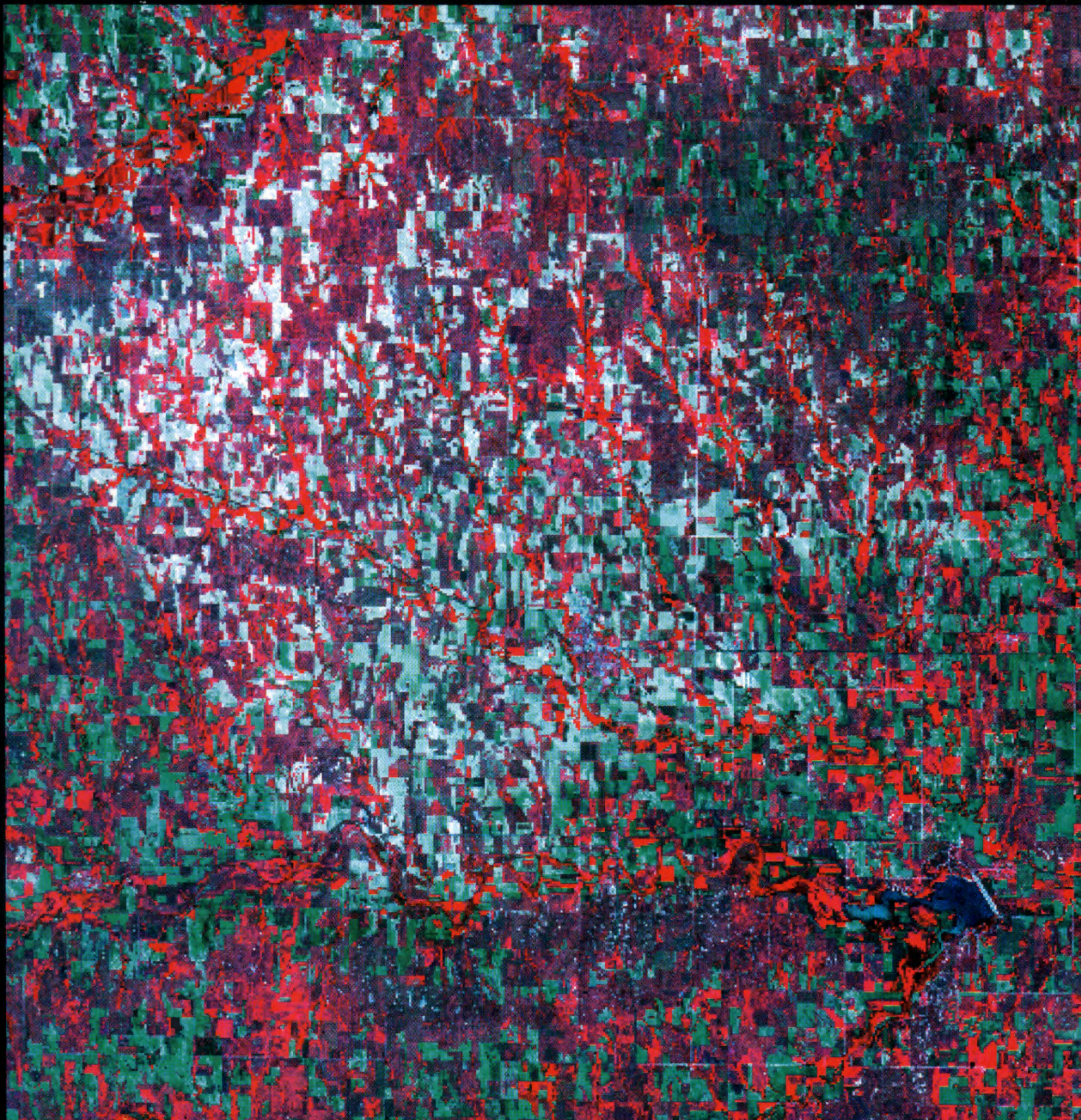


Surficial geology and stratigraphy of Phillips County, Kansas, with emphasis on the Quaternary Period

William C. Johnson

Technical Series 1
Kansas Geological Survey
1993

Cover photo: An image of Phillips County, Kansas, from the LANDSAT 5 Thematic Mapper. The image is a false-color composite with TM band 4 (infrared, 0.76–0.90 μm) displayed as red, TM band 3 (red, 0.63–0.69 μm) displayed as green, and TM band 2 (green, 0.52–0.63 μm) displayed as blue. Bright red areas are cropland, and dark-red to purple areas are grassland; wet soils are dark gray, and dry soils are light gray to white. The bright area in the central part of the image is due to the relatively well-drained nature of the thick late Quaternary loess deposits. Phillipsburg can be seen in the center of the image and Kirwin Reservoir in the lower right. The Thematic Mapper has a resolution of approximately 30 m (98 ft). The image has been provided courtesy of the Kansas Applied Remote Sensing Program, University of Kansas, Lawrence.

Technical Series 1 1993

Surficial geology and stratigraphy of Phillips County, Kansas, with emphasis on the Quaternary Period

William C. Johnson

Department of Geography
University of Kansas
Lawrence, KS 66045

A text to accompany the *Geologic Map of Phillips County*, compiled by W. C. Johnson and A. F. Arbogast (Kansas Geological Survey, Map Series M–29, 1993)

Kansas Geological Survey
Lawrence, KS 66047

The Kansas Geological Survey compiled this publication according to specific standards, using what is thought to be the most reliable information available. The Kansas Geological Survey does not guarantee freedom from errors or inaccuracies and disclaims any legal responsibility or liability for interpretations made from the publication, or decisions based thereon.

Copyedited, designed, and laid out by Mimi Braverman. Figures prepared for publication by Jennifer Sims and Phillip Reed.

This publication was produced using a Macintosh IIsi and the software PageMaker, version 4.2, by the Aldus Corp. and Illustrator by Adobe.

Text printed on recycled paper with soy-based ink.

Contents

Tables

Figures

Abstract

Phillips County is located in northwestern Kansas adjacent to the Nebraska state line. It is also situated along the contact between the Smoky Hills and the High Plains physiographic regions, which is reflected in a diverse array of erosional and depositional Quaternary-age landscapes. Outcropping rock units, ranging in age from Upper Cretaceous to Holocene, include the Carlile Shale, the Niobrara Chalk, the Pierre Shale, the Ogallala Formation, and several unconsolidated Quaternary eolian and fluvial deposits. Although the Carlile Shale underlies the entire county, only a single, limited exposure exists; this outcrop occurs where an anticline has brought the Carlile sufficiently near the surface to be exposed at the base of a valley wall. The Niobrara Chalk consists of two distinct members, the Fort Hays Limestone Member and the Smoky Hill Chalk Member. Because exposures of the Niobrara Chalk occur increasingly higher in the section from south to north in the county, outcrops of the marine Fort Hays Limestone Member are confined to the south, particularly on the south side of Kirwin Reservoir. Outcrops of the Smoky Hill Chalk Member are common in the central and northern parts of the county, frequently with a cap of Ogallala rock. The Pierre Shale, the youngest outcropping Cretaceous rock, is preserved in the northwest in the downwarp of the Long Island syncline. The Miocene-age Ogallala Formation is composed of Rocky Mountain–derived fluvial sediments that progressively filled preexisting valleys and ultimately mantled the uplands. The three regionally recognized members cannot be easily differentiated in Phillips County. However, the carbonate-cemented mortar beds are conspicuous throughout the county, and silica-cemented sandstone lentils form a prominent cap rock in four areas of the county.

Late Quaternary deposits occur extensively, and those exposed range in age from pre-Illinoian to Holocene. Limited exposures of pre-Illinoian materials were reported by earlier researchers but were not recovered in this study. Illinoian stratigraphy consists of the Crete Formation, the Loveland Loess, and the Sangamon soil, which caps the Loveland; exposures of the Loveland and Sangamon are common throughout Phillips County. Sand and gravel of the Crete Formation represent an alluvial phase; the Loveland consists of a widely distributed loess. The Sangamon soil is a major pedogenic complex that apparently spans several tens of thousands of years. Wisconsin-age deposits include early to middle Wisconsin fluvial deposits, the Gilman Canyon Formation, the Peoria loess, and late Wisconsin fluvial deposits. The oldest fluvial deposits are unexposed but underlie the high terraces of the North Fork Solomon River and Prairie Dog Creek. The Gilman Canyon Formation is a loess and was deposited at a sufficiently slow rate to permit pedogenesis to continue in a more or less uninterrupted fashion, forming an isochronous, regionally expressed soil, or geosol. Subsequent loess fall, producing the Peoria loess, occurred toward the end of the Pleistocene and mantles most of the upland. Late Wisconsin fluvial deposits are poorly represented, and their distribution is uncertain.

Holocene stratigraphic elements include the Brady soil, the Bignell Loess, fluvial deposits, and eolian sand deposits. The Brady soil, developed within the top of the Peoria loess, appears discontinuously in Phillips County. Its presence is defined completely on the basis of the existence of overlying Bignell Loess. In most areas deposition of the Bignell has either not occurred or has been so minimal that the loess was incorporated into the surface soil, which developed at least initially within the uppermost Peoria loess. Holocene fluvial deposits occur either as a component of the high terrace or as post–1,000 yr B.P. floodplain deposits. The eolian sand deposits exist either as reworked point bar deposits situated on a low terrace of the North Fork Solomon River or as a large dune tract south of the river in the southwestern part of Phillips County.

Introduction

Purpose and scope of the investigation

This report is an outgrowth of a county-level mapping project, one of several recently initiated for the state of Kansas, with the overall objective of generating high-resolution surficial geologic maps for each county (fig. 1). Some of the counties presently being mapped are part of the COGEOMAP (Cooperative Geologic Mapping Program–U.S. Geological Survey) project, although the Phillips County project is not one of these. The geologic map of Phillips County associated with this project (W. C. Johnson and Arbogast, 1992) is available from the Kansas Geological Survey automated cartography facility. One of the many advantages to having the map stored in this fashion is that revisions can be made by the original investigators or others as deemed appropriate, without the time and expense associated with conventional cartographic approaches. Original project field materials (e.g., maps and aerial photography) are available in the Kansas Geological Survey archives.

Geologic mapping was begun in the spring of 1989 and was completed in the early summer of 1990. The spring of 1989 was spent conducting reconnaissance mapping through remote sensing and field survey. Detailed mapping of alluvium and Cretaceous bedrock was carried out during the summer months, followed by mapping of the Tertiary Ogallala Formation and Pleistocene loess in the fall. The winter and spring of 1990 were spent addressing areas that were geologically complex or that had obscure contacts.

Location and nature of the study area

Phillips County is situated in northwestern Kansas and is bounded on the east by Smith County, on the south by Rooks County, on the west by Norton County, and on the north by Harlan County, Nebraska (fig. 1). It lies along the Smoky Hills–High Plains physiographic boundary and possesses a diverse array of landscapes because of the dissection of Cretaceous chalks and shales, Tertiary (Miocene) sands and gravels, Pleistocene eolian silts, and alluvial fill ranging in age from Pleistocene to Holocene and because of the variety of erosional unconformities separating the various units. The landscape of the county is essentially a product of the Quaternary Period (Pleistocene and Holocene epochs) from early development of the present drainage courses (fig. 2) to deposition of the loess mantle over most of the upland and valley side slopes. Much of the early benchmark research in Pleistocene stratigraphy of the state was carried out in Phillips County by John C. Frye, A. Byron Leonard, and Alvin R. Leonard during the late 1940's and early 1950's. Because of its quantitative and historical importance to surficial geology and its impact on the geomorphology of Phillips County, late Quaternary geology is emphasized in this report.

Previous geologic investigations

Phillips County geology was studied extensively in the late 1940's and early 1950's, with the primary focus on Pliocene and Pleistocene deposits. In 1942 Landes and Keroher discussed the mineral resources, including ground water, and subsurface structure and stratigraphy. Frye and Swineford (1946) studied the silicified rocks of the Ogallala Formation, in part to determine their economic significance. Byrne et al. (1948) investigated Phillips County for sources of riprap, aggregate, and other construction materials for the Bureau of Reclamation and the State Highway Commission. Geology and ground-water resources of Norton and northwestern Phillips counties were addressed in detail by Frye and A. R. Leonard (1949). Subsequently, A. R. Leonard (1952) examined the geology and ground-water resources of the North Fork Solomon River for Phillips and three other counties downstream. Frye and A. B. Leonard (1954) examined the middle and late Pleistocene stratigraphy exposed in the cutoff trench excavated for construction of Kirwin Dam.

Other less extensive or relevant geologic studies have been carried out in the county and adjacent areas. For example, Casey and Wantland (1953) conducted preconstruction seismic investigations at the Kirwin Dam site. The subsurface geology and structure of Phillips County was investigated by Herman (1957). Metz (1954) studied the petrology of the Loveland and Peoria loesses. The invertebrate paleontology was addressed by Hanna and Johnston (1913), Hibbard et al. (1944), A. B. Leonard (1952), Frye et al. (1956), and Ho (1966). Vertebrate material was described by Osborn (1898) and Hibbard (1942).

The ground-water and surface-water hydrology of the area has received considerable attention, in part because of the Kirwin Dam project. C. R. Johnson (1956) assessed the ground-water resources of Prairie Dog Creek valley, including the valley segment in northwestern Phillips County. Stullken (1984) studied the surface-water hydrology of the same valley. Bedinger and Tanaka (1962) reported on the changes in ground-water levels attributed to Kirwin Reservoir. The hydrology of the North Fork Solomon River valley was later examined by Jorgensen and Stullken (1981). Other research not cited here has been conducted and reported for Phillips County. A listing is available in the *Bibliography of Kansas Geology, 1823–1984* (Sorensen et al., 1989, p. 386).

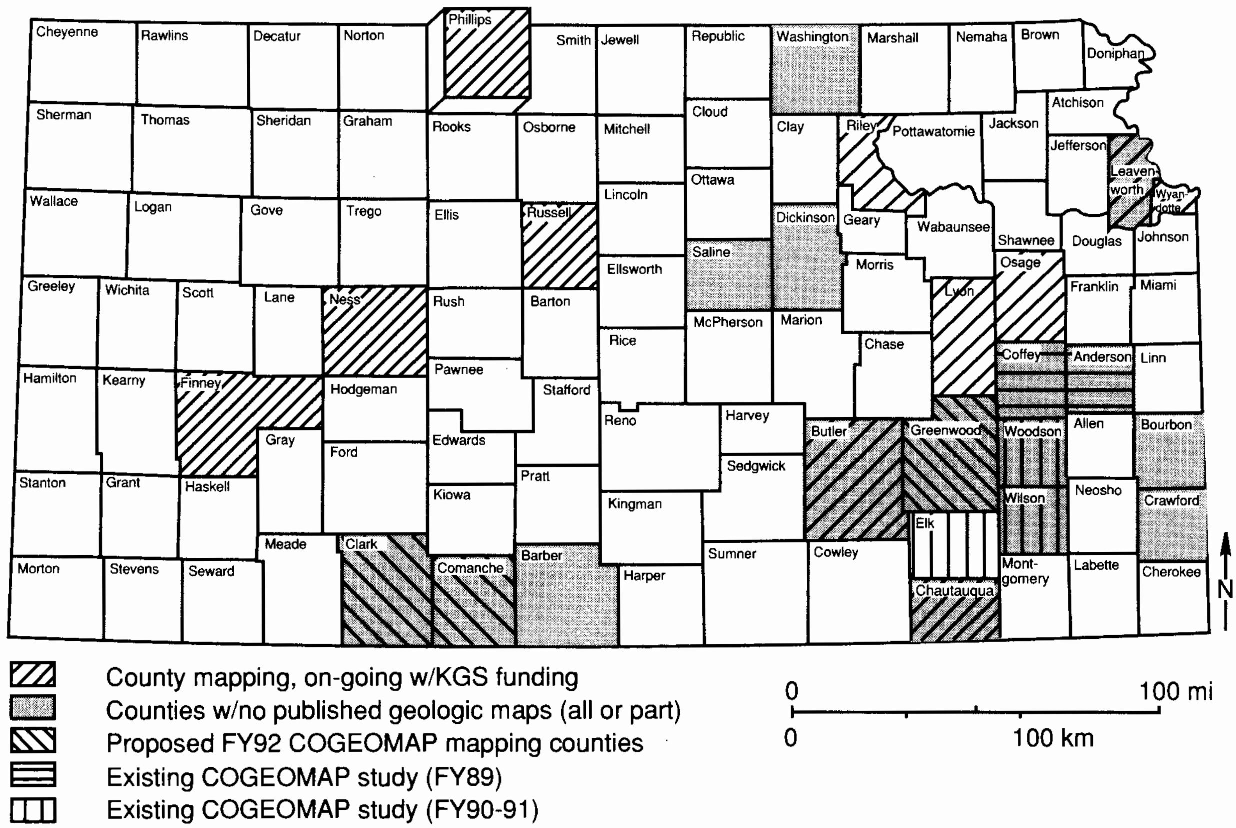


FIGURE 1—Index map of Kansas showing the location of Phillips County and the status of county-scale geologic mapping.

Methods of investigation

The geology of Phillips County was mapped primarily from stereopairs of black and white aerial photography (1:24,000) taken in January 1986 for property reappraisal, $7^1/_2$-minute topographic quadrangle maps, and field survey. A thickness of 1.8 m (6 ft) was considered the minimum necessary for a deposit to be defined as a mappable unit; this criterion was most applicable to alluvium, loess, and sand sheets. No deep drilling or coring was done, but shallow hand and machine augering was used to verify units below the soil zone and to ascertain thicknesses of unconsolidated deposits. Exposures were described, and measurements were taken with a hand level, tape, and pocket transit.

Soil map units from the Soil Survey of Phillips County (Palmer and Hamilton, 1987) were assessed for their correlation with lithology. As anticipated, the relationship was sufficiently poor and too variable to permit use of soil maps as a primary source for the placement of geologic contacts (table 1). It was possible, however, to use the map units of the two major soils developed in loess, the Harney and Holdrege silt loams, to approximate the location of the loess boundary, which was then refined in the field. This was particularly useful because loess presence and extent are frequently difficult to extract from aerial photographs.

Alluvial deposits were mapped first because of the relative ease with which floodplains and terraces can be recognized and delimited. The Upper Cretaceous Series was mapped next, followed by the Miocene-age Ogallala Formation. The upper and lower contacts of the Ogallala were often problematic and, consequently, most time-consuming to determine. Eolian deposits were dealt with in the final phase.

Geologic contacts were first drawn on paper copies of the $7^1/_2$-minute, 1:24,000-scale topographic quadrangles and then transferred to planimetric Mylar base maps of the same scale for digitizing and subsequent map production through computer-aided cartography using the GIMMAP software system employed by the Kansas Geological Survey.

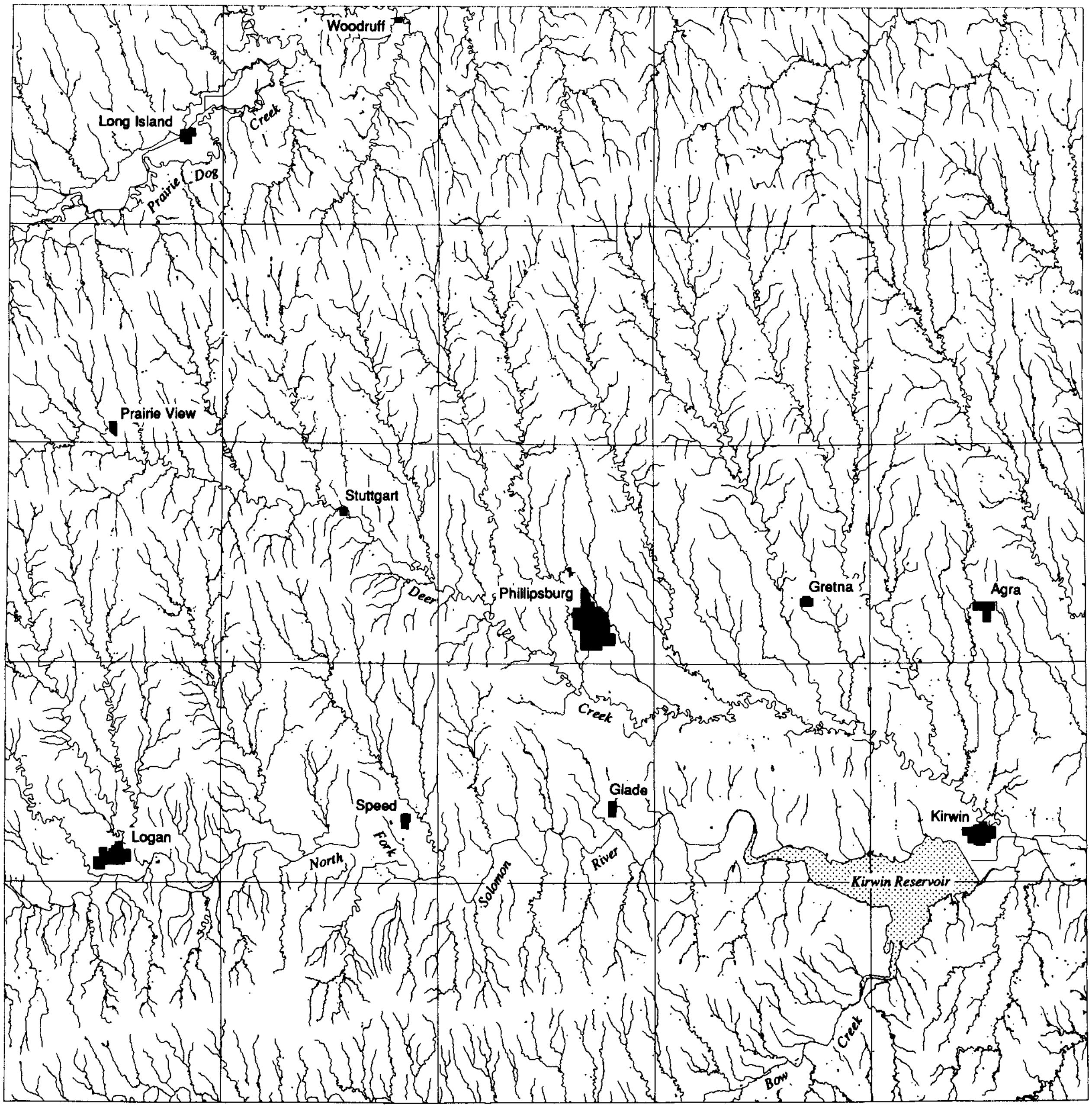


FIGURE 2—Drainage pattern of Phillips County.

TABLE 1—Geology and soil series associations and degree of correspondence between map units

Geologic unit	Soil series	Correspondence of soil distribution to geology[a]
Loess	Harney	good
	Holdrege	good
	Penden	good
	Uly	good
Ogallala Formation	Campus	good
	Valentine	fair
Niobrara Chalk	Brownell-Heizer[b]	fair
	Wakeen[b]	fair
Carlile Shale	Bogue	poor
High terrace	Anselmo	fair
	Bridgeport	good
	Detroit	fair
	Hord	fair
Low terrace and floodplain	Inavale	fair
	McCook	fair
	Munjor	fair
	Roxbury	fair

a. Scaling: Excellent: ≥80% correspondence between geologic and soil-series map units. Good: ≥50 to <80% correspondence. Fair: <50% correspondence. Poor: geologic unit is unmappable from the soil-series map unit.
b. Soil series does not distinguish between the Smoky Hill and Fort Hays Members.

Stratigraphy of outcropping rocks

Rock units that crop out in Phillips County range in age from Upper Cretaceous to Holocene and include the Carlile Shale, the Niobrara Chalk, the Pierre Shale, the Ogallala Formation, and a complex assemblage of unconsolidated Quaternary eolian and fluvial deposits. Rock-stratigraphic and time-stratigraphic units relevant to this investigation are represented in fig. 3. Although not formally adopted by the Kansas Geological Survey, three notable changes have been made on the time-stratigraphic scale. The Ogallala Formation is presently known to be Miocene and perhaps earliest Pliocene. The Pleistocene Series reflects the classical four glacial advance model, which has been largely abandoned within the last two decades, hence the alternative time-stratigraphic designation of "pre-Illinoian stage" (informal use of stage). Also, "Holocene" has replaced "Recent," with a lower boundary change. Although no precise agreement exists regarding the temporal divisions between elements of the geologic time scale (Haq and van Eysinga, 1987), two of the chronologies most commonly used in the United States differ little (fig. 4). Divisions within the Pleistocene are detailed in a later section.

Cretaceous System—Upper Cretaceous Series

Carlile Shale (Colorado Group) Gilbert (1896) first named the Carlile Shale from exposures along the Arkansas River west of Pueblo, Colorado, at Carlile Station. Logan (1899) and Rubey and Bass (1925), among others, later modified and subdivided the Carlile Shale of Kansas. In Kansas the shale crops out in two general areas (Hattin, 1962). The larger of the two areas forms a belt that extends from Finney County in the southwest to Washington County in the northeast; a smaller area of Carlile Shale crops out in northwestern Hamilton County.

The Carlile Shale consists of about 300 ft (90 m) of argillaceous and chalky shale with bentonite, thick chalk beds, dark-gray fissile shale containing large septarian con-

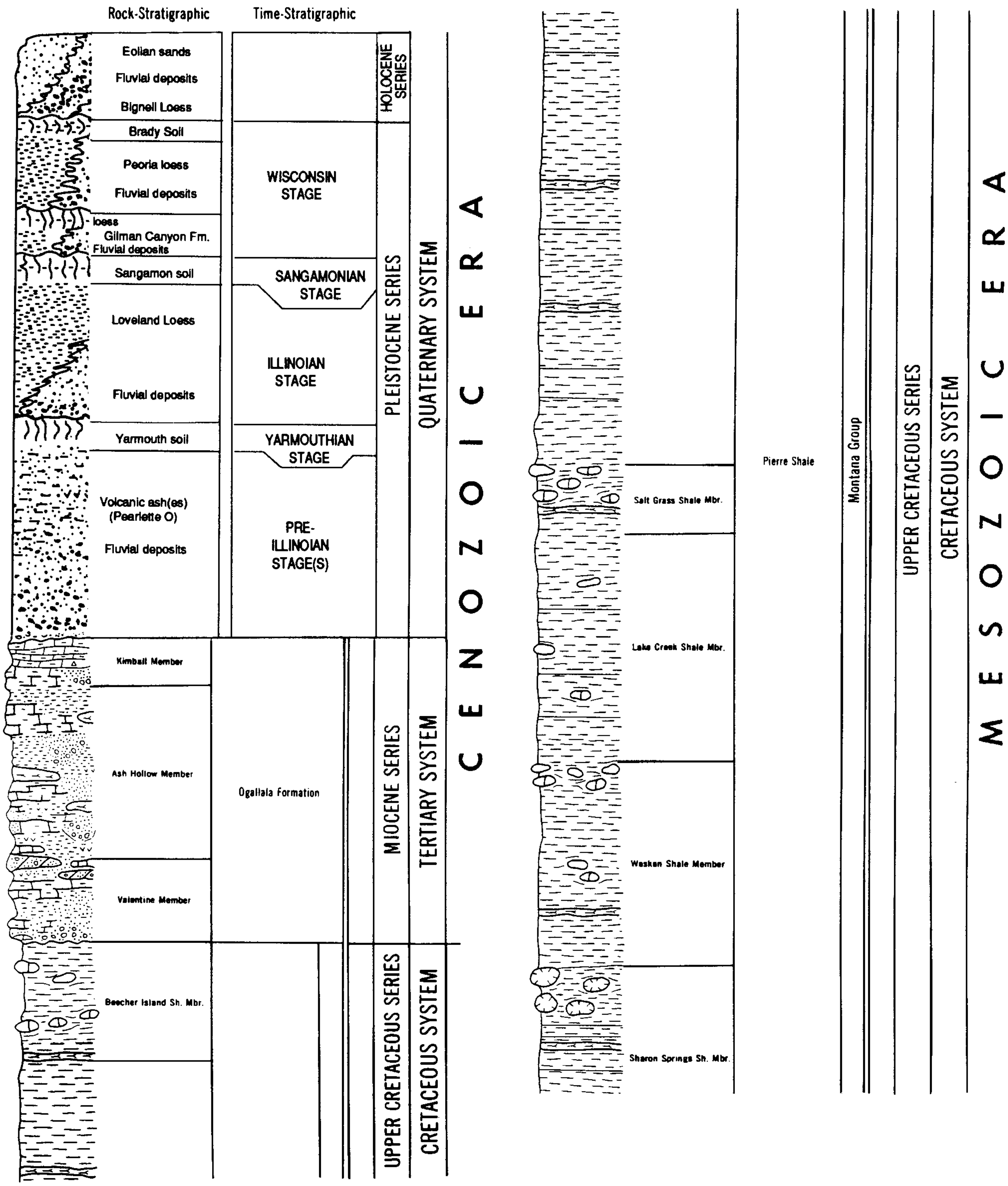


FIGURE 3—Classification of rocks in Phillips County. The chart has been modified from Zeller (1968) and reflects only that part of the column cropping out in the county.

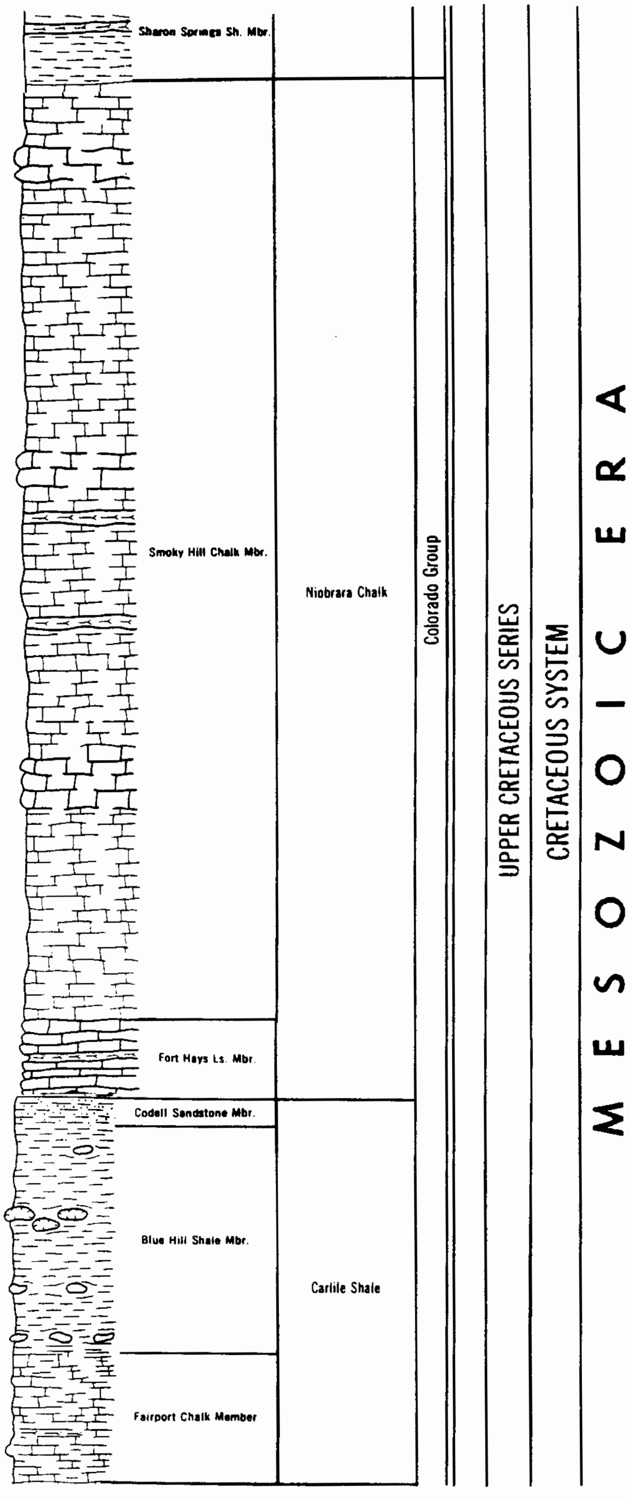


FIGURE 3 (continued)

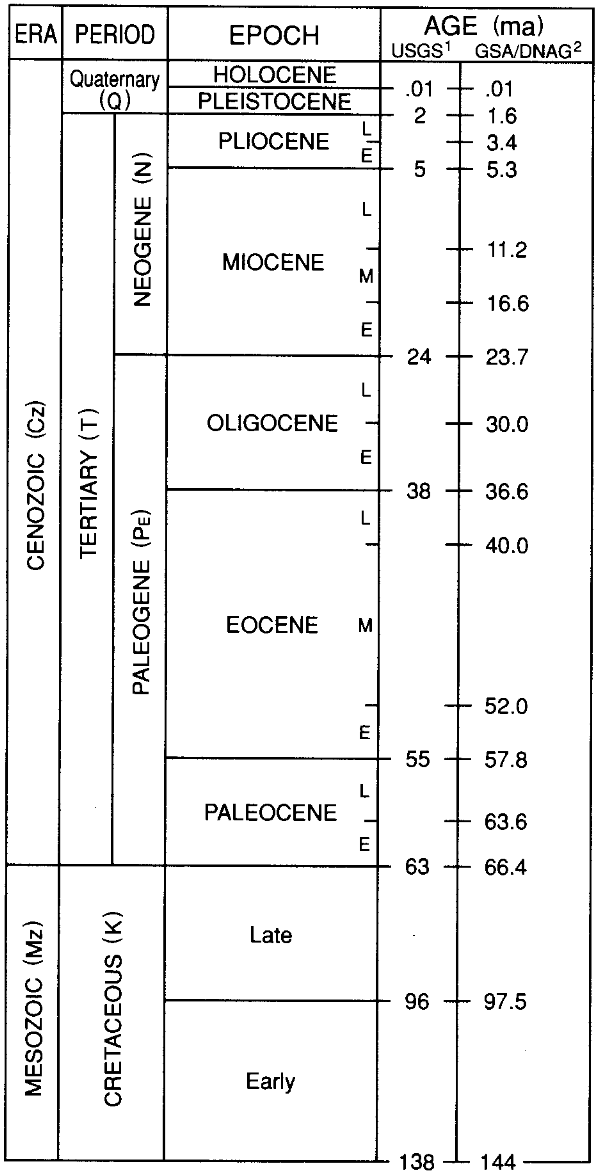
cretions, and fine-grained sandstone. Stratigraphically, the Carlile is situated between the top of the Fence-post limestone bed of the Greenhorn Limestone and the base of the Fort Hays Limestone Member of the Niobrara Chalk. The formation consists of three members: the Fairport Chalk Member, the Blue Hill Shale Member, and the Codell Sandstone Member.

