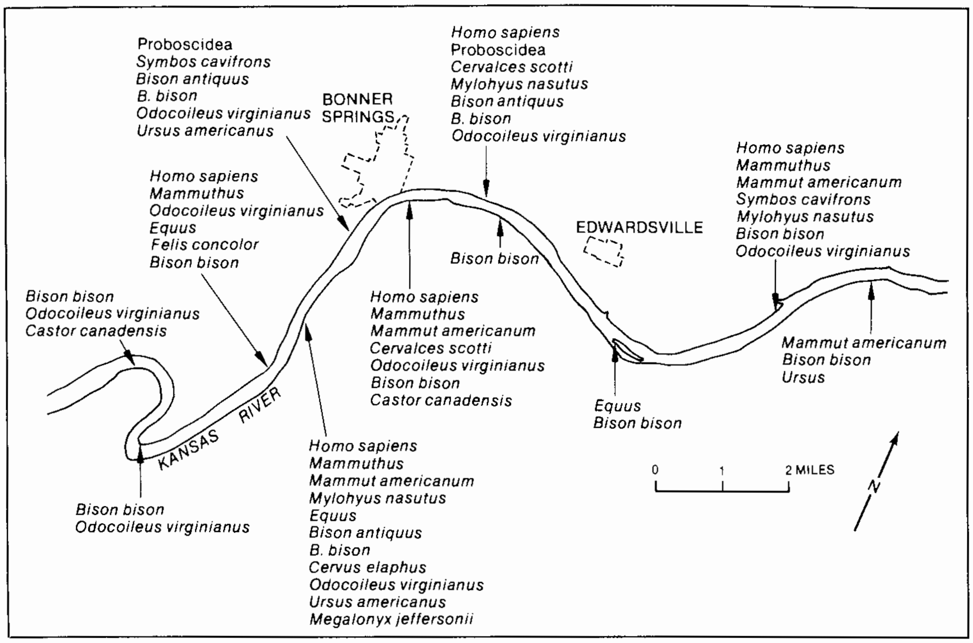

FIGURE 21—LOCATION AND SPECIES LISTS FROM BONE-PRODUCING GRAVEL BARS ON THE LOWER KANSAS RIVER (amended from Rogers, 1984).

The oldest of the projectile points, and according to some (e.g., Haynes, 1971) the oldest clearly recognizable stone artifact type in North America, is the Clovis projectile point. Two of these points were found near Bonner Springs. Although they are generally found associated with kills of *Mammuthus* (mammoth) in the western United States, they have been found associated with mastodon in Missouri (Graham et al., 1981). Mammoths are a rare component of the late Pleistocene fauna near Bonner Springs, while mastodon (*Mammut americanum*) remains are comparatively common. The rest of the late Pleistocene fauna, e.g., *Mammut,* is characteristic of the *Symbos–Cervalces* faunal province of Martin and Neuner (1978) and is the fauna associated with Pleistocene spruce forests in the eastern United States (see Martin and Hoffmann, this volume). Other late Pleistocene mammals from the vicinity of Bonner Springs include *Symbos cavifrons* (woodland musk ox), *Cervalces* (stagmoose), and *Mylohyus* sp. (extinct peccary) among others (table 1). This fauna indicates the environment the Clovis hunters were occupying in eastern Kansas was typical of the *Symbos–Cervalces* faunal province. This faunal province disappeared from Kansas and many of its component mammals became extinct about 10,000 yrs B.P. The spruce woodland began to disappear about 12,000 yrs B.P.; eventually the prairie-deciduous forest ecotone that presently characterizes eastern Kansas developed (see Fredlund and Jaumann, this volume).

Bison is the most common early Holocene faunal taxon. This contrasts with the rarity of late Pleistocene bison in these deposits: it is represented only by two skulls, one from near Kansas City and another at the Bonner Springs site. An abundance of bison skulls intermediate in size, between typical *Bison antiquus* and the modern *B. bison* correlates well with an abundance of early Holocene lithic types found near DeSoto and Bonner Springs. Many of these lithic types are usually associated with bison hunters in western Nebraska and Wyoming. Research on Woodland and Archaic sites in the eastern Kansas region has not produced either an abundance of bison remains or bison-kill sites. It appears from the collections that early Holocene bison are more common than are late Holocene bison. This relationship may provide evidence that prairie expansion in this region began during the early Holocene especially given that most alluvial fill is late Holocene in age. The late Pleistocene–Holocene size reduction of bison is well documented (Schultz and Frankforter, 1946; Schultz and Martin, 1970). The range in size of bison bones found on gravel bars near Bonner Springs suggests that a nearly continuous sequence is present, and the discovery of in situ specimens should make a local biostratigraphy possible. Fig. 23 illustrates the presumed sequence of bison skulls.

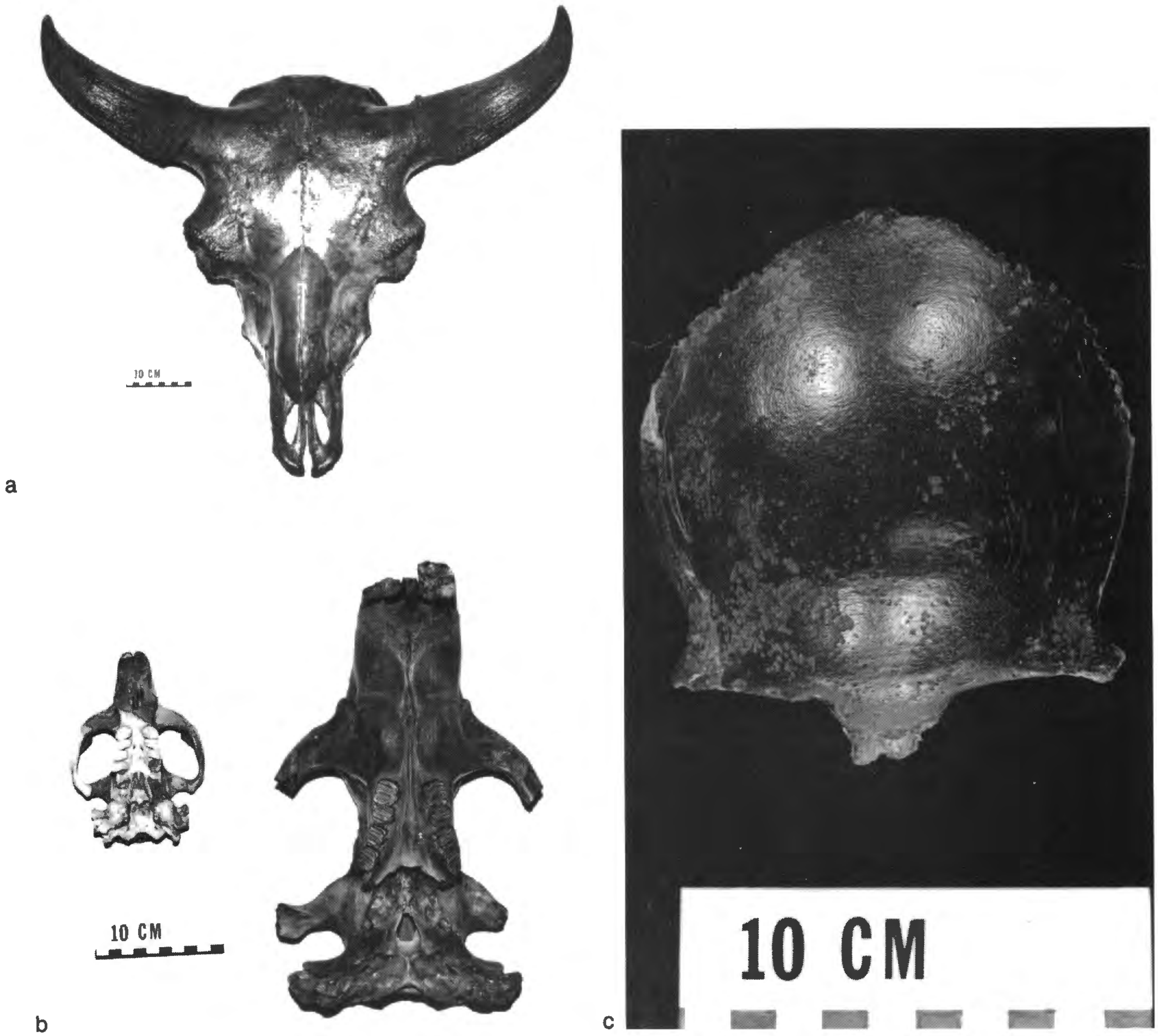

FIGURE 22--THREE EXAMPLES OF FOSSIL SPECIMENS COLLECTED FROM CHANNEL-BAR MATERIAL IN THE VICINITY OF THE BONNER SPRINGS EXPOSURE: a) skull of extinct late Pleistocene-early Holocene bison, *Bison*, cf. *B. antiquus* (University of Kansas Museum of Natural History Vertebrate Paleontology [KUVP] collection 54005). b) skull of extinct giant beaver *Castoroides kansensis* (KUVP 59401); skull of modern beaver *Castor canadensis* is presented for comparative purposes (left). c) skull cap from *Homo sapiens* (KUVP 54001). Photos by J. Chorn.

Many of the bones are found in a well-preserved state and have delicate features still intact, indicating transport only a very short distance, and, consequently, a nearby source. Two bison skulls, *B. bison* and *B. antiquus,* collected by C. Holien on a bar immediately upstream from Bonner Springs, as well as those collected by others, have been recovered filled with sediment consisting of fines and numerous pebbles and cobbles wedged between bones of the inner skull.

The paleoindian period is represented by a number of projectile points. A Clovis projectile point (Rogers and Martin, 1982) was found by R. Smith, U.S. Army Corps of Engineers, on the north bank in this reach (fig. 24A). This artifact, like the other artifacts found on the gravel bars of the Kansas River, had almost certainly been transported by the river and was not recovered in situ. The gray flint from which the artifact was made is probably local in origin as it contains Paleozoic fossils typical of cherts in eastern Kansas. A second Clovis projectile point (fig. 24B) was found by F. Richardson of DeSoto on a gravel bar in the Kansas River upstream of that town. The specimen is the proximal end of the projectile point. The shape and size of the specimen are quite unlike the dimensions of Meserve or Dalton projectile points found in the area.

TABLE 1—SPECIES AND COMMON-NAME EQUIVALENTS OF FAUNA REPRESENTED BY BONES FOUND AT LOCALITIES ON THE LOWER KANSAS RIVER (SEE FIG. 21).

Bison antiquus	late Wisconsinan or early Holocene bison
Bison bison	modern bison
Castoroides kansensis	giant beaver
Castor canadensis	beaver
Cervus elaphus	wapiti
Cervalces scotti	stagmoose
Equus	horse
Felis concolor	mountain lion
Homo sapiens	man
Mammut americanum	American mastodon
Mammuthus	mammoth
Megalonyx jeffersonii	groundsloth
Mylohus nasutus	woodland peccary
Odocoileus virginianus	white-tailed deer
PROBOSCIDEA	elephant
Symbos cavifrons	woodland musk ox
Ursus	bear
Ursus americanus	black bear

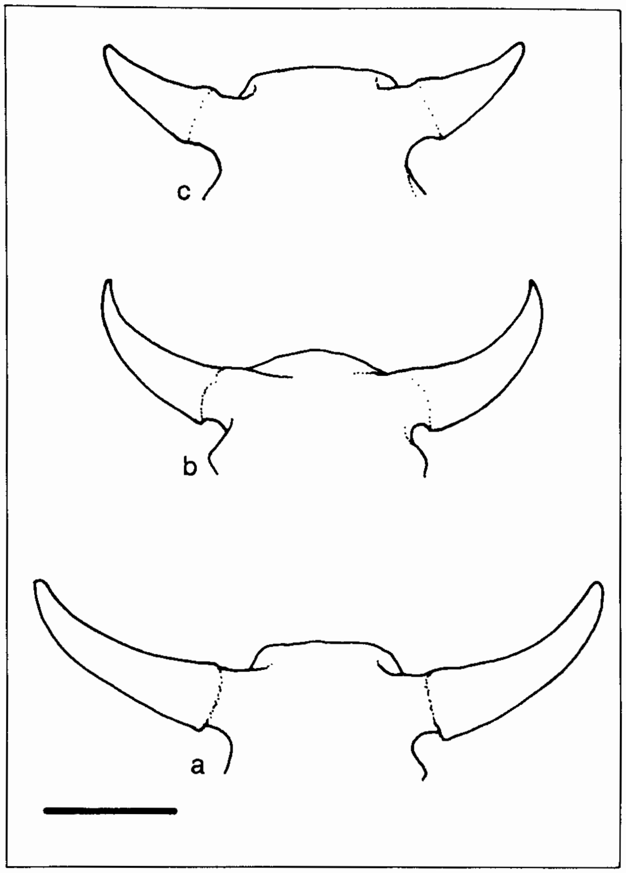

FIGURE 23—SEQUENCE OF *BISON* SKULL-HORN COMPLEXES FROM THE LOWER KANSAS RIVER. a) Pleistocene *Bison* sp., cf. *B. antiquus,* KUVP 9905. b) early Holocene *B. bison* (large variety), KUVP 65707. c) late Holocene *B. bison,* KUVP 54010. Scale bar is 25 cm (from Rogers and Martin, 1983; reprinted from Transactions of the Nebraska Academy of Sciences with permission).

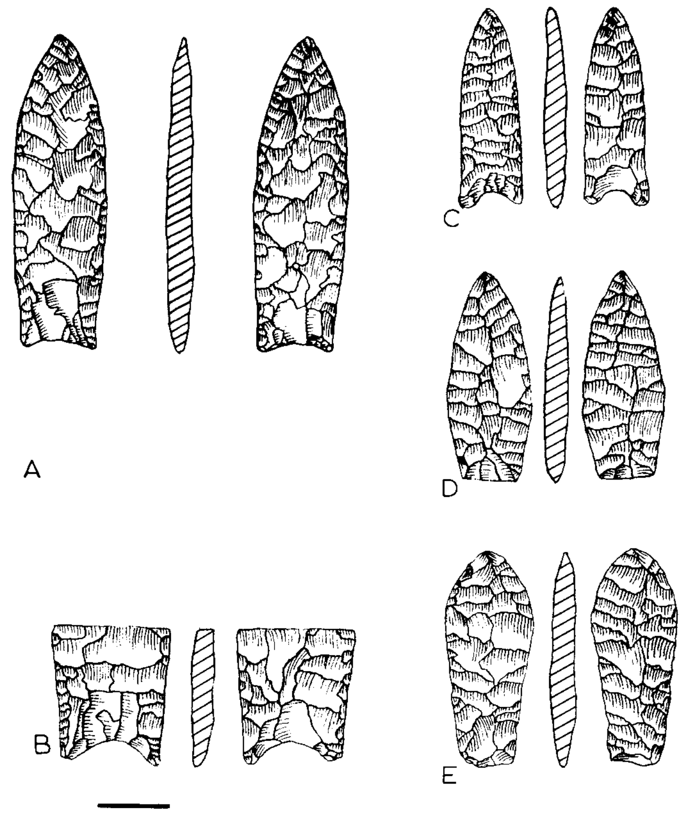

FIGURE 24—PROJECTILE POINTS RECOVERED FROM GRAVEL BARS IN THE LOWER KANSAS RIVER CHANNEL. A) Clovis projectile point found by R. Smith on the north bank immediately above Bonner Springs. B) second Clovis projectile point found by F. Richardson on the south bank immediately upstream of De Soto. C) Meserve or Dalton projectile point typical of several found on lower Kansas River. D) Milnesand projectile point found by F. Richardson at same locality as points b and e. E) Hell Gap projectile point recovered by F. Richardson at same locality as points b and d. Scale bar is 2 cm (from Rogers and Martin, 1982 [A, Kansas Academy of Science], 1983 [B–E, Nebraska Academy of Science]).

A Hell Gap projectile point (fig. 24E) was recovered by Richardson on the same gravel bar on which he found the Clovis projectile point. Radiocarbon dates on the Hell Gap cultural complex in Wyoming were 9,600 ± 230 yrs B.P. and 9,650 ± 250 yrs B.P. at the Sister's Hill site and 9,830 ± 350 yrs B.P. and 10,060 ± 170 yrs B.P. at the Casper site (Frison, 1978, p. 23). A Milnesand projectile point (fig. 24D) was found by Richardson on the same gravel bar as the Hell Gap and Clovis projectile points. The artifact exhibits transverse parallel flaking, and the removal of thinning flakes has given the base a beveled appearance that is typical of Milnesand projectile points (Sellards, 1955, p. 343). Although the Milnesand "type site" is located in Texas, Wormington (1957, p. 112) indicated that Milnesand projectile points have been found in Iowa. The Lime Creek site in southwestern Nebraska (Schultz and Frankforter, 1948) has yielded a projectile-point type that is probably Milnesand (Wormington, 1957, p. 120) in the same stratigraphic zone as a Scottsbluff projectile point. The Milnesand projectile-point type was present at the Olsen–Chubbuck site in eastern Colorado (Wheat, 1967) and was also in association with the Scottsbluff projectile-point type. The Olsen–Chubbuck site has a radiocarbon date on bone collagen of 8,200 ± 500 yrs B.C. (Wheat, 1972).

Several specimens of Meserve or Dalton projectile points (e.g., fig. 24C) were found by Richardson on gravel bars of the Kansas River, including the Bonner Springs area. Meserve or Dalton projectile points were first found in situ at the Meserve site (Barbour and Schultz, 1932) near Grand Island, Nebraska, in association with extinct bison. Very similar projectile points were later found in situ in Missouri where they were named Dalton projectile points.

CONTEMPORARY CHANGES IN THE LOWER KANSAS RIVER—In contrast to the rapid lateral cutting of the Kansas River in the vicinity of Wamego (Stop 5), unusual channel degradation has been occurring for the last 30 yrs in the lower reaches of the river. The reason(s) for the degradation in this reach is still

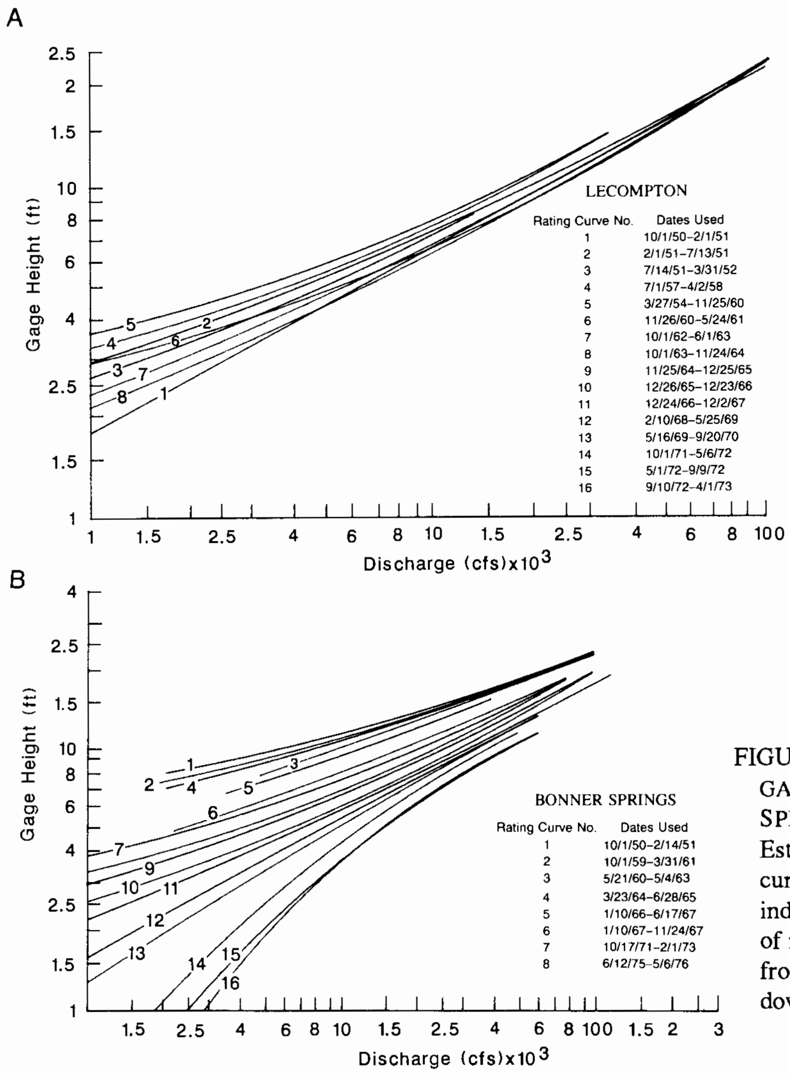

FIGURE 25--DISCHARGE-RATING CURVES FOR TWO GAGING STATIONS, LECOMPTON AND BONNER SPRINGS, ON THE LOWER KANSAS RIVER. A) Established between 1950 and 1976, family of rating curves for Lecompton station shows little variation, indicating a relatively stable cross section. B) Family of rating curves computed for Bonner Springs station from 1950 to 1973 (and since) indicates progressive downcutting at the section (from Holien, 1982).

uncertain, but evidence that it exists has been documented by several different means. Rating curves from a gaging station at Bonner Springs first drew attention to the problem, especially when no such trend was evident at upstream stations such as that at Lecompton (fig. 25). More than half of this degradation occurred between 1952 and 1966, but has continued to present. The same trend is apparent in subsequent water-surface profiles. Comparison of consecutive surveyed channel cross sections at Bonner Springs (fig. 26) demonstrates the lowering of water surfaces recorded at that station. A clay body producing in situ *Alnus* sp. (alder) stumps, one of which was dated at 5,030 ± 90 yrs B.P. (Beta-2160), found exposed in the channel bed near Bonner Springs at low water suggests the river is degrading its channel and is presently eroding into alluvium of at least mid-Holocene age.

The Army Corps of Engineers has contended that the downcutting (and widening) of the river may be due to commercial dredging activity, which is very common on the lower Kansas. Such operations were suggested to be removing more sand and gravel than was being replenished. Simons, Li, and Associates (1984), in a study of the lower Kansas River, indicate that sand and gravel dredging seems to be the major cause of channel degradation and bank erosion. Others have refuted this cause, citing the closure of major reservoirs on the river which would reduce the sediment load, thereby resulting in unfulfilled transport capacity. Other factors such as tectonics and land-use change may have a role as well.

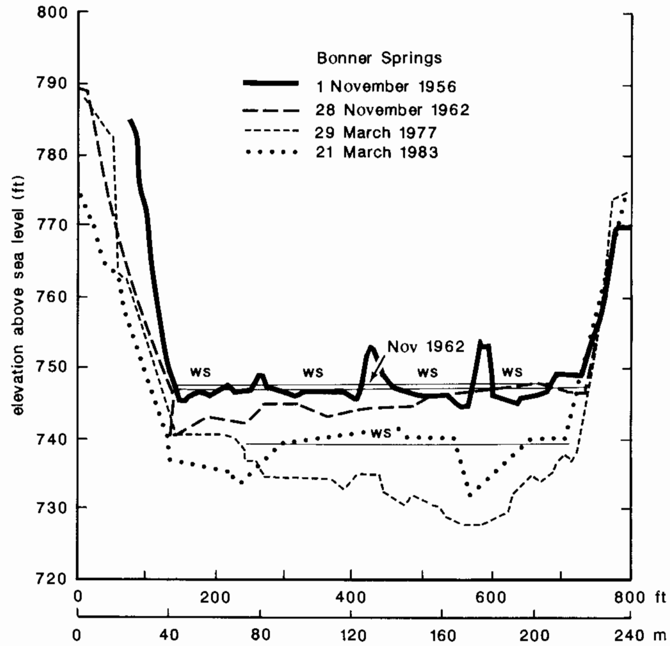

FIGURE 26--COMPARISON OF SUCCESSIVE CROSS SECTION SURVEYS AT THE BONNER SPRINGS SECTION CONDUCTED IN 1956, 1962, 1977, AND 1983. The progressive increase in depth, also reflected in the temporal pattern evident in the rating curves, relates to both gravel-bar preservation and recent downcutting into mid-Holocene or older deposits (data from U.S. Army Corps of Engineers, 1983).

Because of degradation, the water surface has been lowered more than 2 m (7 ft) in the Bonner Springs area in recent years, resulting in a decreased frequency of flow over the gravel bars. Consequently, the bars have become increasingly stable.

(The preceding has been abstracted, in part, from Rogers and Martin, 1983, and Holien, 1982).

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Contributed Papers

Salient aspects of the terminal zone of continental glaciation in Kansas

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Abstract

Extent of glaciation in Kansas and location of the ice-sheet terminus is best determined by mapping the distribution of Sioux quartzite erratics. Even the presence of less than 1% quartzite in a basal chert-limestone gravel is evidence of a temporal and spatial relationship with a glacier. From Wamego to Topeka, the terminus can be located within very narrow limits. Not as clearly defined is the amount of post-glacial erosion that has or has not been accomplished. Ridge-top concentrations of quartzite boulders may be paleovalley lag concentrates preserved by topographic reversal or, conversely, primary concentrations marking the bottoms of major crevasses. Till units of contrasting lithologies, as well as till units separated by a paleosol, provide evidence of at least two advances to the terminal zone. At maximum advance, glacier ice blocked the Kansas River, impounding a lake that extended more than 100 km (60 mi) upstream. Flow over a spillway at 1,165 ft (350 m) above sea level proceeded to Topeka through several small ice-front lakes.

In North America, glacial theory and history understandably developed mainly where the records of past glaciations are most clear. This was in those states bordering the Great Lakes. There the deposits and land forms are youngest, hence best exposed, least modified, and so easiest to understand. This region, extended to included Iowa, has been the cradle of American Pleistocene history and reconstruction. Only the older ice sheets advanced into northern Missouri, northeastern Kansas, and southern Nebraska. Their deposits are thin and scattered and few, if any, actual glacial land forms remain.

The history of glacial geology in Kansas was well summarized by Aber in 1984. It will suffice to say here that early field observations by Hay, Smyth, and Todd demonstrated that continental ice had indeed reached northeasternmost Kansas. They recognized effects the presence of the ice sheets had on local drainageways and they delineated the general limits of ice advance, information that was somewhat modified by Schoewe in the 1920's and 1930's.

The presence of John C. Frye as Director of the Kansas Geological Survey from 1943 to 1954 led to studies of many aspects of Pleistocene geology and publication of results by students, professors, and Survey staff. The 230 pages of Bulletin 99, *Pleistocene geology of Kansas* by Frye and Leonard, provided an outstanding compilation of knowledge available in 1952. However, a paucity of detailed maps, sections, and other explanatory diagrams has been a source of constant frustration to later researchers and markedly reduced the usefulness of many of these publications.

Although most of their research efforts have been directed toward other geographical areas, Dort, Sorenson, Johnson, and Martin, and their students, have recently modified and expanded details of knowledge about the Pleistocene history of Kansas. Notable impetus has been provided by establishment of a palynological research laboratory at the University of Kansas with support from the General Research Fund and by preparations for the 1986 Friends of the Pleistocene field trip. Presented here is a brief summary of salient aspects of their observations and working hypotheses.

Initial concepts

A general framework of Pleistocene history was compiled almost a century ago when it was proposed that four major advances and retreats of the continental ice sheets had occurred in both Europe and North America. Only the first two of these advances were believed to have reached Kansas, one (named the Nebraskan) barely entering the northeasternmost corner, the other (named the Kansan) extending as much as 80 km (48 mi) farther south and southwest (fig. 1).

This purported sequence made it very easy to identify till bodies or determine ages of associated sediments. In the far northeastern part of the state, the upper of two tills had to be, by definition, of Kansan age, the lower one, Nebraskan. Deposits of nonglacial origin could, by their position relative to one or both of those tills, be identified as of pre-Nebraskan, Aftonian, or Yarmouthian age. Furthermore, an apparently positive time line could be recognized in many localities where there were exposures of what was thought to be a single regional airfall, the Pearlette volcanic ash. This was assigned a late Kansan age on the basis of indirect stratigraphic correlations. Another time line seemed to be provided by the post-Illinoian Sangamon soil, supposedly the only red pedogenic unit in the Pleistocene section. Unfortunately, all aspects of this simple stratigraphy have been shown to be erroneous.

Evidence of glaciation

In Kansas, as elsewhere in the world, the former presence of glacier ice is indicated by deposits of unstratified sediment composed of a heterogeneous mixture of grain sizes and shapes—a till. Some of the included fragments bear scratches or striations and the whole deposit may rest on a smoothed and striated bedrock surface.

Although most of the fragments in a till body usually are of rock types that crop out nearby, some will have been derived from distant sources. The presence of these far-traveled erratics helps distinguish a glacial till from colluvium formed by downslope movement of rock debris from nearby outcrops.

In Kansas, pebbles and even small cobbles of granitic rock could conceivably have been carried by streams flowing eastward from the Rocky Mountains in late Tertiary time and deposited to form the Pliocene Ogallala Formation. Their presence in a sediment does not, therefore, constitute unequivocal proof of a glacial origin. On the other hand, certain lithologies are known to crop out only to the north, and glacial transport to Kansas is believed certain. Chief among these is the Sioux quartzite. Its outcrops are restricted to a small area in southwestern Minnesota and nearby parts of Iowa and South Dakota (fig. 2). Its distinctive pink to lavender color makes even tiny pieces of this rock readily identifiable, so it is an excellent indicator rock. Any sediment containing Sioux quartzite either is of direct glacial origin or was derived by reworking of a primary glacial deposit.

In addition, it is believed that fragments of metamorphosed volcanics, or greenstone, which are moderately common in northeastern Kansas, were derived from the Canadian Shield. Also present, though much less common, are pieces of hematitic iron ore, probably from the Iron Ranges of Minnesota, and Lake Superior agates from the Keewenawan volcanics of Minnesota, Wisconsin, and Michigan.

The presence of these "foreign" rock types in sediments not only constitutes almost incontestable evidence of a glacial origin for the original host deposit, but also provides indication of the direction of ice flow. Although movement may not have had straight-line directness from outcrop source to the locus of final deposition, there could not have been much deviation. Even if one admits the possibility that some clasts were picked up by an early ice-sheet advance, carried only part way to Kansas, deposited, then incorporated into a later glacier, movement from outcrops of Sioux quartzite must have been at least almost direct. The presence of the glacier terminus nearby to the west would seem to preclude any sizable detours (fig. 2).

Published here for the first time is a map by J. S. Aber showing locations of striated surfaces and ice-push structures which provide indication of the direction of glacier

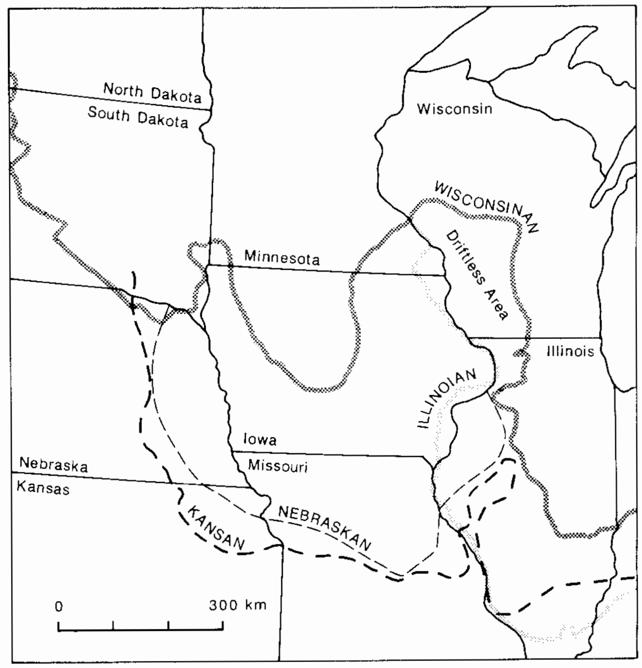

FIGURE 1—KNOWN OR INFERRED TERMINI OF THE FOUR CLASSICAL GLACIATIONS IN CENTRAL UNITED STATES (modified from Flint, 1971). Note the position of Kansas at the southwestern limit of pre-Illinoian ice sheets.

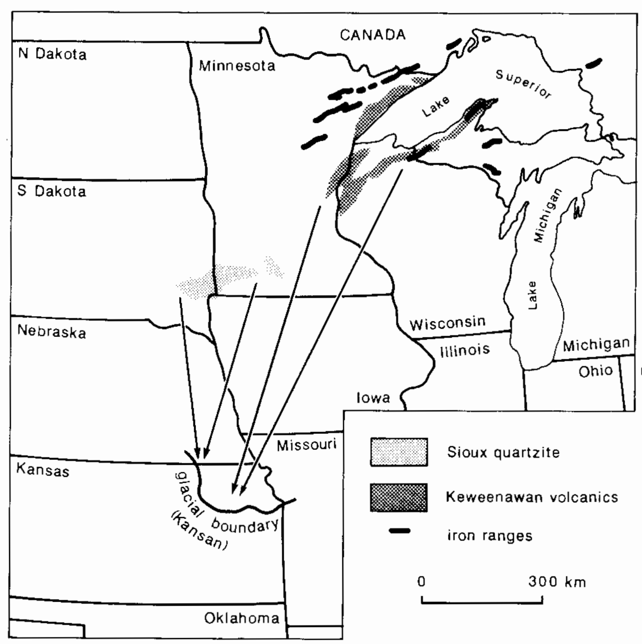

FIGURE 2—SOURCES OF IDENTIFIABLE GLACIAL ERRATICS FOUND IN NORTHEASTERN KANSAS. Fragments of Sioux quartzite are common throughout the terminal zone; specimens of ore from the Iron Ranges are scarce. Distribution of Lake Superior agates from the Keweenawan volcanics is highly localized.

flow (fig. 3). Correlation of a specific indicator with a specific advance of the ice sheets, or with an advancing or retreating hemicycle, may be difficult or impossible. Orientation of indicator travel paths produced during marked lobation of the ice front may deviate considerably from the regional direction of flow.

The presence of pebbles of Sioux quartzite and other erratic fragments is especially important for interpretation of scattered occurrences of a basal gravel. Most of the clasts are composed of chert or limestone. Indeed, the quartzite comprises much less than 1%. Nevertheless, it is believed that these pebbles could have been carried from outcrops in Minnesota only by glacier ice and their presence is taken as positive proof that this gravel was deposited in association with or after an episode of continental glaciation.

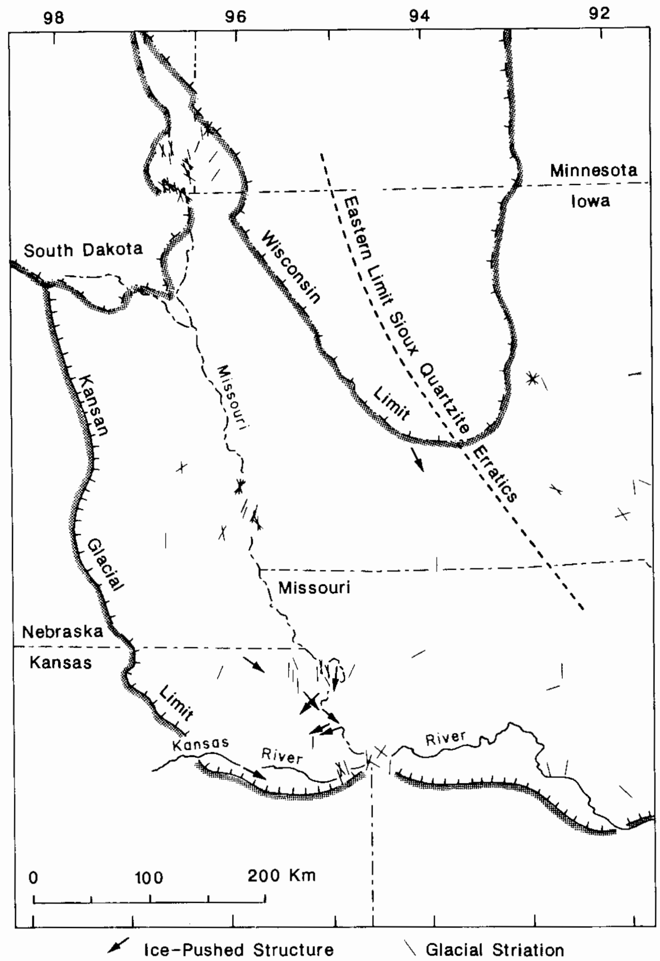

FIGURE 3—MAP SHOWING DIRECTIONAL FEATURES FOR KANSAN AND OTHER PRE-ILLINOIAN GLACIATIONS OF THE LOWER MISSOURI BASIN REGION. Directional features are, for the most part, not stratigraphically controlled and could relate to any of several pre-Illinoian ice advances. In Kansas, northeasterly ice movement is associated with the lower Kansas till, and northwesterly ice advance is related to the upper Kansas till. Primary data sources include Chamberlin (1886), Todd (1899), Barbour (1900), Norton (1911), Schoewe (1941), Flint (1955), Lammerson and Dellwig (1957), Dellwig and Baldwin (1965), and Aber (1985), plus other published and unpublished sources. Eastern limit of Sioux quartzite erratics from Willard (1980); glacial limits adapted from Flint et al. (1959). Compiled and drafted by J. S. Aber in 1986.

Location of terminus

As a consequence of the relatively great antiquity of the glaciation of Kansas, no land forms of direct glacial origin have been recognized. Delineation of the limits of glacier advance must, therefore, be based on the extent of sediments of unequivocal glacial origin—those deposited directly by the ice rather than by streams or in lakes adjacent to the ice. In effect, this is accomplished by finding, in the field, the farthest south distribution of till or of fragments of Sioux quartzite which, on the basis of size or topographic location, are believed to have been left by the ice sheet itself without subsequent redistribution by meltwater or floating icebergs, or post-glacial movement by gravity or streams (figs. 4 and 5).

Meltwater streams are capable of transporting only pebble- or perhaps cobble-size masses of frozen till. Somewhat larger bulks can be floated on icebergs, but not enough to form later an extensive deposit. Exposure of unsorted, unstratified till can therefore be accepted as proof of the former presence of glacier ice at a specific locality. In addition, erratic boulders situated on hill tops or ridge crests or anywhere else clearly above limits of proglacial water flowage or impoundments and unaffected by post-glacial downslope movement also demonstrate where ice was present. These relationships have been very successfully used in the field to locate the glacier terminus.

Along most of the 100-km (60-mi)-long terminal line between Wamego and Topeka, it is believed that the ice-front position can be fixed within a zone at most a few hundred meters wide. In some places the apparent boundary can be placed within less than 100 m (330 ft; fig. 6). This line can be followed across the existing landscape, generally with no apparent topographic control.

Postglacial erosion

Behind the terminus there is not a continuous sheet of till. Only scattered patches are present, leading Schoewe to coin the descriptive term "attenuated drift border." Thicknesses vary markedly over short distances. In most places bedrock underlies loessal soil with no till whatever. Locally there are only erratic boulders on a nearly bare bedrock surface.

Details of the distribution of till and erratic boulders, especially where found on hill tops and ridge crests, have

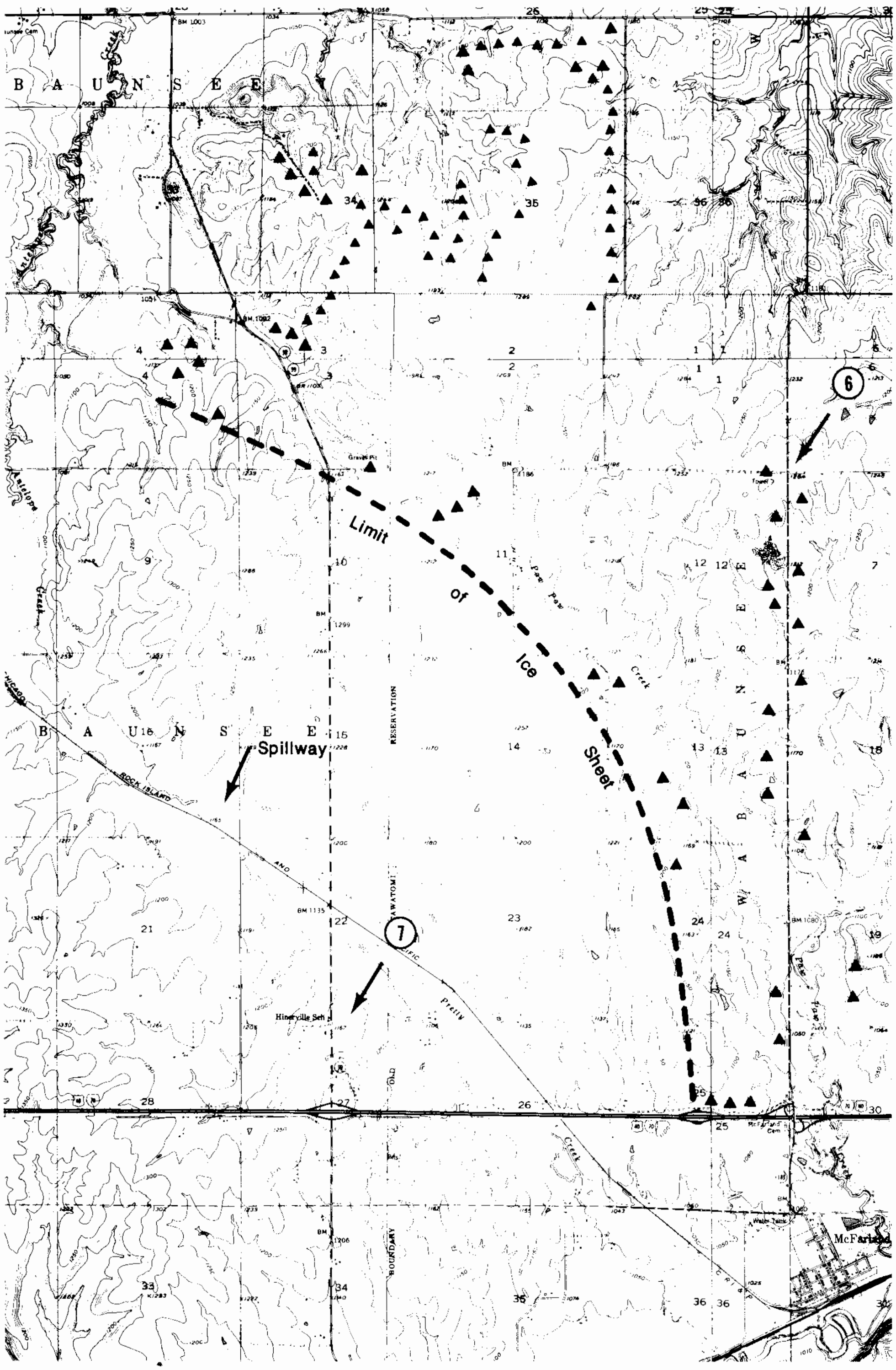

FIGURE 4—GENERALIZED DISTRIBUTION OF SIOUX QUARTZITE ERRATICS (TRIANGLES) AND LOCATION OF THE ICE MARGIN. Wamego is 3 mi (4.8 km) north of the top of this map. The spillway controlled outflow from Kaw lake and stabilized water level at an elevation of 1,165 ft (355 m).

elicited considerable speculation regarding relationships between present topography and that across which the ice sheets advanced. How much general erosion, or even local dissection, has occurred in postglacial time?

A reasonable first assumption is that because the glaciation of Kansas took place at least several hundred thousand years ago, postglacial processes must have been able to modify the glaciated landscape to a considerable degree—whatever that phrase might mean. Indeed, the very patchiness of till has been attributed to just this purportedly extensive removal, and the patches have been spoken of as "remnants." The localized accumulations of Sioux quartzite boulders resting on bedrock have been interpreted as lag deposits, the last, resistant remains of once-thick till.

This debate is especially germane to a locality south of Wamego where a short, narrow ridge rises precipitously about 35 m (116 ft) above flanking creek valleys. The flat crest of this ridge is covered by a sea of thousands of small boulders of Sioux quartzite (fig. 7). Exposures on the sideslopes show, however, that this accumulation is a veneer, at most only a few boulders thick, resting on limestone bedrock. Similar ridge-top accumulations of numerous quartzite boulders occur in perhaps half a dozen localities in the marginal zone of the glaciated area of Kansas.

One possible explanation of localized ridge-top felsenmeer would be based on topographic reversal. The hypothetical sequence would begin with deposition of thick, boulder-bearing till on the preglacial landscape. Postglacial drainage would create narrow, steep-sided gullies in this cover. As erosion proceeded, finer constituents of the till would be differentially removed, resulting in a lag concentration of the larger clasts in the gullies. Wherever the original till was especially rich in boulders, the valleys would become choked with them. Subsequently, the quartzite boulder fill would be more resistant to continuing erosion than the flanking limestone bedrock and whatever till cover remained. The boulder-filled gullies would remain essentially unaffected while the limestone hills would be worn away and, eventually, a reversal of topography would result. The former valley floor would then stand high as a boulder-capped ridge.

This is a very enticing hypothesis, but some problems remain. Chief among these is an explanation of why modern valley floors, no matter of what size or location relative to the ridge-top felsenmeer, show few, if any, quartzite boulders. It might be expected that in most areas, where quartzite boulders were not sufficiently numerous to form a protective cap on the bedrock, the few boulders present would be moved downslope by gravity and streamflow and collect in the modern valleys. Such concentrations are rarely found. At sites where the valley floor consists of bare bedrock, it clearly is not possible to suggest that these boulders are indeed present but covered by younger alluvium. Even the boulder beds encountered by wells bored beneath the floodplain of the Kansas River cannot reasonably account for all of the proposed lag concentration.

An alternative explanation would begin with a subglacial topography essentially the same as that now present. As the frontal zone of the ice sheet began to thin during the recessive phase, major crevasses could be expected to open above submerged ridges. A few of these might be favorably located so as to receive large numbers of quartzite boulders being carried on or within the ice. Concentrations of boulders would thus accumulate on the crests of a few pre-

FIGURE 5—Sioux quartzite boulder 2 mi (3 km) northwest of Dover. Although it is located within the limits of a proglacial lake, its association with till suggests that is was emplaced directly by the glacier rather than rafted on an iceberg.

existing bedrock ridges, remaining there as the flanking ice melted away. One of the problems associated with this hypothesis is the need to explain why the felsenmeer are composed almost entirely of quartzite boulders whereas the glacier was undoubtedly carrying other lithologies as well, as is shown by occurrences of boulders of granite, gabbro, greenstone, basalt, and limestone in other topographic situations.

Questions associated with the distribution of Sioux quartzite boulders also arise for an area southeast of Wamego. Boulders of a wide range of sizes are scattered thickly over several rounded hill tops that stand as much as 100 m (330 ft) above the Kansas River (fig. 4). On some of the summits, these boulders are seen to rest directly on limestone bedrock. Are these a residue, the last remnants of till that was originally deposited there? Or are they the only materials that were left by the ice? This is not typical of deposits in areas of younger continental glaciation such as Illinois or Wisconsin. On the other hand, many areas of late Pleistocene or Holocene deglaciation (northern Canada, Norway, Antarctica come to mind) are characterized by widespread exposures of bedrock on which are scattered only small, thin patches of till, or just boulders alone.

Another basis on which the amount of postglacial erosion might be estimated is the relationship between the apparent terminal and existing topography. Does the glacial limit seem to follow a generally straight line for considerable distances, crossing valleys, hillside slopes, and ridge crests without deviation, or is it diverted, blurred, or interrupted by these land forms?

To answer this question with confidence would require mapping in much greater detail than has yet been accomplished. However, the present impression is that the terminal line is, in general, not affected by details of the topography. Admittedly, there are clear suggestions of a broadly lobate front that advanced into some large lowland areas while being restrained at intervening promontories. But at a smaller scale the line, as defined by the southernmost quartzite boulders in each local area, crosses valleys or ridge crests and is oriented diagonally along slopes with no clear deviation. If this pattern is indeed present, then the preglacial topography must be largely preserved in the present landscape. Major postglacial erosion would have displaced or even obliterated much of the linear record.

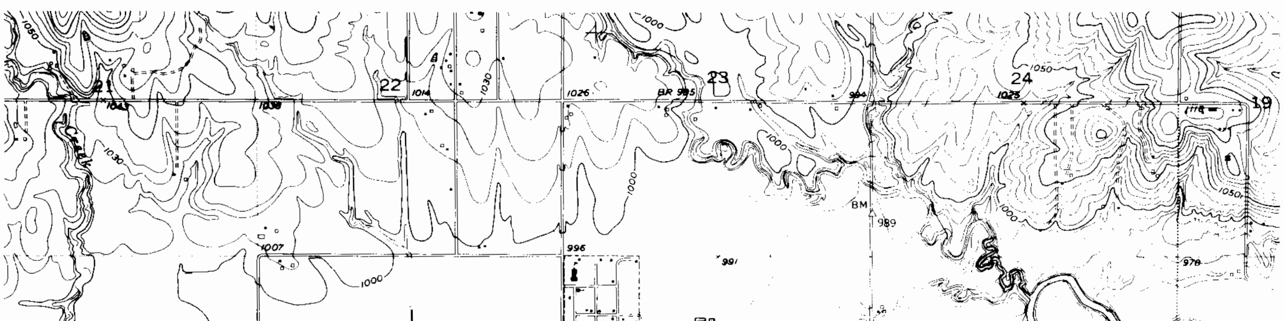

FIGURE 6—LIMIT OF GLACIATION SOUTH OF MILL CREEK VALLEY. Distribution of till and Sioux quartzite erratics (triangles) closely fixes the glacier terminus. The steep-sided ridge on which the glacial debris rests is composed largely of limestone bedrock and is not a true moraine.

Number of glaciations

From the earliest investigations it became accepted dogma that continental ice sheets reached Kansas only twice and that these advances were the first two of four that occurred during the Pleistocene Epoch. It also was believed that nonglacial sediments of late Kansan age could be positively identified by the presence of a layer of the Pearlette volcanic ash. Those concepts have been effectively destroyed by discoveries made during the past 25–30 yrs.

Concurrent studies in northeastern Kansas and southeastern Nebraska found stratigraphic evidence of more than two glacial advances. By the middle 1960's, the Nebraska Geological Survey had formally recognized two Nebraskan tills and two Kansan tills, designations that were at once accepted by the Kansas Geological Survey, even though there were problems of regional correlation (fig. 8, table 1). At the same time, exploration in northeasternmost Kansas found an exposure that contained units indicating five episodes of glaciation separated by deposition of interglacial sediments and formation of paleosols. Discoveries soon followed of similarly complex records of multiple pre-Illinoian glaciations in Iowa, then in Illinois.

The assumed simplicity of fluctuations in early Pleistocene climate is now known to be wrong. However, it is at present impossible to state how many major glaciations actually occurred or how many lesser advances and retreats marked each of those.

It has been established that glacier ice reached the terminal zone in Kansas more than once. Some of the indications are unclear and subject to interpretation, but other evidence seems to be incontestable. At more than a dozen localities spread from west of Topeka to east of Lawrence, exposures of two till units have been found. In each instance these are set apart by a paleosol developed either in the upper part of the lower till or in nonglacial sediments overlying the lower till. Unfortunately, each of these sites has only a thin sedimentary section above bedrock. Therefore, estimating the duration or importance of the interglacial soil-forming interval is difficult, but it may have been relatively short, perhaps only a few thousand years. Whether all of these exposures are of sediments and paleosols of the same age, marking one interglacial interval, or whether the record is more complex also is not yet known.

Less certain is the meaning of exposures of what appear to be two till units without any intervening nonglacial sediments or paleosols. These units can be separated on the basis of differing texture, color, and lithology. Most outstanding are occurrences of red, oxidized till with a clay-rich matrix and a high content of erratic clasts, both quartzite and granitic varieties, overlying a tan, unoxidized till with a sandy matrix and almost no erratics. It is currently believed that these units are of distinctly different ages and represent separate advances of the ice, but this interpretation cannot yet be strongly supported with quantitative data.

Especially noteworthy is the presence of a few clasts of erratic lithology, notably Sioux quartzite, in chert or chert-

FIGURE 7—Sea of erratics on the edge of a ridge east of highway K–99, 5 mi (8 km) south of Wamego. More than 99% of these clasts, displaying a remarkably small range in size, are of Sioux quartzite; the remainder are of assorted igneous lithologies. The flat-topped deposit is at most only a few feet thick on top of limestone bedrock.

limestone pebble gravel that locally underlies the lowest till and also occurs where no till is present. The gravel might be outwash from the glacier that subsequently left the overlying till, as has been proposed frequently in the literature, but there are suggestions that it is considerably older. More puzzling is the presence of a small hill of erratic-bearing gravel and, apparently, till approximately 7 mi (11 km) beyond the supposed terminus of glaciation as indicated by the Sioux quartzite boulder limit.

Age of glaciation

Once it has been shown that more than two identifiable till units occur in northeastern Kansas, a problem in nomenclature arises. Are the additional units assignable to the Kansan glaciation, to the Nebraskan, or to glaciation "X"? The Nebraska Geological Survey solved this quandry by identifying and naming a medial Kansan Cedar Bluffs Till, an early Kansan Nickerson Till, a late Nebraskan Iowa Point Till, and an early Nebraskan Elk Creek Till (table 1). However, distinguishing criteria and age assignments were not based on clear stratigraphic and sedimentologic data. Reliable correlation into Kansas is impossible and will remain so until additional field mapping, augmented by detailed quantitative studies, has been accomplished. Integration of data from deep-sea cores with the terrestrial observations will have considerable influence on development and acceptance of a new classification. It is, however, certain that there must at the very least be a temporal redefining of the names Nebraskan, Aftonian, and Kansan, and the use of stratigraphic names such as Sappa, Grand Island, and Holdredge seems to be unjustifiable in Kansas.

Effects on drainage

Drainage of the northern quarter of Kansas is accomplished mainly by the eastward-flowing Kansas River. Several major tributaries join this trunk stream from the north; those entering from the south are of smaller size. As an ice sheet advanced into Kansas, it progressively covered more and more of the drainage basins of the southward-flowing streams, ultimately obliterating them. The course of the Kansas River from near Junction City to Kansas City closely approximates the southern limit of glaciation. For this reason, it is believed that the Kansas River may have originated as an ice-marginal stream. However, the actual terminal line of ice advance lies several miles south of the Kansas River valley along most of this reach. This means that not only were all northward-flowing tributaries of the Kansas River blocked by the ice front, but almost all of the mainstem valley also was covered by ice. Inevitably, impoundment occurred and a series of ice-front lakes formed.

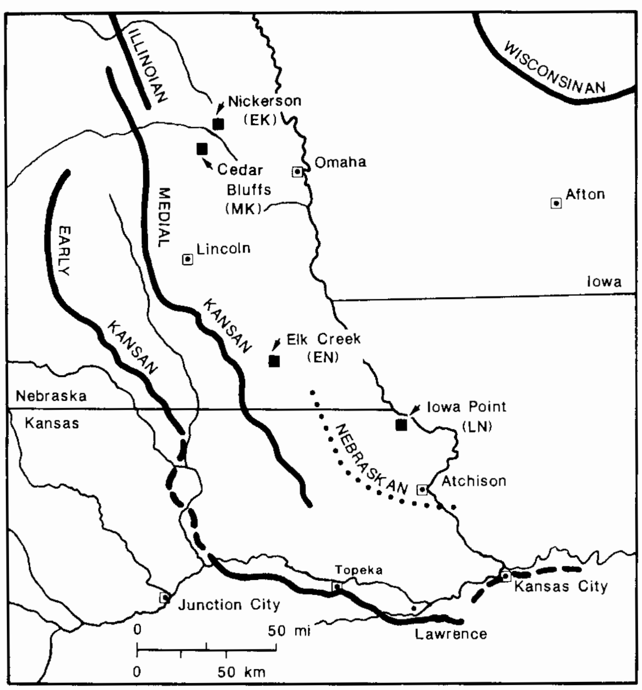

FIGURE 8—LIMITS OF PURPORTED STADIAL ADVANCES OF CONTINENTAL ICE SHEETS (modified from Reed and Dreeszen, 1965). Termini in Nebraska and northernmost Kansas are from Reed and Dreeszen; those farther south are from the geologic map of Kansas and 1986 field mapping by Dort. Locations of designated type sections are shown for Early Nebraskan (EN), Late Nebraskan (LN), Early Kansan (EK), and Medial Kansan (MK).

Till can be observed in exposures only a few feet above the present floodplain of the Kansas River. It also has been encountered in drill holes. Therefore, it can be stated that the Kansas River valley was present prior to one or more advances of the glacier. The occurrence of tills of contrasting lithologies near the present valley floor suggests that the valley was present before at least two glaciations.

If the Kansas River valley as it exists now is at least a fair approximation of the valley that was over-run by the ice sheets, then the shape of the existing valley should approximate the shape of the lake impounded in that valley upstream from the ice limit. The vertical position of the shoreline would have been controlled by some overflow point.

The position of the ice front, as indicated by the distribution of Sioux quartzite erratics, was a short distance south and west of Wamego. Inspection of existing topography outside this limit quickly led to identification of a col that would have permitted water to spill around the blockade. Elevation of the floor of this broad pass is shown on topographic maps as being 1,165 ft (355 m) above sea level. Tracing the 1,165-ft contour then provides the shoreline of the impounded lake, named Kaw Lake by Todd (figs. 9 and 10).

Greatest uncertainty is present where this elevation crosses the floors of major valleys. Postglacial history has undoubtedly included multiple episodes of incision and aggradation, so the location where the 1,165-ft contour now crosses a floodplain probably deviates somewhat from the actual head of any specific arm of the proglacial lake. However, the proposal that bayheads, and consequent delta formation, were indeed present at these general locations is strengthened by Soil Conservation Service recognition there of unusual clay-rich soils that seem to be of possible lacustrine origin.

The floor of the spillway at 1,165 ft (355 m) south of Wamego was not deeply entrenched because the valley of Mill Creek directly east was occupied by a lake having a surface elevation only slightly lower. Indeed, there may have been a drop of as little as 5 m (17 ft) through the 50-km (30-mi)-long series of small lakes that were present along the ice front eastward to Topeka.

Well established in published literature is the hypothesis that water impounded when the Kansas River valley was blocked by glacier ice rose until it was able to spill westward and southward through the so-called McPherson Valley. As early as 1895, Beede pointed out that such a course on the present topography would require water to flow uphill. A solution suggested in later papers was to call on an isostatically raised glacial forebulge to provide a gradient in the proper direction. This suggestion does not withstand close analysis, however, and westward drainage of Kaw Lake apparently did not take place.

Compilation of subsurface data provided by drill holes does indicate the presence of several buried valleys in northeastern Kansas. However, relating these to the glacial chronology has been handicapped by previous efforts to fit all events into a framework of only two major glaciations of the area. As additional information is acquired, it will probably be found that there was a considerably more complex sequence involving several advances of the ice sheets.

Any situation involving impoundment of large volumes of water by an ice dam contains the ingredients necessary for release of one or more catastrophic floods. If blockage continued at the western end of the Kansas River valley after the area around Topeka had become ice free, ultimate failure of that dam could have released a surge of water and

TABLE 1—CLASSIFICATION OF PLEISTOCENE UNITS ACCORDING TO THE NEBRASKA GEOLOGICAL SURVEY (from Reed and Dreeszen, 1965). This classification also was used by the Kansas Geological Survey. However, studies in many areas have shown that the record is much more complex in Kansas and it is probable that all terms below the Illionian will have to be extensively redefined or, more likely, abandoned.

CLASSIFICATION							TERRACE SURFACES		FAUNAL ZONES
TIME STRATI-GRAPHIC		ROCK STRATIGRAPHIC							
		EOLIAN	FLUVIATILE		GLACIAL	SOILS			
Wisconsinan	Late	Bignell Loess and Dunesand	Bignell Formation	silt / sand-gravel	Absent		2a / 2b	2	Late Pleistocene
Wisconsinan	Medial	Peoria Loess and Dunesand	Peoria Formation	silt / Todd Valley sand	Hartington Till	Brady	3 / ?	3	? — ?
Wisconsinan	Early	Gilman Canyon Loess	Gilman Canyon Formation		Absent	Unnamed	4	3	Medial Pleistocene
Sagamonian	Late	Loveland Loess	Loveland Formation	silt / Crete sand-gravel	Absent	Sangamon	4	4	
Illinoian	Medial	Beaver Creek Loess	Beaver Creek Formation	silt / sand-gravel	Santee Till	Unnamed	4	4	
Illinoian	Early	Grafton Loess	Grafton Formation	silt / sand-gravel	Clarkson Till	Unnamed	4	4	
Yarmouthian	Late	Sappa Loess	Sappa Formation	silt (• • •) / Grand Island sand-gravel	Probably Absent	Yarmouth	4	5	
Kansan	Medial	Walnut Creek Loess *	Walnut Creek Formation	silt / sand-gravel	Cedar Bluffs Till	Unnamed	5	5	? — ?
Kansan	Early	Red Cloud Loess *	Red Cloud Formation	silt / sand-gravel	Nickerson Till / Atchison Sand	Fontanelle	5	5	Early Pleistocene
Aftonian	Late	Fullerton Loess *	Fullerton Formation	silt / Holdrege sand-gravel	Iowa Point Till	Afton	5	6	
Nebraskan	Early	Seward Loess *	Seward Formation	silt / basal sand-gravel	Elk Creek Till / David City sand-gravel	Unnamed	5	6	

Interglacial Soil — Interstadial Soil — Minor Erosion — Major Erosion — • • Pearlette Volcanic Ash — * Not currently identified

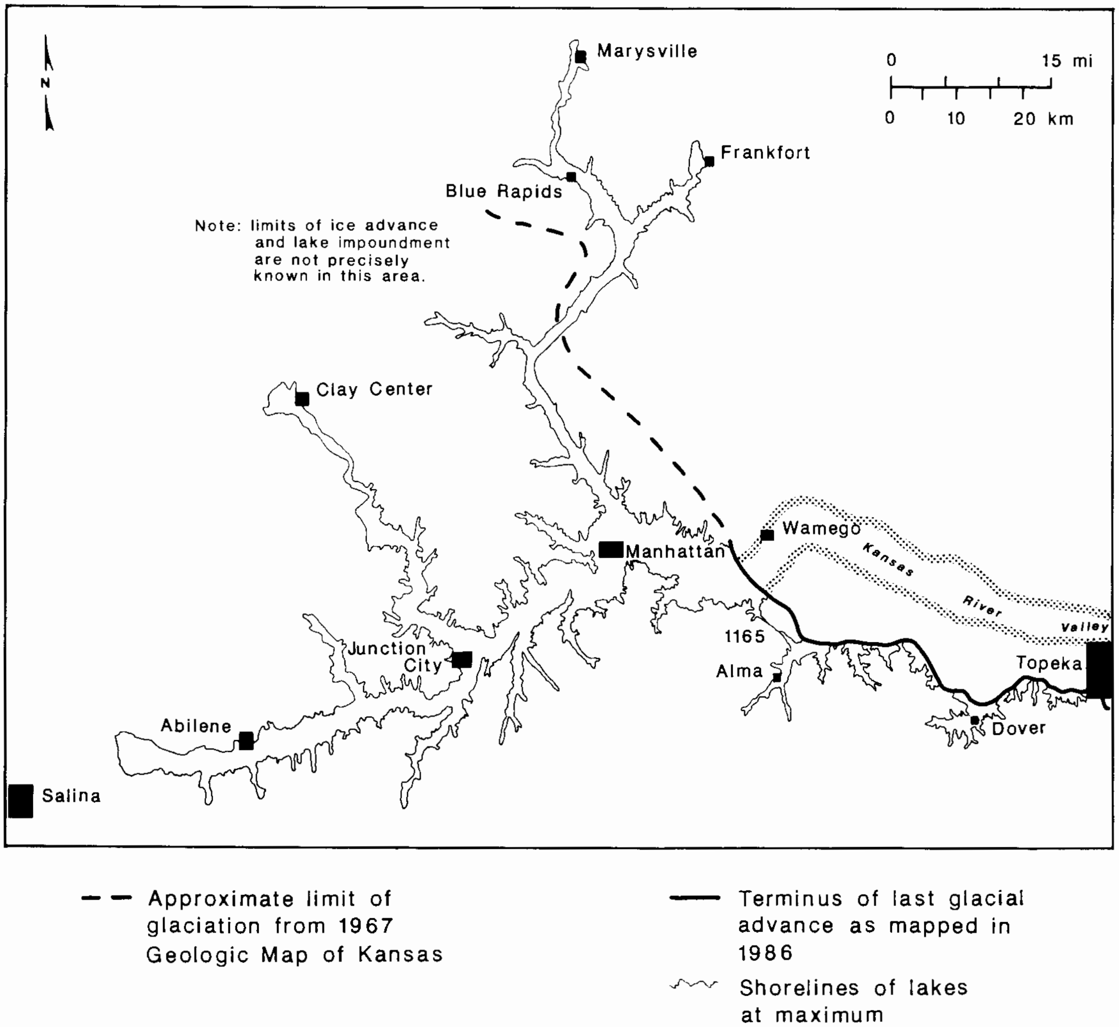

FIGURE 9—PROGLACIAL LAKES WEST OF TOPEKA AT THE TIME OF MAXIMUM ICE ADVANCE. Shorelines depict water levels controlled by spillways against or close to the ice front. It is believed that there has been no significant warping of the land surface since that time and that the glaciated terrain closely approximated that of today, thus permitting plotting on modern topographic maps.

sediment down the deglaciated portion of the valley. Large-scale trough crossbeds in a gravelly sand exposed in a pit just northwest of Topeka might have been formed by such an event. Furthermore, the deep inner bedrock gorge extending more than 60 m (198 ft) below present floodplain level in the Kansas City area could also have been formed, at least in part, by this high-volume discharge.

One other interesting question about Pleistocene drainage relates to the ancestral Missouri River or its precursor. When ice sheets reached northeastern Kansas, all preglacial drainage toward the northeast was effectively blocked. So also was the Missouri River itself, or whatever trunk drainage existed at that time. Yet there still was a vast region in the interior of the continent that received precipitation, as well as at least some flow from the ice itself.

That water had to go somewhere. Flow toward the north and northeast was blocked by ice; toward the west or southwest it was blocked by higher elevations. There seem to be only two possible courses available. Flow might have been diverted through the McPherson Valley, a possibility previously mentioned and discarded, or it could have followed a general ice-marginal route. This latter possibility seems best, but confirmation is frustrated by the absence of a readily identifiable ice-marginal valley large enough to carry drainage from the entire Midcontinental area. It may well be, however, that the broad and deep bedrock valley of the Kansas River, now filled by alluvium to depths of about 30 m (99 ft) away from the narrow inner gorge was carved by this stream and that glacier advance south of the valley, thereby blocking this drainageway, was only short lived.

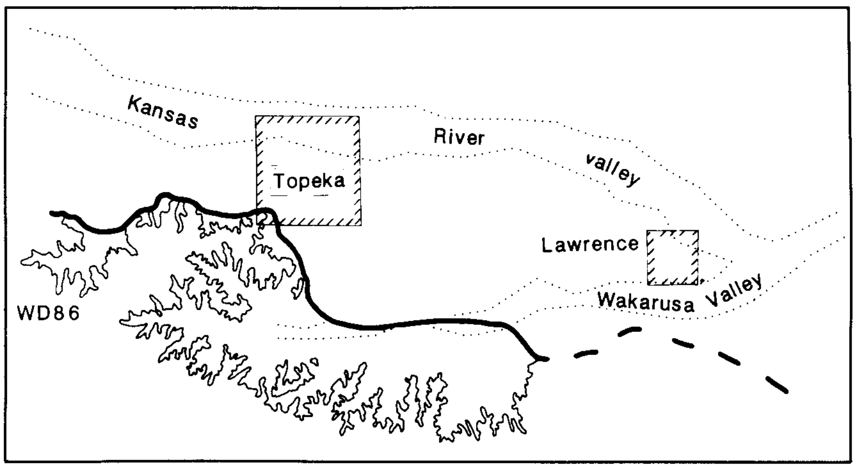

FIGURE 10—Pro-glacial lakes near Topeka and in the Wakarusa Valley.

Conclusion

Study of the Pleistocene history of Kansas is once more in a stage of rapidly expanding knowledge. Recognition of the multiplicity of glacial episodes and of ashfalls from distant volcanoes has made it necessary to revalidate or, more generally, modify previous concepts of stratigraphic relationships. Every sequence or correlation that was published prior to 1960 must be critically re-examined. This is clearly a time of change, but it is to be hoped that the urge to rush into print with new ideas will be tempered by the need for careful testing of hypotheses.

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Pleistocene loess in Kansas—status, present problems, and future considerations

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Abstract

Three major loess units are recognized in Kansas: the Loveland, Peoria, and Bignell formations. These eolian strata were correlated with the glacial succession by Frye and others (1948). Loveland loess is of Illinoian age and Peoria loess is of Wisconsinan age. The age of Bignell loess is in dispute. Some radiocarbon dates place it as late Wisconsinan and others as early Holocene. A new loess-distribution map of Kansas shows that loess comprises about 65% of the surface of the state. Peoria loess is the most exposed and widespread loess in Kansas. Bignell loess is discontinuous and is restricted to central and western Kansas. A statewide systematic study of the thickness of loess in the state has not been attempted. Thickness data for this report were derived from logs of wells and test holes of county geology and hydrology reports. Most of these data are inconsistent and unreliable for a number of reasons. The most abundant and seemingly reliable thickness data on loess in Kansas is that for the northwest and west-central regions where thickness ranges from 100 ft (30 m) in the northwest area to 5 ft (1.5 m) in the southeast area of the two regions. The source of the loess in Kansas has been debated for the last 50 yrs. Three theories have emerged regarding the source of the Peoria loess: 1) glacial (alpine and continental) outwash river floodplains, 2) desert regional sources (areas of sand dunes), and 3) regional fluvial and eolian erosion of the Ogallala Formation. A single-source-area hypothesis does not satisfactorily explain the discontinuity in distribution and variation in thickness of the Peoria loess found in Kansas. We conclude from reviewing loess literature of the past 50 yrs and our generalized loess-distribution map of Kansas that the loess in Kansas was derived from a combination of these three sources. We also conclude that there is not sufficient information available to assess the volume that each source contributed to the total volume of loess deposited in Kansas. The relationship between loess formations and modern soils formed in loess has received little study. We correlated Kansas soils formed in loess with specific loess formations. Several major soils were reported in the literature as having formed in both Peoria and Bignell loess. This contradiction is due to the uncertainty of the areal extent of Bignell loess in Kansas. In eastern Kansas many modern soils formed in old Pleistocene alluvium on broad, flat, upland areas seem to have a loess constituent in their upper profile. Representative profiles of major soils of Kansas developed in loess were sampled by horizon at locations spaced widely around the state. The purpose is to assess the lateral and vertical variation of loess in the state by studying the geochemical variations within and among modern soils formed in the loess. It is hoped that the data acquired will provide answers concerning distribution, multiple sources, and relative ages of loesses in Kansas.

Introduction

Purpose of report

The most comprehensive, most significant, and most recent published information about Pleistocene loess in Kansas is that found in *Pleistocene geology of Kansas* (Frye and Leonard, 1952). That publication reviewed and summarized then-current knowledge (accumulated from 1937 to 1952) about the Pleistocene geology of Kansas. The authors expressed hope that their publication would serve as a source of general data and as a starting point for future, more detailed and complete studies in Kansas Pleistocene geology. The report has been quite successful as a source of general data. Since its publication, no organized and correlated research has been done on Kansas Pleistocene geology. Frye left the Kansas Geological Survey in 1955, and research on Pleistocene geology in Kansas has since waned. This situation has existed for the most part for a little over 30 yrs.

The purpose of this report is to review, consolidate, update, comment on, and summarize knowledge about Pleistocene loess in Kansas and to serve as a starting point for our research on the trace-element geochemistry of loessal soils. Also we intend the report to assist others in studies of Pleistocene loess in Kansas and the Quaternary Period in general.

Kansas loess

Since 1947, three major loess units have been recognized in Kansas: the Loveland, Peoria, and Bignell formations (Frye and Fent, 1947). Loveland loess is the oldest and was named by Shimek (1910). It later was described and classified as loess by Kay and Graham (1943) from exposures along the east bluff of the Missouri River at Loveland, Iowa. Loveland loess at the type section was described by Frye and Leonard (1951) as being 30 ft (9 m) of massive, well-sorted fine sand and silt of which the upper 22–24 ft (6.6–7.2 m) is leached of calcium carbonate. The lower 6–8 ft (1.8–2.4 m) is unleached and commonly includes stringers and nodules of calcium carbonate. Fossil faunas have been recorded, but the general occurrence of fauna in Loveland loess in Kansas is sparse. The upper leached zone has a distinct pink to red-brown tint as a result of weathering. This zone was considered part of the Sangamon paleosol by Frye and Leonard (1951). In northeastern Kansas the leached unit is thicker and more pronounced compared to western Kansas, where it appears as a thin, reddish, compact soil horizon (Prescott, 1953; Walters, 1956; Bayne, 1956). In the glaciated portion of Kansas, Loveland loess is often found overlying Kansan till but elsewhere, it occurs overlying alluvial silts, sands, and gravels of the Crete (Illinoian) and Sappa (Yarmouthian) formations and older bedrock deposits.

Peoria loess, younger than the Loveland but older than the Bignell, consists of massive, yellow-tan to buff-colored, well-sorted, calcareous, very fine sands, silts, and clays. The term Peoria was originally proposed as an interglacial-weathering interval (Peorian) in Iowan loess between the Iowan and Wisconsinan glacial stages by Leverett (1898) from exposures in Peoria, Illinois. When the loess proved to be younger than Iowan, it was designated as Peorian loess by Leighton (1931).

Bignell loess, the youngest loess found in Kansas, was named by Schultz and Stout (1945) from exposures along bluffs south of the Platte River near North Platte, Nebraska. It is morphologically similar to the underlying Peoria loess. However, it is generally more friable and less compact than the Peoria (Frye and Leonard, 1951). The only way to distinguish Bignell loess from Peoria loess in the field is by the Brady soil, first described by Schultz and Stout (1948), which statigraphically separates the two, and by sparse but distinct fauna in the Bignell loess. Because of the strong morphological and major chemical similarities between these two loess units (Frye and Leonard, 1951), the Bignell loess has been speculated to be a product of reworked Peoria loess.

Correlation of loess stratigraphy

Loveland, Peoria, and Bignell loesses were once included within the Sanborn formation named by Elias (1931) for Pleistocene deposits exposed in Wallace County. In Kansas, these loesses, along with their alluvial equivalents, were assigned the rank of member (Loveland silt member, Peoria silt member, and Bignell silt member) within the Sanborn formation by Frye and others (1948; fig. 1). This nomenclature was used by Frye and Leonard (1952) and

Old upper Mississippi Valley region time-stratigraphic units (Leighton, 1933)	Late Pleistocene Series classification of Kansas: (Frye and others, 1948) (SW KS)	(Leonard, 1951)	(Frye and Leonard, 1952)	(Bayne and O'Connor, 1968)	Present upper Mississippi Valley region time-stratigraphic units (Willman and Frye, 1970)
Recent	eolian and fluvial deposits	eolian and fluvial deposits	eolian and fluvial deposits	eolian and fluvial deposits	Holocene
Wisconsinan: Mankatoan Caryan Tazewellian Iowan	Sanborn formation: Bignell m. Brady soil Peoria m. — Kingsdown silt	Sanborn formation: Bignell silt m. Brady soil Peoria silt m.: upper, lower, basal (faunal zone)	Sanborn formation: Bignell silt m. Brady soil Peoria silt m.	Wisconsinan: Bignell Fm. Brady soil Peoria fm. Gilman Canyon Fm.	Wisconsinan: Valderan Twocreekan Woodfordian Farmdalian Altonian
Sangamonian	Sangamon soil — lower Kingsdown and upper Meade	Sangamon soil	Sangamon soil	Sangamon soil	Sangamonian
Illinoian	Loveland m. — lower Kingsdown and upper Meade	Loveland silt m.	Loveland silt m. Crete sand and gravel m.	Loveland fm. Crete Fm.	Illinoian

FIGURE 1—Evolution of Late Pleistocene Series classification of Kansas and old- and present-time stratigraphic units.

continued to be used by the Kansas Geological Survey until 1959 when the Sanborn formation was dropped from the Pleistocene nomenclature of Kansas and the loess members were reassigned as formations (Jewett, 1959). By 1968, the eolian and alluvial phases of the Loveland, Peoria, and Bignell formations had been separated and the Gilman Canyon Formation was recognized (Bayne and O'Connor, 1968; figs. 1 and 2).

Loveland loess in Nebraska and at the type section in Iowa was correlated with equivalent loess deposits in Kansas by Frye and Fent (1947). Frye stated that the Loveland loess was deposited during the waning or retreating phase of the Illinoian Glacial Stage in accordance with his glacial-outwash model of loess origin. However, the presence of minor soils observed within Loveland loess in Kansas (Frye and Leonard, 1954) suggests that the Loveland loess is a complex of loess units in the state. These minor soils which reflect intervals of stability may or may not correlate with the Illinoian substages recognized outside Kansas (fig. 5).

The Wisconsinan Glacial Stage has been subdivided quite precisely as a result of the well-preserved and datable glacial-till deposits within the glaciated portion of the upper Midwest in Illinois. The region along the glacial front is characterized by a complex till stratigraphy created by numerous small- to medium-scale ice advances and retreats. In Illinois, numerous Wisconsinan loess units have been recognized (fig. 3). In northern Illinois the Peoria loess is observed dividing to form two loess units (Morton and Richland loesses) separated by Woodfordian-age tills. Such is not the case in Kansas. Leonard (1951; fig. 1) correlated three distinct faunal zones found in Peoria loess in Kansas with three loess units of the Illinois classification. He correlated a basal zone devoid of faunal fossils with the Farmdale loess (Roxana silt in current Illinois classification), because they had identical molluscan assemblages. A lower faunal zone located above the basal zone was correlated with Iowa loess; an upper faunal zone, separated from the lower faunal zone by a transition zone, was correlated with the Tazewell loess. The lack of any well developed, buried paleosols or other unconformities suggests that Peoria loess in Kansas represents a continuous deposit and the faunal zonation reflects a change in the rate of deposition. Leonard concluded that the Brady soil must have formed in post-Tazewell–pre-Caryan time and the overlying Bignell loess was deposited during Caryan to

Time-stratigraphic units	Rock-stratigraphic units					
	Northeastern area		Southeastern area		Central and Western area	
Recent Stage	Eolian and fluvial deposits					
Wisconsinan Stage	Bignell Formation	Fluvial deposits	Bignell Formation	Fluvial deposits	Bignell Formation	Fluvial deposits
	Brady Soil					
	Peoria Formation	Fluvial deposits	Peoria Formation	Fluvial deposits	Peoria Formation	Fluvial deposits
	Gilman Canyon Formation					
Sangamonian Stage	Sangamon Soil					
Illinoisan Stage	Loveland Formation	Fluvial deposits	Loveland Formation	Fluvial deposits	Loveland Formation	
					Crete Formation	
Yarmouthian Stage	Yarmouth Soil					
Kansan Stage	Loess	Fluvial deposits*	Fluvial deposits*		Sappa Formation*	
	Cedar Bluffs Till					
	Fluvial deposits				Grand Island Formation	
	Nickerson Till					
	Atchison Formation†					
Aftonian Stage	Afton Soil					
Nebraskan Stage	Loess	Fluvial deposits	Fluvial deposits		Fullerton Formation	
	Iowa Point Till				Holdrege Formation	
	David City Formation					

* Locally contains the Pearlette ash bed.
† Atchison Formation has been defined as proglacial outwash of early Kansan age. Similar deposits of sand are found between the Nickerson Till and the Cedar Bluffs Till.

FIGURE 2—CLASSIFICATION OF PLEISTOCENE SERIES IN KANSAS (BAYNE AND O'CONNOR, 1968).

Mankatoan substages.

The current Pleistocene classification of Kansas (fig. 2) has not changed substantially from that proposed by Frye and Leonard (1952). Much of the Kansas Pleistocene classification was adopted from the Nebraska Pleistocene classification (fig. 4). The stratigraphic zonations described by Leonard (1951) are not cited in the present Kansas classification, but Peoria loess and Bignell loess were placed within the time frame suggested by Leonard.

The use of radiocarbon dating has not been utilized in refining the Wisconsinan loess stratigraphy in Kansas. Dates obtained from similar loess deposits in adjacent states raise questions concerning the placement of the Peoria loess, Brady soil, and Bignell loess within the Wisconsinan time frame. Dreeszen (1970) reported dates of 23,000 ± 600 to 27,900 (+ 1,100, − 1,000) yrs B.P. for the upper 18 inches (46 cm) and 31,400 (+ 1,800, − 1,500) to 34,900 (+ 2,100, − 1,700) yrs B.P. for the lower 18 inches (46 cm) of the basal layer of the Gilman Canyon Formation at the type locality in Nebraska. Ruhe (1976) reported a date of 24,100 ± 1,650 yrs B.P. for the upper 23 cm (9 inches) and 31,080 (+ 5,600, − 3,200) yrs B.P. in the basal 23 cm (9 inches) of the lower Wisconsinan loess at the Loveland loess type section in Iowa. The basal layer rests on the A horizon of the Sangamon soil. Time-stratigraphically and rock-stratigraphically this basal zone correlates with the Gilman Canyon Formation in Nebraska. The above dates place the start of Missouri River valley loess deposition at mid-Wisconsinan using the Illinois time-stratigraphy classification (figs. 3 and 5), and at early Wisconsinan using the Nebraska time-stratigraphic classification (figs. 4 and 5).