The Fairport Chalk Member is a bluish-gray to gray chalky shale, chalky limestone, and calcareous shale that weathers to yellowish-gray and grayish-orange. Chalky limestone predominates near the base, and thin bentonite beds are found throughout the member. The thickness of the chalk within Kansas ranges from 85 ft to 147 ft (26–45 m). The Blue Hill Shale Member is a dark-gray clayey, blocky to fissile shale with a sand content that increases upward. Septarian concretions of calcium and clay-ironstone occur throughout. The thickness ranges from 70 ft to 200 ft (21–61 m) within Kansas. The Codell Sandstone Member is a fine-grained silty sandstone, locally shaly, that attains a thickness of no more than 25 ft (7.6 m) and thins to less than 1 ft (0.3 m). The Codell is not always a well-developed bed and can occur as thin lentils of sand.

The Carlile Shale underlies the entire county, but only one surface exposure has been located. A poor-quality exposure is found in NENE sec. 34, T. 5 S., R. 17 W., within a small tributary to the North Fork Solomon River. This single exposure is a product of the north-south-trending Stockton anticline and the low topographic situation created by the river valley. At present, the exposure is badly slumped and overgrown by small trees and shrubs. However, in 1948 Byrne et al. measured, apparently next to a now abandoned road running up a small valley, 33.5 ft (10.2 m) of the Blue Hill Shale Member and 0.2 ft (0.06 m) of the Codell Sandstone Member. The Codell is also exposed directly beneath the Fort Hays Limestone Member in the upper valley wall, but no attempt was made to excavate a fresh exposure for remeasurement.

Because only the Blue Hill Shale and Codell Sandstone Members occur in a single outcrop, they were not differentiated on the county geologic map (W. C. Johnson and Arbogast, 1993; map designation *Kc*).

Niobrara Chalk (Colorado Group) The Niobrara Chalk was named by Meek and Hayden in 1862 to characterize exposures of calcareous marl and chalky limestone in the Niobrara River valley of northeastern Nebraska. The formation was later subdivided into the Fort Hays Limestone Member and the Smoky Hill Chalk Member (Logan, 1897). Subsequently, other researchers [e.g., Bass (1926), Elias (1931), Moss (1932), Russell (1929), Cobban and Reeside (1952), and Hattin (1982)] have described and discussed the paleontology and stratigraphy of the Niobrara in western Kansas. The Niobrara is approximately 650 ft (200 m) thick



[1] Geologic Names Committee, 1984, U.S.G.S. Bulletin 1537-A.
[2] Palmer, A.R., 1983, Geology 11:503-504.

FIGURE 4—Geologic time scale. The scale does not extend beyond the Cretaceous, the limit for the surface geology of Phillips County.

in Phillips County (Landes and Keroher, 1942) and crops out progressively higher in the section from south to north. The Fort Hays Limestone Member forms the lower 45–50 ft (14–15 m) of the formation, and the Smoky Hill Chalk Member makes up the remainder. On the geologic map of the county (W. C. Johnson and Arbogast, 1993) the two members were differentiated and mapped as *Knf* and *Kns*, respectively.

Fort Hays Limestone Member The Fort Hays Limestone Member, a marine limestone, lies conformably on the Carlile Shale. Outcrops of the Fort Hays are limited to the southeastern part of Phillips County. The two major areas of outcrop occur on the north and south sides of Bow Creek valley and the north side of the Solomon River valley near Kirwin Dam. Exposed thicknesses range up to 7.6 m (25 ft). The Fort Hays is considerably more erosion resistant than the Smoky Hill Chalk Member. As it occurs in the county, the Fort Hays is a buff chalky limestone exhibiting massive beds of chalk, up to 1.5 m (5 ft) thick, separated by thin shale partings. Upon weathering, the chalk beds become gray and limonite stained on the surface. The Fort Hays is well exposed in two small quarries within the southeastern part of Phillips County. One of these, presently in an early phase of excavation, is located at the base of the south valley wall of Bow Creek (NWNWNE sec. 25, T. 5 S., R. 17 W.). As of November 1989, 7.6 m (25 ft) of Fort Hays had been exposed. The second quarry, located about 8 km (5 mi) upstream on the north valley wall (SESW sec. 31, T. 5 S., R. 17 W.), provides a vertical face exposing 5.8 m (19 ft) of Fort Hays and 1.2–1.5 m (4–5 ft) of the overlying Smoky Hill Chalk Member (fig. 5). The contact is difficult to locate precisely because of the shaly nature of the upper Fort Hays and the weathered color and exposure of the Smoky Hill. A third exposure exists along the northeast shoreline of Kirwin Reservoir, extending approximately 2 m (7 ft) above the June 1989 pool level.

Smoky Hill Chalk Member The Smoky Hill Chalk Member has recently received intensive and extensive study by Hattin (1982). The type area in western Kansas consists of 12 sections that form a composite section over 596 ft (182 m) thick. In Kansas the outcrop of the Smoky Hill extends from north-central Finney County for 190 mi (306 km) northeastward to the Nebraska state line in northeastern Jewell County. The chalk is olive-gray, impure, well laminated to nonlaminated, and flaky in its weathering habit. Over 100 zones of bentonite have been recognized by Hattin; they range in thickness up to 0.37 ft (0.11 m) but are usually less than 0.1 ft (0.03 m) thick. They are most numerous in the lower portion of the member and weather to a rusty-gray, but the color of the member varies geographically. The basal part, cropping out in the southeastern corner of Phillips County, is blue-gray, and the middle portion of the member, exposed in the central part of the county, is predominantly tan or pink. A pink to orange color characterizes the upper part of the member, which crops out in the northern and western parts of the county. Vertebrate and invertebrate fossil material is common in the chalk, the most obvious fossils being a clam (*Inoceramus grandis*) and an oyster (*Ostrea congesta*).

At several outcrops within Phillips County where the chalk is directly overlain by the Ogallala Formation, the upper chalk beds have been silicified (Byrne et al., 1948, p. 6). The source of the silica was probably volcanic ash from the Ogallala Formation; percolating silica-rich waters presumably replaced the carbonate within some of the chalk

FIGURE 5—Exposure of the upper portion of the Fort Hays Limestone Member of the Niobrara Chalk in the Babcock Quarry. The quarry is located 0.8 km (0.13 mi) north of the Rooks County line in SESW sec. 31, T. 5 S., R. 17 W. At present, the exposure is 7.16 m (23.5 ft) high, with the presumed Smoky Hill chalk contact at 5.7 m (19 ft) (arrow).

beds. This silicified rock is brittle, produces conchoidal fractures, attains an 8-ft (2.4 m) maximum thickness, and frequently is green. In the past the silicified chalk has been quarried for use as fence posts and building stone (Landes and Keroher, 1942). The trace of an old WPA-era quarry still exists in NW sec. 23, T. 2 S., R. 17 W. These silicified zones are persistently near the eroded upper surface of the Smoky Hill Chalk Member and are locally cemented to overlying silicified deposits within the Ogallala.

The Smoky Hill Chalk Member is exposed along stream valleys, except Prairie Dog Creek and its tributaries because of the regional northwest dip of the bedrock. Frequently, the chalk is eroded into a badland topography, an example of which is found in the area south of Glade. Chalk badlands would be more extensive in Phillips County if it were not for the overlying Ogallala Formation (fig. 6) or loess mantle (fig. 7). An example of these contrasting weathering characteristics is in and adjacent to a roadcut in SESE sec. 34, T. 3 S., R. 17 W., where the Smoky Hill crops out both with and without an Ogallala cover. A hill consisting of Smoky Hill chalk remains because of a cap of silicified chalk (secs. 17 and 18, T. 4 S., R. 20 W.). The Smoky Hill is presently well exposed in a quarry 2 km (1.2 mi) northwest of Logan in SESW sec. 29, T. 4 S., R. 20 W. (fig. 8). Over 22 m (72 ft) of chalk are exposed beneath an erosional remnant of the Ogallala Formation, which persists because a silica-cemented sandstone lentil is present. A similar quarry exposure exists west of Speed.

Pierre Shale (Montana group) In 1862 Meek and Hayden designated the Pierre Shale based on exposures at old Fort Pierre, South Dakota. Subsequently, Elias (1931) studied and described the Pierre Shale of Kansas. The shale is the youngest Cretaceous formation in Phillips County and the stratigraphically highest consolidated rock. Of the five members recognized within the Pierre Shale, only the lowermost Sharon Springs Shale Member is exposed in Phillips County. It is composed of black to dark gray-brown fissile, platy, noncalcareous shale with several thin zones of chalky shale and bentonite (Frye and A. R. Leonard, 1949). Thin veins and isolated crystals of gypsum (selenite) and small limonite concretions are found throughout the basal part of the member.

Based on available data, the probable thickness of the Pierre Shale in Phillips County is at most 50 ft (15 m). Frye and A. R. Leonard (1949) observed a maximum exposure thickness of 30 ft (9.1 m) and estimated a thickness of 46 ft (14 m) within a test hole. A thickness of 26.8 ft (8.17 m) was measured in this study along a roadcut on the south valley wall of Prairie Dog Creek in the western half of the western

FIGURE 6—Smoky Hill chalk–Ogallala contact (arrow) in a roadcut in SESE sec. 34, T. 3 S, R. 17 W. Approximately 8.5 m (28 ft) of poorly cemented Ogallala overlie 8.9 m (29 ft) of chalk. The 10-cm-thick (4-in.-thick) chert bed at the top of the Smoky Hill Chalk Member is one of many in the member; these chert beds frequently occur at the top of the member because of their resistance to erosion. There is evidence that Paleo-Indians used this chert for the production of lithics (S. Holen, personal communication, 1990).

half of NW sec. 20, T. 1 S., R. 19 W. (fig. 9). Furthermore, no good exposures of the contact between the Niobrara Chalk and the Pierre Shale were documented. It is difficult to locate this contact because the Niobrara and the Pierre are similar in color and lithology. Consequently, the Pierre Shale was difficult to map, and where it is approximated, the mapping was done conservatively.

Numerous thin beds of bentonite have been recognized across the northern portion of Phillips County (Kinney, 1942, p. 354). Only one active bentonite pit was located within the county; the Bohl Construction Company is extracting small quantities from a location approximately 1.5 km (0.9 mi) southeast of Long Island in SWNESE sec. 25, T. 1 S., R. 20 W. (fig. 10).

Outcrops of the Pierre Shale occur only in the northwestern part of Phillips County along the south side of Prairie Dog Creek and are attributed to downwarping in the Long Island syncline on the west side of the Stockton anticline (Landes and Keroher, 1942, p. 289). Mapping of the Pierre Shale has been difficult because of the lack of exposures and highly weathered nature of surface and near-surface material. Consequently, in many places the contact is approximate, and most mapping is done with the use of a hand-operated bucket auger. One notable structural feature is a normal fault where the Smoky Hill Chalk Member and the Pierre Shale are adjacent to one another; this faulting may be attributable to motion associated with development of the Long Island syncline. This exposure no longer exists because of slumping and overgrowth, but it was documented stratigraphically and photographically by Frye and A. R. Leonard (1949, p. 31). Two of their photographs are reproduced in fig. 11.

Because the Sharon Springs is the only member of the Pierre Shale occurring in Phillips County, it has been indicated on the map with the letters *Kps* (W. C. Johnson and Arbogast, 1993).

Tertiary System—Miocene Series

Ogallala Formation The Ogallala Formation is a heterogeneous massive to crossbedded complex of fluvial deposits laid down by streams flowing from the Rocky Mountain region during the Miocene and early Pliocene. It is the principal geologic formation in the High Plains and serves as the region's major aquifer. Outcrops are limited to the margin of the High Plains where erosion is occurring, such as along the contact with the Smoky Hills in Phillips County. A major discontinuity separates the Ogallala from the overlying

FIGURE 7— Loess-filled channels cut in the upper Smoky Hill Chalk Member exposed in a cut of the Missouri Pacific Railroad 0.5 km (0.3 mi) west of the Kirwin Wildlife Refuge entrance off K–9 (NWNWNE sec. 26, T. 4 S., R. 17 W.). Post-Sangamon pre–Gilman Canyon erosion is apparent from this dissection; that is, the freshly eroded surface of the chalk was buried sometime before 35,000 years ago.

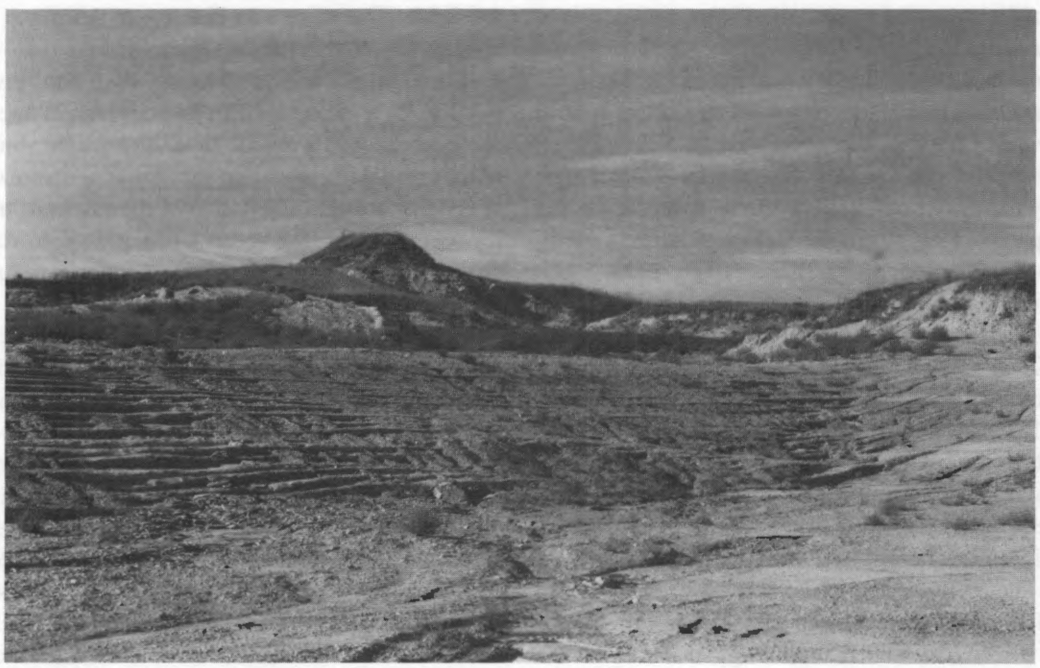


FIGURE 8—The Smoky Hill Chalk Member of the Niobrara Chalk with an overlying remnant of the Ogallala Formation in SESW sec. 29, T. 4 S., R. 20 W. Because the chalk is on a structural high, the Ogallala is relatively thin here but has persisted because of an erosion-resistant silica-cemented sandstone lentil. The quarry exposes 72.2 ft (22.0 m) of the Smoky Hill Chalk Member; 1.52 m (5.0 ft) of the Ogallala cap the hill above the chalk.

FIGURE 9—Pierre Shale exposed in a roadcut and surface in the western half of the western half of NW sec. 20, T. 1 S., R. 19 W. The shale forms the low ridge in the middle ground that extends into the Prairie Dog Creek bottoms. A total of 8.2 m (27 ft) of shale is exposed in the cut. The view is west from outcropping mortar beds of the Ogallala Formation.

Pliocene and Pleistocene deposits; significant thicknesses of the Ogallala were differentially removed during Pliocene and early Pleistocene erosion (Stanley and Wayne, 1972).

The name Ogallala was first proposed by Darton in 1899 based on work at a locality in southwestern Nebraska, although Darton did not actually designate a general type locality (Ogallala Station) until 1920 in a report on the geology of parts of Hamilton and Kearney counties in southwestern Kansas (Darton, 1920). Elias (1931, 1932, 1935, 1942) conducted detailed studies of the Ogallala in western Kansas and defined a precise type locality. Subsequently, the Nebraska Geological Survey classified the Ogallala as a group and subdivided it into four formations.

Darton (1899) believed that the Ogallala was late Tertiary, and Elias (1931), working in Wallace County, thought that the mammalian faunal content indicated a late Miocene to early Pliocene age. Boellstorff (1976) dated volcanic glass shards (fission-track dating) from the Ogallala type section, obtaining a late Miocene age of 7.6 ± 0.7 Ma. In Nebraska initiation of Ogallala time appears to coincide with that of the medial Barstovian land mammal age at about 14 Ma (Voorhies, 1990). The Clarendonian land mammal age of the Ogallala extends from 11.7 to about 9 Ma (Tedford et al., 1987), and the Hemphillian land mammal age of the formation covers the period of approximately 9 to 4.5 Ma (Berggren and Van Couvering, 1974). Fission-track ages compiled by Voorhies (1990) for the Ogallala range from 13.6 ± 1.3 to 5.0 ± 0.2 Ma. Therefore a medial age of 9.5 m.y. (14–4.5 Ma) appears reasonable for the Ogallala in the region.

The Ogallala is capped locally by a hard pisolitic limestone or by a dense caliche layer, which is apparently isochronous, that is, a unique time-stratigraphic unit. The base of the Ogallala is, however, variable in age from one location to another because alluviation of the eastward-trending valleys cut in Cretaceous bedrock began in the lowest areas and continued as increasingly younger deposits transgressed the valley sides and flanking uplands.

Considerable paleoenvironmental information has been derived from fossil floral and faunal material in the Ogallala. Botanical information has come primarily from Elias (e.g., 1942) and Thomasson (e.g., 1979, 1987, 1990). Paleoflora from five localities in Texas, Kansas, and Nebraska indicate that the prevailing plant community was a grassland with scattered trees, perhaps in relatively dense but widely distributed stands (Thomasson, 1990). The coexistence of grazers such as horses and rhinos (Zakrzewski, 1988) supports the notion of expansive grasslands. One of five local faunas in north-central Kansas is located near the village of Gretna in eastern Phillips County (Zakrzewski, 1990). Three diagnostic mammalian taxa of the 22 present suggest that the site dates to about 12 Ma.

Three members The Kansas Geological Survey recognizes three members within the Ogallala Formation (Bayne

FIGURE 10—A small fold exposed in a bentonite bed of the Pierre Shale 1 mi (0.6 km) southeast of Long Island in SWNESE sec. 25, T. 1 S., R. 20 W. The bentonite is presently being excavated by the Bohl Construction Company.

and O'Connor, 1968). Faunal and floral remains, volcanic ash petrology, and gross lithology have been used to differentiate the members and to correlate them with the type sections in Nebraska. The Valentine member was the first to be deposited and is consequently restricted to Cretaceous bedrock valleys. The member is characterized by medium to fine sands and some gravels, is greenish-gray to pink and pale tan, has layers of volcanic ash and bentonite, silica-cemented sand and gravel, and diatomaceous marl, and has a diagnostic fossil grass seed, *Stipidium commune*. Because the member is situated lowermost in bedrock valleys, it is rarely exposed. It is, however, well exposed in eastern Norton County at the Almena site (Frye and A. R. Leonard, 1949).

The Ash Hollow member was deposited on the Valentine and is therefore not associated exclusively with the bedrock valleys; it laps onto valley side slopes and frequently divides, resulting in relatively large-scale coverage of the landscape. It is lithologically heterogeneous (less local bedrock input) and generally coarser in texture than the underlying Valentine, gray to pink, characterized by rich floral zones (e.g., *Krynitzkia coroniformis* seed zone) and molluskan assemblages, rich in volcanic ash (particularly in the lower half), locally silica cemented to form erosion-resistant lentils of sandstone, and weakly cemented with carbonate at many levels to form the conspicuous mortar beds used as a source of lime during the early settlement period.

The uppermost member, the Kimball, was deposited after the filling of the bedrock valleys and is therefore expressed as a thin, unconfined apron of sediments mantling the landscape. Although coarse gravels occur locally at the base (Sidney gravels of Nebraska), the sediments are highly calcareous and predominantly gray fine to medium sand, silt,

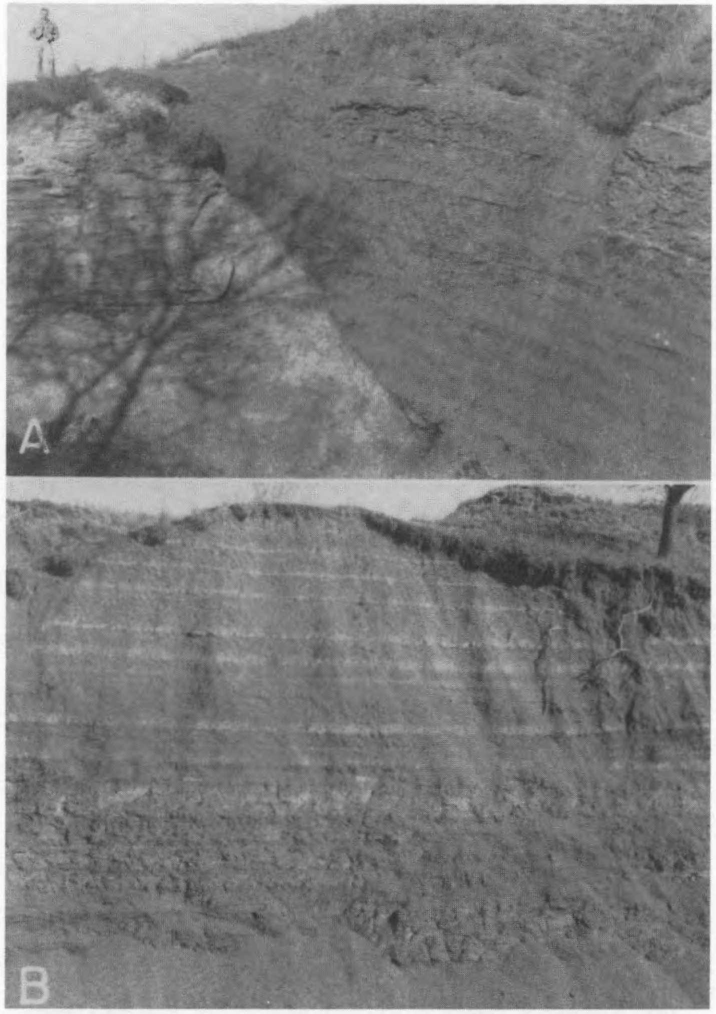


FIGURE 11—Pierre Shale exposed in the right (east) bank of Prairie Dog Creek in SESE sec. 24, T. 1 S., R. 20 W. (A) Smoky Hill Chalk Member faulted against the Pierre Shale; (B) Pierre Shale exposed adjacent to the fault. The photographs are reproduced from Frye and A. R. Leonard (1949, pl. 5, p. 31). Slumping and a dense growth of trees and shrubs presently obscure the view depicted in the photographs.

and clay. A dense pink to white pisolitic nodular caliche (calcrete), 3 ft (0.9 m) or less in thickness, caps the member. Because of the discovery of an alga, *Chlorellopsis bradleyi*, that required a perennial body of water, Elias (1931) believed that the pisolitic layer was an algal limestone originating from a terminal Ogallala lacustrine environment. Darton (1899) originally thought that the Kimball was a secondary deposit, and subsequent studies by Frye et al. (1956) and Swineford et al. (1958) demonstrated that the layer is primarily a product of pedogenesis. The member, easily differentiated by its distinctive basal plant fossils and fossil molluskan assemblages, has observed thicknesses ranging from 2.5 ft to 44 ft (0.76–13 m). However, only isolated erosional remnants of the Kimball member persist.

The three members of the Ogallala Formation are apparently not continuous throughout the unit's distribution. Gustavson and Winkler (1988) report that the Ogallala of Texas and eastern New Mexico is composed of alluvial sediments partially filling paleovalleys and extensive, thick eolian sediments mantling paleo-uplands and most alluvial sediments.

Three major areas of outcrop for the Ogallala can be defined in Phillips County. The thickest and most extensive outcrops occur along and adjacent to the east-west-trending divide across the northern part of the county, that is, in Tps. 1 and 2 S. In particular, extensive exposures and benches created by the mortar beds occur in this area (figs. 12 and 13), as do the silica-cemented sandstones discussed later. A second major outcrop area is in the south-central and southwestern parts of Phillips County along the flanks of the upland between the North Fork Solomon River to the north and Bow Creek to the south. Mortar beds are present here as

FIGURE 12—Small valley cut into the Ogallala Formation, exposing a mortar bed that produces a prominent bench. The view, from a mortar bed outcrop, is southwest from the extreme northwest corner of sec. 11, T. 2 S., R. 20 W. This is an unnamed tributary of Prairie Dog Creek to the north.

well, but the lentils of silica-cemented sandstone are better expressed than elsewhere in the county—or the state. The third area of outcrop is the western portion of another wedge-shaped upland, or divide, in this case separating Deer Creek on the north from the North Fork Solomon River to the south. Where it outcrops, the Ogallala does so on the upper convex slope, or the shoulder, of the divides because loess mantles the crests of the divides and the lower toe slope is Cretaceous bedrock.

The thickness of the Ogallala varies greatly in Phillips County because of differences in the predepositional bedrock topography and the postdepositional denudation and dissection of the surface. The greatest thicknesses exist on the western side of the county. The thickest vertical section of the Ogallala (Ash Hollow member?) in the county occurs in a gravel pit, 3 km (1.9 mi) northeast of Prairie View in the eastern half of NE sec. 26, T. 2 S., R. 20 W. (fig. 14). Byrne et al. (1948, p. 8) report a maximum thickness of 150 ft (45.7 m) near the Norton County line. The overall trend is one of decreasing thickness to the east and south, a function of both preexisting Cretaceous bedrock topography and Pleistocene drainage development.

Because of a paucity of continuously traceable stratigraphic units within the Ogallala, the three members could not be differentiated, and the formation is designated *To* on the county geologic map (W. C. Johnson and Arbogast, 1993).

Silica-cemented sandstone Prominent lenticular bodies of silica-cemented sandstone occur within the Ogallala Formation of Phillips County. The term "quartzite" has been applied [e.g., Bates and Jackson (1987, p. 543)] to these deposits, but it is not used here to avoid confusion with the more common metamorphic definition of quartzite. The resistance of the lenses to erosion is obvious in their topographic expression. As caprock, they have formed small buttes, pinnacles, and benches, such as those south of Glade. Furthermore, the beds have influenced the drainage patterns of at least two major streams in Phillips County (Frye and Swineford, 1946). In the northwestern section just west of Woodruff, northeastward-flowing Prairie Dog Creek assumes an anomalous course back to the west and north around an elongate hill capped by lentils of the sandstone (fig. 15). Upland gravels indicate that, during the late middle Pleistocene, before the present level of entrenchment, the creek was flowing northeastward without this deviation. Similarly, Bow Creek, which flows along the southern boundary of Phillips County, has a channel-bed elevation that is higher than adjacent and parallel major drainages. The gradient steepens abruptly to the west of the sandstone lentils, suggesting that the lentils slowed the rate of downcutting and tributary development.

The lateral extent of the lentils ranges up to 1 km (0.6 mi), and the thickness ranges from 30 cm (1 ft) to 5 m (16 ft) (fig. 16). The average extent and thickness are 0.2–0.4 km (0.13–

FIGURE 13—Outcrop of a mortar bed in the Ash Hollow member of the Ogallala Formation located in NWNW sec. 15, T. 2 S., R. 20 W. This abandoned quarry is located about 1 mi (0.6 km) southwest of the view in fig. 12 and is traceable as the same bed.

0.25 mi) and 45–60 cm (1.5–2 ft), respectively. Bedding planes are rare, but crossbedding has been observed; a few joints were noted, particularly in the area south of Glade. The texture of the lentils varies appreciably across Phillips County, from fine sand to poorly sorted and coarse conglomerates. Frye and Swineford (1946, p. 46) reported boulders with diameters greater than 50 cm (20 in.), but no boulder larger than 32 cm (13 in.) was observed during this study. Boulders that do occur consist of Cretaceous chalk or shaly chalk, and, because they are incompletely silicified, they erode out of the matrix, leaving curiously shaped cavities. The degree of silica cementation varies from one exposure to another, occasionally within the same lentil.

Frye and Swineford (1946) addressed the origin of the silicified rock: source of the silica, factors controlling deposition, time of silicification, and source of the characteristic green color. The silica is almost exclusively opal (some chalcedony), which indicates that the silica was in a colloidal suspension rather than in solution; this is a condition necessary to attain the concentrations required for mobilization and deposition of such large amounts of the cementing agent (Frye and Swineford, 1946). Volcanic ash deposits provide the only known source of silica in the quantities required. The lower half of the Ash Hollow member is greater than 5% volcanic ash and contains 9 of the 10 petrographically distinctive volcanic ashes within the Ogallala Formation (Frye et al., 1956). Moreover, stratigraphic indicators place the lentils within the lower Ash Hollow member, below the most extensive ash deposits. The volcanic ash–silicified sandstone relationship cannot be demonstrated in the field because, where exposed, the sandstone is a caprock with all overlying Ogallala deposits removed. Only one site provided evidence of the ash-sandstone relationship: the large quarry 3.5 km (2.2 mi) west of Woodruff in the western half of sec. 4 and the eastern half of sec. 5, T. 1 S., R. 19 W., has exposures of bentonite in association with silicified sandstone (Frye and Swineford, 1946); that relationship could not be verified in this study. Deposition of the silica was well controlled; the lentils are localized and have sharp contacts with the adjacent uncemented clastics. Frye and Swineford (1946, p. 58) proposed that the silica precipitated from its somewhat acidic, colloidal suspension when calcium and carbonate ions were encountered; that is, cementation (and replacement) occurred only where the preexisting sediments were cemented by calcium carbonate. The relative age of silicification relates to the depositional and ground-water history of the Ogallala. Because the formation is waterlaid, water tables probably stood at high levels during active aggradation. Volcanic ashes, deposited either primarily or secondarily, were soon below the water table and subject to hydration and leaching. The subaqueous environment of the silicification is evidenced by the green color of the sandstone (rock colors 5Y

FIGURE 14—Quarry exposure of the presumed Ash Hollow member of the Ogallala Formation in the eastern half of NE sec. 26, T. 2 S., R. 20 W. The 10.7-m-high (35-ft-high) face (west) exhibits appreciable variation in stratigraphy horizontally and vertically and overall is pink to buff. This is currently one of the highest vertical exposures of the Ogallala in the county.

5/2 to 10Y 5/2), which can be attributed to the presence of ferrous iron, which is readily absorbed by silica gel.

Exposures of the silica-cemented sandstone are widespread across Phillips County but can be grouped geographically into four broad areas (Landes and Keroher, 1942). The most conspicuous and extensive outcrop is located in an east-west belt across the western half of Phillips County along both sides of the divide between the North Fork Solomon River and Bow Creek. The sandstone forms the caprock and is overlain by a thin mantle of loess and underlain by the Niobrara Chalk. The Bohl Construction Company recently reactivated a large quarry area 6.5 km (4 mi) south of Glade in NESE sec. 14, T. 5 S., R. 18 W.; this quarry reportedly was a source for the riprap used in the construction of Kirwin Dam. A second area of occurrence of silica-cemented sandstone lentils is 2.5 km (1.5 mi) northwest and 3–5 km (1.9–3.1 mi) northeast of Logan. These lentils are not extensive, but the larger of the two is to the northwest of Logan in a Smoky Hill chalk quarry. Here, the lentils directly overlie the chalk and form a conspicuous hill on the west side of the quarry. The sandstone is poorly cemented and finely conglomeratic at its base (fig. 17) and fine grained at the top. The third area of lentil exposures is in the northeastern part of Phillips County, west of US–183 on the north and south sides of the divide between the drainages of Deer Creek to the south and Prairie Dog Creek to the north. This area offers fine exposures and a wide variety of textures and colors in the lentils. Landes and Keroher (1942) considered the largest deposits in Phillips County to be located on a large hill protruding into Prairie Dog Creek valley, 5 km (3.1 mi) west of Woodruff. These quarries, formerly referred to as the Tobin or Woodruff quarries, were once serviced by a spur of the Oberlin branch of the Chicago, Burlington, and Quincy Railroad. Lentils, commonly 3.7 m (12 ft) thick, are exposed in the quarry faces.

Perhaps the best exposure of the Ogallala Formation in Phillips County, by virtue of its varied stratigraphy, is found along a roadcut, 6.5 km (4 mi) south of Speed in the western half of SW sec. 13, T. 5 S., R. 19 W. (fig. 18). The section was first documented by Frye and Swineford (1946) and later referenced by Byrne et al. (1948) and A. R. Leonard (1952). Two prominent rock benches are evident: The one near the ridge top is a silica-cemented sandstone (fig. 19), and the slightly lower one is a mortar bed (fig. 20). The Smoky Hill–Ogallala contact is not exposed along the roadcut, but augering indicated a total Ogallala thickness of 14.3 m (47 ft).

Where the silica-cemented sandstone (and conglomerate) is exposed, typically at topographic highs, it is designated

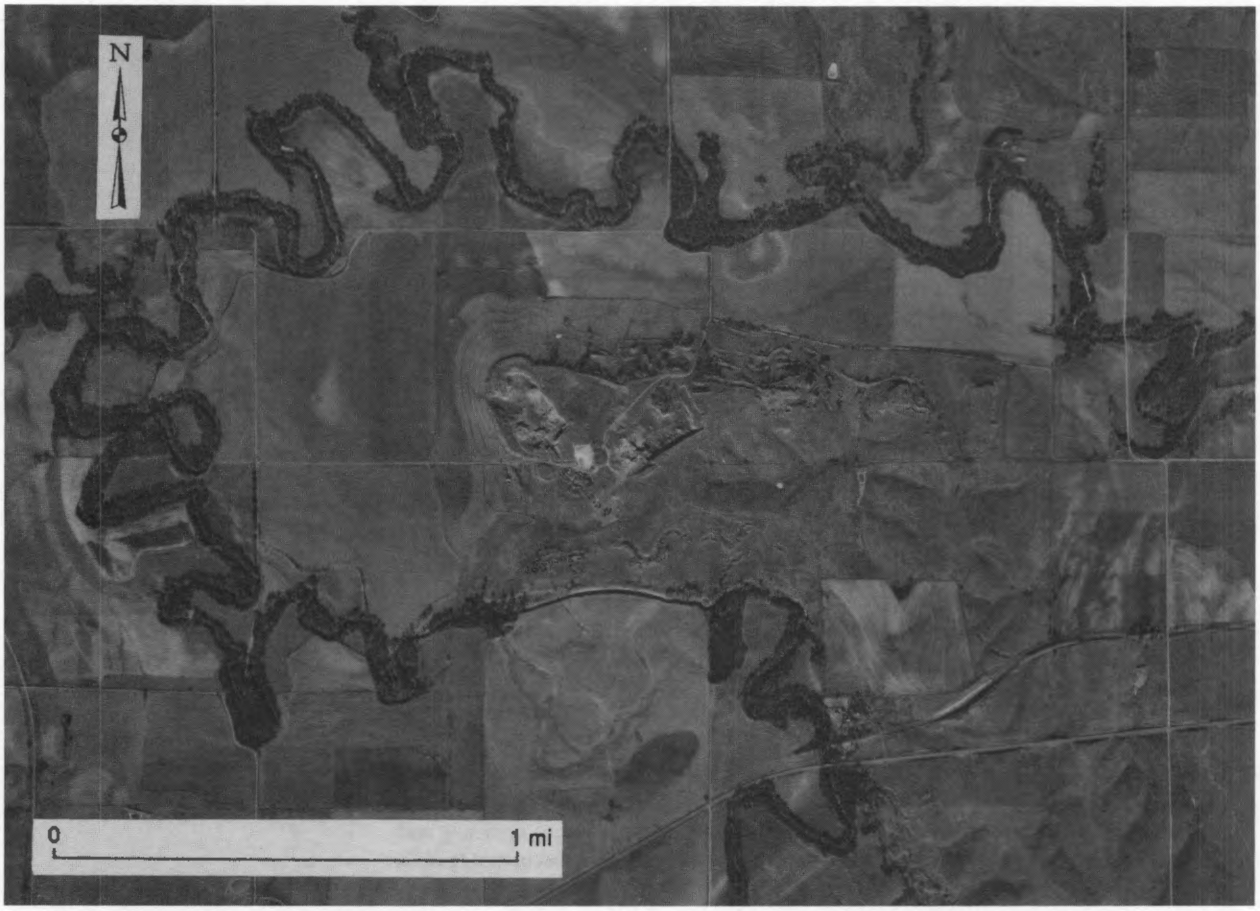


FIGURE 15—The anomalous westward deflection of northeastward-flowing Prairie Dog Creek around a ridge capped by a silica-cemented sandstone bed in the Ogallala Formation. The quarries from which the silica-cemented sandstone has been extracted are apparent on the west end of the ridge. The railroad cut in the lower right sector exposes sand and gravel of Illinoian age overlain by the Gilman Canyon and Peoria formations (loesses).

with the single letter *s* on the county geologic map (W. C. Johnson and Arbogast, 1993).

Quaternary System—Pleistocene Series

Classically, the Pleistocene has consisted of four glacial advances, or stages: the Nebraskan, Kansan, Illinoian, and Wisconsin (fig. 3). In recent years this traditional Pleistocene chronology has been largely abandoned because of the complexity of the stratigraphic record and faulty correlations made by early researchers. Within the United States ten pre-Illinoian glaciations have been recognized, seven of which occur in the Pleistocene (three in the Pliocene). In Iowa and Nebraska alone pre-Illinoian time is known to contain deposits from one Pliocene and five Pleistocene glaciations (Richmond and Fullerton, 1986a), and during the last 900,000 years there have been eleven episodes of glaciation in the United States (Fullerton and Richmond, 1986).

Many of the stratigraphic correlations have been made on the basis of a volcanic ash marker bed, the Pearlette (Frye and A. B. Leonard, 1952; Schultz and Martin, 1970). Although Swineford and Frye (1946) documented the presence of many ashes in Kansas, researchers continued to acknowledge the existence of only one, isochronous "Pearlette" ash. In the last two decades, three separate Pearlette ashes and three other ashes have been identified and named in the Central Plains (table 2). Petrographic and chemical analyses (Izett et al., 1970; Izett, 1981; Izett and Wilcox, 1982) and fission-track dating (Boellstorff, 1973, 1974, 1976; Naeser et al., 1973) have been used to differentiate the three Pearlette ashes. Reed and Dreezen (1965) concluded that two tills in northeastern Nebraska were Illinoian in age because of their position above "the ash," but subsequent fission-track dating

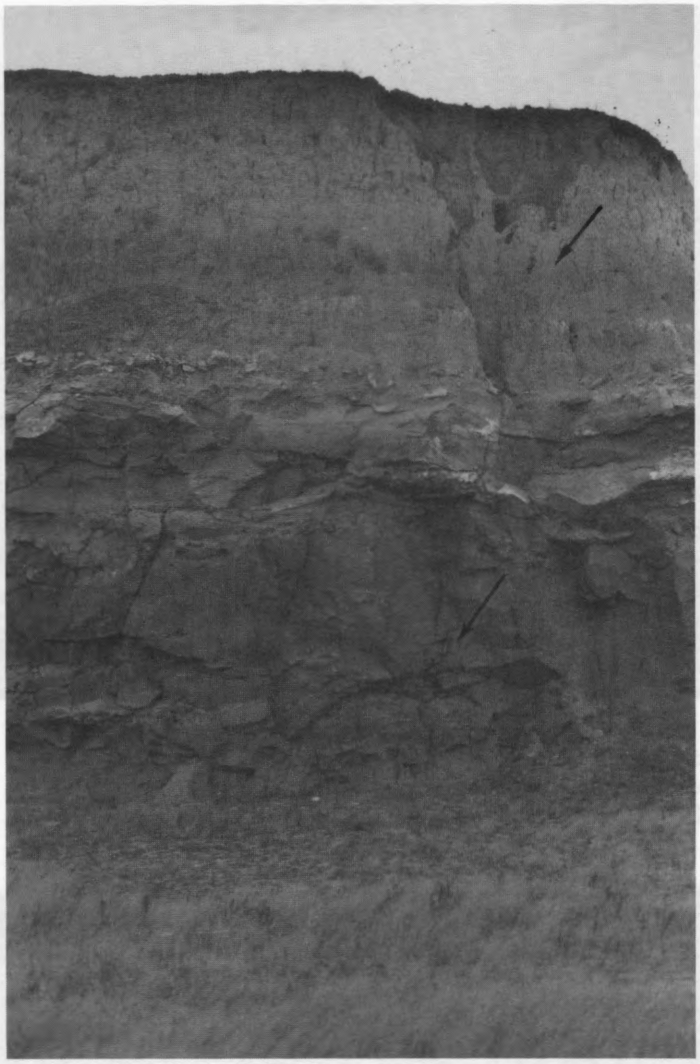


FIGURE 16—Lentil of silica-cemented sandstone in the Bohl Construction Company quarry south of Glade in NESE sec. 14, T. 5 S., R. 18 W. The sandstone is 5.24 m (17.2 ft) thick at this section; note the rock hammer for scale (lower arrow). Uncemented sands underlie the lentil for at least 6 m (20 ft), and 4.3 m (14 ft) of loess mantle it. The paleosol (Gilman Canyon Formation) within the loess (upper arrow) is a ubiquitous stratigraphic marker dating between about 35,000 and 20,000 yr B.P.

of the ash by Boellstorff (1978a,b) produced an age of approximately 1.2 Ma, that is, the Pearlette S ash. Those tills are now known to be older than classic Kansan till. Similarly, Boellstorff (1976) dated the "Pearlette ash" marker bed, assumed to date to about 600 ka, at the Sappa type section in Harlan County, Nebraska (county north of Phillips); its date was 1.26 ± 0.40 Ma, indicating that Sappa deposits are early Pleistocene, that is, not correlated with the classical Kansan glaciation but 500,000 years or more older. Martin and Schultz (1985) corroborated this finding by noting that the Sappa local fauna, situated about 2 m (7 ft) below the ash, is post-Blancan, pre-Kansan.

Regionally, the question remains of whether the use of "Kansan" in the type area of northeastern Kansas is appropriate. Since the term "Kansan" was introduced by Chamberlin (1895), northeastern Kansas has persisted as the type region for deposits identified with the Kansan glaciation (Frye and Leonard, 1952), despite reliance on the glacial stratigraphy of Nebraska and Iowa for interpretation (Jewett, 1963). Aber (1981, 1988, 1991) recognized two advances during Kansan glaciation in northeastern Kansas on the basis of lithologic differences in the glacial stratigraphy. Evidence for three or more advances has, however, been cited by Bayne (1968), Bayne et al. (1971), and Dort (1966, 1985). Subsequently, Aber (1991) identified two diamictons in northeastern Kansas, which he included in a new lithostratigraphic unit, the

FIGURE 17—Poorly cemented and finely conglomeratic lower part of a lentil of siliceous Ogallala Formation exposed in a hill on the western side of a Smoky Hill chalk quarry northwest of Logan (fig. 8). The upper part of the lentil, exposed a short distance to the west, is finer grained.

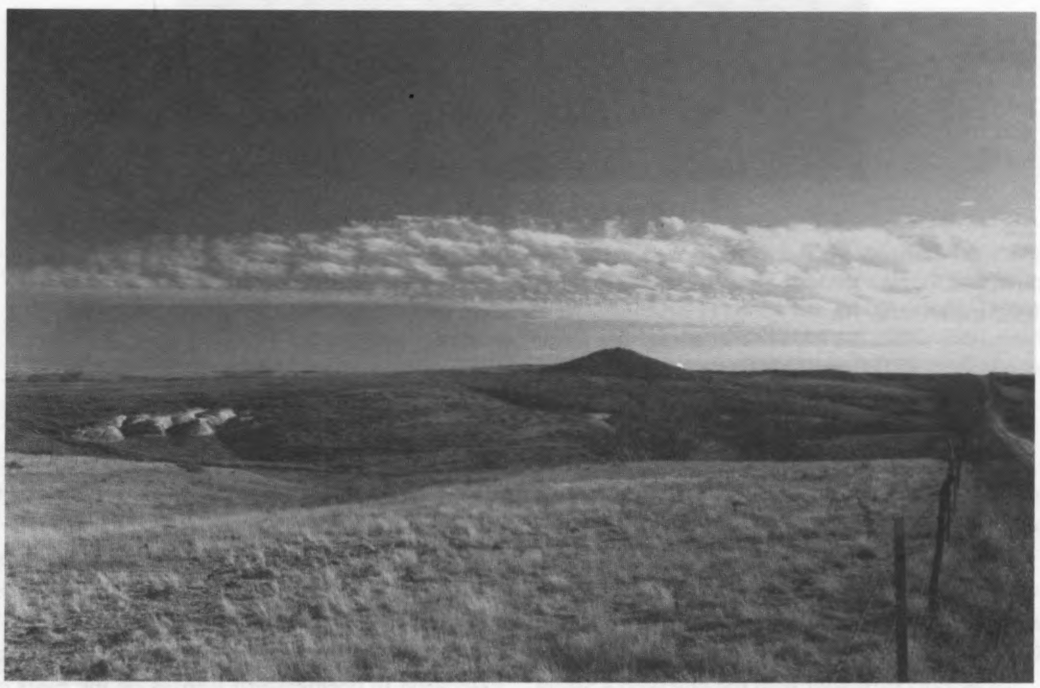


FIGURE 18—View south-southeast of a hill composed of Ogallala rock and capped with a lentil of silica-cemented sandstone, located approximately 7 km (4 mi) south of Speed in the western half of SW sec. 13, T. 5 S., R. 19 W. The underlying Smoky Hill Chalk Member appears as badland topography to the left. A measured section in the Ogallala, first recorded by Frye and Swineford (1946) and provided herein, is located along the road in the distant far right. The ridge on the horizon, right side, is held up by the same sandstone unit.

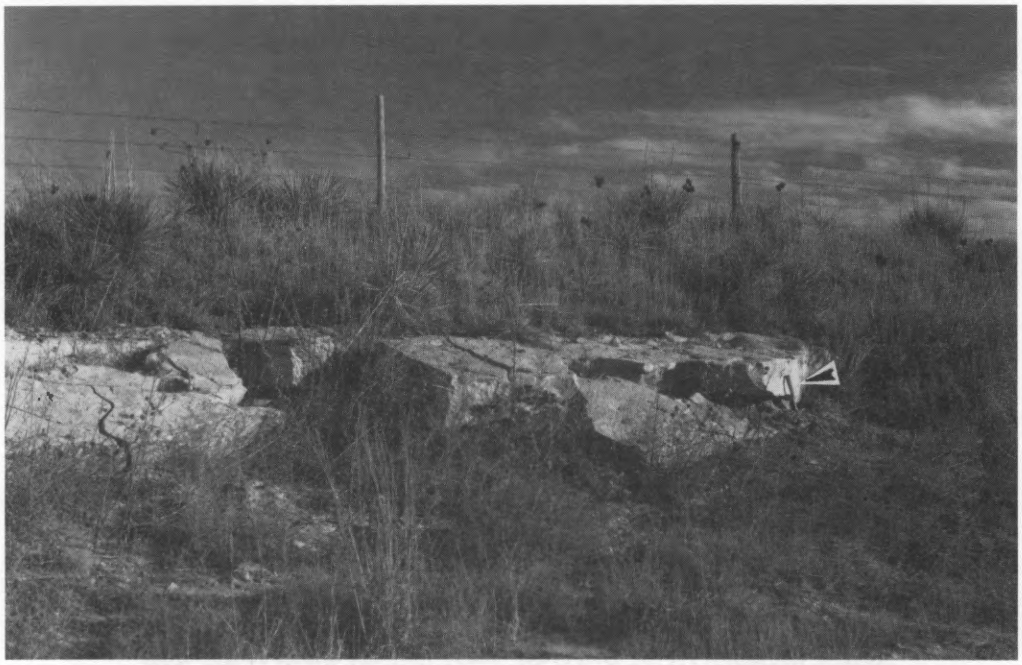


FIGURE 19—Lentil of silica-cemented sandstone at the top of the section noted in fig. 18. The lentil is up to 52 cm (1.7 ft) thick (rock hammer at arrow) and is stratigraphically and elevationally equivalent to the unit capping the hill a short distance to the north-northeast.

FIGURE 20—Mortar bed exposed stratigraphically below [5.5 m (18 ft)] the lentil depicted in fig. 19 (rock hammer for scale). Maximum exposed thickness of the bed is 1.3 m (4.3 ft).

TABLE 2—Fission-track-dated volcanic ashes of major stratigraphic significance in the Central Plains (Nebraska, Kansas, and Oklahoma)

Ash	Alternative names	Source area	Representative age ($\times 10^6$ yr)
Pearlette O	Pearlette restricted, Lava Creek B, Cudahy, Hartford	Lava Creek Tuff, Member B, Yellowstone	0.610
Bishop	Mount Clare	Bishop Tuff, California	0.738
Tsankawi	–	Toledo & Valles caldera, NM	1.12
Pearlette S	Coleridge, Mesa Falls	Mesa Falls Tuff, Yellowstone	1.27
Guaje	–	Toledo & Valles caldera, NM	1.45
Pearlette B	Huckleberry, Ridge, Borchers	Huckleberry Ridge Tuff, Yellowstone	2.01

Sources: Boellstorff (1976), Izett (1981, 1982), Izett and Wilcox (1982), Richmond and Fullerton (1986a), and Ward (1991).

Independence formation, a term intended to replace the traditional name of "Kansan." Aber et al. (1988) dated glaciation in northeastern Kansas on the basis of volcanic ash and paleomagnetism to between 700 and 600 ka, thereby associating the glacial activity with oxygen isotope stages 18–16 (Aber, 1991). Elsewhere in northeastern Kansas (Marshall County), Oviatt (1991), using geochemical and magnetic qualities of a volcanic ash, dated glacial deposits as older than 620 ka and younger than 730 ka. These two ages on glacial deposits in northeastern Kansas are similar and indicate that the deposits are different from "Kansan" deposits in Iowa and are younger than the Lava Creek B ash.

Because the Nebraskan and Kansan glacial stages and the Aftonian and Yarmouthian interglacial stages no longer appear to be appropriate stratigraphic designations in their type regions, most investigators have called for abandonment of the classical pre-Illinoian stratigraphic framework [e.g., Hallberg et al. (1980), Dort (1987), Hallberg (1986), and Richmond and Fullerton (1986a)]. The classical stage names have been used in chronostratigraphic, lithostratigraphic, pedostratigraphic, and event-stratigraphic contexts, and continued adherence to the nomenclature will likely propagate the error and confusion (Hallberg, 1986, p. 12). Boellstorff (1978b) was among the first to call for a new regional stratigraphic framework for the Central Plains.

Richmond and Fullerton (1986a) presented an informal scheme of geologic divisions and associated time scale for the Quaternary of the United States (fig. 21). The Pliocene-Pleistocene boundary was set at 1.65 Ma, in accordance with the estimate of 1.64 Ma derived by Aguirre and Pasini (1985) on the basis of radiometric ages from the Virca section in Italy; this move has apparently resolved the problem of identifying an appropriate stratotype (Rio et al., 1991). Until recently, one age commonly proposed for the boundary was 2.4 Ma (Bowen, 1978; Nilsson, 1983; Pecsi, 1985). The boundary is strictly geochronometric, that is, without stratigraphic basis, in the United States, primarily because many have attempted to define it climatically [e.g., Beard (1969), Lamb and Beard (1972), Boellstorff (1978c), and Beard et al. (1982)]. Specifically, the boundary cannot be located stratigraphically and has no significance to the stratigraphic and chronologic sequence of glaciation, to the history of vertebrate fauna of the North American land mammal ages, or to the record of climatic or environmental change (Richmond and Fullerton, 1986b). For the central Great Plains, Boellstorff (1976) has argued for a change to 1.8 or 2.0 Ma on the basis of land mammal ages or a major ash marker bed, respectively.

The Pleistocene was subdivided by Richmond and Fullerton (1986a) into early, middle, and late, with the middle being further broken down into early middle, middle middle, and late middle Pleistocene. In most instances numerical ages of the boundaries were arbitrarily set within the period of radiometric dating and the marine ^{18}O record. Exceptions were stratigraphic markers at the early-middle Pleistocene boundary at 788 ka (Matuyama-Brunhes polarity reversal) and the early middle–middle middle Pleistocene boundary at 610 ka (Lava Creek tuff and Pearlette O volcanic ash).

A good empirical relationship exists between cold stages in the marine oxygen isotope record and documented times of

Established Time Divisions: Period	Established Time Divisions: Epoch	Informal Time Divisions			Age (ka)	Oxygen Marine Isotope Stages[a]
					0	
Quaternary	Holocene				10[b]/ 12[d]	1
Quaternary	Pleistocene	Late Pleistocene	Wisconsin	Late Wisconsin	35[c]/ 24[d]	2
		Late Pleistocene	Wisconsin	Middle Wisconsin	65[c]/ 59[d]	3
		Late Pleistocene	Wisconsin	Early Wisconsin	79[c]/ 74[d]	4
		Late Pleistocene	Wisconsin	"Eowisconsin"[h]	122[c]/ 123[d]	5 a, b, c, d
		Late Pleistocene	Sangamon		132[c]/ 130[d]	5 e
		Late Middle Pleistocene	Illinoian[i]	Late Illinoian	198[c]/ 190[d]	6
		Late Middle Pleistocene	Illinoian[i]	Early Illinoian	302[c]	7, 8
		Middle Middle Pleistocene	Pre-Illinoian		610[e]	9, 10, 11, 12, 13, 14, 15
		Early Middle Pleistocene	Pre-Illinoian		788[f]	16, 17, 18
		Early Pleistocene	Pre-Illinoian		1,650[g]	19, 20 … 36
Tertiary	Pliocene					37 … 40

FIGURE 21—Quaternary time scale. Modified from Richmond and Fullerton (1986a, p. 6). Notes: (a) Marine oxygen isotope stages 1–22 are from Shackleton and Opdyke (1973, 1976), and stages 22–40 are from van Donk (1976). (b) Pleistocene-Holocene (2-1 isotope stage) boundary after Hopkins (1975). (c) Ages of marine isotope boundaries interpreted by Richmond and Fullerton (1986a) from graphic data presented by R. G. Johnson (1982). (d) Ages of the marine isotope boundaries taken from Martinson et al. (1987, table 2). Values were derived using the Milankovitch orbital tuning technique. (e) K-Ar age of the Lava Creek tuff and Pearlette O volcanic ash bed. Adopted by Richmond and Fullerton (1986a). (f) Astronomical age of the Matuyama-Bruhnes magnetic polarity reversal derived by R. G. Johnson (1982) and adopted by Richmond and Fullerton (1986a). (g) Age of the Pliocene-Pleistocene boundary at the Virca, Italy, section (Aguirre and Pasini, 1985). (h) The "Eowisconsin" is a time interval characterized by the existence of limited glaciation preceding the extensive Wisconsin glaciation (W. H. Johnson, 1986; Richmond and Fullerton, 1986a). The terrestrial record for this interval is yet restricted to the mountains of the western United States (Richmond and Fullerton, 1986b); in the central United States the interval is characterized by development of the Sangamon soil (Oviatt et al., 1988; Forman, 1990a; Forman, Bettis et al., 1992). (i) Richmond and Fullerton (1986a) defined the Illinoian glacial stage as marine isotope stages 6–8 based on the terrestrial glacial record, whereas the Illinoian is alternatively defined as isotope stage 6 using the marine isotope surrogate of climate. The beginning and end of isotope stage 6 (Illinoian glacial stage) has been dated using a geomorphic approach: Oviatt et al. (1988) reported thermoluminescence dates of 130 ± 30 ka and 136 ± 30 ka on the upper part of the presumed Loveland Loess in northeastern Kansas; Forman, Bettis et al. (1992) reported thermoluminescence ages of 125 ± 25 ka and 165 ± 20 ka on the mid-upper and lower parts, respectively, of the Loveland Loess in Illinois; isotopic dating of fossil coral reefs has placed the beginning of the Illinoian at 180–200 ka (Bender et al., 1979), and the end at somewhat less than 125 ka (Ku et al., 1990) and about 120 ka (Edwards et al., 1987a,b; Bard et al., 1990; Chen et al., 1991).

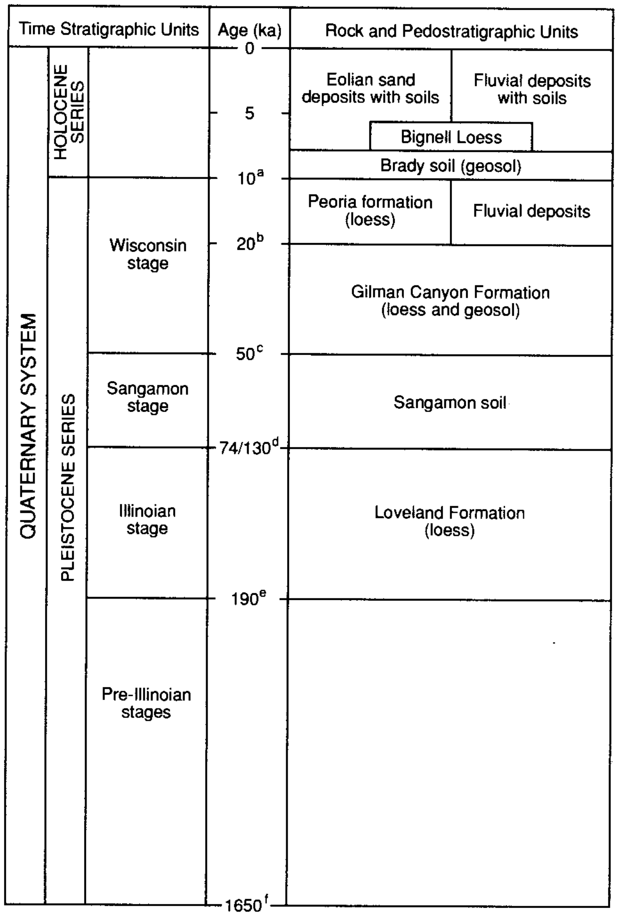


FIGURE 22—Late Quaternary stratigraphic succession in Phillips County. Notes: (a) Pleistocene-Holocene boundary after Hopkins (1975). This appears to be the time of major glacial-nonglacial environmental change in the central Great Plains, as recorded in the pedological record (W. C. Johnson and May, 1992). (b) The uppermost Gilman Canyon Formation dates to about 20 ka (see table 3 and fig. 26). (c) The date of 50 ka is only an estimate of the end of Sangamon time and reflects the current lack of data and apparent time-transgressive nature of the Sangamon soil (Follmer, 1983; Bowen et al., 1986, chart 1). Selection of the age is based on the relatively young age of the lower Gilman Canyon Formation (see table 3 and fig. 26; W. C. Johnson et al., 1993) and a similar basal age reported by Leigh (1991) on the correlative Roxana silt of the upper Mississippi valley. (d) The date of 74 ka (isotope stage boundary 4-5a), taken from Martinson et al. (1987, table 2), was derived using the Milankovitch orbital tuning technique. This date was selected because it is consistent with thermoluminescence ages from below the Sangamon soil in Illinois (Forman, 1990a; Forman, Bettis et al., 1992) and in central Kansas (Feng, 1991). The date of 130 ka (isotope stage boundary 5e-6), also taken from Martinson et al. (1987), represents the isotopically defined end of Illinoian glaciation (see fig. 21, note i). (e) Age of marine isotope boundary 6-7 as determined by Martinson et al. (1987). An alternative date of 302 ka has been proposed for the lower Illinoian (Richmond and Fullerton, 1986a; see fig. 21, note i). (f) Age of the Pliocene-Pleistocene boundary at the Virca, Italy, section (Aguirre and Pasini, 1985). No deposits of this age are believed to exist in Phillips County; the oldest are probably of upper pre-Illinoian age, that is, those classically referred to as the Meade formation of the Kansan Stage. Glacial deposits of northeastern Kansas have been dated to less than 700 ka (Aber, 1988; Oviatt, 1991).

glaciation (ice volume) in the United States (Richmond and Fullerton, 1986a). Given the close correspondence between the glacial record and the marine isotope record and the fragmentary nature of the glacial record, it follows that the nearly continuous loessal record should be an excellent terrestrial cognate of the marine isotope record. Therefore the climatic and chronologic record assembled for the marine sequence should match the loessal record well. The generally accepted model relating climate to the loessal record indicates that periods of stability and pedogenesis were usually associated with warm interglacial periods and that periods of significant loess accumulation coincided with the colder glacial times (Kukla 1977, 1987). Morphologic and isotopic analyses of plant opal phytoliths from loess exposed at the Eustis ash pit in southwestern Nebraska support the model and the relationship with the marine isotope record for the Illinoian, Sangamon, and early middle Wisconsin stages (Fredlund et al., 1985; Fredlund, 1990).

The late Quaternary stratigraphic succession for Phillips County is represented in fig. 22. Pre-Illinoian deposits are recognized in Phillips County but only in limited areas. Illinoian deposits occur more extensively but are restricted to certain stratigraphic and depositional contexts. Wisconsin sediments are widespread, with appreciable surface expression.

Pre-Illinoian stages The nonglacial component of pre-Illinoian time (classical Kansan stage) originally consisted of the Meade formation, which in turn was subdivided into the Grand Island and Sappa members. Frye and Hibbard (1941) described and designated a type locality for the Meade formation in Meade County, Kansas, and Hibbard (1949, 1958) later renamed the deposits at the type locality as the Crooked Creek Formation, deferring the name Meade formation to deposits in Clark County. In general, the deposits of the Meade formation are coarse textured at the base and grade upward into finer textured clastics with isolated lenses of volcanic ash. They occur in the northwestern part of the state as discontinuous and often obscure terrace-fill remnants within the major valleys. Stratigraphically equivalent deposits in Nebraska were designated the Grand Island Formation (Lugn, 1934, 1935) and the Sappa Formation (Condra et al., 1950). These names were adopted in Kansas, but at the member level within the Meade formation (Frye and Leonard, 1952). The name of Meade formation was subsequently abandoned, and the Grand Island and Sappa units were elevated to the formation level (Bayne and O'Connor, 1968).

Grand Island and Sappa Formations Absolute time control by means of fission-track, thermoluminescence, and other dating techniques and regional correlation may eventually validate continued use of "Grand Island" and "Sappa" as formation names or equivalents. The two names are used in this brief discussion but are of unknown pre-Illinoian age because the type sections have not been stratigraphically correlated with adjacent units in Nebraska. The two formations are combined here because they represent at most localities a continuous depositional sequence and because they have no currently known surface exposure in Phillips County; however, they have been encountered in subsurface exploration associated with this study.

Gravel, sand, and minor amounts of silt make up the Grand Island Formation, which occurs in northwestern Kansas as fill beneath a highly dissected terrace in major stream valleys with an average thickness of approximately 20 ft (6.1 m) (Bayne and O'Connor, 1968, p. 66). Lugn (1935) considered the Grand Island Formation to be of Kansan age, but Wayne and Aber (1991) believe it to be younger, at least in part. The Sappa Formation is composed of alluvial silt and to a lesser extent sand and conformably overlies the Grand Island. Lentils of Pearlette volcanic ash have been found locally within the upper Sappa (Frye and Leonard, 1952).

Frye and A. R. Leonard (1949, pl. 3) mapped limited deposits of Meade formation south of Long Island on the south side of Prairie Dog Creek valley in the northwestern part of Phillips County; these deposits were relocated for this study but are buried beneath a loess mantle. An extraordinary exposure created in 1953 during excavation of the cutoff trench for construction of Kirwin Dam is considered the most complete middle and late Pleistocene sequence documented in northwestern Kansas. This outcrop yielded a molluskan faunal assemblage surpassed by only one other exposure in Kansas (Frye and Leonard, 1954). An abandoned valley of the ancestral Solomon River was cut into the Niobrara Chalk and Carlile Shale and was filled with a sequence including the Grand Island and Sappa Formations. In its upper part the Sappa contains Pearlette volcanic ash and is capped by an extremely well-developed Yarmouthian soil, which was in turn overlain by Illinoian deposits: the Crete Formation and the Loveland Loess. Frye and Leonard (1954) noted that the Sappa Formation can be verified only through its molluskan fossil assemblage because the Pearlette volcanic ash is not always present. The molluskan assemblage, however, may be reflecting a 1.2-Ma record, not one of 610 ka, given the 1.27-Ma age of the ash at the type locality (Boellstorff, 1976).

Illinoian Stage All Pleistocene deposits, Illinoian and younger, were originally included in the Sanborn formation. Consequently, the formation differed from all others in that it included two glacial stages and substages as well as two major unconformities, namely, the Sangamon and Brady soils. The Sanborn formation was originally considered a convenient term for designating the unconsolidated Pleistocene deposits, primarily for mapping purposes. The name "Sanborn" was given to unconsolidated deposits by Elias (1931) in northwestern Cheyenne County, Kansas. Subsequently, Frye and Fent (1947) designated a Sanborn type section and subdivided the formation into three members: the Loveland silt, the Peoria silt, and the Bignell silt members. Frye and A. B. Leonard (1949) recognized a fourth member underlying the Loveland silt: the Crete sand and gravel. Because of subdivision into discernible, mappable units, use of the Sanborn formation designation has become inappropriate. Also, confusion results from the name Sanborn Group being used for a thick siltstone exposed in the Borchers Badlands, Meade County, Kansas, which has been dated (fission-track dating) to 1.08 Ma (Carter and Ward, 1991). In 1959 the Kansas Geological Survey abandoned the name Sanborn formation, elevated its members to the rank of formation (Jewett, 1959), and later defined phases within the formations (Bayne and O'Connor, 1968).

Because the Crete sands and gravels are not exposed and because the loesses and associated soils are difficult if not impossible to map individually, the loesses and their soils were undifferentiated, that is, mapped together as *Ql* on the county geologic map (W. C. Johnson and Arbogast, 1993).

Crete Formation The Crete sand and gravel was deposited as channel fill, presumably during the Illinoian Stage, and is probably a complex deposit composed of several cut-and-fill sequences. Lugn (1935) included both eolian and alluvial sediments in the original Loveland unit, but Condra et al. (1947) differentiated the sand and gravel from the loess and instituted the name Crete Formation for Nebraska. In north-central Kansas the Crete is well represented, locally as gully fills and on a larger scale as terrace deposits along the north side of major river valleys (Frye and Leonard, 1952, p. 112). In all instances the lithology of the Crete sand and gravel is consistent with that of the drainage basin within which the deposits occur.

In Phillips County the Crete Formation is well developed and present nearly continuously along the valleys of Prairie Dog Creek in the northwest corner of the county and the North Fork Solomon River. Surface and subsurface exploration in both valleys has indicated the presence of gravels beneath the terrace along the north side of the valleys. Wisconsin loesses have accumulated on the terrace, obliterating the characteristic terrace scarp morphology such that the terrace is typically indistinguishable morphologically. This is particularly true of Prairie Dog Creek, where loess has filled in small drainage ways and removed any expression of the heel or toe of the terrace. On the North Fork Solomon

River, the Wisconsin loess mantle is somewhat thinner, usually preserving the characteristic terrace form. The town of Glade is situated on the Illinoian terrace mantled by the younger loesses (Gilman Canyon and Peoria). This relationship is also evident at the town of Speed but to a lesser extent. Because of the loess covering, the Crete sand and gravel were not mapped in this study (W. C. Johnson and Arbogast, 1993).

The best age information for the Crete Formation in Phillips County comes from an exposure within an abandoned railroad cut west of Woodruff (see fig. 15). A section exposing sand and gravel overlain by loess (the Gilman Canyon and Peoria formations) and underlain by the Ogallala Formation was first described at this locality by Frye and A. R. Leonard (1949) as the Crete Formation. Subsequently, Frye and Leonard (1952) reinterpreted the deposits below the Gilman Canyon Formation as Grand Island sand and gravel with overlying Sappa silt. The Grand Island Formation reportedly contained a diagnostic molluskan fauna, and the deposit apparently occupies a topographically but not stratigraphically higher position than the Illinoian Crete deposits on the north side of the valley wall. The potential for the molluskan fauna to discriminate between the Crete and Grand Island Formations is unknown. The vertical distance between the formations, however, is not a significant factor, given the apparent variability of the top of the Crete elsewhere in the county. Results of this study indicated that a soil exposed within the silt is the late Wisconsin Gilman Canyon Formation. Furthermore, a tooth found by D. W. May was identified by L. D. Martin (personal communication, 1991) as a molar from the wild ass (*Equus cumminsii* or *Asinus* sp.; Kurten and Anderson, 1980, p. 287–288) and of a relatively young age (not pre-Illinoian).

Based on information currently available for Nebraska, Wayne and Aber (1991) suggested that the names "Grand Island" and "Crete" reference the same sedimentary unit, and they opted to discontinue use of the name "Crete Formation."

Loveland Loess The Loveland Loess is the most widespread pre-Wisconsin loess in the midcontinent. Several investigators [e.g., Reed and Dreeszen (1965), Ruhe (1969), Willman and Frye (1970), and Ruhe and Olson (1980)] have described it throughout the Missouri, Mississippi, and Ohio River basins. Furthermore, it has been recognized south into Mississippi and Arkansas (McCraw and Autin, 1989). The Loveland Loess has been far less studied (e.g., absolute chronology, geometry, mineralogic composition) than the Wisconsin loesses, especially the Peoria.