Dreeszen (1970) reported dates of 9,160 ± 250 yrs B.P. and 9,750 ± 300 yrs B.P. for the Brady soil at the Bignell loess type location in Nebraska described by Schultz and Stout (1948). Dreeszen acknowledged that the samples were contaminated with rootlets from modern plants. Radiocarbon dates of 12,550 ± 400 yrs B. P. and 12,700 ± 300 yrs B. P. have been obtained from snails in the basal layer of reputed Bignell loess at the Iowa Point section in Doniphan County, Kansas (Frye and others, 1968). Critics have questioned the reliability of snails for

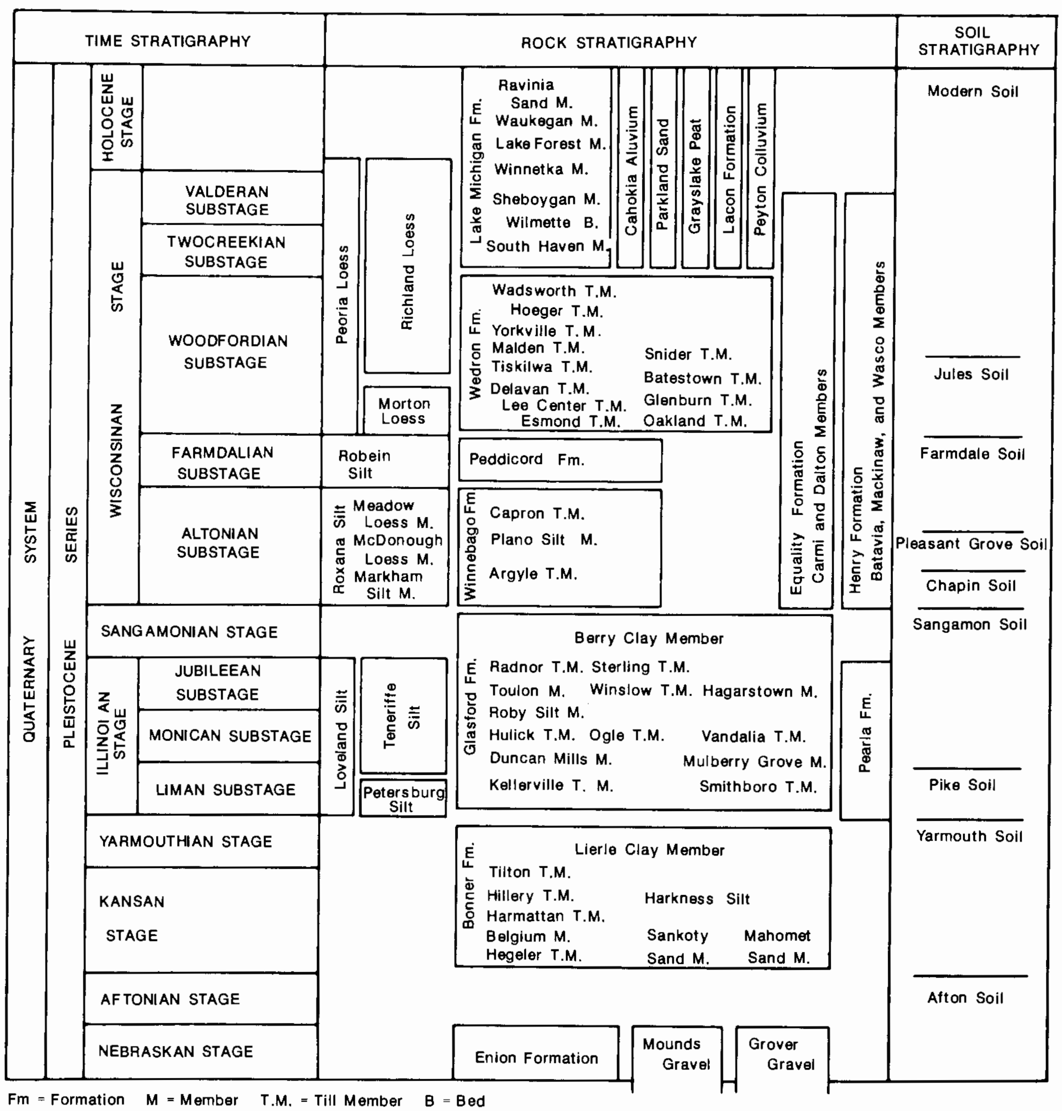

FIGURE 3—CLASSIFICATION OF PLEISTOCENE SERIES IN ILLINOIS (FRYE AND WILLMAN, 1975).

dating purposes. Do snails incorporate old carbon from external sources to construct their shells? In the above case, which is more accurate, the soil date or the snail date? The existence of the Bignell loess in northeastern Kansas is in dispute since the presence of the characteristic Brady soil was questioned by Caspall (1972). He concluded that the Brady soil in northeastern Kansas as described by Frye and Leonard (1949) is not a true soil, but rather a weathering zone developed in Peoria loess during a period of slow loess deposition. Excluding the site described by Frye and Leonard (1949), the Brady soil and Bignell loess have not been observed east of the 97th meridian. The general restriction of the two units to west of the 97th meridian requires further study to determine their actual place in the Quaternary classification.

Ruhe (1976) demonstrated that layers within Peoria loess in western Iowa were time-transgressive. Radiocarbon ages of a buried soil within the loess ranged from 29,000 yrs to 16,500 yrs B.P. among 33 radiocarbon dates. The dates spanned the Farmdalian and half the Woodfordian stages. As a result, the term Peorian loess (Kay and Graham, 1943) was dropped and the loesses in Iowa were reclassified simply as upper and lower Wisconsinan loess (Ruhe, 1954). Analysis of similar layers in Peoria loess in Kansas may produce similar correlation problems. Although relatively short-term migrations of the ice front are significant along the glacial boundary, these events go unrecognized in the unglaciated regions of the Great Plains where direct evidence of glacial movements is absent. Consequently, glacial substages are established from erosion and sedimentation cycles and buried soils (figs. 3 and 4).

The state of Kansas is in a unique geographic position in that Pleistocene loesses and alluvial cycles were related to both continental and alpine glacial events. Alpine glaciers contributed outwash materials by way of the Platte and Arkansas rivers to western portions of the state, and continental glaciers provided similar sediments by way of the Missouri River to eastern Kansas. Local episodes of aggradation and degradation as a result of climate not related to glaciations also must be considered. The loess in western Kansas associated with outwash from the Rocky Mountains may be out of phase with the loess associated with outwash from continental glaciers in eastern Kansas. Although the bulk of the loess deposits in Kansas correlate with the Peoria loess in Illinois, it is time to reevaluate the usage of the term Peoria in Kansas. It has long been recognized that the Peoria loess in Kansas is a complex of several depositions (fig. 5). Additional work is needed to

CLASSIFICATION						TERRACE SURFACES		FAUNAL ZONES
TIME STRATIGRAPHIC		ROCK STRATIGRAPHIC						
		EOLIAN	FLUVIATILE	GLACIAL	SOILS			
Wisconsinan	Late	Bignell Loess and Dunesand	Bignell Formation { silt / sand-gravel	Absent		2a / 2b	2	Late Pleistocene
Wisconsinan	Medial	Peoria Loess and Dunesand	Peoria Formation { silt / Todd Valley sand	Hartington Till	Brady	3	3	
Wisconsinan	Early	Gilman Canyon Loess	Gilman Canyon Formation	Absent	Unnamed	?		? — ?
Sagamonian	Late	Loveland Loess	Loveland Formation { silt / Crete sand-gravel	Absent	Sangamon			
Illinoian	Medial	Beaver Creek Loess	Beaver Creek Formation { silt / sand-gravel	Santee Till	Unnamed	4	4	Medial Pleistocene
Illinoian	Early	Grafton Loess	Grafton Formation { silt / sand-gravel	Clarkson Till	Unnamed			
Yarmouthian	Late	Sappa Loess	Sappa Formation { silt / Grand Island sand-gravel	Probably Absent	Yarmouth			
Kansan	Medial	Walnut Creek Loess *	Walnut Creek Formation { silt / sand-gravel	Cedar Bluffs Till	Unnamed		5	? — ?
Kansan	Early	Red Cloud Loess *	Red Cloud Formation { silt / sand-gravel	Nickerson Till / Atchison Sand	Fontanelle			
Aftonian	Late	Fullerton Loess *	Fullerton Formation { silt / Holdrege sand-gravel	Iowa Point Till	Afton	5		Early Pleistocene
Nebraskan	Early	Seward Loess *	Seward Formation { silt / basal sand-gravel	Elk Creek Till / David City sand-gravel	Unnamed		6	

Interglacial Soil — Interstadial Soil — Minor Erosion — Major Erosion — • • Pearlette Volcanic Ash — * Not currently identified

FIGURE 4—CLASSIFICATION OF PLEISTOCENE SERIES IN NEBRASKA (REED AND DREESZEN, 1965)

correlate Wisconsinan loesses in Kansas with known sections in Nebraska and Illinois. Any attempt at this time to force-fit apparent subdivisions in the loesses of Kansas into the Illinois section would be inappropriate.

Distribution of loess

A map depicting the distribution of Pleistocene (Peoria) loess in Kansas (fig. 6) shows that loess comprises approximately 65% of the present surface of the state as opposed to earlier estimates of 33% by Frye and Leonard (1952) and 50% by Bayne and O'Connor (1968). Areas with a thin, but relatively widespread layer of loess accumulation often are not shown on geologic maps which emphasize bedrock formations. For example, Berry (1952) excluded loess less than 3 ft (.9 m) thick when he prepared the geologic map of Lincoln County. Using modern soil surveys (U.S. Department of Agriculture, Soil Conservation Service), which utilize a 2-ft (.6-m)-thickness minimum for loess, we identified additional areas of loess deposition in Kansas and expanded the areal distribution of loess in the state.

Time-stratigraphic classification		Radiocarbon yrs BP	Representative rock-stratigraphic units: ILLINOIS	NEBRASKA	KANSAS (NE)
Holocene			Cahokia Alluv.	alluvium and dune sand	eolian and fluvial deposits
Wisconsinan	Valderan	7,000		Bignell fm.	Bignell Fm.
Wisconsinan	Twocreekan	11,000		Brady soil	Brady soil
Wisconsinan	Woodfordian	12,500	Peoria Loess: Jules soil, Richland Loess Wedron Fm. (tills)	Peoria Fm. Todd Valley Sand Harington till	Peoria fm.
Wisconsinan	Farmdalian	22,000	Peoria Loess: Morton Loess Farmdale soil	Gilman Canyon Fm.	Gilman Canyon Fm.
Wisconsinan	Altonian	28,000	Roxana Silt: Meadow Loess M. Pleasant Grove soil McDonough Loess M. Chapin soil Markham Silt M. Winnebago Fm. (tills)		
Sangamonian		75,000	Sangamon soil	Sangamon soil	Sangamon soil
Illinoian	Jubileean	?	Loveland Silt: Teneriffe Silt Glasford Formation (tills)	Loveland Fm. Crete sand and gravel	Loveland fm.
Illinoian	Monican		Loveland Silt: Pike soil Glasford Formation (tills)	Beaver Creek Fm. Santee Till	
Illinoian	Liman		Loveland Silt: Petersburg Silt Glasford Formation (tills)	Grafton Fm. Clarkson Till	
Yarmouthian			Yarmouth soil	Yarmouth soil	Yarmouth soil
Kansan			Lierle Clay M. Banner Fm.: (tills) Harkness Silt M.	Sappa Fm. Grand Island s.and gr. Walnut Creek Fm. Cedar Bluffs Till Fontanelle soil Red Cloud Fm. Nickerson Till Atchison sand	loess and fluvial deposits Cedar Bluffs Till fluvial deposits Nickerson till Atchison Fm.
Aftonian			Afton soil	Afton soil	Afton soil
Nebraskan			Enion Fm.	Fullerton Fm. Holdrege s. and gr. Iowa Point Till Seward Fm. Elk Creek Till David City s. and gr.	loess and fluvial deposits Iowa Point Till David City Fm.

FIGURE 5—TIME-STRATIGRAPHIC CLASSIFICATION (ILLINOIS), RADIOCARBON YRS B.P. FOR THE WISCONSINAN, AND REPRESENTATIVE ROCK-STRATIGRAPHIC UNITS IN THREE STATES; VERTICAL SCALE IS NOT LINEAR WITH TIME.

Northeast

Along the Missouri River in northeast Kansas, Pleistocene loess is quite extensive. Except where dissected by large streams, loess covers the entire upland surface of Doniphan County and most of Wyandotte County. A thick cover of loess forms a nearly continuous band paralleling the river valley in Doniphan, Atchison, Leavenworth, and Wyandotte counties. Loess covers most of the uplands in Leavenworth, Marshall, and Clay counties and large areas of northern Nemaha, eastern Brown, Atchison, northeast Jackson, Jefferson, Riley, and southern Washington counties. The land surface in western Brown County is underlain by Lower Permian rocks. Southwest Leavenworth County is underlain by Upper Pennsylvanian rocks. Areas in Marshall County not covered by loess are mostly covered by Pleistocene glacial drift. Some areas are underlain by Lower Permian rocks. Most of the surface in Washington County not covered by loess is underlain by Lower Cretaceous rocks. In eastern and southeastern Riley County, Lower Permian rocks underlie the surface.

Glacial drift is the dominant surface material in areas of Nemaha County not covered by loess. Where loess is absent in western and south-central Atchison County, glacial drift covers the surface. In the eastern portion of the county, where loess is absent, Upper Pennsylvanian rocks underlie the surface not covered by glacial drift. The majority of western and southern Jackson County is underlain by Lower Permian rocks with the remainder covered by glacial drift. The north-central and central areas of the county are covered predominantly by glacial drift with areas underlain by Lower Permian rocks. In Jefferson County, loess covers the uplands in areas in the northeast, southeast, north-central, and central sections. Glacial drift and Upper Pennsylvanian rocks comprise the surface of the uplands over the rest of the county. In Pottawatomie County, loess is found in the north-central and west-central regions on narrow upland areas. The upland surface of the rest of the county is underlain mostly by Lower Permian rocks with some areas covered by glacial drift.

Relatively narrow and discontinuous deposits of loess occur on the uplands adjacent to the Kansas River in Geary, Riley, Shawnee, Douglas, Leavenworth, Wyandotte, and Johnson counties.

East-central and southeast

Except for northern and eastern Johnson, northeastern Miami, northern Dickinson, and western Cowley counties, widespread loess deposits have not been recognized in these two areas. However, several soils of the two regions are thought to contain a loess component. Some upland soils formed in limestone have a surface horizon of loess. The Polo soil is an example. Other upland soils such as Dwight, Irwin, Ladysmith, Parsons, Kenoma, and Woodson that formed in old Pleistocene alluvium are suspected of having a surface horizon of loess or of having loess incorporated into the surface horizon.

Dwight, Irwin, and Ladysmith soils formed in old alluvium derived primarily from Lower Permian rocks. In these two regions, Lower Permian rocks crop out west of a line from southwest Chautauqua County at the Oklahoma state line to northwest Shawnee County at the Kansas River. East of this line Pennsylvanian rocks crop out. Kenoma, Parsons, and Woodson soils formed in old alluvium derived primarily from these rocks. The Woodson soil in Douglas County is reported to have formed in loess and old alluvium. Further south in Allen and Anderson counties, the parent material is reported to be just old alluvium. In Woodson County this soil is reported to have formed in loess and loess-contaminated old alluvium. Combining the areas covered by these old alluvial loessal soils with known loess deposits of the state indicates that the entire state probably was mantled by loess during the late Wisconsinan and early Holocene (fig. 6.).

North-central

East of the Republican River valley from northwestern Republic County to the river's confluence with the Smoky Hill River at Junction City in Geary County, a continuous mantle of loess is present on the uplands adjacent to the Republican River. Republic County is almost entirely covered by loess with the best exposures located along the eastern flanks of the river valley.

West of the valley, loess covers the surface of an extensive plain coextensive with the Carlile Shale formation. In Jewell, Smith, Osborne, Mitchell, and Cloud counties, loess covers the upland surface except where Upper Cretaceous rocks underlie the surface. In Phillips and Rooks counties, loess is the dominant surface material except where the surface is underlain by Upper Cretaceous and Tertiary rocks.

Central

Loess deposits are found on the uplands adjacent to the Saline River in Russell and Lincoln counties. These deposits are more extensive in Russell County. In Ottawa County, loess mantles the uplands east and west of the Solomon River. In Saline County, loess mantles the uplands mostly west of the Smoky Hill River in the north-central, central, and south-central regions. In Ellis and Russell counties, loess occurs on adjacent uplands of both the Saline and Smoky Hill rivers. In Ellsworth County, loess is found on the uplands only in the northwest and southwest portions of the county. In Lincoln and Ellsworth counties loess is absent where Cretaceous rocks underlie the surface. West of the loess deposits in Saline County, Lower Cretaceous rocks underlie the surface while in eastern Saline County, Lower Permian rocks underlie the surface. In northern McPherson County, both Lower Permian and Lower Cretaceous rocks underlie the surface. North of the Arkansas River in Rush, northern Pawnee, and Barton counties; northwest, north-central, northeast, and central Rice County; and most of the southern two-thirds of McPherson County, loess is the dominant surface material. An extensive tract of sand and dunes comprises the land surface south of the Arkansas River in southeast Pawnee, southeast Barton, and southwest Rice counties.

South-central

Loess mantles the uplands in Edwards County northwest of the Arkansas River; in northwestern, central, and southwestern Harvey County; central, south-central, west-central, and southwest Kiowa County; and central, south-central, west-central, and southwest Pratt County. Wisconsinan and/or Holocene dune sands and alluvium overlie the upland surface of Stafford County. Old alluvium overlies the surface in the east-central region of the county. Reno County is also overlain predominantly by dune sands and old alluvium. An area of loess has been observed in the east-central and southeast regions of the county. Most of the northern half of Pratt and the northern third of Kiowa counties is overlain by dune sand. Edwards County, east of the Arkansas River, is also overlain predominantly by dune sand. Small but recognizable areas of loess have been delineated in the southeast and south-central areas of Barber County, extreme north-central Comanche County, and extreme east-central Harper County. The majority of the upland surface of Comanche, Barber, and Harper counties is underlain by Upper Permian rocks except in the northern halves of Comanche and Harper counties where old Pleistocene alluvium is the dominant surface material. Most of Kingman County, except in the west-central and central regions, where areas of loess occur, is overlain by old Pleistocene alluvium. Loess mantles the upland surfaces over much of north-central, central, and south-central Sedgwick County. Almost all the uplands in Sumner County, except in the northwest, are overlain by loess. The upland areas of Sedgwick County not covered by loess are covered by old Pleistocene alluvium except in the extreme eastern section where Lower Permian rocks underlie the surface.

Northwest

In the northwestern region of the state, loess is the dominant upland surface material and forms a nearly continuous mantle over the land. It is absent only where channel erosion has exposed underlying Tertiary rocks.

West-central

Loess also forms a nearly continuous mantle over the upland surface in the west-central region. Loess covers nearly all the surface in Wallace, Greeley, Wichita, Scott, Lane, and Ness counties. It is absent only where underlying Tertiary and Upper Cretaceous rocks crop out. In central Logan County and in southern Gove and southern Trego counties, loess is absent and an extensive and wide band of Upper Cretaceous rocks is exposed.

Southwest

North of the Arkansas River in the north halves of Hamilton, Kearny, Finney, Gray, and Ford counties and in Hodgeman County, loess forms an extensive mantle, being absent only in the alluvial lowlands. In northeast Finney

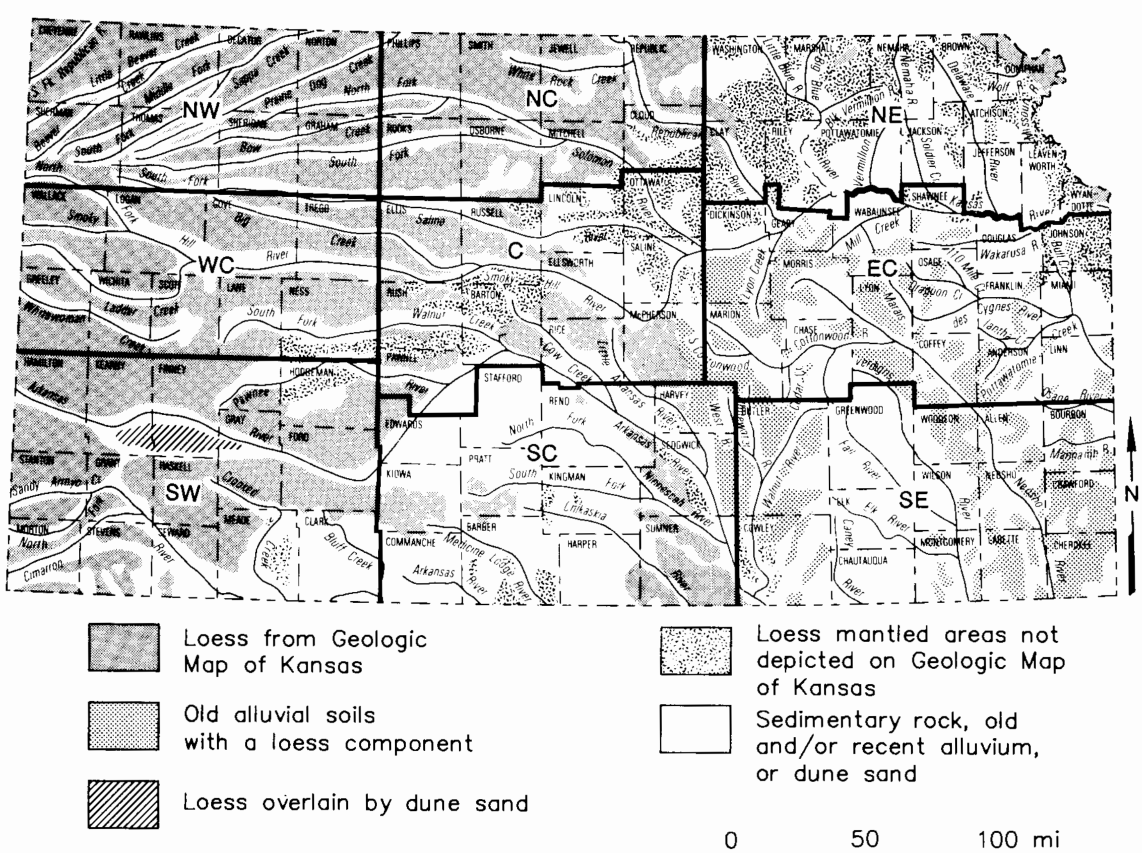

FIGURE 6—GENERALIZED PLEISTOCENE LOESS-DISTRIBUTION MAP OF KANSAS (after Geologic map of Kansas, 1964, Kansas Geological Survey bulletins, and Soil Conservation Service soil surveys).

and central and west-central Hodgeman counties where rather large areas of Upper Cretaceous rocks are exposed, loess is absent. Adjacent to the Arkansas River, loess shows some admixing of eolian sand.

Between the Arkansas and Cimarron rivers from the Colorado state line east across southern Hamilton, southern Kearny, southern Gray, southern Ford, Stanton, Grant, Haskell, northwest and east-central Meade, northeast Seward, and northern Morton counties, loess mantles all the upland surface. The loess is bounded on the north by extensive Holocene and/or Wisconsinan dune sands from the Arkansas River (Frye and Leonard, 1952; Smith, 1940; Simonett, 1960; Madole and others, 1981). In southeast Kearny, southern Finney, and west-central Gray counties, loess has been observed below the dunes. Smith (1940) observed dune sand overlying a thick soil developed in loess along a railroad exposure south of Garden City in Finney County and in a volcanic-ash pit near Fowler in Meade County. Frye and Leonard (1952) observed dune sand overlying Peoria loess in north-central Stanton County. Simonett (1960) analyzed test logs of the dune field south of the Arkansas River near Cimarron in Gray County and found loess underlying the dunes (fig. 7). The dunes taper off at Dodge City in Ford County and then expand into a huge field within the Great Bend area of the Arkansas River in the central and south-central regions in Pawnee, Edwards, Kiowa, Barton, Stafford, Pratt, Rice, and Reno counties.

South of the Cimarron River in extreme southern Morton; northeast, north-central, and southern Stevens; and southwest Seward counties, areas of loess mantle the surface. In southern Stevens County small and patchy areas of dune sand share the landscape with loess. The remainder of the uplands in these three counties is covered by extensive contiguous areas of dune sand. In Clark County, loess is found only in the extreme northwest corner. Upper Permian rocks underlie the surface and dominate the topography of the rest of the county along with smaller areas of exposed Tertiary rocks and dune sand.

The distribution of loess described on the preceding pages is that of Peoria loess within Kansas. Loveland loess which occurs below the Peoria loess has a widespread distribution as well, but it is discontinuous and patchy as a result of erosion through geologic time. It has been recognized across northern Kansas from the Missouri River in the east to the Colorado state line in the west. The best exposures are located along the major valleys of the Missouri, Republican, and Arkansas rivers. In northwestern Kansas, it is recognized locally, although in Sheridan County it is more widespread than in adjacent counties (Bayne, 1956). Massive deposits of Loveland silt have been described occupying an abandoned channel of the Arkansas River in northern Rice County (Fent, 1950). Frye and Leonard (1952) observed Loveland loess in southwestern Kansas in northwest Clark County and southwest Ford County.

Bignell loess, though described in exposures in Doniphan County (Frye and Leonard, 1949), is probably restricted to central and western Kansas. It is poorly represented in north-central Kansas where it is located on the uplands along the Republican and Solomon rivers. Measured sections of Bignell loess have been observed in northwestern Kansas in Norton, Thomas, Decatur, Sheridan, Rawlins, and Cheyenne counties and in west-central Kansas in Gove, Greeley, Logan, and Wallace counties. Caspall (1970, 1972) stated that measured sections have been observed in southwest and south-central Kansas (fig. 8) where the Bignell had not previously been recognized by Frye and Leonard (1952). Because the Bignell loess is almost impossible to recognize in the field without the Brady soil being present, reliable estimates of its areal distribution are not available.

Thickness of loess

A long-term statewide systematic study of the thickness of loess in Kansas has not been attempted to date. Frye and associates made a reconnaissance of the state in the 1940's but collected little quantitative data. Most of the information on the thickness of loess for this paper was derived from logs of wells and test holes of county geology and hydrology reports published cooperatively with the U.S. Geological Survey (Kansas Geological Survey, 1941–1974). With the exception of a few authors, the surficial unconsolidated sediments were not differentiated. For some reports, the loess-bearing formations were included with waterlain deposits (terraces and alluvium) of the same age. Therefore, the loess thicknesses given in this report should be used in a general sense. The loess-thickness values used were selected from upland areas so that erroneous measurements due to alluviation were minimized.

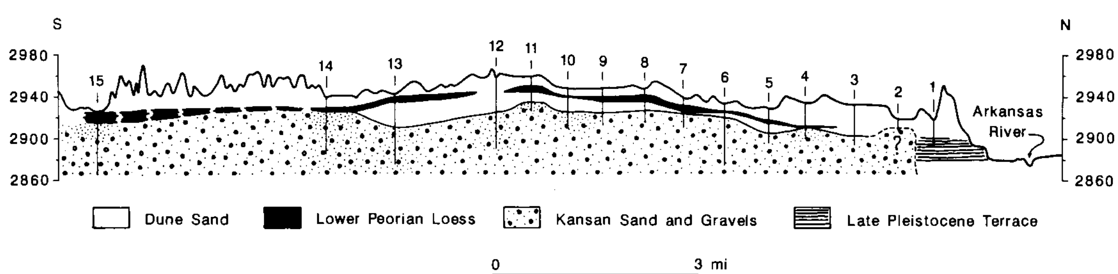

FIGURE 7—Geologic cross section of sand dunes and underlying deposits south of Holcomb, Kansas (Simonett, 1960).

Northeast

Along the Missouri River from Doniphan to Wyandotte counties (fig. 6), loess thickness is in excess of 50 ft (15 m). In Brown County, 86 ft (26 m) and 68 ft (20 m) of Wisconsinan eolian deposits were observed at separate sites (Bayne and Schoewe, 1967). Frye and Leonard (1949) described 75 ft (23 m) of loess overlying till and outwash at Iowa Point in Doniphan County and reported 195 ft (59 m) of loess was penetrated by drilling in the northern part of Brown County. In Leavenworth and Wyandotte counties, absolute thickness is not known. The geographic position of Wyandotte County in relation to the Missouri River and predominant wind direction (northwesterly) suggests that deep accumulations of loess exist in the county.

The thickness of loess decreases over a relatively short distance from the Missouri River. In Brown County the average thickness of loess, exclusive of river-bluff deposits, is approximately 10 ft (3 m). Two counties to the west, in Marshall County, the average loess thickness is approximately 8 ft (2 m). A maximum thickness of 20 ft (6 m) was observed in the northern part of Marshall County (Walters, 1954).

East-central and southeast

Widespread and thick accumulations of loess have not been found in these regions except in Johnson County where 20 ft was measured in the northeastern part of the county (O'Connor, 1971). The loess thins in the county to the south and west where 2–6 ft is common. Thin (less than 10 ft) local deposits of loess occur on the uplands south of the Kansas River in Shawnee County (U.S. Department of Agriculture, 1960–1986) and Douglas County (O'Connor, 1960).

North-central

North of the Republican River in northeastern Cloud County as much as 20 ft (6 m) of loess has been observed capping Illinoian terrace deposits. As much as 40 ft (12 m) overlies the Dakota Formation north of Aurora in east-central Cloud County (Bayne and Walters, 1959). In northern Republic County, Fishel (1948) reported as much as 100 ft (30 m) of loess. Fishel's loess also included alluvial sands, silts, and clays which fill an ancient channel of the Republican River. The amount of accumulation of loess deposited on the valley fill is not known, although Fishel estimates as much as 20–30 ft (6–9 m) of Peoria loess overlies a paleosol.

Central and south-central

In the area drained by the Arkansas River, thicknesses of loess are vague. Fent (1950) and Latta (1950) reported over 50 ft (15 m) of Loveland and Peorian silts north of the Arkansas River in eastern Barton and western Rice counties. Frye and Leonard (1952) suggested that these estimates were too high for loess and most of the deposits represented alluvial filling of the buried Chase channel preceding deposition of loess during Illinoian time. Test-hole records indicated Peoria loess to have a maximum thickness of 20 ft (6 m) in the area. In Cowley County, Bayne (1962) reported a maximum of 33 ft (10 m) of eolian silt deposits on the upland divide separating the Arkansas and Walnut rivers north of Arkansas City.

Northwest and west-central

The most abundant and seemingly reliable data available on loess thickness in Kansas is that for the northwest and

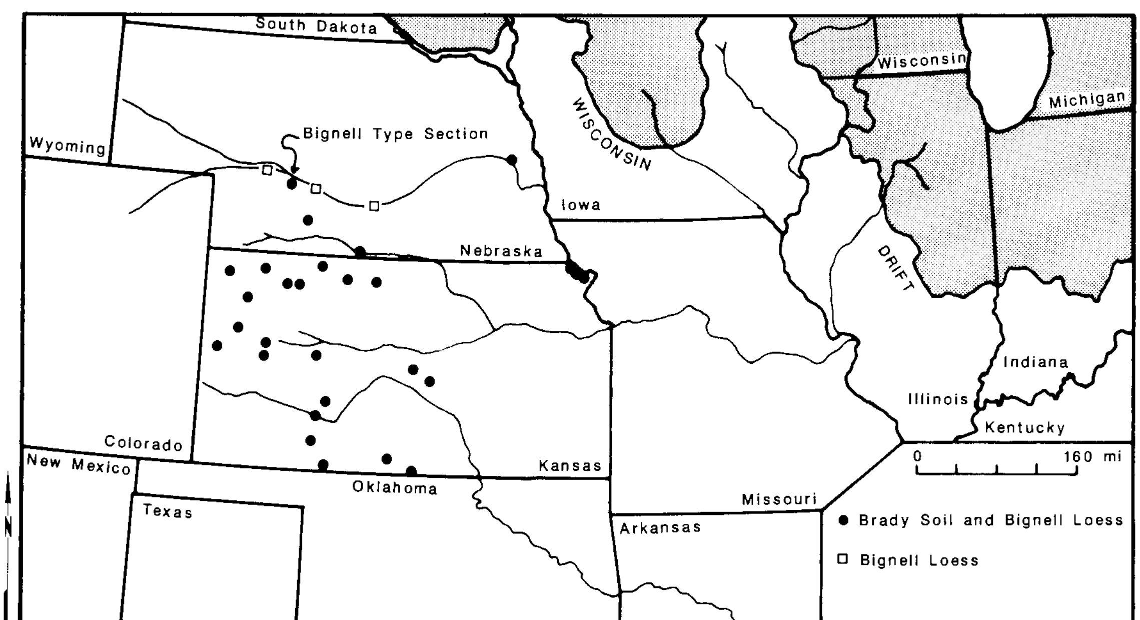

FIGURE 8—Locations of measured sections of Bignell loess and Brady soil in Nebraska and Kansas (Caspall, 1972).

west-central regions with the exception of Thomas, Scott, Lane, and Ness counties where no reliable thickness values are available. The thickness of loess in these two regions ranges from 10 to 25 ft (3–8 m) in Norton, Graham, and Sheridan counties in the northeast and Wallace, Logan, Greeley, and Wichita counties in the southwest. In Gove and Trego counties in the southeast, loess thins to 5–10 ft (1–3 m) in thickness. In the northwest, loess thickness is greatest, ranging from 20 to 40 ft (6–12 m) in Sherman County, 25–60 ft (8–18 m) in Rawlins County, and 25–100 ft (8–30 m) in Cheyenne County. In western Rawlins and eastern Cheyenne counties between McDonald and Wheeler, loess thickness ranged from 79 to 132 ft (24–40 m) with an average of 101 ft (31 m; Prescott, 1952).

These data show a thinning of the loess in northwest and west-central Kansas to the east, southeast, and south which substantiates similar observations by Swineford and Frye (1951).

Southwest

Little information exists regarding the thickness of loess in southwestern Kansas. Smith (1940) estimated the thickness of loess to range from a few feet to several tens of feet. Smith observed good exposures in southern Ford County where he measured 50 ft (15 m) of loess along Mulberry Creek.

Sources of loess

Loess deposition requires 1) a renewable source of silt, 2) wind blowing dominantly from one direction, and 3) a location for deposition to occur (Bryan, 1945). In the central Great Plains, the dominant winds are northwesterly. The form and structure of eolian deposits suggest that the wind direction has not significantly changed from that during the Wisconsinan (Ahlbrandt and Fryberger, 1980; Swineford and Frye, 1951; and Lugn, 1968). The environment during the Wisconsinan favored widespread eolian transportation and accumulation of loess. The relatively flat topography of the Plains allowed for long-distant dispersal of silts and clay-sized particles. The Plains paleovegetation was sufficient to inhibit major removal of loess subsequent to deposition. Interpretation of the Wisconsinan vegetation varies from a grassland with riparian forests not unlike the present (Leonard and Frye, 1954), to a boreal-coniferous forest in northeastern Kansas (Gruger, 1973), and in the Sand Hills of Nebraska (Bradbury, 1980), to mixed coniferous-deciduous forests in the floodplains with aspen groveland and extensive grassland prairies on the uplands (Jaumann and others, 1986).

The source of the loess in Kansas has been debated for the last 50 yrs. Research has focused on Peoria loess because of its widespread distribution, great thickness, and its surficial position on the landscape. Loveland loess also is widespread, but discontinuous and visible only where it crops out. The source history of Loveland loess in Kansas is probably similar to that of Peoria loess. Bignell loess seems to be restricted to central and western Kansas, southern Nebraska, and eastern Colorado. Its extent, continuity, and age have not been established. Recent evidence by Sorenson and Schmit (1985) indicate the presence of a Holocene-age loess (Bignell?) along the Missouri River in east-central Missouri. The apparent restriction of Bignell loess to west of 97° longitude precludes a direct relationship with continental glacial activity. A glacial-outwash source for Bignell loess could have been the alpine glaciers of the Rocky Mountains. If the Bignell loess is of Holocene age, it may be genetically and climatically related to the huge sand-dune fields in central and western Nebraska and northeastern Colorado.

Three theories have emerged regarding the source of Peoria loess in Kansas: 1) glacial (alpine and continental)-outwash river floodplains, 2) desert regional sources (areas of sand dunes), and 3) regional fluvial and eolian erosion of the Ogallala Formation.

A glacial-outwash loess source was proposed by Frye and Leonard (1952) at the Kansas Geological Survey as a result of work done during the late 1930's and 1940's. The principal glacial-outwash streams recognized were the Missouri, the Platte, and the Arkansas rivers. The Missouri River was the principal source for the loess deposited in northeastern Kansas. The Platte River served as the principal source of loess in north-central, central, and western Kansas. The Arkansas River was considered by Frye to have contributed only coarse materials locally to areas adjacent to its channel in southwestern and south-central Kansas. Swineford and Frye (1951) added that the Republican and Arikaree rivers served as important local supplemental sources of loess in Kansas, but other major streams in Kansas (Big Blue, Smoky Hill, and Solomon rivers) were concluded not to be contributors of loess.

The interpretations by Frye and his coworkers were based on a series of sampling traverses of northeast, north-central, and northwest Kansas; north-central and central Kansas; and southwest Nebraska, northwest, west-central, and southwest Kansas (fig. 9). Peoria loess was sampled for particle-size distribution, major element concentrations, and mineral content. Their conclusions were based on textural variations across each traverse and from minor geographic chemical differences. Median particle size of Peoria loess decreased southward and eastward from points near the Platte, Arikaree, and Republican rivers. The chemical and petrographic data suggested a relatively high degree of chemical uniformity within Peorian loess. Minor geographic differences included higher percentages of dolomite and chert in some northeastern Kansas samples and a higher percentage of calcite in western Kansas samples.

A desert regional source area for Peoria loess was postulated by Lugn (1968). Lugn formulated his hypothesis from his observations of the widespread eolian erosion (dust storms) that typified the 1930's. Based on textural evidence, Lugn concluded that the Sand Hills of Nebraska were the source area for Peoria loess. Lugn considered the Sand Hills to represent the remains of the surficial Ogallala Formation after winds had directly carried away the silts and the clays. From particle-size data, he concluded that the loess source was north of the Platte River in the Sand Hills, and that loess contributions from the outwash-carrying streams like the Platte, Republican, and Missouri rivers were supplemental and only contributed to loess accumulations near the rivers.

Data from recent paleoenvironmental investigations of the Sand Hills in the central Great Plains and their adjacent regions dispute Lugn's premise of a desert environment. Faunal fossils have been found in north-central Kansas and southern Nebraska that suggest a boreal climate persisted during the Wisconsinan Stage (Stewart, 1978; Corner, 1977; Hoffman and Jones, 1970). Bradbury (1980) found evidence that a boreal-coniferous forest occupied the entire Nebraska Sand Hills region.

Lugn's premise that the Nebraska Sand Hills and Peoria loess are contemporaneous appears in doubt as well. Muhs (1985), Ahlbrandt and Fryberger (1980), and Ahlbrandt and others (1983) have dated organic sediments and macrofossils beneath dune sands in Colorado, Wyoming, and Nebraska that show an early Holocene age for the major dune formations. A maximum date of 9,930 ± 140 yrs B. P. was obtained from organic-rich sands underlying eolian sands in the southwestern Nebraska Sand Hills (Ahlbrandt and others, 1983). These dates have not been universally accepted.

Lugn's notion that the Sand Hills were a source for loess may indeed be correct, but not as he envisioned. Silts and clays originally deposited with the sand of the Nebraska Sand Hills may have been removed and deposited elsewhere. If the above dates are accurate, it is possible that the Bignell loess is of Holocene age and is genetically related to the Nebraska Sand Hills deposition instead of the Peoria loess.

The last theory favors a fluvial and eolian source for Peoria loess. From data on test holes through Nebraska Sand Hills sediments, Reed and Dreeszen (1965) postulated that the Ogallala Formation, prior to the Wisconsinan glaciation, was eroded into a hill and valley landscape. The main valleys were filled with sediments grading upward from coarse to fine. During the middle and late Wisconsinan, these sediments were reworked by eolian processes. The silt fraction was blown out regionally to the southeast and the coarse sand blown up where it accumulated locally as dunes. Their theory differs from Lugn's only in the origin of the Sand Hills. They agree with him that the Sand Hills area was a regional source for loess in eastern Nebraska and northern Kansas.

A single-source-area hypothesis does not satisfactorily explain the discontinuity in distribution and the variation in thickness of the Peoria loess found in Kansas. From data on loess thickness in northeastern Kansas, it is apparent that the Missouri River was the principal source for Peoria loess. The great thickness of loess adjacent to the Missouri River in Kansas, Missouri, Iowa, and Nebraska and its decrease in thickness and particle size with distance away from the river valley is strong evidence for the river as a major loess source.

The source of loess in central and western Kansas is not so readily apparent. The conclusions made by Swineford and Frye (1951) were based on a relatively small number of samples. Forty-two sites covering 80,000 mi^2 (128,000 km^2) were sampled for textural data. Only seven locations were selected for mineral and chemical analyses. It was erroneous of them to conclude that the minor rivers in western and northern Kansas such as Smoky Hill, Saline,

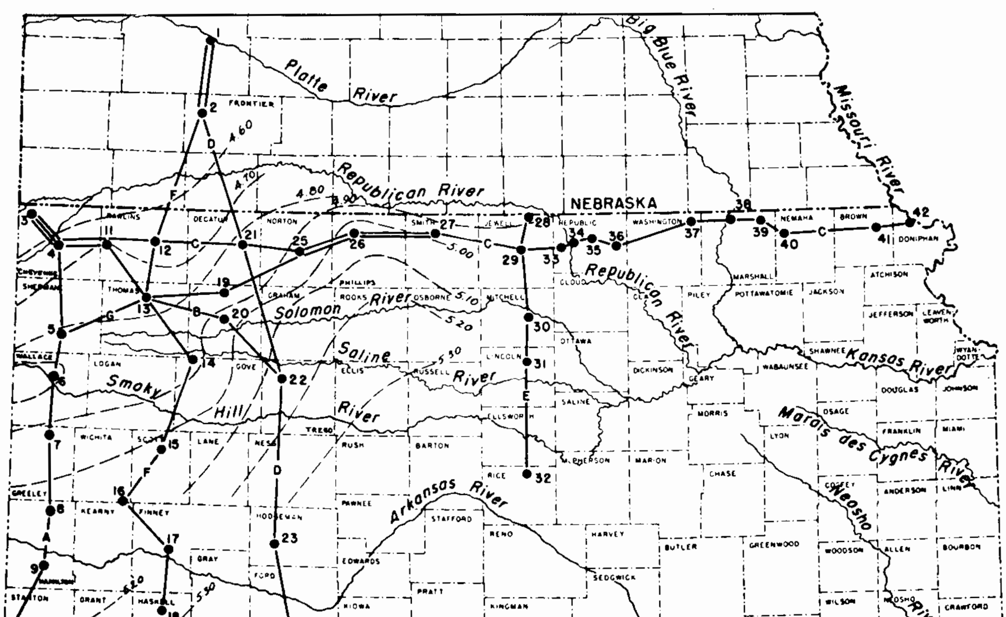

FIGURE 9--MAP OF KANSAS AND SOUTHERN NEBRASKA SHOWING SITES OF PEORIA LOESS SAMPLED BY SWINEFORD AND FRYE (1951). Dashed lines show generalized equivalence of Phi median diameter.

Solomon, Big Blue, and Little Blue were insignificant contributors to loess production based on one or two data points near their respective channels. Additionally, the chemical variability of loess cannot be determined from such a small number of samples. If mineral differences exist regionally as indicated by Swineford and Frye (1951), then chemical differences should also exist. Unfortunately, substantial and reliable chemical data on Kansas loesses have not been collected.

The Platte River undoubtedly contributed massive quantities of loess during glacial stages as reasoned by Swineford and Frye (1951). In addition, nonglacial rivers in western Kansas and Nebraska probably contributed substantially more to the volume of loess in the area than previously suspected. Local loess deposits in excess of 75 ft (23 m) have been measured along the southeastern bluffs of the Arikaree and Republican rivers (Swineford and Frye, 1951; Prescott, 1952; and Weist, 1964). The role of these rivers was not completely explained by Swineford and Frye (1951). These rivers were not under the direct influence of Rocky Mountain glaciation as stated by Leonard (1951); their headwaters are in eastern Colorado.

Swineford and Frye (1951) concluded that the Arkansas River carried too sandy a sediment load to act as a major loess source. They suggested that most of the loess deposited south of the Arkansas River in southwest Kansas was derived from northern sources. Swineford and Frye's conclusions were based on two loess samples south of the river which had median grain sizes progressively smaller than samples along a traverse north of the river (fig. 10). Samples taken adjacent to the Arkansas River were much coarser. Not mentioned was a third sample taken south of the river which would have shown an increase in median grain size of the loess (sample 24, Clark County). Three samples seem insufficient for making any significant interpretations regarding the source of loess for the whole southwestern area of Kansas. The loess deposits south of the Arkansas River from the Colorado state line eastward to Cowley County in south-central Kansas have not been studied in any detail.

As a result of reviewing loess literature of the past 50 yrs on sources of loess in the central Great Plains and our generalized loess-distribution map of Kansas (fig. 6), we conclude that loess in northwest, north-central, west-central, central, southwest, and south-central Kansas was derived from regional sand-dune areas in central and western Nebraska (Sand Hills area) and southwest Nebraska, eastern Colorado, and southwest and south-central Kansas; from alpine glacial-outwash sediments of the floodplains of the Platte and Arkansas rivers; and from floodplain sediments of nonglacial rivers such as the Arikaree, Republican, Solomon, Saline, Smoky Hill, Pawnee, and Cimarron.

East of the Republican River in north-central Kansas and in northeast Kansas, we conclude loess was derived regionally from the Sand Hills area of Nebraska, from continental glacial-outwash sediments in southeast Nebraska and northeast Kansas, and from floodplain sediments of nonglacial rivers such as the Big Blue, Little Blue, and Delaware.

In northeast Kansas along the Missouri River, we conclude loess was derived from continental glacial-outwash sediment in the floodplain of the river.

Lastly, we conclude that there is not sufficient information available to assess the volume that each loess source contributed to the total volume of loess deposited in the state.

The erosion and subsequent sedimentation of the Ogallala Formation in response to the fluctuating climate during the Pleistocene has not been adequately evaluated. Reed and Dreeszen (1965) alluded to this in postulating a regional source for loess in Nebraska. Other large rivers draining the Ogallala sediments such as the Arikaree, Republican, Solomon, Saline, Smoky Hill, and Pawnee may have contributed loess. Thin but recognizable loess deposits occur adjacent to the Solomon River in Ottawa County and adjacent to the Saline River in Ellis, Russell, and Lincoln counties (U.S. Department of Agriculture, 1960-1986).

For east-central Kansas, we believe that a thin loess mantle existed during the late Wisconsinan. Discontinuous but recognizable loess deposits occur adjacent to the Kansas River from Rossville in Shawnee County to Kansas City in Wyandotte County. This loess probably could not originate from a source other than the Kansas River valley. Since the Kansas River was not a continental glacial-outwash river during the late Pleistocene as it was during the early Pleistocene, the loess probably was derived from erosion of upper loess deposits within the drainage basin. The loess blanketing Johnson and northern Miami counties probably was derived from the Missouri River; however, the Kansas River cannot be ruled out as a source.

The suspected loess-related deposits in central and southeast Kansas also probably had multiple sources. The Kansas–Republican river system might have been a source. The Marais des Cygnes, Verdigris, and Cottonwood–Neosho rivers flowing southeastward through the area likely were loess sources. Strong and persistent south winds that typically occur during the summer may have been of sufficient duration to transport loess from the Arkansas River valley. Total accumulations within the region are difficult to determine because little if any loess persists today as a recognizable unit. The rate of erosion evidently exceeded the rate of loess deposition or the rate of deposition equaled the rate of soil formation. The loess is incorporated in surface horizons of modern soils formed in old Pleistocene alluvium on broad, flat, upland areas. The age of these loess deposits is difficult to determine. The loess may be the result of more recent processes of deposition during the Holocene.

Loessal soils

As a result of time, rate of deposition, multiple sources, and distance from sources, loess forms a complex blanket on the Kansas landscape. The relationships between loess thickness and texture to distance from a source have been described quantitatively by several authors (Frazee and others, 1970; Handy, 1976; Simonson and Hutton, 1954). As distance from a loess source increases, the loess deposit becomes thinner and more finely textured. The rate of loess deposition decreases with distance from a source due to differential settlement of particles within the loess. The greatest rate of loess deposition occurs adjacent to the source area.

These relationships are a major influence in the distribution of modern loess-derived soils. In northeastern Kansas, northwestern Missouri, and southwestern Iowa, soils developed in Peoria loess form narrow bands paralleling the Missouri River (Hanna and Bidwell, 1955; Hutton, 1947, 1950; Springer, 1948). The soils farthest from the river show the greatest degree of weathering and soils nearest the river exhibit the least amount of weathering. Hanna and Bidwell (1955) studied soils along a traverse perpendicular to the Missouri River in Brown County, Kansas, and found that the difference in the amount of clay between the alluvial (B) and parent-material (C) horizons was maximum in the Grundy soil sampled 24 mi (38 km) from the river and was minimum in the Monona soil sampled 2 mi (3 km) from the river. Other trends the authors observed with increasing distance from the Missouri River were 1) a decrease in pH, 2) an increase in organic matter, and 3) an increase in the ratio of sand in the surface A horizon to sand in the C horizon.

Springer (1948) studied the Hamburg, Knox, Marshall, and Sharpsburg soils. The Hamburg soil, located on hilly terrain along the Missouri River bluffs, has the least development (no B horizon) and is calcareous throughout the profile. The Knox, Marshall, and Sharpsburg are more weathered than the Hamburg soil and showed about the same degree of development. The soils were sampled within 9 mi (14 km) of the river. Hutton (1947, 1950) examined the physical and chemical composition of loess-derived soils in southwestern Iowa to determine weathering relationships in soils formed in Peoria loess. He concluded the texture of the parent material and the rate of loess deposition were the dominant soil-forming factors that explained the increase in the degree of weathering for the Monona–Sharpsburg–Seymour chronostratigraphic-lithostratigraphic sequence. The Monona silt loam, developed in loess 500–700 inches (1,250–1,750 cm) thick, is the youngest soil morphologically. It contains more sand and coarse silt throughout its profile than the Sharpsburg and Seymour soils. The Seymour silty clay loam is the oldest soil morphologically. It developed in loess 100 inches (250 cm) thick and contains more clay throughout its profile than both the Monona and Sharpsburg soils. The Sharpsburg silty clay loam developed in loess 150–250 inches (375–625 cm) thick. It is texturally similar to the Seymour soil but contains less clay in its profile. The Monona, Sharpsburg, and Seymour soils were sampled 20–40 mi (32–64 km), 90–100 mi (144–160 km), and 160–170 mi (256–425 km) from the Missouri River, respectively. Hutton concluded that within 50-60 mi (125–150 km) of the loess source, the nature of the parent material was the dominant soil-forming

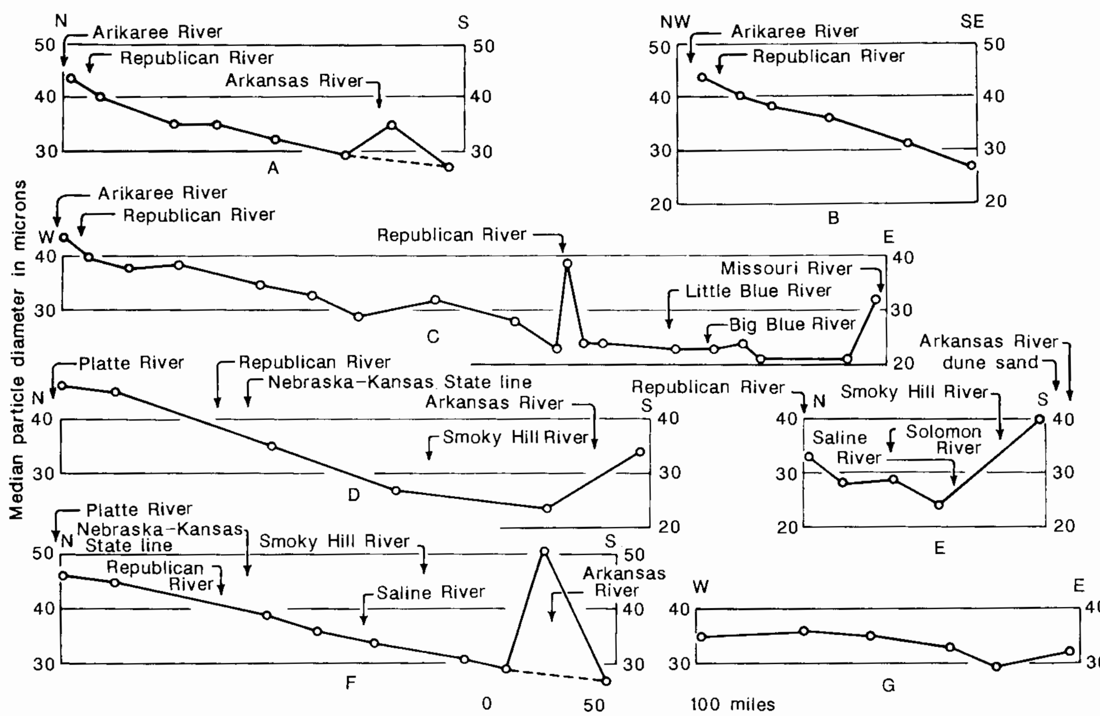

FIGURE 10—Textural traverses of Peoria loess in Nebraska and Kansas (Swineford and Frye, 1951). Letters correspond to lettered traverses in fig. 9.

factor. Beyond 60 mi (150 km), the rate of loess deposition was the dominant soil-forming factor. At this distance the rate of loess deposition approached the rate of weathering and the two processes operated concurrently.

The relationship between loess formations and modern soils formed in loess has received little study. In locations where the Loveland, Peoria, and Bignell loesses are present together, it is not uncommon for all three to be exposed along sloping terrain. Kansas soils mentioned in the literature as having been developed in a particular loess are given in table 1. Ruhe (1984) suggested that the changes in clay parameters along a transect from eastern Iowa to northwestern Kansas were due to a change in loess type from Peoria loess east of the Missouri River to Bignell loess west of the river. According to Ruhe, the Harney and Holdrege and Keith and Ulysses soils of Kansas developed in Bignell loess. These soils are the most widely occurring loess soils in central and western Kansas, respectively. The distribution of the Bignell loess may not be that extensive. Several exposures of Peoria loess have been mapped Holdrege, Harney, Keith, or Ulysses in the soil surveys. This contradiction is due to the uncertainty of the areal extent of Bignell loess in Kansas because of its apparent chemical and physical similarity to Peoria loess. Morphologically the Bignell loess can only be distinguished from the Peoria loess by the presence of the Brady paleosol. The Kuma soil of eastern Colorado contains a well developed buried soil that is over 30 inches (76 cm) thick and probably correlates with the Brady paleosol. In Kansas, the Kuma soil contains a weak buried soil 13 inches (33 cm) thick that may correlate with the Brady paleosol. Other loess-derived soils such as the Holdrege, Harney, Keith, and Ulysses typically do not contain buried soils within their profiles.

In east-central and southeast Kansas, many modern soils formed in old Pleistocene alluvium seem to have a loess constituent in their upper profile (fig. 6). The source and age of the loess component is unknown, although much of the contamination of surface horizons may have occurred during Recent (Holocene) time.

The major reason for reviewing the nature of loess in Kansas was to acquire background information for a study on the spatial variations of loess in Kansas by studying the geochemistry of modern soils formed in loess. Earlier chemical analyses of loess in Kansas (Frye and Fent, 1947; Frye and others, 1949; Swineford and Frye, 1951) included only major elements (Ca, Mg, Na, K) which occur naturally in large amounts. Sampling was not random and was not based on a statistical design and a test for significance. A multi-element study examining trace-element (As, Cd, Co, Cr, Cu, Pb, Ni, Se, and Zn) concentrations and distributions in soils formed in loess is in progress at the Kansas Geological Survey (Welch and Hale, 1985). Representative profiles of major soils of Kansas developed in loess were sampled by horizon. Sample locations spaced

TABLE 1—Association of modern soils and Pleistocene loess formations in Kansas.

Soil	Loess formation	County	Source
Butler	Peoria	Republic	soil survey
Colby	Peoria	Grant and Logan	soil surveys; Paliwal and others, 1964
Coly	Peoria	Ness and Norton	soil surveys
Crete	Peoria	Barton, McPherson, Ottawa, Rice, and Russell	soil surveys
Geary	Loveland	Barton, McPherson, Rice, Riley, and Russell	soil surveys
		Jewell	Fishel and Leonard, 1955; soil survey
Grundy	Peoria	Jefferson and Leavenworth	soil surveys
		Brown	Bayne and Schoewe, 1967; soil survey
Gymer	Loveland	Douglas, Jefferson, and Leavenworth	soil surveys
Haig	Peoria	Leavenworth	soil survey
Hamburg	Bignell	Doniphan	Frye and Leonard, 1949
Harney	Bignell	all locations	Ruhe, 1984
		Lane	soil survey
	Peoria	Jewell	Fishel and Leonard, 1955; soil survey
		Barton, Ellis, Hodgeman, Ottawa, Rush, and Russell	soil surveys
Hastings	Peoria	Republic	soil survey
		Cloud	Bayne and Walters, 1959; soil survey
Holdrege	Bignell	all locations	Ruhe, 1984
		Norton	Frye and Fent, 1947; soil survey
	Peoria	Norton	Frye and Fent, 1947; soil survey
		Graham	Prescott, 1955; soil survey
		Jewell	Fishel and Leonard, 1955; soil survey
Keith	Bignell	all locations	Ruhe, 1984
		Sheridan	Bayne, 1956; soil survey
	Peoria	Logan	soil survey
		Sheridan	Bayne, 1956; soil survey
Kenesaw	Peoria	Republic and Riley	soil surveys
Marshall	Peoria	Leavenworth	soil survey
Monona	Peoria	Doniphan	Frye and Leonard, A. B., 1949; soil survey
Nuckolls	Loveland	Jewell, Russell, and Smith	soil surveys
Richfield	Peoria	Grant, Haskell, and Hodgeman	soil surveys
Sharpsburg	Peoria	Douglas, Leavenworth, and Shawnee	soil surveys
Smolan	Loveland	McPherson, Rice, and Riley	soil surveys
Spearville	Peoria	Haskell and Hodgeman	soil surveys
Uly	Peoria	Norton	Frye and Leonard, A. B., 1949; soil survey
		Graham	Prescott, 1955; soil survey
		Barton, Clark, Ness, and Smith	soil surveys

widely around the state were randomly selected. We hope that the data from this preliminary statistical and systematic analysis of loessal soils in Kansas will provide some answers concerning distribution, multiple sources, and relative ages of loesses in Kansas.

Examination of several trace elements on a horizon-by-horizon basis may also provide evidence of the effects of secondary local processes such as weathering, reworking by wind and water, and mixing of loess with other materials on loess deposits. The Ulysses series just north of the Arkansas River in western Kansas generally has a coarser textured surface (A) horizon than that found in the surface (A) horizon of the Ulysses series further north. This is thought to be from contamination by sand from the Arkansas River floodplain and adjacent dunes.

Summary and conclusions

Modern soil surveys with soil maps based on intensive field sampling and observations have increased our knowledge of the areal distribution of loess in Kansas. However, more data for better control on loess thickness and distribution on a formation basis are needed. Nearly all the available loess-thickness data for Kansas is entombed in drill logs of county geology and hydrology reports. Most of these data are inconsistent and unreliable for a number of reasons. Acquisition of reliable thickness data on a systematic basis is needed to better understand the vertical and lateral variability of loess units. Data on lateral variability of thickness would better delineate source areas of Kansas loess. Data on vertical variability would allow more precise division of Peoria loess.

Radiocarbon dates of Kansas loesses are needed. Dating would allow better correlation of Kansas loess stratigraphy with that of adjacent states and would assist in deciphering between Bignell and Peoria loesses, especially where the Brady soil does not exist. Dating could better delineate the extent of the Bignell loess in Kansas and could assist in determining whether the Bignell loess is Wisconsinan or Holocene in age. Dating may lead to the discovery of Holocene-age loesses in Kansas younger than the Bignell. Loess deposition is occurring in the present, although not at the rate as during the late Wisconsinan and early Holocene.

For almost 35 yrs, research on Kansas Pleistocene geology has been all but nonexistent in Kansas. This report shows there is need for such research. However, due to lack of interest, lack of funding, and the perception of the work by some as basic data gathering, we feel little progress will be made in Kansas in this important area of geology. Similar considerations and perceptions were discussed 24 yrs ago in a symposium paper presented before the geology section of the Kansas Academy of Science.

Two-thirds of Kansas is covered by loess and modern soils have developed in the surface of these loesses where they can be sampled easily and inexpensively. These soils should be studied and analyzed as a starting point for renewed studies on Kansas loesses. A quantitative and statistical trace-element geochemical study of loessal soils could provide, in addition to geochemical identification of loesses, information on the distribution of loess formations, location of source areas, and effect(s) of local processes on distribution.

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Remote sensing and geophysical investigations of glacial buried valleys in northeastern Kansas

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Abstract

Aquifers found in glacial buried valleys are a major source of good-quality ground water in northeastern Kansas. The extent and character of many of these deposits are not known precisely, so a detailed study of the buried valleys was undertaken. Test drilling, Landsat imagery, shallow-earth-temperature measurements, seismic refraction, surface electrical resistivity, and gravity data were used to evaluate two sites in Nemaha and Jefferson counties. Tonal patterns on springtime Landsat imagery and winter/summer anomalies in shallow-earth temperatures were quick and inexpensive methods used in locating some glacial buried aquifers and suggested areas for more intensive field studies. Reversed seismic refraction and resistivity surveys were generally reliable indicators of the presence or absence of glacial buried valleys, with most depth determinations being within 25% of test-drilling results. The effectiveness of expensive test-hole drilling was greatly increased by integrating remote-sensing, shallow-earth-temperature, seismic, and resistivity techniques in the two buried-valley test areas. A gravity profile allowed precise definition of the extent of one of the channels after the other techniques had been used for general information.

Introduction

As population and demand for water increase, ground-water supplies are gaining significance in northeastern Kansas. They are especially important during times of low precipitation, when surface-water supplies decline. Although bedrock formations in the area generally contain little, if any, high-quality water, large quantities of freshwater may be obtained from deposits in glacial buried valleys. To locate these aquifers, a program integrating remote-sensing, geophysical, and test-drilling techniques has been used.

Two small test sites were chosen from the general study region, which includes 16 counties in northeastern Kansas (fig. 1). The distinctive test sites include a broad, deep channel in Nemaha County and a very narrow, deep channel in Jefferson County. They were chosen to evaluate the applicability of the remote-sensing and geophysical methods for delineating buried valleys in the larger study region.

The general study area represents the counties that were entirely or partially glaciated during pre-Illinoian time. Quaternary deposits exposed in northeastern Kansas include glacial drift (till, outwash, and lacustrine deposits), loess, and alluvium. Pennsylvanian and Permian shale, limestone, and sandstone bedrock formations occur near the land surface in other areas.

The general location of preglacial drainage ways is shown in fig. 2. The buried valleys may be up to 3 mi (5 km) wide, 400 ft (120 m) deep, and more than 75 mi (120 km) long. Deposits filling these valleys range from clayey sediments to sand and gravel. Many of the buried-valley aquifers are confined, while others are unconfined. Water levels are commonly between 5 and 50 ft (1.5–15 m) below the land surface, but locally they may exceed 100 ft (30 m). Aquifer yields range to approximately 500 gal/min (31 L/sec).

To investigate the 16-county study area, data have been compiled from such sources as water-, oil-, and gas-well drillers; engineering firms; and previous hydrogeologic studies. Naturally, in the 9,500 mi^2 (24,600 km^2) region are many areas with little or no reliable data. Positive results in the Nemaha and Jefferson County test sites demonstrate the benefit of using remote-sensing, temperature-profiling, seismic, resistivity, and gravity methods to maximize the effectiveness of test drilling for locating and evaluating other glacial buried-valley aquifers.

Techniques

The remote sensing, temperature, seismic, and resistivity methods used in this study are described by Denne et al. (1982). The gravity technique is detailed by Heider (1982). Only a brief discussion of the research methods and references is included here.

Remote sensing utilizing Landsat data

Springtime Landsat imagery has been shown to be useful for analysis of glacial deposits in the Midwest (Peterson et al., 1975; Lucas and Taranik, 1977), so imagery from March, April, and May was evaluated for northeastern Kansas. On several false-color composite images, tonal patterns were identified that were thought to be associated with buried valleys in Nemaha, Marshall, and other counties. These image patterns form faint curving paths that cut across landscape features, but often follow topographic highs. The image patterns have a blue-gray color on the false-color composites and dark-gray tones on black-and-white prints of the infrared spectral bands. They are probably related to variations in surficial materials, which in turn influence variations in soil-moisture content. These differences are most apparent in spring when the growth of vegetation is just beginning. When these images are compared to the preglacial drainage map of the lower Missouri basin (Dreeszen and Burchett, 1971), a general correspondence between image patterns and some mapped buried valleys can be seen.

Computer-enhanced imagery proved to be more useful than unenhanced standard products in delineating tonal patterns thought to be associated with buried valleys. Available EDIES (EROS Data Center Digital Image Enhancement System) imagery was evaluated for the study area. To delineate image patterns even more readily, a linear-contrast-enhancement technique (for a general discussion, see Taranik, 1978) was applied to a springtime Landsat scene at the U.S. Geological Survey's EROS Data Center. An interactive multispectral image-analyzing system (General Electric Image 100) was used to maximize the difference between the light and dark image tones associated with the buried channel in Nemaha County on an infrared band (Landsat, band 7, May 3, 1976, ID #246716171). The enhanced band 7 was recorded on film by a laser-beam recorder. A subscene covering the study area was extracted photographically and printed at 1: 125,000 scale. A pattern analysis was completed for this subscene, and areas thought to have buried valleys were delineated. This approach formed the strategy for more intensive field-exploration techniques.

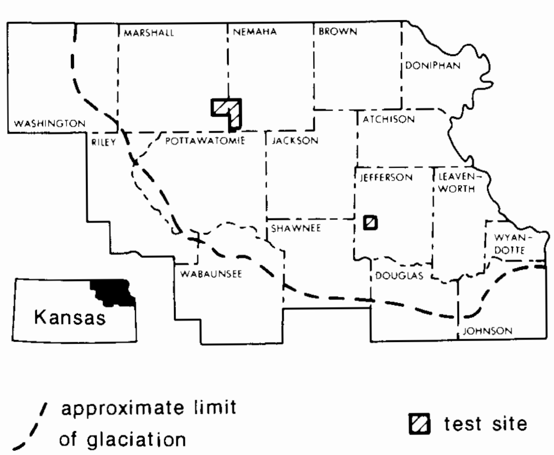

FIGURE 1—General buried-valley study area and test sites.

Reversed seismic refraction

Seismic-refraction techniques were developed largely in the 1920's and 30's for petroleum exploration. Although for petroleum prospecting, reflection profiling has largely supplanted refraction work, seismic refraction remains a viable means of rapid, inexpensive probing of the earth for reconnaissance, for delineation of the deep earth crust, and for very shallow geologic evaluation. In addition, refraction profiling provides a direct means of measuring the seismic P-wave velocity of the high-velocity layers in the earth, a measurement that reflection techniques can only indirectly and inaccurately determine. Refraction prospecting is thoroughly covered in the literature (Musgrave, 1967; Dobrin, 1976).

Reversed-refraction profiling was used in these studies. It involves placing shots at either end of the geophone (receiver) spread such that measurements are made in both directions of the line. This technique can allow appropriate interpretations of many situations which would be unresolved by unreversed, single-ended refraction profiling. For example, reversed profiling provides a measure of true velocity and dip, confirms faults and lateral velocity change, and substantiates the interpretation of travel-time anomalies.

Several assumptions are made in reversed-refraction profiling:

1. Geologic units exist as discrete continuous layers.
2. Units are homogeneous and isotropic to the passage of seismic P-waves; i.e., the scale of heterogeneities is much less than the seismic wavelength [about 100 ft (30 m)].
3. Interfaces between units are roughly planar, even if dipping. Undulations are of small amplitude and long wavelength relative to the spread of geophones [about 100 ft (30 m)].
4. Units are at least as thick as a substantial fraction of the wavelength of seismic P-waves.
5. P-wave velocity of units increases with depth.

Violations of these assumptions affect the interpretability of the data and accuracy of the results. Areas with glacial tills and/or alluvium can challenge some of the assumptions. Sand and clay lenses or channel deposits in tills and velocity anisotropy of alluvium may violate item 2 (Denne et al., 1982), and results of this study suggest that rugosity of the till/alluvium-bedrock interface may be beyond the tolerances of item 3. However, the units being measured are of adequate thickness (item 4). The presence of low-velocity zones (item 5) would cause calculated bedrock depths to be too deep.

Data were recorded onto magnetic tape using an Input/Output DHR (Digital High Resolution) 1632 seismograph. (The use of specific product names throughout the text is for identification only and does not imply endorsement by the Kansas Geological Survey.) In Jefferson County, data were recorded on eight channels using up to 1.5 lbs (0.68 kg) of explosives. The remainder of the data were recorded with 12 channels using either an earth compactor Mini-SOSIE (Barbier and Viallix, 1973) or Betsy Seisgun source. Betsy Seisgun is an eight-gauge ring-blaster kiln gun designed to fire a 3-ounce (85-g) slug into the ground vertically.

Data analyses were done using a hand-held computer and program by Stander (1977). The program solved for true velocity, thickness, and dip for any number of layers. Computer-enhancement processing (filtering) was occasionally done to aid first-pick arrival. In general, the reduction of refraction data is done in the field on a real-time basis. This procedure is advisable as the evaluation of results can then affect the field work.

Resistivity

Surface geoelectric methods can be used to locate hydrogeologic targets of interest in the subsurface, providing the target is sufficiently large and differs enough in resistivity from surrounding material to be distinguished. The minimum relative size of a target necessary for detection increases with depth below the land surface. Layered materials with high-resistivity values [greater than 200 ohm-ft (61 ohm-m)] such as sand, gravel, and limestone can usually be distinguished from lower-resistivity materials such as clay and shale, providing the individual layers are of adequate thickness.

Vertical electrical soundings (VES) are used to determine the vertical differences in apparent resistivity caused by different geologic units (Zohdy et al., 1974). In this study, the Schlumberger electrode array (Zohdy et al., 1974) was used to generate apparent resistivity curves. Values of apparent resistivity were calculated from measurements of a controlled source of current transmitted through the outer probes in the array and the potential difference between the inner probes and a computation of a geometric factor for the array. Inaccuracies caused by lateral inhomogeneities in the shallow subsurface are minimized using the Schlumberger array.

Apparent resistivity data were collected using a Bison Model 2390 Signal Enhancement Resistivity System. The VES curves were interpreted using an automated inversion program developed by Zohdy (1973). The program computes a geoelectric layering of the subsurface that is consistent with the apparent resistivity data.

Temperature profiling

Shallow-earth temperature profiling for aquifers uses variations in the thermal properties of geologic materials and water (Cartwright, 1968). Unconsolidated sediments have relatively low thermal conductivities, water is intermediate, and bedrock units have much higher values. The materials, therefore, respond differently to a changing temperature environment. The presence of water in unconsolidated deposits significantly changes the thermal properties of the deposits because of the very high specific heat of water and its greater thermal conductivity. The water may then cause a shallow aquifer to act as a heat sink or a heat source. If an aquifer has distinct lateral boundaries and if the temperature effects of other heat sources or losses can be eliminated or evaluated, a positive (warm) anomaly would be expected over it in winter, and a negative anomaly would be expected in summer.

Field measurement of soil temperatures in the southwestern part of the general study area indicates that diurnal-temperature effects are not significant there at depths of 4 ft (1.2 m), so this depth was adopted for our study. The 4-ft (1.2-m)-deep measurement holes were drilled using a hand probe or truck-mounted core barrel or auger. The instrumentation for measuring soil temperature consisted of a general-purpose thermistor probe epoxied at the end of a 0.375-inch (0.95-cm)-diameter clear-plastic rigid tube and a battery-powered, lightweight YSI (Yellow Springs Instrument Co., Inc.) model-46 telethermometer.

Gravity

Bedrock formations are typically more dense than the overlying glacial sediments. If the density contrast between glacial sediments and bedrock is large enough, bedrock relief should be detectable by gravity measurements (Carmichael and Henry, 1977). A depression in the bedrock surface, which is filled with sediments, causes a gravity low in comparison to a flat-bedrock topography.

To test the applicability of this technique in the glaciated portion of northeastern Kansas, a gravity profile was taken over a known buried valley in Jefferson County. Gravity measurements, using a Lacoste–Romberg Model G meter (no. 245), were taken every 50 ft (15 m) over a distance of 2,300 ft (690 m). The elevations of measurement stations were surveyed to 0.01 ft (0.003 m), but benchmark control allows certainty to only ± 0.5 ft (0.015 m), which corresponds to a gravity-measurement uncertainty of ± 0.03 milligals. Repeated base-station readings were used to make gravity corrections for the earth's tidal variation and for meter drift. A Bouguer gravity-anomaly value was calculated for each station using a density of 2.0 gm/cm^3. Terrain corrections were not required because of the low relief. A linear regional gradient, determined by least squares, of 0.023 milligals/100 ft (30 m) along the profile was subtracted from the Bouguer anomaly values. A forward modeling program, based on prism calculations of Goodacre (1973), was used to model the bedrock relief underlying the profile. Bedrock and glacial-fill densities were estimated from borehole-density logs in the area. For further details on gravity-data acquisition, reduction, and modeling techniques used, see Heider (1982).

Drill logs

Test drilling was used to verify the presence of buried valleys and to evaluate the character of the aquifers. Shallow (less that 107 ft [33 m]) auger holes and deep (100–400 ft [30–122m]) rotary holes were drilled. In addition, logs were obtained from water-well and oil and gas drillers, engineering firms, and other government agencies. In the two test areas, more holes were drilled in regions where interpretations of remote-sensing and geophysical data suggested the presence of buried valleys. In both drill-hole and geophysical analyses, differentiating glacial clays from shale bedrock was often difficult.

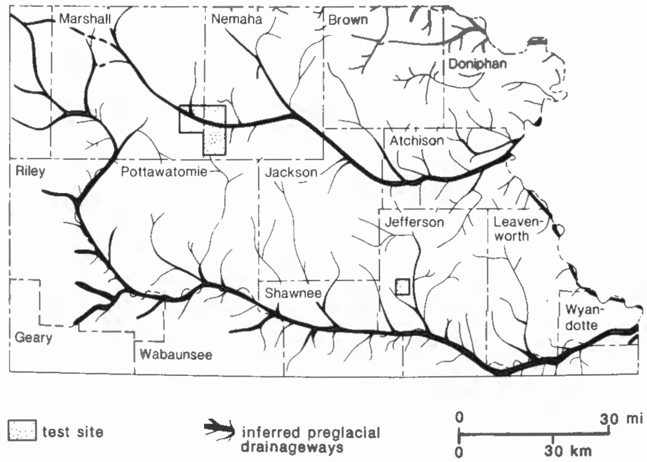

FIGURE 2—PREGLACIAL DRAINAGE MAP OF NORTHEASTERN KANSAS (after Dreeszen and Burchett, 1971) and test sites.

Case studies

Two small areas in Nemaha and Jefferson counties were intensively studied using a combination of the methods previously discussed. These locations were chosen for their distinctive types of buried valleys. One channel ranged up to 3 mi (5 km) in width and 400 ft (120 m) in depth, while the other is only about 500 ft (150 m) wide in places, but is still 100-200 ft (30-60 m) deep.

Nemaha County

The major buried valley of northeastern Kansas is a tributary of the ancestral Grand River in Missouri. It occurs in the southern part of Nemaha County, Kansas (fig. 2), where the valley fill is known to be as much as 380 ft (116 m) thick. A basal gravel, generally less than 20 ft (6 m)

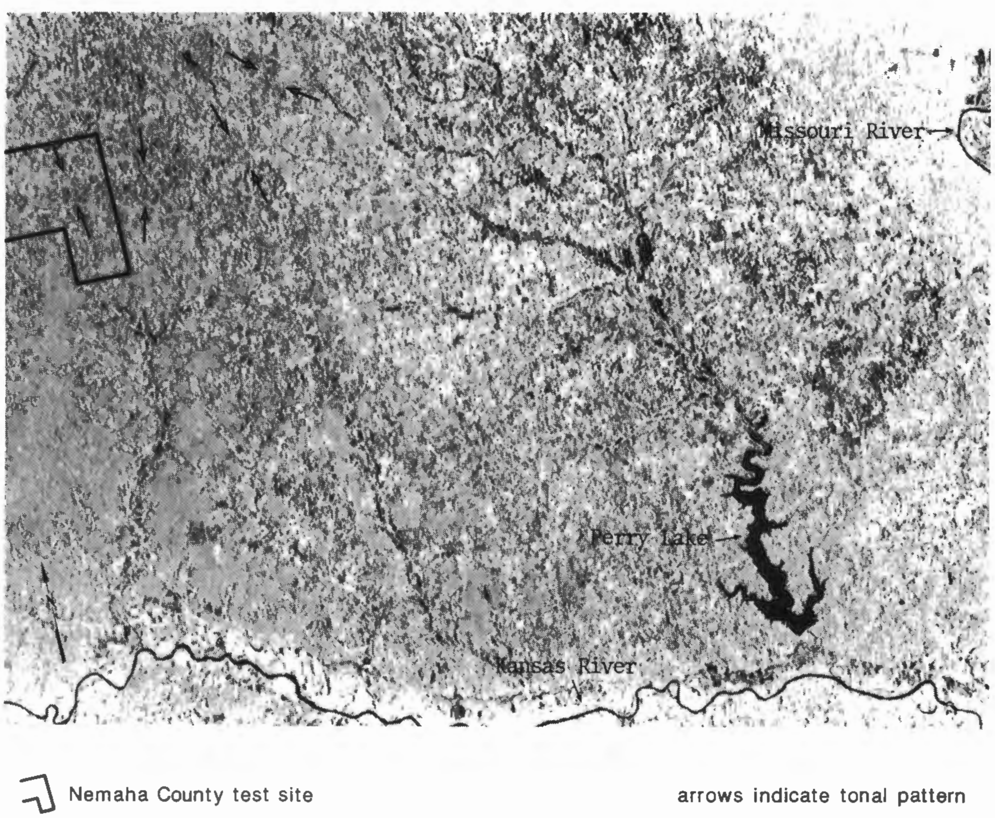

FIGURE 3—ENHANCED BAND 7 LANDSAT SUBSCENE FOR NORTHEASTERN KANSAS. Image ID #246716171, path 29, row 33, May 3, 1976.

thick, is overlain by heterogeneous clayey sediments, and sand and gravel layers are found between the clays. Aquifer yields range to about 350 gpm (22 L/sec).

Most of Nemaha County is covered by glacial drift. Alluvial deposits occur along most of the modern streams, and bedrock outcrops are found in the extreme southern, northern, and locally in the central parts of the county.

On Landsat imagery for Nemaha County, variations in topography, land use, and surficial materials with their attendant moisture content form complex, interrelated patterns to be analyzed. Using conventional techniques of airphoto interpretation, a narrow band of dark-gray tone that curves from the southeast part of Marshall County to the east-central part of Nemaha County was delineated on the enhanced band 7 subscene from May 3, 1976 (fig. 3). For more than 10 mi (16 km) in southwest Nemaha County, the axis of the major buried valley as mapped by Ward (1974) falls within the tonal pattern delineated from the image. Seemingly, the entire pattern may be associated with a lobate-end moraine and ice-marginal drainage.

A test line of thermal, resistivity, seismic, and drill-hole sites in Nemaha County is shown in fig. 4. The buried-valley axes as mapped by Ward (1974), and the orientation and extent of the pattern delineated from the enhanced Landsat imagery also are shown. On the Landsat image, the northern boundary of the tonal pattern is distinct, while the southern edge is less well defined because of gradational changes in tone.

The surface topography and field data from the Nemaha County test line are profiled in fig. 5. The outer limits of the valley system along this profile are defined at least by bedrock exposures at the south end (site J) and 1 mi (1.6 km) north of A. The seven rotary test holes were drilled for the present study.

Test-hole data at B and D indicate a steeply sloping north valley wall. This correlates well with the north edge of the Landsat pattern. The deepest part of the channel occurs between D and E, and these holes contain 8-19 ft (2-5.8 m) of basal gravel and sand. The Landsat pattern extends only about 0.5 mi (0.8 km) south of E, but test-hole F, with 8 ft (2 m) of basal sand and gravel, seems to be on the gently sloping south side of the valley. This interpretation is contrary to Ward's (1974) bedrock topographic map, which shows a bedrock high (between F and G).

The main-channel axis does pass near D as mapped by Ward (1974), but a major tributary does not go through G. A test hole at G revealed 149 ft (45 m) of silty and fine sandy glaciofluvial material overlain by 52 ft (16 m) of till, but the bedrock elevation was 130 ft (40 m) above the 1,000-ft (305-m) contour as previously mapped. Test-hole G also seems to be on the gently sloping south valley wall of the main channel.

Interpretations of resistivity data yielded bedrock depths (fig. 5) that were generally within 25% of actual test-hole values. Bedrock depths were interpreted to be shallower than was indicated from drill-hole data at sites H, F, and D. The resistivity estimate was 3% off at E, and no drill-hole information is available at site I. The discrepancies between the estimated and actual depths to bedrock could be attributed to a number of factors including the accuracy of the instrument, lack of sufficient resistivity contrast between the bedrock and glacial materials, and too few vertical electrical soundings for the complex geoelectric layering in the subsurface. The maximum current that can be transmitted by the Bison instrument is 0.1 amps. The ability to transmit greater amounts of current would have allowed for more reproducible values of the potential-difference measurement, and thus a more accurate apparent resistivity curve. Additionally, more VES sites along the profile would have produced better correlation laterally between VES sites and could have facilitated the depth-to-bedrock determinations in this geologically complex setting.