Shimek (1909) first identified the Loveland (as a waterlaid deposit) based on exposures along the east bluff of the Missouri River northeast of Loveland, Iowa, where the unit is underlain by Kansan till and overlain by Wisconsin loess. Several years later, the Loveland was identified and described in Nebraska by Lugn (1935), who identified both a valley phase (waterlaid) and an eolian phase (loess). Condra et al. (1950) separated the valley phase, naming it the Crete Formation. Since Leighton and Willman (1950) first designated the Loveland as an Illinoian-age loess, it has been assigned as such in both Kansas (Frye and Leonard, 1952) and Nebraska (Wayne, 1963; Reed and Dreeszen, 1965). Frye and Fent (1947) identified the Loveland Loess in Kansas on the basis of comparisons made with the type section in Iowa and deposits recognized in Nebraska. More recently, the Loveland of Nebraska has been separated into three distinct units, or members, based primarily on the presence of paleosols (Reed and Dreeszen, 1965; Schultz, 1968; Schultz and Martin, 1970). The original type section of the Loveland Loess was destroyed by a borrow pit for road construction, and a new type section (paratype) was designated at the end of the borrow pit area (Daniels and Handy, 1959; Bettis, 1990).

The Loveland can be described as a yellowish-brown or reddish-brown eolian silt. Red hues increase toward the top of the formation because of development of the Sangamon soil within the uppermost Loveland. The thickest accumulations occur in north-central Kansas; recorded thicknesses approach 15 m (49 ft). A thinning in the loess occurs both southward and westward such that the distribution becomes discontinuous to the southwest. In Phillips County the Loveland is typically less than 12 m (39 ft) thick, but it produces a distinctive mark on the landscape because of its variation in stratigraphy; it occurs on uplands and valley side slopes. As a result, the Loveland and its capping Sangamon soil are well expressed in natural exposures and particularly in freshly cultivated fields (fig. 23).

Several paleosols of varying degrees of development are present within the Loveland Loess, indicating periodic stability or at least dramatically decreased rates of loess fall. These soils were observed by Frye and Leonard (1954, p. 47) in the cutoff trench created during the construction of Kirwin Dam. Excavation of a trench at the Phillips County sanitary landfill near Phillipsburg provided the best upland exposure of Loveland and post-Loveland deposits in Phillips County for this study. Sampling at the site was not extensive but represents the major strata present. Standard laboratory analyses provided characterization of the sediments and pronounced definition of the stratigraphy (fig. 24). The relatively high carbonate content within the Loveland is consistent with observations elsewhere in Kansas. Textural variation within the Loveland reflects the presence of a sandy unit approximately 9–10 m (30–33 ft) below the surface; this unit has been recognized in central Kansas by Feng (1991) and may have equivalents in Nebraska. Feng named this unit the Barton sand, dated it as 95–70 ka, and detected three weathering zones within it.

The absolute age of the Loveland Loess is unknown for Phillips County, but Oviatt et al. (1988) reported thermoluminescence dates of 136 ka and 130 ka in the upper part of presumed Loveland Loess exposed in an abandoned quarry near Milford in northeastern Kansas. Thermoluminescence

FIGURE 23—Loess stratigraphy exposed in a cultivated field. The arrows, from top to bottom, indicate the modern surface soil, the Peoria loess, the Gilman Canyon Formation, the Sangamon soil, and the Loveland Loess. This view is west-southwest from the north-south section line road in the southern half of sec. 17, T. 1 S., R. 20 W.

data from central Kansas sites indicate that Loveland Loess accumulation ended at about 70 ka, following a sandy phase that began about 90 ka (Feng, 1991; W. C. Johnson, 1991b). Four zones of carbonate enrichment, occurring at about 410–360, 330–290, 250–200, and 130–95 ka, were interpreted to be pedogenic (Feng, 1991). Although Feng (1991) assigns all four carbonate zones to the Loveland stage, I believe that Illinoian time begins after the 250–200-ka carbonate accumulation. These carbonate zones are likely analogous to the soils observed in the Illinoian and pre-Illinoian loess at the Eustis ash pit (Fredlund et al., 1985) and elsewhere in the region (Schultz and Martin, 1970; Frye and Leonard, 1951). The zones are temporally equivalent to the nonglacial, or warm, marine isotope stages (Feng, 1991). Fossil pollen evidence indicates that the grasslands of the Great Plains expanded during the interglacial periods and contracted or perhaps disappeared during the glacial periods (Kapp, 1965, 1970; Fredlund and Jaumann, 1987). This suggests that the carbonate enrichment was a product of grassland pedogenesis, not unlike that of today. Fredlund et al. (1985) extracted grass opal phytoliths from the four soil zones at the Eustis ash pit in south-central Nebraska and found that the soil-forming periods were warmer and the periods of dust accumulation cooler.

Dating results from the Loveland paratype section are consistent with data obtained from loess in northeastern and central Kansas. Four thermoluminescence ages for the Loveland Loess indicate that the sediment was deposited approximately 135 ka (Forman, 1990b; Forman, Bettis et al., 1992).

Sangamon soil The Sangamon soil is strongly developed and occurs throughout the midcontinent beneath deposits of the Wisconsin glaciation and within deposits of the Illinoian glaciation or older deposits. This paleosol has been recognized in Indiana (Hall, 1973; Ruhe et al., 1974; Ruhe and Olson, 1980), Illinois (Bushue et al., 1974; Follmer, 1979) where the type section is located (Follmer, 1978), Iowa (Simonson, 1941; Ruhe, 1956, 1969), Nebraska (Schultz and Stout, 1945; Thorpe et al., 1951), and Kansas (Frye and Leonard, 1952). In Kansas the Sangamon soil is well expressed, occurring throughout the state. The soil has received considerable attention in northeastern Kansas (Frye and A. B. Leonard, 1949, 1952; Tien, 1968; Caspall, 1970; Bayne et al., 1971; Schaetzl, 1986), but it is recognized throughout the state (Bayne and O'Connor, 1968) and was recently studied in central Kansas (Feng, 1991). Historically, the Sangamon soil has been referred to as a "soil in the Sanborn formation" (Hibbard et al., 1944), the Loveland soil (Frye and Fent, 1947), and the Sangamon soil (Frye and Leonard, 1951). The color of the soil ranges from a vivid to pale reddish brown, with a loss of color occurring westward. Regionally, the soil character varies according to the parent material, local drain-

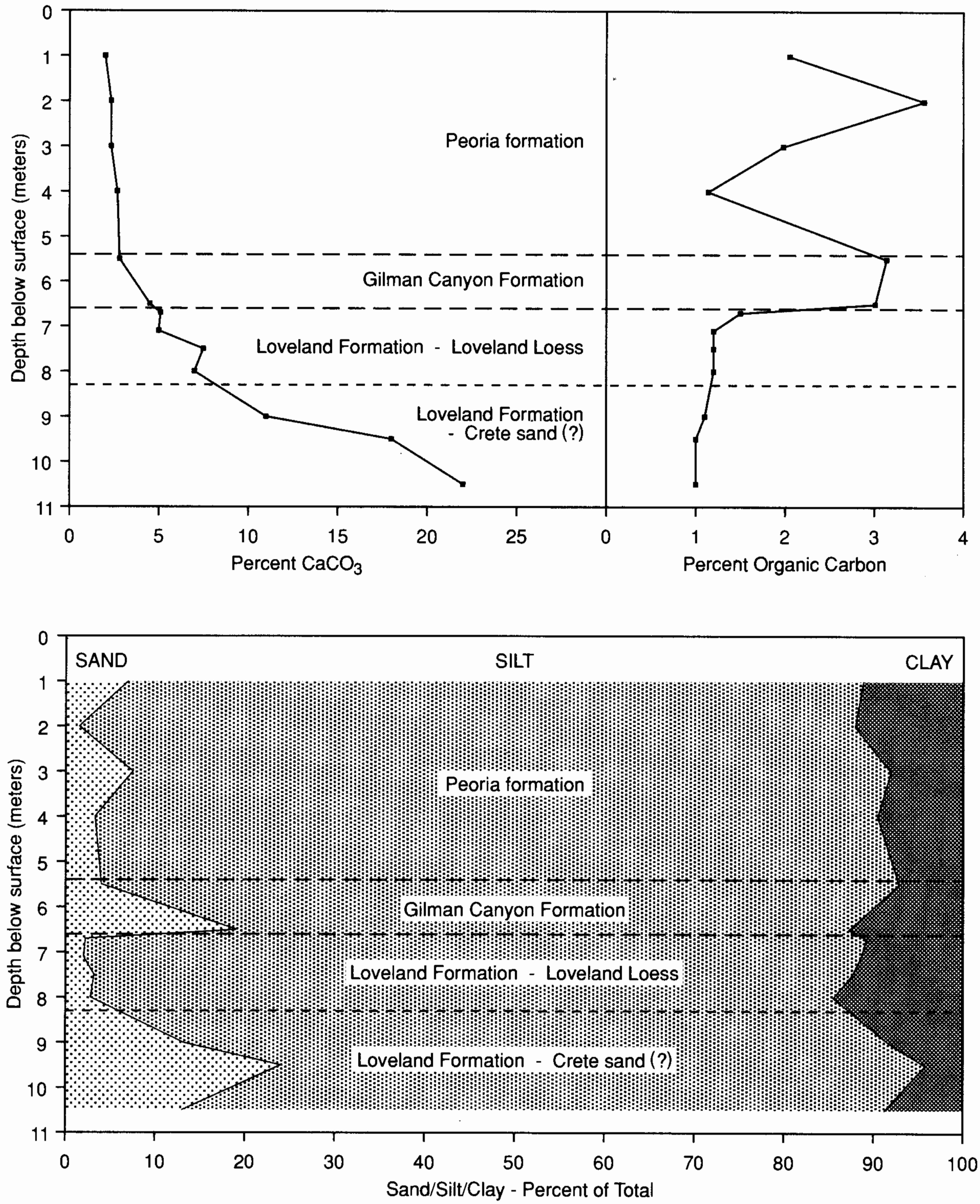


FIGURE 24—Particle size distribution, calcium carbonate content (%), and organic carbon content (%) of samples from the Phillips County sanitary landfill exposure. Data from Feng (1991).

age, and climate that prevailed at the time of pedogenesis. The soil occasionally contains sufficient clay to create a subtle bench on cultivated slopes. Schaetzl (1986) noted that the soil appears to be a strongly developed Ultisol or Mollisol.

The Sangamon soil was first used in a time-stratigraphic context to differentiate deposits of the Illinoian and Wisconsin glacial stages (Leverett, 1899). An appreciable time span for regional landscape stability and soil formation are indicated by intense oxidation, deep leaching, and high clay accumulation. The main problem associated with the Sangamon soil is its diachronous upper and lower boundaries (Follmer, 1978, 1982, 1983; W. H. Johnson, 1986). To further confuse the time element, the lower 1–2 m (3–7 ft) of the early Wisconsin loess is typically weathered and forms a pedologic continuum with the underlying Sangamon soil, and most investigators, until recently, mistakenly included the Wisconsin loess in the Sangamon profile (Follmer, 1983). The Sangamon soil should be considered a pedocomplex rather than a single soil that developed under unique environmental conditions (Schultz and Tanner, 1957; Fredlund et al., 1985; Morrison, 1987). It apparently represents several paleosols welded together to form a complex that reflects significant spatial and temporal variation in environmental conditions and an appreciable time span. Laboratory data from exposures in central Kansas indicate that the Sangamon soil was strongly weathered chemically, presumably under a warm, moist climate (Feng, 1991).

Because of apparent time transgressiveness, the age of the Sangamon soil is not precisely known. Follmer (1983) reported a radiocarbon age of 41,700 ± 1,100 yr B.P. on plant material from the top of the Sangamon in its type area in Illinois. The thermoluminescence ages of 136 ka and 130 ka reported by Oviatt et al. (1988) for the upper Loveland Loess of northeastern Kansas provide a maximum age for the Sangamon soil. Forman (1990a) and Forman, Bettis et al. (1992) reported thermoluminescence ages of approximately 135 ka and 77 ka from loess below the Sangamon soil at two sites in Iowa and Illinois and concluded that the Sangamon soil is diachronous and may consist of several soils. Feng (1991) and Feng et al. (1991) reported a thermoluminescence age of about 70 ka in the lowermost part of the Sangamon soil exposed in central Kansas and associated it with marine isotope stage 3. Although Richmond and Fullerton (1986b) assign Sangamon time to 132–122 ka (isotope substage 5e; see fig. 21), they acknowledged reported ages (relative and absolute) ranging from early Illinoian to middle Wisconsin. Basal ages on the overlying Gilman Canyon Formation from Phillips County and elsewhere in Kansas and Nebraska provide a minimum age of about 35 ka for the Sangamon soil (W. C. Johnson et al., 1990). Also, Forman (1990b) and Forman, Bettis et al. (1992) obtained basal thermoluminescence and radiocarbon ages of 35–30 ka within the loess overlying the Sangamon soil at the Loveland paratype section in Iowa and the Pleasant Grove School section in Illinois.

Post-Sangamon time was one of extensive landscape instability, including upland erosion, as evidenced by the partial or complete removal of the Sangamon soil. In the quarry near Woodruff (see fig. 15) the Loveland and Sangamon have been removed and the top of the Ogallala has been eroded. Similarly, the same units may have been stripped and channels cut into the Smoky Hill Chalk Member before deposition of the Gilman Canyon Formation (see fig. 7). Consequently, erosional truncation of the soil may be responsible in part for the apparent diachrony of the soil. Deposition occurred at some locations; a sandy eolian zone overlying the Sangamon soil in the Phillips County sanitary landfill (see fig. 24) suggests a dry and windy transition to the Gilman Canyon Formation above.

Wisconsin Stage As the most recent glacial episode, the Wisconsin has the greatest resolution and has been traditionally defined with five substages. It is generally accepted that the stage began approximately 79,000 to 70,000 years ago according to radiocarbon dating. The substages, as defined in Illinois, include the Altonian (70,000–28,000 yr B.P.), the Farmdalian (28,000–22,000 yr B.P.), the Woodfordian (22,000–12,500 yr B.P.), the Twocreekan (12,500–11,000 yr B.P.), and the Valderan (11,000–5,000 yr B.P.) (Willman and Frye, 1970; Frye and Willman, 1973). Frye and Leonard (1965) referred to the Altonian, Farmdalian, and Woodfordian substages collectively as the pre-Bradyan and the Valderan as the post-Bradyan, the name Brady coming from the Brady soil. Time divisions within the Wisconsin have since been rescaled and renamed (see fig. 21); the stage is defined as extending from 122 ka to 10 ka, or isotope stages and substages 5d through 2. Divisions consist of the Eowisconsin, and the early, middle, and late Wisconsin. The Eowisconsin is represented by limited glaciation in the western United States and may coincide with continued development of the Sangamon soil.

The Wisconsin rock-stratigraphic units recognized in Phillips County consist of early to middle Wisconsin fluvial deposits, the Gilman Canyon Formation (loess), the Peoria loess, and late Wisconsin fluvial deposits. As noted, the Loveland Loess, Sangamon soil, Gilman Canyon Formation, and Peoria loess of Phillips County were mapped in an undifferentiated fashion as *Ql* (W. C. Johnson and Arbogast, 1993). The early to middle and late Wisconsin fluvial deposits are undifferentiated and not mapped per se but are represented by the map designation *Qt* because both underlie the high terrace in the valley bottoms.

Early to middle Wisconsin fluvial deposits Fent (1950) and Frye and Leonard (1952) noted that valleys of major Kansas streams became entrenched below the level of earlier valley floors during the late Illinoian or early Wisconsin. This is particularly true for the valleys of northern Kansas, including Phillips County. Accordingly, early Wisconsin fill occu-

FIGURE 25—Kirwin terrace and fill exposed in the Siebert gravel pit. The north exposure of the pit reveals a loess cap (vertical face) on early Wisconsin fill. A buried soil (arrow) developed within the loess was radiocarbon-dated to produce ages of 33,590 ± 2260 yr B.P. (Tx–6625) and 24,270 ± 750 yr B.P. (Tx–6624) on the lowermost and uppermost 5 cm (2 in.) of the A horizon, respectively. The view is from the southwest corner of the pit, located in SWNE sec. 29, T. 4 S., R. 18 W.

pies a basal position in the present bedrock valleys and is overlain by late Wisconsin and Holocene stream deposits. Exposures of this fill are therefore exceedingly rare, and earlier studies (Frye and Leonard, 1952, 1965) report its presence exclusively from drillhole data. Frye and Leonard (1952, 1965) assume that the sand and gravel from drillholes within terrace fill are of early to middle Wisconsin age and cite the truncation of Illinoian deposits as evidence. The fill reaches thicknesses of 90 ft (27 m), fines upward rapidly near the top, and underlies an extensive terrace 15–35 feet (4.6–11 m) above the present channel, which has been recognized throughout much of the Kansas River basin. Specific terrace identifications include the Newman terrace of the lower Kansas River valley (Davis and Carlson, 1952), the Schoenchen terrace of the Smoky Hill River valley (Leonard and Berry, 1961), the Almena terrace of Prairie Dog Creek (Frye and A. R. Leonard, 1949), the Kirwin terrace of the North Fork Solomon River valley (Frye and A. R. Leonard, 1949; A. R. Leonard, 1952), the Schoenenburg terrace of the Republican River valley (Martin, 1990), and other unnamed terraces in smaller tributaries. The widespread distribution of these potentially correlative surfaces indicates a Kansas River basinwide sequence of alluvial events in the late Wisconsin.

Although the Almena and Kirwin terraces and one unnamed terrace in Bow Creek occur within Phillips County, the Kirwin is the most extensive. The only exposure of early Wisconsin alluvium occurs in the Siebert gravel pit, 3 km (1.9 mi) east of Glade in SWNE sec. 29, T. 4 S., R. 18 W. (fig. 25). The site is a remnant of early to middle Wisconsin fill beneath the Kirwin terrace. The alluvium is overlain by 6.07 m (19.9 ft) of silt (Gilman Canyon and Peoria formations) and extends to at least 9.1 m (30 ft) below the water table, providing a total exposed thickness of approximately 17 m (56 ft). Lithologically, the alluvium is a mixture of the Niobrara Chalk and Ogallala-derived sand and gravel. A maximum age of early Wisconsin is indicated by the inset position of the alluvium within the Crete gravel along the adjacent valley wall to the north and by two radiocarbon ages determined from a buried soil in the silt overlying the alluvium. The radiocarbon ages, obtained from the uppermost and lowermost 5 cm (2 in.) of the soil A horizon, are 24,270 ± 750 yr B.P. (Tx–6624) and 35,590 ± 2260 yr B.P. (Tx–6625), respectively (W. C. Johnson, 1990). Wisconsin fluvial deposits exposed are here older than 35,000 years, but the absolute age is unknown.

Gilman Canyon Formation The Gilman Canyon Formation, first recognized in Nebraska (Reed and Dreeszen, 1965), is an early late Wisconsin (Farmdalian) loess (see figs. 21 and

22). Equivalents of the formation have been recognized elsewhere; the Loveland Loess is buried by the Roxana silt from Minnesota and Wisconsin to Arkansas and by the Pisgah formation in western Iowa (Bettis, 1990). The Gilman Canyon of Nebraska and Kansas is typically dark colored, silty, leached of calcium carbonate, and heavily enriched in organic carbon through pedogenesis (melanization). It was once considered to be the attenuated A horizon of the Sangamon soil (Thorpe et al., 1951; Reed and Dreeszen, 1965).

Reed and Dreeszen (1965) provide limited textural data and description of the Gilman Canyon Formation at the type section. Their description within the columnar section at the Buzzard's Roost exposures states (p. 62): "Upper 12 inches [31 cm] is medium dark gray, slightly humic, silt; middle 1 foot 1 inch [33 cm] is light brownish-gray silt; basal 3 feet 8 inches [1.1 m] is dark brownish-gray, humic, soil-like silt; entire thickness is noncalcareous ... 5 feet 9 inches [1.8 m]." Although all these attributes described at the type section are observed in Nebraska and Kansas, the bimodal distribution of humus is curious; it suggests the existence of two periods of relative stability, or low accumulation rates, and an intervening period of accelerated accumulation rates. Consequently, the Gilman Canyon Formation often appears as one or more cumulic A horizons that are developed within a variably to noncalcareous loess, usually no more than 1.2 m (4 ft) thick. In a section revealing an expanded valley phase of the Gilman Canyon Formation, May and Souders (1988) recognized three distinct organic zones, each of which may represent a distinct episode of pedogenesis. I have recently observed two such zones at the Eustis ash pit in south-central Nebraska. If two or more distinct periods of soil formation did occur regionally, they are obscured at many localities, perhaps because of bioturbation. Overall, the formation reflects a sufficiently slow rate of loess fall (<0.08 mm/yr) such that pedogenesis was operating more or less continuously but with a decreased intensity at one or more times.

As expressed, the Gilman Canyon Formation is frequently overlain by 0.9–1.5 m (3–5 ft) of leached loess, which is considered basal Peoria formation. Correlative with the Gilman Canyon and overlying leached loess zone is the *Citellus* zone (*Citellus* was a ground squirrel now recognized as the genus *Spermophilus*) of Nebraska (Condra et al., 1950). The leached zone is transitional between the well-developed A horizon(s) in the Gilman Canyon and the calcareous Peoria loess above and probably reflects a sufficiently slow accumulation of Peoria loess such that pedogenesis could keep pace only partially. A. B. Leonard (1951, 1952) supports the contention that the leached, or basal zone was a slowly accumulating early Peoria loess experiencing pedogenesis; Leonard inferred that gastropods were originally present but were subsequently destroyed during weathering. Above the leached zone the rate of accumulation of Peoria loess was sufficiently rapid (0.6 mm/yr) to preclude any soil development.

McKay (1979a,b) noted in Illinois that radiocarbon ages on organic materials from within early Wisconsin loess range from 40,000 to 31,000 yr B.P., and he extrapolated an age of 45,000 yr B.P. for the initiation of loess deposition. Furthermore, McKay (1979b) placed the end of the Farmdalian at about 25,000 yr B.P., that is, when Woodfordian (Peoria) loess fall began. As noted, Forman (1990a) and Forman, Bettis et al. (1992) reported thermoluminescence and radiocarbon ages of 35–30 ka for the loess immediately above the Sangamon. Follmer (1983, p. 141) indicated that about 5,000 years separates the first deposition of glacially derived loess and the time of maximum Woodfordian glacial extent in Illinois at about 20,000 yr B.P. This 5,000-year period may coincide with that for the development of the leached zone overlying the well-developed (organic-enriched) part of the Gilman Canyon. Radiocarbon ages obtained from the Roxana silt in the Upper Mississippi River valley indicate that the loess unit was deposited between 50 and 27 ka (Leigh, 1991).

Radiocarbon ages from the Gilman Canyon Formation range from approximately 35,000 yr B.P. at the base to 20,000 yr B.P. at the top (May and Souders, 1988; W. C. Johnson et al., 1990). Table 3 and fig. 26 present radiocarbon ages for the Gilman Canyon Formation of Nebraska and Kansas, and fig. 27 designates the locations from which the age data were obtained. The basal age of 35 ka agrees well with the time set by Richmond and Fullerton (1986a) (see fig. 21) for the beginning of the late Wisconsin. Although Nebraska has several dated locations forming an arcuate pattern around the eastern and southern sides of the Sand Hills, data come from only three areas in Kansas: Phillips, Barton, and Pratt counties. The ages in Kansas do show, however, good agreement between the south-central and north-central parts of the state and with ages from Nebraska.

Given the radiocarbon time control and stratigraphic information currently available for the Gilman Canyon Formation in Kansas and Nebraska, it is clear that the associated soil is a *geosol*, that is, a laterally traceable, mappable, pedostratigraphic unit with a consistent time-stratigraphic position (Morrison, 1965; North American Commission on Stratigraphic Nomenclature, 1983, p. 865). The entire formation can be considered a geosol, but because of the possible existence of two or more identifiable cumulic A horizons merged or welded together, the Gilman Canyon may ultimately be designated a *composite geosol*.

The Gilman Canyon Formation is a ubiquitous feature in exposures of loess in Phillips County. It is pronounced in vertical faces and where unimproved roads bevel its surface, such as along the east-west section line road near SESE sec. 4, T. 1 S., R. 20 W. Observed thicknesses of the Gilman Canyon within Phillips County range from 0.45 to 1.6 m (1.5–5 ft) and average approximately 1 m (3 ft). The texture is a silt loam to sandy silt loam, and the color is dark brown to purplish black. The purple cast at the Eustis ash pit appears to be derived from a relatively high iron content (S. Valastro, personal communication, 1992) but may also be due to

TABLE 3—Gilman Canyon Formation radiocarbon ages[a]

Location	Source	Age (sample)
Nebraska		
WI, Winslow Hill[b]	Dreeszen, 1970	23,000 ± 600 (I–2191)
		31,400 + 1800, –1500 (I–2192)
YA, Yankee Hill	Reed et al., 1966	26,900 + 1000, –900 (I–2189)
		34,900 + 2100, –1700 (I–2190)
YO, depression near York (auger holes)	Krueger, 1986	20,940 ± 240 (Beta–12273)
		23,740 ± 220 (Beta–12272)
		28,350 ± 610 (Beta–12274)
CE, Central City	Martin and Dort, 1987	19,640 + 230, –240 (DIC–3118)
ON, depression near Ong (core holes)	Kuzila, 1988	22,590 ± 280 (Beta–24268)
		24,990 ± 430 (Beta–23457)
		26,140 ± 530 (Beta–23456)
SO, UNL South-Central Research Extension Center (core hole)	Kitchen, 1987	20,220 ± 330 (Beta–20102)
SP, Spring Ranch	Kuzila, 1988	21,140 ± 220 (Beta–20105)
		33,950 ± 290 (Beta–20104)
FU, Funk	Souders and Dreeszen, 1991	24,260 ± 260 (Beta–40551)
BO, Bone Cove	C. Martin and Johnson, unpub. data, 1992	26,330 ± 400 (PITT–0826)[c]
	Martin, 1990	26,260 ± 680 (Tx–5910)
NO, North Cove	W. C. Johnson, unpub. data, 1991	27,850 ± 830 (Tx–7073)[c]
		29,950 ± 900 (Tx–7074)[c]
		30,700 ± 990 (Tx–7072)[c]
CO, Coyote Canyon	C. Martin, unpub. data, 1992	21,550 ± 500 (Tx–7294)[c]
NA, Naponee	Souders and Kuzila, 1990	19,770 ± 590 (Beta–33940)
		29,870 ± 1650 (Beta–33941)
JO, Johnson Lake	May and Souders, 1988	24,310 ± 530 (Beta–23343)
		29,450 ± 1250 (Beta–21298)
		29,790 ± 520 (Beta–25769)
		31,210 ± 1420 (Beta–25770)
		34,880 ± 1060 (Beta–23495)
EU, Eustis ash pit	Johnson, 1990	25,090 ± 590 (Tx–6633)[c]
LA, La Sena site (Ft–177)	May and Holen, 1993	20,870 ± 1280 (Tx–6707)
		24,830 ± 1340 (Tx–6709)
LI, Lime Creek site (Ft–41)	D. W. May, unpub. data, 1991	27,970 ± 1190 (Tx–6774)[c]
BU, Buzzards Roost	May and Holen, 1993	21,290 ± 290 (Beta–26826)
	Dreeszen, 1970	27,900 + 1100, –1000 (I–2188)
	Dreeszen, 1970	32,000 + 2000, –1600 (I–1851)
OX, Oxford	D. W. May, unpub. data, 1991	28,710 ± 970 (Tx–6657)
MI, Mirdan Canal	Gottula and Souders, 1989	20,660 ± 260 (Beta–28785)
		30,370 ± 750 (Beta–28784)
Kansas		
PH, Phillips County sanitary landfill	This study	24,910 ± 770 (Tx–6746)[c]
KI, Kirwin railroad cut	This study	25,500 ± 820 (Tx–6747)[c]
SI, Siebert pit	Johnson, 1990, and this study	24,270 ± 750 (Tx–6624)[c]
		33,590 ± 2260 (Tx–6625)[c]
BA, Barton County landfill	Johnson, 1990	24,360 ± 570 (Tx–5908)[c]
PR, Pratt County landfill	W. C. Johnson, unpub. data, 1990	19,640 ± 410 (Tx–6449)[c]
		20,550 ± 590 (Tx–6622)[c]

a. Ages from eolian and alluvial phases.

b. Site designation on fig. 27.

c. Reported $\delta^{13}C$ correction.

concentrations of manganese (G. J. Retallack, personal communication, 1992). The paleotopography represented by the soil surface suggests that relief at the close of Gilman Canyon time was appreciably less than at present.

Several good exposures of the Gilman Canyon occur within cuts of the Missouri Pacific Railroad where the tracks parallel K–9 between Glade and Kirwin (fig. 28). A radiocarbon age of 25,500 ± 820 yr B.P. (Tx–6747) was obtained from the upper 5 cm (2 in.) of the Gilman Canyon soil A horizon exposed in one of the cuts (fig. 29). The site illustrates how well the paleosol is developed, relative to the overlying surface soil. The Holdrege silt loam (a fine-silty, mixed, mesic Typic Argiustoll), considered to be a mature loessal soil, is clearly less well developed than the underlying Gilman Canyon soil; this observation has implications for the duration of soil development and landscape stability. At the Siebert gravel pit (see fig. 25) stratigraphic features (e.g., fining upward, small pebbles, lithology) indicate that the buried soil dating to Gilman Canyon time represents, at least in part, an alluvial phase rather than the eolian phase recognized elsewhere.

The best exposure of the Gilman Canyon Formation in an upland position is provided by a freshly excavated trench at the Phillips County sanitary landfill (fig. 30). A radiocarbon age of 24,910 ± 770 yr B.P. (Tx–6746) was obtained from a sample collected in the upper 5 cm (2 in.) of the upper organic-rich zone of the formation (fig. 31). The leached zone often recognized in the uppermost Gilman Canyon above the organic-rich portion is extremely well expressed at this locality. Furthermore, a 15–25 cm (6–10 in.) thick zone of slightly decreased organic carbon (humus) is visible under certain lighting and moisture conditions in the middle of the formation at this site, suggesting the existence of two periods of pedogenesis or an increase in loess accumulation rates during middle Gilman Canyon time. Sediment data from the formation (see fig. 24) indicate low sand (4%), high silt (89%), low clay (7%), low carbonate (leached), and high organic carbon contents. With the exception of the exposure in NWNENE sec. 26, T. 4 S., R. 16 W. (fig. 29), the limited particle size data suggest that clay weathering or translocation was not a major pedogenic process; that is, there is no definable B or Bt horizon. Unpublished data from the Eustis ash pit document 5% or less of clay in the formation (M. M. Kerr, personal communication, 1992). Feng (1991) noted that the Gilman Canyon Formation of central Kansas is strongly weathered physically with extremely low amounts of clay.

Limited paleoenvironmental data are emerging for the Gilman Canyon Formation. Potential sources of proxy data for vegetation type and hence climate are $\delta^{13}C$ values (Krishnamurthy et al., 1982). When determinations are derived from the organic fractions of the soil, they reflect inputs by the plants, particularly grasses, growing on those surfaces. C3 (cool-season) species have an average $\delta^{13}C$ composition of −27‰ and C4 (warm-season/arid) species −13‰ relative

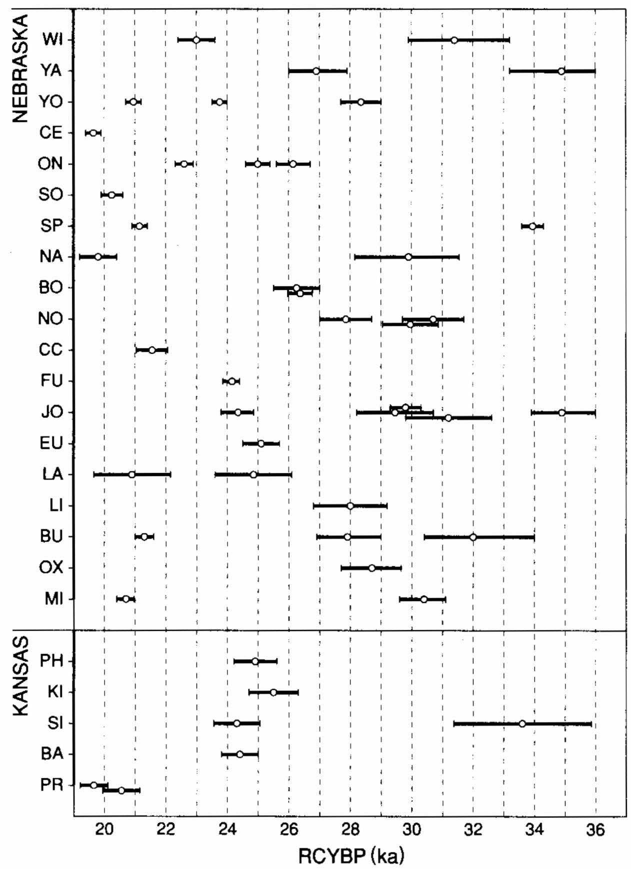


FIGURE 26—Graphic representation of the radiocarbon ages presently available from the Gilman Canyon Formation.

to the PDB standard (Deines, 1980) (table 4). The terrestrial plant ecology of the Gilman Canyon Formation apparently is characterized by primarily C4-type grasses, or a relatively warm, possibly dry climate. From plant opal phytolith morphology (Fredlund et al., 1985; Fredlund and Jaumann, 1987) and isotope data (Fredlund, 1990) it is evident that a panicoid-dominated grassland existed, that is, an environment suitable for moist, temperate-adapted tall grasses. This interpretation is not inconsistent with the $\delta^{13}C$ values because panicoid grasses are C4 types. Furthermore, some of the derived C3-level values, specifically those from the La Sena and Lime Creek sites, reflect former peaty or otherwise local wet valley bottom environments (D. W. May, personal communication, 1992) that are characterized by meso- or hygrophytic C3 plants.

A fossil pollen assemblage from a core extracted from Cheyenne Bottoms, a large marsh in central Kansas, indicates mesic conditions in the marsh and an upland vegetation of grass and sage with scattered trees in the valley and along escarpments during the period from approximately 30 ka to 25 ka (Fredlund, 1991). The Farmdalian-Woodfordian transition, approximately 25–24 ka, was characterized by increased aridity. The Muscotah Marsh fossil pollen record of

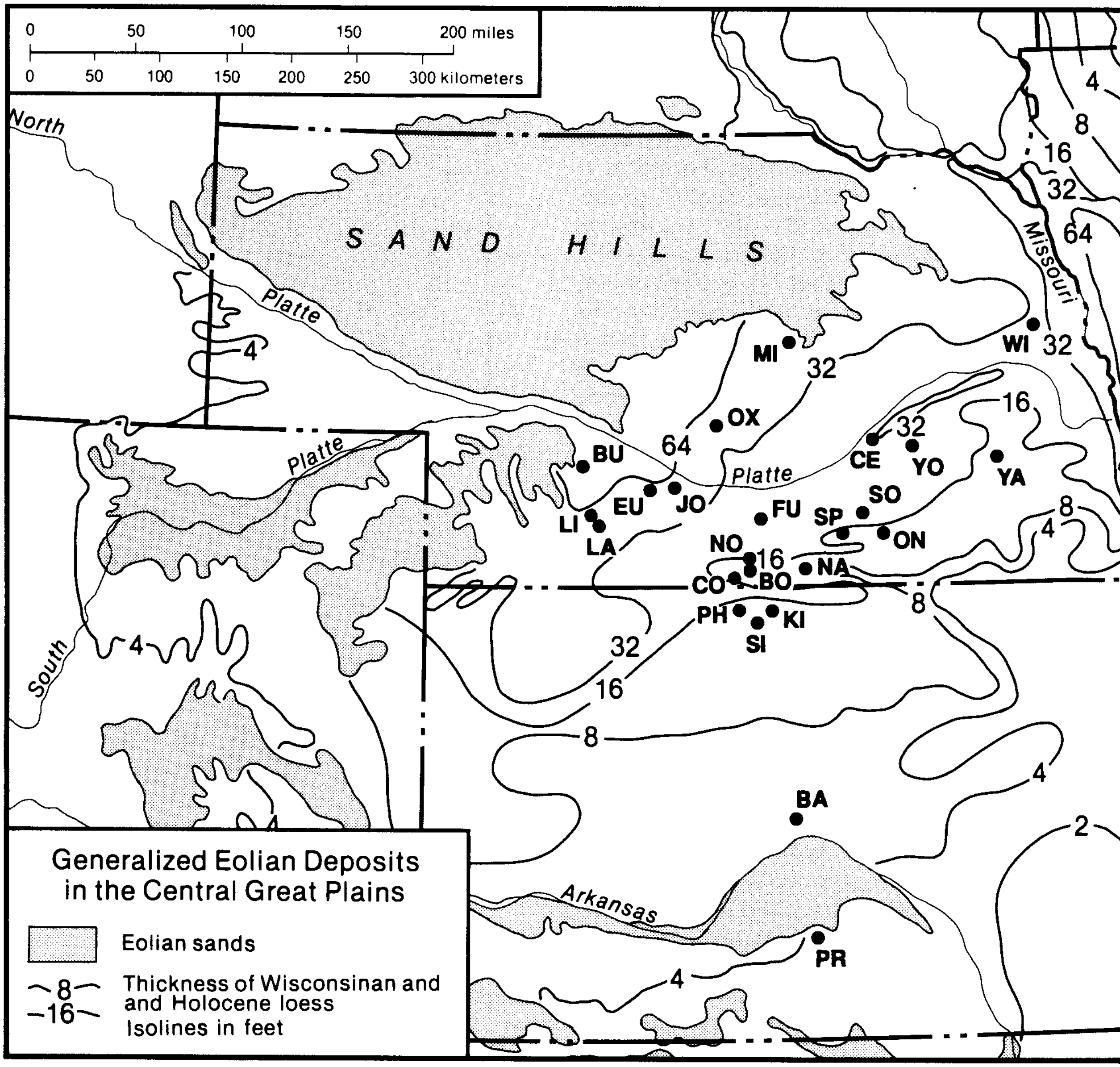


FIGURE 27—Localities from which radiocarbon ages have been obtained on the Gilman Canyon Formation in Nebraska and Kansas. Isolines represent total loess thickness in feet. See table 3 for site names and age data.

northeastern Kansas reflects a mosaic of deciduous forest and prairie (Gruger, 1973; Fredlund and Jaumann, 1987). Regionally, the Farmdalian grasslands apparently spread as far east as Iowa (Baker and Waln, 1985) and as far north as the Sand Hills region of Nebraska (Fredlund and Jaumann, 1987).

Peoria loess Leverett (1899) first proposed the name Peoria for an interglacial period between the Iowan and Wisconsin glacial stages. When Alden and Leighton (1917) demonstrated that the Peoria was younger than Iowan, usage shifted to that of a loess rather than a weathering interval. Within the midcontinent several names have been used for post-Farmdalian loess. Ruhe (1983) preferred the term "late Wisconsin loess" because of the uncertainties in stratigraphic equivalency from one region to another. The Peoria loess is typically an eolian, calcareous, massive, light yellowish-tan to buff silt that typically overlies the Loveland Loess or an approximate equivalent of the Gilman Canyon Formation.

Ruhe (1983) noted three major features of late Wisconsin (Peoria) loess: It thins downwind from the source area, decreases in particle size systematically away from the source area, and is strongly time transgressive at its base. The last feature is problematic and causes correlation problems. Ruhe

FIGURE 28—The Gilman Canyon Formation (arrow) exposed in the north face of a cut on the Missouri Pacific Railroad in NWNENE sec. 26, T. 4 S., R. 16 W. Peoria loess overlies the formation, and the Loveland Loess and Smoky Hill Chalk Member underlie it.

FIGURE 29—Soil of the Gilman Canyon Formation (spade) exposed in the south face of the railroad cut shown in fig. 28. A radiocarbon age of 25,500 ± 820 yr B.P. (Tx–6747) was obtained from the upper 5 cm (2 in.) of the buried A horizon (trowel). The clay-rich B horizon of the paleosol forms the bulge in the profile below the spade.

FIGURE 30—The soil of the Gilman Canyon Formation exposed in the west face of a recently excavated trench at the Phillips County sanitary landfill. The pit is located in the southern half of SWSE sec. 34, T. 3 S., R. 18 W.

(1969) realized a decrease in the age of the soil under the loess from 24,500 yr B.P. near the Missouri River to about 19,000 yr B.P. eastward across southwestern Iowa. A decrease from 25,000 to 21,000 yr B.P. was noted for the base of the loess along a transect in Illinois (Kleiss and Fehrenbacher, 1973). The top of the loess also seems to be time transgressive, ranging from about 12,500 yr B.P. in Illinois (McKay, 1979a) to 14,000 yr B.P. in central Iowa (Ruhe, 1969).

In Kansas the Peoria loess is a reddish, yellowish, or tan-buff homogeneous, massive, locally fossiliferous, variably calcareous coarse silt to very fine sand to medium to fine silt and clay (Frye and Leonard, 1952). Thicknesses vary from 100 ft (30.5 m) adjacent to the Missouri River valley to 2 ft (0.6 m) in discontinuous patches. Any accumulation less than about 2 ft (0.6 m) is presumed unrecognizable in the field because it has become incorporated into the existing surface soil.

The Peoria loess in Phillips County typically rests conformably on the Gilman Canyon Formation and is highly variable in its distribution and thickness. Thicknesses are greatest in the northwest corner of the county on the north side of Prairie Dog Creek. Coverage is continuous except for the young alluvial fill in tributaries. Relatively thick but areally limited deposits occur on the sharply defined divide between the north-flowing tributaries of Prairie Dog Creek and the south-flowing tributaries of Deer Creek. Erosion since loess deposition ceased has been extensive in these high-energy tributaries. Roadcut exposures are common in this area (fig. 32) and may reveal as much as 6 m (18 ft) of the Peoria. Although the average thickness of Peoria loess decreases southeastward in the county, continuous upland coverage appears in the low-gradient tributaries flowing south into Deer Creek. With the exception of the interfluve between Deer Creek and the North Fork Solomon River, deposits in the southern third of the county are relatively small and limited to divides.

Despite the amount of attention given to the Peoria loess in Kansas, the source of the silt is not completely certain. From their review of the available data, Welch and Hale (1987) concluded that a single source was not likely for all loess deposits in Kansas and that the loess was derived from a combination of three sources: glacial outwash river floodplains, present sand dune areas, and fluvial and eolian erosion of the Ogallala Formation. The Peoria loess exposed in the Phillips County sanitary landfill contains moderate but variable amounts of sand and exhibits a general increase in clay upward. If this trend is real, it could be attributable to an influx of clay from the southwest as atmospheric wind patterns changed in response to a diminishing Laurentide ice sheet (COHMAP members, 1988).

A. B. Leonard (1952) subdivided the Peoria loess of Kansas into four zones on the basis of the molluskan fauna assemblages present. The *basal zone* is equivalent to the leached interval above the Gilman Canyon Formation and is void of molluskan material. The *lower molluskan zone*, or Iowan, produced an assemblage containing 14 species, 2 of

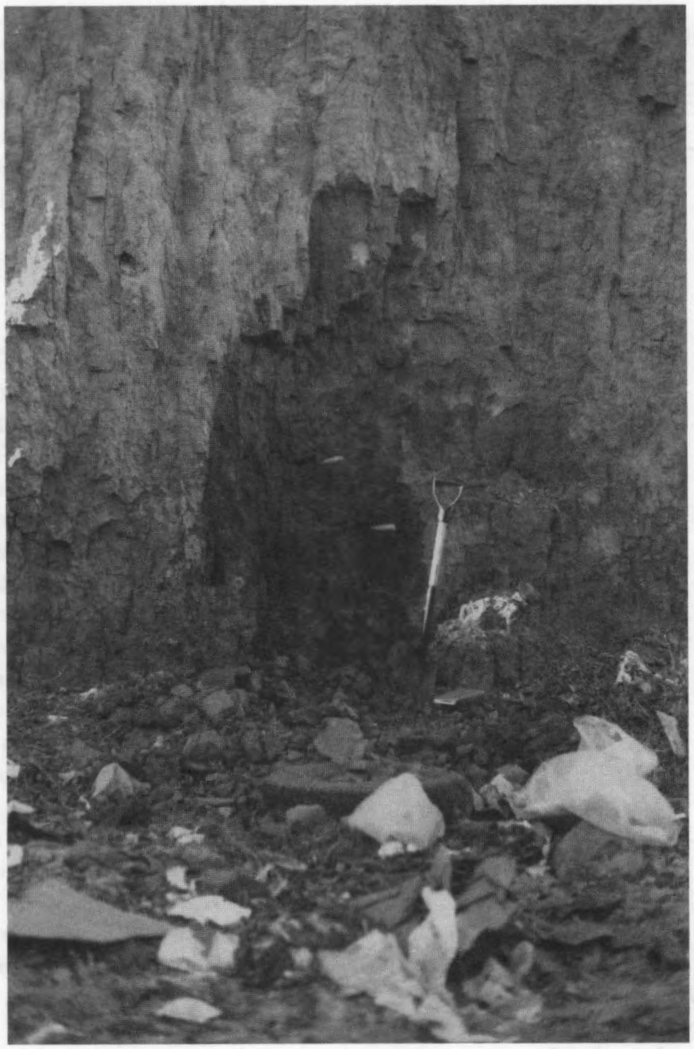


FIGURE 31—Soil of the Gilman Canyon Formation within the landfill trench shown in fig. 30. This photograph was taken after the trench had been partially filled. A radiocarbon age of 24,910 ± 770 yr B.P. (Tx–6746) was determined from a sample collected in the upper 5 cm (2 in.) of the better developed part of the A horizon (lower trowel). The profile section between the two trowels represents somewhat diminished pedogenesis because the Peoria loess fall began slowly.

which are diagnostic of the zone. A *transitional zone*, located between the upper and lower faunal zones, contains elements of both assemblages and does not imply any abrupt change in the depositional environment, although the depositional rate may have slowed somewhat. The *upper molluskan zone*, or Tazewellian, contains 26 species, 14 of which do not occur in the lower zone. Because of the relative youth of the Peoria, little of the upper zone has been lost from the upland. Consequently, the upper zone is frequently exposed, and many localities in Phillips County yield snail assemblages indicative of the upper zone. One of several excellent snail-rich localities is a 2-m-deep (6.6-ft-deep) roadcut located on the road between secs. 2 and 3, T. 1 S., R. 20 W.

Although readily visible stratigraphic breaks, such as the Jules soil recognized in Illinois (Frye and Willman, 1973; Frye et al., 1974; Ruhe, 1976; McKay, 1979a,b) and the soil zones in Iowa (Daniels et al., 1960; Ruhe et al., 1971), have not been identified yet in Kansas and adjacent Nebraska, evidence of one or more stable or vegetated surfaces is common. The only indication of soil development recognized is that of a Bt horizon in the Medicine Creek valley (May and Holen, 1993); interestingly, the soil has a probable Paleo-Indian association (May, 1991b). The most common line of evidence for a discontinuity in Peoria loess deposition is that of plant remains, usually cropping out as lenses. Many of the age determinations were made from *Picea* remains

TABLE 4—$\delta^{13}C$ values derived from the Gilman Canyon Formation

Locality	Sample	$\delta^{13}C$ (‰)
Nebraska		
Harlan County Lake		
BO, Bone Cove	PITT–0826	−22.4
NO, North Cove	Tx–7073	−15.3
	Tx–7074	−14.3
	Tx–7072	−17.4
CC, Coyote Canyon	Tx–7294	−21.3
EU, Eustis ash pit	Tx–6633	−16.3
Harry Strunk Lake		
LA, La Sena site	Tx–6707	−21.8
	Tx–6709	−19.2
LI, Lime Creek site	Tx–6774	−26.4
Kansas		
Phillips County		
PH, landfill	Tx–6746	−16.9
KI, Kirwin railroad cut	Tx–6747	−14.7
SI, Siebert gravel pit	Tx–6624	−14.4
	Tx–6625	−14.4
PR, Pratt County landfill	Tx–6449	−14.5
	Tx–6622	−14.5
Range		−14.4 to −26.4
Mean		−17.6
Mode		−14.4

(table 5), indicating a cool, moist environment. Although radiocarbon data document the burial of vegetative material throughout the Woodfordian, two temporal clusters or modes of ages appear from the limited data: 18–17 ka and 14–13 ka. The 18–17-ka time interval represents the last glacial maximum and the 14–13 ka interval represents the time of major deglaciation (Ruddiman, 1987). By interpreting ice-core data from Greenland, Paterson and Hammer (1987) recorded a dramatic decrease in atmospheric dust content from about 13 ka; this period of reduced atmospheric dust may relate to the time of relative surface stability and tree establishment. Regional geomorphic data also support the existence of a depositional hiatus at this time. May (1989) identified deposition of the Todd Valley Formation in the South Loup River of central Nebraska at about 14 ka; the Todd Valley was subsequently buried by loess. Furthermore, Martin (1990) identified entrenchment in the Republican River of south-central Nebraska at about 13 ka, after which valleys were filled with late Peoria loess.

Late Wisconsin fluvial deposits It is becoming increasingly apparent that entrenchment occurred in channels of the Kansas River basin sometime during the late Wisconsin Stage. A basal soil buried within the fill of both tributary and major stream valleys of the Kansas River basin has an age of 10,500–10,000 yr B.P. (W. C. Johnson and Martin, 1987; W. C. Johnson, 1987; W. C. Johnson and Logan, 1990), thereby providing a minimum age on the preceding entrenchment. As noted, May (1989) has radiocarbon-dated the Todd Valley fluvial sand of Nebraska to about 14,000 yr B.P.; Condra et al. (1950) had postulated a much earlier Wisconsin age. Martin (1990) recognized a late Wisconsin fill in the Republican River valley that was largely removed through entrenchment about 13,000 yr B.P. A radiocarbon age of 14,700 yr B.P. was obtained on spruce wood situated a few centimeters above crossbedded fluvial sand and gravel (Wells and Stewart, 1987; W. C. Johnson, 1989). The depth of entrenchment relative to that of the early Wisconsin fill is unknown, but A. R. Leonard (1952, p. 51) estimates a depth of 30–60 ft (9.1–18 m) below the Crete channel. Subsequent alluviation continued, at least in the larger stream systems, into the late Holocene until the surface elevation was equivalent to that of the late Wisconsin terrace. This sequence is well illustrated within fill of the Kirwin terrace. At the Siebert gravel pit, excavated within the Kirwin terrace fill (see fig. 25), the exposed sequence includes early to middle Wisconsin alluvium, the Gilman Canyon Formation, and a cap of Peoria loess, but the terrace can be physically traced downstream to the Kirwin area, where the exposed upper few meters are of late Holocene age. Despite the absence of any visible scarp, the Kirwin terrace is actually a terrace complex with different aged fills. This is an area in need of much additional research because it is only assumed that late Wisconsin alluvial fill underlies the late Holocene fill; that is, no excavation or drilling has been done to confirm or deny the stratigraphic relationships.

Quaternary System—Holocene Series

At present, the Kansas Geological Survey recognizes the Recent Stage of the Pleistocene Series (Bayne and O'Connor, 1968). As accepted by the Kansas Geological Survey, the Recent is defined as the last 5,000 years, or the time since the end of the Valderan Substage of the Wisconsin Stage. This nomenclature, awkward and regional in nature, has been largely replaced by the use of the term "Holocene" (series status). As the resolution and breadth of absolute chronologies for the late Quaternary of Kansas and adjacent areas have improved, it has become increasingly clear that use of "Recent Stage" be abandoned and that "Holocene" be adopted, as was done by the U.S. Geological Survey (Cohee, 1968).

The beginning of the Holocene, about 10 ka (Hopkins, 1975), is a time of dramatic environmental change and attendant stratigraphic discontinuities. In general, this boundary is considered only geochronometric, that is, without specific stratigraphic reference, although a stratotype in Sweden has been proposed for the boundary (Morner, 1976); the Swedish unit has a reported age of 10,000 ± 250 yr B.P.

FIGURE 32—Peoria loess in a west-facing roadcut approximately 3 mi (5 km) south of Long Island in NWNW sec. 12, T. 2 S., R. 20 W. Loess, 5.2 m (17 ft) thick, is exposed, but total thickness is unknown.

(Fairbridge, 1983). Watson and Wright (1980) contended that a major climatic and environmental change at 10 ka can be documented only on a local scale; that is, all changes recorded in the stratigraphic record are diachronous. This notion now seems to be faulty on the regional and subcontinental scale in that research of the last several years [e.g., W. C. Johnson and Martin (1987), W. C. Johnson and Logan (1990), and W. C. Johnson and May (1992)] has documented major pedogenesis at 10 ka in both alluvial and eolian/upland settings. This is the first major geosol to occur in the stratigraphic record of the region since the Gilman Canyon geosol 10,000 years earlier.

Brady soil The Brady soil was first named and described by Schultz and Stout (1948) at the Bignell Hill type locality, an eolian sequence exposed along a roadcut in the south valley wall of the Platte River of western Nebraska. The soil is developed within the Peoria loess and is overlain by the Bignell Loess. The name was subsequently adopted by researchers in Kansas (Frye and Fent, 1947; Frye and A. B. Leonard, 1949, 1951; Frye et al., 1949). The Brady soil is regionally extensive only in the northwestern and west-central parts of Kansas, and even there it occurs discontinuously. Frye and Leonard (1951) and Caspall (1970, 1972) recognized Brady development in the northeastern and other parts of Kansas. Without the overlying Bignell Loess the Brady soil does not exist; the modern surface soil has incorporated post-Bradyan loess fall into its profile. The Brady soil is typically dark gray to gray-brown and better developed than the overlying surface soil within the Bignell. Strong textural B horizon development and carbonate accumulation in the C horizon are typical, although the soil occasionally displays evidence of having formed under poorer drainage conditions than the associated surface soils (Frye and Leonard, 1951). Feng (1991) noted that the Brady soil, as expressed in Barton County, is strongly weathered both physically and chemically.

Only two exposures of the Brady soil have been found in Phillips County; they are located in west-facing roadcuts in SWSW sec. 24, T. 4 S., R. 19 W., and NESE sec. 26, T. 2 S., R. 20 W. The former locality was recognized by A. R. Leonard (1952, p. 42–43) and revisited in this study. It is the east face of a roadcut, 0.8 km (0.5 mi) north of Speed in which the Peoria loess, the Brady soil, and the Bignell Loess are visible (fig. 33). In the late 1940's and early 1950's the Loveland Loess, Sangamon soil, and Gilman Canyon Formation were also exposed in the roadcut; they can still be distinguished in a poor-quality exposure on the north face at the end of the roadcut. A profile within the roadcut was excavated and sampled for radiocarbon dating in the uppermost and lowermost 5 cm (2 in.) of the A horizon; ages of 8,850 ± 140 yr B.P. (Tx–6626) and 10,050 ± 160 yr B.P. (Tx–

TABLE 5—Wood, charcoal, and humate ages, Woodfordian/Peoria-age deposits in Kansas and Nebraska[a]

Location	Material	Sample	Age	Source
Kansas				
Superior Sand Co., Sedgwick County	peat	Dic–3101	19,340 ± 200/210	Jaumann, 1991
Mt. Hope Sand Co., Reno County	*Picea* litter	Beta–17900	16,420 ± 190	Jaumann, 1991
GMD5 site 1, Edwards County	soil humates	Tx–6742	13,670 ± 290	Johnson, 1991a
GMD5 site 9, Reno County	*Picea* charcoal	Tx–6479	17,970 ± 330	Johnson, 1991a
Coon Creek, Graham County	*Picea* charcoal	GX–9355G	17,930 ± 550	Wells and Stewart, 1987
Courtland Canal, Jewell County	*Picea* charcoal	Beta–9320	14,450 ± 140	Wells and Stewart, 1987
Nebraska				
Coyote Canyon,	charcoal	Tx–7295	19,730 ± 300	Martin, unpub. data, 1992
Harlan County	charcoal	Tx–7293	21,250 ± 530	
North Cove, 25HN164, Harlan County	*Picea glauca*	Beta–12286	14,700 ± 100	Wells and Stewart, 1987
Naponee, Franklin County	charcoal	Beta–33579	17,880 ± 170	Souders and Kuzila, 1990
Bloomington, Franklin County	*Picea* or *Larix* charcoal	Beta–42015	18,830 ± 180	May and Holen, 1993
La Sena site,	humates	Tx–7006	18,860 ± 360	May and Holen, 1993
25FT177, Frontier County	humates	Tx–6708	16,730 ± 490	
South Loup River,	*Abies balsamea*	Tx–6128	14,080 ± 190	May, 1989
Buffalo and Grant counties	fragments	Beta–27758	13,160 ± 450	Swinehart, 1990

a. Ages indicate surface stability or discontinuities in Peoria loess deposition.

6627) were obtained, respectively (W. C. Johnson, 1990) (fig. 34). The results indicate a soil-forming interval that lasted a minimum of 1,200 radiocarbon years; my research elsewhere in the central Great Plains suggests an interval of 1,500–2,000 years.

The age of the Brady soil was uncertain, even at the type locality. Dreeszen (1970, p. 19) reported an age of 9,160 ± 250 yr B.P. (W–234) obtained in 1954 and another in 1965 of 9,750 ± 300 yr B.P. (W–1676), both from the type section but likely contaminated by modern plant roots. Subsequently, Lutenegger (1985) reported an age of 8,080 ± 180 yr B.P. but provided few specifics other than that the source was the A horizon of the Brady soil at the type section. I recently secured better age control for the type section: Ages of 9,240 ± 110 yr B.P. (Tx–7425) and 10,670 ± 130 yr B.P. (Tx–7358) were obtained on the upper and lower 5 cm (2 in.), respectively, of the Brady A horizon.

The Brady soil has been dated recently at localities in Nebraska and Kansas. Souders and Kuzila (1990) obtained a radiocarbon age of 10,130 ± 140 yr B.P. for Brady soil occurring in the Republican River valley of south-central Nebraska. Sites along Harlan County Lake upstream from Naponee have yielded a number of ages, ranging from 10,550 ± 160 yr B.P. to 9,020 ± 95 yr B.P., for exposures of the Brady soil (Cornwell, 1987; W. C. Johnson, 1989; Martin, 1990; W. C. Johnson and May, 1992; C. W. Martin and W. C. Johnson, unpublished data, 1992). Two radiocarbon ages of 9,820 ± 110 yr B.P. (Tx–7045) and 10,550 ± 150 yr B.P. (Tx–7046) have been obtained from the upper and lower 5 cm (2 in.), respectively, of the Brady A horizon exposed in Barton County, central Kansas (Feng, 1991). The two radiocarbon ages from the Speed roadcut in Phillips County agree reasonably well with those from the type section in adjacent Nebraska and central Kansas (table 6; fig. 35).

There is an isochronous alluvial soil found throughout the region that is particularly well expressed in the Kansas River basin (W. C. Johnson and Martin, 1987; W. C. Johnson and Logan, 1990). The two ages of 8,274 ± 500 yr B.P. (C–108a) and 9,880 ± 670 yr B.P. (C–471) determined from alluvial fill (Fill 2A) at archeological sites Ft–50 and Ft–41 on Harry

FIGURE 33—Peoria loess, the Brady soil, and Bignell Loess exposed in the east face of a road cut 0.8 km (0.5 mi) north of Speed in SWSWSW sec. 24, T. 4 S., R. 19 W. The lighter Peoria loess is on the left (north) and the Brady soil (lower part of spade) with overlying Bignell Loess is on the right. The modern surface soil is buried by 30–60 cm (1–2 ft) of road construction fill. The Bignell Loess is here set into a depression, or sag, in the surface of the Peoria on the south (downwind) side of the tributary valley.

Strunk Lake in southwestern Nebraska (Schultz et al., 1951; Libby, 1955) were the first radiocarbon determinations on the Brady soil. The soil, occurring in both eolian and alluvial contexts, qualifies as a geosol, based on present radiocarbon data (W. C. Johnson and May, 1992).

Although it appears that Brady pedogenesis occurred from about 10,500 yr B.P. to as recently as 8,500 yr B.P., greater refinement of the Brady soil chronology is necessary, but present data clearly indicate that the Brady soil was a product of a major period of landscape stability at a time when widespread climatic shifts were occurring at the end of the Wisconsin. This was the first significant period of soil development since Gilman Canyon time and represents the climate of the early Holocene.

Development of the Brady soil correlates well with indicators of regional climatic change. The fossil pollen record at Muscotah Marsh of northeastern Kansas indicates that spruce had essentially disappeared from the region by about 10,500 yr B.P. As this decline occurred, deciduous tree species increased until about 9,000 yr B.P., the time at which grassland expansion began (Gruger, 1973). On a hemispheric scale the abrupt decrease in atmospheric dust noted in the Greenland ice core at 10,750 yr B.P. (Paterson and Hammer, 1987) reflects decreased loess deposition and possibly Brady-age pedogenesis associated with relative terrestrial stability. Further, ^{18}O levels within the same core suggest rapid warming about 10,750 yr B.P., with the characteristic Holocene temperature regime being established at about 9,000 yr B.P. At least early and perhaps all of Brady pedogenesis coincides with an abrupt and brief cool interval correlative with the classic Younger Dryas cold interval of the North Atlantic region, lasting from about 11,000 to 10,000 yr B.P. [e.g., Mott et al. (1986), Wright (1989), and Mathewes et al. (1993)].

Bignell Loess The Bignell Loess was first described and named at the type locality in a bluff exposure on the south side of the Platte River valley southeast of North Platte, Nebraska (Schultz and Stout, 1945). It is typically a gray or yellow-tan massive, calcareous silt, seldom more than 1.5 m (5 ft) thick. Although the Bignell is often less compact and more friable than the underlying Peoria loess, no certain identification can be made without the presence of the Brady soil. The Bignell Loess does not form a continuous mantle on the Peoria; instead, it occurs as discontinuous deposits that are most prevalent in and thickest adjacent to modern-day valleys, particularly the south side, and often occurs in depressions on the Peoria surface. Feng (1991) speculated that the Bignell Loess of central Kansas is relatively well weathered because

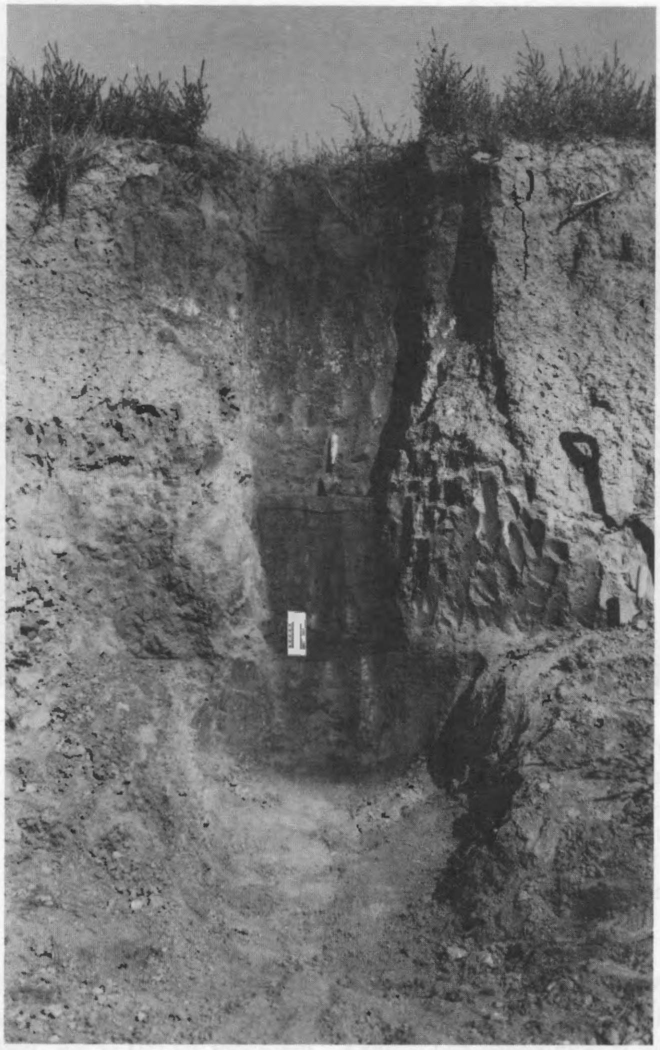


FIGURE 34—Profile of the Brady soil and overlying Bignell Loess in the roadcut of fig. 33. The top of the Brady soil is at the trowel point. Radiocarbon ages of 10,050 ± 160 yr B.P. (Tx–6627) and 8,850 ± 140 yr B.P. (Tx–6626) were determined from the lower and upper 5 cm (2 in.) of the Brady A horizon, respectively.

it was derived from a preweathered source, the Brady soil surface, perhaps eolian and alluvial phases alike. This is consistent with the earlier interpretation derived in Nebraska that the Bignell Loess is at least partially composed of reworked Peoria loess (Condra et al., 1947, p. 33).

It appears from the radiocarbon ages for the type section in Nebraska and for the Speed roadcut that the Bignell Loess is no older than about 8,000 yr B.P. Snails collected by A. B. Leonard from the lower part of the Bignell in Doniphan County, northeastern Kansas, produced ages of 12,500 ± 400 yr B.P. (W–231) and 12,700 ± 300 yr B.P. (W–233) (Frye and Leonard, 1965). Because the shell material had absorbed an indeterminate amount of dead carbonate, Frye et al. (1968) proposed an averaged age of approximately 11,000 yr B.P. Based on the age data available for the Brady soil, the soil-humate-derived ages are probably closest to reality.

A pronounced feature of the Holocene climate of the Plains was an extended warm, dry period (Wright, 1970; Benedict and Olson, 1978; Barry, 1983), identified as the Altithermal (Antevs, 1955) or, less commonly, as the Hypsithermal interval (Deevey and Flint, 1957). This dictates that the Bignell was a warm-climate loess, unlike the cold-climate loess of the Woodfordian. Reconstruction of the general circulation patterns for North America indicates that from the last glacial maximum, about 18–15 ka, there was no detectable change in atmospheric circulation; the westerly jet was split by the Laurentide ice sheet into a north and a south flow around a strong glacial anticyclone (Kutzbach,

TABLE 6—BRADY SOIL RADIOCARBON AGES[a]

Sample	Age	Source
Nebraska		
Bignell Hill (type section)		
n.a.	8,080 ± 180	Lutenegger, 1985
W–234	9,160 ± 250	Dreezen, 1970
W–1676	9,750 ± 300	Dreezen, 1970
Tx–7425	9,240 ± 110	W. C. Johnson, unpub. data, 1991
Tx–7358	10,670 ± 130	W. C. Johnson, unpub. data, 1991
North Cove		
west		
Tx–6319	10,550 ± 160	Johnson, 1989
Tx–6112	10,220 ± 140	Johnson, 1989
Tx–6320	10,270 ± 160	Johnson, 1989
east		
Tx–6321	11,530 ± 150	Johnson, 1989
PITT–824	11,025 ± 90	C. W. Martin and Johnson, unpub. data, 1992
Prairie Dog Bay		
Dic–3310	10,140 + 110, −120	Cornwell, 1987
Tx–5909	10,360 ± 130	Martin, 1990
PITT–825	9,020 ± 95	C. W. Martin and Johnson, unpub. data, 1992
Naponee		
Beta–33939	10,130 ± 140	Souders and Kuzila, 1990
Kansas		
Speed		
Tx–6626	8,850 ± 140	Johnson, 1990
Tx–6627	10,050 ± 160	Johnson, 1990
Barton County		
Tx–7045	9,820 ± 110	Feng, 1991
Tx–7046	10,550 ± 150	Feng, 1991

a. Ages represent the eolian phase only. An alluvial phase has been well documented throughout the Kansas River basin (Johnson and Martin, 1987; Johnson and Logan, 1990) and adjacent river systems, such as the Loup River of central Nebraska (Brice, 1964; May, 1990) and the Pawnee River (Mandel, 1991) and Walnut River (Mandel, 1991) of the Arkansas River system.

1985, 1987; COHMAP members, 1988). By 9 ka the ice had wasted appreciably, the jet was no longer split, orbital parameters were favoring increased temperatures, and zonal flow was dominating (Kutzbach, 1981, 1985, 1987). Model results produced mean summer temperatures 2° to 4° C higher than (COHMAP members, 1988) and annual precipitation up to 25% less than at present in the region (Bartlein et al., 1984; Kutzbach, 1987).

Because of the increasing zonal flow and aridity of the Altithermal interval, species of the tall grass community migrated eastward to the present areas of mixed deciduous-prairie vegetation; that is, the prairie-forest ecozone shifted eastward (Van Zant, 1979; Semken, 1983; Webb et al., 1983). The fossil pollen record from Muscotah Marsh provides a disrupted but interpretable Holocene signal, indicating a middle Holocene prairie expansion (Gruger, 1973). Fossil pollen data from Cheyenne Bottoms suggest consistently lower water levels in the marsh during the middle Holocene (Fredlund, 1991). Molluskan faunas from the Bignell Loess of Kansas suggest that the climate was somewhat drier than during Peoria time (Frye and Leonard, 1951). After a period of soil formation near the end of the Pleistocene, pedogenesis is not recognized until about 5,800 yr B.P. in the sand of the Great Bend Prairie, central Kansas (W. C. Johnson, 1991a). Therefore, based on various climatic proxies and a limited number of radiocarbon ages, it appears that the Bignell Loess was deposited for the most part from the end of Brady pedogenesis, about 9,000 or 8,500 yr B.P. to about 5,500 yr B.P.