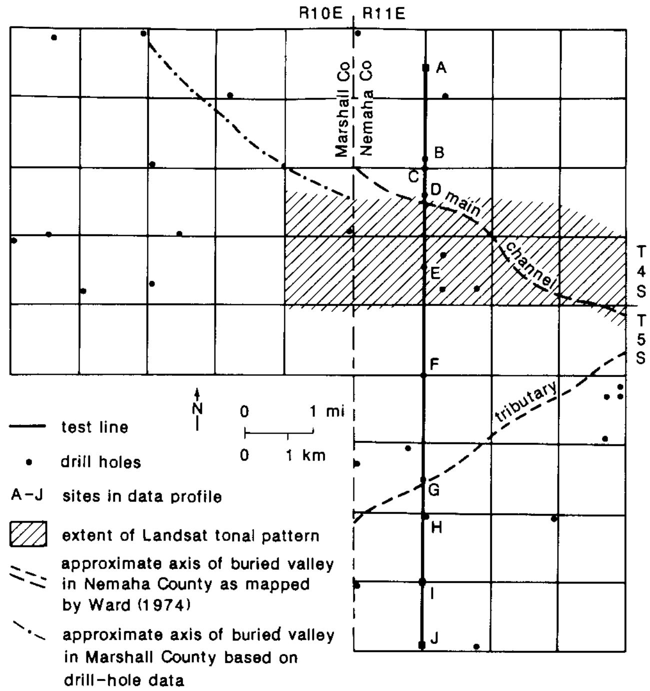

FIGURE 4—TEST SITES IN PARTS OF NEMAHA AND MARSHALL COUNTIES.

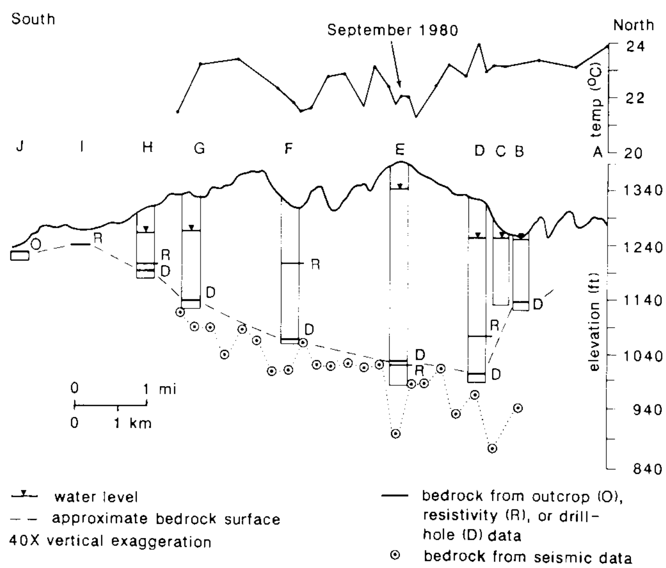

FIGURE 5—DATA PROFILE FOR NEMAHA COUNTY TEST LINE; letter above profile indicates test site.

Results of the reversed seismic-refraction profile suggest general agreement with drill-hole data. There is, however, a consistent tendency for the refraction results to be too deep, suggesting the presence of a low-velocity zone. One of the fundamental problems of seismic work is that frequently some uncertainty exists as to where the measurement comes from. For instance, unlike the drill, seismic energy does not travel straight up and down but rather takes the most expedient path. This means that the depth points may be placed with some error and could even be out of the plane of the profile.

The seismic bedrock point under E shows a deep valley which by drill evidence may not exist. Because this "valley" is determined by only one measurement, it could be an error, but the data defy interpretation that would reduce the error. Possibly the drill hole was close to a narrow valley that the seismic measurement found. At B, the unconsolidated deposits are thin, so a deeper layer within the bedrock may have been selected instead of the first contact. Disregarding the measurements at E and B, the bedrock depth errors are less than 20%.

The temperatures measured in late summer 1980 are profiled above the cross section in fig. 5. The general pattern indicates a broad temperature depression over the main buried valley, a temperature recovery over the shallower bedrock, and a decline over the area formerly mapped as a tributary (G). Data south of G (not plotted) are unreliable because they were obtained after a local thunderstorm.

The average temperature over the northern bedrock high (A to C) is 23.4°C (74.1°F). Over the gently sloping south wall (south of F to just north of G), the average is 22.9°C (73.2°F). The average temperature over the buried valley (D to F) is 22.3°C (72.1°F). The temperature averages include isolated highs, some of which could be due to holes that were several inches less than 4 ft (1.2 m) deep or to surficial deposits with abundant lime concretions. The high-thermal conductivity of carbonates as opposed to clays and sands may be responsible for elevated temperatures. Qualitative corrections for such microenvironmental variables suggest that temperature anomalies relative to the buried topography are even stronger than the raw data shown in fig. 5 indicate.

Jefferson County

Jefferson County (fig. 2) is southeast of Nemaha County and is bounded on the south by the Kansas River. The tributary Delaware River was dammed in 1970 and now forms Perry Lake. The geology of Jefferson County was mapped in the late 1960's (Winslow, 1972), and most of the western part of the county was shown as Upper Pennsylvanian shales and limestones with some glacial drift covering the hilltops.

A narrow buried valley between exposures of bedrock less than 0.5 mi (0.8 km) apart was discovered when a commerical driller put in wells on several 10-acre (40,470 m^2) parcels of land that had been subdivided in connection with the development of Perry Lake. Although shallow bedrock and low yields were found on most lots, more than 100 ft (30 m) of glaciofluvial sands and gravels were found on one lot. A rural-water-district well was subsequently drilled close to the private well, and a 25-hr pump test on the public well at 500 gpm (31 L/sec) produced a water-level decline in this well from the static level of 2 ft (0.6 m) to 40 ft (12 m) below land surface, with stabilization occurring after only about eight hours. Recent work by the Kansas Geological Survey (KGS) has shown that these wells are in a buried valley that is at least 1.5 mi (2.4 km) long and that trends northeast-southwest (fig. 6). The width

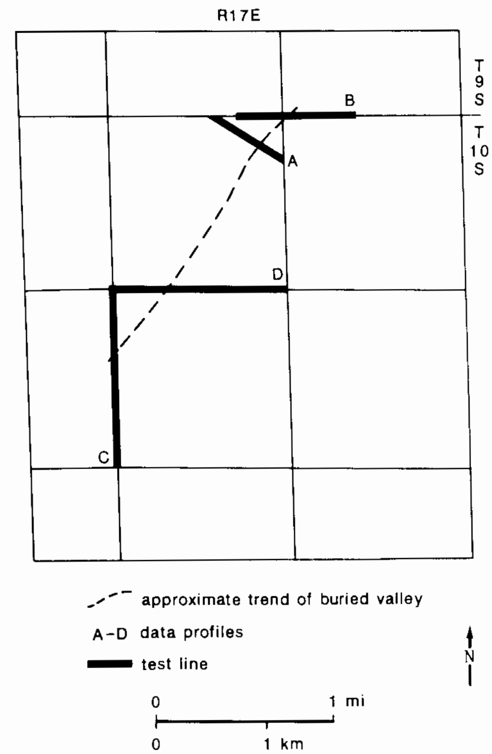

FIGURE 6—Test sites in part of Jefferson County.

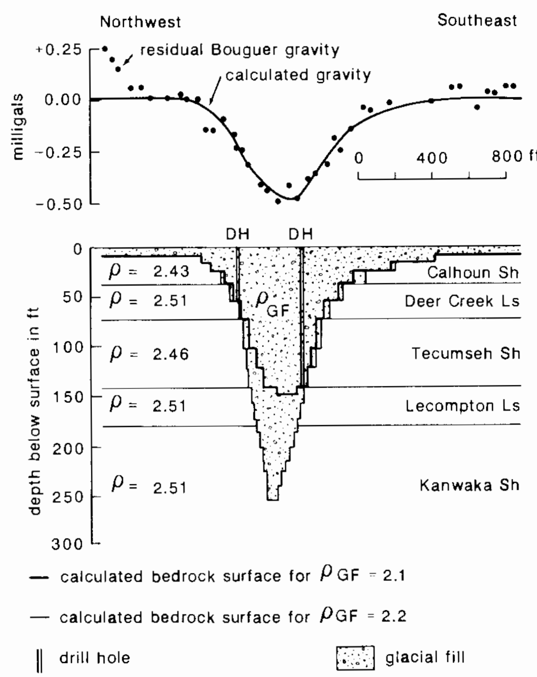

FIGURE 7—Gravity profile along test line A in Jefferson County.

of the deep channel in one location where known is only about 500 ft (150 m).

Landsat imagery has been analyzed for this area, but no tonal pattern that could be associated with the buried valley was identified. The lack of success in differentiating this buried valley probably relates to a channel width being less than two times that of the instantaneous field of view (79 m [260 ft]) of the multispectral scanner and to the landscape spectral characteristics. The low contrast between materials surrounding and those overlying the buried valley prevents differentiation of this alluvial aquifer.

Thermal, resistivity, seismic, gravity, and test-hole studies were conducted along the lines shown in fig. 6. The rural water district drilled its well and several test holes southeast of the middle of line A, but subsequent KGS field work showed considerably greater saturated thicknesses of sand and gravel west of the well. Shallow bedrock occurs in the northwest and southeast parts of the area near line A. The narrow buried valley, up to 200 ft (60 m) deep, occurs between the bedrock highs.

Resistivity data interpreted for sites near line A yielded bedrock depths that were inconsistent with drill-hole values. Apparently the resistivity contrast between the sand and gravel aquifer and the underlying limestone bedrock was insufficient for good evaluations.

Temperature measurements were made at approximately 100-ft (30-m) intervals across the buried valley near the rural-water-district well in the winter of 1979–1980 and the summer of 1980 (Denne et al., 1982). The summer and winter data show general cooling and warming trends, respectively, over the buried valley, but some inconsistencies were observed.

Although resistivity and temperature measurements did not precisely define the bured valley near the rural-water-district well, a gravity profile taken along line A (fig. 6) provided excellent results. Residual Bouguer gravity values were derived by removing a least-squares-determined linear regional trend from the original Bouguer values. The residual gravity profile (fig. 7) exhibits a well-defined and symmetrical negative anomaly (-0.5 milligals) over the buried valley. The depths to bedrock from two drill holes were used as controls for the gravity modeling. The subsurface formation thicknesses were estimated from previous work in Jefferson County (Winslow, 1972) coupled with bottom-hole bedrock-sample descriptions from the two drill holes. The bedrock densities (2.43–2.51 gm/cm^3) were estimated from a compensated neutron-formation-density log run on a drill hole located in Wabaunsee County, approximately 35 mi (56 km) west of the Jefferson County test site. Because all the subsurface beds had dips of less than 1°, they were approximated to be flat-lying for purposes of gravity modeling.

Good agreement between the calculated and measured gravity profiles was achieved for glacial channel-fill densities (ρ_{GF}) between 2.1 and 2.2 gm/cm^3. The gravity modeling predicts a valley depth of 203 ± 52 ft (61 ± 15 m). This result is consistent with a maximum known depth to bedrock of 167 ft (50 m) found in a drill hole located along the glacial-valley trend approximately 200 ft (60 m) southwest of the gravity profile.

To determine the length and orientation of the buried valley, data were collected along lines B, C, and D (fig. 6). Significant variability in topography, cultural features, vegetation, and soil types occurs along these data lines. As could be expected, then, temperature profiles for lines B–D (fig. 8) are not as conclusive as those near line A. In general, however, warm temperatures were found over the buried valley in winter (1979–1980), and cool temperatures were found in the summers of 1979 and 1980.

Reversed seismic-refraction data (fig. 8) suggested the presence of the buried valley in lines B and C, and this was confirmed by drill holes. Seismic data for the middle of line B are not shown because the absolute bedrock depth was not determined; the geophone spread only provided a depth greater than 70 ft (21 m). Resistivity data indicated that the valley axis occurs in the western part of profile D, and preliminary augering (not to bedrock in the channel) supports this interpretation. The east wall of the channel occurs in the middle of line D where resistivity analysis showed the bedrock depth to be 14 ft (4 m). A test hole there encountered a high-resistivity limestone bedrock at 19 ft (6 m) below a relatively low-resistivity glacial clay. The buried channel is now known to extend southwest-northeast for more than 1.5 mi (2.4 km).

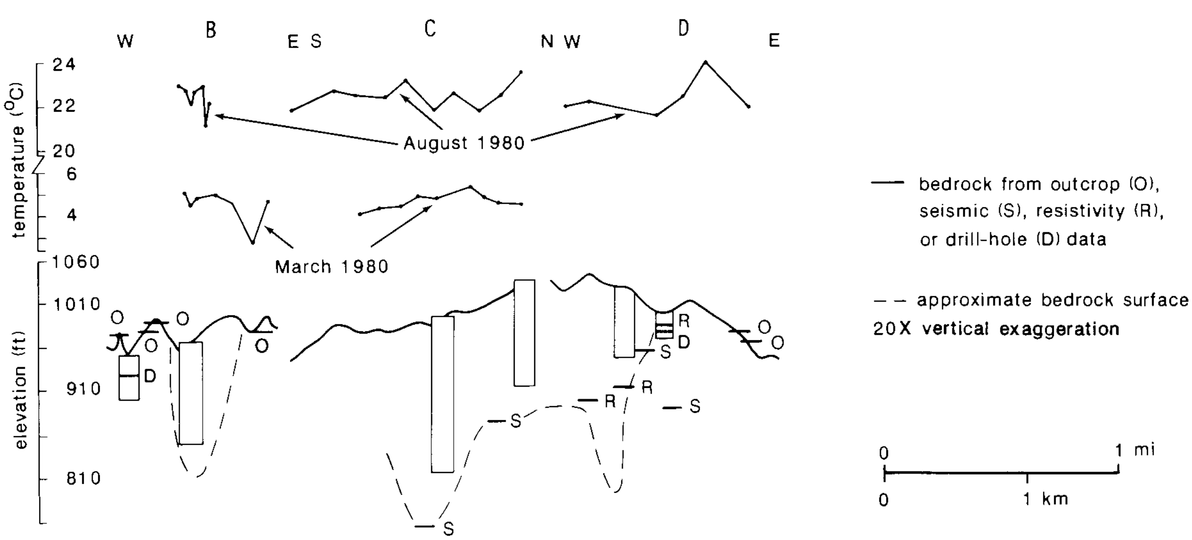

FIGURE 8—DATA PROFILES B, C, AND D FOR JEFFERSON COUNTY TEST LINES.

Conclusions

The combination of remote sensing, geophysical techniques, and test drilling has proved useful for delineating some buried valleys in northeastern Kansas. Analysis of tonal patterns on springtime Landsat imagery provides a quick and inexpensive first step for selecting field-study sites. Buried channels associated with the patterns tend to be relatively large, and the land surface over the buried valley must have distinctive spectral characteristics for it to be differentiated from the surroundings.

Shallow-earth temperature profiling is a good reconnaissance tool for selecting sites for more intensive and expensive field investigations. Cool and warm temperature anomalies occur over buried-valley aquifers in summer and winter, respectively. To avoid data that could mask the effect of an anomaly, measurements should be made with minimal microclimatic and microenvironmental variations, or quantitative factors should be developed to compensate for the variables.

Resistivity and reversed seismic-refraction surveys generally give bedrock depths within 25% of those determined by more expensive and time-consuming test-hole drilling. Errors in depths calculated from the resistivity and seismic data may occur in areas where clays are interbedded with sand or where insufficient contrast occurs between unconsolidated deposits and bedrock (e.g., clayey till over weathered shale). Logs from drill holes should be used to check and to calibrate geophysical interpretations, because they provide the final, most detailed description of aquifer location and character.

The Jefferson County case study demonstrates that the gravity method is very effective in determining cross sectional shape and depth of buried valleys in areas of relatively thin glacial-till cover above bedrock. Gravity modeling, along with drill-hole control, indicates that the density contrast between the Jefferson County channel-fill material (glaciofluvial sands and gravels) and bedrock is -0.33 ± 0.05 gm/cm^3. The density contrast for channel-fill material with a significant component of clayey sediments would probably be greater, thus providing even more favorable conditions for application of the gravity method. In areas of relatively thick glacial-till cover, the gravity method would be less effective. For example, the maximum thickness of till cover over the Jefferson County test area that would have allowed a measurable gravity anomaly (approximately -0.2 mgals) would have been approximately 100 ft (30 m).

The remote-sensing and geophysical techniques help in the selection of optimal drill sites over buried valleys. Data obtained by drilling are expensive and require much time. Although one 300-ft (90-m)-deep hole could be drilled and logged by three people in one day, a seismic profile for the same site would take five or six people one hour. A similar resistivity analysis would take three people about two hours in the field and one person another hour for data interpretation. For the detailed 0.5-mi (0.8-km) gravity profile in Jefferson County, two people were required for approximately two days to survey elevations and to take gravity field measurements. One person was required for about one month to reduce and to interpret the gravity data. Depending on the spacing of measurements, temperature profiles for several miles could be done by two people in one day. Using Landsat imagery, hundreds of square miles could be analyzed by one person in one day.

All of the methods described were applied to the test sites. They helped to define the width and shape of the major buried valley in Nemaha County, and they helped delineate the extent and the orientation of the narrow channel in Jefferson County. The remote-sensing, temperature-profiling, resistivity, reversed seismic-refraction, and gravity techniques are now being used in various combinations together with test drilling to locate and to evaluate buried-valley aquifers in other parts of northeastern Kansas.

ACKNOWLEDGMENTS—We would like to acknowledge the many staff of the Kansas Geological Survey for their assistance in field work, data analysis, and report preparation and review.

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Holocene and Pleistocene soils and geomorphic surfaces of the Kansas River valley

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Abstract

The association of soils and geomorphic surfaces is examined in an effort to better understand the complex of apparent alluvial terraces in the Kansas River valley. Increasingly in recent years, the simple assignment of Wisconsinan through Kansan ages to Newman through Menoken terraces has come into question. Data from soils for example, including R/C dates on buried paleosols in the Newman terrace fill, indicate that the Newman terrace is Holocene in age. Conclusions such as this call into question not only the Wisconsinan age of the Newman but the entire terrace chronology. The complexity of geomorphic forms and processes and of soil types and genetic pathways in the study area argue strongly for landscape instability through time. The notion that terraces represent stable landscapes interrupted by major periods of instability seems untenable given the complex associations of soils and parent materials on these terraces. More likely it appears that these surfaces have been undergoing continual change and we are just now beginning to appreciate the complexity of natural processes in the landscape accompanying these changes.

Introduction

The authors have long felt the need to compile a map of river terraces with cross sections showing their associated soils for the Kansas River valley. Impetus for such a compilation comes from the fact that existing information on alluvial terraces is scattered among several publications, and no previous report links the soils to landforms in the river valley. Additionally we assumed that any such compilation would aid in reinterpretation of the simple terrace chronology that pervades much of the literature for streams in this region.

Setting

The study area includes the Kansas River valley and adjacent upland areas from Junction City, downstream 170 mi (272 km) to Kansas City, Kansas (fig. 1). The Kansas River flows eastward through this area of northeastern Kansas, crossing the Flint Hills, the glaciated region, and the Osage cuestas of the Central Lowlands physiographic province. The surface bedrock consists of Permian sedimentary units in the Flint Hills and Upper Pennsylvanian and Lower Permian sedimentary units in the Osage cuestas region. The glaciated region is a dissected drift plain. During the pre-Illinoian glacial episodes, this area was covered by a continental ice sheet that extended slightly beyond the Kansas River in places on the south and overlapped portions of the Flint Hills on the west. The plain is underlain by Pennsylvanian and Permian bedrock units similar to those of the Osage cuestas, but thick deposits of till, outwash, and loess conceal the cuesta-type topography that prevails south of the Kansas River.

The study area is in Thornwaite's (1948) moist, subhumid (C2) climatic region. This continental-type climate is characterized by a large annual-temperature range and extremes in precipitation. The winters are usually short and cold, and summers are long and hot. The mean annual precipitation decreases westward across the study area, ranging from approximately 96 cm (38 inches) at Kansas City to 73 cm (29 inches) at Junction City.

Two major vegetation associations occur in the study area: tall-grass prairie and prairie-forest mosaic (Kuchler, 1964). The tall-grass prairie is in the Flint Hills region west of Topeka. This area is dominated by warm-season grasses, especially big bluestem (*Andropogon gerardii*), little bluestem (*A. scoparius*), switchgrass (*Panicum virgatum*), and Indian grass (*Sorghastrum nutans*). Eastward from the tall-grass prairie, the land is a mosaic of prairie and oak-hickory forest. Generally components of the tall-grass prairie are found on the level-to-rolling uplands with clay-rich soils. Oak-hickory forests occur on steep slopes and ravines and in areas with coarsely textured soils. The forested areas are dominated by white oak (*Quercus alba*), red oak (*Q. borealis*), shagbark hickory (*Craya ovata*), and bitternut hickory (*C. cordiformis*).

The bottomlands of the Kansas River valley usually are forested, but the species composition differs from the uplands. Here the arboreals include the rapidly growing invaders like cottonwood (*Populus deltoides*), willow (*Salix* ssp.), and hackberry (*Celtis occidentalis*). Shallow depressions and mud flats that are frequently flooded are characterized by wetland communities. The wetlands are preferred sites for such plants as prairie cordgrass (*Spartina pectinata*), smartweeds (*Polygonum* ssp.), docks (*Rumex* ssp.), and chenopods (*Chenopodium* ssp.).

Quaternary stratigraphy and history of the Kansas River valley

The Quaternary landscapes of northeastern Kansas record a complex history of terrestrial deposition, erosion, and soil formation. The complexity of the Quaternary stratigraphy of the Kansas River valley is a product of this varied history.

The formal Quaternary lithostratigraphy of northeastern Kansas is based on the stratigraphy of pre-Illinoian tills and Pleistocene loesses because these deposits are regional in extent and thus provide "marker" units to which more localized fluvial units can be stratigraphically related. Recent investigations (Dort, 1985; Hallberg, 1980; Hallberg et al., 1980) have substantially revised the stratigraphy of Pleistocene tills in the east-central plains. Detailed geomorphic investigations and careful synthesis and reevaluation of previous work have led to the abandonment of the classical glacial- and interglacial-stage terms Kansas, Aftonian, and Nebraskan. A much more complex sequence of glacial deposits than previously recognized is apparent. Thus all Quaternary sediments in the Kansas River valley that are older than Illinoian are referred to in a time-stratigraphic sense as undifferentiated pre-Illinoian deposits.

Pre-Illinoian till, glaciofluvial, and glaciolacustrine deposits are the oldest Quaternary deposits that are common in and adjacent to the Kansas River valley. Till occurs on both sides of the Kansas River in high, intermediate, and low topographic positions. The till deposits are generally 3–15 m (10–50 ft) thick in the area of the Kansas River and only rarely are thicker within 15 km (50 ft) of the valley. Glaciofluvial and glaciolacustrine deposits comprise the bulk of the pre-Illinoian sediments in the valley. Outwash deposits commonly are 10–20 m (33–66 ft) thick but are locally 30 m (99 ft) or more thick (Jewett et al., 1965).

Pleistocene eolian deposits, dominantly loess, but locally including sands, mantle uplands and high-terrace deposits in the Kansas River valley. Where the full eolian sequence is preserved, the deposits consist of two lithostratigraphic units: the lower Loveland loess and the overlying Peorian loess. The Loveland loess is Illinoian in age and consists of reddish- or pinkish-brown, noncalcareous silt with some clay (Frye and Leonard, 1952, p. 116). In most locations the Loveland loess is less than 3 m (10 ft) thick, and it has been greatly modified by Sangamonian and more recent soil development. The Peorian loess is Wisconsinan in age and occurs as a widespread but discontinuous blanket of yellowish-brown to yellowish-gray, noncalcareous silt and very fine sand on the uplands (Frye and Leonard, 1952, p. 128). Within the Kansas River valley, the maximum thickness of Peorian loess is approximately 5 m (17 ft) in eastern Johnson County. Peorian deposits thin to the west and generally are less than 2 m (7 ft) thick west of Jefferson County.

The Bignell Formation, a loess deposit younger than Peorian, is recognized along the Missouri River valley in northeastern Kansas. If the Bignell is present in the Kansas River valley between Kansas City and Junction City, Kansas, it is so thin that it is included entirely within the A horizon of the modern soil.

A large proportion of the Kansas River valley is composed of Pleistocene and Holocene alluvium. Four terraces have been mapped within the lower Kansas River drainage net (Davis and Carlson, 1952; McCrae, 1954; Beck, 1959; Fader, 1974; and Elks, 1979). They are, from oldest to youngest, the Menoken terrace, the Buck Creek terrace, the Newman terrace, and the Holliday terrace complex. These four terrace names have become established in the literature.

The Menoken terrace is pre-Illinoian and is the oldest Quaternary landform in the Kansas River valley. The surface of the Menoken terrace is approximately 25–30 m (83–99 ft) above the modern floodplain. Davis and Carlson (1952) suggested that sediment underlying this terrace was deposited by glacial meltwater during the retreat of Kansan glacial ice. They noted that the Menoken fill consists of coarse outwash containing cobbles and boulders at the base fining upward into thicker units of sand, silt, and clay. However, in many localities, the Menoken terrace is composed of undifferentiated till and glaciolacustrine deposits (Beck, 1959; Jewett et al., 1965; O'Connor, 1971). These deposits rest on bedrock benches at high elevations along the margins of the Kansas River valley. This report recognizes the problem of genesis of the Menoken surface. It seems increasingly accepted that the Menoken deposits and features are remnants of ice-contact deposits of various types including moraines, kames, and outwash. The deposits and features probably are not alluvial terraces even though their proximity to the Kansas River makes them an important part of the valley landscape. Therefore we retain the term Menoken to describe an unusually amorphous form and/or series of deposits in the study area.

The Menoken surface has been severely dissected by erosion and only small remnants remain between Bonner Springs and Wamego, Kansas (fig. 1). These remnants are mantled by Loveland and/or Peorian loess.

According to Davis and Carlson (1952), a cycle of degradation and alluviation during the Illinoian resulted in the formation of the Buck Creek terrace. The surface of the terrace is approximately 11–12 m (36–40 ft) above the modern floodplain of the Kansas River. Deposits underlying the surface consist of sand and gravel which grade upward into silt and clay (Beck, 1959). The terrace surface is capped by several meters of Loveland and/or Peorian loess. A strongly developed Sangamon soil is present in the older loess and often extends down into the alluvial fill of the terrace. The absolute age of the Buck Creek fill is not known. Preliminary petrographic investigations of volcanic ash overlying the fill indicate that it is the 0.6-m.y.-old Lava Creek B ash (Geil, 1985). This identification, if supported by fission-track-dating techniques, indicates that the fill beneath the ash is much older than Illinoian.

The Buck Creek terrace is preserved as scattered remnants in the Kansas River valley between Eudora and Junction City, Kansas (fig. 1). Most of these remnants are located at the mouths of tributary streams. Lateral migration of the Kansas River during Illinoian and Wisconsinan time completely removed the Buck Creek terrace in the narrow section of the valley between Eudora and Kansas City.

The Newman terrace occurs throughout much of the Kansas River valley west of Eudora, Kansas (fig. 1). The

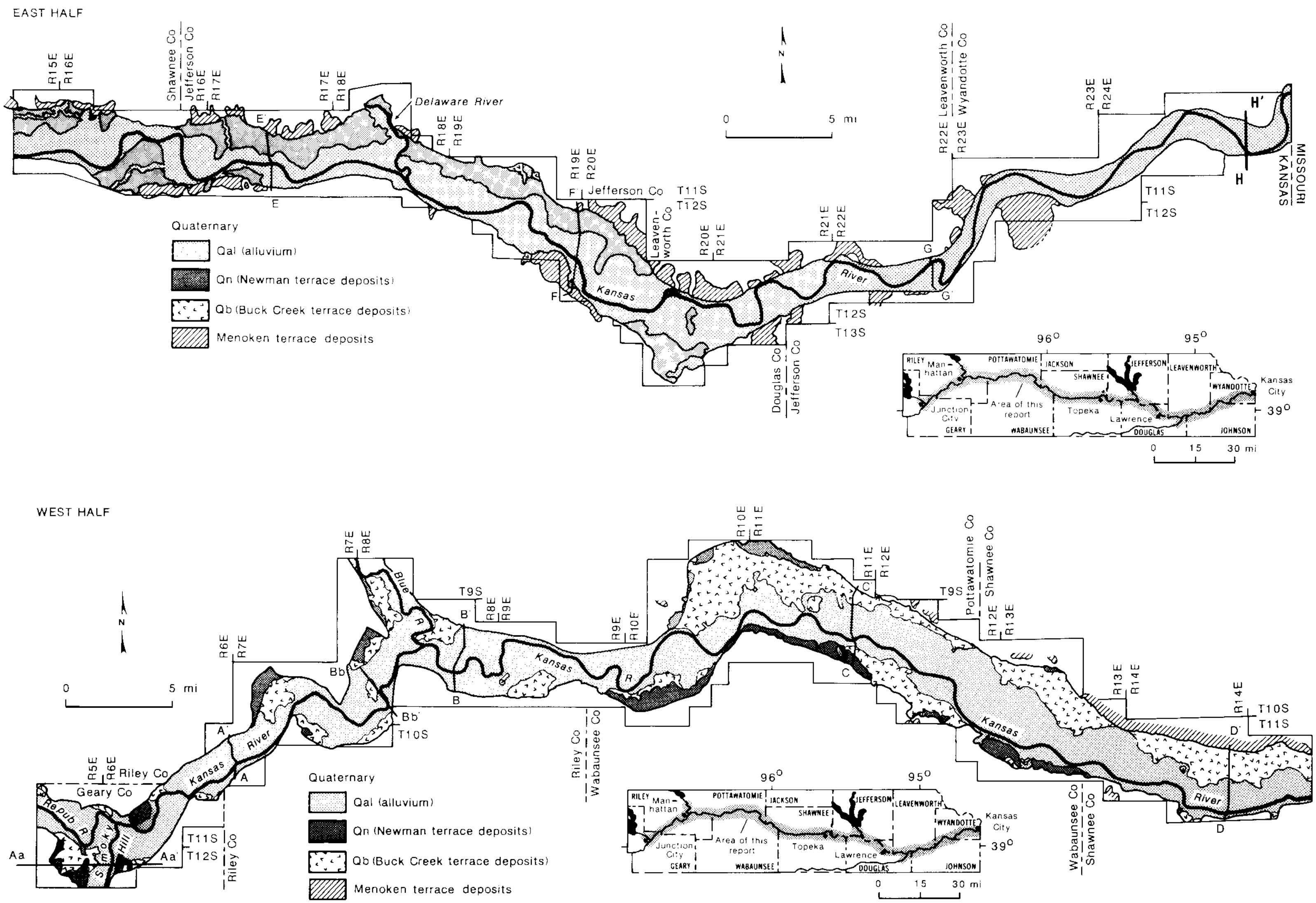

FIGURE 1—MAP SHOWING LATEST COMPILATION OF FLOODPLAINS AND TERRACES, INCLUDING MENOKEN SURFACES, BETWEEN JUNCTION CITY AND KANSAS CITY (map after Fader, 1974).

surface of the terrace is approximately 3 m (10 ft) above the modern floodplain of the river. However, since much of the terrace is covered with water during severe floods, it is technically considered part of the floodplain (Holien, 1982).

The Newman terrace typically is a flat, poorly drained surface bordered by low natural levees (O'Connor, 1960). Unlike the topographically lower surfaces of the valley, it is not marked by old meander scars. The lower part of the alluvium underlying the Newman terrace consists of coarse sand and gravel with cobbles at the base (Beck, 1959; O'Connor, 1960). The alluvium fines upward into dark, silty clay which is found everywhere beneath the terrace surface (O'Connor, 1971). This fine-grained material may represent everything from overwash to backswamp deposits and includes filled-in former channels.

The fill of the Newman terrace has been dated at several locations in the Kansas River valley. Near Bonner Springs, radiocarbon dates of 4,290 ± 310 yrs B.P. and 10,430 ± 130 yrs B.P. were determined on humic acids from paleosols at depths of 5.2 m (17.2 ft) and 8.8 m (29 ft), respectively, below the terrace surface (Holien, 1982). A radiocarbon date of 7,250 ± 110 yrs B.P. was determined on humic acids from a paleosol 3.65 m (12 ft) below the surface near Wamego, Kansas (Bowman, 1985). Based on these dates, sediments of the Newman terrace seem to have aggraded from late Wisconsinan through late Holocene.

During the late Holocene, another episode of degradation and alluviation produced the Holliday terrace complex. This terrace is approximately 2 m (7 ft) above the modern floodplain of the Kansas River and is separated from it by a small natural levee (McCrae, 1954). A complex pattern of meander scrolls and abandoned channels which have surface relief of up to 3 m (10 ft) are present on the terrace surface (Holien, 1982, p. 76). The alluvium consists of sand and silt with fine-grained silts and clays accumulating in abandoned meander scrolls and channels. The Holliday fill has yielded radiocarbon dates of about 4,090, 4,260, 2,620, 2,395, and 1,670 yrs B.P. (Johnson, 1985; this volume).

The modern floodplain is the surface which lies at a lower elevation than the Holliday terrace complex. It is characterized by channel scars that exhibit subtle relief. The floodplain sediments are generally coarser than the alluvium underlying upper portions of the terraces and consist of coarse sands, silts, and occasional sand lenses (Holien, 1982). Lateral migration of the Kansas River has removed the Holliday terrace complex at places in the river valley and as a result, the modern floodplain may be adjacent to the Newman terrace. The absolute age of the floodplain fill is not known, but it is suspected to be less than 3,000 yrs old (Bowman, 1985).

Soil associations of the major terraces

Detailed soil surveys for eight of the 10 counties in the study area were published from 1960 to 1979 (Abmeyer and Campbell, 1970; Bidwell and Dunmire, 1960; Dickey et al., 1977; Dickey, Zimmerman, and Rowland, 1977; Jantz et al., 1975; Plinsky et al., 1979; and Savesky and Boatright, 1977). Surveys for the two remaining counties are near completion and should be published in the next two to three years.

Major changes in soil classification coincided with this period of mapping, and numerous individuals worked on these reports, resulting in some disparity in the recognition and mapping of soils throughout this group of ten counties. Named soil series were correlated, on a county-by-county basis, from 1966 to 1975, but never for the Kansas River basin as a unit. Many of the name differences among counties would not occur had such a basin-wide correlation been made. The purpose of this report is to describe the relationships between soils and landscapes in the lower Kansas River valley.

The map (fig. 1) shows the latest compilation of floodplains and terraces, including the Menoken surfaces, between Junction City and Kansas City (Davis and Carlson, 1952; Dufford, 1958; Beck, 1959; and Fader, 1974). Eight cross sections (fig. 2a-h) are included that are modified somewhat from those of Fader (1974) or are supplemented as necessary to show major geomorphic surfaces and their associated soils along the length of the river in the study area. The eight cross sections, beginning with Aa–Aa' at Junction City, are taken at roughly 20-mi (32-km) intervals downstream to H–H' at Bonner Springs. Cross sections identified with upper- and lower-case letters are new to this report. Those identified with upper-case letters only are taken from Fader (1974). The interval between cross sections is less than 20 mi (32 km) in some cases, but rarely is it much more that 20 mi (32 km) anywhere along the river. The patterns that emerge provide a summary of the soil and landform associations temporally and spatially for the Kansas River valley (table 1).

Principal soils on the Holliday terrace and modern floodplain include the Eudora–Kimo–Sarpy association. The Eudora soil is a coarse-silty Fluventic Hapludoll formed in overbank deposits (see description of Eudora Series in appendix), the Kimo soil is a clayey-over-loamy Aquic Hapludoll formed in fill deposits of oxbows, and Sarpy soil is a mixed Typic Udipsamment formed in coarse overwash mainly from the 1951 flood. Other soils include patches of 1) Haynie, which is a soil like the Eudora except that it is calcareous to the surface and has less organic matter; 2) Carr, which is a soil similar to the Sarpy but is not as coarse in texture; 3) Ivan, which is calcareous throughout and is much like the Kennebec soil (which mainly occurs on the Newman terrace); 4) Muir, which is a soil much like the Eudora but is finer in texture, darker in color to greater depths, and mainly occurs on the Newman terrace; 5) Solomon, which is calcareous throughout and is otherwise much like the Wabash soil (which mainly occurs on the Newman terrace); and 6) Humbarger, which is a soil like the Ivan but is coarser in texture (tables 1 and 2).

Principal soils on the Newman terrace include the Muir–Reading–Wabash association. The Muir soil is a fine-silty mixed Cumulic Haplustoll formed in alluvium (see description of the Muir Series in the appendix); the Reading soil is a fine-silty mixed Typic Argiudoll formed in silty alluvium probably derived from natural levee deposits; and the Wabash soil is a fine, montmorillonitic Vertic Haplaquoll formed in clayey alluvium of backswamp deposits. Other soils include patches of 1) Haynie, Carr, and Eudora, which are near the Muir but are less clayey, are darkened to a shallower depth, and probably originated in overwash from floods; 2) Kennebec, which is a soil that merges onto the terrace from tributaries and buried soils of the Muir–

Reading–Wabash association (it is unlike any of the major soils of the association being silty over a clayey substratum); 3) Judson, which is a soil like the Muir but has a wetter soil-moisture regime; 4) Kimo, which is described in the soil association of the Holliday floodplain surfaces; 5) Chase and Zook, which are soils that are like the Wabash but have less clay in their surface horizons; 6) Tully, which is formed in colluvium transported from adjacent higher valley walls and deposited at the base of steep slopes; 7) Geary and Hastings, which are similar to the Reading soil except that they have formed in loess and have drier soil-moisture regimes; and 8) Sutphen, which is like the Wabash in the upper 40 inches (100 cm) and has a drier soil-moisture regime (tables 1 and 2).

The Buck Creek terrace is poorly preserved throughout most of the Kansas River drainage. Where it is present, it is often at the mouths of tributaries to the Kansas River, so it is difficult to define a principal soil association for the surface. At and near the type locality for the Buck Creek terrace, the soils most commonly associated on the Buck Creek surface are the Gymer, Konawa, and Sharpsburg soils. The Gymer soil is a fine, montmorillonitic Typic Argiudoll and is generally considered to have formed in Loveland loess (see description of the Gymer Series in appendix), and the Konawa soil is a fine-loamy mixed Ultic Haplustalf that has formed in coarser textured eolian deposits than the Gymer. The Sharpsburg soil is a fine, montmorillonitic Typic Argiudoll and often overlies older soils. It is considered to have formed in Peorian loess. The Konawa and Gymer seem to represent a facies change from coarse to fine windblown sediments while the Sharpsburg may bury these and other soils in the regional landscape. Other soils on the Buck Creek surface include 1) Shellabarger, which is a soil like Konawa except that it lacks the grayish subsurface layer that is in Konawa soils, has an argillic horizon, and may be finer textured in the surface horizons; 2) Ortello, which is a soil like the Thurman except that it has finer subsoil texture (the Thurman seems to be mapped exclusively on the Menoken surface); 3) Wymore, which is a soil somewhat like the Sharpsburg

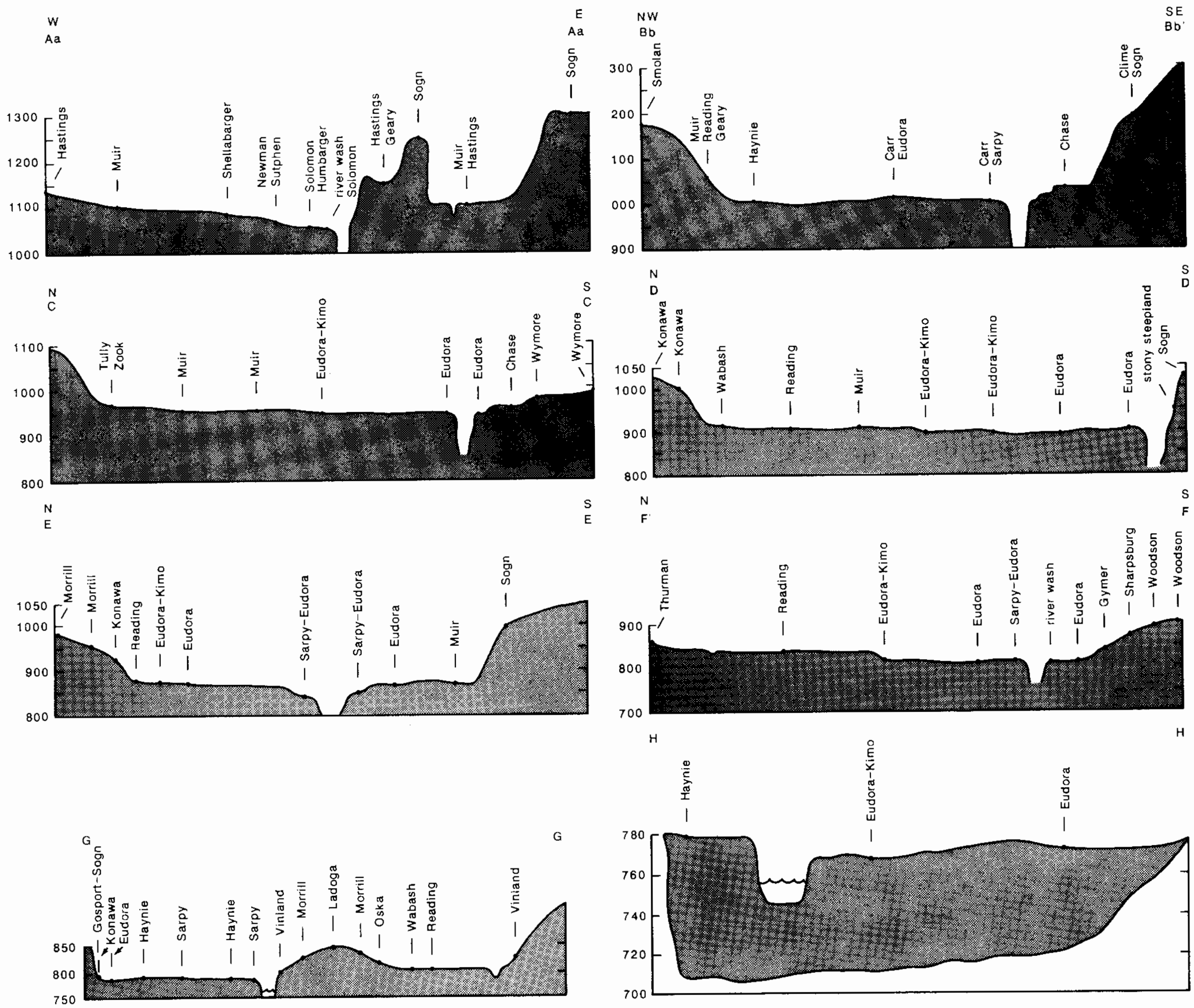

FIGURE 2—EIGHT CROSS SECTIONS (Aa–Aa' to H–H') modified from Fader (1974) OR SUPPLEMENTED, SHOWING MAJOR GEOMORPHIC SURFACES AND ASSOCIATED SOILS ALONG LENGTH OF RIVER IN STUDY AREA.

except that it contains more clay in the argillic horizon and has mottles higher in the solum; 4) Smolan, which is a soil similar to the Gymer except that the Gymer has a wetter soil-moisture regime; 5) Geary, which is soil like the Gymer but has a siltier, less clayey subsoil than Gymer and drier soil-moisture regime; and 6) Hastings, which is a soil similar to the Sharpsburg except that it has a drier soil-moisture regime (tables 1 and 2).

The principal soils on the Menoken surfaces include the Morrill–Konawa–Thurman–Sharpsburg association. The Morrill soil is a fine-loamed, mixed Typic Argiudoll formed in till and glaciofluvial deposits (see description of the Morrill Series in appendix); the Konawa soil is described above as a principal soil on the Buck Creek surface; and the Thurman soil is a sandy, mixed Udorthentic Haplustoll. Their morphology and association with the Morrill soils suggest the Konawa and Thurman formed in sands of glacial outwash, are possibly of kame deltaic origin, and are probably reworked by wind. The Sharpsburg soils are described above as principal soils on the Buck Creek surface. Other soils of the Menoken surface include 1) Gymer, which is described above as a principal soil of the Buck Creek surface; 2) Ladoga, which is a soil associated with the Sharpsburg and is formed from loess, but lacks a mollic epipedon; 3) Woodson, which is a soil of uncertain origin on the Menoken and adjacent uplands. In Douglas County, it may be more accurate to map Woodson as the Wymore or Grundy soils (formed in loess), but these soils are not mapped in the county. The origin of the Woodson is obscure; the Woodson may be of pre-Illinoian lacustrine origin; 4) Pawnee, which is a soil associated with the Morrill soil except that it is more clayey in the argillic horizon, occurs in higher topographic positions and is formed from glacial till; 5) Shellabarger, which is described above as one of the loamy eolian sediments of the Buck Creek surface; 6) Shelby, which is a soil like the Morrill but is not as red in hue; and 7) Ortello, which is described above as one of the soils on the Buck Creek surface (tables 1 and 2).

The principal soils on the adjacent uplands occur on a variety of surfaces and are developed from a variety of parent materials. The principal soils developed in residuum

TABLE 1--SOILS AND MAJOR GEOMORPHIC SURFACES IN THE KANSAS RIVER VALLEY AT SELECTED CROSS-VALLEY TRANSECTS FROM JUNCTION CITY TO KANSAS CITY.

Junction City West	**Aa–Aa′**	**Bb–Bb′**	**C–C′**	**D–D′**	**E–E′**	**F–F′**	**G–G′**	**Hh–Hh′**	**Principal association soils**	**Kansas City East**
Holliday/ floodplain	Solomon, Humbarger	Carr, Sarpy, Haynie, Ivan	Eudora, Kimo, Sarpy, Muir, Haynie	Eudora, Kimo, Sarpy	Eudora, Kimo, Sarpy, Muir	Eudora, Kimo, Sarpy	Eudora, Kimo, Sarpy, Haynie	Eudora, Kimo	Eudora, Kimo, Sarpy	Holliday/ floodplain
Newman terrace	Sutphen, Muir, Hastings	Reading, Carr, Geary, Muir, Eudora, Chase	Muir, Tully, Zook, Chase, Eudora, Kimo	Muir, Reading, Kennebec, Wabash, Eudora	Reading, Kimo, Eudora, Muir, Wabash	Reading, Kennebec, Wabash, Judson	Reading, Wabash	Eudora, Haynie, Judson on alluvium at mouth of tributary to main valley	Muir, Reading, Wabash	Newman terrace
Buck Creek terrace	Shellabarger, Hastings, Geary	Smolan	Wymore, Ortello	Shellabarger, Konawa, Gymer	terrace form not preserved in main valley	Gymer, Sharpsburg	terrace form not preserved in main valley	terrace form not preserved in main valley	Gymer, Konawa, Sharpsburg	Buck Creek terrace
Menoken surfaces	terrace form not preserved	terrace form not preserved	Morrill, Ortello, Thurman	Konawa, Gymer, Shelby, Shellabarger, Morrill	Morrill, Konawa, Gymer	Sharpsburg, Woodson, Morrill, Pawnee, Gymer, Thurman	Konawa, Morrill, Ladoga	Morrill, Sharpsburg	Morrill, Konawa, Thurman, Sharpsburg	Menoken surfaces
Upland residual/glacial loess, etc.	Sogn-residuum, Tully-colluvium, Crete-loess, Hastings-loess	Sogn-residuum, Mayberry-glacial till/ outwash, Hastings-loess	Sogn-residuum, Cline-residuum, Morrill, Pawnee-glacial till/outwash, Ladysmith-loess	Sogn/Vinland-residuum, Morrill/Pawnee-glacial till/ outwash, Ladysmith-loess	Sogn/Martin-residuum, Pawnee/Morrill-glacial till outwash, Ladysmith-loess	Martin/Sogn/ Vinland-residuum, Pawnee-till, Sharpsburg-loess	Martin/Vinland Sogn-residuum, Pawnee-till, Woodson-loess/ lacustrine	Sogn/Vinland-residuum, Pawnee/Morrill-till/outwash, Sharpsburg/ Polo-loess	Sogn, Martin, Vinland	Upland residual/glacial loess, etc.

TABLE 2—Taxonomic class of soils listed in table 1.

Carr—coarse, loamy (calcareous), mesic Typic Udifluvents
Chase—fine, montmorillonitic, mesic Aquic Argiudolls
Clime—fine, mixed, mesic Udic Haplustolls
Crete—fine, montmorillonitic, mesic Pachic Argiustolls
Eudora—coarse-silty, mixed, mesic Fluventic Hapludolls
Geary—fine-silty, mixed, mesic Udic Argiustolls
Gymer—fine, montmorillonitic, mesic Typic Argiudolls
Hastings—fine, montmorillonitic, mesic Udic Argiustolls
Haynie—coarse-silty, mixed (calcareous), mesic Typic Udifluvents
Humbarger—fine-loamy, mixed, mesic Cumulic Haplustolls
Ivan—fine-silty, mixed, mesic Cumulic Hapludolls
Judson—fine-silty, mixed, mesic Cumulic Hapludolls
Kennebec—fine-silty, mixed, mesic Cumulic Hapludolls
Kimo—clayey over loamy, montmorillonitic, mesic Aquic Hapludolls
Konowa—fine-loamy, mixed, thermic Ultic Haplustalfs
Ladoga—fine, montmorillonitic, mesic Mollic Hapludalfs
Ladysmith—fine, montmorillonitic, mesic Pachic Argiustolls
Martin—fine, montmorillonitic, mesic Aquic Argiudolls
Mayberry—fine, montmorillonitic, mesic Aquic Argiudolls
Morrill—fine-loamy, mixed, mesic Typic Argiudolls
Muir—fine-silty, mixed, mesic Cumulic Haplustolls
Oska—fine, montmorillonitic, mesic Typic Argiudolls
Ortello—coarse-loamy, mixed mesic Udic Haplustolls
Pawnee—fine, montmorillonitic, mesic Aquic Argiudolls
Polo—fine, montmorillonitic, mesic Typic Argiudolls
Reading—fine-silty, mixed, mesic Typic Argiudolls
Sarpy—mixed, mesic Typic Udipsamments
Sharpsburg—fine, montmorillonitic, mesic Typic Argiudolls
Shelby—fine-loamy, mixed, mesic Typic Argiudolls
Shellabarger—fine-loamy, mixed, thermic Udic Argiustolls
Smolan—fine, montmorillonitic, mesic Pachic Argiustolls
Sogn—loamy, mixed, mesic Lithic Haplustolls
Solomon—fine, montmorillonitic (calcareous), mesic Vertic Haplaquolls
Sutphen—fine, montmorillonitic, mesic Udertic Haplustolls
Thurman—sandy, mixed, mesic Udorthentic Haplustolls
Tully—fine, mixed, mesic Pachic Argiustolls
Vinland—loamy, mixed, mesic shallow Typic Hapludolls
Wabash—fine, montmorillonitic, mesic Vertic Haplaquolls
Woodson—fine, montmorillonitic, thermic Abruptic Argiaquolls
Wymore—fine, montmorillonitic, mesic Aquic Argiudolls
Zook—fine, montmorillonitic, mesic Cumulic Haplaquolls

from weathered Pennsylvanian sedimentary rocks include the Sogn–Martin–Vinland association. The Sogn soil is a loamy, mixed Lithic Haplustoll formed in residuum from limestone; the Martin soil is a fine, montmorillonitic Aquic Argiudoll formed in residuum from shale; and the Vinland soil is a loamy, shallow, mixed Typic Hapludoll formed in residuum from interbedded coarse- and fine-grained sedimentary rocks. Other soils on the uplands include soils derived from other types of bedrock, soils derived from colluvium, and several soils derived from glacial tills, glaciofluvial deposits, and loess that are reported for the Buck Creek and/or Menoken surfaces plus a host of related soils. Time and purpose do not permit further elaboration on those soils here.

Along transects from the modern floodplain to the adjacent upland, as one might expect, the major trend in soil development is one of increasingly strong soil development as a function of time. The older soils at successively higher positions in the landscape generally have redder colors and greater B-horizon development than the younger ones. This developmental trend is interrupted by a variety of soils that apparently do not fit the pattern described. Loess, colluvium, and younger alluvium have accumulated on Newman, Buck Creek, and Menoken surfaces, and soils that are out of phase with the terrace chronology have developed on each of these surfaces. In other instances loess, alluvium, or colluvium bury older soils resulting in bisequal soils or welded paleosols that mask expected trends in soil development along cross-valley transects. The Kennebec soil is an example of a young soil with an A/C profile developed on the Newman surface where the principal soils have Bt or at least B horizons (see description of Muir Series in appendix). The Kennebec soil occurring in newly deposited sediments is a recent addition to a chronosequence of soils that vary considerably in their development on the Newman surface. In some places soils with B horizons such as Muir and Judson dominate the Newman. Elsewhere Kennebec, Eudora, and other relatively young soils dominate locally.

Recent radiocarbon dates on humates from soils buried in the Newman fill are late Pleistocene or Holocene and range from 10,430 ± 130 yrs B.P. to 4,290 ± 310 yrs B.P. and younger at Bonner Springs, Kansas (Holien, 1982), and 7,250 ± 110 yrs B.P. and younger at Wamego, Kansas (Bowman, 1985). According to these data, the soils in the sediments that make up the Newman are time transgressive and the surface soils likely represent several episodes of development from late Pleistocene to Holocene. Therefore, the age of the different portions of the Newman surface are probably not Pleistocene as previously described by Fader (1974) and earlier researchers. At the risk of belaboring the obvious, the age of a terrace surface does not necessarily correspond chronologically with the age of the deposits beneath that surface. The terrace form may be younger than these deposits, but it cannot be older. The soils of the Newman terrace suggest that a Holocene age is more appropriate for the Newman terrace than the Wisconsinan age assigned previously.

Soils of the Buck Creek surface are loess-derived or are at least modified by the wind. In some cases, two or more sequences of loess are present. The Gymer soil, for example, is often buried beneath Sharpsburg. The Sharpsburg is widely accepted as having formed in Peorian loess so at least two soils of different age are represented in these loesses on the Buck Creek surface. In addition to burial by the Sharpsburg soil, Gymer is found in close association with the Konawa soil. At the type locality for the Buck Creek surface, the Konawa grades to the Gymer. Both soils have similar degrees of oxidation, suggesting they are equivalent in age. The two soils seem to have formed in different facies of a single deposit that may date to Illinoian time or earlier.

At the levels of the Menoken surfaces, the pattern is one of soils that also are highly oxidized with highly variable textures. Soil texture varies widely because parent materials range from coarse glacial till and outwash to fine loess and lacustrine deposits and include a wide variety of intermediate sizes and sources of materials. Overwhelmingly, the dominant soil is the Morrill, a soil with strong red hues and an argillic horizon. The authors suspect that this soil formed in multicyclic sediments that had been severely eroded followed by accumulation of eolian sediments. Cycles of erosion and deposition in this soil and its associates may have been repeated more than once. Like the soils on the Buck Creek surface, some soils of the Menoken surfaces may have formed from different facies of a deposit. The Thurman, for example, is a soil formed in coarse sediments underlain by coarse and fine sediments that are probably kame delta deposits. It grades into Konawa and the Konawa grades into Gymer in the same fashion described above on the Buck Creek surface. The mapped distribution shows Konawa and Gymer on the Buck Creek surface (where they are presumed to be soils formed in parent materials of Illinoian age or perhaps older) and on Menoken surfaces where the ages of the soils may also be Illinoian or younger with the earliest pre-Illinoian soils lost to erosion. The question of ages of similar soils on surfaces and in deposits presumed to be of different ages is wide open for investigation in Kansas. Clearly the presence of the glacial sediments in the Menoken deposits and the position of the Menoken surfaces argue for greater antiquity for the Menoken than the Buck Creek. Still the soils often include the same series on these surfaces suggesting that soils are considerably younger than the Menoken deposits and maybe even much younger than the Buck Creek deposits.

The entire terrace chronology needs reevaluation. At this time little is known of the age of the Menoken deposits other than to assume that they are pre-Illinoian. Geil (1985) reports a 600,000-yr date for volcanic ash (Pearlette O, or Lava Creek B) in material that has been mapped as Menoken (Dufford, 1958; Jewett et al., 1965), but topographically it seems the ash is in sediments of the Buck Creek terrace. Thus the ages of the Menoken and perhaps the Buck Creek deposits excluding loess at the surface are no doubt older than 600,000 yrs, suggesting the chronology of these terraces needs revision.

An additional pattern that emerges from examining soils noted in table 1 is related to a somewhat steep soil-moisture gradient in the area between Junction City and Kansas City. Between these two cities, soils generally make the transition from udic soil-moisture regimes in the east to ustic regimes in the west (Soil Survey Staff, 1975), along an average-annual-precipitation gradient of 5–6 inches (13–15 cm) between these endpoints (Flora, 1948). On the Holliday/floodplain surface, soils of the Eudora–Kimo–Sarpy association give way westward to the Carr, Haynie, and Humbarger soils, but, of these, only the Humbarger has a ustic soil-moisture regime. Among the soils on the Newman terrace, the Judson–Reading–Wabash association gives way to Muir, Geary, and Sutphen soils. The eastern soils are udolls or aquolls whereas the western soils are all ustolls. The soils of the Buck Creek and Menoken surfaces include the Morrill–Gymer–Konawa–Thurman–Sharpsburg association. Clear patterns of soil-moisture regimes among soils on the older two terraces are not so clear as those on the Newman terrace. In several localities, one or both of the older terraces are not preserved, making the establishment of trends difficult. Still a weak trend toward increasingly ustic soil-moisture regimes occurs westward from Kansas City. Climatic transition, for example, plays a major role in determining a mixture of ustic and udic soils among the eastern soils on the Buck Creek surface, which give way westward to the Geary, Hastings, and Shellabarger soils, all of which are ustolls (tables 1 and 2).

The data in the tables and the interpretations of the soils in this paper suggest that a simple linkage of key soils and major alluvial terraces is inadequate as an aid in understanding landscape evolution in the Kansas River valley. Clearly the evaluation and chronology of the existing terrace sequence is in question, and the development of soils on these surfaces also is not clear. We have made a first approximation at identifying some of these soil-geomorphic interactions that may be responsible for some of the complexity we see in the Kansas River landscape. Much more of this work remains to be completed.

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Appendix

Eudora series

The Eudora Series consists of deep, well-drained, nearly level to gently undulating soils on floodplains. These soils formed in loamy alluvium. Native vegetation is tall-prairie grasses and deciduous trees.

In a representative profile, the surface layer is very dark grayish-brown silt loam approximately 2 inches (5 cm) thick. The underlying material is dark-grayish-brown coarse-silt loam.

Natural fertility and available water capacity are high. Permeability is moderate.

Representative profile of Eudora silt loam, in a cultivated field, 125 ft (38 m) south and 50 ft (15 m) west of the northeast corner of sec. 15, T. 12 S., R. 19 E., Douglas County:

Ap—0-7 inches; very dark grayish-brown (10YR 3/2) silt loam; moderate medium granular structure; very friable; slightly acid; gradual smooth boundary.

A12—7-12 inches; very dark grayish-brown (10YR 3/2) silt loam; moderate medium granular structure; very friable; many worm casts; slightly acid; gradual smooth boundary.

C1—12-23 inches; dark-grayish-brown (10YR 4/2) coarse-silt loam; massive; very friable; many worm casts; mildly alkaline; gradual smooth boundary.

C2—23-40 inches; dark-grayish-brown (10YR 4/2) coarse-silt loam; massive; very friable; few worm casts; a layer of silty clay loam at a depth of 33-34 inches (83-85 cm); mildly alkaline; gradual smooth boundary.

C3—40-48 inches; dark-grayish-brown (10YR 4/2) silt loam; massive; very friable; mildly alkaline; clear smooth boundary.

C4—48-72 inches (120-180 cm); grayish-brown (10YR 5/2) coarse-silt loam; massive; very friable; some thin sandy and clayey layers less than 1 inch (2.5 cm) thick; strongly effervescent; mildly alkaline.

The A horizon ranges from 10 to 20 inches (25-50 cm) in thickness. In places where sediment was deposited by the flood of 1951, it is dark grayish brown. It is silt loam, fine sandy loam, or very fine sandy loam. Reaction ranges from slightly acid to neutral. The C horizon above a depth of 36 inches (90 cm) is generally silt loam that has thin layers of more sandy or clayey material. Below a depth of 36 inches (90 cm), it is silt loam, loam, very fine sandy loam, fine sandy loam, or loamy very fine sand that is generally calcareous.

Eudora soils are near Kimo, Sarpy, and Judson soils. Eudora soils contain less clay in the upper 40 inches (100 cm) than Kimo soils. They contain less sand throughout than Sarpy soils. They contain less clay throughout and are dark colored to a shallower depth than Judson soils.

Muir series

The Muir series consists of nearly level, deep, well-drained, loamy soils that formed in alluvium. These soils occur on high terraces or benches in the valley of the Kansas River.

In a typical profile the surface layer is medium acid, dark-gray silt loam approximately 8 inches (20 cm) thick. The subsoil extends to a depth of 62 inches (155 cm). It is silt loam to a depth of 20 inches (50 cm) and silty clay loam below. Colors in the subsoil are dark gray, grayish brown, and light brownish gray. The underlying material is mildly alkaline, pale-brown silt loam.

Muir soils are friable and easily worked. They take in a large amount of water that is available for plants. Crops respond well if proper amounts of fertilizer are added.

Muir soils are suited to the crops commonly grown in the county and most of the acreage is cultivated. They are suitable for irrigation and much of the irrigated acreage in the county occurs on these soils.

Typical profile of Muir silt loam (520 ft [156 m] north, 100 ft [30 m] east of the southwest corner of sec. 18, T. 11 S., R. 15 E., Shawnee County):

Ap—0-8 inches(0-20 cm), dark-gray (10YR 4/1) silt loam, very dark gray (10YR 3/1) when moist; weak granular structure; slightly hard when dry, friable when moist; medium acid; clear boundary.

B1—8-20 inches (20-50 cm), dark-gray (10YR 4/1) heavy silt loam, very dark gray (10 YR 3/1) when moist; moderate, fine, subangular blocky structure; hard when dry, friable when moist; medium acid; gradual boundary.

B21—20-34 inches (50-85 cm), grayish-brown (10YR 5/2) light silty clay loam, very dark grayish brown (10YR 3/2) when moist; moderate, fine, subangular blocky structure; hard when dry, firm when moist; slightly acid; diffuse boundary.

B22—34-49 inches (85-123 cm), grayish-brown (10YR 5/2) light silty clay loam, dark-grayish-brown (10YR 4/2) when moist; moderate, fine, subangular blocky structure; hard when dry, friable when moist; slightly acid; gradual boundary.

B3—49-62 inches (123-155 cm), light-brownish-gray (10YR 6/2) light silty clay loam, dark-grayish-brown (10YR 4/2) when moist; moderate to weak, fine, subangular blocky structure, massive in the lower part; hard when dry, friable when moist; slightly acid; gradual boundary.

C—62-80 inches (155-200 cm), pale-brown (10YR 6/3) coarse-silt loam, brown (10YR 5/3) when moist; massive; slightly hard when dry, very friable when moist; mildly alkaline.

The Ap horizon ranges from 7 to 16 inches (18-40 cm) in thickness. The B horizon ranges from heavy loam to medium silty clay loam and is medium acid to neutral.

Muir soils are coarser in texture than are Reading soils and have weaker structure. They are more clayey and darker colored than Eudora soils.

Gymer series

The Gymer series consists of deep, well-drained, gently sloping to sloping soils on uplands. These soils formed in loamy sediment. The native vegetation is generally tall-prairie grasses, but on some sloping areas, the native vegetation is a combination of oak-hickory forest with an understory of tall-grass prairie.

In a representative profile, the surface layer is very dark grayish-brown silt loam approximately 15 inches (38 cm) thick. The subsoil extends to a depth of more than 60 inches (150 cm). It is dark-brown, firm silty clay loam.

Available water capacity and natural fertility are high. Permeability is moderately slow. Most of these soils are cultivated. They are well suited to all the crops commonly grown in the county.

Representative profile of Gymer silt loam, 3–8% slopes, in a cultivated field, 600 ft (180 m) south and 70 ft (21 m) west of the northeast corner of SE sec. 4, T. 12 S., R. 18 E., Douglas County:

Ap—0–6 inches (0–15 cm), very dark grayish-brown (10YR 3/2) heavy silt loam; moderate fine granular structure; friable; slightly acid; gradual smooth boundary.

AB—6–15 inches (15–38 cm), very dark grayish-brown (10YR 3/2) heavy silt loam; moderate fine subangular blocky structure and moderate fine granular structure; friable; slightly acid; gradual smooth boundary.

B21t—15–20 inches (38–50 cm), dark-brown (7.5YR 3/2) silty clay loam; moderate medium and fine subangular blocky structure; firm; slightly acid; gradual smooth boundary.

B22t—20–34 inches (50–85 cm), dark-brown (7.5YR 4/2) silty clay loam; moderate medium and fine subangular blocky structure; firm; slightly acid; gradual smooth boundary.

B3—34–68 inches (85–170 cm), dark-brown (7.5YR 4/2) silty clay loam; moderate medium and fine subangular blocky structure; firm; slightly acid.

The A1 horizon is mostly silt loam, but it ranges to light silty clay loam in some places. Reaction is slightly acid to strongly acid. The B and C horizons range from brown to reddish brown and from silty clay loam or clay loam to light silty clay. Reaction is slightly acid to medium acid. Limestone is at a depth of more than 5 ft (1.5 m) in places.

Gymer soils are near Martin, Oska, Sharpsburg, and Thurman soils. Gymer soils are browner and less clayey than Martin soils. They are deeper to limestone than Oska soils, which are underlain by limestone at a depth of 40 inches (100 cm) or less. Gymer soils have a brown to reddish-brown B horizon, whereas Sharpsburg soils have a dark-grayish-brown B horizon. Gymer soils are not so sandy as Thurman soils.

Morrill series

The Morrill series consists of deep, well-drained, sloping to strongly sloping soils on uplands. These soils formed in glacial till and glaciofluvial deposits.

In a representative profile, the surface layer is very dark gray light-clay loam approximately 10 inches (25 cm) thick. The subsoil is about 46 inches (115 cm) thick. It is dark-brown, firm clay loam in the upper 6 inches (15 cm) and reddish-brown, firm, and very firm clay loam below. The underlying material is yellowish-red and reddish-brown clay loam. Permeability is moderately slow. Available-water capacity and natural fertility are high.

Representative profile of Morrill clay loam, 3–7% slopes, in a bluegrass pasture, 1,400 ft (420 m) east and 100 ft (30 m) north of the southwest corner of sec. 3, T. 13 S., R. 21 E., Douglas County:

A1—0–10 inches (0–25 cm), very dark gray (10YR 3/1) light-clay loam; moderate medium granular structure; friable; slightly acid; gradual smooth boundary.

B1—10–16 inches (25–40 cm), dark-brown (7.5YR 4/2) light-clay loam; very fine and fine subangular blocky structure; firm; medium acid; gradual smooth boundary.

B21t—16–30 inches (40–75 cm), reddish-brown (5YR 4/3) clay loam; moderate fine subangular blocky structure; firm; medium acid; gradual smooth boundary.

B22t—30–56 inches (75–140 cm), coarsely mottled reddish-brown (5YR 5/4) and yellowish-red (5YR 5/6) clay loam; moderate fine and medium subangular blocky structure; very firm; distinct continuous clay films; slightly acid; gradual smooth boundary.

C—56–66 inches (140–165 cm), coarsely mottled yellowish-red (5YR 5/6) and reddish-brown (5YR 5/4) clay loam; massive; firm; few fine iron and manganese concretions; neutral.

The A1 horizon ranges from very dark gray to dark-brown light-clay loam to loam. Depth to the B2t horizon ranges from 9 to 18 inches (23–45 cm). In some places, the B horizon is sandy-clay loam or gravelly clay loam. The C horizon ranges from loam to sandy-clay loam. Small pebbles are throughout the profile in some places.

Morrill soils are near Oska, Pawnee, Sharpsburg, and Thurman soils. Morrill soils are redder and have less clay in the B horizon than Pawnee soils. They are deeper than Oska soils and contain more sand throughout than Oska and Sharpsburg soils. They contain less sand and more clay throughout and are redder than Thurman soils.

Type descriptions for Kansas River terraces

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Abstract

Names, stratigraphic relationships, and ages of terraces and alluvial fills of the Kansas River valley were initially proposed by Davis and Carlson in separate, though interrelated, Master's theses. The resulting framework of Menoken, Buck Creek, and Newman units, at once adopted by the Kansas Geological Survey, has been followed ever since. Close reading of published descriptions of Kansas River terraces and underlying sediments reveals insufficiency of basic data, as well as many discrepancies. Reported Menoken and Buck Creek elevational maxima and minima show major overlaps. Furthermore, the massive red sandy silt described for the upper part of each fill may be the same unit. Application to localized Kansas River sedimentary units of names derived from far afield is questionable.

A geomorphologist familiar with the magnificent terraces present along many streams in the semi-arid western United States would not be impressed by the poorly developed land forms of the Kansas River valley. Nevertheless, terraces are indeed present and have attracted geological attention for many decades.

Original reports

Although the existence of terraces had previously been mentioned in the published literature, formal names were not proposed until the early 1950's. In Master's theses that were supervised by John C. Frye, then Director of the Kansas Geological Survey, Stanley N. Davis and William A. Carlson named and discussed the three most prominent levels. In order of decreasing elevation, hence decreasing age, these were designated the Menoken, Buck Creek, and Newman terraces. Details of the original descriptions are relevant to present investigations into the geomorphology and Quaternary history of northeastern Kansas. Davis (1951) studied the Kansas River valley near Topeka (from 6 mi [10 km] west to 9 mi [14 km] east); Carlson (1952) examined a reach extending from 11 mi (18 km) west of Lawrence to 2 mi (3 km) east.

Since he observed "pro-glacial outwash" and "pre-Kansan gravel" on the sides of the existing valley, Davis concluded that an "important" valley had been present in pre-Kansan time. Carlson (1952) agreed. Davis stated that because "the contact between early Pleistocene river sediments and bedrock is everywhere at least 20 feet above the present flood plain, it is quite certain that the surface of this ancient valley was at least [this high]." In the Lawrence area, Carlson found that the bedrock surface representing the depth of cutting by the Kansas River prior to the Kansan glaciation stood "8 to 10 feet above the Newman terrace surface," which would mean 15–20 ft (4.5–6 m) above the present floodplain.

Davis found that the "pre-Kansan gravel" contained a scattering of clasts of granite and quartzite. Fragments of granite could reach eastern Kansas only by stream transport from outcrops of the Ogallala Formation farther west or by glacier transport from the north. He suggested that this gravel was either Nebraskan outwash carried far south of the ice front or outwash from the advancing Kansan ice. He accepted the proposal by Lohman and Frye (1940) that the modern Kansas River originated as an ice-marginal stream during the Kansan glacial advance. Both Davis and Carlson agreed that the preglacial Kansas River "headed in the Flint Hills region east of Manhattan."

Menoken terrace

Davis believed that the preglacial Kansas River valley was "cut wider and a little deeper by melt water as the glacier advanced toward the area" and that the valley "was filled with glacial outwash which became progressively finer grained as the glacier was dissipated." He noted that the surface of this alluvial fill was "at least 80 feet above the present flood plain," and reported that in Menoken Township "accordant summits of the terrace are 90 feet above the flood plain." (He erroneously stated that this area is northeast of Topeka, but gave the correct township and range northwest of the city.) This surface was named by Davis—"it is here proposed to name this terrace the Menoken terrace from the township in which it is typically developed." Discussing the Lawrence area downvalley from Topeka, Carlson reported that the Kansas River valley was filled "to a height of 110 feet above the present flood plain."

In the Topeka area, Davis reported the presence, especially along the northern side of the valley, of glacial outwash locally more than 80 ft (24 m) thick. Of three well-defined zones, the lowest, at least 20 ft (6 m) thick, was composed of crossbedded, very coarse gravel containing about 10% erratic clasts. Because some of the boulders were very large, and till interfingered with the gravel, this sediment was correlated with the proglacial Atchison Formation. Overlying this unit was a discontinuous zone of sand and silt identified as the Grand Island member of the Meade formation and believed to represent outwash from the retreating Kansan glacier. The top unit consisted of 30–40 ft (9–12 m) of massive reddish sandy silt containing numerous scattered pebbles. This was assigned by Davis to the Sappa member of the Meade formation. In one statement he included this as part of the "outwash," while another statement, by emphasizing the outwash origin of the Grand Island, seemed to omit the Sappa.

Downriver near Lawrence, Carlson also reported "interfingering of terrace material with Kansas till." He said the "lower half of the terrace deposit" consisted of glacial drift, some of which had been slightly reworked, apparently by both streams and mass movements. Boulders up to 3 1/2 ft (1 m) long were numerous. Within and overlying the coarse debris was a thick zone of well-sorted, crossbedded coarse sand which, because it was composed mainly of quartz and feldspar, he believed to have been derived from breakdown of igneous and metamorphic erratics. In the upper part of the deposit, fine sand graded upward into silt and clay, some of which was a deep-red color, probably produced by "the long period of weathering." The silt was believed to represent the final stage of deposition "immediately following the retreat of the Kansas ice sheet." The silt was called Sappa, the sand and gravel Grand Island.

Both Davis and Carlson believed that sediments they called Grand Island originated as glacial outwash and were, therefore, of Kansan age. This also seemed to hold true for sediments they called Sappa. They spoke of the surface of this deposit as being the Menoken terrace and implied that this is a fill-top or depositional surface. If both of these assumptions are correct, then the surface they called the Menoken terrace was indeed formed during retreat of the Kansan ice sheet.

Buck Creek terrace

In the Topeka area, according to Davis, formation of the Menoken terrace (he must mean the depositional surface) was followed by "a period of erosion in which the bedrock floor of the Kansas River valley was cut 40 to 50 feet below its former level. After this entrenchment the valley was again aggraded to about 40 feet above the present flood plain." Inasmuch as he found the pre-Kansan bedrock surface at least 20 ft (6 m) above the present floodplain, this indicates downcutting of the bedrock to a level 20–30 ft (6–9 m) below the present floodplain, then aggradation of some 60–70 ft (18–21 m)of sediment.

For the Lawrence area, Carlson commented only briefly about events immediately following formation of the Menoken surface. He spoke of "a period of downcutting which occurred during and after the formation of the Menoken terrace which lowered the bedrock channel approximately 60 to 70 feet." That would seem to permit the accumulation of as much as 90 ft (27 m) of fill during the subsequent episode of aggradation.

Davis said that "this terrace has been named the Buck Creek terrace (Carlson, 1951 [sic]) from a well-developed surface northwest of Lawrence." Carlson did not indicate in his thesis that he was proposing a new name, so the statement by Davis provides the only evidence regarding the origin of the designation. On the basis of the selected name, it can be supposed that the type area is where "Buck Creek remnants in the main valley occur along Buck Creek . . . where it flows from the bedrock uplands onto the terrace flats of the Newman level."

In any event, both Davis and Carlson clearly implied that the name was given to the surface formed by the top of the post-Menoken aggradation—a fill-top surface. Carlson reported that "the altitude of the terrace is 20 to 25 feet above the Newman level," which would place it 28–33 ft (8–10 m) above the present floodplain. Davis spoke of terraces "probably equivalent to the Buck Creek terrace" yet only 15–25 ft (4.5–7.5 m) above present floodplains, but these were apparently restricted to tributary valleys.

Davis' geologic map contains no areas specifically identified as Buck Creek terrace, but he spoke of red clayey silt in "probably equivalent" terrace deposits along tributary valleys. Carlson reported that "the material constitutents underlying the Buck Creek terrace surface consist primarily of silt and fine sand." A drill hole in the type area penetrated 90 ft (27 m) of uniform sediment which Carlson suggested had been deposited by a low-gradient, high-discharge phase of the river. He emphasized the "brownish red" color of the sediment, at least along minor tributary creeks.

In keeping with the sparsity of possible Buck Creek terrace remnants in the Topeka area, Davis stated only that "the age of the Buck Creek terrace is not known, but the evidence indicates that it is younger than Kansan and older than Mid-Wisconsinan." Carlson was more precise, though on the basis of little clear evidence. Referring specifically only to a railroad cut west of Lawrence, he reported that "a terrace deposit composed of gravel, sand, and clay considered to be a remnant of the Buck Creek terrace" was overlain by "Loveland and Peoria loess deposits separated by a soil zone." He concluded that "this stratigraphic sequence, together with the physiographic relation to the Kansan age Menoken terrace, places the Buck Creek terrace deposits as the Crete member of the Sanborn formation of Illinoian age." Carlson gave no evidence on which he based identification of the two loess units. However, in a "small patch" near Topeka, Davis also found two loesses. He called the upper one Peoria on the basis of depth of leaching and extent of soil development. The lower loess was believed to be Loveland because "it is much older than the overlying loess," whatever that might mean.

Newman terrace

Both Davis and Carlson noted that most of the Buck Creek terrace had been removed, especially along the Kansas River valley. Davis attributed this to "lateral erosion of the river" and explained that the Menoken terrace is better preserved because "it has a much higher bedrock floor which has effectively resisted erosion." Carlson agreed that the Menoken is a "rock-defended terrace" and that because "the lower portion of the bedrock channel extends beneath the Buck Creek terrace . . . subsequent lateral cutting by the river removed essentially the entire deposit."

For the Lawrence area, Carlson reported that "a minor amount of downcutting of the bedrock may have occurred during the period immediately following removal of the Buck Creek deposits as the bedrock floor seems to have been lowered about 5 to 10 feet." This was followed by "another period of alluviation" which contributed to the formation of a well-developed terrace surface that occupies as much as half of the valley floor in some areas. Davis wrote that "the terrace is jointly named here and by Carlson (1951 [sic]) the Newman terrace."

In the type area, in the vicinity of the town of Newman west of Lawrence, the Newman terrace is "approximately 8 feet above the general flood-plain surface." The extensive terrace surface is characterized by "its almost complete lack of topographic expression"; it is "virtually undissected." This means that almost all information about underlying sediments must be acquired from drill holes.

Davis reported that the alluvial fill in the Kansas River valley reaches "a maximum thickness of 80 feet." Inasmuch as this statement was placed beneath the heading "Late Pleistocene and Recent alluvium," there is at least the implication that this is the depth of fill of that age. He noted that "in general, the alluvial fill grades upward from a very coarse cobble fill to a fine sand or silt at the surface. The upper 40 feet of alluvium is believed to be the result of river deposition similar to that of today," but drilling encountered boulders at greater depths. He also stated that "the Newman terrace is underlain almost entirely by silt and silty clay which ranges from 15 to 30 feet in thickness. Much of this finer material is 'backswamp' deposit."

For the Lawrence area, Carlson found that the alluvium consisted of "alternate layers of clay, silt, and fine to medium sand," but "the progressively older underlying sediments show a distinct continuous gradation to coarser material. Boulders of quartzite 3 to 4 feet in diameter are not uncommon at the base of the deposit in direct contact with the bedrock . . . More commonly the deposits at the base overlying the bedrock consist of coarse gravels of various rock types." He noted that "the upper layers . . . are quite uniform and continuous" and he suggested that "the continuity of the sediments seems to imply that the depositing river flowed in a constricted channel, that it did not meander across its valley."

According to Davis, "the age of the alluvial fill is believed to range from late Wisconsinan to Recent." He noted that the great flood of 1903 overlapped the margins of the Newman terrace and the flood of 1844, supposedly 2 ft (.6 m) higher, probably covered a large part of the terrace. He concluded that "the greater part of the valley is still aggrading." Carlson reported that "considerable quantities of silt were deposited by the flood of 1951."

First formal publication

As soon as they were completed, the Master's theses by Davis and Carlson were combined and published as Bulletin 96, Part 5, of the Kansas Geological Survey (Davis and Carlson, 1952). Very few changes were made in quantitative content and interpretations were not explained more completely.

The height of the base of early Pleistocene river deposits was first given as being "everywhere at least 15 feet above the present flood plain." A second statement reported that the "bedrock base of the Meade formation . . . is at least 10 feet above the present flood plain." This is a little lower than given in Davis' thesis.

It was specifically stated that "the upper surface of these [Meade] deposits forms a high terrace which is mapped as the Menoken terrace, and which is discontinuously mantled with loess, eolian sand, and sand derived from slope wash. These thin surficial deposits range in age from Illinoian to Recent." The lowest, bouldery zone of the Meade was said to "in many localities" attain a thickness of "at least 30 feet."

Bulletin 96 further stated that "following formation of the Menoken terrace there was a period of erosion in which the bedrock floor of the Kansas River Valley was cut 50 to 60 feet below its former level. After this entrenchment the valley was again aggraded to about 35 feet above the present flood plain."

Referring to the Buck Creek terrace, Bulletin 96 remarked that "its age is judged to be Illinoian as the terrace fill truncates deposits of Kansan age and has a well-developed soil (Sangamon) at the surface which is discontinuously mantled by Peoria loess." Furthermore, the silt that was found by drilling to be 90 ft (27 m) thick at Buck Creek School "is classed as the Loveland silt member of the Sanborn formation." In a railroad cut near Tecumseh, it was concluded that "the Loveland silt of this area is in part, if not entirely, an alluvial deposit, the upper surface corresponding to the Buck Creek terrace."

Under the heading "Wisconsinan and Recent alluvium" it was reported that "all river and major stream valleys in the area have deep alluvial fills which reach a maximum thickness of almost 90 feet in the Kansas River Valley" and "the age of the alluvial fill ranges from Wisconsinan to Recent since these deposits truncate Illinoian terrace fills."

Concurrently with completion of theses by Davis and Carlson and preparation of Bulletin 96, the Kansas Geological Survey also published Bulletin 99, *Pleistocene geology of Kansas* (Frye and Leonard, 1952). This latter bulletin repeated previous statements that "the Meade formation underlies the surface of extensive dissected remnants of the Menoken terrace . . . This terrace, where it has been studied eastward from Topeka, stands approximately 80 feet above Kansas River flood plain and has a bedrock floor approximately 20 feet above the flood plain."