Fluvial deposits Holocene fluvial deposits are found in two topographic positions: (1) as a component of the Kirwin terrace fill (overlying late Wisconsin basal fill) and (2) in the

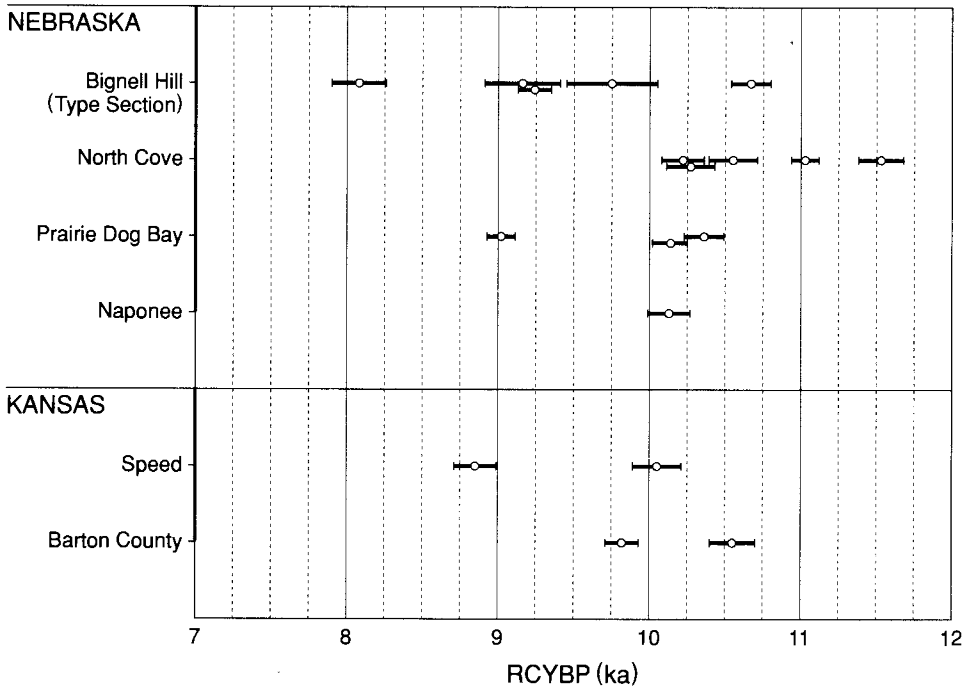


FIGURE 35—Graphic representation of the radiocarbon ages presently available from the Brady soil of Kansas and Nebraska.

bottomland area below the high-terrace level (e.g., Kirwin, Almena). Figure 36 shows both surfaces south of Kirwin; the first and older Holocene alluvium is well exposed throughout the Solomon River and Prairie Dog Creek valleys. In addition to the many natural exposures, several have been created by the excavation of trench silos into the terrace scarp. Two such silos, located south of Kirwin in SWNW sec. 34, T. 4 S., R. 16 W., expose the upper 5 m (16 ft) of the Kirwin terrace fill (fig. 37). A soil buried at a depth of 2 m (7 ft) with a simple A/C horizonation (Entisol) is well expressed in both silos (fig. 38). The upper 5 cm (2 in.) of the A horizon was sampled for radiocarbon dating; an age of 2,880 ± 70 yr B.P. (Tx–6748) indicates that the surface was buried shortly after that time because of an increase in the magnitude and/or frequency of sediment-laden overbank flows. After a short period of stability, the Solomon River then downcut to somewhere near its present level. This occurred after about 2,800 yr B.P., probably later because of the time involved in aggradation and subsequent surface soil development. Immediately north of K–9 at Kirwin where Deer Creek has cut into the Kirwin fill, three or more weakly developed soils are visible above the basal gravels in a high cutbank. May (1991a) has documented Holocene-age fill underlying the Kirwin terrace in the South Fork Solomon River downstream at Lake Waconda.

Excellent cutbank exposures occur throughout most of Deer Creek, revealing two or more buried soils. Radiocarbon ages of 1,890 ± 90 yr B.P. (Beta–2156) and 4,120 ± 270 yr B.P. (Beta–2156) were obtained on two soils in an exposure about 3.5 km (2.1 mi) east of Prairie View (fig. 39). Widespread entrenchment has been documented within the Kansas River basin at approximately 1,200 to 1,000 yr B.P. (W. C. Johnson and Logan, 1990). In this situation where the Holocene alluvium makes up at least the upper component of the high terrace, it was mapped as *Qtk* by W. C. Johnson and Arbogast (1993).

The second, more youthful type of fluvial deposit, or landform, is the recently active floodplain area created by downcutting. The relatively recent age of this activity is evidenced by the narrow nature of the active floodplain; in Prairie Dog Creek it is about 0.4 km (0.25 mi) wide, in Deer Creek and Bow Creek it is 0.2 km (0.13 mi) wide, and in the North Fork Solomon River it is 0.2 to 2.4 km (0.13–1.5 mi) wide. The young age is also attested to by the highly articulated terrace scarp, with its narrow promontories and remnants, sometimes within active channel meanders (fig. 39) (Frye and Leonard, 1952, p. 52). Lateral channel migration will eventually remove such features and widen the floodplain. Like the Kirwin, Almena, and equivalent terraces, the floodplain is a complex of surfaces or features, such as microterraces of limited areal extent, back swamps, meander scrolls, levees, eolian dunes, and scours (fig. 40). The lack of any pronounced low terrace suggests that the channel has

FIGURE 36—Scarp separating the Kirwin terrace from a lower terrace or the floodplain of the North Fork Solomon River 0.4 km (0.25 mi) south of Kirwin in SWNW sec. 34, T. 4 S., R. 16 W.

FIGURE 37—Face of the Kirwin terrace scarp with two trench silos excavated into it. The view is north from the low terrace or floodplain in SWSWNW sec. 34, T. 4 S., R. 16 W. A prominent buried soil is exposed in all faces of both trenches.

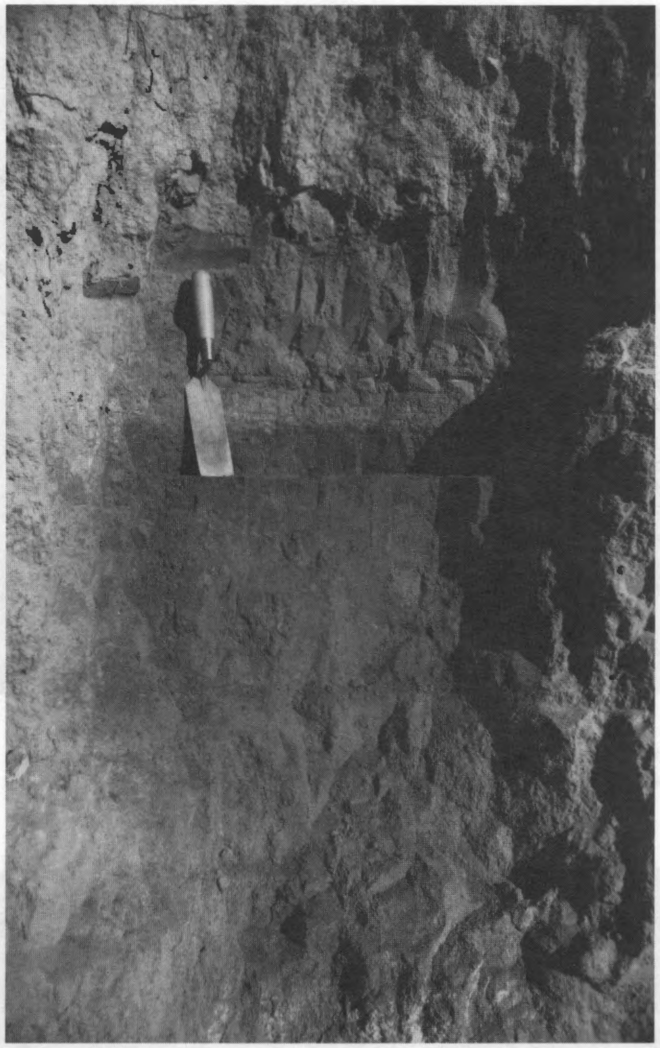


FIGURE 38—Exposure of the soil buried within uppermost fill of the Kirwin terrace (fig. 37). This profile is from the east face of the west silo. A single radiocarbon age of 2,880 ± 70 yr B.P. (Tx–6748) was determined from the upper 5 cm (2 in.) (lower part of trowel) of the buried A horizon. The soil surface was presumed buried shortly after that time.

ceased to entrench and is now moving laterally. The map unit *Qal* (W. C. Johnson and Arbogast, 1993) represents this most youthful portion of the alluvium.

The episodic nature of stream-system change through time has been documented graphically by Knox (1976) and by Wendland (1982) using histograms and cumulative frequency distributions of radiocarbon ages from alluvial deposits. Paleosols and terraces are indicators of the episodic change in streams. Because they represent formerly stable surfaces, paleosols in particular are useful for identifying past periods of alluvial stability because they can be radiocarbon-dated. Furthermore, the extent of paleosol development, represented by A horizon thickness and organic carbon content, can be used as a crude but reasonable indicator of time of pedogenesis, that is, the duration of floodplain stability. The impact of climate on stream system behavior is considered primary by most [e.g., Brakenridge (1980), Baker (1983), Knox (1983), and Waters (1985)], although alluvial histories are complex because of additional responses in the system resulting from adjustments to internal changes (Schumm, 1973; Patton and Schumm, 1981). Episodic stream-system change has been documented for the Kansas River basin by W. C. Johnson and Martin (1987), Martin (1990), and W. C. Johnson and Logan (1990).

Eolian sand deposits Sand deposits represent a stratigraphic equivalent of the Bignell Loess. Although likely maximized during the Altithermal interval, loess deposition

FIGURE 39—Exposure of the Holocene fill beneath the high terrace (Qt) in Deer Creek. The extent of entrenchment during the last 1,200 years is illustrated in this view. The site is located approximately 2.5 km (1.5 mi) east of Prairie View in the eastern half of SWSE sec. 2, T. 3 S., R. 20 W. Two buried soils are visible in the section (arrows).

undoubtedly has occurred throughout the latter part of the Holocene, but it has been sufficiently small and slow as to be incorporated into existing surface soils. Consequently, the loess is not identified as a mappable unit. Because of their obvious nature and ready mobility, eolian sand deposits are of much greater importance and are considered Holocene because most have experienced major activity during this time period, although they may have originally developed during the Wisconsin. Significant Holocene activity has been recorded in the dune fields of eastern Colorado (Forman and Maat, 1990; Forman, Goetz et al., 1992), Nebraska (Ahlbrandt et al., 1983; Swinehart, 1990), and in the Great Bend Sand Prairie adjacent to the Arkansas River of central Kansas (W. C. Johnson, 1991a).

Sand dune tracts, mapped as *Qd* (W. C. Johnson and Arbogast, 1993) have developed in two different topographic situations: within meander bends of the North Fork Solomon River and on the flank of the south valley wall of the Solomon River south of Logan. Eolian dune tracts have developed in alluvial sands (point bar deposits) on a low terrace of the Solomon River (fig. 41). The tracts are found along the entire length of the river valley in Phillips County and have a local relief of 8 m (26 ft) or more. The stratigraphy of one tract (SE sec. 29, T. 4 S., R. 17 W.) is presently exposed as a result of sand extraction by the B&B Sand Company of Phillipsburg (fig. 42). The deposits contain visible stratigraphic elements, such as buried soils, crossbedding, silt drapes of variable thickness, soft-sediment deformation structures, and gastropods. Detrital organic matter in the lower 5 cm (2 in.) of a 13-cm-thick (5-in.-thick) silt drape located near the base of the exposure produced a radiocarbon age of 3,920 ± 90 yr B.P. (Tx–6623) (fig. 43). The radiocarbon age on the fluvial stratum does not indicate the time of major eolian modification but rather provides a minimum age for the event. Also, it is not known whether the age is representative of all the reworked sand deposits along the river valley. Furthermore, the radiocarbon age is problematic because it predates a soil in Kirwin terrace fill dated at 2,880 ± 70 yr B.P.; the fill is apparently stratigraphically lower and topographically higher than the silt drape.

Post 3,900-yr B.P. eolian sand movement is well documented for the Sand Hills of Nebraska (Ahlbrandt et al. 1983; Swinehart, 1990); the best documented interval of eolian activity falls between 3,500 and 1,500 yr B.P. In the Great Bend Prairie of central Kansas, significant post-Altithermal sand shift occurred intermittently after about 4,800 yr B.P. (W. C. Johnson, 1991a).

A large sand dune tract exists 5 km (3 mi) south-southwest of Logan (fig. 44). It is situated on a long, broad and low, north-south-trending interfluve between two tributaries flow-

FIGURE 40—Channel way, floodplain, and low terraces of the North Fork Solomon River. All three elements are ill-defined here and throughout most of the valley in Phillips County. This is a view downstream (southeast) from the bridge south of Speed.

ing north into the Solomon River. The valley of the Solomon River to the north-northwest is unusually wide, thereby providing a long wind fetch over a sandy river bottom. The sands also may have been derived in part or wholly from the Ogallala Formation, upon which the tract rests. Prevailing high-velocity northwesterly winds correspond with patterns of sand roses and dunal morphology within the region (Wells, 1983). The dune tract decreases in width and thickness and grain size toward the south, away from the river. The tract consists of tan and gray fine-grained sands and is underlain by a mortar bed of the Ogallala. No absolute age determination is available, but because the dune tract appears to be stratigraphically above the Peoria loess, it is probably Holocene in age.

Other eolian sand deposits located in Phillips County include sand sheets on the Kirwin terrace of the Solomon River valley, particularly near Logan and Kirwin. However, these are of such limited areal extent and thickness [less than 1.8 m (6 ft)] that they are not represented on the map of the county (W. C. Johnson and Arbogast, 1993).

Recent geologic history

As Ager (1973, p. 34) states, "the sedimentary pile at any one place on the Earth's surface is nothing more than a tiny and fragmentary record of vast periods of Earth's history." This is certainly true of Phillips County. Nonetheless, Frye and A. B. Leonard (1949) and A. R. Leonard (1952) were able to reconstruct a general outline of the geologic history for the Pleistocene, the period during which the present landscape of the region was developed. No major changes have been made in the reconstruction, but details, including absolute ages of events, have come to light in this study. There is an improvement in resolution toward the Holocene because of the preservation of increasingly younger deposits and the readily available radiocarbon dating technique.

During the Miocene and earliest Pliocene, the existing landscape was progressively inundated by Rocky Mountain alluvium (Ogallala Formation), first aggrading river valley bottoms (Valentine member), then filling them to where deposits coalesced on divides (Ash Hollow member), and finally mantling the aggradational landscape (Kimball member). The capping algal limestone probably represents the

FIGURE 41—North Fork Solomon River and sand dune tracts inside meander bends. The sand dunes (d) formed from eolian reworking of paleo–point bar deposits on low terraces. The B&B sand pit in one of these tracts (arrow) appears in figs. 42 and 43. The Siebert gravel pit immediately north of the sand pit exposes Wisconsin alluvial fill and the Gilman Canyon Formation. Heavily dissected Smoky Hill chalk appears along the south side of the river valley.

FIGURE 42—Sand dunes on the inside of a meander bend of the North Fork Solomon River (SE sec. 29, T. 4 S., R. 17 W.) typical of those throughout the valley in Phillips County. The sands are partially reworked alluvial sands. The profile in fig. 43 is located at the arrow.

trace of a calcareous surface soil developed during an indeterminate period of landscape stability.

The Pliocene and earliest Pleistocene was a time of major erosion of Ogallala deposits and stream-system development and entrenchment. Because of the antiquity, unconsolidated nature, and high topographic position of many alluvial deposits of this time period (early pre-Illinoian), no sediments are known to have been preserved. The present drainage patterns were established no later than late pre-Illinoian. This is apparent from the stratigraphic association of pre-Illinoian and younger alluvial deposits with associated terraces and from the accretionary nature of upland loess deposits. Pre-Illinoian (Grand Island and Sappa formations) deposits have been preserved as terrace deposits within the Prairie Dog Creek and North Fork Solomon River valleys.

Illinoian time brought renewed incision, which removed much of the earlier deposits both laterally and vertically. The North Fork Solomon River entrenched approximately 50 ft (15 m) below the base of the pre-Illinoian deposits to within 30 ft (9 m) of the present bedrock valley floors (Frye and A. R. Leonard, 1949, p. 55). Sand and gravel (Crete Formation) were deposited during one or more periods of valley aggradation during the Illinoian, and the fine fraction, primarily silt, was transported by wind and deposited as a mantle of loess on the uplands and valley side slopes, resulting in the Loveland Loess. The several brief periods of landscape stability occurring during deposition of the loess are manifested as a series of paleosols. The Sangamon soil, an extremely well-developed soil capping the Loveland, represents an extended period of landscape stability. Opal phytolith data from the Sangamon soil exposed in the Eustis ash pit, located in south-central Nebraska, indicate that the soil was developing under warm, perhaps dry, grassland conditions. The post-Sangamon period was one of erosion; typically the Sangamon soil is severely or completely eroded and overlain, at least locally, by sandy deposits. By early Wisconsin time major erosion and stream entrenchment were once again occurring. There may have been more than one cycle of cutting and filling during the middle Wisconsin (Altonian Substage), but knowledge of the stratigraphic record is too limited to provide that level of detail. Pre-35-ka fill exists beneath at least some parts of the Kirwin terrace.

The middle and late Wisconsin (latest Altonian and entire Farmdalian) were characterized by deposition of a thin loess mantle (Gilman Canyon Formation) on the uplands, valley side slopes, and bottomlands. The source of the silt-sized material is unknown but was likely from a single large area because of the regional extent of the event. Deposition of the loess was sufficiently slow that pedogenic processes (e.g., melanization and bioturbation) were able to operate nearly

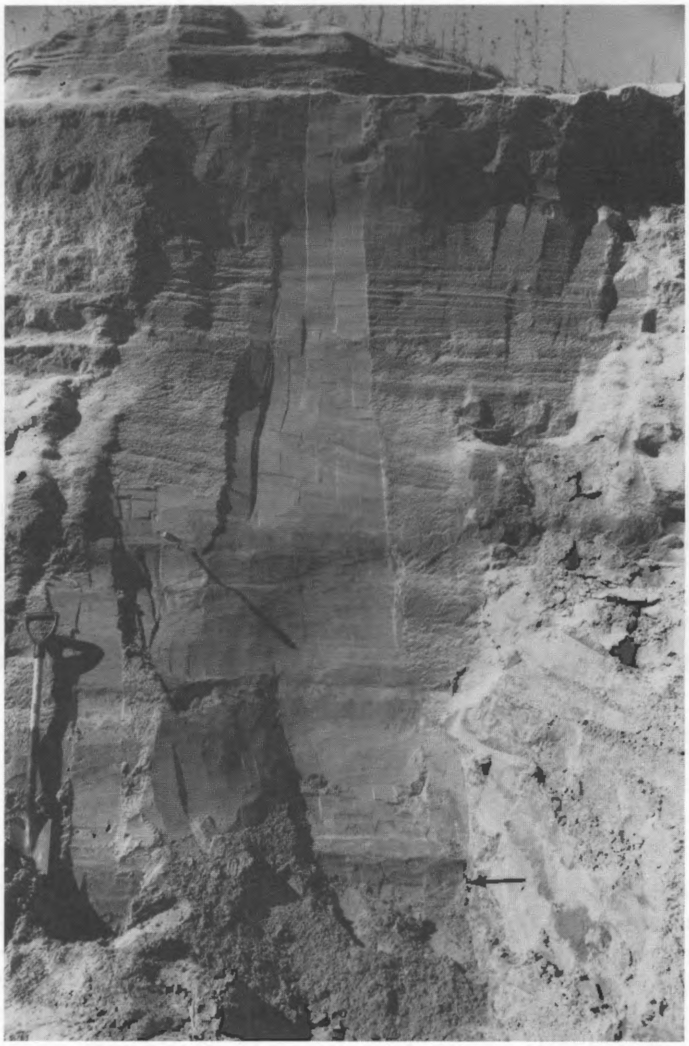


FIGURE 43—Profile of the dune stratigraphy revealing buried incipient A horizons, crossbedding, load flow structures, and silt drapes. The lower 5 cm (2 in.) of the silt drape at the base of the profile (arrow) yielded a radiocarbon age of 3,920 ± 90 yr B.P. (Tx–6623) on detrital carbon. Thickness of this and other meander bend sand deposits is unknown at present.

continuously. There may have been two or more distinct periods of soil formation, but the thin nature of the loess has welded or bioturbated any individual A horizons. Phytolith data from Gilman Canyon sediments at the Eustis ash pit suggest that the soils formed under a mesic tall-grass cover.

Late Wisconsin time was one of large-scale loess deposition, which began slowly and conformably on the Gilman Canyon Formation. The loess fall began at about 20 ka and ended at about 10 ka, based on terminal radiocarbon ages from the Gilman Canyon and on basal A horizon ages from the Brady soil. Although deposition of the Peoria loess was relatively continuous, there is botanical, pedologic, and geomorphic evidence to suggest that at least a reduction in the rate of deposition occurred, perhaps at 18–17 ka and 14–13 ka. The last date was also approximately the time of valley entrenchment, to a level beneath that of the Kirwin terrace and present floodplain. The cutting was not so laterally extensive that all of the Kirwin terrace was removed, and the cutting probably occurred shortly before 10.5 ka, a time of major soil development in fill elsewhere within the Kansas River basin.

Aggradation of stream valleys during the Holocene constructed a terrace level equivalent to the preexisting Kirwin terrace. This aggradation continued in episodic fashion,

FIGURE 44—Sand dune tract southwest of Logan in secs. 17 and 20, T. 5 S., R. 20 W. View south-southeast of the tract.

creating several poorly developed soils within the alluvial fill. Because of the areal synchroneity in periods of soil formation, the impact of climatic variation is directly or indirectly responsible. Recent entrenchment to a depth of 4–11 m (13–36 ft) below the Kirwin terrace occurred after 2,500 years ago and probably as recently as 1,000 years ago. The event must have been recent because of the relatively narrow nature of the floodplain and dissected pattern of the Kirwin terrace. During this same period, the Brady soil formed in the Peoria loess, beginning at about 10.5 ka. Where favorable conditions existed, the Bignell Loess began to bury the Peoria loess, beginning at 9–8.5 ka. With loess deposits on the uplands and entrenched stream channels, the local relief of Phillips County is perhaps greater now than at any other time during the Illinoian and Wisconsin time intervals.

Stratigraphic sections

Because in the past Phillips County has been the focus of a great deal of geologic inquiry, especially of the Pleistocene, measured sections previously reported by Hibbard et al. (1944), Byrne et al. (1948), Frye and A. R. Leonard (1949), Frye and A. B. Leonard (1954), and Frye et al. (1956) have been included, with a few exceptions. Information in brackets is from this study's interpretation of the sections. All previously reported sections were revisited, and some were found to be no longer viable, particularly streambank exposures of alluvium. Also, measured sections from this study have been included.

Section measured in a cutbank along Bow Creek in NWNW sec. 35, T. 5 S., R. 17 W. (Byrne et al., 1948).

Cretaceous
Carlile Shale
Codell Sandstone Member

3.	Sandstone, fine-grained, loosely cemented, rust; limonite-stained	0.2

Blue Hill Shale Member

2.	Shale, noncalcareous, laminated, blue-gray; heavily stained with limonite in upper part	3.5
1.	Shale, very thin bedded, clayey and noncalcareous; thin lenses of selenite interbedded; dark-gray to black with some yellow limonite-stained zones	30.0

Base covered
Total section measured 33.7 ft

Section measured in a cutbank along Bow Creek in NWNW sec. 35, T. 5 S., R. 17 W., immediately above the measured section of the Carlile Shale; top is eroded, but otherwise the section is typical of the stratigraphic unit as it crops out in this area (Byrne et al., 1948).

Cretaceous
Niobrara Chalk
Fort Hays Limestone Member
Top eroded

11.	Limestone, chalky, cream, weathering to buff-gray; limonite-stained and with pipelike concretions of limonite; upper part shattered; *Ostrea*	2.5
10.	Limestone, chalky; cream, weathering to buff-gray; pipelike concretions of limonite; *Inoceramus* and *Ostrea*	2.5
9.	Shale, buff-gray; limonite nodules; abundant organic material	0.3
8.	Limestone, chalky, light-gray, weathers buff; *Inoceramus* and *Ostrea*	1.0
7.	Limestone, chalky, white to cream, massive	2.0
6.	Shale, gray, very thin bedded; *Inoceramus*	0.2
5.	Limestone, chalky, cream, massive, limonite-stained; *Inoceramus* and *Ostrea*	3.7
4.	Shale, chalky	0.2
3.	Limestone, chalky, cream, massive, limonite-stained; *Inoceramus* and *Ostrea*	2.3
2.	Shale, chalky	0.1
1.	Limestone, chalky, cream, massive, limonite-stained; *Inoceramus* and *Ostrea*; basal 0.8 ft somewhat sandy and heavily stained with limonite	3.5

Total section measured 18.3 ft

Section measured on the north face of a quarry in SESW sec. 31, T. 5 S., R. 17 W. (this study).

Cretaceous
Niobrara Chalk
Smoky Hill Chalk Member

10.	Chalk, medium-bedded (to 0.2 ft), very pale brown to yellow, weathered; indistinct boundary with Fort Hays Limestone Member	5.3

Fort Hays Limestone Member

9.	Limestone, massive, chalky, very pale brown with basal 0.9 ft light-gray; *Ostrea*; limonite staining	2.4
8.	Shale, fine-bedded, light-gray to gray; *Inoceramus* fragments	0.3
7.	Limestone, massive, chalky, very light gray; faint limonite stains	4.5
6.	Shale, fine-bedded, light-gray to gray; organic concentrations	0.4
5.	Limestone, massive, chalky, light-gray with basal 0.5 ft very pale brown; scattered small fossil fragments	3.6
4.	Shale, fine-bedded, light-gray to gray; small limonite concentrations	0.2
3.	Limestone, massive, chalky, very pale brown with basal 1.8 ft light-gray; small limonite concretions; *Inoceramus*	4.3
2.	Shale, fine-bedded, gray	0.3
1.	Limestone, massive, chalky, very pale brown; faint limonite streaks	2.5

Total section measured 23.8 ft

Section measured in a cutbank in SESE sec. 35, T. 2 S., R. 17 W. (Byrne et al., 1948).

Cretaceous
Niobrara Chalk
Smoky Hill Chalk Member
Top eroded

12. Chalk, massive, streaked white and tan; fossil fragments 4.5
11. Chalk, flaky, pinkish-tan; fossil fragments 0.2
10. Chalk, massive, tan, weathering to buff; *Ostrea* 0.7
9. Shale, chalky, thin-bedded, alternating pink and tan beds 4.0
8. Chalk, blocky, pink and buff 1.5
7. Shale, chalky, thin-bedded, pink 3.7
6. Shale, bentonitic, rust-brown 0.1
5. Shale, chalky, platy, light-gray and pink 1.5
4. Chalk, blocky, light-gray 1.8
3. Shale, chalky, thin-bedded, gray 1.6
2. Chalk, shaly, blocky, tan, weathering to light-gray 0.4
1. Chalk, shaly, blocky, light-gray, weathering to blue-gray 5.0

Total section measured 25.0 ft

Section measured along creek bank in SW sec. 6, T. 1 S., R. 19 W. (Frye and A. R. Leonard, 1949).

Cretaceous
Pierre Shale
Sharon Springs Shale Member

18. Shale, thin-bedded, dark-gray; fine gypsum crystals and limonite along bedding planes 2.0
17. Shale, fissile, dark-gray, noncalcareous; ochre on bedding planes 1.3
16. Chalky paper shale, yellow-brown 0.05
15. Shale, fissile, dark-gray; noncalcareous; contains bands of ochre, gypsum crystals, and limonite 3.5
14. Bentonite, impure, with limonite and calcareous shale 0.1
13. Shale, fissile, dark-gray; noncalcareous; bands of ochre, gypsum crystals, and limonite on bedding planes 5.0
12. Bentonite with gypsum and limonite 0.05

Niobrara Chalk
Smoky Hill Chalk Member

11. Chalky shale, thin-bedded, gray, weathers to yellow-tan 1.5
10. Bentonite, yellow-tan 0.3
9. Chalk, dark-gray, massive 0.7
8. Bentonite, impure, yellow-tan 0.05
7. Chalk, thin-bedded, dark-gray, breaks with a conchoidal fracture on exposed surfaces, weathers to light-orange 1.5
6. Bentonite, yellow-tan 0.2
5. Chalk, massive, dark-gray, weathers to light-orange 0.9
4. Bentonite 0.05
3. Chalk, thin-bedded, dark-gray 0.8
2. Bentonite 0.01
1. Chalk, thick-bedded, dark-gray; from low water level in Prairie Dog Creek 2.0

Total section measured (approx.) 20 ft

Section measured in a cutbank in SENE sec. 35, T. 1 S., R. 20 W. (Byrne et al., 1948).

Cretaceous
Pierre Shale
Sharon Springs Shale Member
Top eroded

10. Shale, clay, blocky, light-green; small limonite concretions 3.0
9. Shale, clay, thin-bedded, rust with thin gray zones 0.7
8. Shale, clay, thin-bedded, blue-gray; limonite-stained 0.8
7. Shale, bentonitic, blocky, rust 0.4
6. Shale, clay, blocky, blue-gray; thin local lenses of limestone interbedded 0.4
5. Shale, bentonitic, thin-bedded, rust 0.3
4. Shale, clay, thin-bedded, blue-black 1.4
3. Shale, thin-bedded, blue-gray; abundant small selenite crystals; limonite-stained 0.4
2. Shale, somewhat bentonitic, thin-bedded, rusty-blue; abundant selenite crystals 0.3
1. Shale, thin-bedded, blue-black with streaks of limonite stain; abundant selenite crystals 6.0

Base covered

Total section measured 13.7 ft

Section measured along valley and tributary gullies in NWSW sec. 31, T. 1 S., R. 19 W. (Frye and A. R. Leonard, 1949).

Tertiary [Miocene]
Ogallala Formation
Ash Hollow member

11. Sand and silt, cemented with calcium carbonate 1.5
10. Clay, silt, and fine sand, partly cemented, light gray-green; contains nodules and stringers of calcium carbonate 12.0

9. Sand, loosely cemented with calcium carbonate, gray; contains fossil seeds of *Biorbia fossilia* (Berry) 3.0
8. Clay, silt, fine sand, and calcium carbonate, gray 2.0
7. Sand, medium to fine, cemented in upper part, greenish-gray; contains fragments of fossil vertebrates 4.0
6. Sand, coarse to fine, and some silt; massive to irregular bedding, weathers to irregular, pitted surface, greenish-gray; fossil seeds of *Krynitzkia coroniformis* Elias, *Biorbia minor* Elias, *Prolighospermum corrugatus* Elias, *Panicum elegans* mut. *nebraskanse* Elias, *Stipidium intermedian* Elias, and *Stipidium* cf. *grande* Elias occur in this interval and in the upper part of bed 5 6.0
5. Sand, coarse to fine, and some silt, massive to irregularly bedded; cemented more firmly toward top 4.0
4. Partly covered. Sand, fine to medium, loose, pink-tan; contains concretions and nodules of calcium carbonate 15.0
3. Partly covered. Sand, fine to medium, loose, pink-tan; contains concretions and nodules of calcium carbonate 12.9
2. Sand and silt, massive to irregularly bedded, loosely to unevenly cemented with calcium carbonate, pale pinkish-tan to gray 14.8
1. Clay, silt, and sand with some calcium carbonate, gray to green-gray; from bottom of creek 1.8

Total section measured 77.0 ft

Measured section of Ogallala Formation in SW sec. 13, T. 5 S., R. 19 W. (A. R. Leonard, 1952).

Quaternary (Pleistocene)
[Peoria loess]

12. Silt and sand, tan 8.0

Tertiary [Miocene]
Ogallala Formation

11. Quartzite, fine-grained, dense, green 1.5
10. Sand, massive, green and red; contains fragmentary mastodon tooth 5.0
9. Quartzite, fine-grained, fairly well cemented, green 1.0
8. Sand and silt, massive, green, spotted and streaked with calcium carbonate 3.0
7. Silt and sand, massive, partly silicified, hard, light-gray 1.5
6. Sand and silt, massive, green, spotted and streaked with calcium carbonate; weathers to a deeply etched surface of vertical columns and horizontal sheets 1.0
5. Sand, fine, and silt, green; speckled with calcium carbonate 2.5
4. Quartzite, fine-grained, lenticular, light-green 1.5
3. Silt and fine sand, partly covered, light greenish-gray, weathers to ash-gray; contains few nodules of calcium carbonate 2.5
2. Sand, fine and silt, indistinct bedding, very light greenish-gray, weathers to platy and nodular surface; loosely cemented throughout with calcium carbonate; forms indistinct bench along nearby canyon side 4.5
1. Silt, sandy, calcareous; contains calcium carbonate in irregular nodules and stringers; upper part more clayey, darker gray, contains less carbonate 6.0

Total section measured 38.0 ft

Section measured in NWNE sec. 30, T. 1 S., R. 19 W. (Frye et al., 1956).

Tertiary [Miocene]
Ogallala Formation
Ash Hollow member

9. Sand, fine to coarse, a few pebbles, irregularly cemented throughout with calcium carbonate 7.0
8. Silt, fine sand, and clay, uncemented, mottled gray-brown and green 6.0
7. Clay, silty, some fine sand, tan to gray–greenish-tan 5.0
6. Silt and fine sand, some mica flakes and ash shards, laminated, tan, mottled with greenish-gray; contains *Biorbia fossilia*, *Celtis willistoni*, *Krynitzkia coroniformis*, *Stipidium elongatum*, and *S. grande* 1.5
5. Silt, bentonitic clay, and fine sand, interbedded, tan to greenish-tan 8.0
4. Marl and volcanic ash containing diatoms and abundant molds of snails (*Vertigo ovata*, *Pupoides albilabris*, *Physa anatina*, *Helisoma antrosum*, *H. valens*, *Pseudosuccinea columella*); whitish to cream 2.5
3. Volcanic ash, *Rawlins* bed, clean and fresh, uncemented, blue-gray 1.0
2. Sand, some zones of silt and bentonitic clay, locally loosely cemented with calcium carbonate, greenish-gray 3.0

1. Covered interval from bridge (culvert) floor 4.0

Total section measured 38.0 ft

Section measured in the west face of a sand and gravel pit located in the eastern half of NE sec. 26, T. 2 S., R. 20 W. (this study).