Bulletin 99 also stated that "along the Kaw Valley Crete deposits underlie the surface of disconnected small remnants of the Buck Creek terrace" and "alluvial Loveland silt occurs as the upper part of the deposits of the Buck Creek terrace." Furthermore, "a major episode of valley incision occurred after the deposition of the late Kansan Meade formation in the [Kansas River] valley and prior to the deposition of the late Illinoian Crete member."

Later publications

The terrace names, stratigraphic relationships, and ages proposed by Davis and Carlson and, of course, their supervisor, Frye, at once became an accepted framework within which all later studies had to be placed. However, most reports compiled to describe the geology of a specified area, such as a Kansas county, devoted little attention to stream terraces or geomorphic history.

For Wabaunsee County, which lies just west of Topeka, the bulletin by Mudge and Burton (1959) noted that Grand Island, Crete, and Loveland sediments may all have a "red-brown" color but, strangely, not the Sappa, which is described as being red almost everywhere else. It further reported that the Buck Creek terrace is "about 60 feet above the stream bed" and the Newman terrace is "10 to 15 feet above the present stream bed." Surely, the intended meaning was floodplain rather than channel bed, although the bulletin also stated that "the younger terrace [Newman] ranges in elevation above the stream bed from a few feet along the small streams to 60 or more feet along the Kansas River." That statement must include a numerical misprint of the highest elevation.

The bulletin about Douglas County, which includes Lawrence (O'Connor, 1960), remarked that "the name Menoken Terrace is used only as a geomorphic term . . . for a terrace on sediments of Kansan age in the Kansas River Valley." It also was noted that "the Loveland Formation . . . chiefly reddish . . . constitutes most of the [Buck Creek] terrace fill and is at least 62 feet thick locally . . . The Sangamon soil, which is well developed on Buck Creek Terrace deposits, is characterized by its reddish color and thick clayey B horizon."

Bulletins for Shawnee County, in which Topeka is located (Johnson and Adkison, 1967; Johnson and Wagner, 1967), noted that north of the Kansas River, Sappa massive, pale-red, clayey silts "of glaciofluvial and glaciolacustrine origin" are "more than 40 feet thick in places." The Buck Creek deposits were reported to be "about 30–80 feet above the [Kansas] river and are often 'reddish-brown.'" Also included was the startling statement that "the extensive remnant of the Buck Creek terrace along the west side of Cross Creek [4 miles] north of Rossville ranges in height from about 20 feet to as much as 90 feet above the creek . . . the higher part of the deposit overlies bedrock." This upper limit is equal to that usually given for the Menoken terrace.

Dufford (1958) specifically discussed the Quaternary geology of the Kansas River valley from Lawrence downstream to Bonner Springs, although the emphasis was on ground-water resources. He recognized unusually extensive remnants of the Menoken terrace on both sides of the river at a height of about 90 ft (27 m) above the present floodplain in the general vicinity of Eudora. He reported that "locally . . . the entire stratigraphic sequence underlying the Menoken Terrace consists of massive sandy silt. More than 80 feet of Sappa . . . red to light brown . . . silt is present in some parts of the area." He also spoke of "the characteristic red clayey silt underlying the exposed sections of all Buck Creek Terrace remnants throughout the area."

A more detailed discussion of Quaternary history was provided by Beck in his 1959 bulletin about the geology and ground-water resources from Topeka upstream to Wamego. This detail is not surprising since he was a geomorphologist. He reported that "the floor of the Menoken Terrace deposits . . . glacial outwash . . . ranges from 20 to 40 feet above the present flood plain" and "the bedrock surface on which pro-Kansan sediments were deposited is 50 to 75 feet below the surface underlying pre-Kansan gravels . . . The Menoken Terrace is about 60 feet above the Newman Terrace," or about 75 ft (23 m) above present floodplain.

Beck also stated that "the bedrock surface on which Illinoian sediments were deposited is 25 to 50 feet below the surface on which Kansan sediments were deposited . . . In the waning phase of Illinoian time . . . the [Kansas River] valley again was alluviated to a level about 30 feet above the Newman Terrace" or about 45 ft (14 m) above present floodplain. "The remnants of these deposits are the Buck Creek Terrace deposits . . . The thickness of these [Buck Creek] deposits ranges from about 35 feet . . . to 96 feet . . . The upper part of the fill is a reddish-brown silt and clay upon which the Sangamon soil developed . . . Some of the finer material in the upper part of the Buck Creek Terrace deposits may be of eolian origin . . . The bedrock surface on which the Newman Terrace deposits accumulated lies 50 to 80 feet below the terrace surface . . . which may be as much as 15 feet above the flood plain."

Fader (1974) published a report on ground-water supplies in the Kansas River valley which included maps showing areas of Newman and Buck Creek terrace deposits between Junction City and Kansas City. Mapping was limited by what he termed valley margins and all Menoken terrace deposits were excluded. The accompanying text contained no information about the terrace sediments.

Conclusions and evaluations

Close reading of available descriptions of Kansas River terraces and sub-terrace sediments reveals a basic framework (fig. 1) but considerable variation in detail, as well as a notable absence of critical evidence, especially for claimed truncation of one fill sequence by another. All subsequent authors used the three-fold classification established by Davis and Carlson, identifying entities they called Menoken, Buck Creek, and Newman. However, use of terminology has been sloppy. Many authors spoke of a "terrace," a geomorphic surface, when actually discussing the sediment underlying the terrace.

In actuality, there is no necessary equivalency of the age of the sediment and the age of the overlying surface. A

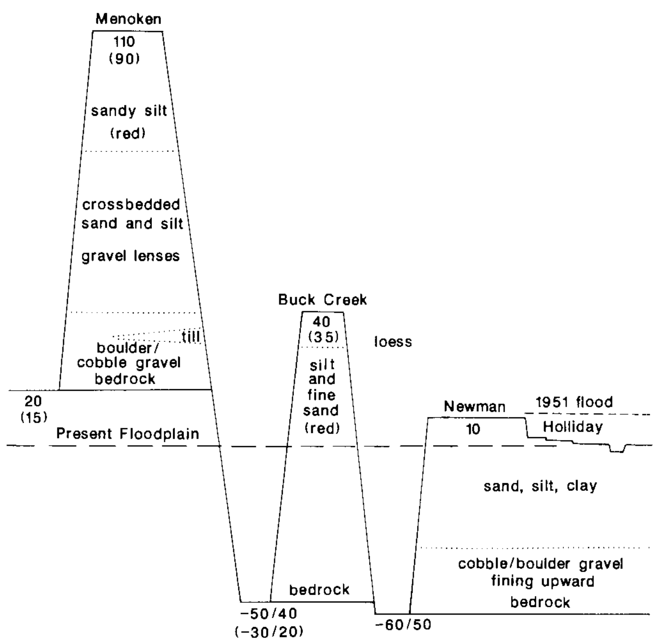

FIGURE 1—SCHEMATIC REPRESENTATION OF THE EROSIONAL/DEPOSITIONAL HISTORY OF THE KANSAS RIVER THROUGH PLEISTOCENE AND HOLOCENE TIME AS PROPOSED BY CARLSON (1952) AND DAVIS (1951) AND FOLLOWED BY SUBSEQUENT AUTHORS.

terrace (surface) at the upper limit of a sedimentary unit might be the same age as that sediment, a fill-top terrace, or it might be significantly younger, an erosional or fill-strath terrace. This latter possibility apparently has not been considered for any Kansas River surface.

There is general agreement that a coarse bouldery gravel, where present, was a product of direct glacial outwash and should therefore be called the Grand Island member of the Meade formation. Other than that, however, most unit identification has been based principally on topographic position. If a sandy silt is "high" above the present floodplain, then it "must be" the Sappa member of the Meade formation and therefore part of the Menoken "terrace fill." If it is "low," it "is" the Loveland silt member of the Sanborn formation and part of the Buck Creek fill. Both the Sappa and the Loveland are described as sandy silt and the color of each has been described as red or reddish brown. A critical reader of these reports is, therefore, led to wonder if the Sappa and the Loveland might be one and the same sedimentary unit that is present through a considerable range of heights above (and below) the modern floodplain.

In its type area, the Menoken fill is described as being a sequence that becomes finer upward, the lowest part bouldery gravel with interfingering till, above which there is pebble gravel, then sand, then silt. However, new excavations visited during the 1986 Friends of the Pleistocene field trip expose till very near the so-called Menoken terrace level with only thin loess above. This relationship obviously raises questions about the original interpretation of that terrace. It may well be an erosional surface that bevels several sedimentary units.

Some authors identified sediment units on the basis of the position of the underlying bedrock floor relative to present floodplain. This criterion also will not bear close scrutiny. A considerable range of positions has been given for each rock floor; there may even be more than the recognized three. Certainly, the nature of the overlying sediment varies from one location to another. An exposure visited by the Friends trip near Rossville shows red sandy silt of the Loveland—or perhaps Sappa?—type, but it rests on a bedrock floor about 20 ft (6 m) above the floodplain, a basal Menoken position.

Finally, serious questions can be raised about the propriety of applying stratigraphic names derived from distant sites to deposits localized along the Kansas River valley. Meade, Grand Island, Sappa, Sanborn, Crete, Loveland—not one of the type localities is related to the mainstem Kansas River; some are not even in the same drainage basin. Lithologies and sedimentary characteristics of the named units seem to vary from one report area to the next. On the other hand, in one report or another every one of the units has been described as red. Furthermore, tabulation of ranges of critical heights as given by various authors shows considerable overlap (fig. 2). Clearly much additional surface mapping and subsurface exploration must be accomplished before the Quaternary history of the Kansas River valley can be accurately reconstructed. The very existence of the conceptual Menoken and Buck Creek terraces needs to be reexamined; only for the Newman does the validity seem secure.

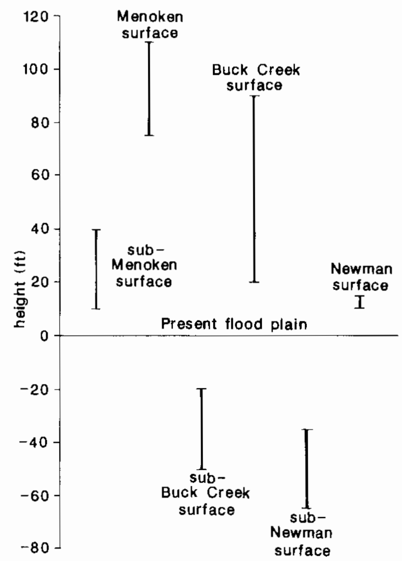

FIGURE 2—RANGES OF ELEVATIONS OF BEDROCK FLOORS AND TERRACE SURFACES ALONG KANSAS RIVER VALLEY AS REPORTED BY VARIOUS AUTHORS.

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Holocene alluvial-stratigraphic studies from Kansas and adjoining states of the east-central Plains

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Abstract

Within recent years, knowledge of the alluvial stratigraphy and associated chronology for the east-central Plains states of Kansas, Nebraska, Missouri, and Oklahoma has expanded significantly. Forty-seven studies for the region, published and unpublished, provide information relevant to the problem. Data are, however, unevenly distributed spatially and temporally and are of varying depth. An examination of sites with radiocarbon control within the Kansas River system of Kansas identifies eight periods of floodplain stability as connoted by soil development: 10,600–10,200, 8,900–8,300, 7,250, 5,100–5,000, 4,300–4,000, 2,600–2,400, 2,100–1,600, and 1,200 yrs B.P. These periods of stability are corroborated by data from research elsewhere in the east-central Plains, indicating regional synchroneity in fluvial events. Resolution and quality of regional correlations would be significantly improved if interpretive problems were reduced through more complete and precise reporting of results.

Introduction

Recent reviews of Pleistocene and Holocene fluvial histories have been presented by Baker (1983) and Knox (1983), respectively. Given the focus herein on the Holocene, the paper by Knox is most relevant but presents a total of only six studies from Kansas and the adjoining states of Nebraska, Missouri, and Oklahoma. Time and space constraints in that study did not permit an in-depth examination of each region, including the east-central Plains. Some of the data was in unpublished or report form, and much has been made available since.

The first detailed basin-wide study of terraces and the age of fill in the region was carried out by Brice (1964) within the Loup River system of central Nebraska. The large number of recent alluvial stratigraphic studies completed since is a function of at least two factors: 1) the advent of easy access to radiocarbon-dating facilities, especially those which provide assays on non-wood organic sources such as soil humates, and 2) legislation enacted to require archaeological evaluation of sites and areas to be impacted by construction, particularly water-resources projects.

Our intent is to examine the Holocene alluvial history of Kansas. This, however, cannot be fully appreciated without discussing it within a regional context. We first summarize the alluvial histories for Kansas and the adjoining states of Nebraska, Missouri, and Oklahoma. Regional correlations are then made within Kansas, primarily within the Kansas River basin, and subsequently between Kansas and the adjacent states.

Regional state summaries of alluvial studies

Alluvial stratigraphy has been studied at 47 localities in the east-central Plains (fig. 1); some studies focus on specific sites, some on valley reaches, and others on entire drainage basins (table 1). Further, the context of these projects has varied from archeology to geomorphology to soils and geomorphology and to paleobotany. Depth of study also varies appreciably, from brief, unpublished, single-section descriptions to well published multi-year, valley-reach or basinwide endeavors.

Kansas

The first alluvial stratigraphic investigations in Kansas focused upon the various terrace systems, the development of which was attributed to Pleistocene climatic fluctuations. Newell (1935), Hoover (1936), Lohman (1941), and Jewett (1949) referred to or described terraces in the Kansas River valley but proposed no nomenclature. Several subsequent works did introduce names: the Kirwin terrace on the North Fork Solomon River (Frye and Leonard, 1949; Leonard, 1952), the Schoenchen terrace on the Smoky Hill River (Frye and Leonard, 1952), the Almena terrace on Prairie Dog Creek (Frye and Leonard, 1949), the Menoken, Buck Creek, and Newman terraces of the Kansas River (Davis and Carlson, 1952), and both the Holliday terrace (McCrae, 1954; Elks, 1979) and the correlative Intermediate

Surface complex (Dufford, 1958), also on the Kansas River. Subsequent research has provided insight into the ages of the fills as well as the terraces (Johnson, 1985).

The first attempt to synthesize Holocene alluvial chronologies of the east-central Great Plains, by Johnson and others (1980), was based upon reconnaissance surveys, radiocarbon dating of material from stream-bank exposures in Kansas and Oklahoma, and examination of the existing literature. Using the available data, they identified an episode of soil formation on floodplains within Kansas and adjacent areas of Oklahoma and Missouri that ended about 2,000 yrs B.P.; alluviation was common until about 1,000–800 yrs B.P., when widespread entrenchment began. During the last 6 yrs, significant expansion of the data base has occurred within the region, and particularly in Kansas. Existing research can be conveniently grouped into four regions: 1) the Kansas River tributaries of central and western Kansas, 2) the Kansas River and tributaries of northeastern Kansas, 3) the Arkansas River and tributaries, and 4) the Osage River tributaries of eastern Kansas.

Of the Kansas River system sites, the westernmost that reports radiocarbon-controlled alluvial information is the 12 Mile Creek site where a paleoindian artifact was found in association with extinct megafaunal remains buried in gully fill. A *Bison antiquus* limb bone produced dates of 10,435 ± 260 (apatite) and 10,245 ± 335 (gelatin) yrs B.P. (Rogers and Martin, 1984). In the T2 terrace fill deposited during the last 10,000 yrs along Wolf Creek, a tributary entering the Saline River below Wilson Lake, Bornowski (personal communication, 1982) recognized at least eight buried paleosols. Radiocarbon assays on soil humates and charcoal from buried soils in two different fills at separate localities produced dates of 10,580 ± 140 and 2,060 ± 140 yrs B.P., respectively. Soil humate dates of 5,090 ± 60 and 1,740 ± 70 yrs B.P. were obtained from two exposures in the upper reaches of Wilson Lake on the Saline River (May, 1986). Research on Deer Creek, a tributary to the North Fork Solomon River, identified two buried soils, dated at 4,120 ± 270 (humates) and 1,890 ± 90 (charcoal) yrs B.P. (Johnson, 1981).

Recent work also has been conducted along the Kansas River. A study by Holien (1982) on the lower Kansas River in the Bonner Springs area used geomorphic, geologic, faunal, and radiocarbon data to assemble the alluvial history dating from the late Pleistocene to present. Two terraces, the Newman and Holliday, were identified, and surfaces buried within the fill were dated at 10,430 ± 130, 4,290 ± 310, and 2,395 ± 65 yrs B.P. A fourth date, 5,-030 ±90 yrs B.P., was obtained from an *Alnus* sp. stump in situ on a surface exposed within the channel bed at low water. Subsequently, the senior author and W. Dort, Jr., have dated the upper 15 cm of two other buried soils at this site to 8,940 ± 40 (DIC–3210) and 1,210 ± 50 (DIC–3209) yrs B.P. A date of 110 ±40 (DIC–3255) yrs B.P. from the outer 20 rings of a 70-cm (28-inch)-diameter log (*Salix* sp.) verified the relative youth of inset fill at this site. The late prehistoric age of fill exposed in a rapidly migrating meander bend on the Kansas River near the town of Eudora was demonstrated by a date of 785 ± 130 yrs B.P. obtained on wood exposed in a clay unit near the base of the bank (Dort, personal communication, 1984). In Holliday terrace fill near Topeka, sand and gravel extraction (Meier sand pit) exposed wood that was dated at 2,620 ± 70 and 1,670 ±55 yrs B.P. by W. Johnson and P. Kopsick (Johnson, 1985). In

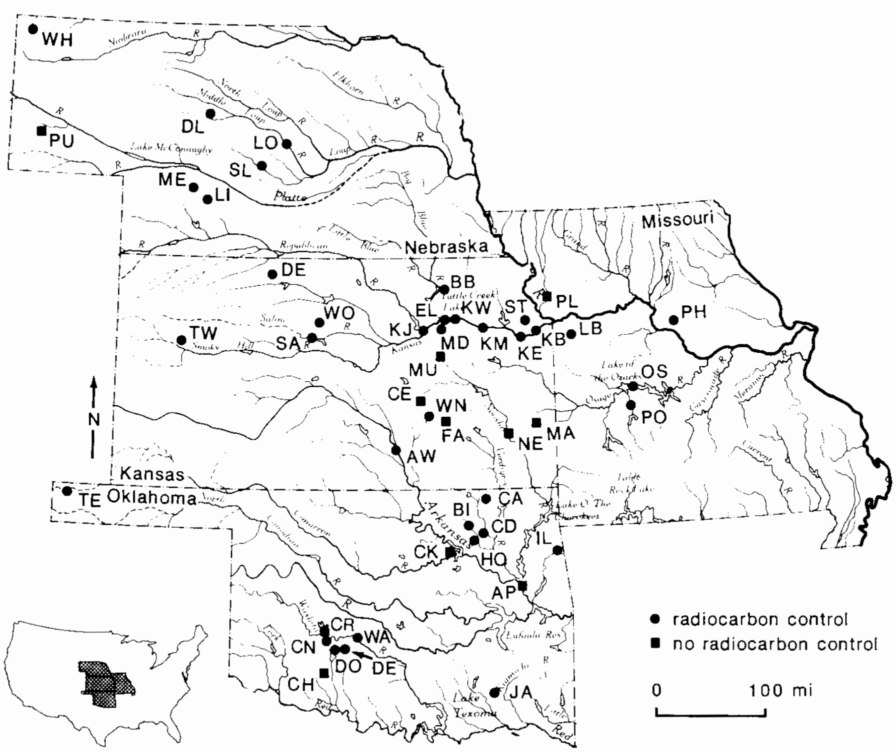


FIGURE 1--MAP OF EAST-CENTRAL PLAINS SHOWING LOCALITIES DISCUSSED IN TEXT.

TABLE 1—ALLUVIAL STRATIGRAPHY, KANSAS, NEBRASKA, MISSOURI, AND OKLAHOMA STUDIES.

Map code[1]	Stream	Site	Study number	Study focus[2]	Study Scale[3]	Investigation(s)
KANSAS						
TW	12 Mile Creek	12 Mile Creek		A	S	Rogers, 1984
DE	Deer Creek			SG	B	Johnson, 1981, 1985
WO	Wolf Creek			SG	B	Johnson, 1981
SA	Saline River	Wilson Lake		SG	V	May, 1986
KJ	Kansas River	Junction City		G	S	Twiss, pers. comm., 1986
MD	McDowell Creek			G	S	Twiss, pers. comm., 1986
EL	Elbo Creek			PB	S	Kurmann, 1985
BB	Big Blue River	Coffey	14PO1	G	S	Schmits, 1978, 1980
KW	Kansas River	Wamego Bend		G	V	Bowman, 1985
KM	Kansas River	Meier sand pit		G	S	Johnson, 1985
KE	Kansas River	Eudora Bend		G	S	Dort, pers. comm., 1986
ST	Stranger Creek	Resco	14LV1046	A	B	Logan, 1985
KB	Kansas River	Bonner Springs		SG	V	Holien, 1982
MA	Marmaton River	Ft. Scott Lake		SG	V	Schmits et al., 1983
MU	Munkers Creek	William Young	14MO304	A	S	Witty, 1982
CE	Cedar Creek		14CS355	A	S	Wood, 1977
NE	Neosho River			A	V	Rogers, 1984
FA	Fall River	Bridwell	14GR38	A	S	Johnson, 1971
WN	Walnut River, east branch	El Dorado Lake		SG	B	Artz, 1983
AW	Arkansas River	Wichita sand pits		PB	V	Jaumann et al., 1985
NEBRASKA						
WH	Whitehead Creek	Hudson–Meng		A	S	Agenbroad, 1978
PU	Pumpkin Creek			G	B	Diffendal and Comer, 1983
DL	Dismal and Middle Loup rivers			G	B	Ahlbrandt et al., 1983
LO	Loup River system			S	B	Brice, 1964
SL	South Loup River			SG	B	May, 1985
ME	Medicine Creek			G	B	Brice, 1966
LI	Lime Creek			A	S	Davis, 1962
MISSOURI						
PL	Platte River			G	V	Davis, 1955
LB	Little Blue River	Sohn	23JA110	SG	S	Johnson, 1978
		May Brook	23JA43	G	S	Kopsick, 1980
		Blue Springs and Longview lakes		G	B	Kopsick, 1982
		Blue Springs Lake		SG	B	Mandel, 1985
PH	lower Perche–Hinkson basins			G	B	Kopsick, 1981
				SG	B	Mandel et al., 1985
OS	Osage River			SG	V	Johnson et al., 1981
				SG	S	Lees et al., 1982
PO	Pomme de Terre River			G	V	Brakenridge, 1981
				G	V	Haynes, 1976, 1985
				G	S	Ahler, 1976
OKLAHOMA						
TE	Tesequite Creek			PB	V	Wilson, 1972
CK	Cimarron River	Keystone Lake		SG	V	Salisbury, 1980
CA	Little Caney River	Copan Lake		SG	V	Hall, 1977a
				A	V	Prewitt, 1980
				SG	B	Reid and Artz, 1984
CD	Candy Creek	Candy Lake		A	V	Saunders, 1980
BI	Birch Creek	Birch Lake		SG	V	Hall, 1977b
HO	Hominy Creek	Skiatook Lake		SG	V	Henry, 1980
AP	Arkansas River	ETSI Pipeline		SG	S	Lees et al., 1982
IL	Illinois River			PB	S	Winter, 1979
CH	Cache Creek basin			SG	B	Hall, 1978
WA	Washita River			G	V	Goss et al., 1972
CR	Cedar Creek	Cowden laterals dam		G	V	Nials, 1977
CN	Carnegie Canyon	Ft. Cobb laterals dam		SG	V	Hall and Lintz, 1983
				SG	V	Lintz and Hall, 1983
DO	Domebo Canyon	Domebo		G	S	Albritton, 1966
DE	Delaware Canyon			SG	V	Hall, 1982
JA	Jackfork Creek	Bug Hill	34PU116	G	V	Johnson, 1983

[1] The map code references locations in fig. 1.

[2] Emphasis upon
A archeology
G geomorphology
SG soils and geomorphology
PB paleobotany

[3] Overall scale
S site specific
V valley segment(s)
B entire basin

a recent endeavor, Bowman (1985) related channel-bank erodibility and rate of channel migration to the character of different-aged alluvial fills in the Kansas River valley near the town of Wamego. Absolute-age control was obtained from a date of 7,250 ± 110 yrs B.P. on humates from a paleosol buried within the Newman fill. Subsequently, we have dated humates from the upper 20 cm (8 inches) of another buried soil at an adjacent exposure to 8,310 ± 120 (DIC-3208) yrs B.P.

Work also has been conducted on several tributaries of the Kansas River. At the Resco site (14LV1046) on Stranger Creek, wood (*Ulmus* sp.) from fill below the terrace has been dated at 4,260 ± 55 yrs B.P. (Logan, 1985; Logan and Johnson, 1986). Twiss (personal communication, 1986) obtained one radiocarbon date of 3,960 ± 135 yrs B.P. on an organic layer buried approximately 6 m (20 ft) below a terrace on McDowell Creek, a tributary to the Kansas River south of Manhattan, and another of 1,210 ± 100 yrs B.P. from organics exposed in a roadcut through Kansas River valley alluvium near Junction City. In a study of opal phytolith and palynomorph assemblages contained within a buried soil exposed in Elbo Creek near Manhattan, Kurmann (1985) reported a radiocarbon date of 1,580 ± 70 yrs B.P. on the soil humates. Schmits (1978, 1980) conducted an intensive archeological and paleohydrological study of the Coffey site (14PO1) adjacent to the Big Blue River in northeastern Kansas. Archeological horizons within a soil formed near the top of channel fill (unit IV) produced dates of 2,320 ± 60 and 2,480 ± 55 yrs B.P. Based on these dates, Schmits (1980) concluded that the buried soil developed between about 2,300 and 2,000 yrs B.P.

Limited geomorphic research has been conducted on the Arkansas River and its tributaries within Kansas. Jamkhindikar (1967) studied sedimentary features and mineralogy of Pleistocene alluvium in the Neosho River drainage, but contributed little to the knowledge of Holocene alluvial geomorphology. Three archeological studies have briefly examined natural alluvial stratigraphy in tributaries of the Arkansas River. Research by Witty (1982) at the William Young site (14MO304) on Munkers Creek in the upper Neosho River drainage suggests a period of stability approximately 4,000 to 2,000 yrs ago. Johnson (1971) and Wood (1977) identified early Plains Woodland sherds associated with a poorly developed buried soil at sites on the upper Fall River (14GR38) and Cedar Creek (14CS355), respectively, two tributaries of the Cottonwood River; the cultural association would suggest an age of 2,000–1,500 yrs B.P. for these buried surfaces. The most intensive research effort reported to date in the Arkansas River basin of Kansas is that by Artz (1983) on the Walnut River. His study, conducted in conjunction with the El Dorado Lake Project, reconstructed the sequence of geomorphic changes and related them to archeological-site distribution and paleohydrology. Of particular note in this late Holocene reconstruction is a period of stability (soil formation) in the valley bottoms from about 4,000 to 2,000 yrs B.P. Rogers (1984) presented a synthetic analysis of archeological-site location and terrace systems for the Arkansas River (particularly the Neosho River) and, to a lesser extent, the Kansas River (Smoky Hill River) drainages. The study, which deals with terraces rather than terrace fills, noted a dramatic difference in terrace age between these two drainage systems and suggested tectonics, rather than climate or other causes, as being responsible for terrace formation and the disparity in terrace ages. In a recent study of the Medicine Lodge River, Martin (1985) recorded the presence of buried paleosols, presumably Holocene in age, and the existence of a prehistoric gully system re-excavated during the historic period.

Little geomorphic study has centered upon the Osage River system of extreme eastern Kansas. Schmits and others (1983), in a study conducted on the archeology and geomorphology of the Fort Scott Lake project area (Marmaton River), mapped and differentiated T1 and T0 surfaces, but did not radiocarbon date the surfaces or the underlying fill. The T1 surface was stabilized 1,500–1,000 yrs ago, based upon pedological and archeological evidence. Schmits (1984) recently assembled existing data for Milford, Melvern, and Pomona lakes in eastern Kansas, the latter two of which are located on the Osage River drainage. Terrace systems were recognized, but time control and stratigraphic information were lacking. We are aware of only one site on the Arkansas River in Kansas where alluvial fill has been radiocarbon dated: a date of 19,340 + 200, − 210 yrs B.P. was obtained on peat extracted from approximately 10 m below a terrace located west of the city of Wichita (Jaumann et al., 1985). Holocene data for the Arkansas are apparently lacking, although reconnaissance surveys indicate a tremendous potential exists.

Nebraska

In Nebraska, the alluvial stratigraphic picture is somewhat more areally concentrated than in Kansas. Works by Brice (1964), May (1985), and May and Holen (1985) on the Loup River; Davis (1962) and Brice (1966) in the Medicine Creek area; Agenbroad (1978) at the Hudson–Meng site on Whitehead Creek; and Schultz and Martin (1970) at several sites across Nebraska all reported radiocarbon control for their stratigraphies and chronologies. The initial work on terraces and alluvial chronologies in Nebraska, conducted by Schultz and Stout (1948), contained no radiocarbon control. Schultz and Martin (1970) combined data from several sites to devise a T0 to T5 terrace sequence and ascribed terrace formation to Pleistocene glacial advances and retreats. This relative chronology dominated the Great Plains' stratigraphic chronologies for nearly 30 yrs. As noted earlier, Brice's (1964) Loup River study contains some of the first radiocarbon dates on alluvial fills in the region. May (1985) subsequently returned to the Loup River systems and greatly expanded upon Brice's work. In the central South Loup River valley, May recognized five Holocene alluvial fills, radiocarbon dated from about 9,800 to less than 900 yrs B.P. In addition to his work on the Loup River, Brice (1966) mapped and dated three terraces along Medicine Creek in southwestern Nebraska; based on these data, he constructed an alluvial chronology for the basin. In a study of the past dynamics of the Nebraska Sand Hills, Ahlbrandt and others (1983) radiocarbon dated organic-rich zones within alluvial sand and silt overlain by dune sand at five sites in the Dismal and

Middle Loup rivers. Ages ranged from 3,000 to 8,410 yrs B.P. Davis (1962) and Schultz and Martin (1970) also developed alluvial chronologies for the state. On Lime Creek in southwestern Nebraska, Davis (1962) described three occupation zones in terrace fill, which is dated on the basis of faunal evidence. Schultz and Martin (1970) reported radiocarbon dates for the T2 and T1 terrace fills in south-central Nebraska. Research in progress at the North Cove site on Harlan County Reservoir, south-central Nebraska, has a late Pleistocene to early Holocene cut and fill sequence (Brown et al., 1986; Johnson et al., 1986). Two studies report data from northwestern and western Nebraska. Agenbroad (1978) obtained early Holocene radiocarbon dates on charcoal flakes and bison bone collagen and apatite from the Hudson–Meng buffalo-kill site on Whitehead Creek. An overlying paleosol was ascribed to stability during the Altithermal. In western Nebraska, Diffendal and Corner (1983) described three alluvial fills along Pumpkin Creek; all three are dated solely on the basis of faunal remains.

Missouri

Moreso than in Nebraska, studies of alluvial geomorphology in Missouri have been related to major cultural-resource studies. Early work, set in the northwestern part of the state, was conducted by Davis (1955) who assigned two terraces along the Missouri River to the Wisconsin. Given recent studies in northeastern Kansas, where similarly defined terraces are now assigned to late Wisconsin and Holocene time, Davis' conclusions apparently need to be reinterpreted. In other work within northwestern Missouri, Kopsick (1980) reconstructed the geomorphic history of the lower May Brook valley, a tributary to the Little Blue River. Although Tl and T0 surfaces were described, absolute-time control came from radiocarbon dates, none of which was greater than 100 yrs B.P. Subsequent studies by Kopsick (1982) and Filer (1985) noted aggradation of Tl fill from about 8,000 to 2,000 yrs B.P. A summary by Mandel and others (1985) of recent work in the Perche–Hinkson drainage of central Missouri identified T1 and T0 surfaces, the former stabilizing between 3,000 and 1,000 yrs B.P. Elsewhere in Missouri, Ahler (1976) used the stratigraphy of Rogers Shelter to reconstruct an 11,000-yr depositional history of the Pomme de Terre River of west-central Missouri. Subsequently, Haynes (1976, 1985) expanded upon the data derived from the rock shelter and defined five alluvial units spanning the last 38,000 yrs. In an expansion of earlier work by others on the alluvial history of the Pomme de Terre River valley, Brakenridge (1981) reconstructed the alluvial history for about the last 50,000 yrs and related variations in the stratigraphic record to changes in atmospheric circulation. Lees, Mandel, and Parker (1982), conducting archeological testing and geomorphic investigations on the Osage River downstream from the Harry S. Truman Dam, bracketed the formation of a buried soil between 3,000 and 1,500 yrs B.P. Some of the alluvial units defined in the Pomme de Terre River studies were possibly identified there as well.

Oklahoma

The most concerted effort on a regional scale in Oklahoma has been the geomorphic research carried out in association with archeological work for several dam sites on tributaries of the Verdigris River system in the northeastern part of the state. Collectively, these studies provide a detailed assessment of late Holocene geomorphology and paleoecology of the region. Stream systems investigated include Hominy Creek (Henry, 1980), Birch Creek (Hall, 1977a), Little Caney River (Hall, 1977b; Prewitt, 1980; Reid and Artz, 1984) and Candy Creek (Saunders, 1980). A pervasive stratigraphic element in these studies is the Copan paleosol, a buried soil which developed from approximately 2,000 to 1,350 yrs B.P. Salisbury (1980) conducted a limited-scale, soil-geomorphic analysis of the Arkansas and Cimarron rivers in the Keystone Reservoir area of northeastern Oklahoma. A buried soil was assumed to be the temporal equivalent of the Copan paleosol but was not verified with radiocarbon dating. The most recent alluvial geomorphic investigation in this part of the state pertained to stream crossings of the proposed ETSI Pipeline Project (Lees, Mandel, and Brockington, 1982); at one site crossing of the Arkansas River, a soil buried in alluvium was equated with the Copan paleosol, although no absolute-time control was indicated.

The first alluvial study to be reported from the canyons of the Washita River system in west-central Oklahoma was that of Albritton (1966), who reported an 11,200-yr geomorphic and stratigraphic record at the Domebo paleoindian site. Nials (1977) surveyed the geomorphology of Cedar Creek, another canyon in the region. Four Holocene terraces and two buried paleosols of Pleistocene age were identified; radiocarbon dating placed temporal limits on the terrace fill. In a third canyon, Delaware Canyon, 9 m (30 ft) of fill, dating to 3,000 yrs B.P. and less, exhibits a well-developed buried soil, the Caddo County paleosol, which formed between 2,050 and 1,050 yrs B.P., and the younger Delaware Creek paleosol, dated 600–400 yrs B.P. (Hall, 1982a). More recently, mollusks, radiocarbon-dated tree stumps buried in situ, paleosols, and a carbonate zone were used to reconstruct the geomorphology and climate for the last 3,000 yrs in Carnegie Canyon; of note was the recognition of the Caddo County paleosol, forming 2,-050–1,050 yrs B.P. (Hall and Lintz, 1984; Lintz and Hall, 1983). Goss and others (1972), in reconstructing the geomorphic history of a segment of the Washita River valley, dated the A horizons of two soils buried within alluvium at 1,760 and 1,000 yrs B.P.

As part of an archeological reconnaissance on Fort Sill, a military reservation in southwestern Oklahoma, Hall (1978) detailed the late Quaternary stratigraphy and geomorphology of several small stream valleys. Although he noted terraces and a buried soil set in the context of three Holocene fills, no radiocarbon data were available. In Tesequite Creek of panhandle Oklahoma, Wilson (1972) observed buried soils and cut and fill sequences; tree stumps buried in situ were radiocarbon dated at an average of 474 yrs B.P. Johnson (1983) provided a geomorphic interpretation of the Jackfork River valley, southeastern Oklahoma, in the vicinity of the Bug Hill archeological site. A surface, the Jackfork terrace, was assigned an early- to middle-Holocene age.

Regional correlations

The episodic nature of stream-system change has been graphically illustrated in studies by Knox (1976) and Wendland (1982). These two investigators used histograms and cumulative frequency distributions of radiocarbon dates to accentuate the discontinuities which occur within the alluvial record. Buried paleosols and terraces have long been recognized as indicators of the episodic change in stream systems. Paleosols, representing formerly stable surfaces, are particularly useful in identifying past periods of alluvial stability in that they are readily radiocarbon dated. It is these stable surfaces that form the basis of alluvial chronologies and will be focused upon in the following discussion.

Kansas

In constructing alluvial chronologies, radiocarbon control is essential, although cultural data is useful in a corroborative capacity. To the best of the our knowledge, table 2 includes existing radiocarbon dates obtained from alluvium in valleys of the Kansas River and tributaries within Kansas. Distribution of radiocarbon dates is notably concentrated in the eastern (lower) portion of the Kansas River system (fig. 1). This is likely explained, at least in part, by the proximity of population centers, which include the University of Kansas and Kansas State University, and the construction of reservoirs on lower segments of the

TABLE 2—Radiocarbon assays, Kansas River basin, Kansas.

Map code	Stream site	Lab number	Age (RCYBP)	Source
TW	12 Mile Creek	GX-5812-A (apatite)	10,435 ± 260	bone (*Bison antiquus*)
	(12 Mile Creek site)	(gelatin)	10,245 ± 335	
DE	Deer Creek	Beta-2156	1,890 ± 90	charcoal
		Beta-2157	4,120 ± 270	humate
WO	Wolf Creek	Beta-2161	2,060 ± 140	charcoal
		Beta-2158	10,580 ± 140	humate
SA	Saline River	Beta-14136	1,740 ±70	humate
	(Wilson Lake)	Beta-14135	5,090 ± 60	humate
KJ	Kansas River	Beta-12979	1,210 ± 100	humate
	(Junction City site)			
MD	McDowell Creek	Beta-12978	3,960 ± 135	humate
EL	Elbo Creek	Beta-9509	1,580 ± 70	humate
BB	Big Blue River	DIC-1357	2,320 ± 60	charcoal
	(14PO1)	DIC-1358	2,480 ± 55	charcoal
		N-1549	4,840 ± 95	charcoal
		WIS-776	5,030 ± 65	charcoal
		WIS-778	5,070 ± 70	charcoal
		WIS-774	5,080 ± 65	charcoal
		WIS-634	5,125 ± 70	charcoal
		WIS-779	5,140 ± 65	charcoal
		WIS-618	5,155 ± 70	charcoal
		WIS-628	5,160 ± 70	charcoal
		WIS-623	5,170 ± 70	charcoal
		WIS-624	5,240 ± 70	charcoal
		WIS-636	5,255 ± 70	charcoal
		WIS-629	5,285 ± 70	charcoal
		WIS-711	5,355 ± 70	charcoal
		UGa-382	5,505 ± 105	charcoal
		N-1550	5,850 ± 135	charcoal
		WIS-715	6,285 ± 145	charcoal
KW	Kansas River	DIC-2946	7,250 ± 110	humate
	(Wamego bend)	DIC-3208	8,310 ± 120	humate
KM	Kansas River	DIC-1760	1,670 ± 55	wood (*Platanus* sp.)
	(Meier sand pit)	DIC-1761	2,620 ± 70	wood (*Quercus* sp.)
KM	Kansas River	GX-5731	785 ± 130	wood (no id.)
	(Eudora bend)			
ST	Stranger Creek	DIC-3148	4,260 ± 50	wood (*Ulmus* sp.)
	(14LV1046)			
KB	Kansas River	DIC-3255	110 ± 40	wood (*Salix* sp.)
	(Bonner Springs)	DIC-3209	1,210 ± 50	humate
		WIS-1030	2,395 ± 65	wood (*Quercus* sp.)
		Beta-2159	4,290 ± 310	humate
		Beta-2160	5,030 ± 90	wood (*Alnus* sp.)
		DIC-3210	8,940 ± 90	humate
		Beta-2931	10,430 ± 130	humate

drainage system. The 13 sites recorded exhibit one to 18 radiocarbon dates and include the Late Pleistocene–Holocene transition (10,580 yrs B.P.) to the historic period (110 yrs B.P.). Focus is on the Kansas River system because, with the exception of two radiocarbon-controlled studies at East Branch Walnut River (Artz, 1983) and the Wichita Sand Pit site (Jaumann et al., 1985), other studies in the state do not provide sufficient time control. Studies from the Kansas River system within Kansas that provide radiocarbon-dated evidence of stable surfaces during Holocene time have been represented by a plot of the dates; fig. 2 illustrates the clusters of dates which comprise eight periods of apparent stability. With the data available, a period is defined by anywhere from one to five dates. Periods include 10,600 to 10,200, 8,900 to 8,300, 7,250, 5,100 to 5,000, 4,300 to 4,000, 2,600 to 2,400, 2,100 to 1,600, and 1,200 yrs B.P. A given period of stability may, and probably often does, represent more than one soil-forming period. At least two periods, 2,100 to 1,600 and 2,400 to 2,600 yrs B.P., are not clearly temporally distinct when one examines the individual radiocarbon dates: the sigma values of extreme dates nearly bridge the gap between these two periods. What is important is that about 2,600 to 1,600 yrs B.P. was a time characterized generally by stream and floodplain stability, not that it comprises one or two distinct periods.

The degree of paleosol development, assessed by A1 thickness and organic-matter content is taken as a crude, but credible, indicator of length of time for formation, i.e., the duration of floodplain stability. Although the two measures can be affected by other factors such as level of biomass associated with the soil during its formation, truncation, and degree of post-burial oxidation, viable information is extractable. Table 3 provides a qualitative indication of the perceived degree of development and presumed length of surface stability. Thus the better developed the soil, the greater the spatial component should be. Well-developed soils are noted for 10,600 to 10,200, about 8,300, 5,100 to 5,000, 2,100 to 1,600, and 1,200 yrs ago. Periods of stability indicated by the radiocarbon data are further grouped by location within the drainage system (table 4): major valleys only, tributary valleys only, and valleys common to both. This categorization is admittedly subjective, but it provides an interesting result; some periods identified in the major valleys occur exclusively there, i.e., the same period, and have not yet been detected in tributaries. Either insufficient observations have been made in tributaries, no record remains of these deposits in tributaries, or these events did not occur within the tributary valleys. No periods of paleosol development are indicated for the tributaries exclusively. This would suggest that changes in the system occurred throughout its entirety. Three periods apparently common to both major and tributary valleys likely correspond to major events: the first period, which occurred about 10,600–10,200 yrs B.P., probably represents the last major time of stream stability prior to fluvial change that came about in response to the altered hydrologic regime signaling the end of the late Pleistocene. The second period, from 4,300 to 4,000 yrs B.P., is characterized by only moderate soil development, yet is apparently a pervasive event without any documented climatic association as with the former. The third period, from 2,100 to 1,600 yrs B.P., is characterized by strong soil development throughout the east-central Plains. Paleoclimatic and paleoecologic studies in the Southern Plains (Hall, 1982b; Hall and Lintz, 1984) indicate a marked increase in precipitation or effective moisture availability at approximately 2,000 yrs B.P. Although this exercise extends the data to its limit, some interesting insight into the Holocene alluvial history of the Kansas River system is provided and points to the potential for future endeavors.

Table 5 summarizes all presumed periods of stream stability for Kansas, including sites with and without radiocarbon data. Though little radiocarbon control exists for the Arkansas River and Osage River basin sites, they correlate well with the Kansas River system sites, particularly for the period about 2,600–1,600 yrs B.P. Sufficient data presently do not exist to permit speculation on the spatial significance of the 19,340 yrs B.P. date reported by Jaumann and others (1985) from Arkansas River alluvium near Wichita, Kansas.

TABLE 3—Degree of soil development for various periods of stability.

Period of stability (RCYBP)	Relative paleosol development
10,600–10,200	strong
8,900–8,300	weak (8,940 BP) strong (8,310 BP)
7,250	moderate-strong
5,100–5,000	strong
4,300–4,000	moderate
2,600–2,400	moderate
2,100–1,600	strong
1,200	strong

TABLE 4—Time-space distribution of paleosols, RCYBP, Kansas River system.

Major valleys (only)	Tributaries (only)	Both positions (common)
1,200		
		2,100–1,600
2,600–2,400		
		4,300–4,000
5,700–5,000		
7,250		
8,900–8,300		
		10,600–10,200

TABLE 5—PERIODS OF STREAM-SYSTEM STABILITY.

Stream	Site/project name	Site number	Periods (yrs B.P.)[1]
KANSAS RIVER SYSTEM			
12 Mile Creek	12 Mile Creek		10,200–10,400
Deer Creek			1,900, 4,100
Wolf Creek			2,100, 10,600
Saline River	Wilson Lake		1,700, 5,100
Kansas River	Junction City		1,200
McDowell Creek			4,000
Elbo Creek			1,600
Big Blue River	Coffey	14PO1	ca. 2,300–2,000 (est.)
Kansas River	Wamego bend		7,300, 8,300
Kansas River	Meier sand pit		1,700, 2,600
Kansas River	Eudora bend		800
Stranger Creek	Resco	14LV1046	4,300
Kansas River	Bonner Springs		1,200, 2,400, 4,300, 5,000, 8,900, 10,400
ARKANSAS RIVER SYSTEM			
Munkers Creek	William Young	14MO304	ca. 4,000–2,000 (est.)
Cedar Creek		14CS355	ca. 2,000–1,500 (est.)
Neosho River			ca. 1,000–500 (est.), 2,000 (est.)
Fall River	Bridwell	14GR38	ca. 2,000–1,500 (est.)
Walnut River,			ca. 4,000–2,000
east branch	El Dorado Lake		ca. 2,000–1,500 (est.)
Arkansas River	Wichita sand pits		19,300
OSAGE RIVER SYSTEM			
Marmaton River	Ft. Scott Lake		ca. 1,500–1,000 (est.)

[1] Where present, radiocarbon dates rounded to nearest 100-yr interval.

Kansas and adjoining Plains states

When the Holocene alluvial record of Kansas is compared with those of Nebraska, Missouri, and Oklahoma, significant correlations are evident in the records. Despite the spatial and temporal distribution of the data, regional synchroneity is indisputable. In the Kansas River system record, soil formation is noted at 10,600 to 10,200 yrs B.P., in particular by humate dates of 10,580 and 10,430 yrs B.P. obtained from well-developed buried soils exposed along Wolf Creek and at the Bonner Springs site on the lower Kansas River, respectively. This period occurs during the late Pleistocene–Holocene transition in the Central Plains: a time of major atmospheric circulation shifts which resulted in dramatic hydrologic changes within the Central Plains, as well as elsewhere. This change in climate is well-documented for Kansas in vegetation records reconstructed via the pollen data from Muscotah Marsh (Gruger, 1973) and Sanders' well (Fredlund and Johnson, 1985). For a regional paleophytogeographic review, the reader is referred to Fredlund and Jaumann (this volume). Deposits and associated soils of such antiquity are apparently quite limited, perhaps because of the high potential for removal during the Holocene. However, one notable exposure occurs in the North Loup River system: Brice (1964) radiocarbon dated snail shells collected from the Coopers Canyon gley soil at 10,500 yrs B.P., a date that corresponds closely with those acquired in the Kansas River system. Ahlbrandt and others (1983) reported a date of 9,930 yrs B.P. from the base of a 2.1-m (6.9-ft)-thick accumulation of organic sands exposed within alluvium on the upper reaches of Whitetail Creek in west-central Nebraska. The stratigraphic record indicates stability and floodplain-soil formation ended in the Kansas River basin with renewed alluviation during the early Holocene. A period of pronounced alluviation is also recorded by Brakenridge (1981) for the Pomme de Terre River valley from 10,000 to 8,100 yrs B.P.

Although soil formation is indicated from 8,900 to 8,300 yrs B.P. within the Kansas River System, the recent end of that period, 8,310 yrs B.P., is characterized by strong soil development. On the North Loup River of central Nebraska, Brice (1964) obtained two radiocarbon dates of 9,000 and 8,400 yrs B.P. from peat beds buried at two separate localities within fill of the Elba terrace. Ahlbrandt and others (1983) dated organic accumulations in alluvial sands at 8,410 yrs B.P. from a site on the Dismal River, a tributary to the Middle Loup River. May (1985) obtained radiocarbon dates of 8,780 and 8,160 yrs B.P. from buried soils in fill from the South Loup River valley. Dates from the Loup River system sites correspond well with the 8,310 yrs B.P. date obtained on the lower Kansas River system. Subsequently, alluviation occurred within the Kansas River basin and apparently within the North Loup system. Evidence of instability elsewhere comes from the Pomme de Terre River valley where Brakenridge (1981) recognized an episode of erosion from about 8,100 to 7,500 yrs B.P. is recognized by Brakenridge (1981).

TABLE 6—CORRELATION OF ALLUVIAL STRATIGRAPHIC INVESTIGATIONS/INTERPRETIVE PROBLEMS.

Precise location of documented sites not always provided
Existence of few complete Holocene stratigraphies
Inadequate stratigraphic description especially in archeological reports
Many studies without absolute-time control
Assumptions regarding ages of stratigraphic units from dated sections in drainage systems removed
Inconsistencies in radiocarbon-sample collection, especially from buried soils
Lack of uniformity in reporting radiocarbon data

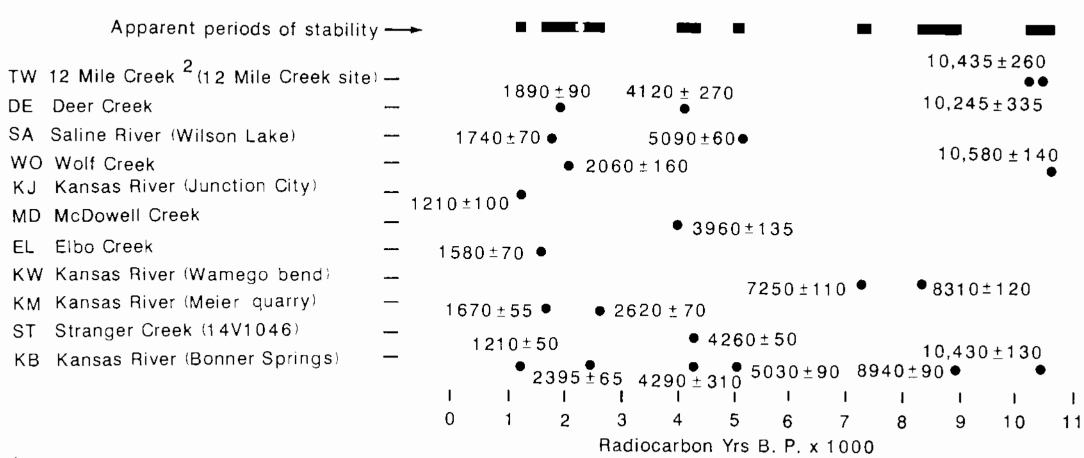
The soil-forming period about 7,250 yrs B.P., documented to date at only one locality in Kansas, has been corroborated by data from the Loup River system of Nebraska. Ahlbrandt and others (1983) radiocarbon dated organics in alluvial sands at 7,220 yrs B.P. May (1985) obtained radiocarbon dates of 7,750 and 7,110 yrs B.P. on soils buried within his fill IV on the South Loup River. With present data, the middle Holocene, here defined as 7,000-5,000 yrs B.P., is void of any indications of soil development within the Kansas River basin (fig. 2). Studies in the region suggest the middle Holocene was a time of stream-system instability, or at least low potential for strong soil development. At the Coffey site on the Big Blue River of northeastern Kansas, Schmits (1980) recorded aggradation at about 6,300 yrs B.P. and the development of a wide, shallow channel, indicative of a more arid hydrologic regime in the late Hypsithermal. Ahler (1976) documented an episode of intense upland erosion at Rogers Shelter in the Pomme de Terre River valley of east-central Missouri. In the same valley, Brakenridge (1981) noted alluviation for a short period following about 7,500 yrs B.P. Of the ten radiocarbon dates Ahlbrandt and others (1983) reported from organic alluvial sands buried along the Middle Loup and Dismal rivers, none occurs within the period 7,000 to 5,000 yrs B.P., indicating a lack of stability and/or sufficient biomass for organic enrichment. Within fill at the Horn site on the South Loup River, which exhibits several buried soils, no discernable soil formation occurred from 7,100 to 4,780 yrs B.P. (May, personal communication, 1985).

The concept of a middle Holocene (about 7,000-5,000 yrs B.P.) cultural hiatus on the Great Plains has become well-entrenched within the archeological literature. Of the various theories put forth to explain the hiatus (Reeves, 1973), fluvial erosion or aggradation sufficient to dramatically alter the record for the region during the interval 7,000-5,000 yrs B.P. is most pertinent here. The similarity in the alluvial stratigraphic record from eastern humid portions of the region to the more arid western areas, as well as with chronologies further afield (e.g., Knox et al., 1981), indicates that regionally anomalous erosion and deposition do not explain the hiatus. Rather, the increased dryness during the Altithermal was likely sufficient to reduce populations on the Plains (Wedel, 1961; Frison, 1975; Knox, 1978; Wendland, 1978).

The period 5,100 to 5,000 yrs B.P. was one of renewed soil formation on bottomlands within the Kansas River system. Corroborative evidence once again comes from the Loup River system of Nebraska where May (personal communication, 1985) obtained a radiocarbon date of 4,780 yrs B.P. on a buried A horizon at the Horn site. Three of the radiocarbon dates Ahlbrandt and others (1983) reported from organics within sandy alluvium on the Middle Loup and Dismal rivers occur around this time: 5,150, 5,040, and 4,900 yrs B.P. Mandel (1985) bracketed geomorphic stability and soil formation between 6,660 and 4,000 yrs B.P. in the Little Blue River of northwest Missouri.

Stream stability and soil formation dated about 4,300 to 4,000 yrs B.P. at four localities within the Kansas River system is not well-documented outside Kansas. Elsewhere within Kansas, Artz (1983) radiocarbon dated soil formation from about 4,000–2,000 yrs B.P. on the East Branch Walnut Creek; this period is, therefore, apparently correlative with the soil formation noted within the adjacent Kansas River basin. Although a period not yet recorded in Kansas, five radiocarbon dates ranging from 3,000–3,810 yrs B.P. are reported by Ahlbrandt and others (1983) for the Middle Loup and Dismal rivers. Further, May (1985) obtained an age of 3,030 yrs B.P. on bone collagen from within his fill III, i.e., not in apparent association with a former surface of stability.

Regardless of whether the soil formation indicated at 2,600 to 2,400 and 2,100 to 1,600 yrs B.P. (fig. 2) actually represents two discrete periods, extremely good indication for stability and soil formation is found elsewhere in the state of Kansas and adjoining Plains states. Within the Arkansas River system of Kansas, soil formation is indicated for this time at the Munkers Creek (Witty, 1982), Cedar Creek (Wood, 1977), Neosho River (Rogers, 1984), and Fall River (Johnson, 1971) sites, and for the East Branch Walnut Creek (Artz, 1983). A radiocarbon date of



[1] Only includes those studies and carbon-14 dates clearly correlative with stability.

[2] Apatite and gelatin on same bone specimen.

FIGURE 2—CARBON 14-DATED HOLOCENE FLOODPLAINS STABILITY, KANSAS RIVER SYSTEM.[1]

2,200 yrs B.P. obtained on charcoal within Dry Creek, a tributary of the Medicine Creek of southwestern Nebraska (Brice, 1966), may perhaps indicate a period of stability. This also is the only radiocarbon-dated Holocene site in the Kansas River system within Nebraska. May (1985) documented the initiation of soil formation at 1,660 yrs B.P. in the South Loup River. The T1 deposits of the Little Blue River of northwest Missouri apparently stabilized between about 2,000 and 1,500 yrs B.P. (Mandel, 1985). Radiocarbon dates from charcoal situated in a cultural context above and below a buried soil indicate the latter formed between 3,000 and 1,500 yrs B.P. within the Osage River valley (Lees, Mandel, and Parker, 1982). A third study from Missouri, in the Perche–Hinkson River basins, proposed T1 surface stability between about 3,000 and 1,000 yrs B.P. (Mandel et al. 1985). Goss and others (1972) dated the lower of two buried soils at 1,700 yrs B.P. within the Washita River system of southwestern Oklahoma. A major stratigraphic unit, the Copan paleosol, has been documented throughout the upper Verdigris River basin (Hall, 1977a, 1977b; Reid and Artz, 1984). Formation of this well-developed soil occurred between 2,000 and 1,350 yrs B.P. A second major paleosol, the Caddo County paleosol, has been widely recognized in the canyons of the Washita River of southwestern Oklahoma. Dates on this soil range from 2,050 to 1,050 yrs B.P. (Hall, 1982a; Hall and Lintz, 1984; Lintz and Hall, 1983).

The most recent period of soil formation recognized in the Kansas River basin is about 1,200 yrs B.P. ascertained from radiocarbon dates of soil humates at two disparate localities. At least two localities elsewhere indicate contemporaneity. Based upon an estimate of the time for argillic-horizon development and archeological data, the T1 surface identified on the Marmaton River near Fort Scott, Kansas, stabilized 1,500–1,000 yrs B.P. (Schmits et al., 1983). Goss and others (1972) radiocarbon dated a buried soil at 1,000 yrs B.P. within the Washita River valley of southwestern Oklahoma. No radiocarbon-dated sites for the last several hundred years which point directly to soil formation and/or long-term stability are in Kansas. Stability has been documented, however, at about 800 yrs B.P. in the South Loup River system of Nebraska (May, personal communication, 1985) and 600–400 yrs B.P. in Delaware Canyon, southwestern Oklahoma (Hall, 1982a).

Interpretation of available data

Interpretive problems

When reviewing alluvial stratigraphic studies, several interpretive problems soon become apparent (table 6). With more concise and complete data reporting, interpretations will be more meaningful to others, especially when attempting to correlate among studies. Also, the precise location of documented sites is not always provided in order to facilitate examination by other interested parties. Since so few data exist and sites/exposures are frequently ephemeral, making locations recoverable is important.

Few localities provide a stratigraphic record for the entire Holocene. The majority of studies provide a record only since middle to late Holocene time, or of a window on a portion of the Holocene. Inadequate stratigraphic description, especially in archeological studies, further limits potential interpretations. This shortcoming is rapidly being resolved by increased involvement of geomorphologists in archeological research, as reflected in part by creation of the new journal *Geoarchaeology.*

Major difficulties relate to radiocarbon dating of sediments. The obvious is a lack of radiocarbon control, although this has become less of a problem in recent years because of the ready availability of inexpensive assays from commercial laboratories and increasing access to the tandem accelerator mass-spectrometer method of dating (TAMS). In absence of radiocarbon control, assumptions have been made regarding ages of stratigraphic elements, particularly paleosols, through correlation with dated sections in other drainage systems, often far removed. Assumptions such as this, often poorly founded, become entrenched in the literature and re-emerge in subsequent research.

Inconsistencies in the collection of radiocarbon samples, especially from buried soils for humate dates, may lead to misinterpretations of the results by others. Humates from buried-paleosol A horizons are dated extensively; samples may be collected from the top, bottom, middle, or as a composite of the A horizon. Since up to 1,000 yrs, or more, could easily exist between dates from the top and bottom of the A horizon, researchers need to indicate the position of samples taken from soils. Dates derived from lower A-horizon samples would reflect the initiation of stability, whereas upper A-horizon samples would reflect the latter stages of stability. Also, a general lack of uniformity exists in reporting the laboratory basis of the assay: half-life used, if ^{13}C–^{14}C adjusted, and if calibrated. Half-life is least problematic in that commercial laboratories now use 5,568 yrs by international convention, although it is generally accepted that 5,730 yrs is a better estimate. Adjustment for $^{13}C/^{14}C$ aberrations (effects of isotopic fractionation) is becoming commonplace; studies should report both adjusted and unadjusted dates for the benefit of the reader. Several formulas are available for the calibration of both unadjusted and adjusted assays (e.g., Ralph et al., 1973; Damon et al., 1974; Klein et al., 1982; Stuiver, 1982). Calibration is more commonly reported in archeological studies and would likely serve no important purpose in alluvial studies until a standard calibration curve is adopted. Overall, the appreciation and correlation of alluvial stratigraphic studies would be greatly enhanced if radiocarbon control was reported in a uniform and concise fashion.

Complex response

This discussion has demonstrated that, given the resolution and potential interpretative problems of available data, discernable synchroneity exists among periods of stability and soil formation within the east-central Plains states of Kansas, Nebraska, Missouri, and Oklahoma. Although climate is the primary forcing function, the role of non-progressive internal changes must be considered in the alluvial record.

Climate's impact on stream-system behavior is generally accepted as being primary. The two basic models of Holocene climate are 1) the slow rise in temperature, broad peak (Altithermal), and slow decline to present (Antevs, 1955) and 2) a series of distinct episodes with abrupt transitions (Bryson and Wendland, 1967; Bryson et al., 1970; Wendland and Bryson, 1974). The latter is based upon the analysis of compiled, environmentally significant, radiocarbon dates; distinct episodes and abrupt transitions led to the adoption of the Blytt–Sernander environmental sequence of northwestern Europe. Because the model is derived from the observed stepwise behavior of atmospheric circulation, Knox (1976, 1983) and Wendland (1982) argue that climate, as the underlying determinant of fluvial behavior, will be mirrored in the alluvial record. They demonstrate the existence of distinct fluvial episodes on the basis of the temporal distribution of alluvial radiocarbon dates. Upon reviewing the Holocene vegetation record, Wright (1976), however, advised against adoption of a climatic model featuring distinct eposides separated by abrupt discontinuities. Hall (1982b) also notes that pollen and land-snail records from the Southern Plains indicate gradual, rather than abrupt, changes in climate. The reconciliation of these two apparently inconsistent models will soon come to pass because of ongoing research by many on the response of vegetation to Holocene changes in climate. Also, it must be borne in mind that stream systems are more sensitive to climatic shifts and respond far more quickly than vegetation.

Many researchers have lent support to the strong correlation between alluvial stratigraphy, or stream behavior, and episodic climate behavior. Among those, Baker and Penteado–Orellana (1977) associate shifts in climate with changes in river morphology and periods of incision and aggradation on the Colorado River of Texas. Brakenridge (1980, 1981) related the timing of aggradation, erosion, and stability within the Pomme de Terre River to synchronous changes in upper-atmospheric circulation patterns.

Schumm (1973, 1976, 1977) stressed that alluvial histories are complex due to the response of stream systems to both external events, such as climate change, and internal controls inherent to the evolving system. Thus, the erosion and deposition occurring within a system reflects, according to Schumm, the sequence of responses to the crossing of extrinsic and geomorphic (intrinsic) thresholds of stability. Further, the response to the crossing of a threshold can often be abrupt in nature (Schumm, 1973; Schumm and Kahn, 1972; Schumm and Parker, 1973; Patton and Schumm, 1975, 1981). The concepts of stream-system responses to either extrinsic or intrinsic controls are not mutually exclusive. Researchers are recognizing that major elements in alluvial records relate to climatic shifts, whereas geomorphic variables account for second order-changes or those occurring during climatically stable periods (Patton and Schumm, 1981; Knox, 1983; Waters, 1985).

To improve our understanding of stream response to intrinsic and extrinsic variables and the relationship with alluvial stratigraphy, the latter must be carefully examined and radiocarbon dated throughout the entire extent of drainage basins, i.e., all levels of the drainage hierarchy. Even though some research professes to have been basinwide in extent, the study sites are often too widely distributed and may not consider tributary valleys, preventing one from evaluating any response differences which might exist between them and the main valley. Given the interpretive problems outlined above, we need a greater quantity and quality of data before the response of east-central Plains stream systems will be understood to the point where extrinsic and intrinsic parameters and time-transgressive elements can be sorted out. Toward this end, we and others are focusing resources on the Kansas River system, a large basin with many major tributaries and extending from semiarid to humid environments.

Summary

A relatively rapid increase has taken place in the alluvial stratigraphic data base for the east-central Plains in recent years. A survey of available information for the states of Kansas, Nebraska, Missouri, and Oklahoma produced nearly fifty sites, valley reaches, or stream systems that have been studied.

An examination of data from radiocarbon-documented sites for the Kansas River system in Kansas identifies several periods of stream stability: 10,600–10,200, 8,900–8,300, 7,250, 5,100–5,000, 4,300–4,000, 2,600–2,400, 2,100–1,600, and 1,200 yrs B.P. These periods represent times of relative floodplain quiescence during which soils developed, in many instances to be subsequently buried and preserved for a time in the stratigraphic record. Qualitative analyses of the data suggest marked differences in the spatial extent and duration of the individual periods of stability. Definite times of stability have not yet been identified exclusively for tributary valleys: they have been realized in fill of either major valleys or major valleys and tributary valleys, i.e., both extremes of the system. Further, the duration of stable periods, as assessed by the relative degree of paleosol development, also varies appreciably from one period to the next. Those times of presumed long duration occur during the late Pleistocene–Holocene transition, 10,600–10,200 yrs B.P.; the middle Holocene, 5,100–5,000 yrs B.P.; and the late Holocene, 2,100–1,600 and 1,200 yrs BP.

When data from the adjoining states of Nebraska, Missouri, and Oklahoma are correlated with the periods of stability extracted from the Kansas River system, unmistakable coincidence exists, indicating strong regional synchroneity in alluvial events. Other than the Kansas River system, only the Loup River system of Nebraska and Pomme de Terre River of Missouri provide data for the entire Holocene. Very good late Holocene data, however, come from northeastern and southwestern Oklahoma.

Problems of interpretation and correlation quickly emerge during a survey of data for the region. The bulk of these difficulties relate to the presentation of insufficient information for a full appreciation of the contribution to our knowledge of alluvial stratigraphy. The nature and relative small number of alluvial stratigraphic studies within the region do permit sufficient resolution to articulate the effects of episodic climate change on stream systems but do not allow a credible evaluation of the impact of geomorphic (intrinsic) variables on the alluvial record.

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Equability in the late Pleistocene

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Abstract

The traditional idea that continental glaciation was accompanied by a harsh, cold environment does not seem to apply to North America. Abundant evidence now supports a glacial climate of cooler summers and warmer winters over most of nonglaciated North America. The low seasonality of this climate permitted plants and animals to have broader ranges than they have today, and these broader ranges resulted in overlaps of species ranges that do not now occur. This created very complex Pleistocene community structures in North America that do not have close modern analogs. The development of highly seasonal climates during the Holocene resulted in the destruction of these Pleistocene communities and the development of the modern biomes. Megafauna extinction and changes in human cultural evolution were closely associated with this climatic change.

Introduction

Our understanding of the Pleistocene has undergone many changes in the last decade. For instance, the idea that there were more glacial advances in North America than the traditional four (Nebraskan, Kansan, Illinoian, and Wisconsinan) was quite radical in 1966 (Dort, 1966), but is now widely accepted (Boellstorf, 1978). Previously interglacials were accepted as having been many times longer in duration than were glacials, but the new deep-sea evidence (Hays et al., 1976) shows that the opposite was true with interglacials about 10,000 yrs in length and glacials nearer 100,000. Also our present climate has been generally accepted to be typical for an interglacial, but evidence is accumulating that the Holocene climate is unique for the Quaternary.

The most useful change in our way of viewing the Ice Age has had to do with the concept of climatic equability. Throughout continental interiors the modern world is dominated by climates with high seasonal variability. In order to exist in these climates, organisms must maintain a suite of conflicting adaptations. They must survive extended periods of both arctic and tropical conditions, utilize seasonal rains, and survive in seasonal deserts. In order to do this, they commonly adjust their reproductive timing to a narrow interval of favorable climate and thereby become vulnerable to permutations of this interval. Organisms that have solved these problems are now present in enormous numbers and cover vast areas of the continental interiors. They exist in biotic systems that are quite different from those of the Pleistocene. In the Pleistocene the differences between seasons must have been greatly reduced; thus a general theory of climatic equability has been developing during the last three decades (Hibbard, 1960; Taylor, 1965; Martin and Neuner, 1978; Graham and Lundelius, 1984).

Abundant evidence now supports a glacial climate of cooler summers and warmer winters over most of nonglaciated North America (Lundelius, 1967; Slaughter, 1975). The low seasonality of this climate permitted plants and animals to have broader ranges than they have today, and these broader ranges resulted in overlaps of species ranges that do not now occur. This created very complex Pleistocene community structures in North America that do not have close modern analogs; this was true for plants (Van Devender and Mead, 1976) as well as for animals.

Almost all of unglaciated North America was more forested during the Wisconsinan, and no extensive steppes or deserts existed. Tundra was restricted to a very narrow band along the margins of the continental glaciers and to areas of high altitude. Beringia and a few places south of the continental ice seemed to have been occupied by steppe tundra.

We know little about the people who occupied these special Pleistocene environments, and indeed some (Martin, 1973) think that people arrived in North America after the beginning of the collapse of these environments. They would accept a duration of man in North America of only about 12,000 yrs. We believe that this viewpoint can no longer be supported against numerous reports of sites dated at ages greater than 12,000 yrs (MacNeish, 1976). The archeological data suggest at least 20,000 yrs for the duration of man in the New World.

Distinctive floral regions during the Wisconsinan had distinctive faunas (Martin and Neuner, 1978). The western region of North America, south of the ice, was occupied by a montane conifer parkland that contained the *Camelops* faunal province. The *Ovibos* faunal province falls along the edge of the continental ice and in high-altitude sites in the mountains. The northeastern United States was occupied by a spruce-forest taiga that contained the *Symbos–Cervalces* faunal province. The southeastern region was occupied by a deciduous forest that contained the Chlamythere–Glyptodont faunal province.

Beginning about 12,000 yrs ago, the complex Pleistocene communities began to break up and by 8,000 yrs ago, we have essentially the modern distribution of plants and animals. The collapse of the Ice Age floral communities was accompanied by the extinction of over half of the species of North American large mammals.

Disharmonius associations

Almost all Pleistocene biota contain some associations of organisms that cannot be found living together today and commonly include taxa that are presently allopatric by many hundreds or thousands of miles. Semken (1974) termed these disharmonius associations. The implication is that the modern associations are in "harmony" with known requirements of the organisms, and modern associations could be called "harmonius associations." This terminology carries a false implication that modern associations are normal while Pleistocene ones are not. The reverse is more likely, but the term itself does call attention to an interesting aspect of Pleistocene communities.

The limits of the distribution of organisms are fixed by a wide variety of factors, but the controlling factors may only be limiting for short periods of time. In other words, seasonal averages do not limit the range of organisms so much as do periods of extremes. The reduction of seasonal extremes is the one overall factor that could cause animals and plants of both southern and northern environments to simultaneously expand their ranges and create overlaps. This results in the creation of greater local diversities and the development of new coevolved systems and more complex community structures.

Disharmonius assemblages seem to be ubiquitous throughout the Pleistocene and to occur in both putative glacial and interglacial assemblages. Their presence is one of the most distinctive contrasts between Pleistocene biota and those from the Holocene. As such, they demarcate the Holocene very dramatically from the Pleistocene and are part of the reason that Martin and Neuner (1978) argued that the Pleistocene had really ended.

Winter warmth

Our understanding of past organisms and environments is rooted in our understanding of modern analogs, and there is a tendency to read too much of present conditions into the fossil record. Such an error seems likely to have largely dominated our intepretation of Cenozoic climates in North America. In spite of the occurrence of clearly tropical animals such as tapirs and crocodilians, researchers often interpret the Tertiary environments of central North America as the same treeless steppes with cold snowy winters that exist in that region today. The Pleistocene with its vast continental ice sheet was taken to be evidence of harsh climates as severe or more severe than those existing in the high arctic today. Strangely the fossil record has never lent support to such interpretations, and many of them must now be abandoned.

Hibbard (1960) probably deserves the major credit for our reassessment of late Cenozoic climatic conditions. Hibbard pointed out that modern large tortoises (*Geochelone*) cannot tolerate extended periods of below-freezing temperatures and that the common occurrence of the extinct giant tortoise, *Hesperotestudo,* in North American late Cenozoic faunas also must indicate the absence of long periods of such temperatures. During the Pliocene (Blancan), this frost-free line may have extended at least as far north as north-central Nebraska (Sand Draw local fauna). Similar tortoises continue into the Irvingtonian and Rancholabrean, but their range becomes progressively more southerly so that the northernmost late Irvingtonian (Sheridanian) *Hesperotestudo* is from the Angus local fauna in south-central Nebraska and the northernmost Rancholabrean record is from central Oklahoma.

Some researchers (including Hibbard, 1960) have tried to restrict the Pleistocene giant tortoise records to the interglacials which were considered exceptionally warm periods. Most Pleistocene faunas are mixtures of animals that are both at present more southerly in distribution and more northerly. The northernmost Rancholabrean records of tortoises in Oklahoma are much more northern than we could at present expect these tortoises to occur, but radiocarbon dating shows their age to be well within the generally accepted period of Wisconsinan glaciation. Giant tortoises also continued in Florida until the very end of the Pleistocene and it would seem that glacial temperatures in Florida were not so low as to exclude giant tortoises until the end of the Pleistocene.

Deducing a picture of glacial winters from this information may be possible. Climates undoubtedly were severe near the continental glacial front. This must have been a region of cold-air drainage continually swept by cold dry winds. The presence of frost-wedge casts and local areas of patterned ground indicate that glacial climates along the glacial front could be as severe as those presently found in the high arctic. This area was occupied by typical arctic-tundra animals (Martin and Neuner, 1978). Distances much greater than 200 km (120 mi) from the front may have been quite different. In some ways the growth of the glacier would demand more warmth. The upper surface of the continental ice must have been a cold desert as are the modern Arctic and Antarctic ice sheets. The glaciers did most of their growing on the margins where warm moist air would contact the glacial front. Winter warmth would actually increase the amount of available moisture and, up to the limit where melting exceeded snowfall, could actually enhance the growth of the glaciers.

Summer cool

All large Pleistocene faunas contain elements that are at present restricted farther north. This is as true for the so-called interglacial faunas as it is for the glacial ones. In fact it has been extremely difficult to demonstrate that any fauna is interglacial, although many have been suggested. In virtually all cases these assignments are based on the presence or absence of only one or two taxa. For instance Cragin quarrry and the closely associated Jinglebob local fauna have both been considered Sangamonian (Hibbard, 1970), but of the two, the Jinglebob local fauna contains the most warmth-adapted mammal (Rice rat, *Orizomys*). The Jinglebob local fauna has since been assigned to the early portion of the Wisconsinan glacial stage (Kapp, 1970).

Kansas winters are at present adequately cold for even arctic species. Colder winters offer no advantage to boreal taxa, but cooler summers do and it must surely be hot dry summers that prevent the colonization of Kansas by cool-steppe species like the ground squirrel *Spermophilus elegans.*

Vegetation and seasonal climates

In the tropics the reproductive activities of plants can be scattered throughout the year. This provides fruits and flowers continuously and permits specialists in these rich food sources to develop among the herbivores. In highly seasonal climates the reproductive activities of plants tend to be concentrated into relatively short periods when temperature and moisture are favorable. Herbivores must either depend on the vegetative parts of plants or remain inactive when food is not available. When food is available it may be so plentiful that only small portions of it can be utilized by any one taxon. Seed eating becomes particularly important because seeds keep for long periods past the fruiting season and constitute a more reliable food supply.

Pleistocene grasslands were largely dominated by C_3 plants. C_3 grasses tend to be green throughout the year and to store more of their energy in their vegetative parts, as opposed to their roots. C_4 plants turn brown during the summer drought and during the winter and thus have a shorter growing season. They store more of their energy in their roots and less in the stems and leaves. C_4 grasses also become green later in the spring. On the whole, they are a less consistent source of food than are the C_3 plants, and the changes to C_4-grass domination may have had serious consequences for grazing mammals. This effect would be intensified for groups that synchronized the birth of their offspring to the first spring growth of the C_3 grasses. This would likely be weeks before the first growth of C_4 grasses.

Seasonal climates would have an additional effect on vegetation. In wet climates the spread of fires is limited by abundant rainfall and in dry climates by the scarcity of plant material. Seasonal climates are often wet part of the year and then very dry for the rest of it. Under these conditions a lush growth of vegetation that later drys out and burns is possible. Under such conditions fires may be severe and become important determining factors influencing the nature of vegetation. The modern prairies need such fires for their maintenance (Wells, 1976; Wells and Hunziker, 1976).

Pleistocene extinctions

Martin and Gilbert (1978) proposed a then-novel hypothesis for the extinction of the North American megafauna. They suggested that the Pleistocene communities were not analogous to the modern ones that succeeded them so what had really happened was the extinction of entire Pleistocene biomes. They described this mechanism for extinction in the following way (Martin and Gilbert, 1978, p. 115):

> It seems likely that the animals which became extinct at the end of the Pleistocene were adapted to habitats which ceased to exist in North America and that their extinction was due to habitat destruction on a massive scale. This hypothesis implies that we are presently living under the same climatic conditions which resulted in the extinction of the large Pleistocene mammals.

This theme is also supported in the same volume by Martin and Neuner (1978, p. 124):

> We believe that the low seasonality of Pleistocene environments permitted the establishment of very complex communities that lack modern analogues. These communities were composed in part of animals and plants extant today but presently allopatric and by animals which are now extinct. The modern highly seasonal environment is thought by us to be unique for the Pleistocene and its establishment along with the modern pattern of floral distributions is the underlying cause of the end-Pleistocene extinction. This mechanism would be world-wide in scope and applicable to Tertiary extinctions.

Since then, Graham and Lundelius have proposed a similar scheme where they argue that the breakup of the disharmonius biotic assemblages would also destroy coevolved relationships and result in a sort of "coevolutionary disequilibrium" and extinction. Graham and Lundelius (1984, p. 243) describe how the

> Environmental changes at the end of the Pleistocene caused a major biotic reorganization. Instead of simple shifts of biotic zones, individual species responded to these environmental changes in accord with their own tolerance limits. This individualistic response of each species reduced the predictability of the composition and structure of the new communities. In coevolved systems these changes would disrupt coevolutionary relationships between plants and animals, thus creating a disequilibrium in the system.

Pleistocene equability and cultural evolution

Ice Age man lived in a world very different from the barren habitat often ascribed to him. In North America he may have lived in a relatively lush environment with warm winters and cool summers. The hunting and gathering options in any given locality were better than they would be today, and the chance for success at either hunting or gathering would vary less with the seasons. The collapse of these environments between 12,000 and 10,000 yrs B.P. must have severely stressed cultures and subjected humanity to selective pressures that had either not been present or so marked since the inception of tool-using humans some two million years earlier.

In a more equable climate, the need for clothing and shelter and the probability of finding food is more nearly uniform throughout the year. With comparatively diverse hunting and gathering resources available during the entire year, utilizing a nomadic way of life and specializing on hunting would be more advantageous. Very little planning may have been necessary because the odds of success did not vary much from one season of the year to the other. Seasonal specializations would not have been so important because the development of vast migrating herds or flocks had probably not yet developed, and the growing seasons of plants may have been extended.

Beginning about 12,000 yrs ago, the climate began to change to modern highly seasonal conditions. This change resulted in our present distribution of plants and animals and probably also caused the Pleistocene megafauna extinction. The mammals that survived this extinction are without exception forms that are rare in faunas older than 12,000 yrs B.P. With the close of the Pleistocene, the resources for human exploitation that were most important during the Pleistocene became rare or absent (Martin and Martin, 1982, 1983, 1984).

The basic structural changes that took place in floral communities between 12,000 and 10,000 yrs B. P. included a general decrease in forested regions with the development of treeless steppes and deserts. This was accompanied by the extinction of a diverse large-mammal fauna and a progressive increase in abundance of certain specialized grazers (bison and pronghorn antelope). Much of the evidence for Pleistocene big-game hunters in North America is from the central Great Plains, and the Pleistocene/Holocene transition in this area is mostly a record of a shift from hunting large extinct prey like mammoths to progressively larger mass kills of bison (Rogers and Martin, 1984). The appearance of mass kills is probably the result of two factors. One of these is the developing severity of the winter season so that winter hunting might have been curtailed and a need arose to acquire a large meat reserve. The other factor would be the development of large herds of bison on the newly developing steppes. Changes of the distribution of small vertebrates and mollusks show that the understory vegetation was greatly affected, and gathering patterns must have changed profoundly (Martin et al., 1985).

During the Pleistocene trees were much more abundant in the central Great Plains than they are in the Holocene, and many of these trees were conifers. This means that wood, bark, and resin would be readily available for the manufacture of weapons, tools, and baskets. We would expect a more wood-dominated culture with a greater reliance on fire-hardened points, bark baskets, and other wooden artifacts. A much higher percentage of the lithics from this period should be specialized tools for the working of wood. Pleistocene localities, both in North America (Rogers, 1984) and elsewhere, have often been characterized by the presence of large chopping tools. Large numbers of such tools would be required for any culture that depended much on wooden artifacts. We would suggest that the Pleistocene cultures in general are characterized by lithic assemblages composed of higher percentages and varieties of wood-working tools than are found in Holocene collections from the central Great Plains.

Storing food was a greater need as seasonal extremes made it temporally difficult to hunt or to gather. On the other hand seasonal migrations or seasonally clustered fruitings of plants may have made some resources locally abundant for short periods of time. These seasonal abundances would require planning and preparation, and selection for the development of a calendar would increase. This might also promote the banding together of groups of people in order to cooperate and to utilize more fully the seasonal resource. Once these resources were collected and stored, the ability of these people to travel would be limited by their need to remain and care for their food reserve. The very existence of large reserves of resources would also create an incentive for warfare and theft. The threat of these activities might also tend to bind people together in sedentary groups. The existence of permanent or semi-permanent base camps would seem to be a necessary precursor to the development of agricultural societies (Martin and Martin, 1983, 1984). In other words the development of highly seasonal climates would create a selection regime favoring the development of more efficient food storage, seasonal planning and calendars, cooperative seasonal acquisition, and sedentary cultures ultimately leading to agriculture. It may be no accident that cultural evolution was so much more rapid during the Holocene than in the Pleistocene and that most sedentary agricultural societies have their roots in the first half of the Holocene.

Conclusions

For the bulk of the last two million years, plants and animals have been evolving in North America under conditions of lesser seasonality than we now have. Modern evidence suggests that there has been a progressive increase in seasonality and aridity during the last 500,000 yrs culminating in our modern highly seasonal climates (Schultz et al., 1972). This change caused the complex Pleistocene biomes to break up and destroyed coevolved systems among plants and animals. The modern distributions of plants and animals were achieved at this time, and steppes and deserts first appeared. The reduction in forests at this time may have been partially the result of an increase in the significance of fire due to newly seasonal climates. These major environmental changes are associated with an important megafauna extinction similar in scope to extinctions that occurred during the Tertiary (Martin, 1985); the Tertiary extinctions may also have been associated with periods of increased seasonality. All of these environmental changes must have had profound effects on humans, and the rapid cultural evolution of the Holocene may be in part due to the inception of increased climatic seasonality.

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Spruce charcoal, conifer macrofossils, and landsnail and small-vertebrate faunas in Wisconsinan sediments on the High Plains of Kansas

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Abstract

Macrofossils of white and blue spruce (*Picea glauca* and *P. pungens*) and limber pine (*Pinus flexilis*), supplemented by rich landsnail and small-mammal faunas, indicate a taigalike successional mix of coniferous forest and aspen parkland on the loessal High Plains of western Kansas and Nebraska (now semiarid steppe) during the latest (Wisconsinan) glaciation of the Pleistocene. The fossil assemblages are most closely matched in the existing subalpine taiga of the Rocky Mountains.

Introduction

Direct evidence on the paleovegetation and climate of the central and western Great Plains during the last glacial maximum (18,000 ±4,000 yrs ago) has been sparse relative to other regions of North America. The semiarid climate of the flat or undulating steppes is correlated with a general scarcity of lake sediments or bogs suitable for preservation of pollen or plant macrofossils. The region has largely frustrated palynologists, although substantial work has been published on Pleistocene records from the eastern periphery or from a few scattered sites within the Great Plains (Wendorf, 1961; Kapp, 1965, 1970; Wright, 1970; Wells, 1970a; Ritchie and DeVries, 1964; Moir, 1958; Watts and Bright, 1968; Watts and Wright, 1966; Ruhe, 1969; Gruger, 1973; King, 1973; Baker and Waln, 1985).

We now report dated plant and animal macrofossil evidence that indicates a taigalike, coniferous biome of Cordilleran (subalpine, Rocky Mountains) character on the central Great Plains of western Kansas and adjacent states during the latest (Wisconsinan, Weichselian) Pleistocene glaciation. Charcoalized wood and intact cones and leaves of conifers have been uncovered in close association with abundant shells of forest landsnails and bones of diverse small vertebrates in pleniglacial sediments; the fossil species are predominantly subalpine or boreal (even subarctic), though a small but significant contingent is now associated with temperate-deciduous, deep forest. Because the modern Plains region is largely treeless and, furthermore, has excessively hot summers with severe droughts, many of the species recorded in the late Pleistocene assemblages are now provincially extinct on the Great Plains. The central and northern Rocky Mountains, however, harbor extant populations of most of the boreal-subalpine species thus far recovered from Pleistocene sediments at our sites in the Central Plains (except, of course, the almost entirely extinct megafauna). Moreover, even within the northern Plains, there are numerous refugia for Pleistocene-relict species of trees, landsnails, and small mammals on forested ecological islands surrounded by steppe; the outstanding example is the Black Hills of South Dakota (fig. 1), but nonmountainous escarpments and canyons also serve as refugia for boreal or Cordilleran relicts (Wells, 1970b, c; McGregor and Barkley, 1977).

Spruce and limber-pine macrofossils on Central Plains

While reexamining the landsnail faunas that are ubiquitously preserved in the late Wisconsinan (Peorian) loess and associated alluvium in western Kansas and southwestern Nebraska (Leonard, 1952), we uncovered charcoalized wood fragments of spruce (*Picea*) at four widely spaced localities (Jewell, Graham, and Logan counties, Kansas, and Harlan County, Nebraska; fig. 1, table 1). At the Jewell County site (fig. 1, site 2; elevation 485 m [1,600 ft]), a thin streak of spruce charcoal extended horizontally for more than 100 m (330 ft) along a vertical cut in an upland deposit of Peorian loess (below the Brady paleosol). The *Picea* charcoal was ^{14}C-dated to 14,450 yrs B.P., thus documenting a local forest fire in a late-Wisconsinan spruce flat. Scanning-electron microscopy of the charcoals from all four sites indicates that wood structures of *Picea* are almost perfectly preserved (fig. 2), but the species of spruce are difficult to distinguish on the basis of wood anatomy. Fortunately, however, several intact cones and numerous twigs and leaves, as well as abundant wood and charcoal of spruce were discovered together (in situ) at the Harlan County, Nebraska (North Cove), site (fig. 1, site 3; elevation 605 m [1,997 ft]), 110 km (66 mi) west-northwest of the Jewell County site. *Picea* wood from Harlan similarly dates to 14,770 yrs B.P. The cones and needles (fig. 3) enable the positive identification of the spruce as *Picea glauca,* the boreal white spruce of the Nearctic taiga that now grows from Alaska to Newfoundland and along the eastern flank of the Rocky Mountains to Montana, with outliers to the east on the Great Plains in the Cypress Hills of Saskatchewan and the Black Hills of South Dakota. The latter population is 600 km (360 mi) northwest of Harlan County and nearly 1,000 m (3,300 ft) higher in elevation. The fossil-rich North Cove site in Nebraska was uncovered by the authors in October 1983.

On the other hand, the Logan County spruce-charcoal site (fig. 1, site 7; elevation 850 m [2,805 ft]) had a carbonized leaf of *Picea pungens,* a spruce now endemic to the Rocky Mountain region. The *Picea pungens* (blue spruce) was recovered from a paleoindian *Bison*-kill site in alluvial fill; a radiocarbon age on bone collagen of *Bison* was 10,245 yrs (Rogers and Martin, 1984). The Logan County site is 200 km (120 mi) southwest of the Harlan site and 90 km (54 mi) east of the Colorado/Kansas line. Ecologically, *Picea pungens* is the most likely cordilleran spruce to have extended eastward from the Rocky Mountains onto the High Plains during late-glacial time, as it extends downward along streams to lower elevations (to 2,000 m [6,600 ft]) than *P. engelmannii* in the Front Range of Colorado today; however, this is 300 km (180 mi) to the west and approximately 1,200 m (3,960 ft) higher than the Logan County spruce site. The alluvial records reported here are from small tributaries of streams with headwaters on the High Plains surface and not from stream systems arising in the Rocky Mountains (Platte, Arkansas); thus, the fossil materials must have been local in origin and not washed down from the mountains.

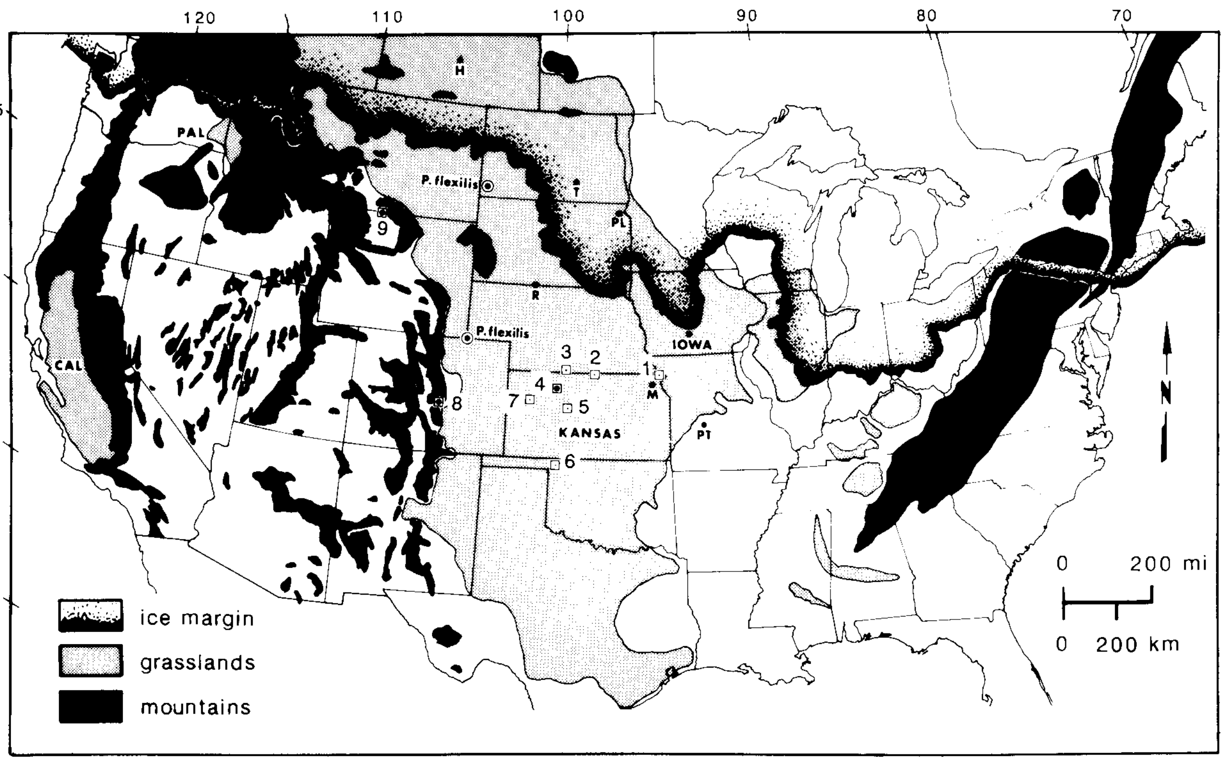


FIGURE 1—MAP OF UNITED STATES AND SOUTHERN CANADA WITH APPROXIMATE EXTENT OF PRESETTLEMENT GRASSLANDS (GRAY); MOUNTAINOUS AREAS (BLACK) AND MAXIMAL LIMITS OF CONTINENTAL ICE SHEET DURING LAST GLACIAL MAXIMUM (CA. 18,000 YRS AGO) ALSO ARE SHOWN. Numbered square symbols are the sites of fossil records of cordilleran-boreal conifers, landsnail faunas, and small-mammal faunas located in or near the grassland province of the Great Plains and reported here: 1) Doniphan Co., KS, 12,420 yr BP; 2) Jewell Co., KS, 14,450 yr BP; 3) Harlan Co., NE, 14,770 yr BP; 4) Graham Co., KS, 17,930 yr BP; 5) Ellis Co., KS, 17,700 yr BP; 6) Harper Co., OK, 17,750 yr BP; 7) Logan Co., KS, 10,245 yr BP; 8) Fremont Co., CO, 22,720 yr BP (*Neotoma* middens); and 9) Bighorn Co., WY, 27,000–40,000 or more yr BP (*Neotoma* middens). Squares with dots (4, 8, 9) are macrofossil records of limber pine (*Pinus flexilis*); circles with dotted centers labeled *P. flexilis* are sites of **living** populations of limber pine, relict on scarps of Plains. Sites 2, 3, 4, and 7 have macrofossils records of spruce (*Picea glauca* at 3 and *P. pungens* at 7). Lettered dots north or east of above sites are previous macrofossil records of white spruce (*P. glauca*) from the Plains region: **H** = Hafichuk, Saskatchewan, Canada, 11,650 yr BP (Ritchie and DeVries, 1964); **T** = Tappen, Kidder Co., ND, 11,480 yr BP (Moir, 1958); **PL** = Pickerel Lake, Day Co., SD, 10,670 yr BP (Watts and Bright, 1968); **R** = Rosebud site, Todd Co., SD, 12,580 yr BP (Watts and Wright, 1966); **IOWA** group = ca. 20 spruce sites described by Ruhe (1969), 11,120–40,000 or more yr BP; **M** = Muscotah Marsh, Atchison Co., KS, 23,040 yr BP (Gruger, 1973); **PT** = Pomme de Terre group, Benton and Hickory cos., MO, 13,700, 16,580 yr BP, et al. (King, 1973). Isolated grasslands of Pacific Slope are **PAL** = Palouse Prairie; **CAL** = California Prairie.

A definitively cordilleran character is imparted by the presence of fossil leaves of the Rocky Mountain limber pine (*Pinus flexilis*) at the Graham County *Picea* charcoal site (fig. 1, site 4; elevation 675 m [2,228 ft]), 120 km (72 mi) east-northeast of the Logan site or 90 km (54 mi) southwest of the Harlan site. Nine needle leaves of limber pine have thus far been retrieved from a silty loessal matrix containing abundant cordilleran-boreal animal fossils (landsnails and small vertebrates); collagen from bone of extinct *Bison* present in this fossil assemblage yielded a radiocarbon age of 17,930 ±550 yrs (Wells, 1983). The *Pinus flexilis* leaves were fragmented but are firmly identified (fig. 4). A major displacement of the subalpine limber-pine zone also is indicated by an independent source of macrofossil evidence: *Neotoma* (wood rat) middens (Wells, 1976) of full-glacial age from low elevations near the base of the Rocky Mountains. All the Pleistocene deposits thus far uncovered are dominated in composition by *Pinus flexilis* at sites ranging in elevation from 1,300 to 1,920 m (4,290–6,336 ft; fig. 1, sites 8 and 9). A deposit from the Front Range of Colorado, south of Pike's Peak (fig. 1, site 8), with a radiocarbon age of 22,720 ±270 yrs (GX–5925), is composed of almost pure limber pine (many thousands of five-needled leaf fascicles), but this site is 1,250 m (4,125 ft) higher in elevation and 450 km (270 mi) farther west than the Graham County, Kansas, record of *Pinus flexilis* (dated at 17,930 yrs B.P.). Today, limber pine is usually found only above 2,400 m (7,920 ft) in the Front Range; a few anomalous populations occur on escarpments of the High Plains, however, with the pine persisting as low as 1,600 m (5,280 ft) about 60 km (36 mi) east of Cheyenne, Wyoming (Wells, 1965). The closest living limber pines to the Wisconsinan fossil site in western Kansas are nearly 1,000 m (3,300 ft) higher in elevation and approximately 400 km (240 mi) to the northwest at Pawnee Buttes on the plains of northeastern Colorado (fig. 1 shows location of **living** populations on scarps in grasslands of North Dakota and Colorado, labeled *P. flexilis*). The remarkable High Plains populations of *Pinus flexilis* are widely disjunct and extremely local and are undoubtedly relicts of plains-wide Pleistocene populations.

Late Pleistocene ubiquity and Holocene extinction of forest landsnails on Great Plains

South of the Laurentide Ice Sheet, large areas of the Missouri–Mississippi River drainage system were blanketed with sheets of loess (eolian silt) of varying thicknesses. The late Wisconsinan (Peorian) loess is thickest on bluffs along streams with silt-rich valley trains (a putative source), but also mantles the vast upland interfluves of the plains, thinning with distance from sources (Thorp and Smith, 1952). Loess is unfavorable for preservation of fossil materials prone to decay because of excellent aeration imposed by the interstitial pore space; pollen and plant macrofossils (except charcoal) are rare and poorly preserved in the loess, unless capped by an overburden of clayey till that impedes the diffusion of oxygen. For example, the Des Moines lobe of the Laurentide Ice in a late surge sealed with till the underlying, full-glacial Peorian loess, thus preserving the logs and stumps of a dozed-down forest of spruce and other conifers that grew on the loess of central Iowa (Ruhe, 1969). Plant macrofossils are excellently preserved in other unoxidized sediments, as in clay-rich pond and stream fills, occasionally exposed by fresh cuts in the loess.

The general scarcity of plant macrofossils, pollen, and vertebrate fossils in the loess itself is offset, on the other hand, by the wide occurrence of exquisitely preserved shells of landsnails in astonishing numbers (on the order of 10–100 shells per dm^3 or liter of matrix). During the last glaciation, approximately 30 species of landsnails were extensively distributed on the immense, interfluvial uplands of the Great Plains and its eastward salient, the "Prairie Peninsula" of the Midwest (fig. 1), where the blanket of calcareous Peorian loess ensured preservation (Shimek, 1888, 1930; Frye and Leonard, 1952; Taylor, 1965). Many of these upland species of gastropods (the more characteristic loess snails are illustrated in fig. 5) are preserved also in clay-rich alluvial and lacustrine sediments, along with a rich fauna of aquatic mollusks that is entirely lacking in the upland loess. The remarkable ubiquity of pleniglacial landsnail faunas in loess on the High Plains of western Kansas (fig. 6) and their cordilleran-boreal character has been well documented by Leonard (1952).

Perhaps the outstanding event of North American molluscan history in the late Quaternary was the virtual disappearance of this rich landsnail fauna from upland habitats of the Great Plains. At some time during the transition from late-glacial to Holocene climate (beginning at least 12,500 yrs ago), the pleniglacial landsnails of the Central Plains began to shift their ranges radically until they eventually became more or less restricted to the existing position of cordilleran-boreal forests in the Rocky Mountains, Canada, and the Northeast.

A small contingent of the loess snails of the Plains is now confined to the eastern deciduous forest. A notable example is *Hendersonia occulta,* formerly widespread on the loess sheets of the Midwest as far west as central Kansas, but now regionally extinct in the Plains and distinctly local even in the forests east of the Mississippi River (fig. 7). The few other species of this type extend westward in the Great Plains today only in riparian woodlands (e.g., *Helicodiscus parallelus*).

Aside from the deciduous-forest species, all of the landsnails that suffered extinction on the Plains have survived in the Rocky Mountains and some are now endemic to the Rockies (table 1). On the other hand, none of the erstwhile Plains species is endemic to the boreal taiga belt, although most range widely from Alaska to Newfoundland, and some are circumboreal through Eurasia (fig. 7).

Remarkably, the species that contracted to endemism in the Cordillera had pleniglacial ranges that entirely spanned the Great Plains, extending then across Iowa even into Illinois, east of the Mississippi River (e.g., *Oreohelix strigosa, Discus shimekii;* cf. fig. 8). The cordilleran-

TABLE 1—FOSSIL ASSEMBLAGES OF CONIFERS AND/OR LANDSNAILS AND SMALL MAMMALS FROM THE CENTRAL GREAT PLAINS; localities indexed to numbers on maps (figs. 1, 3). Quantitative landsnail data as % composition in samples of 10^3 to 3×10^4 fossil shells; Oklahoma site from Miller (1975). Lab numbers for ^{14}C dates in order (left to right): Beta-12286, Beta-9320, GX-9355g, GX-9356, I-3460, GX-5812b, Beta-9321. Modern biogeographic headings in species list are generalized to indicate degree and direction of Holocene withdrawal from Plains.

^{14}C date, yrs BP: Locality: Elevation, m:	**14,700 ± 100 Harlan Co., NE (3) 605**	**14,450 ± 140 Jewell Co., KS (2) 485**	**17,930 ± 550 Graham Co., KS (4) 675**	**17,700 ± 350 Ellis Co., KS (5) 560**	**17,750 ± 360 Harper Co., OK (6) 610**	**10,245 ± 335 Logan Co., KS (7) 850**	**12,420 ± 180 Doniphan Co., KS (1) 310**
CONIFERS							
Cordilleran-boreal							
Picea spp. (charcoal)	+	+	+			+	
Picea glauca (leaves, twigs, cones)	+						
Cordilleran							
Picea pungens (leaf)						+	
Pinus flexilis (leaves)			+				
LANDSNAILS							
Cordilleran							
Discus shimekii	0.9	1.9	0.4	+			
Pupilla blandii	0.6		3.9	+	+		
Cordilleran-boreal							
Columella alticola	0.1	2.2	0.7				
Pupilla muscorum	0.6	0.1	5.3	+	+	+	
Vallonia gracilicosta	56.2	15.4	63.4	+	+	+	26.3
Vertigo modesta	5.1	35.1	13.0	+			1.5
Cordilleran-boreal-eastern deciduous forest							
Cochlicopa lubrica	0.6		0.4	+	+		0.3
Discus cronkhitei	5.6	20.0	1.2	+	+		7.6
Euconulus fulvus	0.4	4.7	0.6	+	+		0.3
Nesovitrea electrina	1.7	3.0		+	+		1.0
Vertigo gouldii	5.5	10.7	4.0				
Cordilleran-eastern deciduous (disjunct)							
Helicodiscus singleyanus					+		
Punctum minutissimum	0.1	0.2	0.3		+		36.1
Eastern deciduous forest							
Helicodiscus parallelus	0.1			+	+	+	
Hendersonia occulta		0.1					0.5
Stenotrema leai					+		
Strobilops labyrinthica	0.1				+		
Triodopsis albolabris							0.9
T. multilineata							0.4
Wide-ranging							
Gastrocopta armifera	5.2		0.3	+	+		
Hawaiia minuscula	1.3		0.9	+	+		0.1
Zonitoides arboreus	2.7		0.5	+	+		1.4
SMALL MAMMALS							
Cordilleran							
Eutamias minimus	+						
Microtus montanus	+		+				
Cordilleran-boreal							
Clethrionomys gapperi	+		+	+			
Lepus americanus	+	+					
Microtus xanthognathus	+		+				

(table 1 continued)

^{14}C date, yrs BP: Locality: Elevation, m:	14,700 ± 100 Harlan Co., NE (3) 605	14,450 ± 140 Jewell Co., KS (2) 485	17,930 ± 550 Graham Co., KS (4) 675	17,700 ± 350 Ellis Co., KS (5) 560	17,750 ± 360 Harper Co., OK (6) 610	10,245 ± 335 Logan Co., KS (7) 850	12,420 ± 180 Doniphan Co., KS (1) 310
Phenacomys intermedius	+		+				
Sorex arcticus	+		+	+			
Synaptomys borealis	+		+	+			
Tamiasciurus hudsonicus	+						
Cordilleran-Northern Plains							
Microtus pennsylvanicus (wide N., E.)	+		+	+			
Spermophilus kimballensis	+		+				
S. tridecemlineatus (to Southern Plains)	+		+				
Thomomys talpoides	+		+	+			
Zapus princeps	+		+				

boreal *Columella alticola* reached Ohio (LaRocque, 1966; Miller and Wittine, 1972). However, the more subalpine or subarctic species have been recorded as fossils only within a limited zone to the south of the Laurentide Ice, and they did not occur in the southern Great Plains (fig. 8). For example, the presently montane *Oreohelix* is unrecorded even in Kansas, but their shells have been found in Peorian loess closer to the ice in Nebraska, Iowa, and Illinois (Frest and Rhodes, 1981). Perhaps along the front of the mountainous Ice Sheet, a marginal orographic zone of cool, cloudy climate stretched continuously from the Rockies in Montana southeastward through the Plains to the interior lowland of the Midwest, thus providing a migrational corridor for cordilleran landsnails (fig. 8).

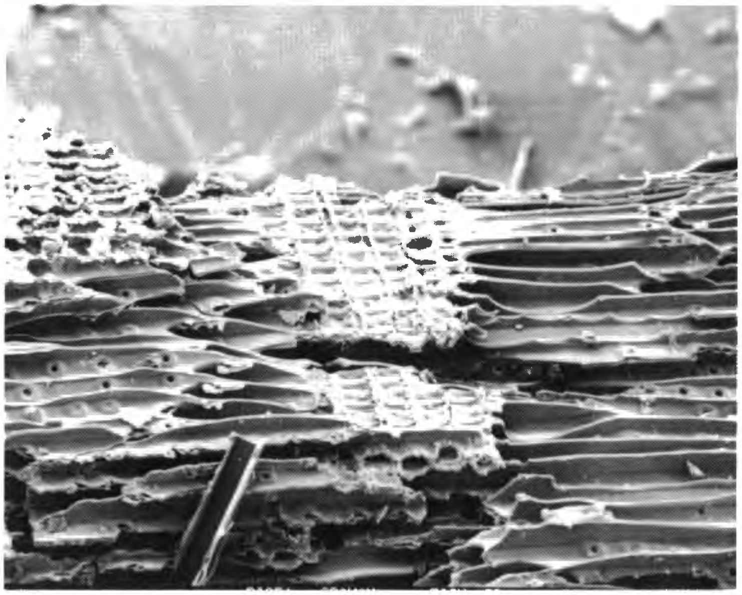
Other perhaps less-exacting species of cordilleran landsnails, such as *Pupilla blandii,* extended far from any mountains or ice on the southern Plains, e.g., on the Llano Estacado and Edwards Plateau of Texas; *P. blandii* was widely associated there with boreal-cordilleran *Pupilla muscorum* and *Discus cronkhitei* during the last glacial (Frye and Leonard, 1957), indicating much cooler and probably moister summers then in the southern Great Plains as well.

The timing of the great demise of cordilleran-boreal landsnails on the Great Plains is as yet poorly known. We have uncovered a rich landsnail fauna from stratigraphically young loess in northeastern Kansas (fig. 1, site 1; elevation only 310 m [1,023 ft]) that documents a partial persistence of full-glacial ("Upper Peorian") species mingling with perhaps more recently arrived "early Holocene" ("Bignell") species (e.g., the large polygrids *Triodopsis albolabris* and *T. multilineata,* indicative of temperate deciduous forest); this assemblage was dated to 12,420 yrs B.P. on the *Triodopsis* shells, which are supposed to be lacking (Leonard, 1952) in older loess here (table 1).

Ecological significance of North American loess snails

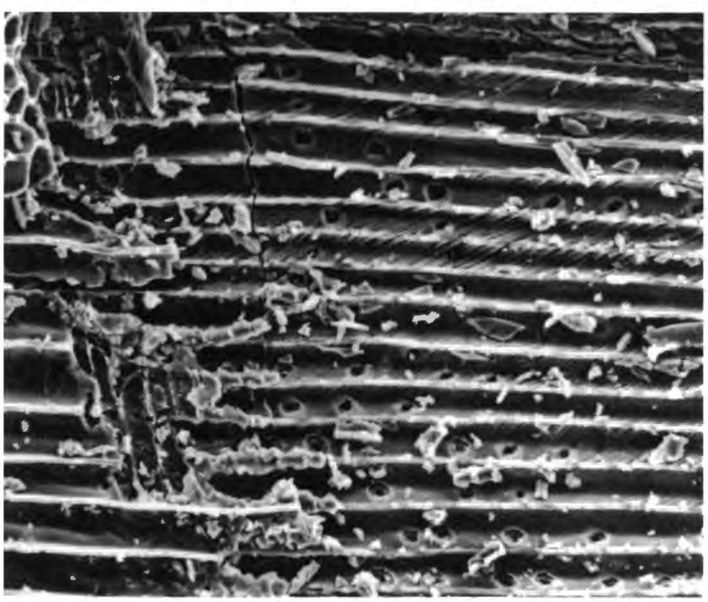
The main biogeographic implications of the late Pleistocene landsnail faunas preserved in pleniglacial loess and alluvium of the Great Plains are indicated in the organization of table 1. Clearly, the full-glacial environment of the Plains and entire Midwest was radically different from that of the modern grasslands, where very few of the ubiquitously abundant loess snails have persisted into the Holocene (Leonard, 1959). All of the loess snails of pleniglacial age (18,000 ± 4,000 yrs ago) are more or less abundantly extant today, however, in forested regions adjacent to the Great Plains. Aside from the small contributions from snail fauna of the eastern deciduous forest, the loess assemblages are almost exactly matched by the main landsnail fauna from the subalpine taiga of the Rocky Mountains (Leonard, 1952; Pilsbry, 1939; Bequaert and Miller, 1973).

Ecological data on the modern landsnails of taiga indicate that they feed on decomposing plant litter, especially of leaves, twigs, or wood of forest trees or on associated fungi involved in the decomposition (LaRocque, 1966; Pilsbry, 1939). Grasslands are inhabited today by only a few wide-ranging generalists among the pleniglacial loess snails (e.g., *Hawaiia minuscula, Zonitoides arboreus*), which are also present in forest vegetation (where they are much more abundant). Like most of the invertebrate fauna of forest soils (Lutz and Chandler, 1951), landsnails are most abundant and diverse in litter provided by nutrient-pumping, broadleaf-deciduous trees (mull-type soils) and much less so in needle-leaf duff from conifers (mor-type soils). Thus, in the modern cordilleran-boreal taiga, assemblages almost identical to the Plains-wide Pleistocene loess-snail faunas are mainly restricted to successional phases of the forest dominated by deciduous trees (Karlin, 1961; Kralkaj, 1986), notably the ubiquitous aspen (*Populus tremuloides*).



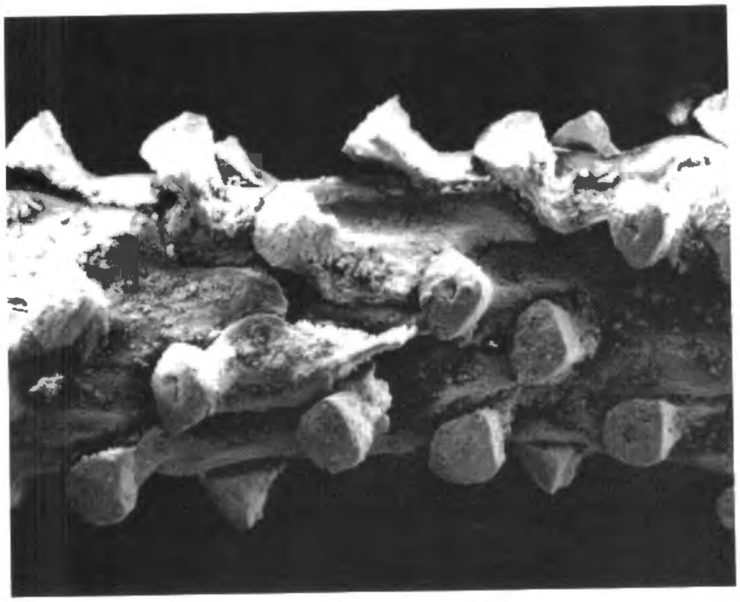
a) *Picea* charcoal, radial section with vertical tracheids and ray tracheids (waffle pattern), the ray also sectioned tangentially (fore), x 131, Graham County, western Kansas (fig. 1, site 4), 17,930 yr B.P.

b) uniseriate-bordered pits with tori, from (a) x 512.



c) spiral thickenings and bordered pits of vertical tracheids radial section, x 134, Harlan County, Nebraska (site 3) 14,770 yrs B.P.

FIGURE 2—Scanning electron microscopy of conifer charcoal from the grassland province of central Great Plains.



a) branchlet with peglike leaf cushions of genus, x 8.

b) leaves, x 4.

c) cones, opened and unopened (center), x 1.5.

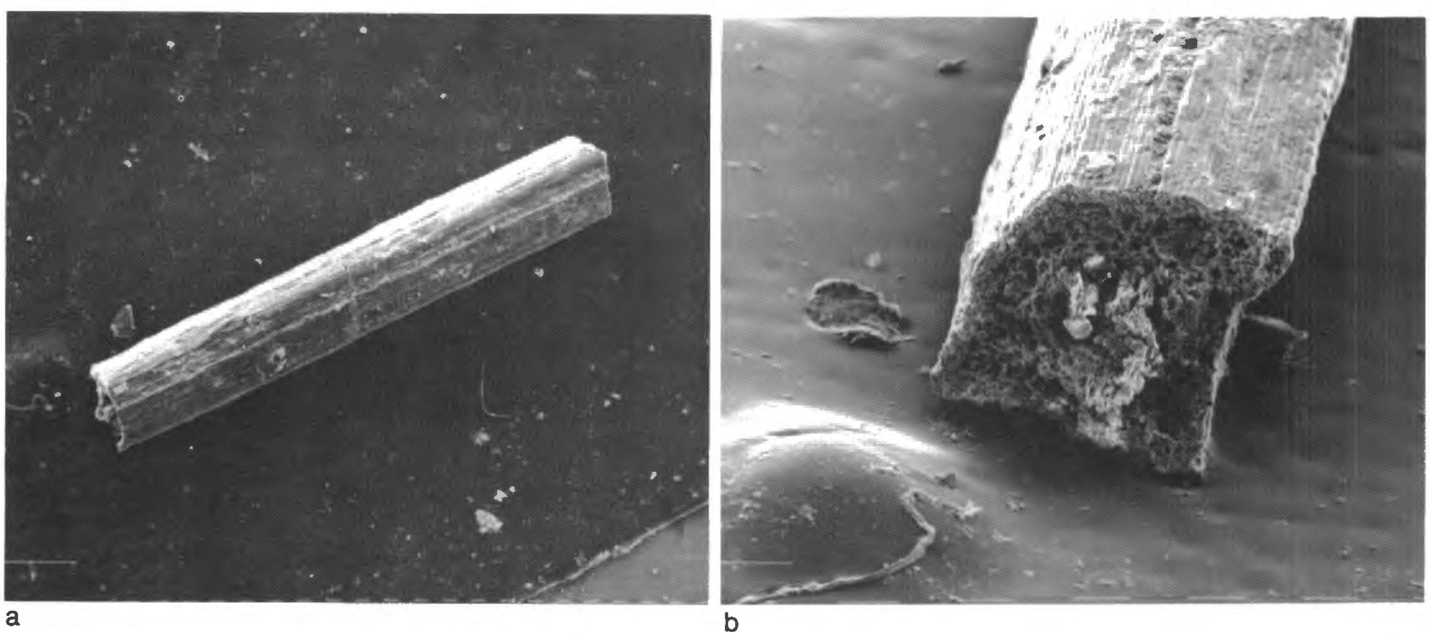
FIGURE 3—Macrofossils of *Picea glauca* from North Cove site, Harlan County, south-central Nebraska (fig. 1, site 3), 14,770 yrs B.P., the date on *Picea* wood. North Cove site was discovered October 1983, by Wells and Stewart, who later provided polleniferous sediments, other materials, and radiocarbon dates to other authors in this volume.

The snails are especially abundant and diverse in species in older stands of aspen with an understory of regenerating spruce, probably because there has been a longer buildup of rich, broadleaf litter and a cumulative recruitment of landsnails since the last forest fire. Catastrophic destruction by fire is the almost inevitable fate of the coniferous phase of subarctic or subalpine taiga (Slaughter et al., 1971; Ahlgren and Ahlgren, 1960; Lutz, 1956), even near the limits of forest growth (Payette and Gagnon, 1985), and spruce charcoal is of wide occurrence in the taiga (Payette and Gagnon, 1985). Quick-growing deciduous woodlands of aspen and birch are an almost taiga-wide feature of the fire-spawned succession (Halliday and Brown, 1943).

Because of the featureless continuity of the flat or gently undulating Plains, fires raging through the postulated Pleistocene spruce flats would have burned over immense areas, checked only at long intervals by abrupt topographic breaks (scarps, rivers), serving as fire breaks (Wells, 1965, 1970 a, b, c). Hence, transient successional phases of cool-season grasses and other herbs using the Calvin or C_3 photosynthetic pathway (e.g., fireweed, *Epilobium angustifolium;* fringed sage, *Artemisia frigida*) and more persistent deciduous trees (particularly aspen, which proliferates laterally by suckering from the widely spreading roots) are predictable components of a fire-mosaic in the full-glacial landscape of the Central Plains and Midwest (Wells, 1983). Direct evidence of fire in the spruce component, dating back to the last glacial maximum, is provided by our findings of spruce charcoal at four of the sites (table 1); the 100-m streak of *Picea* charcoal in the loess at one site affords a glimpse of a 14,500-yr-old burn in an upland stand of white spruce. Indirect evidence for the widespread upland occurrence of cool-temperate deciduous trees, such as aspen or birch (*Betula papyrifera*), is more widely contributed by the ubiquitous Pleistocene landsnail faunas (of cordilleran-boreal affinities) in the endless sheets of eolian silt that mantle the uplands of the Great Plains and Midwest.

Vertebrate microfauna associated with landsnail and conifer fossils on Plains

A further indication of seral patterning in a taigalike biome on the Great Plains is seen in the fossil bones of small vertebrates (chiefly rodents), co-occurring with the full- to late-glacial remains of the conifers and snails at several sites. Small, herbivorous mammals with limited feeding territories are more sensitive and faithful indicators of their plant communities than the widely mobile megafauna. Again, an outstanding predominance of cordilleran-boreal taxa is found among the retrieved fossils from the Central Plains (table 1). Most suggestive of the coniferous phase of taiga are the red squirrel (*Tamiasciurus hudsonicus*), redbacked vole (*Clethrionomys gapperi*), another boreal vole *(Microtus xanthognathus),* and the northern bog-lemming (*Synaptomys borealis*); all are present in the Rocky Mountains today, but the hyperboreal bog-lemming and Arctic shrew (*Sorex arcticus*) barely enter the United States in Montana and Minnesota. The phase of aspen with grassy openings is perhaps suggested by the western jumping mouse (*Zapus princeps*), the heather vole (*Phenacomys intermedius*), and the varying hare (*Lepus americanus*), all surviving today in the Cordillera. Stronger indicators of a more open, grassland phase include fossil



a b

FIGURE 4—Macrofossils of limber pine (*Pinus flexilis*) from Graham County, Kansas (fig. 1, site 4), 17, 930 yrs B.P. **a)** fragment of needle-leaf, showing stomatal grooves on outer, convex face, x 8; **b)** transverse section of (a), showing characteristic pie-wedge shape of a pine with a five-needled fascicle, x 33.

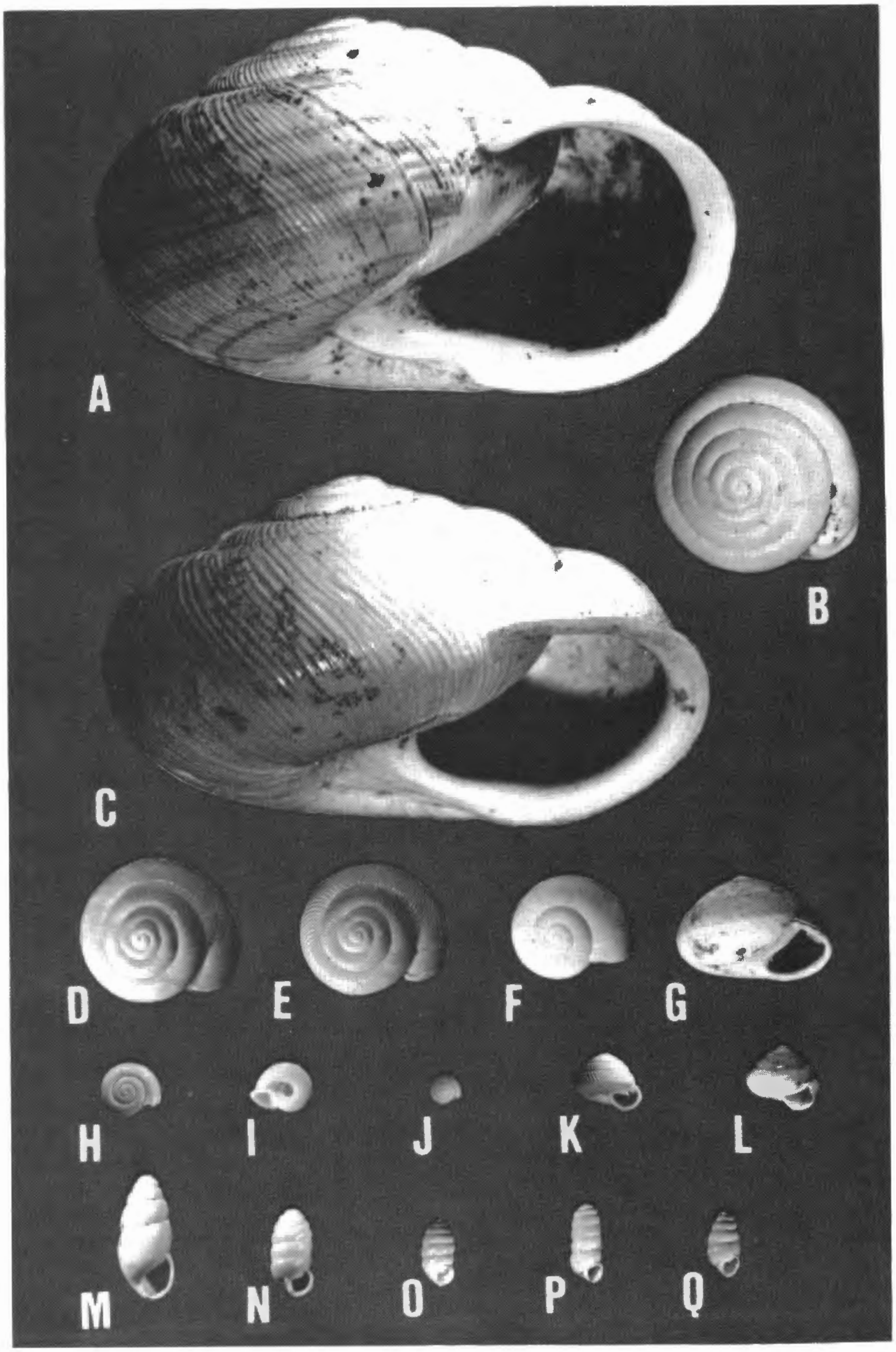


FIGURE 5--LOESS SNAILS OBSERVED IN PRESENT STUDY (ALL X 4), ILLLUSTRATING MOST OF THE MORE EXTRALOCAL SPECIES (LISTED IN TABLE 1) THAT ARE NOW EXTINCT ON THE CENTRAL PLAINS. The megasnails (*Triodopsis* sp.) were recorded only in northeastern Kansas, the shells of *T. albolabris* directly dated at 12,420 yrs B.P. The other species ranged westward on the Great Plains during the last glacial, leaving myriad fossil shells in loess and alluvium dated 14,000-18,000 yrs B.P.

A. *Triodopsis multilineata*
B. *Stenotrema leai*
C. *Triodopsis albolabris*
D. *Discus shimekii*
E. *Discus cronkhitei*
F. *Nesovitrea electrina*
G. *Hendersonia occulta*
H. *Helicodiscus singleyanus*
I. *Vallonia gracilicosta*
J. *Punctum minutissimum*
K. *Strobilops labyrinthicus*
L. *Euconulus fulvus*
M. *Cochlicopa lubrica*
N. *Pupilla muscorum*
O. *Pupilla blandii*
P. *Columella alticola*
Q. *Vertigo modesta*

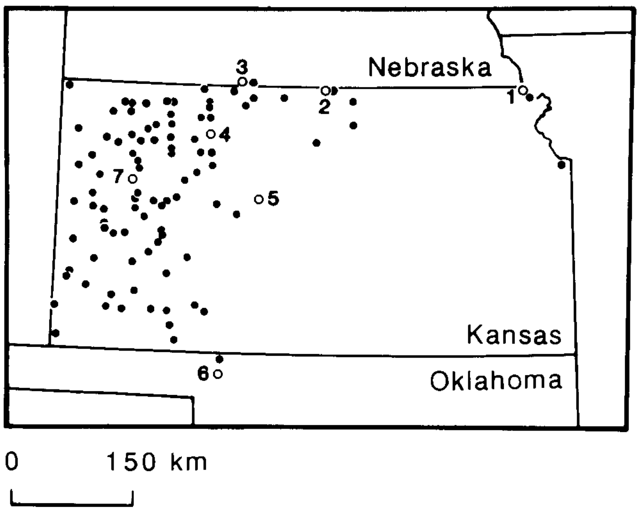


FIGURE 6—LOCATION OF 93 LANDSNAIL FAUNAS DATING BACK TO THE MOST RECENT (WISCONSINAN) GLACIATION OF THE PLEISTOCENE IN KANSAS AND ADJACENT STATES; most were analyzed by Leonard (1952). Numbered sites (open circles) are analyzed in this paper (table 1); site 6 from Miller (1975). Most of the 93 sites are in full-glacial loess of western Kansas.

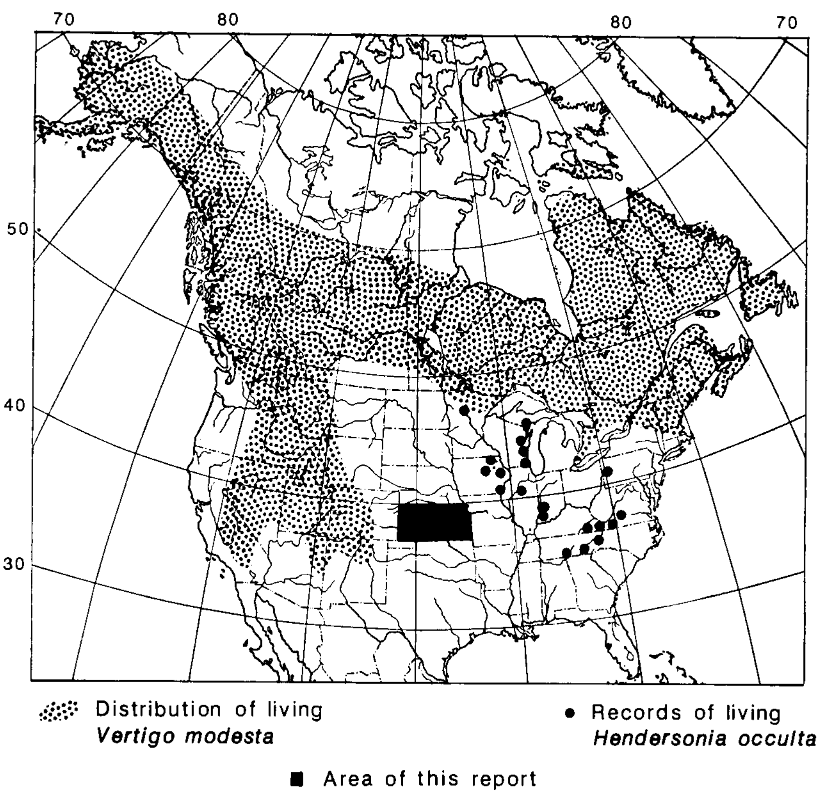


FIGURE 7—DISTRIBUTION OF A TYPICAL CORDILLERAN-BOREAL LANDSNAIL, *VERTIGO MODESTA*, AND AN EASTERN-DECIDUOUS-FOREST LANDSNAIL, *HENDERSONIA OCCULTA*, BOTH COMMON IN PLENIGLACIAL AND LATE-GLACIAL (AT LEAST AS LATE AS 12,420 YRS B.P.) LOESS OF KANSAS. The *Vertigo* was confined to the northern half (cf. *Discus shimekii*, fig. 8) and the *Hendersonia* to the eastern half of Kansas (solid black), where both species became extinct and are now widely extralocal (map from Leonard, 1952).

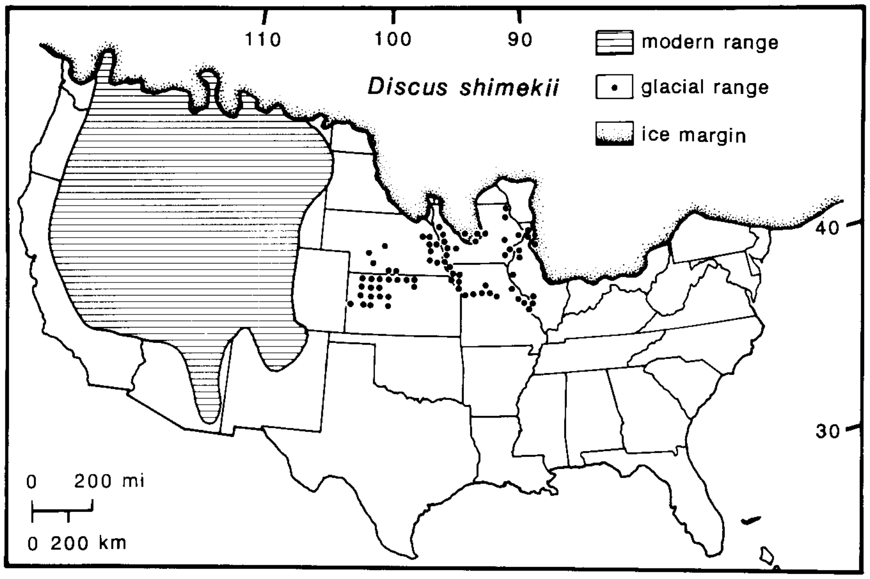


FIGURE 8—Distribution of the cordilleran-subalpine landsnail, *Discus shimekii,* at present and during the last glacial maximum (of which it is considered to be an index fossil by Leonard, 1952); documented Wisconsinan occurrences are indicated by dots. The eastward limit in Illinois seems to correlate with the Laurentide ice barrier and farther south with a shift in forest composition. Note relatively northern southern limits along the east-west gradient from the Mississippi River west to western Kansas.

remains of ground squirrels (*Spermophilus tridecemlineatus* and the extinct *S. kimballensis,* the latter represented today in the Rockies by *S. elegans*), a pocket gopher (*Thomomys talpoides*), and meadow voles (*Microtus montanus* and *M. pennsylvanicus*); again, these mammals are abundantly extant in the Rocky Mountain taiga (in the grassy-parkland phase).

The coexistence of all these ecologically diverse, taiga-inhabiting mammals with tell-tale charcoal of spruce is in agreement with the well-known fire cycle of the modern subalpine or subarctic taiga, entailing a relatively rapid succession from aspen parkland to spruce forest within a century or two (Slaughter et al., 1971; Ahlgren and Ahlgren, 1960; Lutz, 1956). Of course, the more open phases of the fire-induced succession could have accommodated the rich Pleistocene megafauna (e.g., *Bison, Camelops, Equus, Mammuthus*) as well, affording enhanced carrying capacity with both browsing and grazing niches. An increase in the tempo of burning after the advent of man in North America is a retrodicted possibility with intriguing consequences for the late Pleistocene biota of the Great Plains (Sauer, 1944).

Conclusions

Direct macrofossil evidence of cordilleran-boreal conifers (spruce, limber pine) at four scattered sites on the central Great Plains in western Kansas and southwestern Nebraska documents a taigalike vegetation during the latest Wisconsinan glacial (14,000–18,000 yrs ago) in habitats now dominated by grassy steppe of semiarid character. Closely associated fossil landsnail and small-mammal faunas also are cordilleran-boreal in their modern distributions, and most are regionally extinct in the Great Plains. The ecological requirements of the loess landsnails strongly indicate forest vegetation and more specifically suggest a cold-temperate, moist, broadleaf-deciduous phase, probably aspen (*Populus tremuloides*).

Some small-mammal fossils indicate a coniferous phase, while others suggest aspen-parkland or grassland-opening phases. Occurrence of spruce charcoal at four sites is direct evidence of fire in the coniferous phase. Hence, the diverse ecological indications at all of our sites are in agreement with the expected successional sequence in taiga vegetation following fire: 1) herbaceous phase with fireweed, sedges, grasses; 2) aspen-parkland phase; 3) aspen/spruce phase; and 4) mature spruce-forest phase. Fire in the mature-conifer stands reinitiates the cycle on a time scale that appears penecontemporaneous in the local fossil record, telescoping the various seral stages. The unbroken flatness of the vast interfluves on the Plains would permit a regional ravaging by fire, maintaining the vegetation in a state of successional flux that would maximize the coexistence of ecologically disparate fauna and flora among a kaleidoscopically shifting mosaic of seral niches in time and space. Thus, the central Great Plains was not a "loess steppe" during the most recent glaciation of the Pleistocene, but rather a biotically diverse, taigalike biome, with numerous species that now survive in the cooler and summer-rainy Rocky Mountains. The pleniglacial climate of the Great Plains was undoubtedly more equable than that of today, with much cooler, cloudier, and therefore effectively moister summers, minus the modern droughts.

ACKNOWLEDGMENTS—We thank Wayne Ostlie for laboratory and field assistance. Research supported by National Science Foundation grants DEB 78-11187 and BSR-8320529 and by General Research Fund grants from the University of Kansas in 1983-84 and 1984-85 are all gratefully acknowledged.

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Pleistocene glaciation and historical biogeography of North American central-highland fishes

by *Richard L. Mayden*, University of California, Los Angeles, California

Abstract

Rivers of the central highland regions of North America contain one of the most diverse assemblages of fishes of the continent. Each region is distinctive, with a high degree of endemism and only a few species shared between any two of the areas. For many years biologists have noted this pattern of diversity and commented on possible explanations for its origin. They noted similarities between regions either with allopatric populations of conspecifics or hypothesized close relatives in two or more areas. Previous explanations have adopted the philosophy of evolutionary biogeography. Centers of origin were recognized and species were hypothesized to have dispersed outward to unoccupied regions. This philosophy is compared with that of vicariance biogeography for central-highland fishes and found to be inferior with respect to its ability to provide a general explanation of common patterns. The known geological history of the region and observed pattern of relationships and distributions of central-highland fishes are consistent with the tenets of vicariance biogeography and necessitate fewer ad hoc explanations with this model. Although the three major highland regions are separated by lowland environments, geological evidence suggests that the intervening lowland areas are recent formations since the Pleistocene and that the isolated areas were once a single expansive highland region. Highland topography, and presumably rivers, extended north of the existing highland areas into the central lowlands. The impact of continental glaciers on this region and the fauna was tremendous. Ice sheets destroyed highland habitats in all areas of coverage and essentially separated this expansive region into large western and eastern components. The western component, interior highlands, underwent vicariance at sometime prior to the Sangamonian interglacial, resulting in the existing separate Ozark and Ouachita highlands. Species relationships of highland-fish groups suggest several patterns with one pattern being common. That is, species in the Ouachita and Ozark highlands are more closely related to each other than either is to species in the eastern highlands. Species of the upper Mobile Bay drainages form the sister group to interior and eastern highland species. The Mobile Bay separation is the oldest event, perhaps dating to the Miocene. The separation of the interior highlands can minimally be dated as pre-Sangamonian. Speciation events between the eastern and interior highlands predate the Pleistocene. Only with the methods and philosophy of phylogenetic systematics and vicariance biogeography can the temporal sequence of these historical events be uncovered. Further, hypotheses presented herein form general explanations that may be tested with additional geological and phylogenetic data as they become available. Such is not the case with the previous explanations of dispersal from designated centers of origin. Dispersal is not excluded as a viable explanation in vicariance. Dispersal is a very real phenomenon and must have occurred at some stage. However, it is a difficult proposition to test since everything is possible given this philosophy. The dispersal explanation shadows other, perhaps more parsimonious, explanations in biogeographic studies and should be a conclusion in these studies, not an assumption.

Introduction

Biogeography, as generally defined, is that area of biology dealing with the geographical distribution of animals and plants. Although very elementary on the surface, this area of biology is diverse in its methods and philosophy and becoming ever more important in areas of evolutionary biology. Very generally, it may be subdivided into two major areas of emphasis: descriptive and interpretive biogeography. Historical biogeography forms the interpretive portion of the field and seeks to explain the present distributions of plants and animals elucidated by the field of descriptive biogeography. Historical explanations for present species distributions are sought through the use of species relationships and ecological and geological histories of regions inhabited by them. The two areas of biogeography have been compared by Platnick and Nelson (1978), Nelson and Platnick (1980), and Wiley (1981) to the collection and analysis of data in any scientific study.

Little variation exists among biogeographers concerned with descriptive biogeography, but the same cannot be said for interpretive biogeography. The former is primarily concerned with present-day species distributions and how they are controlled, maintained, or lost. On the other hand, the latter area is one of varied thought, but common to all is their interest in the spatial and temporal distributions of species or higher taxa and what historical events provide explanations for present-day distributions. The division between ecological and historical biogeography is tenuous. It is difficult to separate the two fields because they are, in fact, interdependent and are best considered two extremes of a continuum. Although inseparable, emphasis in this paper is on the historical extreme of this continuum. This paper complements ideas presented by Cross (1970) by incorporating ideas of vicariance biogeography of other North American fishes and represents a broader view of how these distributions and distributions of other central North American fishes have changed since the Pleistocene. More specifically, this paper concerns how the Pleistocene glaciation affected those fishes thought to have been restricted to an uplifted region in east-central North America with typically clear, high-gradient streams, commonly referred to as the central highlands (Mayden, 1985; Wiley and Mayden, 1985).

Historical biogeography

As previously observed by Nelson and Platnick (1980), the field of historical biogeography is unlike many areas of biology in that many researchers interested in this field are not biogeographers per se, but are systematists primarily interested in developing hypotheses of species relationships. However, they also are interested in discovering factors influential in producing observed patterns of species relationships. As biogeographers, these researchers are concerned with species distributions, geological histories, and biotic regions and how these regions are interrelated. These latter concerns are not unique to systematics; they are of general interest to other areas of organismic biology. Only with these historical kinds of data can certain evolutionary and ecological questions be answered. For example, factors influential in producing present-day patterns of species distributions, regions, etc., are products of historical phenomena and are best estimated with historical data in the form of species phylogenies and geological histories. Thus, the field is occupied primarily by systematists, the only biologists with the data base for direct estimates of historical events.

Reconstructed species phylogenies represent an estimate of the past history of a group and are presented in the form of trees, representing genealogies. From these reconstructions the biologist can determine relative ages of species and speciation events and can superimpose species trees onto areas occupied by the species to obtain direct estimates of histories of regions (Nelson and Platnick, 1980). These predictions can then be tested using geological data (also in the form of trees), if available, and then congruence between the two independently derived data sets can be examined. Such a philosophy, that the earth and its inhabitants evolve together and can be studied in concert, was termed hologenesis by Rosa (1918).

Basically, two approaches to historical biogeography exist: evolutionary biogeography and vicariance biogeography. A third approach exists, phylogenetic biogeography, but its methodology is very similar to the vicariance approach. Vicariance biogeography is the most robust area of biogeography and is employed later in this paper. However, before further discussing the vicariance method, these other areas must be addressed.

The field of phylogenetic biogeography was principally developed by Hennig (1960) and Brundin (1966, 1972) and does not differ extensively from vicariance biogeography. When applied, however, it is most fequently with a single group of organisms and general explanations usually are not sought. The birth of this field of biogeography was in the development of phylogenetic systematics. The biogeographic history of a group is inferred from its phylogenetic history. The philosophy of phylogenetic biogeography is employed in vicariance biogeography, except the latter school of thought deals with multiple groups of organisms in search for common patterns and general explanations.

The philosophy of evolutionary biogeography is embodied by a dispersalist viewpoint. Here researchers place emphasis on centers of origin of groups and from these centers new species evolve and displace more primitive species to the periphery. This philosophy primarily is derived from ideas of progressive evolution. New species are better adapted and distributional patterns of organisms can be explained in terms of dispersal. Although dispersal is a very real phenomenon in nature, it is difficult to test. Further, in assuming that all patterns can be explained in terms of dispersal, a researcher is likely to lose valuable information. Even if only a small proportion of speciation events and geographic distributions are the result of some mode (i.e., vicariance) other than dispersal, these processes will never become known when one only employs a dispersalist explanation. With an increasing percentage of vicariance or other modes, we would only see an increase in lost information. If we assume that disjunctions in distributions are the result of dispersal, then we will never uncover cases to the contrary. Thus, the philosophy of evolutionary biogeography is not employed in this paper.

Vicariance biogeography as a discipline represents the union of the principles of phylogenetic systematics (Hennig, 1966) and track analysis (Croizat, 1952, 1958, 1964). It is a method whose basic tenets are to furnish a general method of biogeographic analysis applicable at any level and to seek general explanations for patterns (see Nelson and Rosen, 1981). Thus, it minimizes the number of unnecessary explanations for a common pattern. The method attempts to explain common distributional patterns with a general explanation such as the fracturing of a once widespread biota into smaller, distinctive biotas. Also, it allows one to separate these common patterns from those which require additional and unique explanations such as long-distance dispersal. This approach to biogeography is less dependent on ad hoc dispersal explanations.

The vicariance biogeographer seeks distributional data from several monophyletic groups (all descendents of a common ancestor) inhabiting a region, and the replicated patterns of distributions of these groups are termed *tracks* (fig. 1.1). From these tracks, areas of endemism are identified and relationships of these areas, in terms of species inhabiting them, are studied. The relationships of the organisms found in areas of endemism are compared to the geological relationships of the regions for concordance. The degree to which we have congruence between the geological and species cladograms is related to the frequency of common factors affecting the evolution of the groups. If we see congruence between the geological cladogram (fig. 1.2) and one or more of the biological cladograms (fig. 1.3-1.5), then we may hypothesize that factors responsible for producing the former pattern were responsible for the latter phylogenetic relationships. These methods are very powerful and offer considerable predictive potential for both geologists and biogeographers. Given that one of these two historical data sets (geological or biological cladogram) is missing, one may make predictions concerning the missing component based on available data. As an example, in fig. 1 if only species relationships are available, then one may predict that areas contained in track 2 share a more recent history than either has with the third area contained in track 1. These hypotheses may then be tested later when additional data on these areas are available. The vicariance approach is superior to other existing areas of biogeographic analysis and is employed here for studying the biogeographic history of central-highland fishes.

Biogeography of central-highland fishes

Information presented below represents an abbreviated review and synthesis of contributions by several researchers interested in this topic. It summarizes, with a few examples, our present knowledge of the history of the fishes and the region presently inhabited by them. For more detailed information concerning the descriptive aspects of this fauna, the reader is referred to references in Mayden (1985, in press) and Wiley and Mayden (1985). Information concerning the geological history of the region is scattered but is more fully outlined in Thornbury (1965), Bretz (1965), and other references in Mayden (1985, in press). Interpretive studies of highland biogeography include Dowling (1956), Metcalf (1966), Cross (1970), Pflieger (1971), Mayden (1985, in press), Wiley and Mayden (1985), and Cross et al. (1985). Below, I discuss the biogeography of these fishes and how the Pleistocene glaciation has affected their present distributions. The methodology of vicariance biogeography is employed in determining the temporal history and relationships of the regions. Further, the distributions of some central Kansas fishes, which are typically highland species, are evaluated in terms of their probable origin.

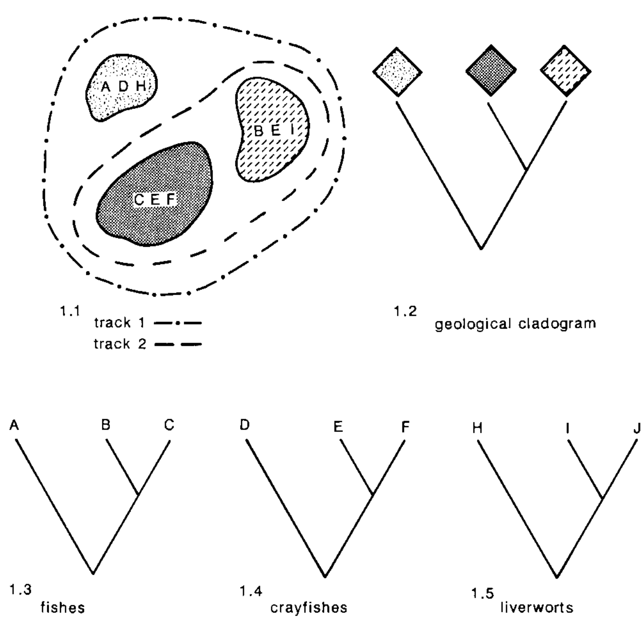

FIGURE 1—Distributions of three areas of endemism, two biogeographic tracks, a geological cladogram of areas of endemism, and phylogenetic relationships of three monophyletic endemic groups of organisms.

The central highland region includes three areas east and west of the Mississippi Valley (Mayden, 1985, in press). Included are the Ozark highlands, Ouachita highlands, and eastern highlands (fig. 2). These geological formations are described in more detail in Mayden (1985, in press). Presently, the areas are typically drained by high-gradient and clear streams, all part of the Mississippi River system. Separating the areas are low-gradient habitats with typically silt-loaded streams, generally not occupied by fishes typical of the highland regions. To the south, the highlands are bounded and partially dissected by the Coastal Plain province. The Ozark and Ouachita highlands (interior highlands) also are divided by this province and the floodplain of the Arkansas River. Between the interior highlands and the eastern highlands is the floodplain of the Mississippi. North of the highlands lies the characteristically low-gradient Central Lowlands province, an area displaying the impact of Pleistocene glaciation. West of the interior highlands are the unglaciated central lowlands and Great Plains. The Ouachita highland region is the smallest of the three regions and is drained by the Ouachita, Kiamichi, and Little rivers. The Ozark highlands are intermediate in size and are drained by portions of the Missiouri, White, and Arkansas river systems. The eastern highlands is by far the largest area and has the largest number of species. This region is drained by portions of the Ohio, Cumberland, and Tennessee rivers, and the upper Mobile Bay and Appalachicola rivers of the Gulf Coast.

The three major regions of the central highlands contain one of the most diverse faunas in North America. As a whole, it contains greater than half the total diversity of the Mississippi River system. Each highland area is known for its diverse and endemic fauna (fig. 3; Mayden, in press). The highland areas also are known to have several exclusively shared species or species groups between two or three of the regions. Fish species groups involved include darters of the *Etheostoma variatum* and *E. maculatum* species groups; the subgenera *Ozarka, Swainia, Littocara, Odontopholis, Ericosma,* and *Imostoma;* minnows of the genera *Erimystax, Phenacobius, Nocomis, Pimephales;* the *Notropis zonatus-coccogenis, N. leuciodus, N. telescopus, N. spectrunculus, N. venustus,* and *N. xaenocephalus* species groups; and the sucker genus *Hypentelium.* Single species illustrating this pattern include the topminnow *Fundulus catenatus,* the darter *Etheostoma blennioides,* the sculpin *Cottus carolinae,* the cavefishes *Typhlichthys subterraneus, Ambylopsis,* and others listed by Mayden (in press).

With endemic faunas found in one or more of the highland regions, ichthyologists have noted a faunal pattern unique to this area and in need of explanation. Also of interest, but rarely commented on, are populations of some species in the central and western Plains region, an area west of the interior highlands.

For many years the explanation advanced for the observed distribution pattern in the central highlands was one of centers of origin and dispersal, commonly proposed by advocates of the school of evolutionary biogeography. Given the diverse nature of the eastern highlands, most species were thought to have evolved here and dispersed to the other two areas where they would become isolated and perhaps differentiated. Given that this could have happened several times, we would then have the diverse and endemic faunas of the regions. This explanation was not completely without merit or logical basis. Proponents believed that species dispersed from east to west or west to east along the front of an ice sheet during the Pleistocene. Alternately, dispersal could have occurred at some stage during the Pleistocene when the base level would have been lowered enough to give the Mississippi River in southern Illinois and Missouri the high-gradient characteristics required for the survival and successful movement of highland species. Such an explanation was used to explain dispersal of surface species as well as subsurface cavefishes. For the latter, drainages beneath the Mississippi were hypothesized to have connected the two major highland areas. Thus, under this model the present diversity of the central highlands has been in existence since the Pleistocene.

More recently, an alternative hypothesis, that of vicariance, was proposed by Mayden (1985, in press), Wiley and Mayden (1985), and, in part, by Pflieger (1971) as a general explanation of this pattern of distributions and species relationships. These authors proposed that the present highland regions and faunas represent the remnants of a fragmented, once-widespread highland region. They proposed that prior to the Pleistocene the highlands were all interconnected and drained by river systems different from those today. These drainages contained a diverse fauna that was dissected by advancing glaciers and associated glacial processes to produce the existing pattern. Thus, a single general explanation is employed to explain the observed patterns, not multiple dispersals in various directions. Further, this hypothesis is testable. If closest relatives of species in one of the highland regions are not in another highland area, but are outside of the area, then this hypothesis may be falsified. If, on the other hand, species from one region have their closest relatives in another region, then this hypothesis is corroborated and remains to be falsified.

Hence, we have two potential explanations for the historical biogeography of central-highland fishes, one from each of the two competing philosophies of historical

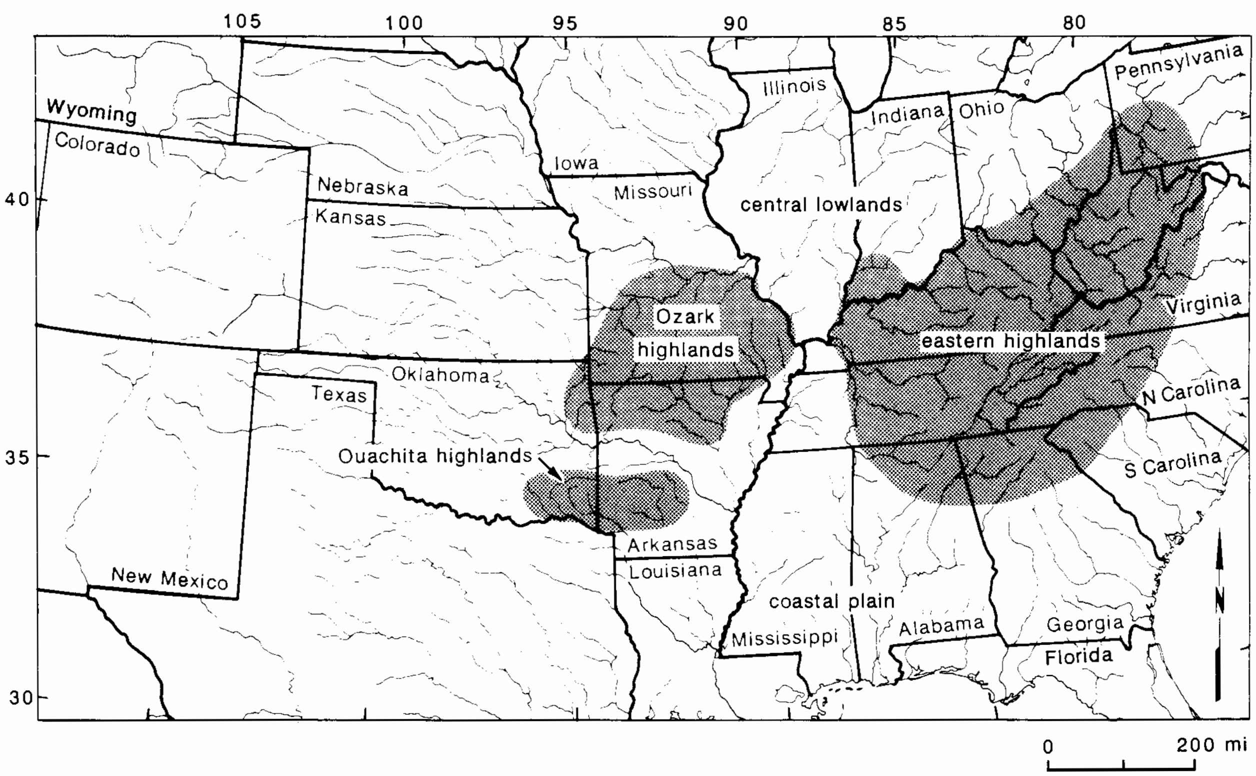

FIGURE 2—MAJOR CENTRAL HIGHLAND REGIONS IN NORTH AMERICA (after Mayden, in press).

biogeography. One explanation invokes centers of origin and dispersal and a second invokes vicariance. Which, if either, of these hypotheses forms the most parsimonious explanation of the pattern? Which is consistent with the phylogenetic histories of the species and the geological history of the region and supplies us with a general theory? Were these regions ever connected to produce the observed faunal patterns without invoking long-distance dispersal? We may examine the evidence below.

Geological evidence

All available data suggest that the three highland areas are very old. The Ozark province itself has been above ground since the Pennsylvanian and had its last episode of uplift in the Eocene or before (Bretz, 1965). The Ouachita Mountains and a large portion of the eastern highlands represent an old geomorphic formation extending beneath the Coastal Plain province. This formation dates to the orogeny of the Appalachian Mountains (Thornbury, 1965). Although these three regions are now independent of each other, it is now known that they are, in fact, remnants of a once more widespread highland region. It is now believed that this region extended north (and perhaps west) of the existing highlands and was dissected by the several glacial advances of the Pleistocene (Mayden, 1985, in press; Wiley and Mayden, 1985). Before the advance of glaciers over north-central North America in the Pleistocene, a highland topography and presumably streams with highland characteristics ranged from the Appalachians to at least the Great Lakes region, south to the Coastal Plain, and west to eastern Kansas, perhaps even farther.

The Central Lowlands province is a result of this glacial advance south to the present highland areas. Prior to the Pleistocene, the topography of this area was presumably like that of the existing central highlands. Studies of preglacial bedrock topography from Ohio, Illinois, and Indiana, all areas now in the central lowlands, indicate that the Tertiary geomorphic history of the areas paralleled that of the central highlands to the south (Ver Steeg, 1934, 1936; Hornberg, 1950; Wayne, 1952, 1956). Further supporting the theory of a once-continuous highland region are studies of erosional surfaces from driftless areas throughout the central lowlands which support an expansive highland region (Thornbury, 1965). With the glacial advance, much of the pre-Pleistocene highland topography was destroyed and converted into the existing topography characterized by relatively low relief.

The impact of Pleistocene glaciation on highland habitats goes beyond the destruction of the northern highland areas. Two major events may be attributed to the Pleistocene glaciation. The first is the direct result of moving ice and the second is more indirect, related to sea-level fluctuation. First, advancing glaciers allowed total separation of the large eastern highlands from the western interior highlands, and second it divided the interior highlands into the Ozark

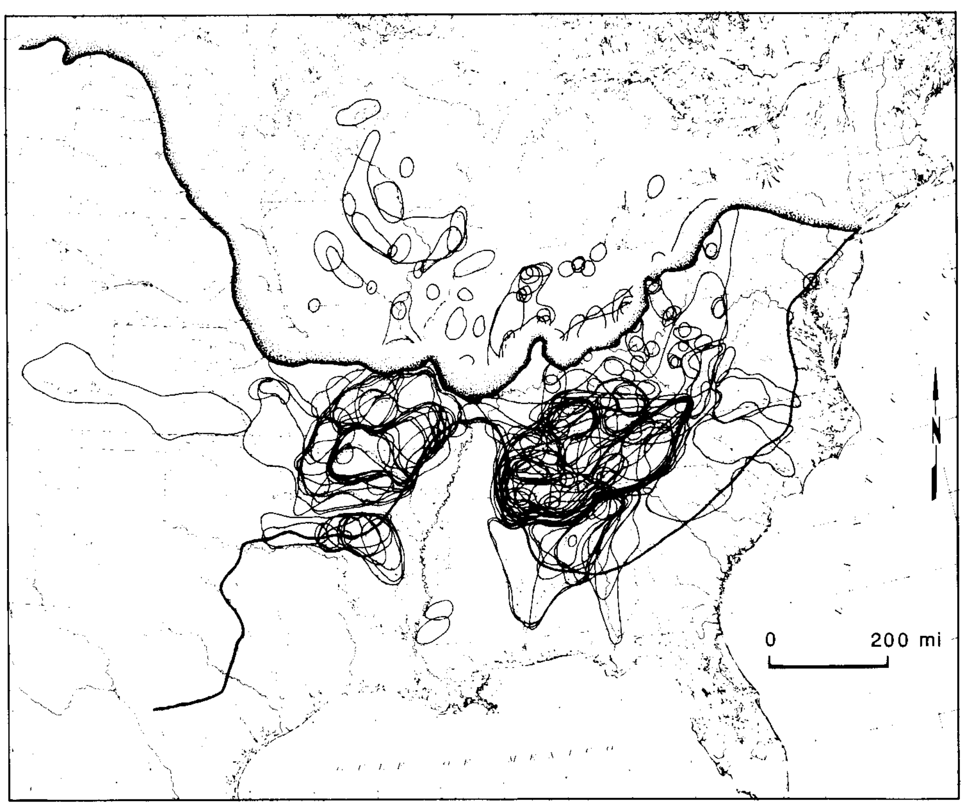

FIGURE 3—Distributions of central highland fishes (dark lines) and composite of maximum glacial advances superimposed on present-day drainage patterns in North America, identifying areas of endemism, northern disjunct populations of some central highland fishes, and the impact of glaciation on the previous widespread ichthofauna. Figure modified from Mayden (in press).

and Ouachita provinces (Mayden, 1985, in press). Because of the predominate shape of glacial fronts (Flint, 1957), with maximum advance near the Mississippi Valley, the multiple glacial advances, together with the northward extension of the Coastal Plain province in the Mississippi Valley, effectively severed the highland area into eastern and western regions (fig. 2). A small highland "bridge" in southern Illinois (Thornbury, 1965) still remains, but connection between the two regions is prohibited by the Mississippi River and associated floodplain. Separation of the interior highlands into the Ozark and Ouachita regions was made possible with fluctuating sea level and the development of the Arkansas River system (Quinn, 1958). This event occurred in the Pleistocene and has been minimally dated as pre-Sangamonian.

In summary, although our reconstructed knowledge of past geological events is weak, we may infer from a collection of geological data that the present central highland regions were once part of an old, widespread highland area dating at least to the Eocene. This region was dissected by events of Pleistocene glaciation. First, it was split into two areas, one east and one west of the Mississippi River. The western region later became dissected with the development of the Arkansas River whose floodplain produced lowland habitats similar to those of the central lowlands and Mississippi Valley (see fig. 5 in Mayden, 1985).

Phylogenetic evidence

Using methods of phylogenetic systematics outlined by Hennig (1966), the historical relationships of species in the central highlands may be examined. This method employs only shared-derived characters to infer relationships within monophyletic (single origin) groups and is superior to other methods when answers to genealogical questions are being sought (Wiley, 1981). Primitive characteristics are those inherited by species through ancestry, are found also outside the group of interest, and are not characteristics indicative of a unique ancestry.

Species relationships in the highland regions do, in fact, suggest a common pattern but not a single pattern. Stated briefly, in the most frequently occurring pattern (fig. 4), species in the highlands of the upper Gulf Coastal drainages form the sister group to the remaining highland species and thus are the result of the oldest speciation event for the groups. This event is presumably correlated with the breakup of the Appalachian River (Starnes and Etnier, 1985; Mayden, in press). Next, species of the eastern highlands form the sister group to species of the interior highlands (fig. 4). This relationship is slightly more complicated than appears in that it is not always a species from the same drainage which is most closely related to the western members. This topic will be addressed more fully below. Within the interior highlands, if a species of a central highland clade is present in the Ouachita highlands, its closest relative is in the Ozark highlands. Thus, we have a generalized temporal sequence of speciation events for central-highland fishes (fig. 4) which is consistent with what we know of the geological history of the area. Some potential problems of extinction in the eastern highlands remain, however, and will be addressed below.

Other biogeographic tracks are observed for central-highland fishes. These patterns are much less common, are not inconsistent with the general Pleistocene-central-highland hypotheses presented here, and need only be listed. Some species of the Ouachita highlands have their closest relatives to the south of the mountains in the Coastal Plain province from eastern Texas to the Atlantic slope. Others have sister species with a widespread distribution over eastern North America (Mayden, 1985). Some species of the eastern highlands have their closest relatives in Atlantic-slope drainages east of the Appalachians (Mayden, in press). In all probability, other patterns will be elucidated once relationships of other highland species are determined, but the temporal sequence of highland areas listed above will remain a common pattern.

Another frequently observed pattern for these highland fishes, relating to the most common pattern mentioned above, is that some species with the common pattern also have disjunct populations to the north of the Ozarks or eastern highlands in the central lowlands (fig. 3; Mayden 1985, in press). The origin of some of these populations may be debatable, but for others it is not. Some are found in driftless areas, regions presumably never glaciated and represent glacial relicts. Others are found in regions previously covered with at least one continental ice sheet. These populations either represent refugia left over from the Pleistocene, or they represent long-distance dispersal after the last glaciation. Because of the disjunct nature of the appropriate habitat of many of these refugia, separate from the nearest highland region by adverse environments for highland species, dispersal seems an unlikely explanation for the origin of these populations unless, however, these species dispersed north following the last melting ice sheet and settled into preferred areas. Alternatively, they may actually represent northern relict populations of species left by glaciation, like *Notropis nubilus* (fig. 5) and *Campostoma oligolepis* in the driftless region, and are indicative of a diverse pre-Pleistocene fauna (Mayden, 1985). Because each glacial advance left many areas unglaciated, considering the potential for many "driftless" areas to be present with each advancing glacier is not unreasonable.

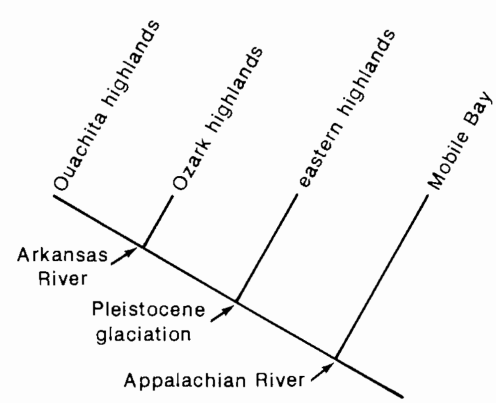

FIGURE 4—Area cladogram for major central highland regions.

Notropis nubilus is an important species in the overall picture of the biogeography of central-highland fishes (fig. 5). The significance of this species includes its relationships to other members of the *N. leuciodus* species group, a unique morphological trait possessed by the species, and its distribution. *N. nubilus* represents one of the best supporting examples of an intact pre-Pleistocene fauna in the highlands.

The Ozark minnow is found in the Ozark highlands, the driftless region, and as a fossil in southwestern Kansas. Populations of this species have a derived coiled intestine, a characteristic unique to this group. Thus, the species evolved this morphological characteristic at the time of the speciation event responsible for its existence. Relationships of *N. nubilus* are with *N. leuciodus* of the eastern highlands, and these two together are most closely related to *N. chrosomus* of the upper Mobile Bay drainage (fig. 5). The significance of these particular findings is that if the populations of *N. nubilus* present in the northern unglaciated region represent Pleistocene relicts, then the origin of the species must predate the Pleistocene, because both isolated recent populations have the unique coiled intestine. Other species, some with disjunct northern populations, have distributions and relationships also in support of an intact pre-Pleistocene fauna (see Mayden, 1985, in press).

Vicariance or dispersal

As seen above, the predominate pattern of phylogenetic relationships of central-highland fishes suggests that closest relatives of a species found in one highland region are with species in another highland region. Closest relatives of these highland fish groups are located outside the central highlands. Further, the temporal sequence of speciation events of some groups suggests that the fauna was diverse, widespread, and in existence before the Pleistocene. Distribution patterns and relationships of all other highland species are consistent with this hypothesis. The impact of the Pleistocene glaciation on the central-highland fishes was tremendous but probably had little significance with respect to speciation of these fishes; the only exception being the division of the interior highlands province by the Arkansas River. This event is correlated with the evolution of closest relatives in the Ouachita and Ozark highlands (Mayden, 1985). Massive continental ice sheets were responsible for the vicariance between the interior and eastern highlands, but events responsible for species patterns between the two regions predate the Pleistocene in river systems only partially reconstructed today (see Hocutt and Wiley, 1985).