Quaternary (Pleistocene)
Peoria loess

5. Silt, fine to medium, noncalcareous, very dark gray, humus-rich, bioturbated; surface soil developed throughout 2.3

Tertiary [Miocene]
Ogallala Formation, upper Ash Hollow member (?)

4. Sand, fine, soft, calcareous, modular structure, very light gray; degree of cementation increases upward 7.5
3. Coarse sand and fine gravel, calcareous, pinkish-white; channel fill; forms a vertical face due to carbonate cementation 2.4
2. Coarse sand and medium to coarse gravel, calcareous, very pale brown, carbonate nodules 10.7
1. Coarse sand and medium gravel, with clasts to 2.8-in. diameter, calcareous, soft, poorly cemented, thinly bedded, olive-green; Rocky Mountain lithology apparent; clay balls up to 7-in. diameter 12.2

Total section measured 35.1 ft

Kirwin Dam section, measured in cutoff trench excavation in the high terrace of North Fork Solomon River valley, SW sec. 28 and SE sec. 29, T. 4 S., R. 16 W.; November 1, 1953 (Frye and A. B. Leonard, 1954).

Quaternary (Pleistocene)
Peoria loess

9. Silt, massive, well-sorted, calcareous (except 0.5 ft), light-tan; contains transition zone in base above contact on Sangamon soil; lower part oxidized to pale pinkish-tan; terrestrial gastropods in middle part 10.0

Crete-Loveland Formation

8. Silt, sand, and clay, massive to thinly bedded and crossbedded, light-brown to tan; coarser in lower part; contains lentils of sand and chalk gravel and locally coarse crossbedded gravel at base; middle and upper parts relatively poorly sorted with thin dispersed sand and gravel lentils. Top 2.5 ft is Sangamon soil; upper 0.5 ft (A horizon) is friable brown silt loam; 1 ft (B horizon) light-brown silty clay loam with well-developed prismatic structure; 1 ft (upper C horizon) massive light-brown sandy silt with sparse lime mottling along joints and dispersed lime nodules. Five weakly developed soils occur below the Sangamon soil; upper four soils pale pinkish-brown, less than 1 ft thick, with weak textural contrast and structures; lowermost soil, 5 ft above base, nearly 2 ft thick with silty clay loam B horizon. Terrestrial gastropods occur sparsely throughout lower half 32.0

Sappa Formation

7. Silt and sand; lower 1 ft massive tan sandy silt containing terrestrial and freshwater gastropods. Yarmouth soil (Frye and A. B. Leonard, 1954, pl. 2) profile in upper 3.5 ft; upper 0.5 ft (A horizon) friable gray-brown massive to granular loam; 1.5 ft (B horizon) dark gray-brown sandy clay loam with strongly developed prismatic structure; 1.5 ft (C horizon) massive silt and sand, dark gray-brown at top to tan, with lime mottling throughout but concentrated in upper part; lime nodules rare 4.5

Grand Island Formation (66.5 ft)

6. Sand and gravel, lenticular, interbedded fine and coarse with a few silty zones; contains pebbles and cobbles (up to 1 ft in diameter) of Cretaceous chalk and sand and fine gravels predominantly of quartz, feldspar, and granitic grains similar to those of the Ogallala Formation farther west; discontinuous zone of yellow-brown limonitic staining at top; at southeast end of trench is a lentil of [presumed] Pearlette volcanic ash, 2–3 ft thick, near top of this interval above high Cretaceous bedrock
5. Silt and fine sand, well-sorted, thin-bedded to laminated, locally intricately crossbedded in zones 1–3 in. thick, tan to gray-tan; laterally replaced by sand and gravel 4.5
4. Silt, sand, and clay, massive in a persistent zone of lentils; black, dark-gray, and tan; dark organic coloring distributed lenticularly through zone; calcareous throughout; locally sand and gravel occur in this zone; shells of terrestrial gastropods throughout 5.0
3. Sand and gravel, crossbedded, lenticular, gravels predominantly of Cretaceous chalk; similar in lithology to unit 6 above 5.0

2. Silt, sand, and clay, massive, black to gray-brown, calcareous, similar in lithology to unit 4; occurs as discontinuous lentils in sand and gravel; contains shells of terrestrial gastropods 2.0
1. Sand and gravel, crossbedded, lenticular; contains pebbles and cobbles of Cretaceous chalk; coarser textured than unit 3 above and locally gradational with it 8.0

Total Pleistocene section measured 113 ft

Measured section of Pleistocene deposits in SWSW sec. 24, T. 4 S., R. 19 W. (A. R. Leonard, 1952).

Quaternary [Holocene]
Bignell Loess
4. Silt, light-gray; fills a shallow depression and thins to north and south (max.) 5.0

Quaternary (Pleistocene)
Peoria loess
3. Silt, fossiliferous, light yellow-buff; contains black clayey, sandy soil zone (Brady fossil soil) at top and slight caliche accumulation 2 ft below top (avg.) 11.0

Loveland Loess
2. Silt, calcareous, reddish-buff; contains much chalk material in lower part; upper 4 ft is fossil soil zone, clayey, dark chocolate-buff 8.0

Cretaceous
Niobrara Chalk
Smoky Hill Chalk Member
1. Shale, chalky, soft, yellow-buff, deeply weathered –

Total Pleistocene section measured 24.0 ft

Section measured in NW sec. 9, T. 2 S., R. 16 W. (Hibbard et al., 1944).

Quaternary (Pleistocene)
[Peoria loess]
4. Silt, massive, gray, pipelike concretions of calcium carbonate throughout; gray-tan in part 45.0

[Gilman Canyon Formation]
3. Soil zone, massive, dark gray-brown to black; weathers to a checked surface 4.0

[Loveland-Crete Formation (?)]
2. Silt and sand in basal part consisting of grains and a few pebbles of chalk and chalky shale and quartz; becomes finer and more even textured upward; light red-brown at top and yellow-gray at base; massive; snails occur 10 in. above base 5.5

Niobrara Chalk
1. Chalk and chalky shale –

Total Pleistocene section measured 54.5 ft

Section measured in SE sec. 5, T. 2 S., R. 17 W. (Hibbard et al., 1944).

Quaternary (Pleistocene)
[Peoria loess]
5. Silt, massive, gray in lower part grading into light buff-tan in upper part, porous, tubular concretions rare except in a few localities; snails occur in zones 6 ft and 10 ft above base 30.0

[Gilman Canyon Formation]
4. Soil zone, massive, gray-brown to very dark gray, weathers to dark purple 4.5

[Loveland-Crete Formation]
3. Silt, red, massive, a few quartz sand grains throughout 3.5
2. Silt, sand, and gravel, mostly of chalk but some quartz and granite, contains a few large pebbles of chalk, light-gray; a few snails 4.5
1. Sand, silt, and gravel, cemented with calcium carbonate; gravel composed mostly of Cretaceous rock fragments; numerous irregular hollow concretions 9.0

Total Pleistocene section measured 51.5 ft

Section measured in a trench excavated for refuse at the Phillips County sanitary landfill, located in the southern half of SWSE sec. 34., T. 3 S., R. 18 W. (this study).

Quaternary (Pleistocene)
Overburden
5. Silt, medium to coarse, wind-deposited, massive, calcareous, pale-brown (10YR 6/3); modern surface soil truncated to thickness of 2.3 ft; flecks of carbonate in lower 7.6 ft; terrestrial gastropods in upper third indicate Leonard's upper zone (e.g., *Columella alticola* and *Discus shimeki*) 11.6
4. Silt, medium, wind-deposited, noncalcareous, leached, grades upward from dark-brown (10YR 3/3) to grayish-brown (10YR 5/2); Leonard's basal zone; attenuated A horizon of Gilman Canyon Formation below 3.1

Gilman Canyon Formation

3.	Silt, medium to fine, wind-deposited, humus-rich, leached, bioturbated; very dusky red (10R 2.5/2) to very dark brown (10YR 2/2); fragments of small mammal bone; increase in clay at base; fine carbonate root traces; lower solum (Btkb) developed into underlying silt	3.5

Loveland Loess

2.	Silt, coarse to medium, wind-deposited, massive, compact, calcareous, yellow (10YR 7/8); upper 1.6 ft clayey, very compact, with carbonate nodules and root traces; truncated Sangamon soil	7.6

Crete Formation

1.	Sand, very fine to fine grained, few small granitic pebbles, calcareous, soft, yellow (10YR 7/6) to brownish-yellow (10YR 6/6)	4.0
	Total section measured	29.8 ft

Acknowledgments

Appreciation is expressed to the many residents of Phillips County who provided access to their land and information concerning local geology, soils, stream systems, and historical events. D. W. May of the University of Northern Iowa and graduate students in the Department of Geography at the University of Kansas contributed many useful field observations. Two anonymous reviewers kindly provided constructive comments.

Mapping the geology of Phillips County would have proven a much more difficult task and would have taken far longer had it not been for the assistance and dedication of Alan Arbogast, co-author of the county geologic map. The Dane Hansen Foundation of Logan, Kansas, generously contributed funds for the project.

References

Aber, J. S., 1981, Two-ice-lobe model for glaciation of Kansas: Kansas Academy of Science, Transactions, v. 84, p. 162–163

________, 1988, The glaciation of Kansas: Heritage of the Great Plains, v. 21, no. 4, 36 p.

________, 1991, The glaciation of northeastern Kansas: Boreas, v. 20, p. 297–314

Aber, J. S., Abdelsaheb, I., Nutter, B., Denne, J. E., and MacDonald, W. D., 1988, Composition, paleomagnetism, and age of the Kansas drift (abs.): Kansas Academy of Science, Abstracts, v. 7, p. 1

Ager, D. V., 1973, The nature of the stratigraphical record: London, Macmillan, 114 p.

Aguirre, E., and Pasini, G., 1985, The Pliocene-Pleistocene boundary: Episodes, v. 8, p. 116–120

Ahlbrandt, T. S., Swinehart, J. B., and Maroney, D. G., 1983, The dynamic Holocene dune fields of the Great Plains and Rocky Mountain basins, U.S.A.; *in*, Eolian sediments and processes, Brookfield, M. E., and Ahlbrandt, T. S., eds.: Elsevier Science Publishers, Amsterdam, The Netherlands, p. 379–406

Alden, W. C., and Leighton, M. M., 1917, The Iowan drift, a review of the evidence of the Iowan stage of glaciation: Iowa Geological Survey, Annual Report, v. 26, p. 49–212

Antevs, E., 1955, Geologic-climatic dating in the West: American Antiquity, v. 20, p. 317–335

Baker, R. G., and Waln, K. A., 1985, Quaternary pollen records from the Great Plains and central United States; *in*, Pollen records of late Quaternary North American sediments, Bryant, V. M., and Holloway, R. G., eds.: American Association of Stratigraphic Palynologists Foundation, Dallas, Texas, p. 191–203

Baker, V. R., 1983, Pleistocene fluvial systems; *in*, Late Quaternary environments of the United States—v. 1, The late Pleistocene, Porter, S. C., ed.: University of Minnesota Press, Minneapolis, p. 115–129

Bard, E., Hamelin, B., and Fairbanks, R. G., 1990, U-Th ages obtained by mass spectrometry in corals from Barbados—sea level during the past 130,000 years: Nature, v. 346, p. 456–458

Barry, R. G., 1983, Climatic environment of the Great Plains, past and present; *in*, Man and the changing environments in the Great Plains, Caldwell, W. W., Schultz, C. B., and Stout, T. M., eds.: Transactions of the Nebraska Academy of Sciences, v. 11, p. 45–55

Bartlein, P. J., Webb, T., III, and Fleri, E., 1984, Holocene climatic change in the northwestern Midwest—pollen derived estimates: Quaternary Research, v. 22, p. 361–374

Bass, N. W., 1926, Geologic investigations in western Kansas: Kansas Geological Survey, Bulletin 11, pts. 1 and 2, p. 1–83

Bates, R. L., and Jackson, J. A., 1987, Glossary of geology: American Geological Institute, Alexandria, Virginia, 788 p.

Bayne, C. K., 1968, Evidence for multiple stades in the lower Pleistocene of northeastern Kansas: Kansas Academy of Science, Transactions, v. 71, p. 340–349

Bayne, C. K., and O'Connor, H. G., 1968, Quaternary System; *in*, The stratigraphic succession in Kansas, Zeller, D. E., ed.: Kansas Geological Survey, Bulletin 189, p. 59–67

Bayne, C. K., Davis, S. N., Howe, W. B., and O'Connor, H. G., 1971, Regional Pleistocene stratigraphy: Kansas Geological Survey, Special Distribution Publication 53, p. 4–8

Beard, J., 1969, Pleistocene paleotemperature record based on planktonic foraminifers, Gulf of Mexico: Gulf Coast Association of Geological Societies, Transactions, v. 19, p. 535–553

Beard, J., Sangree, J., and Smith, L., 1982, Quaternary chronology, paleoclimate, depositional sequences and eustatic cycles: American Association of Petroleum Geologists, Bulletin, v. 66, p. 158–169

Bedinger, M. S., and Tanaka, H. H., 1962, Effect of the Kirwin Reservoir, Kansas, on ground-water levels: U.S. Geological Survey, Open-file Report, 11 p.

Bender, M. J., Fairbanks, R. G., Taylor, F. W., Matthews, R. K., Goddard, J. G., and Broecker, W. S., 1979, Uranium-series dating of the Pleistocene reef tracts of Barbados, West Indies: Geological Society of America, Bulletin, v. 90, p. 577–594

Benedict, J. B., and Olson, B. L., 1978, The Mount Albion complex—a study of prehistoric man and the Altithermal: Research Report of the Center for Mountain Archaeology, v. 1, 213 p.

Berggren, W. A., and Van Couvering, J. A., 1974, The late Neogene biostratigraphy, geochronology, and paleoclimatology of the last 15 million years in marine and continental sequences: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 16, nos. 1–2, p. 1–216

Bettis, E. A., III, ed., 1990, Holocene alluvial stratigraphy and selected aspects of the Quaternary history of western Iowa: Midwestern Friends of the Pleistocene, University of Iowa, Quaternary Studies Group Contribution 36, 197 p.

Boellstorff, J. D., 1973, Fission-track ages of Pleistocene volcanic ash deposits in the central Plains, U.S.A.: Isochron/West, v. 8, p. 39–43

________, 1974, Fission-track ages of Pearlette family ash beds—comment: Geology, v. 2, p. 21

________, 1976, The succession of late Cenozoic ashes in the Great Plains—a progress report: Kansas Geological Survey, Guidebook Series 1, p. 37–71

________, 1978a, Chronology of some late Cenozoic deposits from the central United States and the Ice Ages: Transactions of the Nebraska Academy of Sciences, v. 6, p. 35–49

________, 1978b, A need for redefinition of North American Pleistocene stages: Gulf Coast Association of Geological Societies, Transactions, v. 28, p. 65–74

________, 1978c, North American Pleistocene stages reconsidered in light of probable Plio-Pleistocene glaciation: Science, v. 202, p. 305–307

Bowen, D. Q., 1978, Quaternary geology: Pergamon Press, Oxford, England, 221 p.

Bowen, D. Q., Richmond, G. M., Fullerton, D. S., Sibrava, V., Fulton, R. J., and Velichko, A. A., 1986, Correlation of Quaternary glaciations in the Northern Hemisphere; *in*, Quaternary glaciations in the Northern Hemisphere, Sibrava, V., Bowen, D. Q., and Richmond, G. M., eds.: Quaternary Science Reviews, v. 5, p. 509–510

Brakenridge, G. R., 1980, Widespread episodes of stream erosion during the Holocene and their climatic cause: Nature, v. 283, p. 655–656

Brice, J. C., 1964, Channel patterns and terraces of the Loup Rivers in Nebraska: U.S. Geological Survey, Professional Paper 422–D, 41 p.

Bushue, L. J., Fehrenbacher, J. B., and Ray, B. W., 1974, Exhumed paleosols and associated modern till soils in western Illinois: Soil Science Society of America, Proceedings, v. 34, p. 665–669

Byrne, F. E, Beck, H. V., and Houston, M. S., 1948, Construction materials in Phillips County, Kansas: U.S. Geological Survey, Circular 21, 12 p.

Carter, B. J., and Ward, P. A., 1991, A prehistory of the Plains border region: Guidebook, South-central Friends of the Pleistocene, Agronomy Department, Oklahoma State University, Stillwater, 121 p.

Casey, R. D. and Wantland, D., 1953, Seismic investigations at Kirwin Dam site, Solomon Unit, Kansas River District, Missouri River Basin Project: U.S. Bureau of Reclamation, Engineering Geology Branch, Geology Report G–124, 5 p.

Caspall, F. C., 1970, The spatial and temporal variations in loess deposition in northeastern Kansas: Ph.D. dissertation, University of Kansas, Lawrence, 294 p.

________, 1972, A note on the origin of the Brady paleosol in northeastern Kansas: Proceedings of the Association of American Geographers, v. 4, p. 19–24

Chamberlin, T. C., 1895, The classification of American glacial deposits: Journal of Geology, v. 3, p. 270–277

Chen, J. H., Curran, H. A., White, B., and Wasserburg, G. J., 1991, Precise chronology of the last interglacial period—^{234}U-^{230}Th data from fossil coral reefs in the Bahamas: Geological Society of America, Bulletin, v. 103, p. 82–97

Cobban, W. A., and Reeside, J. B., Jr., 1952, Correlation of the Cretaceous formations of the Western Interior of the United States: Geological Society of America, Bulletin, v. 63, p. 1,011–1,044

Cohee, G. V., 1968, Holocene replaces Recent in nomenclature usage of the U.S. Geological Survey: American Association of Petroleum Geologists, Bulletin, v. 52, p. 852

COHMAP members, 1988, Climatic changes of the last 18,000 years—observations and model simulations: Science, v. 241, p. 1,043–1,052

Condra, G. E., Reed, E. C., and Gordon, E. D., 1947, Correlation of the Pleistocene deposits of Nebraska: Nebraska Geological Survey, Bulletin 15, 71 p.

________, 1950 Correlation of the Pleistocene deposits of Nebraska: Nebraska Geological Survey, Bulletin 15–A, 74 p.

Cornwell, K. J., 1987, Geomorphology and soils; *in*, Prehistoric and historic cultural resources of selected sites at Harlan County Lake, Harlan County, Nebraska, Adair, M. J., and Brown, K. L., eds.: U.S. Army Corps of Engineers, Kansas City District, p. 29–46

Daniels, R. B., and Handy, R. L., 1959, Suggested new type section for the Loveland loess in western Iowa: Journal of Geology, v. 67, p. 114–119

Daniels, R. B., Handy, R. L., and Simonson, G. H., 1960, Dark-colored bands in the thick loess of western Iowa: Journal of Geology, v. 68, p. 450–458

Darton, N. H., 1899, Preliminary report on the geology and water resources of Nebraska west of the One Hundred and Third Meridian: U.S. Geological Survey, 19th Annual Report, pt. 4, Hydrology, p. 719–785

________, 1920, Description of the Syracuse and Lakin quadrangles: U.S. Geological Survey, Atlas Folio Serial 212, 10 p.

Davis, S. N., and Carlson, W. A., 1952, Geology and ground-water resources of the Kansas River Valley between Lawrence and Topeka, Kansas: Kansas Geological Survey, Bulletin 96, pt. 5, p. 201–276

Deevey, E. S., and Flint, R. F., 1957, Postglacial Hypsithermal interval: Science, v. 125, p. 182–184

Deines, P., 1980, The isotopic composition of reduced organic carbon; *in*, Handbook of environmental isotope geochemistry—v. 1, The terrestrial environment: Elsevier, Amsterdam, The Netherlands, p. 329–406

Dort, W., Jr., 1965, Nearby and distant origins of glacier ice entering Kansas: American Journal of Science, v. 263, p. 598–605

________, 1966, Nebraskan and Kansan stades—complexity and importance: Science, v. 154, p. 771–772

________, 1985, Field evidence for more than two early Pleistocene glaciations of the Central Plains: Nebraska Academy of Sciences, Institute for Tertiary-Quaternary Studies, TER-QUA Symposium Series, v. 1, p. 41–51

________, 1987, Salient aspects of the terminal zone of continental glaciation in Kansas; *in*, Quaternary environments of Kansas, Johnson, W. C., ed.: Kansas Geological Survey, Guidebook Series 5, p. 55–66

Dreeszen, V. H., 1970, The stratigraphic framework of Pleistocene glacial and periglacial deposits in the Central Plains; *in*, Pleistocene and Recent environments of the Central Great Plains, Dort, W., Jr., and Jones, J. K., Jr., eds.: Department of Geology, Special Publication 3, University Press of Kansas, Lawrence, p. 9–22

Edwards, R. L., Chen, J. H., and Wasserburg, G. J., 1987a, ^{238}U-^{234}U-^{230}Th-^{232}Th systematics and the precise measurement of time over the past 500,000 years: Earth and Planetary Science Letters, v. 81, p. 175–192

Edwards, R. L., Chen, J. H., Ku, T.-L., and Wasserburg, G. J., 1987b, Precise timing of the last interglacial period from mass spectrometric determination of thorium-230 in corals: Science, v. 236, p. 1,547–1,553

Elias, M. K., 1931, The geology of Wallace County, Kansas: Kansas Geological Survey, Bulletin 18, 254 p.

________, 1932, Grasses and other plants from the Tertiary rocks of Kansas and Colorado: University of Kansas, Science Bulletin, v. 20, no. 20, p. 333–367

________, 1935, Tertiary grasses and other prairie vegetation from the High Plains of North America: American Journal of Science, ser. 5, v. 29, p. 24–33

________, 1942, Tertiary prairie grasses and other herbs from the High Plains: Geological Society of America, Special Paper (Regular Studies) 41, 176 p.

Fairbridge, R. W., 1983, The Pleistocene-Holocene boundary: Quaternary Science Reviews, v. 1, p. 215–244

Feng, Zhaodong, 1991, Temporal and spatial variations in the loess depositional environment of central Kansas during the past 400,000 years: Ph.D. dissertation, University of Kansas, Lawrence, 250 p.

Feng, Zhaodong, Johnson, W. C., and Sprowl, D. R., 1991, Loess depositional history and the climatic implication during the last 400,000 years in central Kansas (abs.): Nebraska Academy of Sciences, Institute for Tertiary-Quaternary Studies, TER-QUA Symposium Series, p. 6

Fent, O. S., 1950, Pleistocene drainage history of central Kansas: Kansas Academy of Sciences, Transactions, v. 53, no. 1, p. 81–90

Follmer, L. R., 1978, The Sangamon soil in its type area—a review; *in*, Quaternary soils, Mahaney, W. C., ed.: Geo Abstracts Limited, Norwich, England, p. 125–165

________, 1979, A historical review of the Sangamon soil; *in*, Wisconsinan, Sangamonian, and Illinoian stratigraphy in central Illinois: Illinois State Geological Survey, Guidebook 13, p. 79–91

________, 1982, The geomorphology of the Sangamon surface—its spatial and temporal attributes; *in*, Space and time in geomorphology, Thorn, C. E., ed.: Allen and Unwin, London, England, p. 117–146

________, 1983, Sangamon and Wisconsinan pedogenesis in the Midwestern United States; *in*, Late Quaternary environments of the United States—v. 1, The late Pleistocene, Porter, S. C., ed.: University of Minnesota Press, Minneapolis, p. 138–144

Forman, S. L., 1990a, Chronologic evidence for multiple episodes of loess deposition during the Wisconsinan and Illinoian in the midcontinent, U.S.A. (abs.): Geological Society of America, Abstracts with Programs, v. 22, no. 7, p. A86

________, 1990b, Thermoluminescence and radiocarbon chronology of loess deposition at the Loveland paratype, Iowa; *in*, Holocene alluvial stratigraphy and selected aspects of Quaternary history of western Iowa, Bettis, E. A., III, ed.: Midwestern Friends of the Pleistocene, University of Iowa, Quaternary Studies Group Contribution 36, p. 165–172

Forman, S. L., and Maat, P., 1990, Stratigraphic evidence for late Quaternary dune activity near Hudson on the piedmont of northern Colorado: Geology, v. 18, p. 745–748

Forman, S. L., Goetz, A. F. H., and Yuhas, R. H., 1992, Large-scale stabilized dunes on the High Plains of Colorado—understanding the landscape response to Holocene climates with the aid of images from space: Geology, v. 20, p. 145–148

Forman, S. L., Bettis, E. A., Kemmis, T. L., and Miller, B. B., 1992, Chronological evidence for multiple periods of loess deposition during the late Pleistocene in Missouri and Mississippi River valleys, United States—implications for the activity of the Laurentide Ice Sheet: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 93, p. 71–83

Fredlund, G. G., 1990, Paleoenvironmental interpretations of stable carbon, hydrogen, and oxygen isotopes from opal phytoliths, Eustis ash pit, Nebraska: Department of Geography, University of Wisconsin, Milwaukee, 33 p. (unpublished)

________, 1991, A comparison of Pleistocene and Holocene vegetation in the central Great Plains of North America—palynological evidence from Cheyenne Bottoms, Kansas: Ph.D. dissertation, University of Kansas, Lawrence, 303 p.

Fredlund, G. G., and Jaumann, P. J., 1986, The influence of topography and fire disturbance on late Wisconsinan vegetation in eastern Kansas (abs.): American Quaternary Association, 9th Biennial Meeting, Champaign, Illinois, Program and Abstracts, p. 81

________, 1987, Late Quaternary palynological and paleobotanical records from the central Great Plains; *in*, Quaternary environments of Kansas, Johnson, W. C., ed.: Kansas Geological Survey, Guidebook Series 5, p. 167–178

Fredlund, G. G., and Johnson, W. C., 1985, Palynological evidence for late Pleistocene vegetation from Sanders's well locality in east-central Kansas (abs.): Institute for Tertiary-Quaternary Studies, 4th Annual Symposium, Lawrence, Kansas, Program with Abstracts, p. 15

Fredlund, G. G., Johnson, W. C., and Dort, W., Jr., 1985, A preliminary analysis of opal phytoliths from the Eustis ash pit, Frontier County, Nebraska: Nebraska Academy of Sciences, Institute for Tertiary-Quaternary Studies, TER-QUA Symposium Series, v. 1, p. 147–162

Frye, J. C., and Fent, O. S., 1947, The late Pleistocene loesses of central Kansas: Kansas Geological Survey, Bulletin 70, pt. 3, p. 29–52

Frye, J. C., and Hibbard, C. W., 1941, Pliocene and Pleistocene stratigraphy and paleontology of the Meade basin, southwestern Kansas: Kansas Geological Survey, Bulletin 38, pt. 13, p. 389–424

Frye, J. C., and Leonard, A. B., 1949, Pleistocene stratigraphic sequence in northeastern Kansas: American Journal of Science, v. 247, p. 883–899

________, 1951, Stratigraphy of late Pleistocene loesses of Kansas: Journal of Geology, v. 59, no. 4, p. 287–305

________, 1952, Pleistocene geology of Kansas: Kansas Geological Survey, Bulletin 99, 230 p.

________, 1954, Significant new exposures of Pleistocene deposits at Kirwin Phillips County, Kansas: Kansas Geological Survey, Bulletin 109, pt. 3, p. 29–48

________, 1965, Quaternary of the southern Great Plains; *in*, The Quaternary of the United States—a review volume for VII Congress of the International Association for Quaternary Research, Wright, H. E., Jr., and Frey, D. G., eds.: Princeton University Press, Princeton, New Jersey, p. 203–216

Frye, J. C., and Leonard, A. R., 1949, Geology and ground-water resources of Norton County and northwestern Phillips County, Kansas: Kansas Geological Survey, Bulletin 81, 144 p.

Frye, J. C., and Swineford, A., 1946, Silicified rock in the Ogallala Formation: Kansas Geological Survey, Bulletin 64, pt. 2, p. 33–76

Frye, J. C., and Willman, H. B., 1973, Wisconsinan climatic history interpreted from Lake Michigan lobe deposits and soils; *in*, The Wisconsinan Stage, Black, R. F., Goldthwait, R. P., and Willman, H. B., eds.: Geological Society of America, Memoir 136, p. 135–152

Frye, J. C., Leonard, A. B., and Swineford, A., 1956, Stratigraphy of the Ogallala Formation (Neogene) of northern Kansas: Kansas Geological Survey, Bulletin 118, 92 p.

Frye, J. C., Willman, H. B., and Glass, H. D., 1968, Correlation of Midwestern loesses with the glacial succession; *in*, Loess and related eolian deposits of the world, Schultz, C. B. and Frye, J. C. eds.: Proceedings, 7th Congress, International Association of Quaternary Research, University of Nebraska Press, Lincoln, p. 3–21

Frye, J. C., Plummer, N., Runnels, R. T., and Hladik, W. B., 1949, Ceramic utilization of northern Kansas Pleistocene loesses and fossil soils: Kansas Geological Survey, Bulletin 82, pt. 3, p. 49–124

Frye, J. C., Leonard, A. B., Willman, H. B., Glass, H. D., and Follmer, L. R., 1974, The late Woodfordian Jules soil and associated molluscan faunas: Illinois State Geological Survey, Circular 486, 11 p.

Fullerton, D. S., and Richmond, G. M., 1986, Comparison of the marine oxygen isotope record, the eustatic sea level record, and the chronology of glaciation in the United States of America; *in*, Quaternary glaciations in the Northern Hemisphere, Sibrava, V., Bowen, D. Q., and Richmond, G. M., eds.: Quaternary Science Reviews, v. 5, p. 197–200

Geologic Names Committee, 1984, Geologic time chart; *in*, Stratigraphic notes, 1983: U.S. Geological Survey, Bulletin 1537–A, p. A1–A4

Gilbert, G. K, 1896, The underground water of the Arkansas Valley in eastern Colorado: U.S. Geological Survey, 17th Annual Report, pt. 2, p. 551–601

Gottula, J. J., and Souders, V. L., 1989, Radiocarbon dates in an anomalous sequence within the Gilman Canyon Formation near Ord, Nebraska (abs.): Proceedings of the Nebraska Academy of Sciences, p. 50

Gruger, J., 1973, Studies on the late Quaternary vegetation history of northeastern Kansas: Geological Society of America, Bulletin, v. 84, p. 237–250

Gustavson, T. C., and Winkler, D. A., 1988, Depositional facies of the Miocene-Pliocene Ogallala Formation, northwestern Texas and eastern New Mexico: Geology, v. 16, no. 3, p. 203–206

Hall, R. D., 1973, Sedimentation and alteration of loess in southwestern Indiana: Ph.D. dissertation, Indiana University, Bloomington, 103 p.

Hallberg, G. R., 1986, Pre-Wisconsin glacial stratigraphy of the Central Plains region in Iowa, Nebraska, Kansas, and Missouri; *in*, Quaternary glaciations in the Northern Hemisphere, Sibrava, V., Bowen, D. Q., and Richmond, G. M., eds.: Quaternary Science Reviews, v. 5, p. 11–15

Hallberg, G. R., Wollenhaupt, N. C., and Wickham, J. T., 1980, Pre-Wisconsin stratigraphy in southeastern Iowa: Iowa Geological Survey, Technical Information Series 11, 110 p.

Hanna, G. D. and Johnston, E. C., 1913, A Pleistocene molluscan fauna from Phillips County, Kansas: Kansas University, Science Bulletin, v. 7, no. 3, p. 111–121

Haq, B. U., and van Eysinga, F. W. B., 1987, Geological time table: Elsevier Science Publishers, Amsterdam, The Netherlands, 1 sheet

Hattin, D. E., 1962, Stratigraphy of the Carlile Shale (Upper Cretaceous) in Kansas: Kansas Geological Survey, Bulletin 156, 155 p.

________, 1982, Stratigraphy and depositional environment of Smoky Hill Chalk Member, Niobrara Chalk (Upper Cretaceous) of the type area, western Kansas: Kansas Geological Survey, Bulletin 225, 108 p.

Herman, C. W., 1957, Subsurface geology of Phillips County, Kansas: M.S. thesis, Kansas State University, Manhattan, 67 p.

Hibbard, C. W., 1942, The occurrence of *Eucastor tortus* Leidy in Phillips County, Kansas: Kansas Academy of Science, Transactions, v. 45, p. 248–252

________, 1949, Pleistocene stratigraphy and paleontology of Meade County, Kansas: University of Michigan, Museum of Paleontology, Contribution, v. 7, no. 4, p. 63–90

________, 1958, New stratigraphic names for early Pleistocene deposits in southwestern Kansas: American Journal of Science, v. 256, no. 1, p. 54–59

Hibbard, C. W., Frye, J. C., and Leonard, A. B., 1944, Reconnaissance of Pleistocene deposits in north-central Kansas: Kansas Geological Survey, Bulletin 52, pt. 1, p. 1–28

Ho, T.-Y., 1966, Stratigraphic and paleoecologic applications of water-insoluable fraction of residual shell-proteins in fossil shells: Geology Society of America, Bulletin, v. 77, no. 4, p. 375–392

Hopkins, D. M., 1975, Time-stratigraphic nomenclature for the Holocene Epoch: Geology, v. 3, p. 10

Izett, G. A., 1981, Volcanic ash beds—recorders of upper Cenozoic silicic pyroclastic volcanism in the western United States: Journal of Geophysical Research, v. 86, p. 10,200–10,222

________, 1982, The Bishop ash bed and some older, compositionally similar ash beds in California, Nevada, and Utah: U.S. Geological Survey, Open-file Report 82–582, 44 p.

Izett, G. A., and Wilcox, R. E., 1982, Map showing localities and inferred distributions of the Huckleberry Ridge, Mesa Falls, and

Lava Creek ash beds (Pearlette family ash beds) of Pliocene and Pleistocene age in the western United States and southern Canada: U.S. Geological Survey, Miscellaneous Investigations Map I–1325, 1 sheet, scale 1:4,000,000

Izett, G. A., Wilcox, R. E., Powers, H. A., and Desborough, G. A., 1970, The Bishop ash bed—a Pleistocene marker bed in the western United States: Quaternary Research, v. 1, p. 121–132

Jaumann, P. J., 1991, Evidence for late Quaternary boreal environments in the Arkansas River valley, south-central Kansas—theoretical aspects of paleoecology and climatic inferences: M.A. thesis, University of Kansas, Lawrence, 283 p.