The hypothesis of centers of origin and dispersal seems unjustified in light of the phylogenetic and geological data presented above and in previous papers. It is true that this

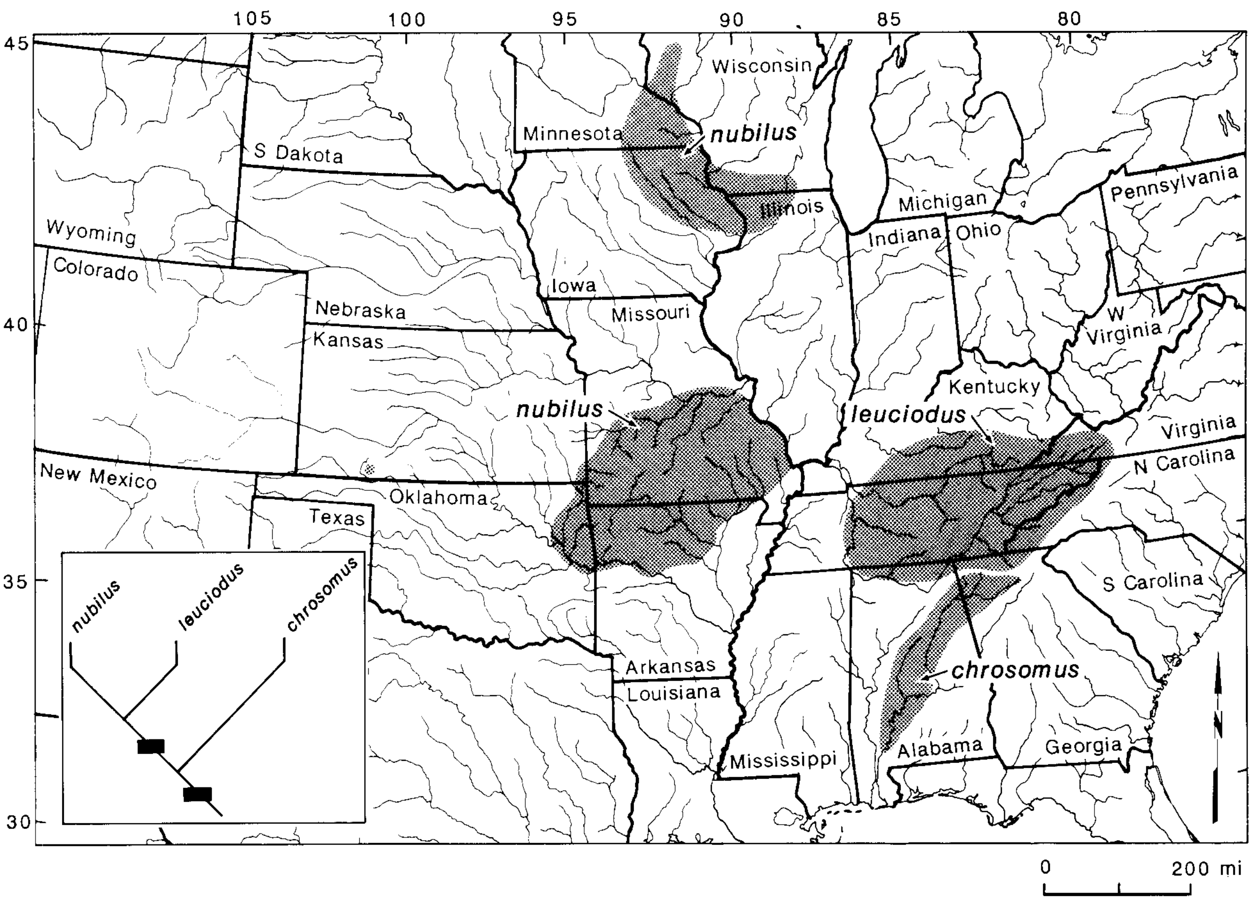

FIGURE 5—DISTRIBUTIONS AND PHYLOGENETIC RELATIONSHIPS OF SPECIES IN THE *NOTROPIS LEUCIODUS* GROUP (see Mayden, in press, for species relationships). The solid circle in southwestern Kansas represents fossil locality for *N. nubilus*.

explanation can account for all of the observed patterns; it has the potential to account for any and all patterns. However, it is not a general explanation. As mentioned earlier, the center of origin and disperal hypothesis is difficult, if not impossible, to test. Acceptance of such an explanation would result in the loss of valuable information to geologists and organismal biologists concerned with historical events occurring over a landscape of North America only partially reconstructed today. This hypothesis seems to be further unjustified in light of Pleistocene findings presented by Dort (1983). Presently no data are available to support the hypothesis that base level was lowered enough during the Pleistocene to alter the habitat characteristics of the Mississippi River near southern Illinois (see Mayden, 1985).

Interior highlands and western disjunctions

As mentioned previously and discussed by Cross (1970), disjunct populations of some species typically thought of as ozarkian are found in the Plains region west of the interior highlands in central and western Kansas and eastern Colorado. The question is, do these populations represent independent dispersal events westward into the Central Plains, or could this region have been at one time more favorable for highland fishes, such that the interior-highland fauna primarily extended farther west? Geologically we have little information from this area concerning previous environmental conditions. However, using historical biogeography, can we make predictions as to the origins of these populations?

Species of primary concern here include the minnows *Phoxinus erythrogaster, Nocomis asper, Notropis pilsbryi, N. nubilus, Hybopsis amblops,* and the darters *Etheostoma flabellare* and *E. zonale* (fig. 6). These species are common in the Ozark highlands and have disjunct populations in the Flint Hills region of central Kansas. Other taxa to be considered here include the minnows *Erimystax x-punctata* and *Notropis camurus,* the madtom *Noturus placidus,* and the darter *Etheostoma cragini* (fig. 6). These species have populations in central Kansas and some species are known from western Kansas and eastern Colorado. *Erimystax x-punctata* and *Noturus placidus* extend only up the Neosho River, but *Notropis camurus* and *E. cragini* are distributed farther west. These species differ from those listed above in that their distributions are more continuous and that recent populations exist between the central and western populations and the Ozarks, although disjunctions between the populations are common. So, we may ask if there is a general explanation for the distributions of these species in the Central Plains region.

For *Notropis camurus, Noturus placidus,* and *Erimystax x-punctata,* dispersal from the Ozarks to some western regions in recent times seems plausible. Individuals of these species can be found in the Neosho River. Thus, the river apparently is not a barrier to their movement. Dispersal to areas further west seems improbable, however, because of adverse habitats in intervening areas. For the remaining taxa, habitat restrictions preclude their long-distance dispersal within historic time. The present distributions of these species suggest a previously more widespread distribution of the taxa with later extinction. This was discussed in more detail for some species by Cross (1970).

From these data the most parsimonious explanation is that a highland environment must have extended farther west than the existing interior highlands at some time in the past, at least in the Pleistocene, if not before. Geological data are weak for reconstructing this history, but fossil data add some insight. Late Pleistocene fossils of *Notropis nubilus* are known from southwestern Kansas (Meade County), indicating that at least at this time conditions were favorable here for this species (Smith, 1963; Cross, 1970) and perhaps other highland taxa. Further supporting a more widespread highland environment are several Pleistocene fossils of a *Noturus* species in the *furiosus* group reported by Eshelman (1975), Neff (1975), Bennett (1979), and Cross et al. (1985) from Nebraska and Kansas (fig. 6). Four species are presently in this group, the closest member geographically being *N. placidus.* These fossils support a more widespread distribution of the *furiosus* group in the Pleistocene, whether or not they are eventually determined to be *N. placidus.*

Thus, based on fossil materials, distributional data, and environmental restrictions of recent populations of these species, we may predict that these species and possibly others were more widely distributed west of the interior highlands before and during the Pleistocene. In light of present-day habitat selectivity of many species, especially those of the central highlands, we may predict that this region also was highland in character. Cross (1970) reached

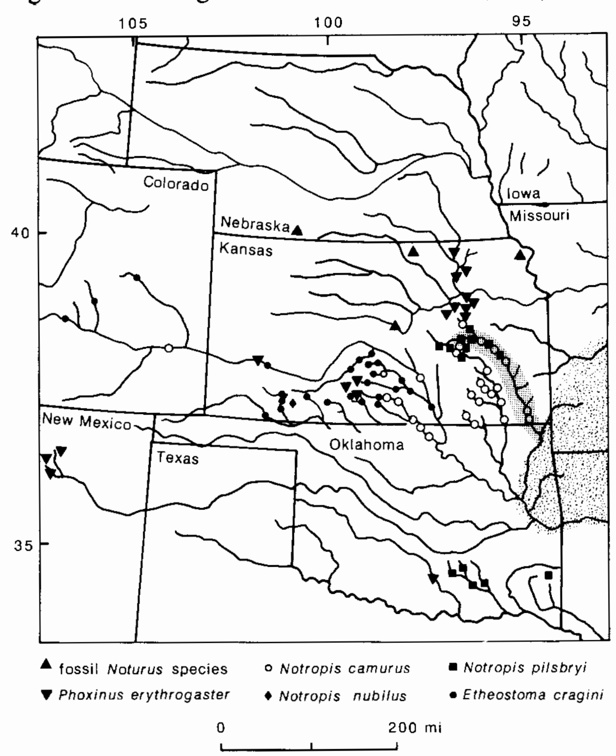

FIGURE 6—Disjunct populations of fishes with highland habitat preferences in the Central Plains region. Stippled pattern represents area of co-occurrence of Ozark species with western disjunctions. Area of Neosho River in Kansas enclosed by shaded area demarks distributions of *Noturus placidus* and *Erimystax x-punctata.*

a similar conclusion concerning some of these species, remarking that the region of the central plains must have had more water and that the streams would have been cooler. These characteristics, combined with clear streams, would probably have been acceptable to many highland fishes.

Pleistocene extinctions

Given the pattern of isolated populations of highland fishes in the Central Plains region, the differential in numbers of species present in the central-highland regions and those present in the glaciated central-lowland province, together with the hypothesis that the central highlands were once continuous with an intact fauna before the Pleistocene, speculating that extinction occurred during the Pleistocene is not unreasonable. This is not a new idea. Previous researchers have hypothesized that extinction (species and/or populations) during the Pleistocene was a real phenomenon. The magnitude of this natural process is, however, very difficult to determine.

Examination of distribution patterns and available fossil data of the Plains fishes listed above indicate extinction at least on the population level and perhaps at the species level (e.g., *Noturus* sp.) of some taxa occurring in this region during the Pleistocene and/or later (also see Cross, 1970). The same may be said for populations of highland fishes which previously inhabited areas north of the interior and eastern highlands. However, at present we have no fossil data to suggest that species extinction occurred in the central lowlands during the Pleistocene. Is this really the case? I would suggest not. Based on distributions of extant fishes and their phylogenetic relationships, it seems very likely that some species extinctions probably occurred during the Pleistocene, never to be recorded in the fossil record. As mentioned earlier, the closest relative to interior-highland fishes is an eastern-highland species, but the distribution of this taxon is variable. The species may be from any or all of the three major drainages, the Ohio, Cumberland, and Tennessee rivers. This pattern, together with species relationships, may be an indication that extinction has occurred in fish groups of this region. We may examine the evidence below.

The primary basis for the extinction statement involves the distributions and relationships of members of the *Etheostoma variatum* group relative to other species groups found in the highlands. Members of the *E. variatum* group are limited to the central highlands (fig. 7). Two species are in the interior highlands, four are in the eastern highlands, and one is endemic to the northern Atlantic slope. *Etheostoma blennius* is the sister to all members of the group and is found in the Tennessee River system. The two interior-highland species form the sister group to the three members in the Ohio River system and *E. sellare* of the east coast is most closely related to these five taxa (fig. 7). If we compare this group with other central-highland groups, we can see where extinctions may have occurred. Examples include the *Notropis zonatus-coccogenis* group of the subgenus *Luxilus* (fig. 8) and the subgenus *Ozarka* of *Etheostoma* (fig. 9). In these groups we see that the Tennessee representatives are present in all three, as well as the interior-highlands representatives. However, in the latter

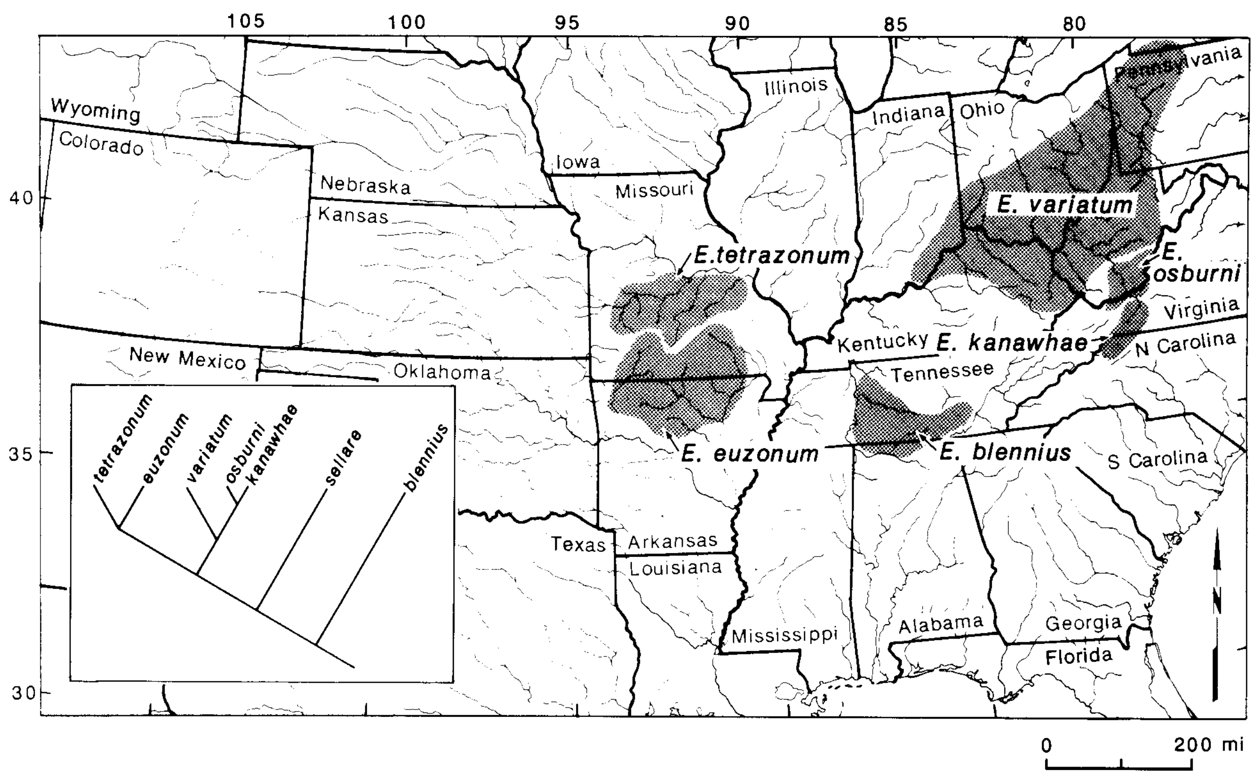

FIGURE 7—DISTRIBUTION AND RELATIONSHIPS OF SPECIES IN THE *ETHEOSTOMA VARIATUM* GROUP (see Wiley and Mayden, 1985, for species relationships). *Etheostoma sellare* of the Atlantic Coast is not included.

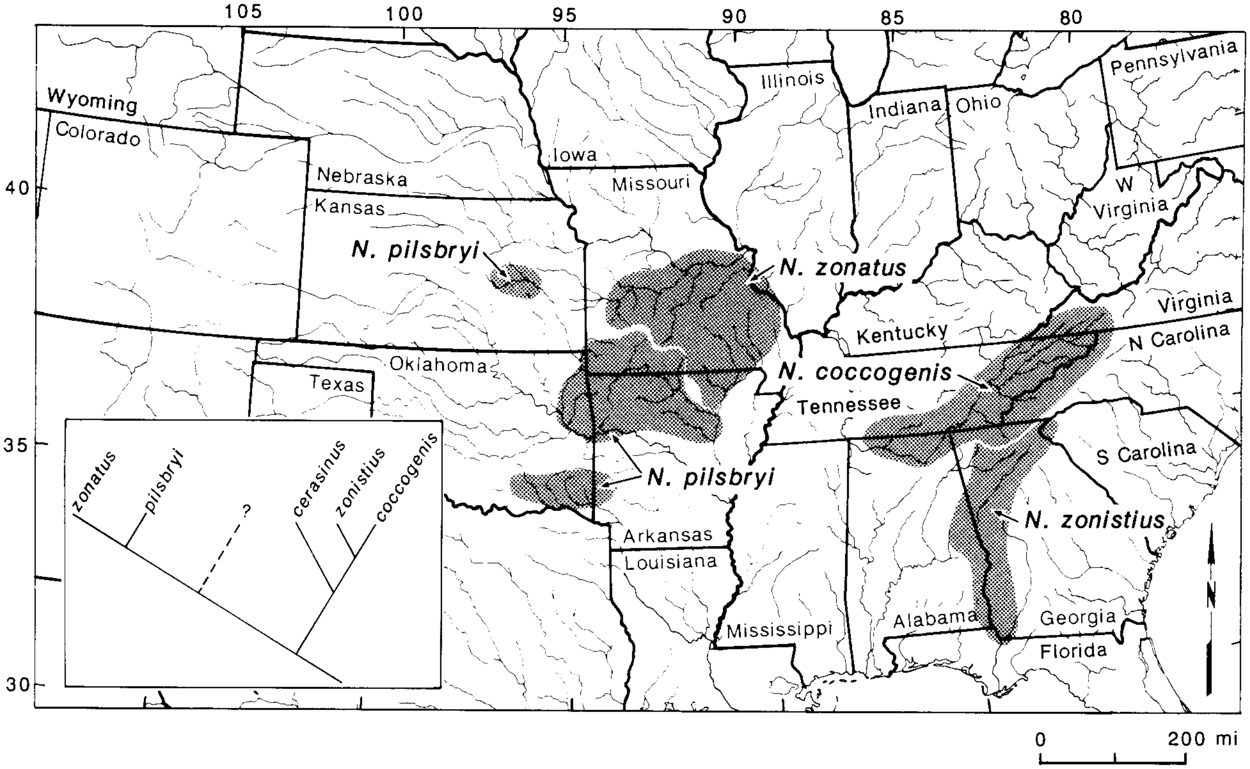

FIGURE 8—DISTRIBUTIONS AND RELATIONSHIPS OF SPECIES IN THE *NOTROPIS ZONATUS-COCCOGENIS* SPECIES GROUP (see Mayden, in press). Dashed line in phylogenetic hypothesis represents proposed extinct taxa or taxon. *Notropis cerasinus* of the Atlantic Coast is not included.

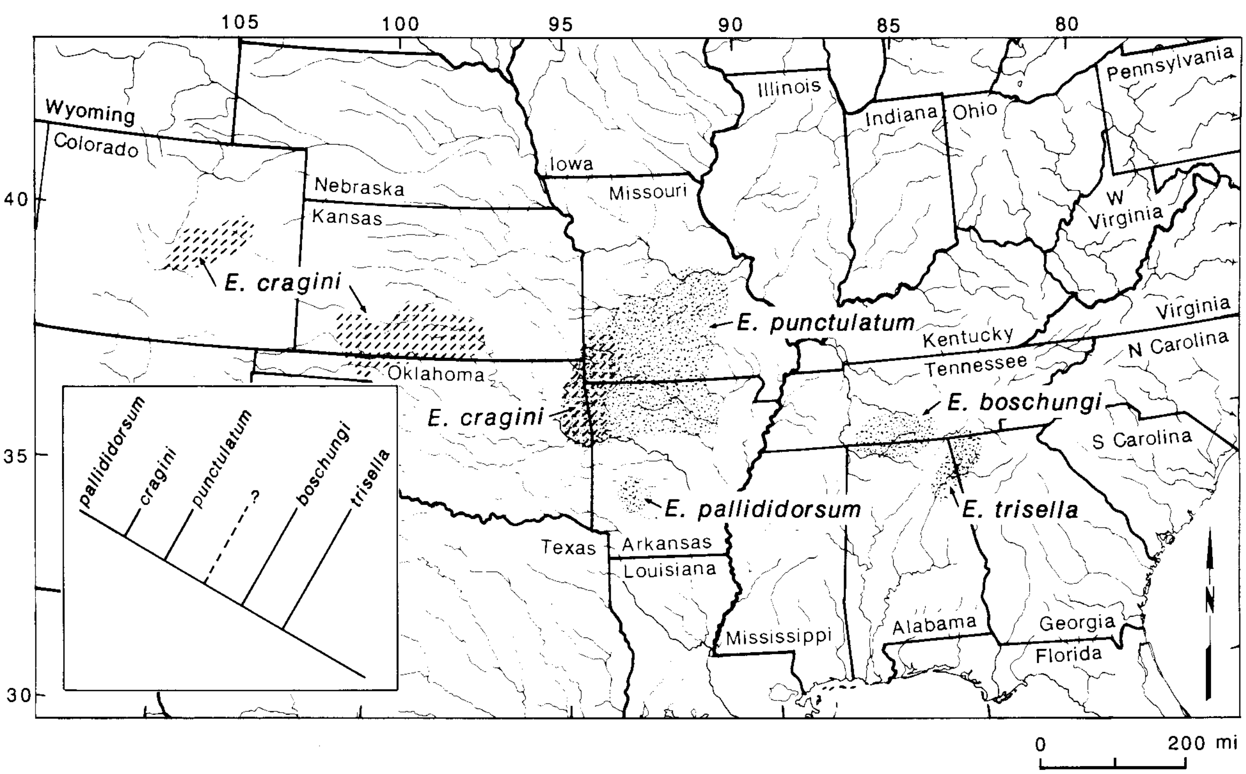

FIGURE 9—DISTRIBUTIONS AND RELATIONSHIPS OF SPECIES IN THE SUBGENUS *OZARKA* (see Mayden, in press, for species relationships). Dashed line in phylogenetic hypothesis represents proposed extinct taxa or taxon.

two groups, Ohio River and northern Atlantic-slope members are missing. One explanation is that they were never present. If so, then one would have to hypothesize long-distance dispersal between the eastern and western highland regions to explain existing relationships. However, given that we have ample data to suggest a previous widespread fauna which was subsequently altered by glaciation, these two groups suggest some degree of extinction has occurred, specifically those members of the subgenera *Luxilus* and *Ozarka* that would have been present in the upper Ohio River system. *Etheostoma sellare* and *Notropis cerasinus* illustrate fairly unique patterns for central-highland fishes, perhaps peripheral isolates (Wiley and Mayden, 1985), and can essentially be ignored for this comparison. Following Rosen's (1978) work on area cladograms of Central American fishes, the significant comparisons here are those common to both the interior and eastern highlands. If *E. variatum, E. kanawhae,* and *E. osburni* (fig. 7) were to be removed from their phylogeny, relationships in the *variatum* group would be like those of the *zonatus* group (fig. 8) and the subgenus *Ozarka* (fig. 9). Thus, with reference to the phylogenies of these groups (figs. 7–9), it is possible that other species were present between the interior-highland members and those in the Tennessee River system. This scenario also may be the case for several other species groups (see Wiley and Mayden, 1985; Mayden, in press). If true, extant taxa in the two highland regions may represent apparent rather than actual sister groups.

The frequency of missing representatives of Ozark sister species in the Ouachita highlands deserves comment. Although extinction via glaciation cannot be directly attributed to this pattern since the Ouachita highlands were never glaciated, one would predict, based on data from other groups, that more species related to Ozark taxa should be present in the Ouachita highlands. Two possible explanations seem obvious. First, the existing Ouachita sister taxa may represent independent dispersal events from the Ozarks across the Arkansas River valley and not a vicariant event. This seems rather unlikely since these two areas were once a continuous region dissected by the Arkansas River in the Pleistocene (Quinn, 1958) and the present-day Arkansas River floodplain contains unfavorable habitats for highland fishes. Alternatively, the "missing" elements represent examples of extinction due to the small size of the region, relative to the size of other highland areas. Extinction rates are known to be greater on smaller oceanic islands than on larger islands (MacArthur and Wilson, 1967). Whether the principles of island biogeography apply to these highland "islands" has yet to be demonstrated.

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Latitudinal effects in Wisconsinan mammalian faunas of the Plains

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Abstract

This paper reviews seven previously published and two new Wisconsinan mammalian local faunas from northern Texas to northern Nebraska. Dates for these faunas span the last 18,000 yrs of the Pleistocene. These faunas are analyzed for latitudinally related trends of species composition based on historic distribution of climatically significant mammalian taxa. A very clear latitudinal trend appears in the nine faunas taken as a whole and also within temporally restricted subgroupings. Composition of arvicolid and soricid faunal components is a better latitudinal indicator than is diversity of those components. Unlike Wisconsinan mammalian faunas of the southern and eastern United States, those of the Central and Northern plains consist almost entirely of steppe and boreal taxa. Boreal taxa predominate in the northern faunas.

Introduction

In 1937, Claude Hibbard published the first of many studies concerning Pleistocene vertebrate faunas of the Southern and Central plains. Many of his students have continued to contribute to this wealth of information. Hibbard's collecting of late Pleistocene vertebrates rarely extended north of Meade County, Kansas, but did include visits to Peoria loess localities in northern Kansas. At the time of the last review of Great Plains Wisconsinan vertebrate faunas (Hibbard, 1970), only two local faunas (the Robert and Jones) were known north of Texas, and none was known north of southern Kansas. The last decade has witnessed a marked increase in collecting of Wisconsinan microvertebrates in Kansas and Nebraska. A considerable amount of information has been available concerning the larger vertebrates of Wisconsinan horizons in Nebraska, but almost nothing has been published until recently concerning the microfauna (Voorhies, 1984). This brief review is intended, in part, as a summary of published and unpublished data now available on the Wisconsinan mammalian microfaunas of the Central and Northern plains. Although very informative nonmammalian microfaunas have been obtained for this region, they are beyond the scope of this work.

Graham (1976) demonstrated that a gradient is found in the diversity of both the Soricidae and Arvicolidae in the late Pleistocene faunas of the United States, with the greatest diversity in the Northeast and the least in the Southwest. Even at the time of that publication, published records of representative Wisconsinan vertebrate microfaunas north of extreme southern Kansas did not exist, and this precluded an examination of any latitudinal gradients throughout the Plains states. Recent advances in research in northern Kansas and Nebraska now permit these comparisons. Therefore, the second purpose of this report is to assess the evidence for latitudinal effects in Plains faunas and to compare these findings with Graham's conclusions (Graham, 1976) regarding the northeast-southwest gradient.

The criteria I will employ here for examining latitudinal effects on faunas are based on historic distributions of mammals, particularly insectivores and rodents. In the Great Plains, *Didelphis virginiana, Cryptotis parva,* and *Procyon lotor* are austral indicators. *Sorex cinereus* is a moderately boreal indicator. *Sorex arcticus* and *S. palustris* are much more so. *Lepus americanus* occurs at higher elevations and latitudes than do jackrabbits (*L. californicus* and *L. townsendii*). Heteromyid rodents have an austral connotation. *Perognathus fasciatus* is somewhat of an exception. *Geomys* generally occurs at lower elevations and in more southerly areas than does *Thomomys. Sigmodon hispidus* is an austral cricetid. Among arvicolid rodents, *Pedomys ochrogaster* is the most austral of the Plains taxa. Occurring at progressively higher latitudes are *Synaptomys cooperi, Microtus pennsylvanicus, Clethrionomys gapperi, Phenacomys intermedius, Synaptomys borealis, Microtus xanthognathus,* and *Dicrostonyx torquatus. Zapus hudsonius* is often cited as a boreal taxon (Hoffmann and Jones, 1970; Semken, 1984; Voorhies and Corner, 1985). Yet *Zapus princeps,* while overlapping the range of *Z. hudsonius,* has a more northerly distribution. Species today restricted to cordilleran regions are used here as montane indicators. The *Spermophilus richardsonii* complex requires special comment. Two sibling species exist today: *Spermophilus richardsonii* occupies the Northern Plains, and three subspecies of *Spermophilus elegans* occur in montane and intermontane-basin habitats in many western states. A member of this complex inhabited vast areas of the Central and Northern plains during the middle and late Pleistocene. Morphological evidence suggests that the Pleistocene population is not assignable to either species (Neuner, 1976; Neuner and Schultz, 1979) but may be ancestral to both extant species. Although the Pleistocene population cannot be deduced to have strictly the same ecological requirements of either extant taxon, its requirements were not radically dissimilar. Hall (1981) illustrates ranges for all the extant taxa referred to in this paper.

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Faunal analysis

In order to facilitate faunal comparisons, table 1 shows a compilation of the occurrences of most of the austral or boreal or montane taxa in the local faunas discussed in this section. Hibbard (1940) first reported mammalian taxa from the Jones local fauna (fig. 1, no. 3) of Meade County, Kansas, and supplemented this account with later reports (Hibbard, 1942, 1949). Davis (1975) recorded additional taxa. The only taxa from this local fauna which could be said to have boreal or montane affinities are *Sorex arcticus, S. cinereus, Thomomys* sp., *Microtus pennsylvanicus,* and a member of the *Spermophilus richardsonii* complex. Davis (1975) also deduced the presence of *Microtus* "alpha," having a dentition similar to *Microtus longicaudus* or *M. montanus. Geomys* is present in addition to *Thomomys. Pedomys ochrogaster* and one heteromyid are present. Mollusks for this horizon yielded dates of 26,700 ± 1,500 yrs B.P. (I–3461) and 29,000 ± 1,300 yrs B.P. (I–3462), placing it in the Farmdalian substage of the Wisconsinan stage.

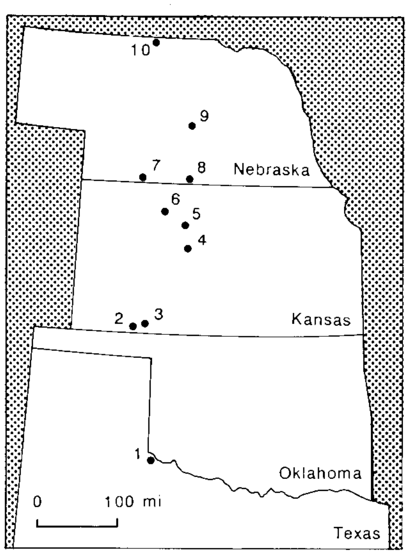

FIGURE 1—MAP SHOWING LOCATIONS OF WISCONSINAN FAUNAS DISCUSSED IN THIS WORK. The sites are 1) Howard Ranch local fauna, 2) Robert local fauna, 3) Jones and Classen local faunas, 4) Duck Creek local fauna, 5) Trapshoot local fauna, 6) Coon Creek local fauna, 7) Red Willow quarries, 8) North Cove local fauna, 9) Litchfield local fauna, and 10) Smith Falls local fauna.

Shells from the only Woodfordian site in southern Kansas, the Classen local fauna (fig. 1, no. 3) of Meade County, produced a date of 16,100 ± 250 yrs B.P. (I–4930). Davis (in press) described the vertebrate remains of that fauna. Also occurring within this county is a fauna of Twocreekan age, the Robert local fauna (fig. 1, no. 2), for which Schultz (1967) reported a date of 11,100 ± 390 yrs B.P. (SM–762). Mammalian taxa with boreal affinities include *Sorex cinereus, S. palustris, Thomomys* cf. *T. talpoides, Microtus pennsylvanicus, Synaptomys cooperi, Zapus* cf. *Z. hudsonius,* and a member of the *Spermophilus richardsonii* complex. *Geomys* also is present, although Schultz (1967) did not signify whether it is more abundant than *Thomomys.* Likewise, he did not indicate the abundance of *Pedomys ochrogaster* relative to *Microtus pennsylvanicus.* No heteromyids are known from this fauna.

Moving 197 km (118 mi) north, we next encounter the Duck Creek local fauna from Ellis County, Kansas (fig. 1, no. 4). It has been the basis of several articles (Zakrzewski and Maxfield, 1973; Kolb et al., 1975; McMullen, 1975, 1978; Holman, 1984). All these studies considered the local fauna to be of "Illinoian" age; geomorphologic and biostratigraphic evidence, however, corroborate a Woodfordian radiocarbon date of 17,700 ± 350 yrs B.P. (GX 9354), obtained from shells of *Sphaerium* cf. *S. striatinum.* Two of its arvicolid taxa never occur in Wisconsinan faunas of the Southern Plains. These are *Clethrionomys gapperi* (Zakrzewski and Maxfield, 1973) and *Synaptomys borealis* (McMullen, 1978). *Sorex arcticus, S. palustris, Microtus pennsylvanicus,* a member of the *Spermophilus richardsonii* complex, and either *Mustela ermina* or *M. nivalis* also are present. No heteromyids are present. McMullen (1978) also reported two M^2's, which he assigned to *Pedomys ochrogaster.* The presence of a four-element M^2 in a microfauna is insufficient basis for an identification of *P. ochrogaster* (Stewart, 1978). *Microtus montanus* has such an M^2 and occurs in all described Wisconsinan microfaunas north of Ellis County. In light of this fact and also the observation that arvicolid M_1's are more frequently preserved than M^2's (no *P. ochrogaster* M_1's were found), these teeth probably belong to *M. montanus.* The geomyids of this site include both *Geomys* and *Thomomys*, although the latter is markedly more numerous. This local fauna comes from fluvial sediments.

A lesser known Wisconsinan fauna, the Trapshoot local fauna, comes from the next county to the north, Rooks County (fig. 1, no. 5). In contrast to most Plains microfaunas, it lies essentially within a paleosol. The local fauna may be a correlative of the "*Citellus* zone" fauna of the basal paleosol of the Wisconsinan loess of Nebraska. Upland organisms strongly dominate the faunal list as a result of this geological context (Stewart and Rogers, 1984). In accordance with this fact, it lacks any record of aquatic mollusks, fishes, *Rana, Synaptomys,* or *Ondatra.* Another consequence is that the soricid record is very poor, represented by only a single femur. Species present here, but not known from faunas to the south, include *Zapus princeps, Perognathus fasciatus, Phenacomys intermedius,* and *Sorex nanus* (Stewart, 1978; Hoffmann and Owen, 1980). The second most common species at this site is a member of the *Spermophilus richardsonii* complex. The montane vole, *Microtus montanus,* also is well represented here. This is probably the identity of the *Microtus* "alpha" of Davis (1975) from the Jones local fauna (Stewart, 1978). *Microtus pennsylvanicus,* the most common species in the Trapshoot local fauna, outnumbers *M. montanus* by a factor of two to one. A single individual documents the presence of *Pedomys ochrogaster* in the Trapshoot local fauna. Another fauna of this age and upland character comes from central Rooks County, but it lacks any arvicolids. In both these faunas, *Thomomys* is the only known geomyid, and the only *Lepus* species are *L. californicus* and *L. townsendii.* No absolute dates are available for these faunas, but faunistic evidence indicates a Wisconsinan age. A more detailed account of this local fauna is forthcoming (Stewart, in press).

A third fauna, which continues this increasingly boreomontane trend, is the Coon Creek local fauna, 50 km (30 mi) to the west-northwest in Graham County, Kansas (fig. 1, no. 6). As in all local faunas discussed thus far, *Microtus pennsylvanicus* and a member of the *Spermophilus richardsonii* complex occur here. Also present is *Mustela nivalis.* Like the Duck Creek and Trapshoot local faunas, the Coon Creek produces *Clethrionomys gapperi.* It also shares *Phenacomys* and *Zapus princeps* with the Trapshoot local fauna. *Microtus montanus* furnishes a montane aspect and outnumbers *M. pennsylvanicus* by a factor of two to one. The yellow-cheeked vole, *Microtus xanthognathus,* here marks its southernmost occurrence in the Plains. Neither *Pedomys ochrogaster* nor heteromyids are present. Again, *Thomomys* is the only geomyid. A date obtained from *Bison* bones was 17,930 ± 550 yrs B.P. (GX 9355; Wells, 1983). The local fauna occurs in a redeposited loess. Numerous remains of *Rana, Ambystoma,* cyprinids, and catostomids indicate that this deposit represents alluvium rather than colluvium.

In extreme southern Nebraska, 88 km (53 mi) north of the Trapshoot local fauna and 87 km (52 mi) northeast of the Coon Creek local fauna, lies the recently discovered North Cove local fauna in Harlan County (fig. 1, no. 8). Taxa which continue the trend of boreal affinities include *Sorex cinereus, S. arcticus,* a member of the *Spermophilus richardsonii* complex, *Phenacomys, Clethrionomys, Synaptomys borealis, Microtus xanthognathus, Zapus princeps,* and *Mustela nivalis.* The trend is further accentuated by *Lepus americanus* and the southernmost Plains records of *Tamiasciurus hudsonius, Eutamias minimus,* and *Marmota* cf. *M. flaviventris.* An extinct marten, *Martes nobilis,* and *Microtus montanus* emphasize the montane influence on this local fauna. As in the Coon Creek and Trapshoot local faunas, *Thomomys* is the only geomyid. As in the former, *Pedomys ochrogaster* and heteromyids are absent. This is the first fauna in this survey which has arboreal taxa. Wood of *Picea glauca* provided a date of 14,700 ± 100 yrs B.P. (Beta 12286) for this site. All evidence indicates a fluvial origin for this deposit. The megafaunal component of this local fauna is rather limited but probably would be similar to the fossils recovered from the Red Willow quarries just 80–114 km (48–68 mi) upstream on the Republican River (fig. 1, no. 7). Taxa collected there include *Panthera atrox, Ovis canadensis, Symbos cavifrons, Ovibos moschatus,* and *Rangifer tarandus* (Corner, 1977). No date is available for the Red Willow quarries, but the bulk of the assemblage accords with a Wisconsinan age.

The next Wisconsinan microfauna that we encounter along our northward transect is the Litchfield local fauna of Sherman County, Nebraska (fig. 1, no. 9). This site lies 120 km (72 mi) north of the North Cove fauna. Certainly this local fauna, reported by Voorhies and Corner (1985), exhibits some of the boreal characteristics observed in the previous faunas. *Sorex cinereus,* a member of the *Spermophilus richardsonii* complex, *Microtus montanus, M. xanthognathus, Phenacomys, Clethrionomys, Thomomys,* and *Lepus americanus* occur there. If this fauna were to follow all the trends we have observed, we would expect to see no *Pedomys,* no *Geomys,* and *Synaptomys borealis* rather than *S. cooperi.* However, this is not the case. *Geomys* is five times more abundant than *Thomomys,* and *Pedomys* is more numerous than *Microtus pennsylvanicus* and *M. montanus* combined. The only bog lemming is *Synaptomys cooperi,* and *Zapus hudsonius* is the only zapodid present (personal observation). I believe that these findings may indicate that the Litchfield local fauna is either significantly older (early Wisconsinan) or later (latest Wisconsinan) than the other faunas being considered in this region, as will be detailed below. This local fauna comes from alluvium capped by loess and apparently incised into older loess.

The Smith Falls local fauna (fig. 1, no. 10), which is the northernmost local fauna in this survey, actually comprises samples from 11 sites along the Niobrara River in Cherry, Brown, and Keya Paha counties, Nebraska (Voorhies and Corner, 1985). These sites are approximately 210 km (126 mi) north-northwest of the Litchfield local fauna. Boreal or montane mammalian taxa seen in other local faunas surveyed include *Lepus americanus, Tamiasciurus, Phenacomys, Microtus montanus,* and *M. xanthognathus.* Four taxa that are, within the context of the Plains, unique to the Smith Falls local fauna include *Ochotona, Dicrostonyx torquatus, Martes americana,* and *Gulo gulo.* As in most of the more northerly faunas, *Pedomys ochrogaster* and heteromyids are absent. Conspicuous by its absence is *Microtus pennsylvanicus,* which is common in every other Plains Wisconsinan microfauna from the Texas panhandle northward. Although *Thomomys* is not the only geomyid, it outnumbers *Geomys* by a factor of four to one. This is the only Plains local fauna which has what might be termed tundra components. No radiocarbon date for this local fauna is available, but Voorhies and Corner (1985) suggested that it is somewhat older than the Litchfield local fauna. As these authors demonstrated, the fluvial sediments that produce this fauna constitute a high terrace, presumably of the Niobrara River.

Discussion

The climate during the Wisconsinan glacial stage was not static. Thus, testing for environmental gradients without regard for heterochroneity is inappropriate. The majority of the dated sites in this study are of Woodfordian age, falling within the dates of 15,000–20,000 yrs B.P. These include the Duck Creek, Coon Creek, and North Cove local faunas. The Smith Falls local fauna probably belongs to this group. The Trapshoot local fauna may be of this age or may be older. The published Meade County Wisconsinan local faunas are of Farmdalian and Twocreekan ages. Voorhies and Corner (1985) suggest that the Litchfield local fauna is younger than the Smith Falls local fauna. Some aspects of the Litchfield local fauna certainly indicate less boreal conditions than in the nearby Woodfordian faunas. Among these aspects are the high proportion of *Geomys* to *Thomomys,* the presence of *Zapus hudsonius* rather than *Z. princeps,* and an extremely high representation of *Pedomys ochrogaster.* These characteristics could accord with either a pre- or post-Woodfordian date. However, the presence of several mammalian taxa including *Microtus xanthognathus* and mollusks such as *Discus shimekii* and *Columella alticola* indicates that its age does not antedate the Woodfordian. These species could possibly persist for some time after the glacial maximum. For example, *Microtus xanthognathus* occurs as late as 11,300 yrs B.P. at the New Paris No. 4 site in Pennsylvania. However, no date for this taxon is older than 20,530 yrs B.P. in the coterminous United States.

Within the Woodfordian faunas, we see a definite correlation between increasing latitude and increasingly boreal affinities of the local faunas. With the exception of the North Cove local fauna, each has one or two arvicolid rodent taxa not seen in the local faunas to the south. All have some mammalian taxa not found in faunas to the south. Likewise, austral elements such as heteromyids and *Pedomys ochrogaster* drop out with increasing latitude. All these faunas contrast starkly with Woodfordian faunas no farther south than the Texas–Oklahoma border (Dalquest, 1965). If we assume a Twocreekan age for the Litchfield local fauna (possibly an underestimate), we may compare it to the Robert local fauna in southern Kansas. Nearly all the taxa of the Robert local fauna occur in the Litchfield local fauna. However, many additional boreal elements appear in the latter.

Graham (1976) formulated five conclusions resulting from his study of Wisconsinan microfaunas from Pennsylvania to Texas. I wish to examine each of these conclusions in relation to the faunas of the Central and Northern plains.

Graham first concluded that most late Wisconsinan mammalian local faunas were composed of more boreal and deciduous species than are the modern faunas in these areas. This is certainly not true for the area of the present study. Hoffmann and Jones (1970) noted that the Jones local fauna, in contrast with the Texas local fauna, was composed almost entirely of steppe taxa, with a few boreal taxa. The fauna of southwestern Kansas today has many more deciduous elements and almost no boreal elements. The Woodfordian local faunas of northern Kansas and Nebraska accord with the Jones local fauna in this respect. However, they have a higher percentage of boreal taxa. The relative proportions of steppe and boreal components seem to be related to latitude. In some of the northern Kansas local faunas, the boreal component becomes predominant. Not far south of the Kansas–Nebraska border, the boreal component is larger than the steppe and nondiagnostic components combined.

Graham's second conclusion was that arvicolid and soricid species diversity was greater during the late Wisconsinan, but formed a gradient as in the modern fauna. While sampling of the soricids of the Plains Wisconsinan faunas may be incomplete, no well-defined gradient in soricid diversity has been found in either the Woodfordian or Twocreekan faunas. In fact, there are as many soricid taxa (4) in the Woodfordian Howard Ranch local fauna of Hardeman County, Texas (Dalquest, 1965), as in any of the Central and Northern plains faunas. Wisconsinan diversity is as great or slightly greater than that of the modern fauna at any given site. The Twocreekan fauna seems to have a slightly greater soricid diversity than does the Woodfordian fauna. The arvicolids show a different pattern. A slight latitudinal increase in diversity occurs in the Woodfordian fauna, but we see an apparently stronger gradient in the Twocreekan fauna. In all cases, the Pleistocene diversity of arvicolids (4–7) is significantly greater than the current diversity at those sites (1–3). Clearly, the composition of soricid and arvicolid faunal components is of greater significance than the diversity of these components.

Further, Graham (1976) concluded that the soricid and arvicolid gradients in the second conclusion indicate moderated longitudinal and latitudinal gradients in temperature and moisture during the late Pleistocene. As observed above, I have not detected as much evidence of Pleistocene diversity gradients in the Plains. However, even if this were not so, how greater Pleistocene faunistic gradients translate into moderated climatic gradients is not clear. I would not, however, contest a moderated Pleistocene climate.

The fourth conclusion that Graham listed was that, although species restricted today to boreal regions were wide-ranging during the late Wisconsinan, resident species were not displaced further to the south. Certainly the Plains sites show that such taxa as *Sorex arcticus,* the *Spermophilus richardsonii* complex, *Thomomys talpoides, Microtus montanus,* and *Microtus xanthognathus* were more widespread in the Wisconsinan than they are today. However, examination of the modern faunal lists of those areas readily show that many current residents did not range as far north as they do today. Among soricids and arvicolids,

TABLE 1—Distribution of some austral and boreal taxa in nine local faunas discussed in text. Site numbers refer to same sites as in fig. 1; they also are listed in approximate order of increasing latitude.

	Taxa	Sites								
		South 1	2	3	4	5	6	8	North 9	10
	Dicrostonyx torquatus									X
	Ochotona princeps									X
	Gulo gulo									X
	Tamiasciurus hudsonicus							X		X
	Marmota flaviventris							X	?	
	Eutamias sp.							X	?	
	Lepus americanus							X	X	X
	Microtus xanthognathus						X	X	X	X
	Phenacomys intermedius					X	X	X	X	X
	Zapus princeps					X	X	X		
boreal/montane	*Synaptomys borealis*				X		X	X		
boreal/montane	*Clethrionomys gapperi*				X	X	X	X	X	
boreal/montane	*Sorex arcticus*			X	X		X	X		
boreal/montane	*Microtus montanus*			?	?	X	X	X	X	X
boreal/montane	*Sorex palustris*		X		X					
boreal/montane	*Thomomys* sp.	X	X	X	X	X	X	X	X	X
boreal/montane	*Spermophilus richardsonii* complex	?	X	X	X	X	X	X	X	X
boreal/montane	*Sorex cinereus*	X	X	X			X	X	X	
boreal/montane	*Microtus pennsylvanicus*	X	X	X	X	X	X	X	X	
boreal/montane	*Zapus hudsonius*		X						X	
boreal/montane	*Synaptomys cooperi*	X	X						X	?
austral	*Geomys* sp.	X	X	X	X				X	X
austral	*Pedomys ochrogaster*	X	X	X	?	X			X	
austral	*Cryptotis parva*	X							X	X
austral	*Perognathus* sp.	X		X					X	
austral	*Perognathus hispidus*	X							X	
austral	*Dipodomys ordii*	X								
austral	*Sigmodon hispidus*	X								
	Procyon lotor	X								
	Didelphis virginia	X								

Cryptotis parva, Pedomys ochrogaster, and in one case, *Microtus pennsylvanicus* are examples. *Didelphis, Procyon,* heteromyids, *Zapus hudsonius, Oryzomys palustris,* and *Sigmondon hispidus* are other mammalian examples of the case in point. Dozens of additional examples could be cited among the herpetofaunas.

Graham (1976) finally concluded that the modern patterns in distribution and diversity of small mammals are the result of a more continental post-glacial climate. I support this conclusion for the Wisconsinan microfaunas of the Plains.

Hibbard (1970) mentioned that today's extreme winter temperatures developed during Wisconsinan times. To say that some of the organisms then living in the Plains, today live in regions with cold winters is not a demonstration that these taxa indicate extreme winter temperatures. They may merely require moderate summer temperatures. If Hibbard were correct in his contention, then a most remarkable climatic gradient would have had to exist to accommodate *Geochelone* at that time only approximately 700 km (420 mi) to the south in Oklahoma, Texas, and New Mexico.

Conclusions

Recent discoveries in the Central and Northern plains enable us to discern definite latitudinal effects in the Wisconsinan mammalian faunas of the Plains. Arvicolid diversity generally reflects this trend, but soricid diversity does not. Composition of arvicolid and soricid faunal components are much better indicators of latitudinal effects than is diversity of those components. In contrast to Wisconsinan faunas of the south and east, those of the Central and Northern plains consist almost entirely of steppe and boreal taxa. Boreal taxa predominate in those to the north.

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Pleistocene faunal provinces and Holocene biomes of the central Great Plains

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Abstract

Pleistocene faunal provinces in North America correspond to modern biomes. These Pleistocene biomes were antecedent to but different from modern biomes. Community structure within the Ice Age biomes was more complex and niche width would have been less. The simplification of these biomes at the end of the Pleistocene may have been a major factor in the extinction at the end of the Pleistocene.

Introduction

The study of faunal provincialism is dependent on the generation of maps depicting the distribution of species comprising the fauna. Such maps are uncommon in vertebrate paleontology and very little serious work has been done on the interpretation of fossil-vertebrate distributions. Vegetational data are much more likely to be summarized, but usually for a very restricted region, and until quite recently, enormous regions lacked data. This severely handicapped studies of even Pleistocene vegetational distributions. In the west, the addition of vegetational data collected from woodrat middens of Pleistocene age (Wells, 1976; Wells and Hunziker, 1979; Van Devender and Mead, 1976) has filled in much that was missing, and recent studies in the central Great Plains have made it possible to provide a vegetational reconstruction for North America during the Wisconsinan glacial maximum. Wells (unpublished) prepared such a reconstruction and made it available to Martin and Neuner (1978) who were then able to compare the distribution of Wisconsinan mammals with the vegetational reconstruction.

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Late Pleistocene faunal provinces

Martin and Neuner (1978) recognized distinct assemblages of Pleistocene mammals that tended to co-occur with each other and found that their regions of co-occurrence corresponded very closely to mapped areas of roughly uniform vegetational types (fig. 1). These regions of co-occurring plants and animals correspond closely to the classical "biome" concept of ecologists (fig. 2). However, following standard practice in invertebrate paleontology, Martin and Neuner (1978) called these regions faunal provinces and gave them names based on characteristic animals that occurred in them. This was done in part to emphasize that they are not defined by their geographic location, but by biota, and might change size, shape, and location during geological time. Only regions south of the continental ice were included and Beringia, which was intimately connected with Siberia at that time, was not considered. The Wisconsinan flora of Beringia seems to have been in part a unique sort of grassy tundra called Steppe Tundra by Guthrie (1968). A number of animals inhabited this region that are not known to have occurred south of the continental ice sheet, including the yak *Bos (Poephagus) grunniens* and the so-called steppe antelope *Saiga tatarica.* We have since termed this the "Saiga faunal province" (Martin et al., 1985).

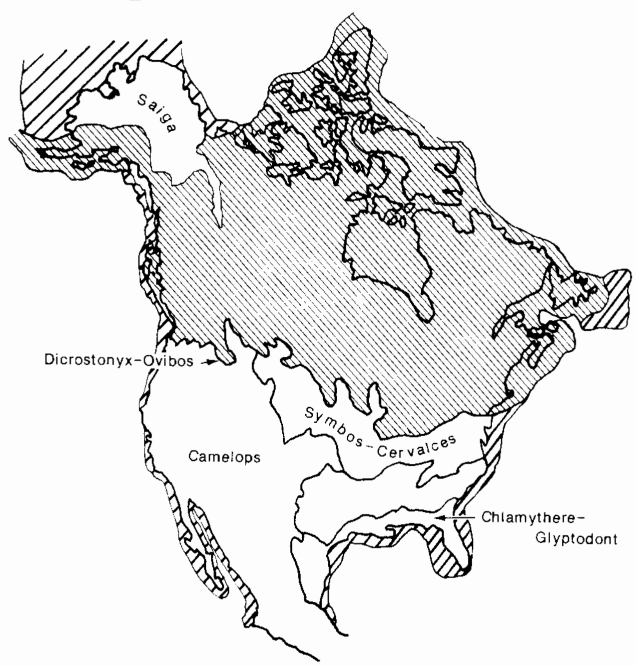

FIGURE 1—NORTH AMERICAN WISCONSINAN FAUNAL PROVINCES (based on Martin and Neuner, 1978). Narrow hatching indicates continental ice and wide hatching indicates areas of exposed continental shelf.

In parts of Beringia, as well as along the southern glacial margins and in regions of high elevations, true tundra like

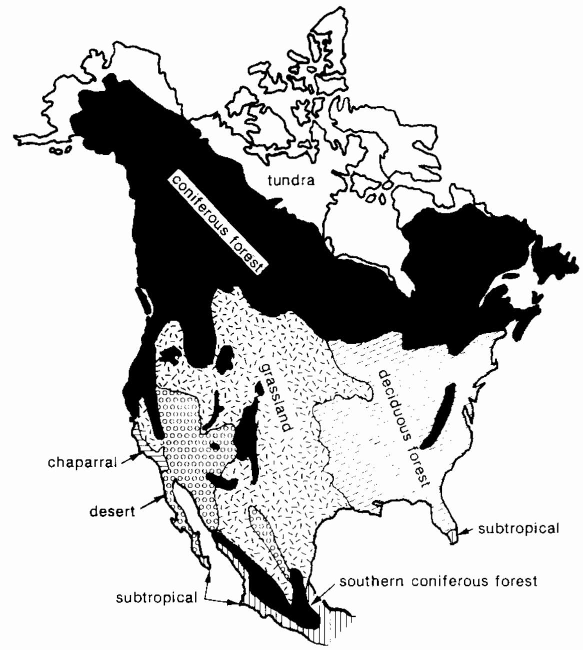

FIGURE 2—SCHEMATIC MAP OF MAJOR BIOMES IN NORTH AMERICA, based on Shelford (1963). The woodland biome of the Southwest is not represented for reasons of clarity and scale, but it occurs at intermediate elevations between grassland/desert and coniferous forest.

the modern high arctic or alpine occurred, along with the tundra muskox (*Ovibos*), caribou (*Rangifer*), and collared lemming (*Dicrostonyx*). This assemblage characterizes the Ovibos faunal province and still exists although in a very different location from its Pleistocene distribution.

South of the continental ice sheet, the tundra was bordered on the south by a boreal forest largely dominated by spruce (*Picea*). This forest contained a highly characteristic fauna including the American mastodon (*Mammut*), woodland muskox (*Bootherium*) (= *Symbos*), extinct stag-moose (*Cervalces*), and the giant beaver (*Castoroides*). The above association defines the *Symbos–Cervalces* faunal province. South of the southeastern half of this faunal province was a large region of mixed boreal and deciduous forest that in fact seems to have included the primary refugia for the taxa that now dominate the eastern deciduous woodlands. It contains an interesting fauna largely dominated by more widely ranging forms. Even though no taxa are endemic, certain ones had their principal distributions here; we term this the *Odocoileus–Pitymys* faunal province.

Farther south the region that included Florida and the Gulf Coast seems to have had a remarkably tropical aspect even during periods of glacial advance. Wells mapped this region as mostly southern deciduous woodlands (although evergreen broadleafed trees and shrubs also were present), and the associated animals are forms that now have their closest relatives in Central and South America, including glyptodonts (*Glyptotherium*), chlamytheres (*Holmesina*), capybaras (*Hydrochoerus*), and the spectacled bear (*Tremarctos*).

The lowlands of the western United States, including most of the region that is now desert and steppe, were occupied by a variety of conifer parklands. The trees that dominated these parklands varied but the structure of the vegetation (scattered stands of trees with large areas of intervening grass) may have been consistent over most of this region. This is the area where we find most of the large grazers and the large pursuit predators that hunted them, including the American camel (*Camelops*), the extinct antilocaprid (*Capromeryx*), most of the records of the imperial mammoth (*Mammuthus*), the short-faced bear (*Arctodus simus*), and the American lion (*Panthera atrox*). This fauna had grassland aspects but many of the constituent species seem to also have browsed and may have been tied to the C_3 grasses that were abundant in this region during the Pleistocene.

One thing which seems evident when we compare the reported floras from these regions with the faunas occupying them is that the individual species associations did not control the animal distributions as much as the general structure of the vegetational community. The presence or absence of large open spaces is especially important. The types of trees (conifer or deciduous) also must strongly influence the associated fauna, and even the carbon pathway used by the grasses (C_3 or C_4) affects the quality of summer and winter forage and the time of the year when it would have been desirable to have young.

The occurrence of such distinct vegetational regions during the Pleistocene resulted in diversification so that each area may be characterizied by its particular species. The most obvious example may be found among the Ovibovinae (fig. 3). The *Ovibos–Dicrostonyx* faunal province is dominated by the tundra muskox *Ovibos*, the *Symbos–Cervalces* faunal province by the forest muskox *Bootherium*, and the *Camelops* faunal province by the shrub-ox *Euceratherium*. Among the large cats of the genus *Panthera*, we find the American lion (*P. atrox*) mostly in the *Camelops* faunal province while the American jaguar *P. onca augusta* occurred mainly in the Chlamythere–Glyptodont faunal province. The American camels (*Camelops*,

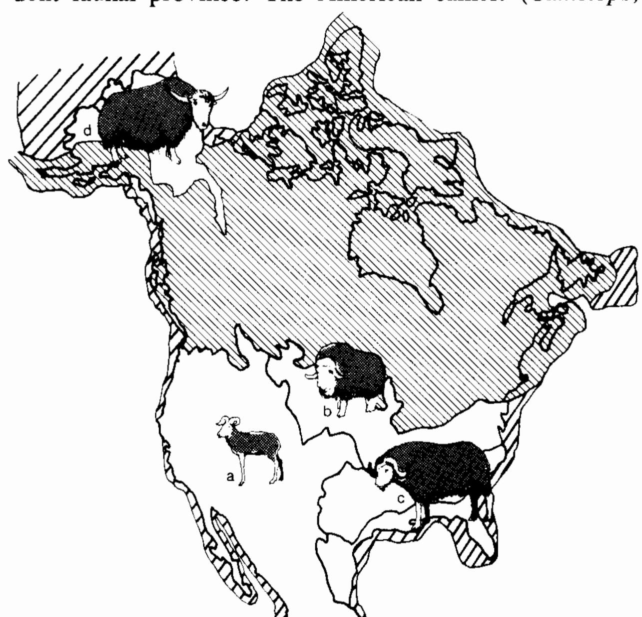

FIGURE 3—BOVIDS CHARACTERISTIC OF DIFFERENT FAUNAL PROVINCES: a) shrub-ox *Euceratherium;* b) tundra muskox *Ovibos;* c) woodland muskox *Bootherium,* (= *Symbos*); d) yak *Bos (Poephagus)*.

FIGURE 4—CAMELIDS CHARACTERISTIC OF DIFFERENT FAUNAL PROVINCES: a) American camel *Camelops;* b) stout-legged llama *Palaeolama.*

Hemiauchenia) are restricted to the *Camelops* faunal province while the llama (*Palaeolama*) is found in the Chlamythere–Glyptodon faunal province (fig. 4).

The prairie dogs (*Cynomys*) were characteristic of the *Camelops* faunal province while the giant beaver (*Castoroides*) and the capybara (*Hydrochoerus*) were characteristic of the *Symbos–Cervalces* and *Glyptodont–Chlamythere* faunal provinces respectively (fig. 5).

One of the characteristics of the modern depauperate large-mammal fauna is that many of the surviving forms actually seem to have been more wide-ranging in the Pleistocene than their extinct relatives and continued to occupy very extensive ranges in the Holocene. Examples include the bison (*Bison bison*), wapiti (*Cervsu elaphus*), and white-tailed deer (*Odocoileus virginianus*). Some, however, were (and are) more restricted; the pronghorn (*Antilocapra*) and mountain sheep (*Ovis canadensis*) to the *Camelops* faunal province and the moose (*Alces alces*) to the *Symbos–Cervalces* faunal province and its taiga-forest successor.

While the influence of regional climate may determine the overall character of any particular faunal province, the actual boundaries between faunal provinces must be controlled by local factors of microclimate, soils, and topography. These factors usually are integral parts of the local physical geography such as elevation change, major substrate change, or drainages. The geographical positions of these local factors may be geologically constant so that we might expect them also to influence the position of boundaries between past, as well as present, biomes. This seems to be the case, and many of the vegetational areas proposed by Wells share similar boundaries with major changes in modern vegetations. The very close correspondence between fossil-mammal distributions and the boundaries of the Pleistocene vegetations supports the validity of his procedure.

A very striking case occurs with the Pleistocene fauna in Kansas where the boundary between the *Camelops* faunal province and the *Symbos–Cervalces* faunal province falls along the Tatschl line proposed by Kuchler (1970; fig. 6). This line seems to mark a major division between many species and subspecies of plants and animals, and some of the speciation related to this line might possibly have involved Pleistocene biogeography.

Modern faunal provinces

As noted above, the term "faunal province" is not usually employed by biogeographers in dealing with modern biota. However, the concept of the "biome" is the modern analog. Biomes of North America have been described in great detail by Shelford (1963), and while there is some variation in usage by different authorities (cf. Kendeigh, 1961; Udvardy, 1975), there is general comparability (fig. 2). The Pleistocene faunal provinces, delineated by Martin and Neuner (1978) and employed in this paper, are far from identical with any modern biomes, yet they serve as antecedent and, in part, ancestral communities to modern biomes (fig. 1). The Saiga faunal province, with its steppe-tundra vegetation and fauna, has no modern analog, but the *Ovibos* faunal province has been succeeded by the tundra biome. Similarly, the *Symbos–Cervalces* faunal province has been succeeded by the boreal-coniferous forest, or taiga, biome. The Chlamythere–Glyptodont faunal province is represented today in North America only by relict fragments of subtropical/tropical-forest biome in southern peninsular Florida and along the coastal Mexican lowlands (fig. 2). These last three biomes now occupy areas that are far removed from the areas covered by their antecedent Pleistocene faunal provinces,

FIGURE 5—RODENTS CHARACTERISTIC OF DIFFERENT FAUNAL PROVINCES: a) prairie dog *Cynomys;* b) giant beaver *Castoroides;* capybara *Hydrochoerus.*

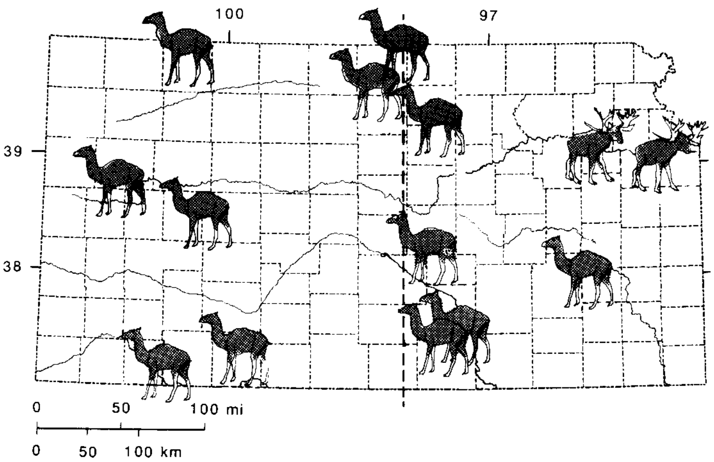

FIGURE 6—DISTRIBUTION OF WISCONSINAN CAMELS (*CAMELOPS*) AND STAG-MOOSE (*CERVALCES*) IN KANSAS. The vertical line indicates the approximate modern position of the Tatschl line.

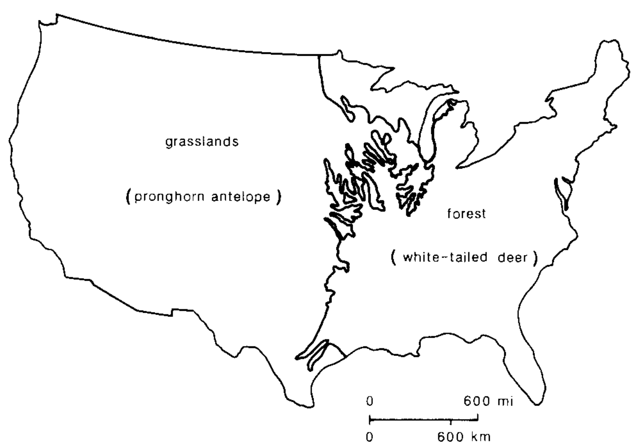

FIGURE 7—GENERALIZED DISTRIBUTION OF PRONGHORN, A GRASSLAND SPECIES, AND WHITE-TAILED DEER, A DECIDUOUS-FOREST SPECIES, RELATED TO THE DISTRIBUTION OF RIPARIAN FORESTS ACROSS THE MIDCONTINENT. Eastward dispersal of pronghorns across the upper Missouri River was possible because the riparian forest barrier thinned to the north.

the first two being more northerly now, while the last is more southerly. This is strong evidence for a marked decrease in mid-latitude climatic equability in Holocene time, compared with late Pleistocene conditions.

In contrast to this situation, the ecotone between *Symbos-Cervalces* and Chlamythere-Glyptodont faunal provinces, which we herein name as the *Odocoileus-Pitymys* faunal province, contained the principal species that now occupy the temperate deciduous-forest biome. This Holocene biome is centered on the Pleistocene ecotone and has essentially developed in situ by expansion of deciduous and evergreen broadleafed trees and emigration north and south respectively of those boreal and subtropical elements that formerly comprised the ecotone. Similarly, the *Camelops* faunal province gave rise, by segregation and differentiation of vegetational elements, not only to the Holocene woodland biome, but also to the temperate grassland and desert biomes of western North America. These too evolved basically in situ, and the modern biomes occupy the same area covered by the lowland portion of the *Camelops* faunal province.

The ecotone between *Camelops*, *Symbos-Cervalces*, and *Odocoileus-Pitymys* faunal provinces was fairly narrow and well-defined (fig. 1) The same is true of the ecotone between the grassland and deciduous-forest biomes today (fig. 2). Moreover, both ecotones are in the same position, approximately along the Tatschl line (fig. 6). This also may be seen in the geographic ranges of certain modern ungulate species that survived the Pleistocene/Holocene megafaunal extinction (fig. 7). The pronghorn (*Antilocapra americana*), which was a rare member of the *Camelops* faunal province, became a common species of the grassland and desert biomes. The mule deer (*Odocoileus hemionus*) manifests a similar Pleistocene and Holocene distribution. In contrast, the closely related white-tailed deer (*O. virginianus*) has a Pleistocene record ". . . concentrated in the central and eastern parts of the continent" (Kurten and Anderson, 1980, p. 310), though it also has been found in late Pleistocene sites in Nevada and New Mexico. Modern populations also are concentrated in the temperate-deciduous biome, but not restricted therein.

While these two species of *Odocoileus* represent sister species, their divergence is at least early Pleistocene. In contrast, certain sister taxa of small mammals possess genetic and behavioral characters that suggest much more recent divergence, perhaps as recent as the beginning of the Holocene. A recently studied example involves those populations of Plains pocket gophers usually referred to *Geomys*

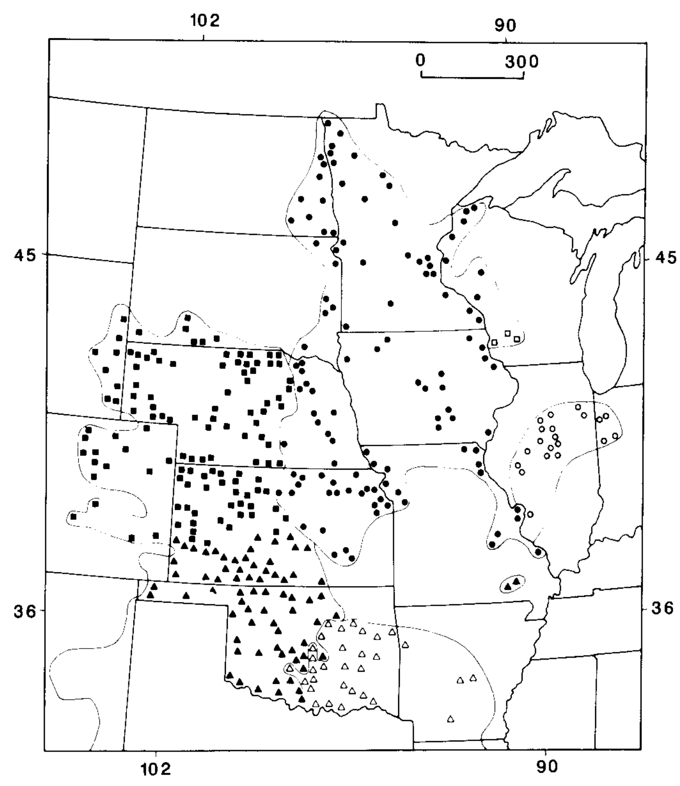

FIGURE 8—DISTRIBUTION OF *GEOMYS* IN THE CENTRAL AND NORTHERN GREAT PLAINS. Solid circles = *G. bursarius bursarius*, open circles = *G. b. illinoensis*, open squares = *G. b. wisconsinensis*, solid squares = *G. lutescens lutescens*, solid triangles = *G. l. major*, and open triangles = *G. breviceps sagittalis* (Heaney and Timm, 1983).

bursarius. Careful analysis (Heaney and Timm, 1983; Burns et al., 1985) has shown that in Kansas and Nebraska there are actually two distinct morphs, the western *lutescens* and the eastern *bursarius* (fig. 8). These two taxa show no evidence of intergradation in morphological characters except in one restricted locality in north-central Nebraska, where a narrow (2-km [1.2-mi]) contact zone occurs (fig. 9). However, here there is morphological, chromosomal, and biochemical evidence of gene flow between the two taxa. These results are open to different interpretations; Burns et al. (1985, p. 102) regard the gene flow as evidence that ". . . the two taxa should be regarded as subspecies of *G. bursarius* rather than distinct species," while Heaney and Timm (1983) hold the opposite viewpoint. Of broader biogeographic and evolutionary significance is the fact that the present boundary between these two taxa also is roughly along the Tatschl line. This suggests that this long-standing ecotonal region may be continuing to play a role in the evolutionary divergence of populations.

Several more examples may be cited. Big brown bats (*Eptesicus fuscus*) have a dark eastern subspecies *E. f. fuscus* in the temperate deciduous biome and a pale subspecies *E. f. pallidus* in the grassland biome. These two taxa are distinct physiologically as well as morphologically, because *fuscus* gives birth to two young, while *pallidus* produces only one. The nature of variation in litter size across the ecotone has not been reported. Other subspecies boundaries among grassland small mammals also show this geographic coincidence, for example in the thirteen-lined ground squirrel (*Spermophilus tridecemlineatus*) and the northern grasshopper mouse (*Onychomys leucogaster*). This is not to say, of course, that the boundaries of all species and subspecies fall within this ecotone, as a glance at any general source (e.g., Hall, 1981) will show. Nevertheless, a general concordance exists among a large number of taxon boundaries in this ecotone. If one regards well-defined subspecies as incipient species, then the Tatschl line may mark a zone of significant evolutionary divergence that has been of evolutionary importance for several million years.

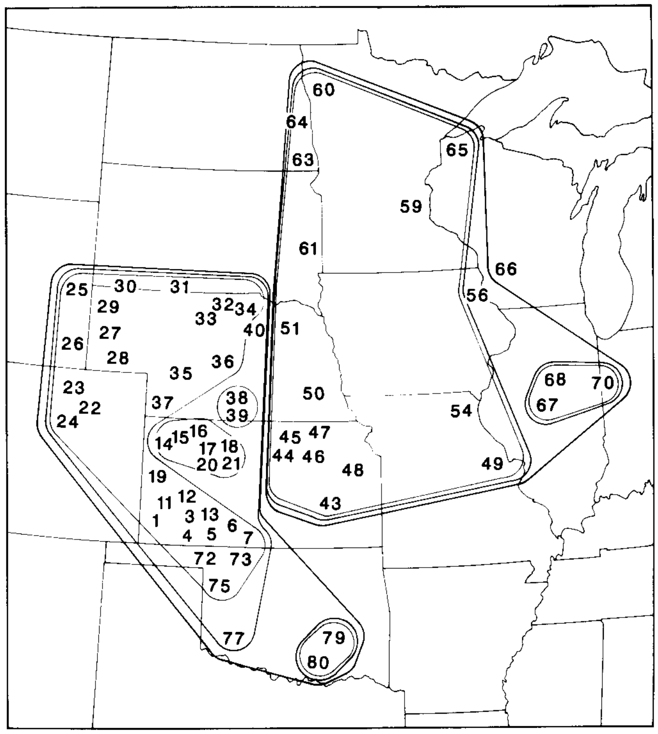

FIGURE 9—MAP OF CENTRAL AND NORTHERN GREAT PLAINS SHOWING LEVELS OF SIMILARITY OF POPULATIONS OF ADULT FEMALE *GEOMYS* BASED ON CLUSTER ANALYSIS (Heaney and Timm, 1983); scale as in fig. 8. Numbers indicate location of populations sampled.

Conclusions

The late Pleistocene faunal provinces of Martin and Neuner (1978) really correspond to Ice Age "biomes," which while analogous are not directly comparable to the Holocene biomes that replace them. The Pleistocene biomes contained a greater diversity of both plants and animals and may be thought of as being more complex, with more opportunities for coevolved systems, and probably with selection for narrower species niches. These complex biomes were maintained by climates of low seasonality (Graham and Lundelius, 1984). With the inception of higher seasonality in the Holocene, overall biotic diversity went down and the community structures simplified. This resulted in the disruption of a wide variety of adaptive relationships and finally to widespread extinction and range retraction. The new Holocene biomes were composed largely of surviving subsets of plants and animals that had previously occupied the areas of the antecedent Pleistocene biomes and to a smaller extent immigrants from other regions. The animals and plants that now dominate the Holocene biomes are often forms that had very restricted niches and seem to have been present in low densities during the Pleistocene. In many instances they may have been narrowly specialized to habitats that were limited in extent and importance during the Ice Age but became important constituents of Holocene biomes.

If we are correct in our speculation that mammal species in Pleistocene biomes usually possessed narrower ecological niches than those of Holocene biomes, then this would have permitted greater sympatry and large ranges, thus contributing to greater species richness at any one place. The causal chain may in fact be reversed, in that high species richness in an environment with low seasonality might lead to a higher level of interspecific competition, which would lead to compression of realized niche breadth.

Alternatively, intensified competition could result in allo- or parapatric distribution of species possessing limiting similarities of their fundamental niches. This would have led to geographic vicariance of similarly adapted species seen in some of the Pleistocene fauna, such as the Ovibovinae and others (see above, figs. 3–5).

With the onset of rapid climatic change at the end of the Pleistocene, species with narrow niches, which also exhibited strong competitive interactions with other sympatric species, would have been particularly vulnerable to the breakdown of existing community structure. Those species that would have had the greatest probability of surviving would be of two sorts. One class of Holocene survivors would be those generalists with broad niches which, although perhaps scarce in any particular community, nevertheless were widespread. As communities were restructured across the Pleistocene–Holocene transition, these species had sufficient adaptability, because of their niche breadth, to succeed and eventually to prosper in the new communities, often without major changes in their distribution. Deer (*Odocoileus* sp.), wapiti (*Cervus elaphus*), and bison (*Bison bison*) may be examples of this sort of survivor.

A second class of survivor species may have been those which, though characterized by narrow niches and perhaps scarcity, were "fortunate" in that they were adapted to one of the reduced suite of niches that continued to exist in Holocene communities. Examples may be the tundra muskox (*Ovibos moschatus*), caribou (*Rangifer tarandus*), and moose (*Alces alces*) among large ungulates, and the taiga vole (*Microtus xanthognathus*) or round-tailed muskrat (*Neofiber alleni*) among small rodents. Such species must have "tracked" their niches through space and time, for they are often found far from their Pleistocene range today. They also may have become more abundant in the Holocene, as some of their competitors became extinct locally or globally, but some still persist only as relict species with limited distribution and numbers.

The depauperate Holocene fauna show particular reduction of the megafaunal component. This is in large part a phenomenon of scale. The larger the species, the larger its home-range requirements and the less likely that it would be able either to adapt to (class 1) or track (class 2) habitats that met its niche requirements during the Pleistocene–Holocene transition. This would have been particularly true of those large species with narrow niches and many congeners, such as North American Pleistocene horses (*Equus*). Thus not surprisingly the probability of an *Equus* surviving the restructuring of communities during the post-Pleistocene climatic shift would have been low. Species of smaller body size, with smaller home-range needs to satisfy niche requisites, would conversely have a greater probability of adapting to, or tracking, suitable habitats.

The result is a Holocene fauna with fewer large mammals, lacking certain groups (horses, camels, proboscidians, etc.) entirely, and with most surviving species being the only representative of their genus or higher taxonomic groups, but having large distributions and usually broad niches. Medium- to small-mammal species have mostly survived the transition but often with reduced distributions; niche breadth may have remained about the same. If congeners occur, distinct patterns of geographical vicariance are often seen. These may be inferred to be 1) competitive in ultimate cause, as for example in the two species of lynx (*Lynx canadensis, L. rufus*) or wolves (*Canis lupus, C. niger*); 2) a combination of competition and specific-niche adaptation, as among the flying squirrels (*Glaucomys sabrinus, G. volans*); or finally, 3) recency of species divergence, as in the Great Plains pocket gophers (*Geomys*) discussed above (see figs. 8 and 9) or in prairie dogs (*Cynomys*) or some ground squirrels (*Spermophilus*) and chipmunks (*Tamias*), where final species separation may date only to the Wisconsinan or early Holocene (Hoffmann, 1981).

Actual boundaries of both Pleistocene and Holocene biomes seem to be largely fixed by physical parameters such as rain-shadows, elevation changes, and river drainages. The position of the environmental effects produced by parameters may be relatively constant geologically, so that in many cases the boundaries of Pleistocene and Holocene biomes closely approximate each other. In the case of the Tatschl line across the Midcontinent, which presently delineates the approximate boundary between the western grassland biome and eastern deciduous-forest biome, the critical environmental effects seem to be the amount and frequency of precipitation and the probability of fire occurrence. Warm-season precipitation derives primarily from storms moving up the Mississippi Valley from the Gulf of Mexico, whereas winter precipitation is usually from storms that are Pacific in origin and often move up across the southern cordillera. The Tatschl line may be thought of as a "tension zone," east of which precipitation is sufficient to support a variety of temperate deciduous trees and to reduce the probability of natural fire. To the west, lower precipitation is less favorable to tree growth, while increasing the probability of fire, which further inhibits woody vegetation while encouraging grasses.

During the Wisconsinan, the same physical parameters (i.e., Gulf and Pacific storm tracks) were present, and while their relative magnitudes may have been modified by differences in general atmospheric circulation under Ice Age conditions, they nonetheless formed a tension zone in approximately the same position as the Tatschl line. The greater extent of woodland and savanna then, in what is now mostly grassland and desert, may be attributable to the greater relative importance of the Pacific storm track bringing more precipitation, especially in summer, to the Southwest and the Midcontinent. Fire must still have been of some importance in maintaining these communities, however, as it is today in Holocene savannas and woodlands.

If this proposed model of the establishment of Pleistocene and Holocene biome boundaries and of the nature of the post-Pleistocene faunal transition is correct, it should be applicable to other biomes and faunas. We hope to examine some of its predictions in future studies.

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Late Quaternary palynological and paleobotanical records from the central Great Plains

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Abstract

The central Great Plains is the heart of the North American grasslands province. Using published and unpublished pollen and other botanical evidence, an outline of the late Quaternary vegetational history for the region is presented. Pre-Wisconsinan pollen records indicate that grasslands were characteristic of the central Great Plains during several interglacial or interstadial climatic episodes but were greatly reduced or even absent during glacial maxima. During the Farmdalian mid-Wisconsinan interstadial, grassland vegetation extended northward at least to the Sandhills of Nebraska, and eastward to Missouri and Iowa where it merged with open coniferous forest. At the onset of the Woodfordian (ca. 22,000 yrs B.P.), the regional vegetation rapidly changed toward greater forest cover. Spruce forest invaded as far south as northeastern Kansas and the Missouri Ozarks. To the west and south the forest was broken into a mosaic of spruce, mixed spruce-deciduous, and aspen with extensive prairie openings. Much of eastern Kansas may have been aspen forest or parkland. Few data are available for the Woodfordian vegetation of western Kansas and Nebraska and eastern Colorado. An open parkland dominated by grasses and sage, with pine and aspen confined to protected sites, is hypothesized. During the Woodfordian–Holocene transition (12,000–9,000 yrs B.P.), mixed spruce-deciduous forest may have briefly expanded, perhaps even touching the Black Hills. By 9,000 yrs B.P., grasslands had reinvaded the entire region, leaving a few disjunct arboreal populations scattered over the region. Changes in the central Great Plains Holocene climate and vegetation have proved more subtle and less discernible in the pollen record.

Introduction

Over the last five years (1980–85), 19 late Quaternary paleobotanical records in the central Great Plains have come to light (fig. 1; table 1). Much of the data, occurring as single macrofossil, charcoal, or pollen samples, has not been available in recent syntheses (Bradbury, 1980; Wright, 1981; Watts, 1983; Axelrod, 1985; Baker and Waln, 1985). Other analyses of more promising localities are yet underway. In this short review, we will present preliminary results from these unpublished localities and, in the context of previously published data, offer some hypotheses on the chronology and geography of late Quaternary vegetation. The data will be presented chronologically, from oldest to most recent, as follows: pre-Wisconsinan, early Wisconsinan (Altonian and Farmdalian), Woodfordian (late Wisconsinan), Woodfordian–Holocene transition, and Holocene.

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Interpretation of Great Plains pollen assemblages

Before the data are reviewed, several factors in the interpretation of Great Plains pollen assemblages warrant consideration. Any interpretation of pollen assemblages as vegetational reconstruction, no matter how statistically sophisticated, must be based upon appropriate analog studies of modern vegetation and pollen. In the central Great Plains, pre-Holocene climatic and historic biogeographic contexts theoretically may have resulted in the encroachment of a variety of forest or steppe vegetational associations (Axelrod, 1985). In this region, the appropriate modern analogs for fossil assemblages, if any, are not always readily apparent. Some useful studies of modern pollen and vegetation in and peripheral to the region include Potter and Rowey (1960), Potter (1967), and Hall (1985) in the Southwest; McAndrews (1966), Janssen (1966, 1967, 1984), Mott (1969), and Lichti-Federovitch and Ritchie (1968) along the boreal to eastern-deciduous forest transition; Webb and McAndrews (1976), Peterson (1978), Webb et al. (1981), and Delcourt et al. (1984) in the eastern deciduous forests to the Great Plains border; and Kapp (1965) and McAndrews and Wright (1969) in the Great Plains. Even with adequate modern vegetational and pollen data for comparison, intuitive interpretations of fossil data may be misleading (Davis, 1963; Janssen, 1970). In this paper, in which preliminary percentage data from a variety of depositional environments are being compared, much of the vegetational reconstruction is still conjecture.

Additionally, in the central Great Plains region where ideal wet depositional sites are rare, differential pollen preservation is a problem. Modern analogs are a basis for late Quaternary environmental reconstruction only where pollen deterioration has not significantly biased the information content of the fossil pollen assemblage (Delcourt and Delcourt, 1980, p. 215). In Kapp's (1965, 1970) analysis of pre-Wisconsinan Great Plains localities with poor pollen preservation, pollen assemblages were either reported as raw counts or prefaced with a warning that reported percentages were questionable. As other studies of pollen preservation have shown, Kapp's concern was well founded (Cushing, 1967; Delcourt and Delcourt, 1980; Hall, 1981). The fact that not all pollen taxa deteriorate uniformly is firmly and empirically established (Sangster and Dale, 1964; Havinga, 1967; Holloway, 1981). Differential preservation has been shown to be responsible for tremendous over representation of *Pinus* (Hall, 1985) in some situations, while elsewhere rendering *Populus* invisible (Cushing, 1967) in the pollen record. Poor pollen preservation is the limiting factor for many of the late Quaternary records reviewed in this paper.

Pre-Wisconsinan record

Over the last decade several revelations have changed the way in which pre-Wisconsinan Great Plains chronology and stratigraphy are approached. First, the Pearlette ash was recognized in fact to represent multiple ash falls spaced over more than a million years (Boellstorf, 1978). Secondly, using the deep-sea stable-oxygen-isotope record as a model, the sequence of major climatic perturbations potentially affecting the region is far more complex than the four-stadial model traditionally presumed. The pre-Wisconsinan loess and paleosol sequence documented at the Eustis ash pit, Nebraska, is believed to reflect this climatic complexity (Fredlund, Johnson, and Dort, 1985).

The primary palynological data for pre-Wisconsinan central Great Plains vegetation and climate were published prior to these changes in stratigraphic and chronological assumptions (Kapp, 1965, 1970). The chronologic and stratigraphic placement of these pre-Wisconsinan pollen records has not been reconciled with the new chronological model. Nevertheless, Kapp's research remains a landmark. Kapp's work first established that major phytogeographic shifts from forest to steppe conditions were not unique to the Wisconsinan–Holocene transition (Kapp, 1970).

Of the sites investigated by Kapp (1965, 1970), those which produced the best preserved pollen seem to represent glacial conditions with cooler temperatures, more effective precipitation, and open coniferous forest. These sites include Berends Draw and Doby Springs in northwestern Oklahoma and the Adams locality (Butler Springs sites), Meade County, Kansas (fig. 1, table 2). At both of the Oklahoma sites, *Pinus* was the most abundant pollen taxon, typically comprising about 50% of the pollen sum. *Picea* pollen also occurred consistently in significant amounts (2–10%) at these sites. The Doby Springs site also contained a small but significant number of *Pseudotsuga* pollen. Poaceae and Asteraceae types, excluding *Artemisia* and *Ambrosia,* were the most important nonarboreal pollen

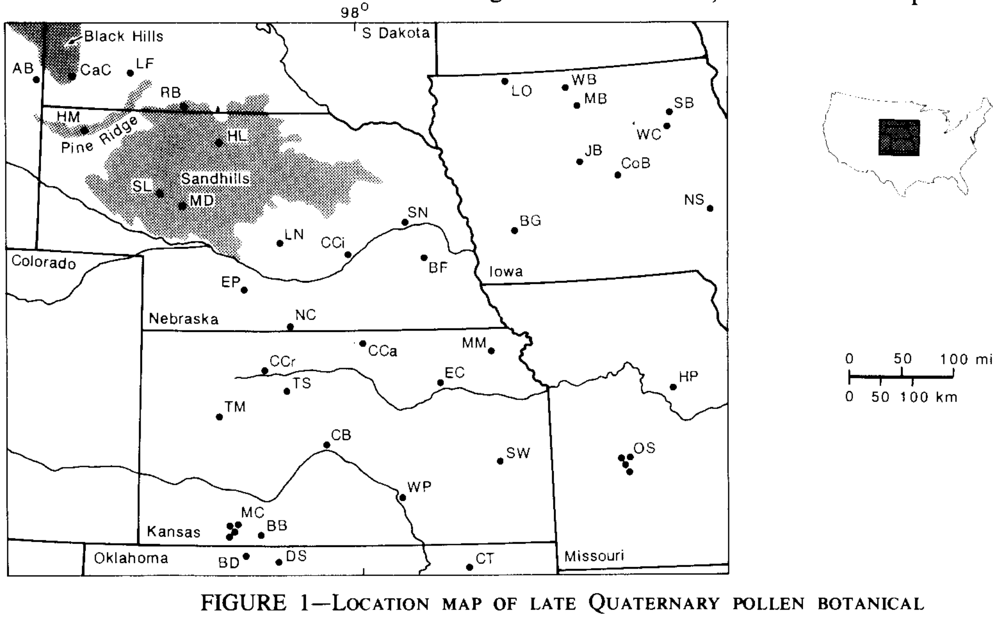

FIGURE 1—Location map of late Quaternary pollen botanical sites in the central Great Plains; letter codes of sites refer to table 1.

(NAP) taxa. Collectively, the NAP typically contributed more than 50% of these pollen assemblages. The pollen assemblages from the Adams locality differed slightly. At this site *Artemisia* pollen was consistently more common (ca. 20%), while *Pinus* percentages were lower (ca. 30%). At this site, like the others, *Pinus* and *Picea* pollen frequencies seem to indicate regional presence of these taxa. Based on the occurrence of *Pseudotsuga* at the Doby site and the geographical context of the sites, Kapp (1965, 1970) hypothesized that open, western needle-leaf forest extended into the southern High Plains during Illinoian time.

The interpretation of pollen from sites believed to be Sangamon in age (Cragin quarry, Hart Draw, and Mount Scott localities, Meade County, Kansas) is somewhat hampered by poor preservation (Kapp, 1965, 1970). At Hart Draw where preservation was best, Kapp reported high NAP (greater than 70%) and low *Pinus* (less than 15%). He noted that the primary difference between these fossil assemblages and modern grassland assemblages is that Chenopodiaceae/Amaranthaceae pollen is significantly lower in the fossil record. The signal from other "Sangamon" samples is less consistent. It was found that as pollen preservation and abundance decreased, *Pinus* percentages tended to increase, reaching over 90% in some Mount Scott and Cragin quarry samples. Kapp (1970, p. 153) attributed this to differential pollen degradation and easy recognition of the distinctive bisacate *Pinus* morphology (cf. Hall, 1981, 1985). Where pollen was well preserved, Kapp's analysis clearly indicates a "Sangamon" grassland steppe.

An additional pre-Wisconsinan record comes from the Bartek Brothers farm locality in eastern Nebraska (Fredlund et al., n.d.), where fossil-bearing sedge-peat beds lie above a weathered till and below multiple loesses, paleosols, and alluvial deposits. The pollen assemblages from this peat are dominated by NAP taxa (greater than 70%), with Poaceae, *Petalostemum, Ambrosia,* and other Asteraceae types being among the most significant. *Quercus* and an assortment of other deciduous taxa dominate the AP assemblage, while *Pinus* and *Picea* occur relatively infrequently. This mid-Pleistocene pollen record is interpreted as an open grassland similar to that of the eastern Great Plains today.

Early Wisconsinan record

Sparse but consistent evidence indicates that the Altonian, Farmdalian, and Woodfordian substages of the Wisconsinan were accompanied by major climatic and biogeographical shifts in the central Great Plains. Recently Baker and Waln (1985) used pollen and paleontological data to argue for mid-Wisconsinan (Farmdalian) grasslands in the region. Outside the Central Plains, in south-central Illinois (Grueger 1972a, 1972b), and in the Southeast (Delcourt, 1980), parallel palynological evidence for climatic substages of the Wisconsinan exists. The few previously unreported records offered here support this hypothesis.

The only Great Plains record spanning all three of these substages comes from the Llano Estacado to the south of our area of focus (Hafsten, 1961, 1964; Oldfield and Schoenwetter, 1975). The earliest Wisconsinan (Terry Pluvial or pre-Tahoka) records from this area indicate that open pine and spruce forest characterized the southern High Plains during much of this period. From about 33,500 to 22,500 yrs B.P., open *Artemisia* steppe replaced these forests. During the late Wisconsinan (Tahoka Pluvial), pine and spruce forest again became the dominant regional vegetation. The exact physiognomy of these southern High Plains Wisconsinan forests—whether savannas, parklands, woodlands, or full forests—is not clear (Bryant and Holloway, 1985).

A very similar early Wisconsinan (Altonian?) record comes from the Jinglebob site, Meade County, Kansas (Kapp, 1970). High percentages (ca. 50%) of *Pinus* pollen indicate that pine was at least regionally present. Also reported are a variety of eastern deciduous-tree pollen taxa in trace amounts (Hibbard, 1955, 1970; Kapp, 1965, 1970). The age of this locality is based solely on stratigraphy and vertebrate fossils.

Farmdalian record

From McPherson County in the Sandhills of Nebraska, a diatomaceous-peat sample recovered from a depth of approximately 200 ft (60 m) below the modern surface of an interdunal site has been radiocarbon dated to 32,130 ± 1,280/1,520 yrs B.P. (James Swinehart, Conservation and Survey Division, Nebraska, personal communication, 1986). A pollen analysis of this peat by Linda Shane of Limnological Research Center, University of Minnesota, indicates a grassland (H.E. Wright, personal communication, 1986). NAP contributed 88% of the nonaquatic pollen sum in this sample. Poaceae, *Artemisia,* and Cheno-Ams were the dominant pollen taxa. *Pinus* and *Picea* pollen comprised only about 7%, indicating a distant source. This is at present the only radiometrically dated early Farmdalian pollen assemblage from the region.

Rogers (*in* Voorhies and Corner, 1985) offers a preliminary pollen assemblage from the Litchfield vertebrate faunal site of central Nebraska. Although poor pollen preservation prevented reliable quantitative interpretation, the presence of *Ambrosia,* Poaceae, *Pinus,* and three other AP taxa were noted. Absent are *Picea* or other boreal indicators expected in later, Woodfordian sites. The absolute age of this site is yet to be determined. Voorhies and Corner (1985), noting a diversity of reptiles and amphibians and relatively few individuals of boreal-indicative small mammals, suggested an environment less severe than the Woodfordian full-glacial. Certainly Rogers's pollen work supports this. We hypothesize here that the Lichfield site may date either to the Farmdalian or Farmdalian–Woodfordian transition.

The best indications that the middle Wisconsinan climate and vegetation were significantly different from the Woodfordian comes from records which span the Farmdalian–Woodfordian boundary (24,000 to 21,000 yrs B.P.). The Ozark Springs records (Mehringer et al., 1970; King, 1973) indicate that jack-pine (*Pinus banksiana*) parkland or

TABLE 1—KEY TO MAP OF LATE QUATERNARY BOTANICAL/POLLEN SITES IN THE CENTRAL GREAT PLAINS.

Map Symbol	Site name and state	Depositional Environment	Time range	Oldest and youngest C^{14} dates in yrs B.P. and material dated	Reference
AB	Agate basin, WY	alluvial/paleosol	early Holocene	11,450 ± 110, 10,430 ± 670, charcoal	Beiswenger, 1982
BB	Big basin/Little basin, KS	karst sink, colluvium	late Holocene	535 ± 130, organic sediments	Shumard, 1974
BD	Berends Draw, OK	karst sink, lacustrine	pre-Wisconsinan		Kapp, 1965, 1970
BF	Barteck farm, NB	prairie fen	pre-Wisconsinan		Fredlund et al., in press
BG	Brayton gravel pit, IA	alluvial	Woodfordian	12,420 ± 420, wood and plant fragments	Baker et al., 1980
CB	Cheyenne Bottoms, KS	lacustrine/marsh	Wisconsinan?		Fredlund, unpublished field notes
CaC	Capes' Cave, SD	alluvial	late Holocene	230 ± 160, modern charcoal	Fredlund, Weston, and Mandel, 1985
CCa	Courtland canal, KS	loess/colluvial	Woodfordian	14,450 ± 140, charcoal	Wells and Stewart, this vol.
CCi	Central City, NB	loess/colluvial	Woodfordian	19,640 ± 230/240, charcoal	Martin, p.c., 1986
CCr	Coon Creek, KS	colluvial/loess?	Woodfordian	17,930 ± 550 bone collagen	Wells, 1983
CoB	Colo bog, IA	bog	Woodfordian, Holocene	13,775 ± 300, 3,100 ± 300, peat	Brush, 1967
CT	Cross Timbers, OK	rock shelters, alluvial/colluvial	late Holocene	1,980 ± 75, 70 ± 55, charcoal, organics	Hall, 1982
DS	Doby Springs, OK	karst/springs	pre-Wisconsinan		Kapp, 1965, 1970
EC	Elbow Creek, KS	alluvial/paleosol	late Holocene	1,580 ± 70, charcoal	Kurmann, 1985
EP	Eustis pit, NB	loess/paleosol	pre-Wisconsinan to Holocene		Fredlund, Johnson, and Dort, 1985
HL	Hackberry Lake, NB	interdunal lake	Holocene	5,040 ± 95, 1,110 ± 75 gyttja	Sears, 1961
HM	Hudson–Meng, NB	colluvial	early Holocene	9,820 ± 160, 8,990 ± 190, charcoal and bone	Agenbroad, 1978
HP	Hinkson–Perche, MO	pond/alluvial	late Woodfordian	12,430 ± 80, wood	Schmits, 1985
JB	Jewell bog, IA	bog	Woodfordian, Holocene	10,640 ± 270, 9,570 ± 180 peat	Brush, 1967
LF	Lange–Ferguson, SD	marsh/colluvial	late Woodfordian, early Holocene	10,730 ± 530, bone collagen	Fredlund, 1985
LN	Litchfield, NB	alluvium	Farmdalian (?)		Rogers, *in* Voorhies and Corner, 1985
LO	Lake Okoboji, IA	lacustrine	Woodfordian, historic	13,990 ± 135, 390 ± 55, gyttja	Van Zant, 1979
MB	McCulloch bog, IA	bog	Woodfordian, Holocene	14,500 ± 340, 3,170 ± 190, peat	Brush, 1967
MC	Meade County, KS (Adams Spring, Cragin Quarry, Hart Draw, Mount Scott, Jinglebob)	karst sinks, springs/alluvium	pre-Wisconsinan except Jinglebob Altonian (?)		Hibbard, 1970; Kapp, 1965, 1970
MM	Muscotah Marsh, Arrington Marsh, KS	bogs/marshes and alluvial	Farmdalian, Holocene	24,500 ± 800, 5,100 ± 250, wood, peat	Grueger, 1973
MD	McPherson Co. Drill Hole, NB	lake?	Farmdalian	32,130 ± 280/1,520, diatomaceous peat	Swehart; p.c., 1986; Wright, p.c., 1986
NC	North Cove, NB	spring deposits	Woodfordian	14,770 ± 100, wood	Johnson et al., 1986
NS	Nichols Silt, IA	alluvial	late Woodfordian	11,800 ± 200, wood	Baker et al., 1980
OS	Ozark Springs, MO (Boney Spring, Jones Spring, Kirby Spring, Koch Spring, Trolinger Spring)	springs on alluvial terrace	Farmdalian, Woodfordian, some late Holocene	39,020 ± 2,600, 1,900 ± 80, wood, peat, charcoal	Mehringer et al., 1970; King, 1973
RB	Rosebud site, SD	interdunal marsh, alluvium	Woodfordian, Holocene	12,630 ± 160, 12,580 ± 160, peat, plant fragments	Watts and Wright, 1966
SB	Sumner bog, IA	bog	early Holocene	9,270 ± 90, 5,520 ± 70, peat	Baker et al., 1980
SL	Swan Lake, NB	interdunal lake	early Holocene to present	8,950 ± 160, 3,680 ± 70, gyttja	Wright et al., 1985

(table 1 continued)

Map Symbol	Site name and state	Depositional Environment	Time range	Oldest and youngest C^{14} dates in yrs B.P. and material dated	Reference
SN	Schuyler, NB	loess, colluvial	Woodfordian (?)		Wayne, p.c., 1984
SW	Sanders's well, KS	spring-fed bog	Farmdalian, Woodfordian	23,740 ± 340/350, 12,820 ± 220, muck	Fredlund and Johnson, 1985; Fredlund and Jaumann, 1986
TM	12 Mile Creek, KS	alluvium	early Holocene	10,435 ± 260, 10,245 ± 335, bone apatite, collage	Rogers and Martin, 1984
TS	Trapshoot site, KS	loess/paleosol	Woodfordian (?)		Stewart and Rogers, 1984
WB	Woden bog, IA	bog	late Woodfordian, Holocene	11,570 ± 330, 2,830 ± (?), gyttja	Durkee, 1971
WC	Wapsipinicon cutbank, IA	bog	Farmdalian, early Woodfordian	34,500 ± 2,000/2,760, 20,850 ± 450, peat	Mundt and Baker, 1979
WP	Wichita peat, KS	bog(?)/alluvial	Woodfordian	19,340 ± 200/210, peat	Rogers and Martin, 1985; Jaumann et al., 1985

savanna was overrun by spruce (*Picea glauca*) forest during this climatic shift. Farmdalian–Woodfordian transitional pollen records from east-central Iowa show a similar shift from jack-pine with spruce to spruce forests (Mundt and Baker, 1979; Hallberg et al., 1980; Van Zant et al., 1980).

At the Muscotah and Arrington marshes in northeastern Kansas, this transition is not as well documented (Grueger, 1973). Below the 24,500-yrs-B.P. radiocarbon-dated level at Arrington, NAP, especially Poaceae and Asteraceae types, increases significantly while *Picea* decreases to 30%. At Muscotah, *Picea* percentages drop substantially below the 23,000-yrs-B.P. radiocarbon-dated level. Most enlightening is the pollen assemblage recovered from organic-rich sands below those reported on the Muscotah diagram (Grueger, personal communication, 1986). This assemblage believed to represent Farmdalian conditions has an AP:NAP ratio of aproximately 50:50. In this sample, *Picea* was almost absent, but the percentage of *Quercus* was significantly higher than in full-glacial samples. Because this pollen assemblage came from sands, rather than peat, the age and affinity were uncertain. Current investigations at Sanders's well (discussed below) support the interpretation of this as a Farmdalian assemblage. The Muscotah Farmdalian assemblage is hypothesized to represent a mosaic of deciduous forest and prairies in northeastern Kansas.

One of the most significant Wisconsinan sites now under investigation is Sanders's well, Coffey County, Kansas. As at Muscotah, the Farmdalian record (radiocarbon-dated at 23,740 yrs B.P.) indicates a mosaic of prairie and oak-hickory forest. NAP characteristic of prairie (Poaceae, *Ambrosia*, and other Asteraceae types) comprises more than 70% of the pollen sum exclusive of local, wet-site taxa. *Quercus*, *Carya*, *Ulmus*, and *Populus* are the most abundant AP taxa in the Farmdalian zone of the Sanders's well record. The overlying Woodfordian pollen zone indicates that an aspen parkland replaced the Farmdalian grassland at this site. This pollen record is presented more fully in the Woodfordian discussion below.

These few Farmdalian pollen records are further supported by the geomorphological, paleosol, and phytolith record from the Eustis ash pit in south-central Nebraska (Fredlund, Johnson, and Dort, 1985). In this loess record is a mid-Wisconsinan period during which eolian deposition slowed or halted (cf. Frye et al., 1968; Ruhe, 1983). In central Nebraska, this zone, the Gilman Canyon Formation (Dreeszen, 1970), is a minor Farmdalian paleosol development in early Wisconsinan loess. Opal phytolith assemblages from this Farmdalian paleosol contain tremendous quantities of panicoid forms suggesting an abundance of moist, temperate-adapted tall grasses.

Woodfordian record

Several newly discovered sites with Woodfordian macrofossil and pollen evidence have caused us to modify our working hypothesis of regional vegetation during this period (Fredlund and Jaumann, 1986). Prior to our investigations at these sites we assumed that white-spruce (*Picea glauca*) forest characterized the late-Wisconsinan vegetation in the central Great Plains. Certainly, Muscotah and Arrington marshes (Grueger, 1973), the Ozark Springs sites (Mehringer et al., 1970; King, 1973), and numerous sites in Iowa (Brush, 1967; Baker et al., 1980) indicated that spruce-dominated coniferous forests were the rule to the north and east of the region during the last glacial maximum (figs. 1 and 2). Also well documented is that the range of white spruce during this time extended as far south as northern Louisiana and possibly Texas (Delcourt and Delcourt, 1985; Holloway and Bryant, 1984; Bryant and Holloway, 1985) and as far west as the Nebraska Sandhills, if not farther (Watts and Wright, 1966). Therefore with some surprise and consternation we discovered two Woodfordian sites in eastern Kansas in which *Picea* pollen frequencies were much lower than anticipated.

One of these sites is in the Arkansas River floodplain near Wichita, Kansas. Bones of Pleistocene fauna (Rogers and Martin, 1985), spruce wood, and balls of woody peat containing *Picea glauca* needles, twigs, cone fragments, and other macro- and microfossils are being recovered from a depth of more than 30 ft (9 m) below the surface. One of these spruce-bearing peat samples has yielded a

TABLE 2—IDENTIFIED POLLEN TAXA AND POSSIBLE REPRESENTATIVE MODERN SPECIES AND THEIR COMMON NAMES.

Pollen taxa	Representative species	Common name
	AP (trees and large woody shrubs)	
Picea	*P. glauca* (Moench.) Voss.	white spruce
	P. mariana (Mill.) BSP.	black spruce
Abies	*A. balsamea* (L.) Mill.	balsam fir
Larix	*L. laricina* (DuRoi) K. Koch	tamarack
Pinus	*P. ponderosa* Laws	ponderosa pine
	P. flexilis James	limber pine
	P. banksiana Lamb	jack pine
Juniperus	*J. virginiana* L.	red cedar
	J. communis L.	common juniper
	J. horizontalis Moench.	creeping juniper
Populus	*P. tremuloides* Michx.	quaking aspen
	P. balsamifera L.	balsam poplar
	P. deltoides Marsh	cottonwood
Salix	*S. discolor* Muhl.	pussy-willow
	S. candida Fluegge	sage-leaf willow
	S. interior Rowlee	sand-bar willow
Betula	*B. papyrifera* Marsh	paper birch
	B. glandulosa Michx.	swamp birch
	B. nigra L.	river birch
Corylus	*C. cornuta* Marsh	beaker hazelnut
	C. americana Walt.	hazelnut
Alnus	*A. rugosa* (DuRoi) Spreng	speckled alder
	A. serrulata (Ait.) Willd.	smooth alder
Myrica	*M. gale* L.	sweet gale
	M. cerifera L.	wax-myrtle
Quercus	*Q. macrocarpa* Michx.	bur oak
	Q. alba L.	white oak
Juglans	*J. cinerea* L.	butternut
	J. nigra L.	black walnut
Fraxinus	*F. nigra* Marsh	black ash
	F. pennsylvanica Marsh	green ash
Acer	*A. saccharinum* L.	silver maple
	A. saccharum Marsh	sugar maple
	A. negundo L.	boxelder
Ostrya/Carpinus	*O. virginiana* (Mill.) Koch.	ironwood
	C. caroliniana Walt.	hornbeam
Ulmus	*U. rubra* Muhl.	slippery elm
	U. americana L.	american elm
	U. thomasi Sarg.	rock elm
Carya	*C. tomentosa* (Poir.) Nutt	mockernut
	C. glabra (Mill.) Sweet	pignut hickory
Rhus	*R. glabra* L.	smooth sumac
	R. radicans L.	poison oak
Cornus	*C. drummondii* C. A. Mey	rough-leaved
	C. racemosa Lam.	dogwood
Shepherdia	*S. canadensis* (L.) Nutt.	buffalo berry
Elaeagnus	*E. commutata* Bernh.	silver berry
Sambucus	*S. canadensis* L.	common elder
	NAP (nonarboreal pollen)	
Ambrosia	*A. trifida* L.	giant ragweed
	A. tomentosa Nutt.	bursage
Artemisia	*A. filifolia* Torr.	sand sagebrush
	A. tridentata Nutt.	big sagebrush
Iva	*I. xanthifolia* Nutt.	marsh elder
Helianthus	*H. annuus* L.	sunflower
Asteraceae	(other members of the aster family)	asters, goldenrod, thistle, groundsel
Poaceae	(the grass family)	grass
Cheno/Am	(the Chenopodiaceae and Amaranthaceae families)	goosefoot, lamb's quarters, amaranth
Petalostemum	*Dalea purpurea* Vent.	prairie clover

radiocarbon date of 19,340±200/210 yrs B.P. Although the stratigraphy of this site is not yet fully known, we believe these Pleistocene materials to be of local origin. Pollen of aquatic plants indicating open, still-water deposition is common in the peat samples. Although alluvial transport and mixing in this floodplain depositional environment remain a possibility, we argue that the pollen and macrofossils contained in the peat samples accurately reflect the local and regional Woodfordian vegetation of the site.

Characteristic pollen assemblages of the Wichita Woodfordian peat are high in AP (fig. 2). Although *Picea* is the most common AP taxa in this peat, its relative frequency (35%) is far less than that found at the Ozark Springs or Muscotah Marsh localities during the approximate same time. *Pinus* percentages seem to indicate a limited presence of the taxon. A diversity of deciduous AP taxa is also identified, including *Populus, Quercus, Salix, Ostrya/Carpinus, Fraxinus, Alnus, Acer, Betula, Corylus, Ulmus, Carya,* and *Cornus*. The frequency of occurrence for any one of these taxa seems relatively inconsequential; however, taken together they represent a significant constituent of the fossil-pollen assemblage. We interpret this arboreal-dominated pollen spectrum as a mixed, coniferous-deciduous forest in the mesic Arkansas River valley. The substantial NAP portion of the Wichita pollen record, principally Poaceae, *Ambrosia, Artemisia, Iva,* and *Petalostemum,* gives the record an open-forested aspect.

During the 1936 excavation of a well in a small, upland, spring-fed bog, Mr. Albert Sanders unearthed the partial remains of a mammoth. Recent reinvestigation of this site, positioned along a first-order tributary above the Neosho River, Coffey County, Kansas, documents a 2.6-m (8.6-ft)-thick organic-rich layer of muck underlain by sands. The late Pleistocene portion of this section lies below an apparent erosional unconformity 1.6 m (5.3 ft) below the surface. Two radiocarbon dates, 12,820 ± 220 and 23,740 ± 330/350 yrs B.P., bracket this 1-m (3-ft) portion of the section.

Pollen preservation in these muck deposits is exceptional. Estimates of pollen concentration are typically 200,000 to 400,000 grains per cm^3. Changes in relative frequencies of pollen taxa reflect good zonation within the Wisconsinan portions of the section. The lowest pollen zone, representative of Farmdalian conditions, has been discussed above. Like the Farmdalian zone, the Woodfordian zone is dominated by NAP. The most important of these NAP taxa are Poaceae (22%), *Ambrosia* (26%), and a variety of other Asteraceae types (14%). Both Cheno-Am types and *Artemisia* are relatively rare in these sediments. *Quercus* (8%) and *Populus* cf. *tremuloides* (7%) are among the most common AP taxa. *Pinus* and *Picea* occur relatively less frequently (each less than 5%) and indicate distant, rather than local, presence of these trees. *Myrica* pollen is also common in the Woodfordian zone. The unusually high amounts (up to 24%) of *Myrica* indicate a local presence of this wet-loving shrub. This record indicates aspen parkland or groveland was the dominant Woodfordian vegetation of the uplands surrounding the Sanders's well locality.

The Sanders's well record is unique. Although the site lies between the documented occurrences of spruce at Wichita and Muscotah Marsh, spruce seems to be absent in the vicinity of Sanders's well. In view of the Sanders's well record, the relatively high NAP and *Populus* pollen percentages at Wichita probably also represent aspen parklands. Two factors are hypothesized to be responsible for the observed differences among Woodfordian sites in eastern Kansas. Most important is the unique topographic situation of the Sanders's well site. It is located in gently rolling, interfluvial uplands, rather than within a river valley. Fire protection and a more mesic micro-climate allowed mixed spruce and deciduous forest to dominate in the river valleys, while the exposed, edaphically poorer uplands were burned frequently enough to prevent succession to spruce forests.

The second hypothesized reason for the differences among central Great Plains Woodfordian pollen records is climate. It has been proposed that major Woodfordian air-mass boundaries were centered over the region (Bryson, 1966; Bryson and Wendland, 1967; Bryson et al., 1970). Such a boundary would create a northeast-southwest moisture and temperature gradient across the central Great Plains analogous with that currently in the Manitoba and Minnesota region (Borchert, 1950). The evidence from Wichita and other localities south and west of Muscotah all indicate a more open and mixed forest during the Woodfordian.

The Courtland Canal in north-central Kansas provides one of these mixed spruce-deciduous forest records (figs. 1 and 2). The Courtland Canal locality deposition is reported to be loess, with some colluviation possible. *Picea* charcoal from the site has been dated to 14,450 ± 140 B.P. (Wells and Stewart, this volume). Pollen has been recovered from a sample of the dated horizon, but unfortunately is poorly preserved. Only one out of every four or five grains was identifiable; however, *Picea* and a variety of AP taxa have been identified (fig. 2). The diversity of pollen types with the presence of *Picea* qualitatively resembles the assemblages recovered from the Wichita peat and the North Cove locality discussed below.

The North Cove site, exposed along the Harlan County Lake on the loess plain of south-central Nebraska, has produced a variety of paleoenvironmental data (Johnson et al., 1986; Wells and Stewart, this volume; Stewart, this volume). Persistently flowing springs seem to be responsi-

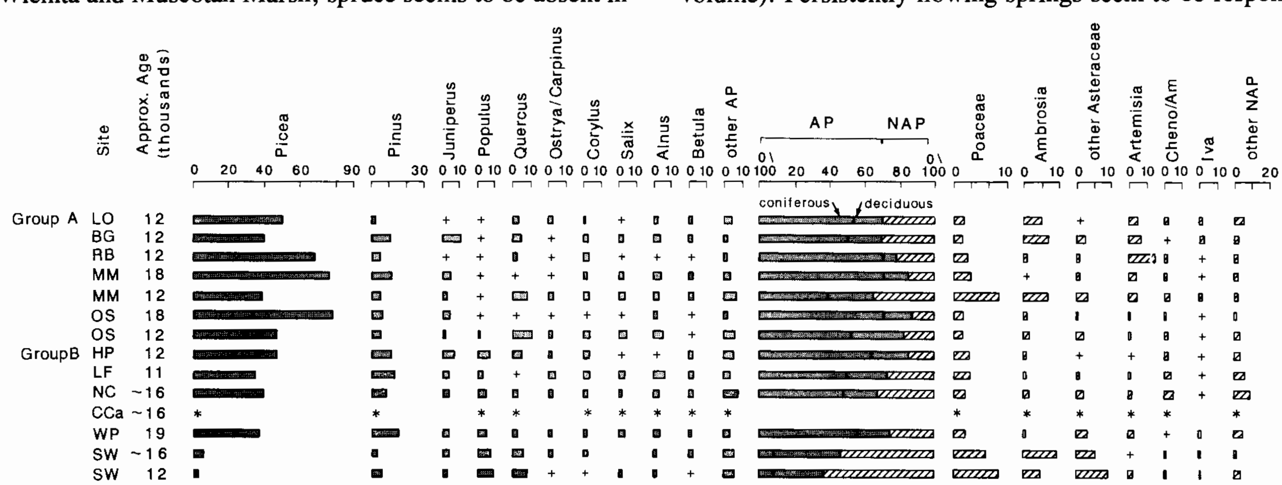

FIGURE 2—COMPARISON OF LATE WISCONSINAN (WOODFORDIAN) POLLEN ASSEMBLAGES FROM THE CENTRAL GREAT PLAINS; + trace (less than 1%), * pollen taxa present, insufficient pollen preservation for quantitative analysis. Group A generalized from previously published data; group B from previously unpublished data.

ble for the excellent preservation of botanical macrofossils and pollen at this locality. A sample of spruce wood has yielded a radiocarbon date of 14,770 ± 100 yrs B.P. Organic-rich sediments from this dated level have produced an assemblage of pollen very similar to that recovered at Wichita (fig. 2). *Picea* pollen and diverse deciduous AP comprise 68% of the pollen assemblage. *Populus* cf. *tremuloides* is again among the most common deciduous AP. Pollen of woody shrubs including *Elaeagnus, Shepherdia canadensis,* and *Sambucus* occurs in very low relative frequencies.

The Woodfordian vegetation of eastern Nebraska is not yet fully documented. So far only a few charcoal-bearing sites are known. *Picea* charcoal from a Peorian loess section near Central City in Merrick County, Nebraska, has produced a 19,640 ± 230/240 yrs B.P. date (Larry D. Martin, personal communication, 1986). A similar section from near Schuyler in Colfax County also has produced *Picea* charcoal (William Wayne, personal communication, 1984). A radiocarbon date from this locality is still pending. Our attempts to extract pollen from these localities have been unsuccessful. It is anticipated that when found, full-glacial Woodfordian pollen from eastern Nebraska will be *Picea*-dominated with less deciduous diversity than documented at the North Cove site. Both these spruce-charcoal sites and the macrobotanical and pollen sites from central Nebraska and Kansas indicate that some forest cover was present in the region during Peorian loess deposition.

One hypothesized source of Woodfordian (Peorian) loess-forming silts is the Sandhills of central Nebraska (Fredlund, Johnson, and Dort, 1985). The Woodfordian vegetation of the Sandhills themselves is not documented. The major period of dune formation is generally accepted to have occurred during the Woodfordian with later (Holocene) sand movement being secondary (Wright et al., 1985). The development and perpetuation of this massive dune field would have severely retarded the vegetational succession (Wright, 1970; Bradbury, 1980; Wright et al., 1985); however, we believe that this does not necessarily translate into a treeless landscape. Within the boreal forest today, active, albeit smaller, dune fields encroach on interdunal areas of open-coniferous forest (e.g., Raup and Argus, 1982). Pollen evidence for the Woodfordian vegetation both south and east of the Sandhills indicates that the regional climate would have supported open spruce or mixed spruce-deciduous forest probably with large areas of aspen parkland. Until Pleistocene botanical fossil-bearing interdunal deposits are found, the Woodfordian vegetation of the Nebraska Sandhills will remain uncertain.

In south-central South Dakota on the northern edge of the Sandhills, the Rosebud locality provides the critical record of late Woodfordian (ca. 13,000–12,000 yrs B.P.) vegetation (Watts and Wright, 1966). *Picea* was by far the most abundant AP taxon recorded. A diversity of deciduous AP taxa was present but lower in overall relative frequency than at the North Cove site (fig. 2). Another difference between these two localities is the significant occurrence of *Artemisia* pollen at Rosebud. None of the other Woodfordian central Great Plains records discussed above included high frequencies of this NAP taxon. It is hypothesized that the unique edaphic situation of the Sandhills may be responsible for the higher *Artemisia* percentages at Rosebud (Watts and Wright, 1966).

That area of the region least understood is western Kansas and Nebraska and eastern Colorado. We currently do not have evidence for the western limits of *Picea glauca* or any of the deciduous arboreal taxa present in eastern Kansas and central Nebraska during the Woodfordian. Based on paleontological data, the western Kansas and eastern Colorado region has been hypothesized to have been an open-pine savanna or parkland during the last glacial maximum (Guilday, 1964; Hoffmann and Jones, 1970; Martin and Neuner, 1978; Graham, 1979; Martin and Hoffmann, this volume). Unfortunately, Woodfordian botanical data from this region are scarce. The palynological evidence from the Llano Estacado (Oldfield and Schoenwetter, 1975), as well as that from the few recently investigated localities, supports the conifer-parkland hypothesis.

J. D. Stewart and P. V. Wells (Wells, 1983; Wells and Stewart, this volume) recently recovered needles of *Pinus flexilis* from highly calcareous loess or colluviated loess deposits at the Coon Creek paleontological site, Graham County, Kansas. Bone collagen from this deposit has produced a date of 17,930 ± 550 yrs B.P. Our first attempt to extract pollen from these sediments yielded mixed results. *Pinus* pollen was present but too poorly preserved to identify to subfamily or genera. Also present were a large number of insect-pollinated taxa, which further confused the quantitative results. These insect-pollinated types are suspected to have been emplaced by burrowing bees or other insects and probably are not contemporaneous with the other fossils at this site.

Palynological investigations at the Trapshoot site, Rooks County, Kansas, another Wisconsinan paleontological site, have produced similar results (Stewart and Rogers, 1984). Probably because of poor preservation, only four pollen taxa were identified from this site: *Pinus,* Poaceae, Asteraceae types (primarily *Ambrosia),* and Cheno-Am types. From the presence of 18% *Pinus* in this assemblage, Stewart and Rogers argued that pines probably were present in limited stands in the region of the site; however, poor preservation makes such quantitative interpretations questionable.

All the data accrued so far indicate that pine was present in the western reaches of the central Great Plains during the Woodfordian. The documented occurrence of limber pine (*P. flexilis*) suggests that western (montane) conifer forests were in part the source for the flora of this western Great Plains Woodfordian vegetation (Wells and Stewart, this volume). The exact physiognomy and geographical extent of this vegetation zone remain unknown. None of the records available so far indicate closed forest or even savanna. Instead, more open vegetation, with conifers and probably aspen confined to escarpments and other fire-protected sites, can be hypothesized.

One Wisconsinan site currently under investigation may help in understanding the nature of the transition from the western parklands to the open, mixed spruce-deciduous forest of eastern Kansas. With the cooperation of the Kansas Geological Survey, a 15-m (50-ft) core of lacustrine sediments from Cheyenne Bottoms in central Kansas has been obtained and is currently being analyzed at the University of Kansas Palynological Laboratory. This record should add significantly to our understanding of the history of central Great Plains vegetation.

Woodfordian–Holocene transition

Between about 12,000 and 9,000 yrs B.P., the climate and vegetation of central North America underwent dramatic changes (Wright, 1970; Watts, 1983; Webb et al., 1983). The pollen record from Muscotah Marsh presents the most complete record of this critical 3,000-yr period in the eastern central Great Plains (Grueger, 1973). Around 12,000 yrs ago relative frequencies of *Picea* pollen began to fall sharply, indicating the rapid demise of the spruce forests. A diversity of deciduous AP taxa (*Corylus, Salix, Quercus, Ulmus, Ostrya/Carpinus,* and *Fraxinus*) and NAP taxa (principally Poaceae and *Ambrosia*) increased simultaneously. This assemblage is very similar to the open, mixed spruce-deciduous assemblages now documented for the mid-Woodfordian sites southeast of Muscotah (fig. 2). The Muscotah record indicates that by 10,500 yrs B.P., spruce had all but disappeared from the region. During this final spruce decline, deciduous trees apparently increased until about 9,000 yrs B.P. when grasslands in the region expanded significantly.

The late Woodfordian pollen assemblages from Missouri indicate that mixed spruce-deciduous forest replaced the coniferous forest early in the transition period. At Boney Springs, one of the Ozark Springs sites, this mixed forest was present by about 13,500 yrs B.P. (Mehringer et al., 1970; King, 1973). A very similar pollen assemblage (fig. 2) from the Hinkson–Perche archeological site near Columbia, Missouri, has an associated radiocarbon date of 12,430 ± 80 yrs B.P. (Schmits, 1985). Neither of these localities has the complete late Woodfordian–early Holocene succession of vegetation.

The late Woodfordian–early Holocene transition in northern Iowa at Lake Okoboji (Van Zant, 1979) and Woden Bog (Durkee, 1971) generally parallels that recorded at Muscotah Marsh. The Iowa records, however, exhibit better zonation of deciduous AP taxa during this period. At Lake Okoboji, as *Picea* pollen declines, the deciduous pollen taxa that show increases are *Fraxinus nigra,* followed by *Betula* and *Alnus,* and finally *Quercus* and *Ulmus* prior to the 9,000-yrs-B.P. rise in grasslands. The zonation present at these Iowa localities reflects both the proximity of the deciduous taxa refugia and the differential rates of their dispersion (Wright, 1970).

No continuous records of this Woodfordian–Holocene transition exist for the western half of the central Great Plains. Even the Rosebud record is apparently broken by an unconformity (Watts and Wright, 1966). Although as a rule archeological sediments are not ideal depositional environments for pollen preservation, a number of early Holocene archeological sites have produced significant palynological records. By piecing these chronologically short archeological records with other data, an outline of the Woodfordian–Holocene transition in the western part of the region has begun to emerge. As yet many unexplained discrepancies exist among these records.

The presence of disjunct populations of *Picea glauca* and a variety of eastern deciduous trees indicates that these late Pleistocene forests probably extended westward at least to the Black Hills (Buttrick, 1914; Watts and Wright, 1966). Pollen extracted from late Woodfordian–early Holocene sedge-marsh sediments from the Lange–Ferguson paleoindian mammoth-kill site, along the Pine Ridge escarpment in the White River Badlands of South Dakota, supports this hypothesis (Fredlund, 1985). Although pollen preservation was mixed and pollen concentration relatively low (3,000 grains/gram sediment), the pollen diversity and consistency with other records warranted quantitative representation and interpretation of the data (fig. 2). The pollen indicates that at the time of the mammoth kill (circa 11,000 yrs B.P.), the vegetation was an open-spruce forest with a diverse understory of small trees and shrubs including *Populus, Juniperus, Alnus, Betula, Corylus, Salix, Shepherdia,* and *Ostrya/Carpinus.* All of these taxa except *Alnus* are extant in the Black Hills approximately 80 km (48 mi) northeast of the site. This record is similar to many of the Pleistocene–Holocene transition sites of the northern and eastern portions of the central Great Plains (fig. 2).

How widespread such forests were in the late Woodfordian western Great Plains is unclear. Recently published data from the Powder River basin, Wyoming, west of the Black Hills, indicate that steppe vegetation and a semi-arid climate have persisted in the area since 13,000 yrs B.P. (Markgraf and Lennon, 1986). At the Hudson–Meng early Holocene archeological site on the Pine Ridge escarpment just south of the Black Hills, fossil-pollen assemblages show no similarity to the Lange–Ferguson record (Kelso, reported in Agenbroad, 1978). The Hudson–Meng pollen record, dated at approximately 9,000 yrs B.P., indicates a grassland and *Artemisia*-steppe regional vegetation. No pollen evidence exists for either open spruce forests or the ponderosa pine for which this escarpment is known today. These other regional records suggest that the hypothesized open mixed spruce-deciduous forest bridge to the Black Hills was not widespread, but an ephemeral late Wisconsinan phenomenon confined to favorable topographical and edaphic situations, such as the north-facing Pine Ridge escarpment.

A palynological investigation of the Agate Basin archeological site just southwest of the Black Hills was less successful (Beiswenger, 1982). Inadequate pollen preservation, low concentration, and recycling of older fossil palynomorphs precluded quantitative interpretation.

An early Holocene (ca. 10,300 yrs B.P.) pollen assemblage relatively high in *Pinus* pollen has been reported from the 12 Mile Creek bison-kill site in Logan County, Kansas (Rogers and Martin, 1984). Although dominated by NAP, *Pinus* comprised approximately 37% of the assemblage. *Quercus* and *Populus* were reported only in trace amounts. These data were interpreted as most likely indicating the persistence of pine, possibly limber pine (*Pinus flexilus*), along escarpments or other protected situations in the vicinity of the site at the time of the bison kill (cf. Wells, 1965, 1970).

The southernmost central Great Plains late Woodfordian–early Holocene pollen record comes from the Domebo archeological site in central Okalahoma (Wilson, 1966). This NAP-dominated record roughly spans the 11,000-9,000-yrs-B.P. transitional period. The ca. 11,000-yrs-B.P. assemblages are dominated primarily by Poaceae (ca. 45%) and Asteraceae (ca. 25%). These increase even more after 10,000 yrs B.P. *Pinus* is relatively unimportant (5%) when compared to the 12 Mile Creek record. *Picea* pollen occurs even less frequently. Several deciduous pollen taxa, *Quercus, Carya, Ulmus,* and *Rhus,* are present but rare. Most significant, especially considering its typically low production and susceptibility to deterioration, is *Populus* (4-5%). This *Populus* pollen may represent either local cottonwoods (*P. deltoides*) or the southern extent of the aspen (*P. tremuloides*) parklands hypothesized for the eastern Kansas Woodfordian. The Domebo pollen record indicates that grasslands dominated the vegetation of central Oklahoma in the earliest Holocene.

Holocene record

Changes in vegetation and climate in the central Great Plains since 9,000 yrs B.P. are expected to have been less dramatic and to have resulted in more subtle changes in the pollen record. In the Midwest, pollen evidence for Holocene vegetation change resulting from species migration as well as climatic fluctuations has been mapped in detail (Webb et al., 1983). With only a few continuous records available, these types of analyses are not yet possible for the central Great Plains. This is in part due to lack of suitable sites. Only along the eastern side of the region, where a few lakes and bogs are present and changes in forest-prairie border are detectable, is there pollen evidence for climatically significant Holocene vegetation change.

In northern Iowa, at both Woden Bog (Durkee, 1971) and Lake Okoboji (Van Zant, 1979), an increase in prairie forbs occurred beginning about 7,500 yrs B.P. (Webb et al., 1983). Between 5,000 and 3,000 yrs B.P., the relative frequencies of these prairie-indicative pollen taxa decreased somewhat and the prairie-forest mosaic charactéristic of the region in historic times (Kuechler, 1964) began to develop.

A similar record occurs at the Muscotah Marsh in northeastern Kansas (Grueger, 1973). Although the Holocene portions of the Muscotah Marsh profile are broken by unconformities and lack close-interval radiocarbon dates, the data clearly indicate that a mid-Holocene prairie expansion and contraction occurred in northeastern Kansas.

A late Holocene prairie-forest fluctuation has been shown in the Cross Timbers of northeastern Oklahoma (Hall, 1982). Hall employed a variety of differing proxy data sets to build a convincing argument for late Holocene climate change in the southern Great Plains. Based on snails, small mammals, and pollen, especially the record from the Big Hawk rockshelter, a more mesic period from 2,000 to 1,000 yrs B.P. followed by a significantly drier episode is hypothesized. During the wetter episode *Carya* pollen increased, while Poaceae pollen was relatively more frequent during the later drier period. We plan to replicate Hall's pollen record independently in the upper Holocene portions of the Sanders's well section from the Osage Hills of Kansas.

Capes's Cave, a late Holocene alluvial pollen record from the grassland-pine forest ecotone in the Black Hills, documents the historic or protohistoric (ca. 200 yrs B.P. to present) expansion of the ponderosa-pine forest (Fredlund, Weston, and Mandel, 1985). The encroachment of the pine forest into grassland steppe was probably due to a combination of climatic change and historical land-management changes resulting in control and containment of fire.

These climatically induced changes in vegetation have not been documented in the region away from sensitive grassland-forest ecotones. Even the best central Great Plains Holocene pollen records, those from the interdunal lakes in the Sandhills of Nebraska, show no climatically significant change. Sears' (1961) investigation of Hackberry Lake produced only a discontinuous, 5,000 yrs B.P. to present, record of pollen. More recently, Wright et al. (1985) have published a continuous 9,000 yrs B.P. to present pollen record from Swan Lake, Garden County, Nebraska. However, in both of these records variation in pollen percentages is most easily explained by local, site-specific edaphic changes. No clear, climatically induced signal in these grassland-pollen records has been identified.

Big basin and Little basin, karst sinkholes in Clark County, Kansas, also have been demonstrated to have considerable continuous Holocene deposits (Shumard, 1974). A 535 ± 130-yrs-B.P. radiocarbon date was obtained from the base of a 3.2-m (10.6-ft) core used for pollen analysis. The minor fluctuations in the percentage pollen record do not seem to have regional climatic or vegetational significance.

Measuring climatic changes within the Holocene grasslands may prove more challenging than mapping the Pleistocene vegetation of the region. On the central Great Plains Holocene grasslands, major climatic perturbations may result only in a change of grass and forb species. To detect such subtle changes, more sensitive measures of the environment are needed. One approach to this problem is synthetic where a variety of data sets are pooled to test for significant changes (e.g. Hall, 1982). Within pollen analysis, finer resolution in prairie forb classification may also help, especially in the Asteraceae. Another approach is to combine pollen and phytolith analysis. Kurmans's (1985) investigation of the Elbow Creek paleosol is an example of the usefulness of these combined techniques. Phytolith analysis may enable the discrimination of Poaceae subfamilies, which are indistinguishable in the pollen record (Twiss, this volume).

Summary

This review of central Great Plains late Quaternary pollen and botanical data has proceeded chronologically from the pre-Wisconsinan to the Holocene. The only new pre-Wisconsinan locality record confirms Kapp's (1965, 1970) conclusion that the grassland steppes of central North America are not unique to the Holocene. The general late

Quaternary hypothesis holds that the grasslands expanded during the interglacials and contracted or even disappeared during the glacial maxima. Surprisingly, this effect was felt even during the Farmdalian interstadial which is often perceived as a minor climatic perturbation relative to the Holocene or Sangamon. Botanical evidence for Farmdalian grasslands is found as far east as eastern Kansas and Iowa (Baker and Waln, 1985) and as far north as the Sandhills of Nebraska.

Woodfordian data now available from the eastern side of the central Great Plains indicate that boreal forest overran the Farmdalian grasslands about 24,000–22,000 yrs B.P. and persisted until the Holocene. These hypothesized forests were a mosaic of spruce, mixed spruce-deciduous, and aspen, with open parkland more common to the south and west. If the Sanders's well record is representative, the larger part of eastern Kansas, the interfluvial uplands, were open aspen parkland or grovelands throughout the Woodfordian.

Woodfordian vegetation of the western portions of the region is poorly documented. The data do indicate that limber pine was present but in unknown amounts. Pines and other western conifers may have been confined to escarpments or other protected sites. Scattered groves of aspen probably also were present throughout western Kansas and eastern Colorado during this time. The best current hypothesis is an open parkland physiognomy, with grass or *Artemisia* steppe being arealy far more important than forest.

Vegetational change during the central Great Plains Holocene has been given less attention than that of the Pleistocene. The few recent investigations of localities away from grassland-forest ecotones have not been able to detect hypothesized Holocene climate variations. New tools sensitive to subtle changes in grass and forb communities must be developed to test for these Holocene climatic changes.

A great potential exists for late Quaternary palynological research in the central Great Plains, both Holocene and Pleistocene. Although the number of investigated localities in the region has more than doubled in the past five years, the area has only just begun to be explored. The pool of potentially productive palynological localities in the central Great Plains is anything but exhausted.

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Grass-opal phytoliths as climatic indicators of the Great Plains Pleistocene

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Abstract

Opal phytoliths from the epidermal cells of grass leaves occur with pollen and spores in atmospheric-dust deposits, soils, paleosols, and sediment of the Cenozoic Era in the Great Plains. Phytoliths can be traced to three groups of subfamilies of grass and to two photosynthetic pathways. Circular, rectangular, and elliptical forms (pooid class) occur in C_3 grasses that thrive in cool temperatures and high available soil moisture. Saddle-shaped bodies (chloridoid class) occur in C_4 grasses that flourish in warm temperatures where available soil moisture is low. Cross- and dumbbell-shaped phytoliths are dominant in C_4 grasses that thrive in warm temperatures and high available soil moisture. All three classes of phytoliths occur with palynomorphs in sediment of the Great Plains and are important indicators of past climates and environments.

Introduction

Grasses are probably the most widely distributed flowering plants on the earth today. The more than 600 genera and 7,500 species range from the warm tropics to within the Arctic Circle and include such diverse forms as bamboo, sugar cane, cereal grains, domestic grasses, and the tall and short grasses of the prairies (Gould and Shaw, 1983). The grasses reproduce sexually and asexually; asexual reproduction by development of stolens, rhizomes, and tillers is especially prevalent during years of drought (stress).

Commonly, the grasses and other flowering plants are classified mainly on the structure of the plant including emphasis on the structure of the flower and seed. Unfortunately, as with fossils of other organisms, the remains of the entire plant, or of distinctive parts, are extremely rare in the geologic record.

Grass-opal phytoliths from the epidermal cells of the leaf, culm, root, and inflorescence are released as discrete particles after the plant dies. Phytoliths are resistant to dissolution and accumulate in atmospheric dust, soil, paleosol, and sediment. Because of their size, phytoliths are transported along with pollen and spores and, if processed carefully, will be recovered with them.

Classification of phytoliths

Taxonomists have long recognized the importance of the micromorphology of the leaf in the classification of grasses (Prat, 1936; Metcalfe, 1960). Distribution of epidermal cells in the grass leaf is illustrated by a spodogram of the corn leaf (*Zea mays* L.) in fig. 1. The organic matter has been removed by ashing at 450° C (842° F); only silicified opaline cells remain. The silica cells and one long cell have been nearly filled with bodies of opal-A (Jones and Segnit, 1971), which are recognized by marked negative relief (bold outlines) when mounted in Canada balsam (n = 1.54). The stoma and other cells have been encrusted with opal, so the relief is lower. Most phytoliths occur over the veins, but some cells in the intercostal zone are silicified also.

In describing the micromorphology of 345 genera of grasses, Metcalfe (1960) used the orientation, location, concentration, size, and shape of the different types of cells and silica bodies as viewed on the surface of the leaf epidermis and in transverse section of the leaf. Even where the diagnostic vegetative characters are in growth position, classification is still difficult. Metcalfe (1960, p. xli) emphasized that

> we are not dealing with a problem comparable with classifying postage stamps which conform to specific designs drawn up in agreement with a printing firm. We have before us biological material that does not conform exactly to immutable designs.

Consequently, Metcalfe (1960) arranged the descriptions of genera and species in alphabetical sequence and urged that this information be combined with that on exomorphology and the data supplied by cytologists, embryologists, and other specialists. He concluded (Metcalfe, 1960, p. lix) that ". . . it is only by a synthesis of these specialized approaches that any real advance in the taxonomic treatment of the Gramineae is to be expected." Relating discrete phytolith bodies from soil and sediment to the plant from which they came is even more difficult.

Ehrenberg (1847) recognized grass-opal phytoliths in several samples of atmospheric dust, some of which were collected on the H.M.S. Beagle by Charles Darwin. Ehrenberg believed these bodies to be microorganisms and proposed 10 genera and 90 species of *Phytolitharia.* This classification was genetic so that widely different-shaped bodies were placed under one genus. He also was instrumental in classifying diatoms, and many forms retain his names. Baker (1959a, 1959b, 1960a, 1960b) identified several shapes of phytoliths in atmospheric dust and soils

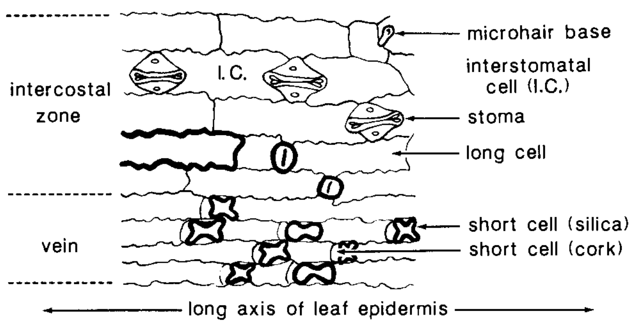

FIGURE 1—SPODOGRAM OF *ZEA MAYS* L. (from Twiss and others, 1969, as adapted from Metcalfe, 1960).

and traced them to grass plants but did not propose a classification.

Relying heavily on the works of Prat (1936, 1948a, 1948b, 1951) and Metcalfe (1960), Twiss et al. (1969) proposed a morphological classification of discrete opal phytoliths that is related to grass taxonomy (fig. 2). The shapes of the phytoliths fall in four classes and 26 types that can be traced to three groups of subfamilies of grass. Class 4, the elongate class, consists of silicified long cells, from 30 to 150 micrometers long, and is characteristic of the grasses generally but cannot be used to identify subfamilies or tribes. Classes 1, 2, and 3 consist of silicified short cells and silica bodies from 10 to 35 micrometers long, which are representative of three groups or subfamilies; festucoid (pooid), chloridoid, and panicoid.

Sase and Kondo (1974) studied phytoliths from 23 wild-grass species and phytoliths recovered from the A-horizon of buried volcanic-ash soils in Hokkaido (Japan). They expanded the classification to seven classes by introducing the sasaoid class for bamboo, the fan-shape class, and the point-shape class. In the panicoid class, they added several types that are strings of complex dumbbells of types 3i and 3j of Twiss et al. (1969). Sase and Kondo (1974) stated that the silica bodies of the elongate, fan-shape, and point-shape classes were "nonspecific to taxonomic groups" of grasses. They determined that sasaoid phytoliths from bamboo were dominant in paleosols of the last 6,000 yrs, but earlier soils contained festucoid phytoliths.

Brown (1984) concentrated on 112 grass species common in central North America in developing a phytolith key based entirely on eight major shape classes. The eight classes are I, plates; II, trichomes; III, double outline; IV, saddles; V, trapezoids; VI, bilobates; VII, polylobates; and VIII, crosses. Each class is subdivided to accomodate the great range of forms and the key can be expanded as needed. This system includes many more shapes than any other classification system.

Brown (1984) also reported important exceptions to the classification of Twiss et al. (1969). Festicoid (pooid) types occur in nearly all grasses. Panicoid types form in species of *Danthonia* (subfamily Arundinoideae) and chloridoid saddles occur in *Phragmites australis,* the only species of tribe Arundineae native to the United States (Gould and Shaw, 1983, p. 129). All workers (Prat, 1948a; Metcalfe, 1960; Twiss et al., 1969; Brown, 1984) have cautioned that morphological classifications of discrete silica bodies can be related to grass taxonomy only with caution.

I) FESTUCOID CLASS
- 1a. Circular
- 1b. Rectangular
- 1c. Elliptical
- 1d. Acicular, variable focus
- 1e. Crescent, variable focus
- 1f. Circular crenate
- 1g. Oblong
- 1h. Oblong, sinuous

II) CHLORIDOID CLASS
- 2a. Chloridoid
- 2b. Thin chloridoid

III) PANICOID CLASS
- 3a. Cross, thick shank
- 3b. Cross, thin shank
- 3c. Dumbbell, long shank
- 3d. Dumbbell, short shank
- 3e. Dumbbell, long shank, straight or concave ends
- 3f. Dumbbell, short shank, straight or concave ends
- 3g. Dumbbell, nodular shank
- 3h. Dumbbell, spiny shank
- 3i. Regular, complex dumbbell
- 3j. Irregular, complex dumbbell
- 3k. Crenate

IV) ELONGATE CLASS (no subfamily characteristics)
- 4a. Elongate, smooth
- 4b. Elongate, sinuous
- 4c. Elongate, spiny
- 4d. Elongate, spiny with pavement
- 4e. Elongate, concave ends

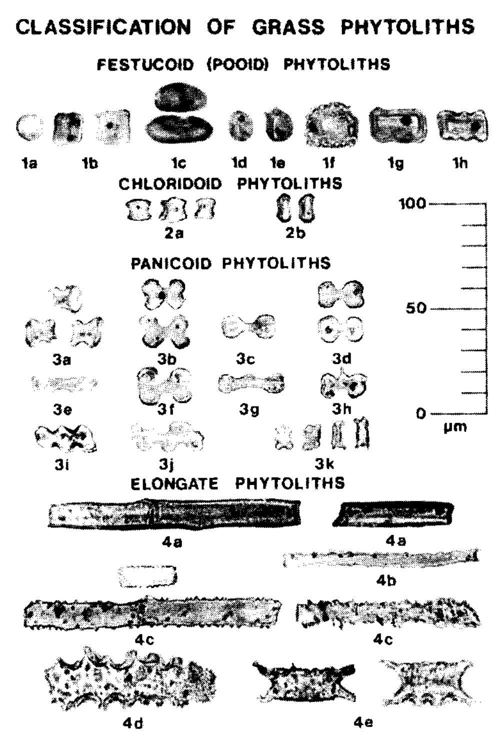

FIGURE 2—CLASSIFICATION OF GRASS-OPAL PHYTOLITHS (adapted from Twiss and others, 1969).

Because opal phytoliths occur in plants other than the grasses, Bertoldi de Pomar (1971) and Rovner (1971) proposed morphological classifications that include other monocotyledonous and dicotyledonous plants. All forms occur as discrete bodies and have been recovered from soil and sediment. As yet, no comprehensive classification of individual silica bodies derived from plants exists, so that any study of opal phytoliths in soils and sediment must include a careful study of the above references.

Photosynthetic pathways and phytoliths

The grasses, as do other higher plants, possess two photosynthetic pathways: the Calvin–Benson cycle or C_3 pathway and the Hatch–Slack cycle or C_4 pathway. The C_3 and C_4 designations refer to whether the first fixed-carbon compound contains three or four carbon atoms. Both cycles are dark reactions which do not require light to occur and involve the formation of starch from carbon dioxide by a series of chemical reactions (Gould and Shaw, 1983, p. 48).

In the C_3 photosynthetic pathway, carbon dioxide from the atmosphere enters the grass leaf through the stomate and passes through the epidermis to the mesophyll which contains the chloroplasts. Here, the CO_2 is catalyzed and phosphoglyceric acid (PGA), containing three carbon atoms, is produced as the first fixed-carbon compound (Gould and Shaw, 1983, p. 48). The chlorenchymal cells contain chlorophyll and are distributed throughout the interior of the leaf and enclose the vascular bundles. This C_3 pathway occurs almost universally in photosynthetic plants.

In the C_4 photosynthetic pathway, carbon dioxide entering the leaf through the stomate into the mesophyll reacts with "phosphoenolpyruvate (PEP) carboxylase in the chlorenchymal cells to form the four-carbon molecule oxaloacetate (OAA)" (Gould and Shaw, 1983, p. 48). OAA is converted to form malic and aspartic acids which are transported into the bundle-sheath cells. Here the acids are decarboxylated and CO_2 is released to the C_3 cycle in the bundle-sheath cells.

The C_3 grasses flourish in cool seasons or high elevations where available soil moisture is high. The warm-season C_4 grasses occur in either areas of low or high soil moisture. Although the pathways are identified by the structure of the mesophyll, only opal phytoliths from the epidermis remain after the plant dies.

Twiss (1980, 1983) suggested that grass-opal phytoliths could serve as indicators of C_3 and C_4 pathways in grasses. The festucoid (pooid) class of phytoliths (fig. 2) occurs dominantly in taxa of Subfamily Pooideae which use the Calvin–Benson (C_3) pathway and are most abundant in cool, moist climates. The chloridoid class (fig. 2) occurs in the arid to semi-arid, warm-season C_4 grasses belonging to Subfamily Chloridoideae and requires less available soil moisture. The panicoid class (fig. 2) occurs in the warm-season, more humid C_4 grasses of Subfamily Panicoideae. According to Gould and Shaw (1983, p. 110), more than 97% of native U.S. grass species (1,026 of 1,053) are divided equally among three subfamilies Pooideae, Chloridoideae, and Panicoideae.

In the United States, Subfamily Pooideae contains nine tribes and all utilize the C_3 pathway. Gould and Shaw (1983) reported that of the 68 genera, 55 occur in the tribes of Poeae (17), Aveneae (30), and Triticeae (8); the dominant phytoliths are round, elliptical, crescent shaped, and long and narrow (festucoid and elongate classes). They also listed Stipeae as containing festucoid, cross-shaped, and dumbbell-shaped phytoliths, and Brachyelytreae, Nardeae, and Monermeae as containing dumbbell-shaped phytoliths. Species of this subfamily are most abundant in the northern United States and in high elevations where available soil moisture is high during the growing season.

The Subfamily Panioideae is represented in the United States by 32 genera and 325 species; both C_3 and C_4 pathways occur (Gould and Shaw, 1983, p. 118). All genera of tribe Andropogoneae are C_4 grasses and contain panicoid phytoliths; however, *Zea mays* contains festucoid (pooid) types 1d and 1e (fig. 2) in the intercostal areas (Twiss and others, 1969). Tribe Paniceae is represented by 25 genera (20 are native) in the United States; some are C_3 and some are C_4. Even the genus *Panicum* contains 104 C_3 species and 137 C_4 species (Brown, 1977). The distribution and types of phytoliths in the Paniceae have not been reported in detail so that it is not known whether all species and genera contain panicoid phytoliths, or more importantly, whether the taxonomic associations are correct. The Subfamily Panioideae comprises the majority of grasses in the tropical and subtropical regions of the world; in the United States these grasses are most abundant in the east and south but do extend throughout the Great Plains.

The eight tribes of the Subfamily Chloridoideae are all C_4 and are represented in the United States by 42 genera and 310 species of native grasses (Gould and Shaw, 1983, p. 120). These grasses are most abundant in the hot, arid climates near the tropics of Cancer and Capricorn. They are an old group and according to Hartley and Slater (1960), may have originated in tropical or subtropical Africa at least as early as the Oligocene. In the United States this group is most abundant in the Southwest (Gould and Shaw, 1983, p. 120). Saddle-shaped phytoliths are common in members of the Eragrosteae and Chlorideae (Brown, 1984), which account for 34 genera. Gould and Shaw (1983) have included tribe Aristideae with the Chloriodeae, but Brown (1984) lists eight species of *Aristida* that contain bilobate (panicoid) phytoliths, and Twiss et al. (1969) listed one species as containing both festucoid (pooid) and panicoid forms.

Although some exceptions do exist, festucoid, chloridoid, and panicoid phytoliths are related to the photosynthetic pathways used by the majority of grasses. Fortunately, the exceptions occur in rare groups, many of which are restricted to specialized environments. The C_4 grasses can be split into two groups: chloridoid and panicoid. Chloridoid phytoliths represent those grasses which are abundant in relatively warm and dry areas with low available soil moisture. Panicoid phytoliths occur in grasses which flourish in warm and more moist areas where the available soil moisture is higher.

Recovery and analysis of phytoliths

The specific gravity of opal phytoliths is below 2.3, so that recovery from soil and sediment can be accomplished by gravity separation after some preliminary treatment. Several techniques have been used (Twiss et al., 1969; Rovner, 1971; Carbone, 1977), but the technique of Fredlund and others (1985) is especially effective. From 2 to 250 grams of soil or sediment can be processed by 1) dissolution of carbonates with dilute hydrochloric acid, 2) dispersal and removal of some clay minerals with a solution of sodium pyrophosphate or sodium hexametaphosphate, and 3) flotation of phytoliths and other light constituents out of the heavier mineral fraction with zinc bromide (specific gravity 2.35), a water-soluble heavy liquid. Included in the light fraction are opal phytoliths from grasses and other plants, diatoms, siliceous sponge spicules, carbonized plant remains, and other light silicate minerals. The concentrate is weighed and aliquots are mounted in Canada balsam ($n = 1.54$) on petrographic glass slides, mounted on SEM stubs, and stored in vials.

Wilding et al. (1977) urged that the weight of the biogenic opal concentrate must be compared to the weight of the total soil or sediment. Biogenic opal is ubiquitous in atmospheric dust, soils and paleosols, and sediment of the Cenozoic Era. The quantity ranges according to geography, climate, geomorphology, plant species, maturity of the plant, and type of soil and sediment.

A large proportion (perhaps up to 80–90%) of plant opal cannot be identified and must be classed as "unclassified" forms. Wilding et al. (1977) reported that opal encrustations and epidermal hairs from dicotyledonous and moncotyledonous plants have been recovered from soils. Opaline trichomes, bulliform cells, silica cells, long cells, and large proportions of unidentified epidermal fragments of grasses have been recovered from atmospheric dust, soils, and ancient sediment (Wilding et al., 1977).

In reporting types of grass phytoliths, the following major classes are proposed: 1) sasaoid (Sase and Kondo, 1974), 2) pooid (festucoid of Twiss et al., 1969; some double outline, some trapezoids of Brown, 1984), 3) chloridoid (saddles of Brown, 1984), 4) panicoid (bilobates, polylobates, and some crosses of Brown, 1984), 5) elongate (plates of Brown, 1984), 6) fan-shape (Sase and Kondo, 1974), 7) point-shape (Sase and Kondo, 1974), and 8) unidentified. These major classes can be further subdivided using the types proposed by Sase and Kondo (1974), Twiss et al. (1969), and Brown (1984); any number of additional types can be added as needed. For paleoenvironmental interpretations, the types in the first four classes are most useful.

Occurrence of grass phytoliths in the Great Plains

Careful sampling and processing reveal that opal phytoliths occur widely in the soil and sediment of the Quaternary and Tertiary periods and especially in the Great Plains.

Phytoliths in atmospheric dust

Collections of monthly deposits of dust from nine stations in the Great Plains (fig. 3) from 1963 to 1967 commonly contained grains of biogenic opal which were mostly from grasses (Smith and Twiss, 1965; Twiss et al., 1969; Smith et al., 1970; Twiss, 1983). The quantity of grass phytoliths ranged from 35% at North Platte, Nebraska, Tribune, Kansas, and Hays, Kansas, to 2% at Manhattan, Kansas, and Riesel, Texas, and at each station were most abundant in the spring and summer. The abundance of phytoliths and phytolith fragments correlated positively with the several wind parameters, number of dusty days, dust-deposition rates, median silt diameter, and abundances of quartz, smectite, and illite (Smith et al., 1970).

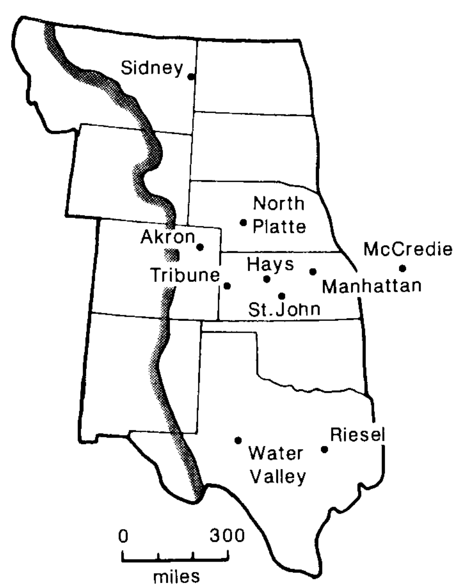

FIGURE 3—Dust-deposition network in the Great Plains (Twiss, 1983).

Photomicrographs of the silt-plus-sand fractions of the dust are shown in fig. 4. Most particles in the photos are biogenic opal and some can be positively identified as grass-opal phytoliths. Although the types of phytoliths have yet to be counted, a relationship does seem to exist between phytolith type and extant vegetation. Tribune, Kansas, is in the short-grass prairie and chloridoid and elongate phytoliths are common. Hays is in a region of mixed short and tall grasses; the dust deposits contain chloridoid and panicoid phytoliths that represent the two groups of C_4 grasses. Manhattan, in the tall-grass region of the Flint Hills, contains panicoid phytoliths in the dust deposits.

Phytoliths in association with pollen grains, spores,

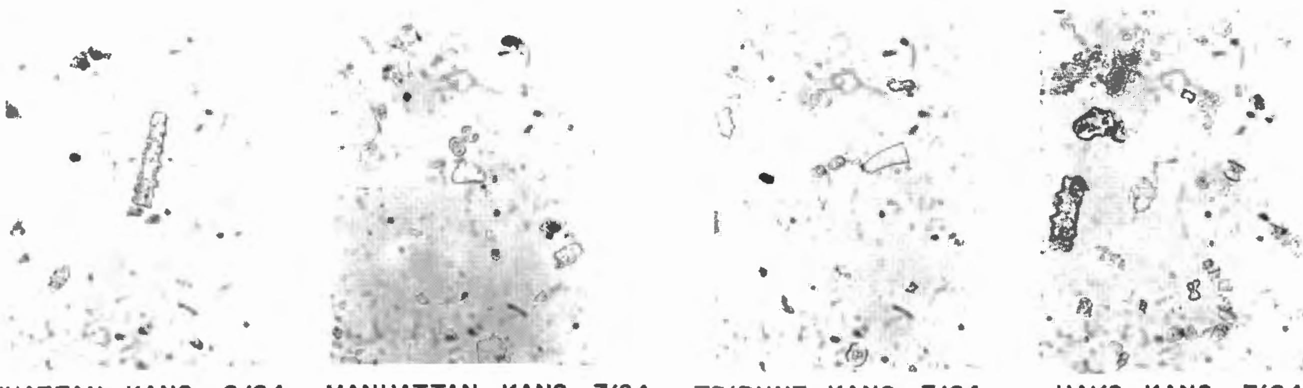

FIGURE 4--PHOTOMICROGRAPHS OF GRASS PHYTOLITHS IN ATMOSPHERIC-DUST DEPOSITS FROM KANSAS: elongate (4c) phytolith (55 µm long) at Manhattan, June 1964; panicoid (3f) phytolith (18 µm long) at Manhattan, July 1964; chloridoid (2a, 2b) phytoliths (11 µm long) at Tribune, July 1964; and chloridoid (2a, 2b), panicoid (3d), elongate (4d), and unclassified phytoliths at Hays, July 1964.

freshwater diatoms, and silt-sized mineral grains can travel several hundreds of kilometers in the atmosphere (Ehrenberg, 1847; Folger et al., 1967; Folger, 1970). Grass phytoliths have been recovered from deep-sea sediments many kilometers from land (Ehrenberg, 1854; Kolbe, 1955; Diester–Haass et al., 1973; Parmenter and Folger, 1974).

Phytoliths in extant soils and alluvium

Wilding et al. (1977) cited many examples of biogenic opal in soils and reported that opal phytoliths constitute the major part in nonaquatic environments ranging from less than 0.1 to 3% of the total soil. Some soils and alluvium in the Flint Hills region near Manhattan, Kansas, were examined (Twiss et al., 1969). In all samples, phytolith fragments and elongate phytoliths are dominant, followed by panicoid forms (fig. 5). The surface vegetation is dominated by tall grasses belonging to Subfamily Panicoideae.

The scanning-electron microscope, because of its magnifying power, depth of field, and tilt capabilities of the sample holder, is an effective instrument for examining the three-dimensional form of phytoliths (fig. 6). By studying the shape variations of type-3a phytoliths (fig. 2), Pearsall (1978, 1982) and Piperno (1979, 1980, 1984) have made advances in distinguishing maize phytoliths in soils from other types of panicoid grasses.

Phytoliths in paleosols

Gravity concentrates of phytoliths from two unnamed paleosols near Manhattan, Kansas, are shown in fig. 7. The Derby buried soil contains pooid and chloridoid phytoliths in addition to the panicoid, elongate, and unclassified fragments which occur in the Derby loamy sand. The surface vegetation consists dominantly of tall grasses of the Subfamily Panicoideae. The SEM photo (fig. 8) shows chloridoid, panicoid, and unclassified phytoliths in the buried soil below the Monona silt loam. All phytoliths contain small (about 300Å) spheres of opal-A (Jones and Segnit, 1971) that can be observed with highest magnification of the SEM (fig. 8). The SEM is useful in demonstrating that unidentified opal fragments possess this fine structure and are therefore biogenic.

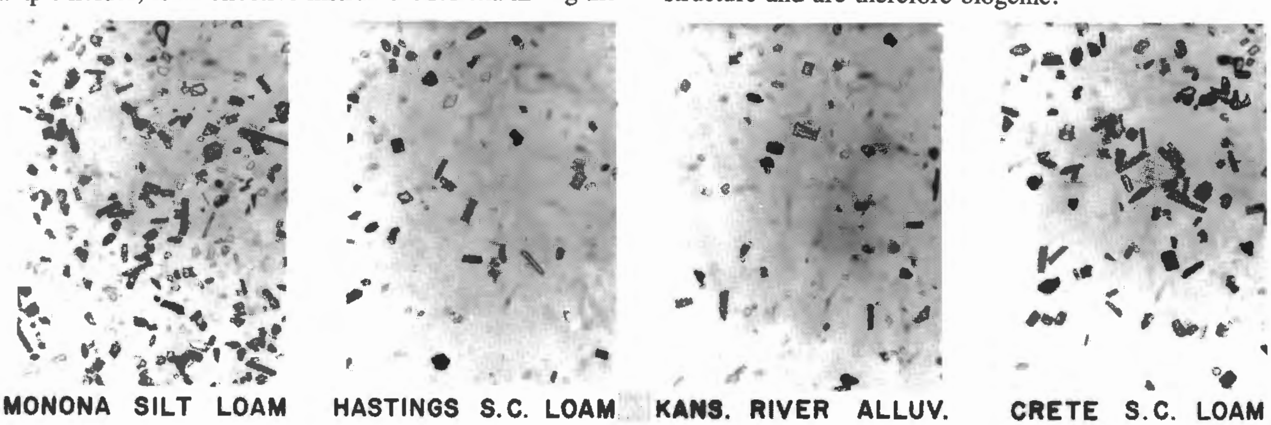

FIGURE 5--PHOTOMICROGRAPHS OF GRASS PHYTOLITHS IN EXTANT SOILS AND ALLUVIUM NEAR MANHATTAN, KANSAS. Gravity concentrates of biogenic opal that consist mostly of elongate phytoliths (115 µm long) and unclassified phytolith fragments.

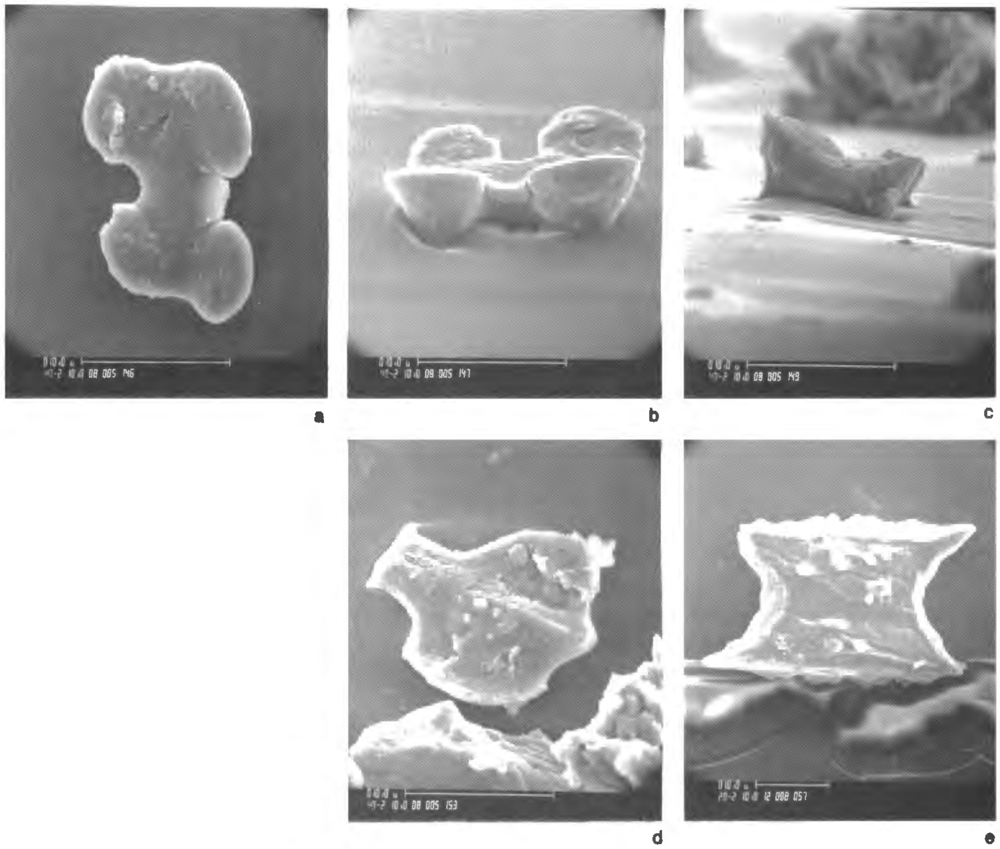

FIGURE 6--SEM PHOTOS OF GRASS PHYTOLITHS IN EXTANT SOILS OF THE FLINT HILLS REGION IN KANSAS: **a**, **b**, and **c**) top view, side view, and end view of panicoid (3f) phytolith from the Hastings soil; **d**) broken panicoid (3e) phytolith in Hastings soil, and **e**) elongate (4e) interstomatal phytolith in Crete soil.

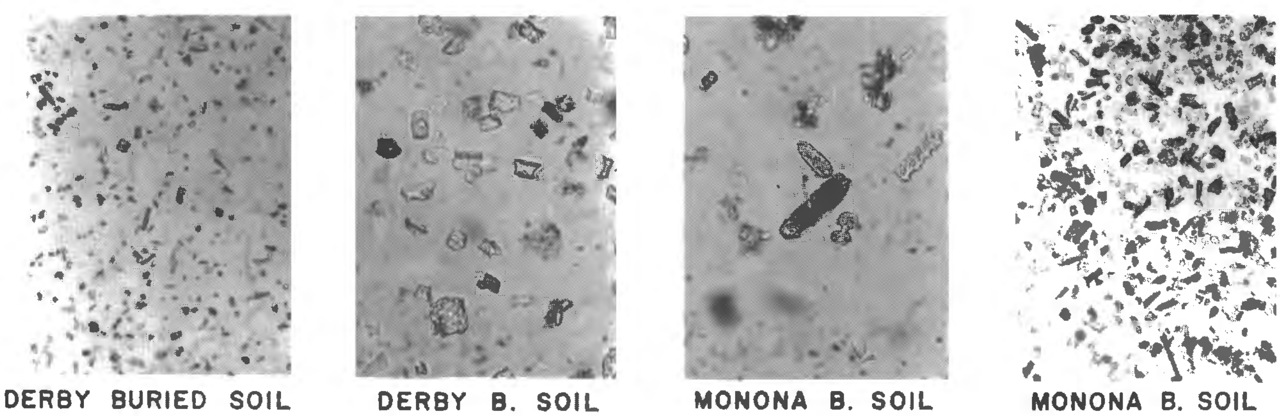

FIGURE 7--PHOTOMICROGRAPHS OF GRASS PHYTOLITHS IN BURIED SOILS NEAR MANHATTAN, KANSAS. Gravity concentrates of biogenic opal in unnamed paleosols below the Derby and Monona soils. The Derby buried soil contains pooid (festucoid; 1a, 1g), chloridoid (2a), panicoid (3f), elongate (4a, 4c), and unclassified phytoliths. The Monona buried soil contains panicoid (3d), elongate (4a, 4c), and many unclassified phytoliths.

Phytoliths in Pleistocene sediment

Four samples of Pleistocene sediment from the Iowa Point section in northeast Kansas contained severely corroded elongate and unclassified fragments of grass phytoliths (fig. 9). The paleosols and loess contained more phytoliths than the Kansas till. Others have reported phytoliths in sediment much older (Wilding et al., 1977; Baker, 1960b; Abbott, 1975).

Grass phytoliths as climatic indicators

Pollen spectra are essential for interpreting the history of plant groups and species, plant communities, and climate (Moore and Webb, 1978, p. 2). Pollen diagrams of stratigraphic sections or boreholes are commonly arranged in groups from left to right, with arboreal types first, followed by nonarboreal types consisting of shrubs, then herbs, and finally spores. Gramineae usually are listed separately in pollen diagrams and their relative abundance can range from a trace to several percent to the total composition. Unfortunately, grass pollen cannot be traced to tribes or subfamilies of Gramineae.

Because pollen, spores, and opal phytoliths have low specific gravities (<2.3) and are approximately the same size (10–150 micrometers), they are transported together by wind and water and occur together in soil and sediment. An SEM photograph (fig. 10) of a gravity separate of the Kansas till from the Iowa Point section in northeast Kansas shows two spherical pollen grains, a dumbbell-shaped (panicoid) opal phytolith, and three fragments of unidentified opal residue. The pollen grains are not diagnostic and are grouped under the Gramineae. The panicoid phytolith (fig. 2, type 3f) is probably from a C_4 grass that flourished in warm seasons where available soil moisture was high. The combination of data from pollen, spores, and opal phytoliths can be powerful in interpreting the paleoenvironment.

Few workers have reported palynological and opal-phytolith data together. Salgado-Labouriau (1978) reported panicoid phytoliths as discrete bodies and as epidermal fragments in pollen and spore rain in central Brazil. Kurmann (1981, 1985) identified opal phytoliths, pollen grains, and fungal spores in Kansas soils in order to correlate them with local vegetation. These results were applied to those of a paleosol. Pollen analysis was used to distinguish woodland sites from prairies but was unsuccessful in distinguishing tall-grass and short-grass prairie as was the phytolith analysis. Her results demonstrated the importance of combined phytolith and palynological analysis in characterizing woodland and grassland communities.

Fredlund et al. (1985) tabulated the abundance and type of opal phytoliths from a vertical loess section at the Eustis ash pit in Nebraska. They found that pooid (festucoid) phytoliths were the most abundant regular forms followed by significant vertical changes in the chloridoid and panicoid types. They concluded that increases in the proportion of chloridoid phytoliths in paleosol complexes indicated that the soil-forming periods must have been warmer and drier than the periods of loess accumulation. The data from opal phytoliths correlated well with the data from pollen analysis. Also they included an excellent review of the present status of opal-phytolith analysis.

Some reasons why data from pollen and spore analyses have not been reported with those of phytolith analyses are differences in 1) processing of soil and sediment samples, 2) mounting media, 3) methods of examination, and 4)

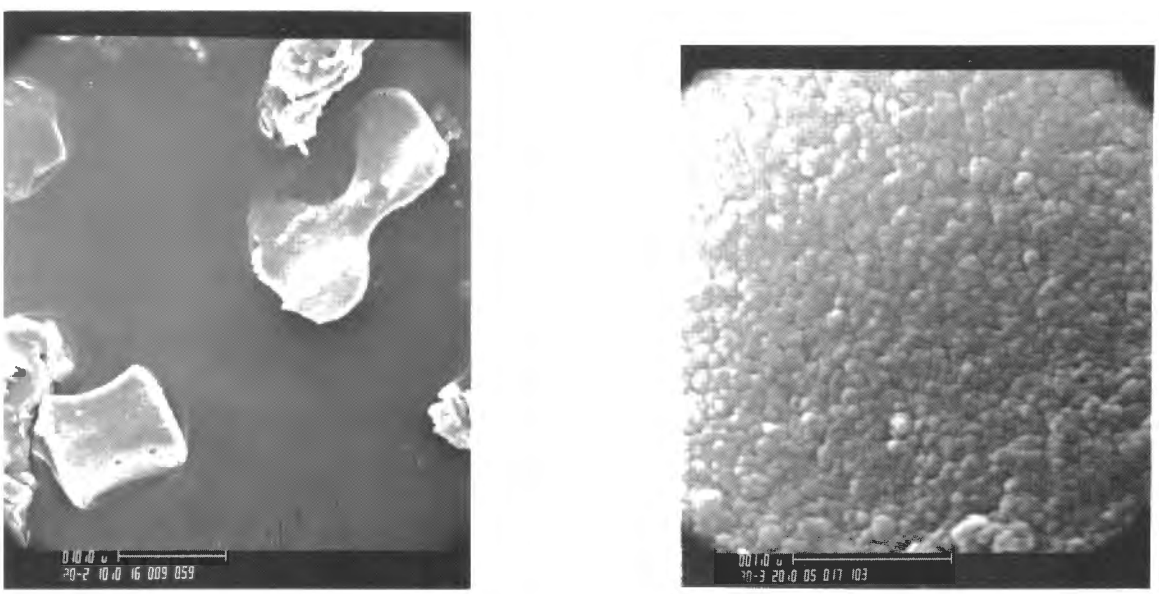

FIGURE 8—SEM PHOTO OF UNNAMED PALEOSOL BELOW THE MONONA SILT LOAM IN GEARY COUNTY, KANSAS. Gravity concentrate of biogenic opal contains chloridoid (2a), panicoid (3e), and unclassified opal phytoliths. Fine structure of biogenic opal shows opal spheres that are about 300 Å in diameter without the conducting coating.

training and experience of scientists. Palynologists frequently treat samples with hydrofluoric acid to remove silicate minerals and siliceous residue from the pollen and pore concentrate, and this destroys opal phytoliths (fig. 11).

Because pollen and spores have refractive indices that range from 1.55 to 1.60, palynologists use mounting media of low refractive index (n = 1.40–1.47) to emphasize characteristic structural features (Faegri and Iversen, 1975, p. 111). The indices of the mounting media overlap those of phytoliths (n = 1.41–1.47) (Wilding et al., 1977, p. 472) so that phytoliths are barely visible in microscope mounts. Conversely, petrographic mounting media have indices near 1.54, which renders pollen and spores nearly invisible.

Palynologists commonly use phase-contrast microscopy to enhance the structure of the grains of pollen and spores. Most phytolith workers examine biogenic opal with a polarizing microscope which aids in mineral identification and observation of the external form of the opal. Generally, a worker lacks proficiency in one of these types of microscopy.

Finally, palynologists are specialists in the structure and formation of pollen grains and spores and in their dispersal and preservation. Those individuals interested in phytoliths often have been trained in other disciplines such as geography, geology, soil science, and archeology, and many have little knowledge of palynology. Opal phytoliths are not mentioned in standard texts in pollen analysis, paleobiology, or micropaleontology.

Using grass phytoliths for documenting paleoenvironments and paleoclimates is in its infancy. Although problems in classification of phytoliths and the distribution of these forms in specific grass taxa still remain unsolved, some generalizations can be made. Chloridoid phytoliths occur in C_4 grasses that thrive in warm, relatively dry regions where the available soil moisture is low. Panicoid phytoliths occur dominantly in warm-season C_4 grasses in regions where available soil moisture is high. Pooid phytoliths are abundant in cool-season C_3 grasses but also occur in the intercostal zones of the epidermis of panicoid and chloridoid grasses. Perhaps ratios of classes of phytoliths may be the most useful for documentation.

Diester–Haass et al. (1973) proposed a climatic index that is the ratio of chloridoid phytoliths to the total number of chloridoid and panicoid phytoliths based on a total count of 100. A high index, close to 100, indicates an arid climate whereas a low index suggests a humid climate; the range gives the relative abundance of the two classes of C_4 grasses in the source area.

Where pooid, chloridoid, and panicoid phytoliths occur, an index of the ratio of chloridoid to the total count of the three classes can be used as an aridity index. The ratio of C_3 to C_4 grasses can be approximated by comparing the ratio of pooid phytoliths to the total count of the three classes.

Studies are needed in which phytoliths from Holocene soils and sediment are compared to those that occur in extant vegetative regions. If these studies are successful, then phytoliths can be used with more confidence in interpreting environments throughout the Cenozoic Era.

Summary

Progress has been made in the morphological classification of discrete phytoliths from leaves of grasses. These forms reflect the photosynthetic pathway used by the grass and even whether the plant flourished in an arid, warm region or in a moist, warm region. Grass-opal phytoliths can add additional climatic information to pollen and spore analyses. Reconstructing paleoenvironments and paleoclimates is a multidisciplinary task; the value of opal phytoliths has yet to be realized.

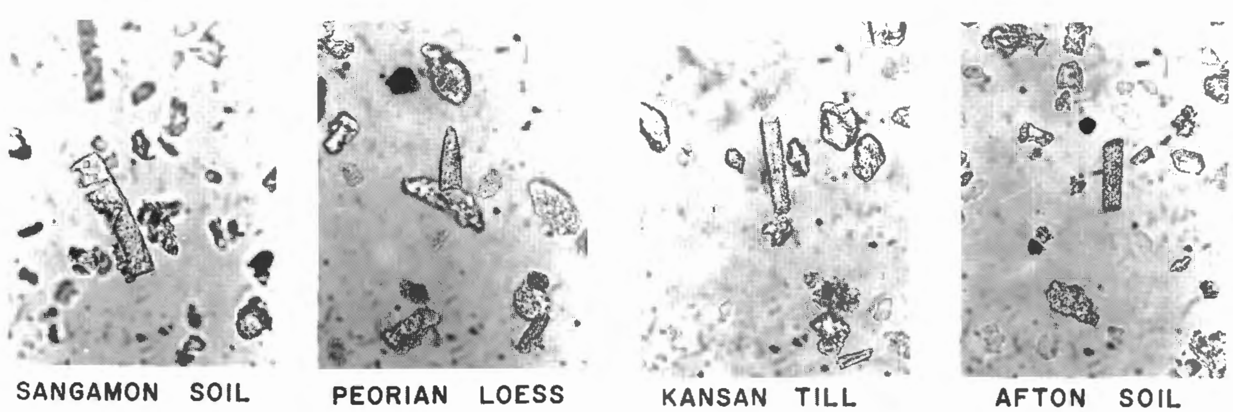

FIGURE 9--PHOTOMICROGRAPHS OF GRASS PHYTOLITHS IN PLEISTOCENE SEDIMENT FROM THE IOWA POINT SECTION IN DONIPHAN COUNTY, KANSAS. Phytoliths are severly eroded elongate forms and unclassified phytolith fragments.

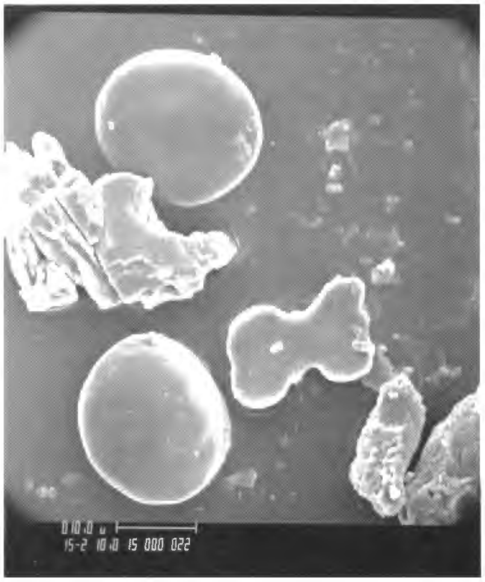

FIGURE 10—SEM PHOTO OF GRAVITY CONCENTRATE OF KANSAS TILL FROM THE IOWA POINT SECTION IN DONIPHAN COUNTY, KANSAS. Two spherical grains of grass pollen, a panicoid phytolith, and three unclassified opalized epidermal fragments are all from grass.

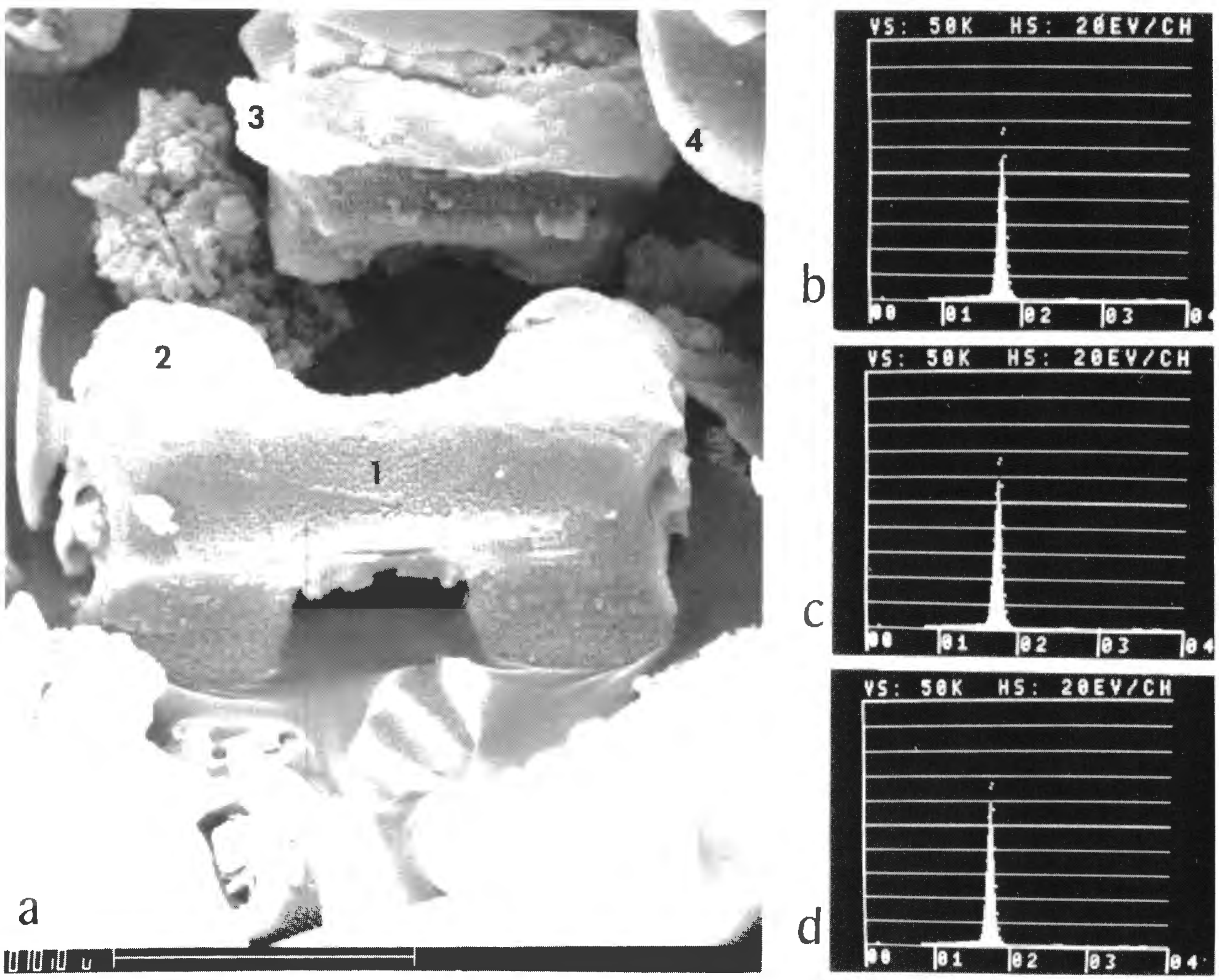

FIGURE 11—MORPHOLOGY AND COMPOSITION OF OPAL EPIDERMAL FRAGMENTS FROM THE LAMINA OF LITTLE BLUESTEM, *SCHIZACHYRIUM SCOPARIUM (ANDROPOGON SCOPARIUS)*. Numerals in **a**) are locations of energy dispersive x-ray fluorescence analyses shown in (**b**), (**c**), and (**d**). Dots in b, c, and d are from location 1; solid peaks in b, c, and d are XRF analyses from 2, 3, and 4, respectively. The silicon peaks indicate that the epidermal fragments are nearly pure silica in the form of opal-A.

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The distribution of paleoindian sites in Kansas

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Abstract

The archeological record of the paleoindian occupation of present Kansas is scant and consists, for the most part, of 27 recorded sites and additional isolated finds of temporally and culturally diagnostic projectile points. A compilation of locational and typological data concerning this record as it is known to date is presented. The few excavated sites of late Pleistocene and early Holocene human populations in Kansas are briefly discussed. An attempt is made to discern any pattern in the association of paleoindian sites with topographic features and soil complexes. It is suggested that the distribution of paleoindian sites in Kansas reflects archeological-survey biases in certain topographic settings, primarily stream valleys, and regions, primarily the eastern half, of the state. Finally, it is suggested that adequate surveys for evidence of paleoindians must coincide with geomorphic research into the age and evolution of the late Pleistocene and Holocene landscape.

Introduction

The archeological record of the paleoindian occupation of present Kansas consists of 27 recorded sites (i.e., those for which site forms have been filed) and isolated finds (tables 1-2, figs. 1-2) of culturally and/or temporally diagnostic projectile points (figs. 3-4). Relative to the record of this period in other states that cover the High Plains region, including Montana, Wyoming, Colorado, Texas, and New Mexico, that in Kansas is scant and as yet poorly understood. The following discussion of the paleoindian period will focus on evidence of the Llano, Folsom, and Plano complexes, which date from about 12,000 to 8,000 yrs B.P.

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TABLE 1—PALEOINDIAN SITES RECORDED IN KANSAS.

Site	Topography	Elevation	Soil complex and slope
14AD318	terrace	1030	Mason silt loam
14AN10	terrace	950	Verdigris silt loam
14AT411	stream bank	—	Kennebec silt loam
14AT412	—	—	Kennebec silt loam
14AT424	terrace	935	Kennebec silt loam
14BT402	bluff top, bluff slope	 —	Holdredge silt loam, 1-3% Uly silt loam, 3-6%
14BN4	alluvium	—	alluvial land; Shelby clay loam, 4-10%; Marshall and Sharpsburg soils, 4-10%
14BU301	gravel pit	—	Olpe–Norge complex, 2-7%
14CS16	terrace	1245	Osage silty clay; Irwin silt clay loam, 1-3%
14DO137	terrace	—	Martin–Oska silty clay loam, 3-6%; Sogn–Vinland complex, 5-20%; Vinland–Martin complex, 7-15%
14GL467	—	—	Ulysses silt loam, 1-3%
14GR618	terrace	985	Chase silty clay loam
14HM314	—	—	active dunes
14JN309	terrace	—	Kennebec silt loam
14KY305	upland	3010	Ulysses-Colby silt loam
14LO1	bluff slope	—	alluvial land
14ML402	uplands	—	Harney silt loam, 0-1% and 1-3%
14MN12	terrace	1340	Verdigris silt loam; Wells clay loam, 3-7%; Clime–Sogn silty clay loam, 3-7%
14MN15	terrace	1400	Verdigris silt loam; Wells loam, 1-3%
14MN16	terrace	1430	Verdigris silt loam; Wells clay loam 3-7%
14MN29	terrace	1450	Verdigris silt loam; Wells loam, 1-3%
14NT604	terrace	—	Uly
14PO1	terrace	—	—
14PO358	—	—	—
14RP8	terrace	1500	alluvial land, breaks
14SH327	terrace	—	broken alluvial land; Morrill clay loam, 3-8%
14SM408	terrace	—	Harney silt loam, 3-7%; Holdredge silty clay loam, 3-7%, Holdredge silt loam, 3-7%; Nuckolls silt loam, 7-12%

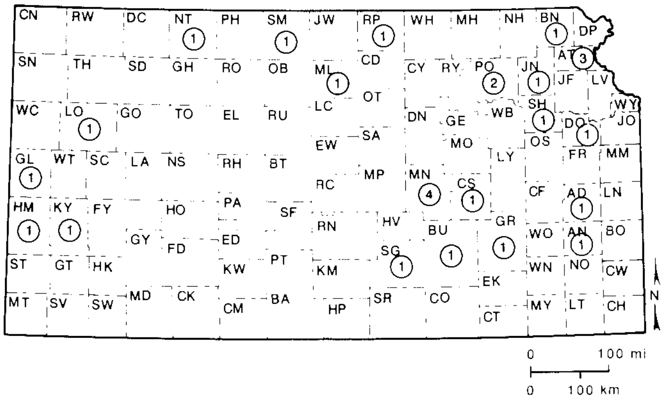

FIGURE 1—MAP SHOWING LOCATION OF RECORDED PALEOINDIAN SITES IN KANSAS ACCORDING TO COUNTY.

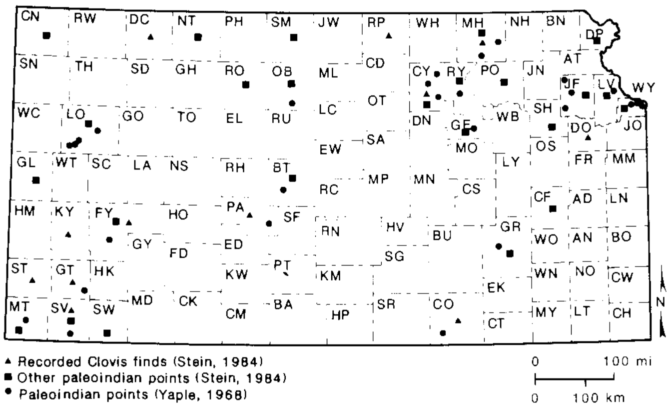

FIGURE 2—MAP SHOWING LOCATIONS, BY COUNTY, OF RECORDED PALEOINDIAN PROJECTILE POINTS (adapted from Yaple, 1968, and Stein, 1984).

Llano complex

The term Llano was originally applied to a complex of artifacts found in direct association with extinct megafauna, especially mammoth, in the southern High Plains (Sellards, 1952). However, Clovis projectile points (fig. 3a), distinctive fluted points diagnostic of this complex, have been found throughout the Great Plains region. Haynes (1970) dates the occurrence of Clovis points between 11,000 and 11,500 yrs B.P. and hypothesizes a "population explosion" keyed to the Two Creeks deglaciation of North America in order to account for the sudden appearance of the Llano complex. The Llano complex in Kansas is known only from surface finds of Clovis points (fig. 5). At present, no sites of this paleoindian complex in Kansas have been excavated and no evidence has been found at any of the known localities of a direct association between Clovis points and extinct fauna.

Folsom complex

The Folsom complex was first recognized in 1926 during the excavation of a bison-kill site near Folsom, New Mexico, by paleontologists from the Colorado Museum of Natural History. The bison remains were identified as *Bison antiquus* (Figgins, 1927). The discovery of 19 fluted projectile points in direct association with the bison bones provided the earliest "accepted" evidence for the contemporaneity of humans and Pleistocene fauna in North America. The Folsom complex is radiocarbon dated from about 10,200 to 10,850 yrs B.P. (Frison, 1978, p. 23; Frison and Zeimens, 1980, p. 231). Technologically, the Folsom point (fig. 3b) developed from the earlier Clovis-point form. Folsom points are distributed throughout the High Plains region and have been reported as far east as northeastern Kansas (Wedel, 1959, p. 537) and Missouri (Chapman, 1975, p. 60–94). Surface finds of Folsom points occur throughout Kansas (Yaple 1968; Glover 1978; Stein 1984; fig. 6).

Although the Folsom site in New Mexico was the first "accepted" evidence for the presence of humans in North America during the late Pleistocene, the first discovery by professionals of a human artifact in direct association with extinct mammals on this continent occurred in Kansas, at the 12 Mile Creek site (14LO1), in 1895. The 12 Mile Creek site, located along a small tributary of the Smoky Hill River, was excavated by H. T. Martin and T. R. Overton of the University of Kansas Paleontology Department (Williston, 1902, 1905; Sellards, 1947, p. 965). During excavation of fossil bison that were eroding out of a cut-bank, a projectile point was found beneath a scapula. At that time, however, the clear association of an artifact with late Pleistocene fauna did not have any effect on the anthropological community (Rogers, 1984, p. 76–78; Rogers and Martin, 1984). A recent revision of data from the site included two radiocarbon-age determinations of a bison tibia. The apatite fraction was dated to $10{,}435 \pm 260$ yrs B.P. (GX-5812-A) after being C–13 corrected and the bone-gelatin fraction was dated to $10{,}245 \pm 335$ yrs B.P. (Rogers and Martin, 1984, p. 758).

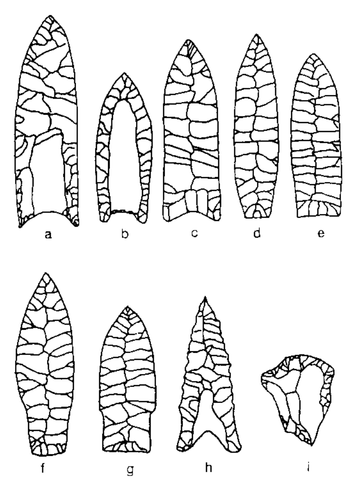

FIGURE 3—ILLUSTRATIONS OF PALEOINDIAN PROJECTILE POINTS (A–H) AND "SPURRED SCRAPER" (I): **a)** Clovis, **b)** Folsom, **c)** Plainview, **d)** Agate Basin, **e)** Firstview, **f)** Hell Gap, **g)** San Jon, and **h)** Meserve/Dalton. (e) and (g) are from Wheat, 1972; (i) is from Frison, 1978.

The projectile point recovered from the 12 Mile Creek site was stolen shortly after its discovery. Its typological identification has been based on a photograph and crude drawings of the find. On the basis of a review of the

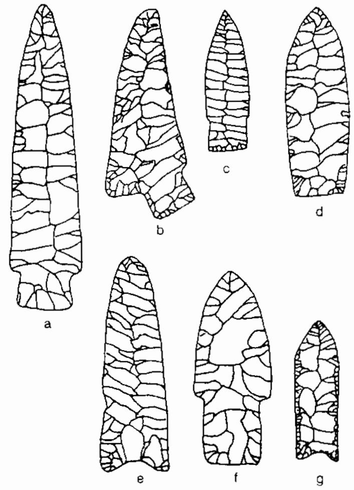

FIGURE 4—Illustrations of paleoindian projectile points: **a**) Scottsbluff, **b**) Cody Knife, **c**) Eden, **d**) Milnesand, **e**) Frederick (Myers, 1977), **f**) Alberta, and **g**) Midland. (b) is from Frison, 1978.

photograph, Rogers (1984) and Rogers and Martin (1984, p. 781) classify it as a Clovis point. Given the radiocarbon dates from the associated bison bone, however, such an identification is not consistent with the temporal range of the Llano complex. Moreover, its identification as Clovis from the photograph is debatable because the presence of a flute is not clear. Regarding the projectile point as it appears in this photograph (Williston, 1905, p. 336), Wedel (1959, p. 89) has stated that

> it appears to have had a relatively short broad outline, with convex edges and slightly concave base; there are no shoulders nor is there definite fluting of the faces. There is nothing outstanding in the chipping and workmanship. It does not conform closely to any of the recognized early Plains types, such as Folsom fluted, Clovis, San Jon, Eden, Scottsbluff, Plainview, etc., although Howard (1935, p. 144) thought it resembled "a rather crude type of Folsom-like point. . ."

Rogers and Martin (1984, p. 761), however, state "the photograph shows a projectile point with a concave base, a flute, and a somewhat asymmetrical point with an indentation on one side of the tip." They go on to say "the radiocarbon dates of this bison kill are somewhat surprising because they suggest that Clovis projectile points were

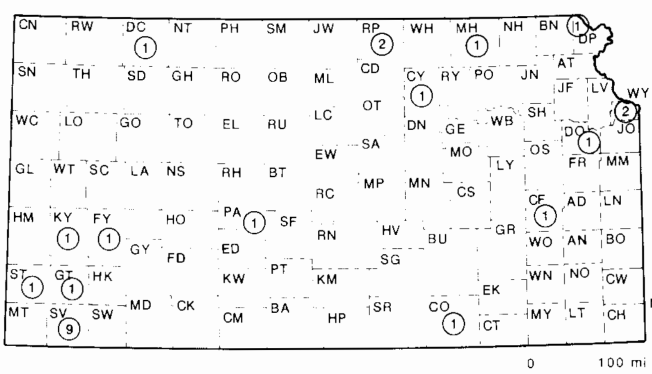

FIGURE 5—Locations of Clovis projectile-point finds.

being used at a time period when one would expect to find Folsom projectile points" (Rogers and Martin, 1984, p. 761). The 12 Mile Creek site, where a single projectile point of no definite typological identity was found in association with the remains of an extinct form of bison, cannot be satisfactorily assigned to the Llano complex. A more supportable interpretation, one consistent with the radiocarbon dates, the faunal association, and the presently accepted range of the Llano, Folsom, and Plano complexes, is that the 12 Mile Creek site is a Folsom or transitional Folsom/Plano site.

Plano complexes

Paleoindian complexes, collectively referred to as Plano, that temporally overlapped and succeeded the Folsom complex are characterized by a variety of chipped stone projectile point and knife forms with parallel flaking and the absence of fluting (figs. 3c–g, 4). Named projectile-point forms that are attributed to Plano complexes and that have been reported in Kansas include Plainview, Hell Gap, Meserve/Dalton, Milnesand, Midland, Agate Basin, Scottsbluff, and Eden (table 2, figs. 7–9). Most of the Plano point-type designations refer to the sites in the High Plains region at which they were first discovered. These sites generally consist of large mammal-kill and butchering sites. Because of the paucity of information regarding the Plano sites in Kansas, almost all the information concerning them must come from other areas of the High Plains. The following summaries of Plano complexes are primarily from Frison (1978, p. 31–40, 1983, p. 109–124).

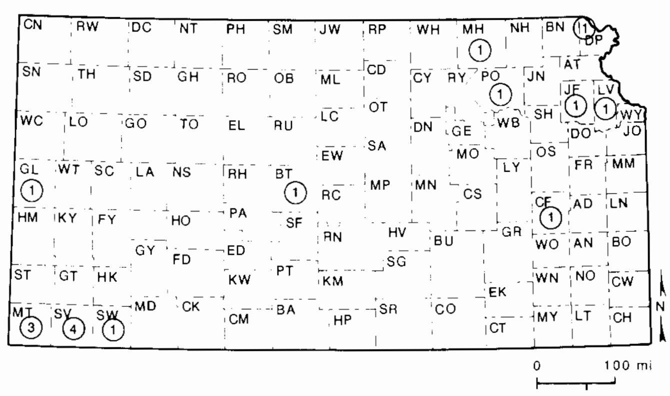

FIGURE 6—Locations of Folsom projectile-point finds.

Agate Basin complex

The Agate Basin complex is radiocarbon dated between 10,500 and 10,000 yrs B.P. The best sequences for this complex are provided by the Hell Gap and Brewster sites in Wyoming. The characteristic artifact of the complex is the Agate Basin point (fig. 3d). The complex is restricted to the northern and northwestern part of the Central Plains (Frison, 1978, 1983).

Plainview complex

The Plainview complex is radiocarbon dated between approximately 11,000 to 10,000 yrs B.P., or contemporaneous with the Agate Basin complex. The Plainview

TABLE 2—FREQUENCIES OF REPORTED PALEOINDIAN PROJECTILE POINTS IN KANSAS BY COUNTY.

Clovis		Folsom		Plainview		Plano		Hell Gap		Meserve/Dalton		Agate Basin		Scottsbluff		Midland		Eden	
Clay	1	Barton	1	Barton	1	Clay	1	Cheyenne	1	Jefferson	2	Morton	4	Morton	1	Stevens	1	Morton	1
Coffey	1?	Coffey	1	Doniphan	1	Geary	1	Norton	1	Leavenworth	1	Stevens	1	Stevens	4				
Cowley	1	Doniphan	1	Finney	1	Grant	2	Saline	1	Stevens	5								
Decatur	1	Greeley	1?	Jefferson	2	Greenwood	1	Wyandotte	1	Wyandotte	7								
Doniphan	1	Jefferson	1	Marshall	4	Leavenworth	1												
Douglas	1	Leavenworth	1	Norton	1	Logan	4												
Finney	1	Marshall	1	Rooks	1	Morton	4												
Grant	1?	Morton	3	Stevens	8	Osborne	1												
Kearney	1	Pottawatomie	1	Morton	6	Riley	1												
Marshall	1	Seward	1	Leavenworth	1	Shawnee	1												
Pawnee	1	Stevens	4			Smith	1												
Stanton	1?					Stanton	1												
Stevens	8 + 1?					Stevens	15												
Republic	2					Wyandotte	1												
Wyandotte	1																		

Milnesand	
Stevens	1
Wyandotte	1

complex, however, occurs in the Central and Southern plains. The characteristic point of this complex is the Plainview point (fig. 3c). Technologically, a direct relationship may exist between Plainview and Folsom points. The best sequence for the Plainview complex is at the Lubbock Lake site in Texas (Johnson and Holliday, 1980; Frison, 1983, p. 114). Figure 8 presents the distribution of Plainview points in Kansas.

Hell Gap complex

The Hell Gap complex is radiocarbon dated between 10,000 and 9,600 yrs B.P. The best sequences for this complex are the Casper, Agate Basin, Sister's Hill, Carter/Kerr-McGee, and Jones-Miller sites of the High Plains (Frison, 1978, 1983). The Jones-Miller site is nearest to Kansas, located in northeast Colorado near the town of Wray. The characteristic artifact of the Hell Gap complex is the Hell Gap point (fig. 3f). Technologically, the Hell Gap point may be derived from the Agate Basin point type.

O'Brien (1984) reports a Hell Gap quarry site in Norton County, northwest Kansas. This site, the Tim Adrian site (14NT604), is unique because it is believed to represent a quarry and associated workshop. All other reported Hell Gap sites are associated with mass bison kills and butchering activities. Test excavations were conducted at the Tim Adrian site in 1981 by personnel from Kansas State University (O'Brien, 1984). Recovered cultural remains included "spurred" endscrapers (fig. 3i), bifaces, choppers, cores, and the base of a Hell Gap point. This material was confined to the upper 10 cm of the site area and had been subject to agricultural disturbance. The Tim Adrian site is noteworthy, however, because it represents a different activity from that most commonly associated with other Hell Gap sites and provides information on the lithic-procurement aspect of paleoindian lifeways. This site is one of only three late paleoindian or transitional paleoindian/Early Archaic sites in Kansas to have been excavated or tested.

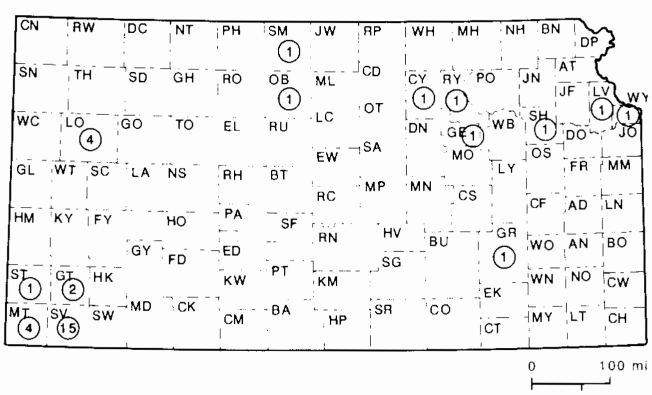

FIGURE 7—LOCATIONS OF PLANO PROJECTILE-POINT FINDS.

Meserve/Dalton complex

The Meserve/Dalton complex is radiocarbon dated between 10,000 and 9,000 yrs B.P. Myers and Lambert (1983) suggest that the Meserve biface, a late paleoindian-Early Archaic point commonly found in the mixed- and short-grass prairie-plains of Nebraska and Kansas, is conspecific with similar Dalton points of the eastern deciduous woodland. On the basis of that identification, they hypothesize that peoples with a Dalton point-reduction technology exploited the oak-hickory gallery forests that threaded the Central Plains. They suggest that the Meserve/Dalton folk of the Central Plains were a clinal variant of the more broadly dispersed Dalton culture complex and that their settlement-subsistence practices were probably characterized by a greater reliance on both woodland and prairie resources than those of the Dalton folk. The best sequences for the Dalton complex are from Graham Cave and Arnold Research Cave in eastern Missouri. The combined Meserve/Dalton complex is characterized by the Meserve/Dalton point or knife (fig. 3h). The complex is widespread and surface finds of Meserve/Dalton points have been reported in Kansas (Reichart, 1974, 1976; Logan, 1981; Rogers and Martin, 1983). Technologically, these points probably developed from preceding fluted-point forms found in the eastern woodlands.

Cody complex

The Cody complex is radiocarbon dated between 8,800 and 8,400 yrs B.P. The best sequences for the complex occur at the Horner, Finley, Medicine Lodge Creek, and Hell Gap sites. The characteristic artifacts of the Cody complex are the Scottsbluff and Eden points and the Cody knife (fig. 4a-c).

Site 14SG516, located near Wichita, may have a Cody complex component. Test excavations indicated the presence of a possible campsite. If the suggested cultural affiliation is correct, this site is noteworthy because it occurs within the southernmost range of the Cody complex and because it is a campsite rather than a "kill site," a site type more commonly associated with the Cody complex. No further investigations which might have supported the suggested cultural identification, however, were conducted at the site (Hovde and Blakeslee, 1977).

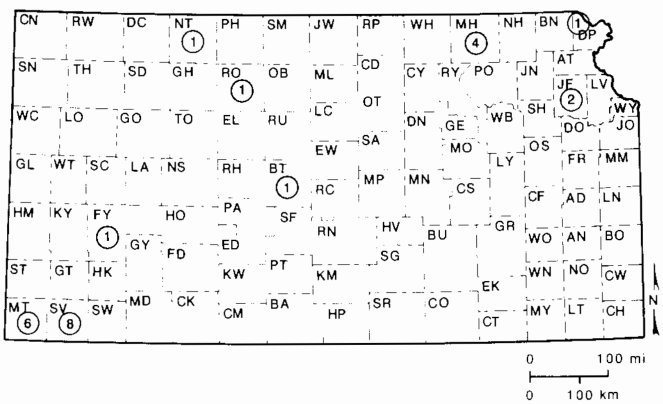

FIGURE 8—LOCATIONS OF PLAINVIEW PROJECTILE-POINT FINDS.

Frederick complex

The Frederick complex, which is not well defined and has few excavated components, is radiocarbon dated between 8,400 and 8,000 yrs B.P. The best sequence for this complex is at the Hell Gap site. The Frederick complex is characterized by lanceolate projectile points with parallel-oblique pressure flaking and without shoulders and stems (Frison, 1978, 1983; fig. 4e). The occupation at zone III of the Lime Creek site in southwestern Nebraska is assigned to the Frederick complex by Wheat (1972, p. 144). A Frederick point has been recovered from the Republican River in south-central Nebraska (Myers, 1977).

The Sutter site (14JN309), located on the west fork of Muddy Creek in Jackson County, Kansas, is believed to have a Frederick component. Salvage archeological investigations at this site, buried below some 30 ft (9 m) of deposits, resulted in recovery of lanceolate and square-stemmed projectile points, blades, and a large scraper that Katz (1971) suggests compare favorably to the Frederick and McKean complexes of the northwestern Plains. Three accepted radiocarbon dates from the site place the occupation of the Sutter site at 7,990 ± 245 to 7,668 ± 237 yrs B.P. (Katz, 1972). Katz (1971, p. 17) interprets this site as evidence that its hunter-gatherer occupants procured modern bison that probably became mired in a nearby bog on the valley floor and then processed them in the immediate vicinity of the kill. The presence of a fire area, consisting of charcoal and burned earth, suggests consumption of the game at the site as well. Two handstones and two grinding slabs were recovered and these are interpreted as evidence that plant-food processing also occurred. The quantity of lithic artifacts and animal remains indicated "intensive or lengthy activity in the valley" (Katz, 1971, p. 17). The radiocarbon dates, associated modern fauna, and evidence for plant-food processing suggest this site is transitional from a paleoindian to an Archaic form of adaptation in north-central Kansas between 7,500 and 8,000 yrs ago. The deep burial of the cultural material from the Sutter site suggests other sites of that age in alluvial settings in the Central Plains may occur in similar geomorphic contexts.

Site and soil-topography associations and distributions of projectile points

Soil complexes, as defined by the Soil Conservation Service, for the 27 recorded paleoindian sites of Kansas are shown in table 1. Site frequencies and relative percentages of sites and their soil associations are shown in table 3. Frequencies of sites and their topographic contexts also are shown in table 3. Because of the low site frequencies, no detailed inferences or conclusions can be obtained from the soil complex and topographic associations. However, a few general trends are observable in the data. Concerning soil associations, paleoindian sites are most frequently found associated with the Verdigris, Wells, Harney, Holdredge, and Kennebec soil complexes. Recorded paleoindian sites are most frequently associated with terraces. Examination of both the soil and topographic data indicates over 60% of the recorded paleoindian sites are associated with river and stream valleys. This suggests two possibilities: 1) a bias has been towards surveys of river valleys and subsequent site-locational information is, therefore, also biased, or 2) the present site-locational data are representative of reality and few paleoindian sites are located on bluff slopes, bluff tops, and the uplands. Because of the small sample size, no definitive conclusions can be made; however, the former situation is believed likely. That is, a bias exists in present survey methods toward river valleys. Paleoindian sites are likely to occur in high frequencies in other topographic contexts. In addition, recorded paleoindian sites are biased toward the eastern part of the state (fig. 1).

Two prior studies have been done regarding the distribution of paleoindian projectile points in Kansas (Yaple, 1968; Stein, 1984). Most of the locations of these reported paleoindian points used in their studies are "isolated finds" and few have been systematically field checked and verified by professional archeologists. Site forms, therefore, have not been recorded for most of these projectile-point finds. Figure 2 is a composite map of projectile-point distributions by Yaple (1968) and Stein (1984).

The recorded-site information files (fig. 1) do not agree, in distribution of paleoindian projectile-point types, with the "surface finds" reported in the literature (Yaple, 1968; Glover, 1978; Stein, 1984). Table 2 shows a compilation of "surface find" information from the above sources, in addition to others. Figures 5–9 show the distributions of the reported surface finds for each of the major paleoindian projectile-point types. Several trends are apparent. Clovis points tend to be distributed throughout the entire state (fig. 5), with large gaps in the Smoky Hill and Arkansas River drainages. At present, a study of the Arkansas River area is being conducted by the Archeology Laboratory at Wichita State University. This spatial-data gap, therefore, is currently being addressed (Arthur Rohn, personal communication, 1985). The data for their study, however, are not presently available. High expectations are anticipated for the results of their study. Regarding the Smoky Hill River drainage, the lack of reported Clovis points from this region is attributed to the general lack of surveys conducted by professional archeologists. The reconnaissance conducted by Glover (1978) in Morton and Stevens counties indicates the potential for finding local collectors who possess a wide variety of paleoindian projectile-point types.

Folsom projectile points also have been recovered from portions of the entire state (fig. 6). Several "gaps" exist where Folsom points have not been reported and these include the Arkansas, Smoky Hill, Upper Republican, and Solomon River drainages. The distribution for reported "surface finds" of Folsom points also is attributed to the lack of systematic surveys in western Kansas to locate paleoindian sites, with the exception of Glover's (1978) investigation.

The distribution of Plano points in general is presented in fig. 7. As a whole, these points have been reported from most regions of the state. The distribution of Plainview points (fig. 8) is similar to that for Folsom points. The distribution of other paleoindian points that have been reported in Kansas including the Hell Gap, Meserve/Dalton, Milnesand, Midland, Agate Basin, Scottsbluff, and Eden point types, is shown in fig. 9. Most of these point types occur in western Kansas. Notable exceptions include the Meserve/Dalton point type, which, not surprisingly, is more frequently encountered in the tallgrass prairie-deciduous woodland ecotone area in the northeastern part of the state. Meserve/Dalton points have been found in Doniphan (Wedel, 1959, p. 537), Jefferson (Reichart, 1974), and Leavenworth (Logan, 1981) counties.

The discrepancies between the number of recorded paleoindian sites and reported "surface finds" are attributed to several factors. These include, but are not limited to, the greater time depth for these sites that has permitted natural agents to destroy site integrity. Most of the reported "surface finds" are in topographic contexts not conducive to site preservation, such as unstable sand (e.g., the Cimarron River drainage) and river channels. In brief, the distribution of reported "surface finds" shows a greater density and spatial distribution of paleoindian localities in the state than would otherwise be determined by examination of only recorded sites (fig. 1). In situ paleoindian sites are expected to be of low visibility because they are buried in alluvial and loessal deposits.

Given the deep burial of sites dating to the late Pleistocene and early Holocene, such as the Sutter site, and the fact that most of the recorded finds of Paleoindian points have occurred on stream terraces, future archeological surveys aimed, in whole or in part, at the discovery of paleoindian sites must be conducted in tandem with geomorphological investigations that address the age and evolution of the late Pleistocene and Holocene landscape (e.g., Rogers, this volume). For example, current geoarcheological research in the lower Kansas River basin demonstrates the differential effects of fluvial processes in preserving or eroding late Pleistocene–early Holocene deposits and any archeological evidence they may have contained (Logan, 1985; Logan and Johnson, 1986). Paleosols buried beneath the Newman terrace at two localities on the lower Kansas River have been dated by the carbon-14 method at 7,250 ± 115 yrs B.P. (DIC 2946) and 10,430 ± 130 yrs B.P. (BETA 2931), indicating the fill was being deposited during late Pleistocene and early Holocene time (Johnson and Martin, this volume). The presence of at least one buried soil that dates to a time when paleoindian groups occupied the Central Plains indicates some potential for discovering evidence of their activities. It is interesting that the Newman terrace constitutes 50% of the valley floor from the city of Topeka downstream to the village of Eudora and that below Eudora it has been largely destroyed by lateral planation. Along the latter reach, perhaps not entirely by coincidence, sand and gravel bars contain skeletal remains of Rancholabrean fauna, including mam-

TABLE 3—PALEOINDIAN SITES AND ASSOCIATED TOPOGRAPHIC AREAS AND SOIL COMPLEXES.

SITES AND TOPOGRAPHIC CONTENT

Unknown	T	U	SB	BT–BS	A	BS	GP
5	15	2	1	1	1	1	1
18.5%	55.6%	7.4%	3.7%	3.7%	3.7%	3.7%	3.7%

Key:
T: terrace
U: uplands
SB: stream bank
BT: bluff top
A: alluvium
BS: bluff slope
GP: gravel pit

SITES AND ASSOCIATED SOIL COMPLEXES

Soil complex	Number of sites	Percentage
active dunes	1	2.4
alluvial lands	2	4.8
broken alluvial lands	2	4.8
Chase	1	2.4
Clime	1	2.4
Goshen	1	2.4
Harny	3	7.1
Holdredge	3	7.1
Irwin	1	2.4
Kennebec	4	9.4
Marshall	1	2.4
Martin	1	2.4
Mason	1	2.4
Morrill	1	2.4
Nuckolls	1	2.4
Olpe	1	2.4
Osage	1	2.4
Richfield	1	2.4
Shelby	1	2.4
Sogn	1	2.4
Uly	1	2.4
Ulysses	2	4.8
Verdigris	5	11.8
Vinland	1	2.4
Wells	4	9.4
Unknown	3	

moth, mastodon, musk ox, sloth, peccary, and stag moose (Martin et al., 1979) and the few finds of fluted projectile points that form our only evidence to date of the presence of paleoindians in the Kansas River valley (Rogers and Martin, 1982, 1983). Although not yet demonstrated conclusively, such finds may reflect, in part, the erosion and redeposition of Newman terrace deposits. In this case, geomorphological investigation of the age of the Newman terrace fill and its relative presence or absence in certain areas along the lower Kansas River provides a predictive guide for archeologists who seek the most promising areas of in situ deposits that date to the paleoindian period.

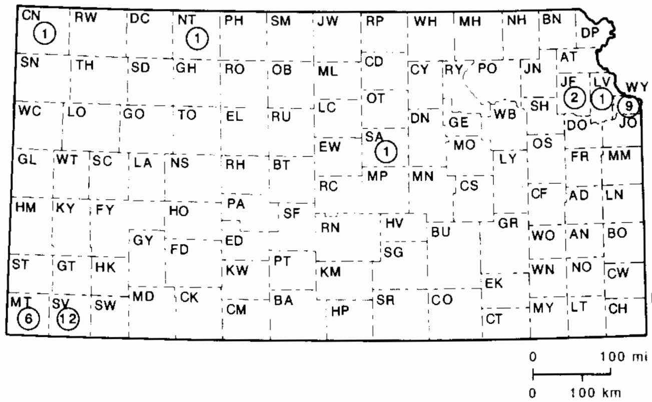

FIGURE 9—LOCATIONS OF HELL GAP, MESERVE/DALTON, AGATE BASIN, SCOTTSBLUFF, MIDLAND, EDEN, AND MILNESAND PROJECTILE-POINT FINDS.

Conclusions

The archeological record of the paleoindian occupation of Kansas as it is presently known is poor. However, the distribution of paleoindian sites and "isolated finds" of diagnostic projectile points throughout the state and with regard to their topographic contexts suggests the record reflects a survey bias and not necessarily the fact that the paleoindian occupation was ephemeral. Moreover, it is becoming increasingly clear that future attempts to correct the survey biases of the past must be carried out in conjunction with geomorphological investigations of the age and evolution of late Pleistocene and Holocene landforms.

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Frequency of occurrence of paleoindian sites in the Neosho River drainage of Kansas—a geomorphological analysis

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Abstract

Paleoindian sites have been considered to be rare in the state of Kansas (see Logan and Brown, this volume). A stream-terrace analysis of the Neosho drainage suggests that paleoindian sites are relatively abundant on stream terraces of Wisconsinan age. Archeological sites with diagnostic paleoindian artifacts represented approximately 28% of all sites on the Wisconsinan terraces, and this figure should be considered a minimal estimate.

Introduction

Kansas archeologists have been puzzled for many years by the relative lack of paleoindian sites in the state; whereas, a number of important paleoindian sites have been excavated in the neighboring states of Colorado, Wyoming, Nebraska, Missouri, and Oklahoma, and a significant number of paleoindian surface sites have been found in some of these areas. The only buried paleoindian site from Kansas is the 12 Mile Creek site, excavated in 1895 (Williston, 1902; Rogers and Martin, 1984). A few surface indications of a Kansas paleoindian presence have been found (Witty, 1964; Yaple, 1968; O'Brien, 1972, 1984; Reichart, 1972; Glover, 1974; and Rogers and Martin, 1982, 1983), but these sites represent only a very small proportion of the total number of prehistoric sites identified in the state.

An analysis of stream terraces was undertaken to see if a geomorphological explanation existed for the apparent lack of paleoindian material in Kansas. The area analyzed was the Neosho River drainage (Arkansas River drainage) in southeastern Kansas (fig. 1A). Because much of the archeological field work in the state of Kansas has been done in stream valleys, it was thought appropriate that stream-terrace analysis should be used to examine the cause of the scarcity of paleoindian sites in Kansas.

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Stream-terrace analysis

The stream terraces of the Neosho River drainage of southeastern Kansas were surveyed for archeological sites. One hundred and one sites were found on four terraces. These terraces chronologically span the Wisconsinan and the Holocene. The floodplain (Terrace 0) and Terrace 1 were formed during the Holocene and contain artifacts from the Ceramic Period and the Archaic Period (including the early Archaic). These Holocene terraces contain the remains of *Bison bison* but not the remains of extinct Pleistocene megafauna. The remains of *Mammuthus* sp. and *Equus* sp. were recovered from both Terrace 2 and Terrace 3 but not the remains of Holocene *Bison bison.* Fluted projectile points were recovered from sites on Terrace 2. The presence of Pleistocene fauna and fluted points on Terrace 2, but not on Terrace 1, strongly indicates that the break between Terrace 2 and Terrace 1 marks the Wisconsinan–Holocene boundary. Additional support for this interpretation was the absence of Holocene *Bison bison* on Terrace 2 and the presence of early Holocene cultural material on Terrace 1. The heights of the terraces and what diagnostic taxa of fauna were found in the terraces are illustrated in fig. 1B. Terrace 4 was not intensively surveyed for archeological sites and therefore was not included in the analysis. The dental morphology of a mammoth molar recovered from Terrace 4 suggested a middle Pleistocene date. For further information on the dating, geomorphology, and other details of this terrace system, see Rogers (1984).

The inhabitants of the area at any particular time period could camp on the active floodplain or on any of the higher terraces but not on floodplain surfaces that had yet to form. Thus, older archeological sites will be found on or within higher terraces and not on or within lower terraces whose surfaces or fills had not come into existence at the time of occupation. This applies to both surface sites and buried sites. The break between the Wisconsinan and Holocene occurs between Terrace 2 and Terrace 1. This provides an opportunity to examine two different categories of archeologically relevant land surfaces: Terrace 2 and Terrace 3, which could have been occupied either during the Wisconsinan or the Holocene, and the floodplain (Terrace 0) and Terrace 1, which could have been occupied only during the Holocene.

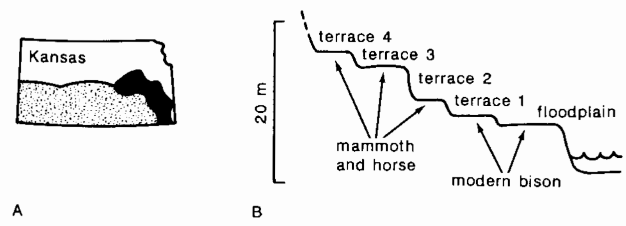

FIGURE 1—A) Map of Kansas illustrating extent of Neosho River drainage (solid area) and larger Arkansas River drainage (stippled area) of which Neosho River drainage is part. B) An idealized cross section of half a stream valley in Neosho River drainage, illustrating heights of terraces and typical fauna recovered from each terrace.

A study of the paleoindian occupation in this terrace system obviously would focus on Terrace 2 and Terrace 3, the only terrace surfaces that would be relevant chronologically. This would be a stratified sample (Binford, 1964).

Diagnostic artifacts used to indicate the existence of a paleoindian component were fluted projectile points and spurred end scrapers. The fluted projectile points all were Clovis projectile points except for one Folsom projectile point, and all probably would date prior to 10,000 yrs B.P. Spurred end scrapers are a probable diagnostic paleoindian artifact type (Frison, 1978). The number of sites examined on each terrace was 21 on the floodplain (Terrace 0), 51 on Terrace 1, 11 on Terrace 2, and 18 on Terrace 3.

Eight of the 101 archeological sites examined yielded either fluted projectile points, spurred end scrapers, or both. This is approximately 8% of the total number of sites. None of the sites with these diagnostic paleoindian artifacts was found on Terrace 1 or the floodplain. However, they represented approximately 45% of the sites on Terrace 2, approximately 17% of the sites on Terrace 3, and approximately 28% of the Terrace 2 and Terrace 3 sites combined. All fluted projectile points and spurred end scrapers were recovered from the surfaces of the sites. All were found on the scarps of the terraces, which leaves open the possibility that they may have been eroding from buried components in the terraces. Future excavation is needed to determine the positions of these artifact classes relative to the terrace fills. Terrace analysis can chronologically sort archeological data from either surface or buried sites. Additional information on the artifacts recovered from the sites found on the terraces can be found in Rogers (1984).

The difference in terrace distribution of sites with diagnostic paleoindian artifacts can be examined statistically. The Kolmogorov–Smirnov One Sample Test (Siegel, 1956, p.47–52) was used for statistical analysis. The actual proportion of sites on a terrace with diagnostic paleoindian artifacts is the number of such sites found on a terrace compared to the total number of such sites on all terraces. The expected proportion of sites on a terrace with diagnostic paleoindian artifacts (assuming random distribution) is the proportion of the number of sites on the terrace to the total number of sites on all terraces.

The actual proportion of sites with diagnostic paleoindian artifacts compared to the expected proportion for the floodplain was .0000 compared to .2079; for Terrace 1, .0000 compared to .5050; for Terrace 2, .6250 compared to .1089; and for Terrace 3, .3750 compared to .1782. These differences are statistically significant at the .05 level when analyzed by the Kolmogorov–Smirnov One Sample Test.

Conclusions

The absence of sites with diagnostic paleoindian artifacts on the floodplain (Terrace 0) and Terrace 1 is in agreement with the dating of these terraces as Holocene. These Holocene terraces comprise the bulk of the area of the stream valleys of the Neosho River drainage. This suggests that stream erosion during the Holocene destroyed much of the Wisconsinan land surfaces in the stream valleys where the paleoindian inhabitants would once have camped. This is particularly true of Terrace 2, which is not extensively preserved. Because stream valleys have been the focus of much of the archeological effort in the state of Kansas, it is not surprising that paleoindian sites have seemed to be rare, especially when concerted efforts were not made to locate and to survey Wisconsinan terraces.

The survey in this study indicated that 28% of the sites on the Wisconsinan terraces had paleoindian affinities. This should be considered a minimal estimate because many of the sites occupied by paleoindians may not have yielded diagnostic artifacts. Paleoindian sites would not seem to be rare in this area if the chronologically appropriate terraces were searched.

Particularly interesting is the observation that 45% of the sites on Terrace 2 yielded diagnostic paleoindian artifacts. Terrace 2 is composed of remnants of the floodplain that was active during the end of the Wisconsinan when populations known to have used fluted projectile points and spurred end scrapers were living in the area. Proportionately fewer sites (17%) with these diagnostic artifacts are found on Terrace 3. This suggests that paleoindians, when residing in these stream valleys, may have preferentially camped on the lowest terrace surface, perhaps to keep as near to water as possible. The limited technology that hunter-gatherers would have possessed to contain and to transport water would favor this interpretation.

Different problems present themselves when the paleoindian record outside the stream valleys is analyzed. Extensive Wisconsinan land surfaces may be preserved on the uplands. Unfortunately, almost all the upland areas in the Neosho River drainage are in pasture and any of the possible paleoindian sites there will tend to be "invisible" to standard archeological surveys.

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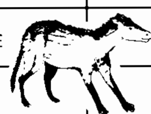
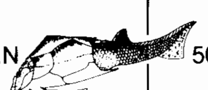
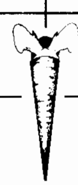
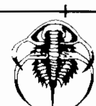
Appendix

Maps and Charts

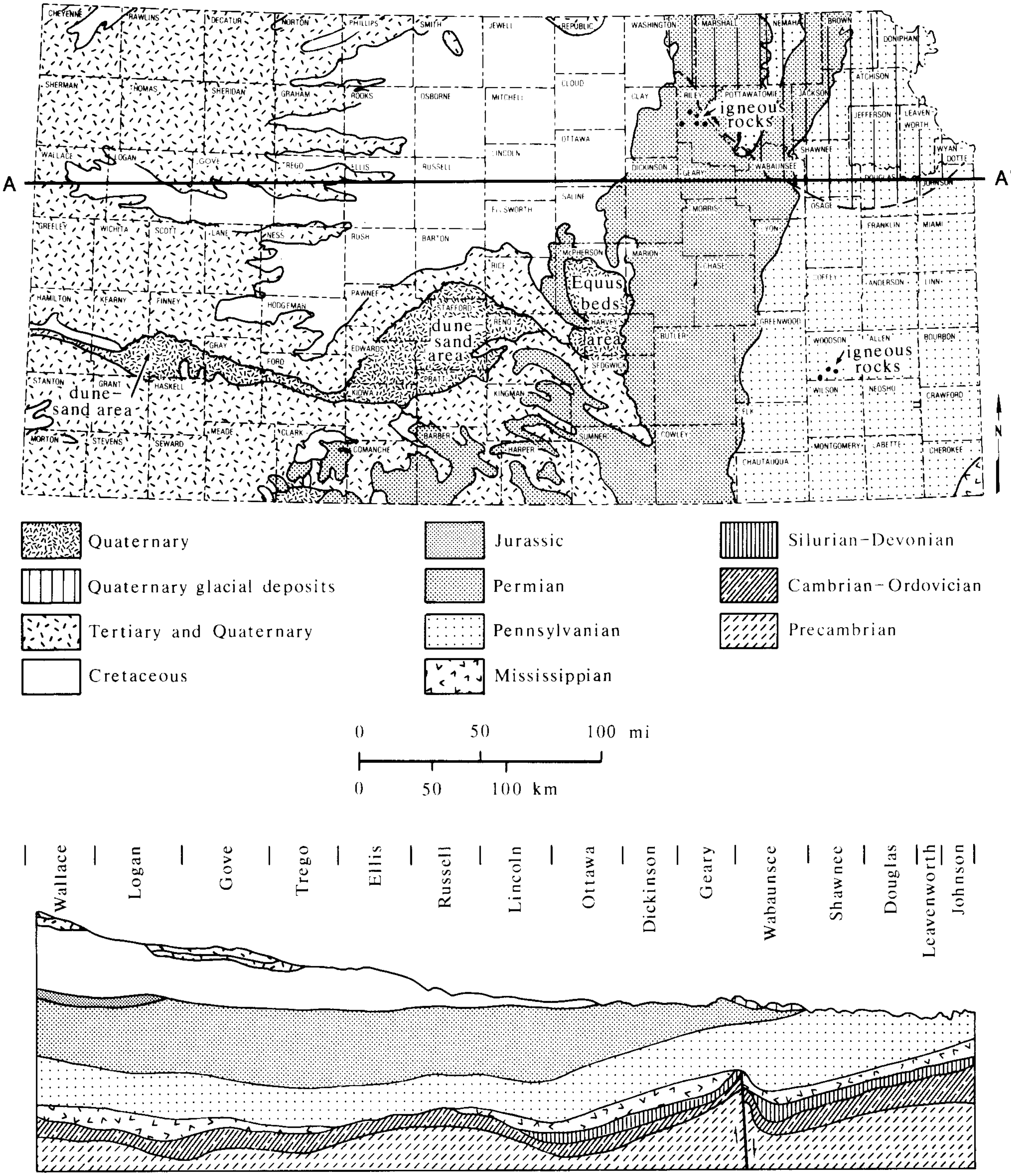
Geologic timetable and Kansas rock chart

(Not scaled for geologic time or thickness of deposits)

ERAS	PERIODS	EPOCHS	EST. LENGTH IN YEARS*	TYPE OF ROCK IN KANSAS	MILLION YEARS PAST
CENOZOIC	QUATERNARY	HOLOCENE	10,000 +	Glacial drift; river silt, sand, and gravel; dune sand; wind-blown silt (loess); volcanic ash.	0.010
		PLEISTOCENE 	1,990,000		2
	TERTIARY	PLIOCENE	3,000,000	River silt, sand, gravel, fresh-water limestone; volcanic ash; bentonite; diatomaceous marl; opaline sandstone.	5
		MIOCENE	19,000,000		24
		OLIGOCENE 	14,000,000		38
		EOCENE	17,000,000		55
		PALEOCENE	8,000,000		63
MESOZOIC	CRETACEOUS		75,000,000	Limestone, chalk, chalky shale, dark shale, varicolored clay, sandstone, conglomerate. Outcropping igneous rock.	138
	JURASSIC		67,000,000	Sandstones and shales, chiefly subsurface. Siltstone, chert, and gypsum.	205
	TRIASSIC		35,000,000		240
PALEOZOIC	PERMIAN		50,000,000	Limestone, shale, evaporites (salt, gypsum, anhydrite), red sandstone; chert, siltstone, dolomite, and red beds.	290
	PENNSYLVANIAN		40,000,000	Alternating marine and nonmarine shale, limestone, sandstone, coal; chert and conglomerate.	~330
	MISSISSIPPIAN		30,000,000	Limestone, shale, dolomite, chert, oölites, sandstone, and siltstone.	360
	DEVONIAN		50,000,000	Subsurface only. Limestone, predominantly black shale; sandstone.	410
	SILURIAN		25,000,000	Subsurface only. Limestone.	435
	ORDOVICIAN		65,000,000	Subsurface only. Dolomite, sandstone.	500
	CAMBRIAN		70,000,000	Subsurface only. Dolomite, sandstone, limestone, and shale.	~570
PRECAMBRIAN			1,930,000,000	Subsurface only. Granite, other igneous rocks, and metamorphic rocks.	
			1,100,000,000 +		3,500

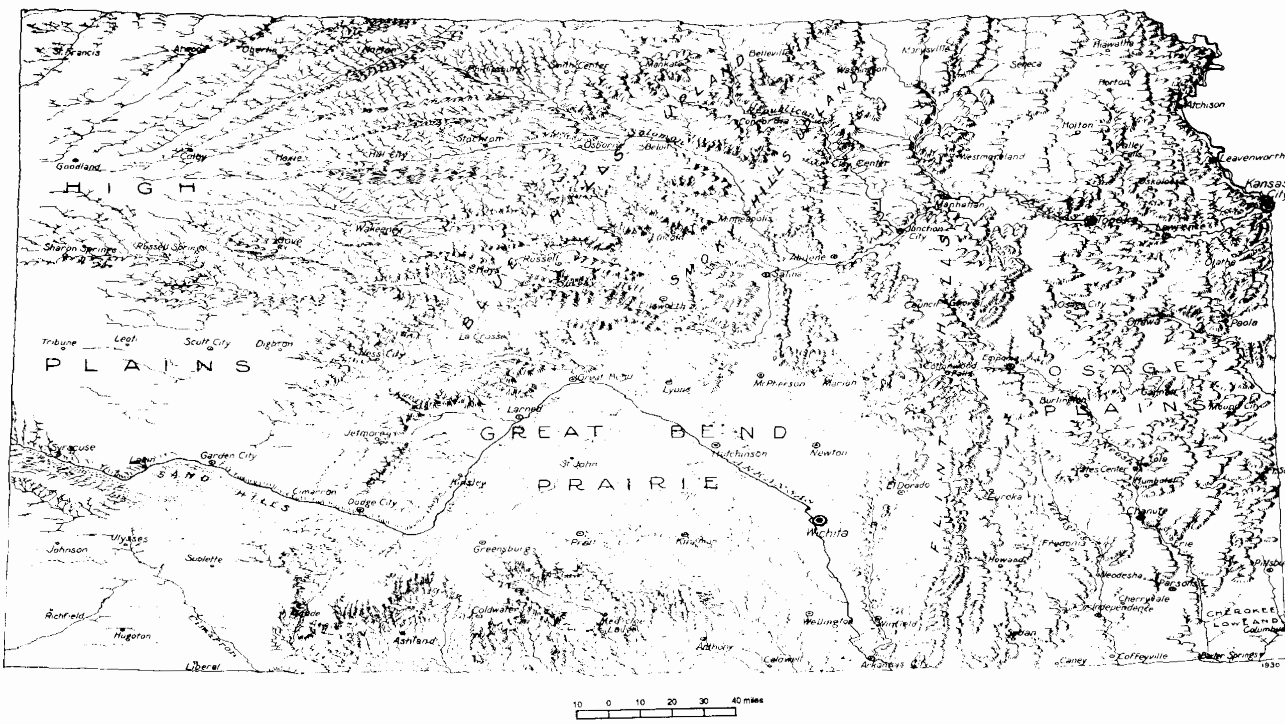
KANSAS GEOLOGICAL SURVEY — Eons not shown. — *U.S. Geological Survey, Geologic Names Committee, 1980

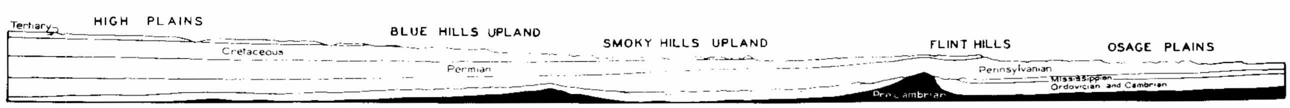
Generalized geologic map and cross section of Kansas



Surface features map of Kansas

by *Raymond C. Moore*





Kansas is part of the Great Plains country that extends for thousands of miles north and south along the east side of the Rocky Mountains. This plain is not flat and featureless. On the contrary, there are innumerable hills and picturesque valleys. In some places the surface of the land slopes steeply, or even precipitously, and local differences in elevation may exceed 400 feet. In parts of western and southwestern Kansas, there are small canyons with steep bare rock walls that call to mind parts of Wyoming or Arizona.

As a whole, the land surface of Kansas slopes eastward from a maximum elevation of 4,135 feet in Wallace County, adjoining the Colorado line, to the lowest point about 700 feet where Verdigris River crosses the Oklahoma boundary from Montgomery County. As shown by the accompanying map there are several natural topographic divisions in Kansas, each distinguished by certain peculiarities of land form, which in turn are explainable for the most part by the nature of the rock formations at the surface in these areas.

The eastern one-third of the state--that is the country east of a north-south line drawn approximately through Wichita and Abilene, belongs in what has been called the **Osage Plains**. They are distinguished by the presence of many east-facing escarpments which trend very irregularly from north to south across the state. The escarpments range in height from 50 feet or less to more than 400 feet, the most prominent being the so-called **Flint Hills** which are very well seen near Manhattan, Cottonwood Falls, west of Eureka and elsewhere. The escarpments are made by the edges of hard limestones which slope gently westward. Between the escarpments are flat or gently rolling plains formed by the softer rocks of this region.

The **Smoky Hills Upland** in the north-central part of the state owes its origin to exposure of moderately hard thick brown sandstone, the Dakota. This formation also forms an east-facing escarpment, but it is somewhat less regular than the limestones and there are numerous outlying hills.

The **Blue Hills Upland**, a short distance to the west, is produced by hard limestone in the Cretaceous. Here there are many long spurs running eastward forming the divides between the east-flowing streams.

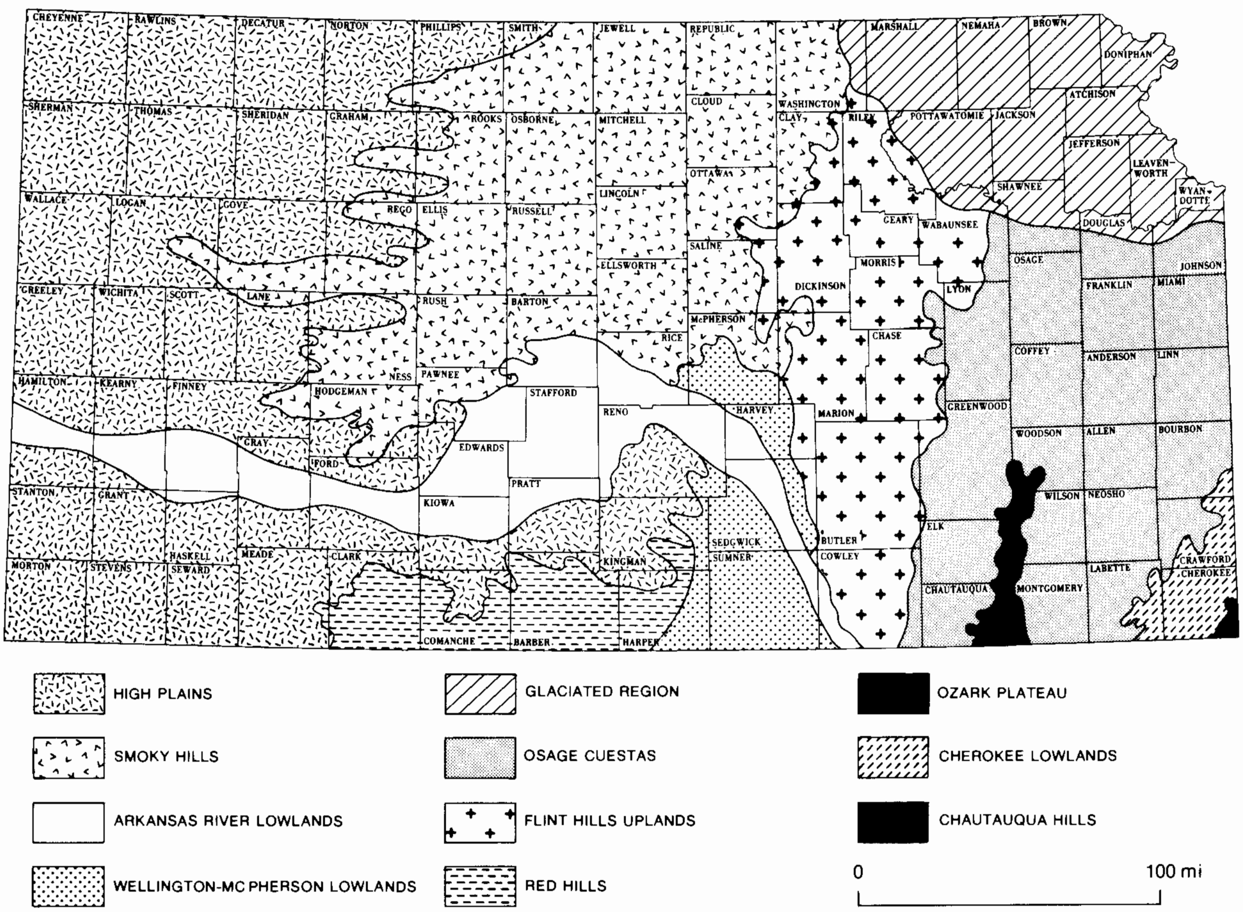
South of the Blue and Smoky hills is a large area of nearly flat land which may be called the **Great Bend Prairie.** It comprises mainly the country embraced by the great bend of the Arkansas River between Dodge City and Wichita, but also the nearly flat region northeast of the river around McPherson and Newton. Parts of this region are very sandy and are covered by many sand dunes or by small hummocky hills that were once sand dunes.

South of the Great Bend Prairie are the **Cimarron Breaks**, in which the higher country to the north and west is suddenly interrupted by a prominent escarpment carved by steep southward-flowing streams, tributaries mostly of the Cimarron and Medicine Lodge. Much of the rock in this area is red shale or fine red sandstone, and accordingly both rock exposures and soils are colored red.

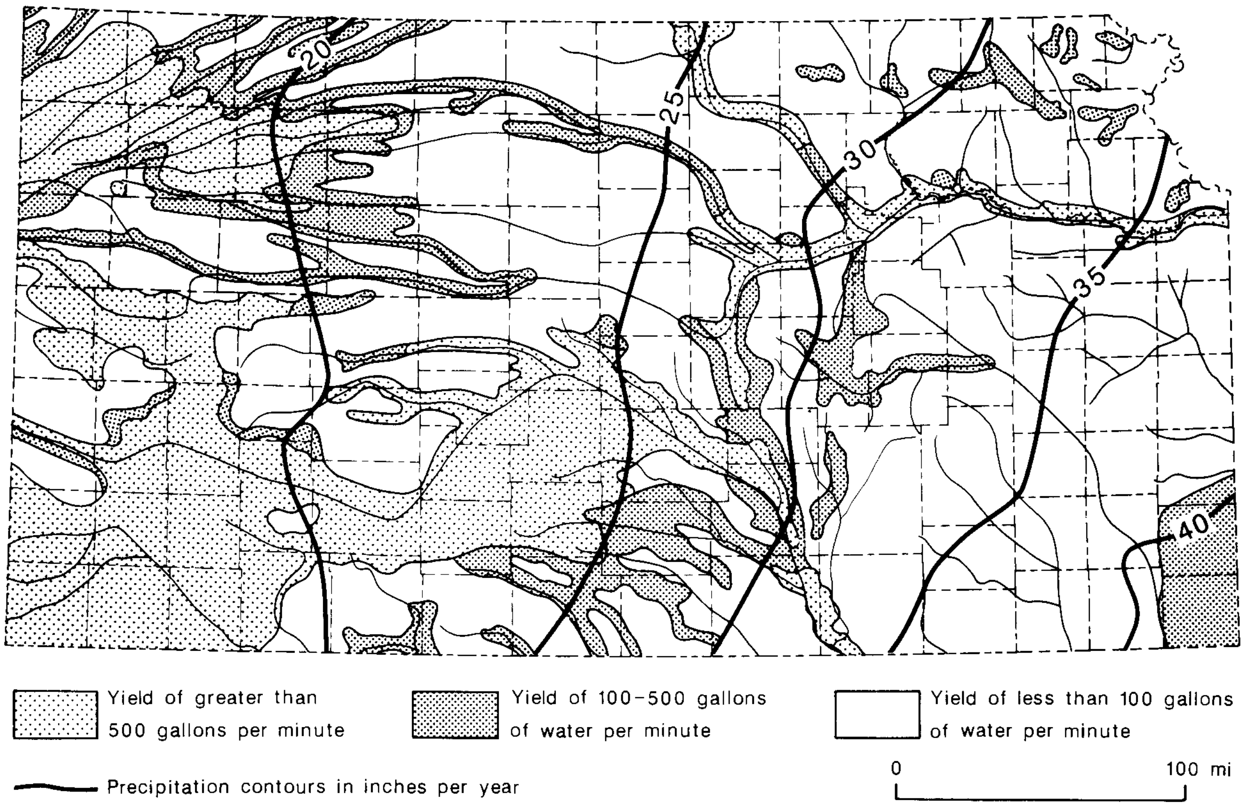
The remaining part of Kansas, constituting approximately the western one-third, is called the **High Plains.** The land surface rises very gradually westward to the flanks of the Rockies in central Colorado where it is more than a mile above sea level. In northwestern Kansas, the High Plains have been carved by east- and northeast-flowing streams so as to form long and fairly prominent uplands between the streams with innumerable rounded hills formed by the tributary smaller drainage. In central western and southwestern Kansas, on the other hand, the country is almost undissected. Low bluffs border the Arkansas on the north and in part on the south. East of Lakin there is a belt of prominent sand hills on the south side of the river.

All of the larger stream valleys are flat-floored and only slightly above the level of the water in the streams. The width varies from less than a mile to as much as four to five miles, depending on the size of the stream and the hardness of the rocks in which the valley is carved. The fertile alluvial soil of these valleys furnishes excellent farm land, and the valleys are natural routes for highways and railroads.

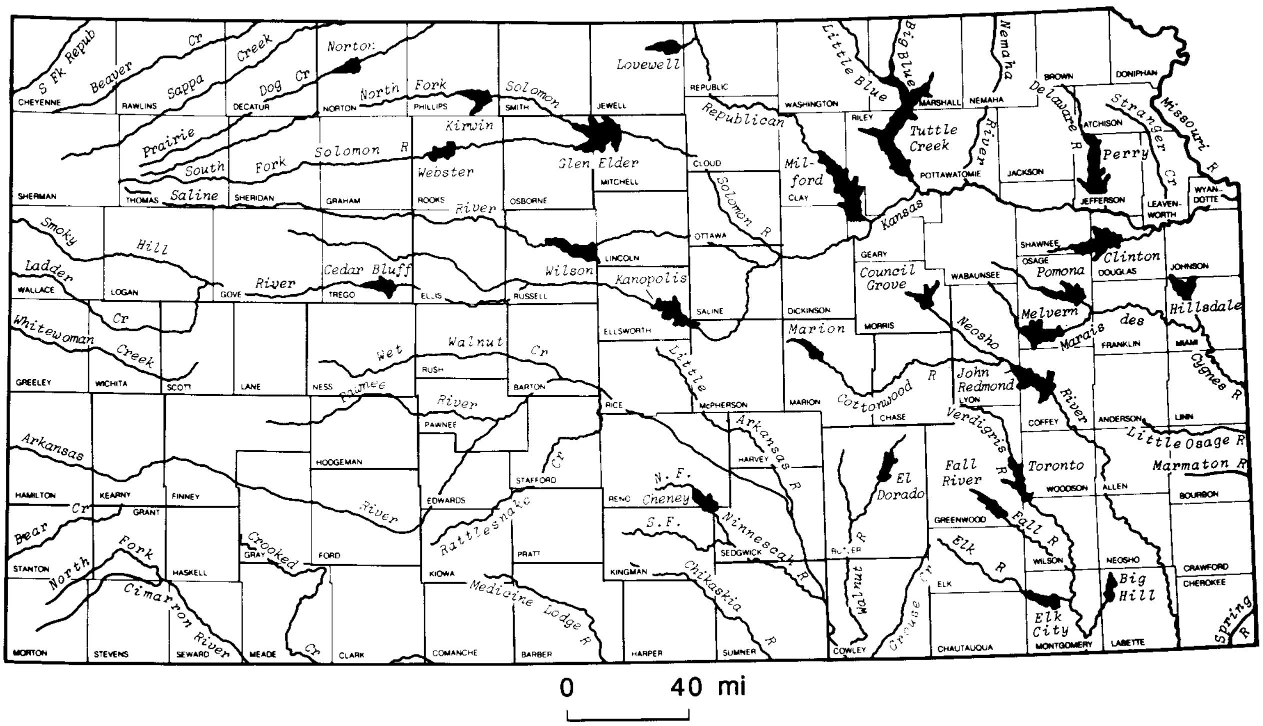
Generalized physiographic map of Kansas



General availability of ground water and normal annual precipitation in Kansas



Rivers and reservoirs in Kansas



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