Jewett, J. M., 1959, Graphic column and classification of rocks in Kansas: Kansas Geological Survey, 1 sheet

________, 1963, Pleistocene geology in Kansas: Kansas Academy of Science, Transactions, v. 66, p. 347–358

Johnson, C. R., 1956, The ground-water resources of the Prairie Dog valley area in Kansas: U.S. Geological Survey, Open-file Report, 176 p.

Johnson, R. G., 1982, Brunhes-Matuyama magnetic reversal dated at 790,000 yr B.P. by marine-astronomical correlations: Quaternary Research, v. 17, p. 135–147

Johnson, W. C., ed., 1987, Quaternary environments of Kansas: Kansas Geological Survey, Guidebook Series 5, 206 p.

________, 1989, Stratigraphy and late Quaternary landscape evolution; *in*, Archaeological investigations at the North Cove site, Harlan County Lake, Harlan County, Nebraska, Adair, M. J., ed.: University of Kansas, Office of Archaeological Research, p. 22–52

________, 1990, Age determinations on the Gilman Canyon Formation and Brady paleosol in Kansas (abs.): American Quaternary Association, Program and Abstracts, p. 21

________, 1991a, Buried soil surfaces beneath the Great Bend Prairie of central Kansas and archaeological implications: Current Research in the Pleistocene, v. 8, p. 108–110

________, 1991b, Late Pleistocene and Holocene eolian stratigraphy of the central Great Plains and paleoenvironmental reconstructions (abs.): Geological Society of America, Abstracts with Programs, v. 23, p. A284

Johnson, W. C., and Arbogast, A., 1993, Geologic map of Phillips County, Kansas: Kansas Geological Survey, Map Series 29, 1 sheet, scale 1:50,000 (in press)

Johnson, W. C., and Logan, B., 1990, Geoarcheology of the Kansas River basin, central Great Plains; *in*, Archaeological geology of North America, Lasca, N. P., and Donahue, J., eds.: Geological Society of America, Decade of North American Geology, Centennial Special Volume 4, p. 267–299

Johnson, W. C., and Martin, C. W., 1987, Holocene alluvial-stratigraphic studies from Kansas and adjoining states of the east-central Plains; *in*, Quaternary environments of Kansas, Johnson, W. C., ed.: Kansas Geological Survey, Guidebook Series 5, p. 109–122

Johnson, W. C., and May, D. W., 1992, The Brady geosol as an indicator of the Pleistocene/Holocene boundary in the central Great Plains (abs.): American Quaternary Association, Programs and Abstracts, p. 69

Johnson, W. C., May, D. W., and Souders, V. L., 1990, Age and distribution of the Gilman Canyon Formation of Nebraska and Kansas (abs.): Geological Society of America, Abstracts with Programs, v. 22, p. A87

Johnson, W. C., May, D. W., and Valastro, S., 1993, A 36,000-year chrono-, bio-, and magnetostratigraphic record from loess of south-central Nebraska (abs.): Association of American Geographers, 89th Annual Meeting, Abstracts (in press)

Johnson, W. H., 1986, Stratigraphy and correlation of glacial deposits of the Lake Michigan lobe prior to 14 ka B.P.; *in*, Quaternary glaciations in the Northern Hemisphere, Sibrava, V., Bowen, D. Q., and Richmond, G. M., eds.: Quaternary Sciences Review, v. 5, p. 17–22

Jorgensen, D. G., and Stullken, L. E., 1981, Hydrology and model of North Fork Solomon River valley, Kirwin Dam to Waconda Lake, north-central Kansas: Kansas Geological Survey, Irrigation Series 6, 34 p.

Kapp, R. O., 1965, Illinoian and Sangamon vegetation in southwestern Kansas and adjacent Oklahoma: University of Michigan, Museum of Paleontology, Contributions, v. 19, p. 167–255

________, 1970, Pollen analysis of pre-Wisconsinan sediments; *in*, Pleistocene and Recent environments of the central Great Plains, Dort, W., Jr., and Jones, J. K., eds.: University Press of Kansas, Lawrence, p. 143–155

Kinney, E. D., 1942, Kansas bentonite—its properties and utilization: Kansas Geological Survey, Bulletin 41, pt. 10, p. 349–376

Kitchen, L., 1987, Nitrate-N profiles of fine to medium textured sediments of the unsaturated zone of southeast and south-central Nebraska: M.A. thesis, University of Nebraska, Lincoln, 139 p.

Kleiss, H. J., and Fehrenbacher, J. G., 1973, Loess distribution as revealed by mineral variations: Soil Science Society of America, Proceedings, v. 37, 291–295

Knox, J. C., 1976, Concept of the graded stream; *in*, Theories of landform development, Melhorn, W. N., and Flemal, R. C., eds.: Publications in Geomorphology, State University of New York, Binghamton, p. 169–198

________, 1983, Responses of river systems to Holocene climates; *in*, Late Quaternary environments of the United States—v. 2, The Holocene, Wright, H. E., Jr., ed.: University of Minnesota Press, Minneapolis, p. 26–41

Krishnamurthy, R. V., DeNiro, M. J., and Pant, R. K., 1982, Isotope evidence for Pleistocene climatic changes in Kashmir, India: Nature, v. 298, p. 640–641

Krueger, J. P., 1986, Development of oriented lakes in the eastern rain basin region of south-central Nebraska: M.A. thesis, University of Nebraska, Lincoln, 115 p.

Ku, T.-L., Ivanovich, M., and Luo, S., 1990, U-series dating of last interglacial high sea stands—Barbados revisited: Quaternary Research, v. 33, p. 129–147

Kukla, G. J., 1977, Pleistocene land-sea correlations—I, Europe: Earth-Science Review, v. 13, p. 307–374

________, 1987, Loess stratigraphy in central China: Quaternary Science Reviews, v. 6, p. 191–219

Kurten, B., and Anderson, E., 1980, Pleistocene mammals of North America: Columbia University Press, New York, 442 p.

Kutzbach, J. E., 1981, Monsoon climate of the early Holocene—climatic experiment with the Earth's orbital parameters for 9,000 years ago: Science, v. 214, p. 61

________, 1985, Modeling of paleoclimates: Advances in Geophysics, v. 28A, p. 159–196

________, 1987, Model simulations of the climatic patterns during the deglaciation of North America; *in*, North America and adjacent oceans during the last glaciation, Ruddiman, W. F., and Wright, H. E., Jr., eds.: Geological Society of America, The Geology of North America, v. K–3, p. 425–446

Kuzila, M. S., 1988, Genesis and morphology of soils in and around large depressions in Clay County, Nebraska: Ph.D. dissertation, University of Nebraska, Lincoln, 199 p.

Lamb, J., and Beard, J., 1972, Late Neogene planktonic foraminifera in the Caribbean, Gulf of Mexico, and Italian stratotypes: University of Kansas, Paleontological Contributions, v. 57, p. 1–67

Landes, K. K., and Keroher, R. P., 1942, Mineral resources of Phillips County: Kansas Geological Survey, Bulletin 41, pt. 8, p. 277–312

Leigh, D. S., 1991, Origin and paleoenvironment of the Upper Mississippi valley Roxana silt: Ph.D. dissertation, University of Wisconsin, Madison, 186 p.

Leighton, M. M., and Willman, H. B., 1950, Loess formations of the Mississippi valley: Journal of Geology, v. 58, p. 599–623

Leonard, A. B., 1951, Stratigraphic zonation of the Peoria loess in Kansas: Journal of Geology, v. 59, p. 323–332

________, 1952, Illinoian and Wisconsinan molluscan faunas in Kansas: Kansas University, Paleontological Contributions, Mollusca, art. 4, 38 p.

Leonard, A. R., 1952, Geology and ground-water resources of the North Fork Solomon River in Mitchell, Osborne, Smith, and Phillips counties, Kansas: Kansas Geological Survey, Bulletin 98, 150 p.

Leonard, A. R., and Berry, D. W., 1961, Geology and ground-water resources of southern Ellis County and parts of Trego and Rush counties, Kansas: Kansas Geological Survey, Bulletin 149, 156 p.

Leverett, F., 1899, The Illinois glacial lobe: U.S. Geological Survey, Monograph 38, 817 p.

Libby, W. F., 1955, Radiocarbon dating: University of Chicago Press, Chicago, Illinois, 175 p.

Logan, W. N., 1897, The Upper Cretaceous of Kansas: University Geological Survey of Kansas, v. 2, p. 202–234

________, 1899, Some additions to the Cretaceous invertebrates of Kansas: Kansas University Quarterly, v. 8, ser. A, p. 87–98

Lugn, A. L., 1934, Pleistocene geology of Nebraska: Nebraska State Museum, Bulletin 41, v. 1, pt. 1, p. 319–356

________, 1935, The Pleistocene geology of Nebraska: Bulletin of the Nebraska Geological Survey, ser. 2, v. 10, 223 p.

Lutenegger, A. J., 1985, Desert loess in the midcontinent, U.S.A. (abs.): First International Conference on Geomorphology, Manchester, England, Abstracts of Papers, p. 378

Mandel, R. D., 1990, Holocene landscape evolution in the Pawnee River valley, southwestern Kansas: Ph.D. dissertation, University of Kansas, Lawrence, 377 p.

________, 1991, Geomorphology; *in*, Cultural resource investigations for the U.S. highway 166 corridor, Schoen, C. M., ed.: Kansas State Historical Society, Topeka, p. 8–59

Martin, C. W., 1990, Late Quaternary landform evolution in the Republican River basin, Nebraska: Ph.D. dissertation, University of Kansas, Lawrence, 289 p.

Martin, L. D., and Dort, W., Jr., 1987, Significance of Peoria loess thickness and age in relation to conditions and rates of accumulation in central Nebraska (abs.): International Union for Quaternary Research, Program with Abstracts, XII International Congress, p. 221

Martin, L. D., and Schultz, C. B., 1985, Small mammals of the Seneca and Sappa local faunas (post-Ogallala of Nebraska): Nebraska Academy of Sciences, Institute for Tertiary-Quaternary Studies, TER-QUA Symposium Series, v. 1, p. 163–179

Martinson, D. G., Pisias, N. G., Hays, J. D., Imbrie, J., Moore, T. C., Jr., and Shackleton, N. J., 1987, Age dating and the orbital theory of the Ice Ages—development of a high-resolution 0 to 300,000-year chronology: Quaternary Research, v. 27, p. 1–29

Mathewes, R. W., Heusser, L. E., and Patterson, R. T., 1993, Evidence for a Younger Dryas–like cooling event on the British Columbia coast: Geology, v. 21, p. 101–104

May, D. W., 1989, Age and distribution of the Todd Valley Formation in the lower South Loup River valley (abs.): Proceedings of the Nebraska Academy of Sciences, p. 53

________, 1990, The potential for buried archaeological sites along the Fullerton and Elba canals, North Loup and Loup River valleys, Nebraska: Report to the Bureau of Reclamation, Grand Island, Nebraska, 25 p.

________, 1991a, Holocene fluvial landforms and alluvial stratigraphy in the Solomon River valleys, Lake Waconda, Kansas: Report submitted to Department of Anthropology, Wichita State University, Wichita, Kansas, 21 p.

________, 1991b, The stratigraphic context of fractured mammoth bones at the La Sena site (25FT177), Harry Strunk Lake (Medicine Creek Reservoir), Nebraska: Report prepared for the Department of Anthropology, University of Nebraska, Lincoln, 25 p.

May, D. W., and Holen, S. R., 1993, Radiocarbon ages of soils and charcoal in late Wisconsinan loess, south-central Nebraska: Quaternary Research, v. 39, p. 55–58

May, D. W., and Souders, V. L., 1988, Radiocarbon ages for the Gilman Canyon Formation in Dawson County, Nebraska, (abs.): Nebraska Academy of Sciences, Proceedings, p. 47–48

McCraw, D. J . and Autin, W. J., 1989, Lower Mississippi Valley loesses: Field guide, 1989 Mississippi Valley loess tour, INQUA Commission on Loess and the North American Loess Working Group

McKay, E. D., 1979a, Stratigraphy of Wisconsinan and older loesses in southwestern Illinois; *in*, Geology of western Illinois: Illinois State Geological Survey, Guidebook 14, p. 37–67

________, 1979b, Wisconsinan loess stratigraphy of Illinois; *in*, Wisconsinan, Sangamonian, and Illinoian stratigraphy in central Illinois: Illinois State Geological Survey, Guidebook 13, p. 95–108

Meek, F. B., and Hayden, F. V., 1862, Description of new Cretaceous fossils from Nebraska Territory: Philadelphia Academy of Natural Science, Proceedings, v. 13, p. 21–28

Metz, H. L., 1954, A petrographic comparison of the Loveland and Peoria loesses of northern Kansas: M.A. thesis, Kansas State University, Manhattan, 45 p.

Morner, N.-A., 1976, The Pleistocene-Holocene boundary—a proposed boundary-stratotype in Gothenburg, Sweden: Boreas, v. 5, p. 193–275

Morrison, R. B., 1965, Principles of Quaternary soil stratigraphy; *in*, Quaternary soils, Morrison, R. B., and Wright, H. E., Jr., eds.: INQUA VII Congress, Proceedings, v. 9, p. 1–69

________, 1987, Long-term perspective—changing rates and types of Quaternary surficial processes—erosion-deposition-stability cycles; *in*, Geomorphic systems of North America, Graf, W. L., ed.: Geological Society of America, Decade of North American Geology, Centennial Special Volume 2, p. 167–176

Moss, R. G., 1932, The geology of Ness and Hodgeman counties, Kansas: Kansas Geological Survey, Bulletin 19, 48 p.

Mott, R. J., Grant, D. R., Stea, R., and Occhietti, S., 1986, Late glacial climatic oscillation in Atlantic Canada equivalent to the Allerod/Younger Dryas event: Nature, v. 323, p. 247–250

Naeser, C. W., Izett, G. A., and Wilcox, R. E., 1973, Zircon fission-track ages of Pearlette family ash beds in Meade County, Kansas: Geology, v. 1, p. 187–189

Nilsson, T., 1983, The Pleistocene—geology and life in the Quaternary ice age: Ferdinand Enk Verlag, Stuttgart, Germany, 651 p.

North American Commission on Stratigraphic Nomenclature, 1983, North American Stratigraphic Code: American Association of Petroleum Geologists, Bulletin, v. 67, p. 841–875

Osborn, H. F., 1898, A complete skeleton of *Teleoceras*, the true rhinoceras from the upper Miocene of Kansas: Science, n.s., v. 7, p. 554–557

Oviatt, C. G., 1991, New data on the age of glacial deposits in Kansas (abs.): Institute for Tertiary-Quaternary Studies, TER-QUA Symposium Series, p. 15

Oviatt, C. G., Karlstrom, E. T., and Ransom, M. D., 1988, Pleistocene loess, buried soils, and thermoluminescence dates in an exposure near Milford Lake, Geary County, Kansas (abs.): Geological Society of America, Abstracts with Programs, v. 20, no. 2, p. 125–126

Palmer, A. R., 1983, The decade of North American geology—1983 geologic time scale: Geology, v. 11, p. 503–504

Palmer, C. D., and Hamilton, V. L., 1987, Soil survey of Phillips County, Kansas: U.S. Department of Agriculture, Soil Conservation Service, 109 p.

Paterson, W. S. B., and Hammer, C. U., 1987, Ice core and other glaciological data; *in*, North America and adjacent oceans during the last deglaciation, Ruddiman, W. F., and Wright, H. E., Jr., eds.: Geological Society of America, Decade of North American Geology, The Geology of North America, v. K–3, p. 91–109

Patton, P. C., and Schumm, S. A., 1981, Ephemeral-stream processes—implications for studies of Quaternary valley fills: Quaternary Research, v. 15, p. 24–43

Pecsi, M., 1985, Chronostratigraphy of Hungarian loesses and the underlying subaerial formation; *in*, Loess and the Quaternary, Pecsi, M., ed.: Akademia Kiado, Budapest, Hungary, p. 19–33

Reed, E. C., and Dreeszen, V. H., 1965, Revision of the classification of the Pleistocene deposits of Nebraska: Nebraska Geological Survey, Bulletin 23, 65 p.

Reed, E. C., Dreeszen, V. H., Drew, J. V., Souders, V. L., Elder, J. A., and Boellstorff, J. D., 1966, Evidence of multiple glaciation in the glacial-periglacial area of eastern Nebraska: Guidebook, 17th Annual Meeting, Midwestern Friends of the Pleistocene, University of Nebraska, Lincoln, 25 p.

Richmond, G. M., and Fullerton, D. S., 1986a, Introduction to Quaternary glaciations in the United States of America; *in*, Quaternary glaciations in the Northern Hemisphere, Sibrava, V., Bowen, D. Q., and Richmond, G. M., eds.: Quaternary Science Reviews, v. 5, p. 3–10

________, 1986b, Summation of Quaternary glaciations in the United States of America; *in*, Quaternary glaciations in the Northern Hemisphere, Sibrava, V., Bowen, D. Q., and Richmond, G. M., eds.: Quaternary Science Reviews, v. 5, p. 183–196

Rio, D., Sprovieri, R., and Thunell, R., 1991, Pliocene–lower Pleistocene chronostratigraphy—a re-evaluation of Mediterranean type sections: Geological Society of America, Bulletin, v. 103, p. 1,049–1,058

Rubey, W. W., and Bass, N. W., 1925, The geology of Russell County, Kansas: Kansas Geological Survey, Bulletin 10, 86 p.

Ruddiman, W. F., 1987, Synthesis—the ocean/ice sheet record; *in*, North America and adjacent oceans during the last deglaciation, Ruddiman, W. L., and Wright, H. E., Jr., eds.: Geological Society of America, The Geology of North America, v. K–3, p. 463–478

Ruhe, R. V., 1956, Geomorphic surfaces and the nature of soils: Soil Science, v. 82, p. 441–455

________, 1969, Quaternary landscapes in Iowa: Iowa State University Press, Ames, 255 p.

________, 1976, Stratigraphy of midcontinental loess, U.S.A.; *in*, Quaternary stratigraphy of North America, Mahaney, W. C., ed.: Dowden, Hutchinson, and Ross, Stroudsburg, Pennsylvania, p. 197–211

________, 1983, Depositional environment of late Wisconsin loess in the midcontinental United States; *in*, Late Quaternary environments of the United States—v. 1, The late Pleistocene, Porter, S. C., ed.: University of Minnesota Press, Minneapolis, p. 130–137

Ruhe, R. V., and Olson, C. G., 1980, Clay-mineral indicators of glacial and nonglacial sources of Wisconsinan loesses in southern Indiana, U.S.A.: Geoderma, v. 24 , p. 283–297

Ruhe, R. V., Hall, R. D., and Canepa, A. P., 1974, Sangamon paleosols of southwestern Indiana, USA: Geoderma, v. 12, p. 191–200

Ruhe, R. V., Miller, G. A., and Vreeken, W. J., 1971, Paleosols, loess sedimentation and soil stratigraphy; *in*, Paleopedology—origin, nature, and dating of paleosols, Yaalon, D. H., ed.: Hebrew University Press, Jerusalem, Israel, p. 41–60

Russell, W. L., 1929, Stratigraphy and structure of the Smoky Hill chalk in western Kansas: American Association of Petroleum Geologists, Bulletin, v. 13, p. 595–604

Schaetzl, R. J., 1986, The Sangamon paleosol in Brown County, Kansas: Kansas Academy of Science, Transactions, v. 89, p. 152–161

Schultz, C. B., 1968, The stratigraphic distribution of vertebrate fossils in the Quaternary eolian deposits in the midcontinent region of North America; *in*, Loess and related eolian deposits of the world, Schultz, C. B., and Frye, J. C., eds.: University of Nebraska Press, Lincoln, p. 115–138

Schultz, C. B., and Martin, L. C., 1970, Quaternary mammalian sequence in the central Great Plains; *in*, Pleistocene and Recent environments of the Central Great Plains, Dort, W., Jr., and Jones, J. K., eds.: University Press of Kansas, Lawrence, p. 341–353

Schultz, C. B., and Stout, T. M., 1945, Pleistocene loess deposits of Nebraska: American Journal of Science, v. 243, p. 231–244

________, 1948, Pleistocene mammals and terraces in the Great Plains: Geological Society of America, Bulletin, v. 59, p. 553–591

Schultz, C. B., and Tanner, L. G., 1957, Medial Pleistocene fossil vertebrate localities in Nebraska: University of Nebraska, State Museum, Bulletin, v. 4, p. 59–81

Schultz, C. B., Lueninghoener, G. C., and Frankforter, W. D., 1951, A graphic résumé of the Pleistocene of Nebraska (with notes on the fossil mammalian remains): University of Nebraska, State Museum, Bulletin, v. 3, no. 6, p. 1–41

Schumm, S. A., 1973, Geomorphic thresholds and complex response of drainage systems; *in*, Fluvial geomorphology, Morisawa, M., ed.: Publications in Geomorphology, State University of New York, Binghamton, p. 299–310

Semken, H. A., 1983, Holocene mammalian biogeography and climatic change in the eastern and central United States; *in*, Late Quaternary environments of the United States—v. 2, The Holocene, Wright, H. E., Jr., ed.: University of Minnesota Press, Minneapolis, p. 182–207

Shackleton, N. J., and Opdyke, N. D., 1973, Oxygen isotope and paleomagnetic stratigraphy of equatorial Pacific core V28–238—oxygen isotope temperatures and ice volumes on a 10^5 year and 10^6 year scale: Quaternary Research, v. 3, p. 39–55

________, 1976, Oxygen-isotope and paleomagnetic stratigraphy of Pacific core V28–239, late Pliocene to latest Pleistocene; *in*, Investigation of late Quaternary paleoceanography and paleoclimatology, Cline, R. M., and Hays, J. D., eds.: Geological Society of America, Memoir 145, p. 449–464

Shimek, B., 1909, Aftonian sands and gravels in western Iowa: Geological Society of America, Bulletin, v. 20, p. 399–408

Simonson, R. W., 1941, Studies of buried soils formed from till in Iowa: Soil Science Society of America, Proceedings, v. 6, p. 373–381

Sorensen, J. H., Johnsgard, S. J., and Wozencraft, C., 1989, Bibliography of Kansas geology, 1823–1984: Kansas Geological Survey, Bulletin 221, 418 p.

Souders, V. L., and Dreeszen, V. H., 1991, Evolution of the big bend of the Platte River, south-central Nebraska (abs.): Proceedings of the Nebraska Academy of Sciences, p. 65

Souders, V. L., and Kuzila, M. S., 1990, A report on the geology and radiocarbon ages of four superimposed horizons at a site in the Republican River valley, Franklin County, Nebraska (abs.): Proceedings of the Nebraska Academy of Sciences, p. 65

Stanley, K. O., and Wayne, W. J., 1972, Epeirogenic and climatic controls of early Pleistocene fluvial sediments in Nebraska: Geological Society of America, Bulletin, v. 83, p. 3,675–3,690.

Stullken, L. E., 1984, Hydrology of Prairie Dog Creek valley, Norton Dam to state line, north-central Kansas: U.S. Geological Survey, Water-Resources Investigation 84–4162, 49 p.

Swineford, A., and Frye, J. C., 1946, Petrographic comparison of Pliocene and Pleistocene volcanic ash from western Kansas: Kansas Geological Survey, Bulletin 64, pt. 1, 32 p.

Swineford, A., Leonard, A. B., and Frye, J. C., 1958, Petrology of the pisolitic limestone in the Great Plains: Kansas Geological Survey, Bulletin 130, pt. 2, p. 97–116

Swinehart, J. B., 1990, Wind-blown deposits; *in*, An atlas of the Sand Hills, Bleed, A., and Flowerday, C., eds.: Conservation and Survey Division, University of Nebraska, Resource Atlas 5a, p. 43–56

Tedford, R. E., Skinner, M. F., Fields, R. W., Rensberger, J. M., Whistler, D. P., Galusha, T., Taylor, B. E., Macdonald, J. R., and Webb, S. D., 1987, Faunal succession and biochronology of the Arikareean through Hemphillian interval (late Oligocene through earliest Pliocene epochs) in North America; *in*, Cenozoic mammals of North America—geochronology and biostratigraphy, Woodburne, M. O., ed.: University of California Press, Berkeley, p. 153–210

Thomasson, J. R., 1979, Late Cenozoic grasses and other angiosperms from Kansas, Nebraska, and Colorado—biostratigraphy and relationships to living taxa: Kansas Geological Survey, Bulletin 218, 68 p.

________, 1987, Late Miocene plants from northeastern Nebraska: Journal of Paleontology, v. 61, p. 1,065–1,079

________, 1990, Fossil plants from the late Miocene Ogallala Formation of central North America—possible paleoenvironmental and biostratigraphic significance; *in*, Geologic framework and regional hydrology—upper Cenozoic Blackwater Draw and Ogallala Formations, Great Plains, Gustavson, T. C., ed.: Bureau of Economic Geology, Austin, Texas, p. 99–114

Thorpe, J., Johnson, W. M., and Reed, E. C., 1951, Some post-Pliocene buried soils of central United States: Journal of Soil Science, v. 2, p. 1–22

Tien, P. L., 1968, Differentiation of Pleistocene deposits in northeastern Kansas by clay minerals: Clay and Clay Mineralogy, v. 16, p. 99–107

van Donk, J., 1976, ^{18}O record of the Atlantic Ocean for the entire Pleistocene Epoch; *in*, Investigation of late Quaternary paleoceanography and paleoclimatology, Cline, R. M., and Hays, J. D., eds.: Geological Society of America, Memoir 145, p. 147–163

Van Zant, K. L., 1979, Late glacial and postglacial pollen and plant macrofossils from Lake West Okoboji, northwestern Iowa: Quaternary Research, v. 12, p. 358–380

Voorhies, M. R., 1990, Vertebrate biostratigraphy of the Ogallala Group in Nebraska; *in*, Geologic framework and regional hydrology—upper Cenozoic Blackwater Draw and Ogallala Formations, Great Plains, Gustavson, T. C., ed.: Bureau of Economic Geology, Austin, Texas, p. 115–151

Ward, P. A., 1991, Preliminary correlations of southern High Plains border ashes; *in*, A prehistory of the Plains border region, Carter, B. J., and Ward, P. A., eds.: Guidebook, South-central Friends of the Pleistocene, Department of Agronomy, Oklahoma State University, p. 65–72

Waters, M. R., 1985, Late Quaternary alluvial stratigraphy of Whitewater Draw, Arizona—implications for regional correlation of fluvial deposits in the American Southwest: Geology, v. 13, p. 705–708

Watson, R. A., and Wright, H. E., Jr., 1980, The end of the Pleistocene—a general critique of chronostratigraphic classification: Boreas, v. 9, p. 153–163

Wayne, W. J., 1963, Pleistocene formations in Indiana: Indiana Geological Survey, Bulletin 25, 85 p.

Wayne, W. J., and Aber, J. S., 1991, High Plains and plains border sections in Nebraska, Kansas, and Oklahoma; *in*, Quaternary nonglacial geology—conterminous U.S., Morrison, R. B., ed.: Geological Society of America, Geology of North America, v. K–2, p. 462–469

Webb, T., III, Cushing, E. J., and Wright, H. E., Jr., 1983, Holocene changes in the vegetation of the Midwest; *in*, Late Quaternary environments of the United States—v. 2, The Holocene, Wright, H. E., Jr., ed.: University of Minnesota Press, Minneapolis, p. 142–165

Welch, J. E., and Hale, J. M., 1987, Pleistocene loess in Kansas—status, present problems, and future considerations; *in*, Quaternary environments of Kansas, Johnson, W. C., ed.: Kansas Geological Survey, Guidebook Series 5, p. 67–84

Wells, G. L., 1983, Late-glacial circulation over North America revealed by aeolian patterns; *in*, Variations in the global water budget, Street-Perrott, A., Beran, M., and Ratcliffe, R., eds.: Reidel Publishers, Boston, Massachusetts, p. 317–330

Wells, P. V., and Stewart, J. D., 1987, Cordilleran-boreal taiga and fauna on the central Great Plains of North America, 14,000–18,000 years ago: American Midland Naturalist, v. 118, p. 94–106

Wendland, W. M., 1982, Geomorphic responses to climatic forcing during the Holocene; *in*, Space and time in geomorphology, Thorn, C. E., ed.: Allen and Unwin Ltd., London, England, p. 355–371

Willman, H. B., and Frye, J. C., 1970, Pleistocene stratigraphy of Illinois: Illinois State Geological Survey, Bulletin 94, 204 p.

Wright, H. E., Jr., 1970, Vegetational history of the Central Plains; *in*, Pleistocene and Recent environments of the Central Great Plains, Dort, W., Jr., and Jones, J. K., eds.: University Press of Kansas, Lawrence, p. 157–172

________, 1989, The amphi-Atlantic distribution of the Younger Dryas paleoclimatic oscillation: Quaternary Science Reviews, v. 8, p. 295–306

Zakrzewski, R. J., 1988, Plio-Pleistocene rocks, Borchers Badlands, Meade County, southwestern Kansas; *in*, Centennial field guide, v. 4, Hayward, O. T., ed.: Geological Society of America, p. 69–74

________, 1990, Biostratigraphy of fossil mammals from the Ogallala (Miocene) of north-central Kansas (abs.); *in*, Geologic framework and regional hydrology—upper Cenozoic Blackwater Draw and Ogallala Formations, Great Plains, Gustavson, T. C., ed.: Bureau of Economic Geology, Austin, Texas, p. 98

Zeller, D. E., 1968, The stratigraphic succession in Kansas: Kansas Geological Survey, Bulletin 189, 81 p.

State of Kansas
Joan Finney, Governor

Board of Regents

Stanley Z. Koplik, *Executive Director*
Robert Caldwell
Rick Harman
Charles H. Hostetler
John G. Montgomery
Shirley Palmer, Chair
Frank Sabatini
Jack S. Sampson
Donald C. Slawson
Sidney Warner

Kansas Geological Survey Advisory Council

Joyce Allegrucci
Gary Baker
Tom H. Collinson, Chair
R. A. Edwards
Frank D. Gaines
David J. Heinemann
Gary Hulett
Deloyce McKee
John Prather
Richard D. Smith
William W. Hambleton, Emeritus Member
A. Scott Ritchie, KU Geology Assoc. Rep.

Kansas Geological Survey, The University of Kansas

Gene A. Budig, Ed.D., *Chancellor of the University* and *ex officio Director of the Survey*
Lee C. Gerhard, Ph.D., *State Geologist* and *Director*

Acker, Patricia M., *graphic designer, exploration services*
Adkins–Heljeson, Dana, *programming/ technical support, SURFACE III*
Adkins–Heljeson, Marla D., *editor*
Anderson, Joe M., *engineering technician*
Anderson, Neil, *geophysicist*
Baars, Donald, *petroleum research geologist*
Beene, Douglas L., *systems analyst*
Bennett, Brett C., *electrical engineer*
Berendsen, Pieter, *economic geologist/geochemist*
Berger, Winifred M., *utility worker (Wichita)*
Bohling, Geoffrey, *research assistant, mathematical geology*
Brady, Lawrence, *associate director*
Braverman, Mimi S., *assistant editor*
Brohammer, Mary, *word-processing typist, Exploration Services*
Brownrigg, Richard L., *data-systems specialist, tech. inf. services*
Buchanan, Rex, *assistant director, publications and public affairs*
Buddemeier, Robert W., *chief, geohydrology*
Butler, James J., *hydrogeologist*
Carr, Timothy, *chief, petroleum resources*
Catron, Joseph A., *general maintenance technician (Wichita)*
Charlton, John R., *scientific photographer*
Cherry, Frank, *admin. asst., geohydrology*
Collins, David R., *resource assessment, policy analysis*
Cowan, Cora E., *word-processing typist, mathematical geology*
Cox, Sharon, *personnel*
Crumet, Juanita, *clerk, business office*
Davidson, Lea Ann, *word-processing typist, petroleum research*
Davis, John C., *chief, mathematical geology*
DeGraffenreid, Jo Anne, *research assistant, mathematical geology*
Delaney, Annette, *payroll clerk*
Deputy, James O., *systems programmer*
Douglass, Debra, *executive secretary*
Doveton, John D., *mathematical geologist*
Feldman, Howard R., *post-doctoral asst./paleontologist*
Franseen, Evan K., *carbonate sedimentologist/stratigrapher*
Galle, O. Karmie, *analytical chemist*
Goddard, Diane Hoose, *associate director*
Grisafe, David A., *materials scientist*
Guy, Willard Jennings, Jr., *geologist*
Hambleton, William W., *Director emeritus*
Harff, Jan E., *visiting scientist*
Harkness, Jenna, *manager, publication sales*
Hathaway, Lawrence R., *manager, analytical services*
Healey, John M., *field hydrogeologist*
Hensiek, Renate, *graphic designer, mathematical geology*
Kaufman, Bradley, *systems analyst, SURFACE III*
Keener, Barbara, *library assistant (Wichita)*
Kleinschmidt, Melvin K., *drilling/field operations*
Knapp, Ralph W., *geophysicist*
Kraxner, Anna, *word-processing typist, geohydrology*
Kroeger, Melvin D., *GIS technician, DASC*
Macfarlane, P. Allen, *hydrogeologist*
Magnuson, Larry Mike, *analytical chemist*
Maples, Christopher, *paleontologist; chief, geologic investigations*
McCauley, James R., *geologist*
McClain, Thomas J., *manager, technical information resources*
McElwee, Carl D., *hydrologist/geophysicist*
Merriam, Daniel F., *geologist*
Mettille, Thomas, *cartographic technician, tech. info. services*
Miller, Richard D., *chief, exploration services*
Mitchell, James E., *hydrologic data analyst*
Moore, Patricia, *computer-operations supervisor*
Newell, K. David, *petroleum geologist/stratigrapher*
Olea, Ricardo, *petroleum engineer*
Parham, Kerry D., *geologist*
Ross, Charles G., *systems analyst, technical information services*
Ross, Jorgina, *production manager, automated cartography*
Saile, Donna, *administrative secretary, technical information services*
Sampson, Robert, *systems designer, mathematical geology*
Schoneweis, Mark, *graphic designer, geohydrology*
Sheldon, Kathleen, *chief of operations*
Sims, Jennifer, *graphic designer, editing*
Skelton, Lawrence H., *geologist/manager (Wichita)*
Sophocleous, Marios, *hydrogeologist*
Sorensen, Janice H., *librarian/archivist*
Spitz, Owen T., *manager, computer services*
Taylor, Lois, *accountant*
Terry, Fred, *small-systems specialist*
Townsend, Margaret A., *hydrogeologist*
Watney, W. Lynn, *special assistant to Director, Energy Research Center (ERC) liaison*
Waugh, Truman C., *analytical chemist*
Whittemore, Donald O., *environmental geochemist*
Wilson, Frank W., *geologist*
Wong, Jan-Chung, *systems analyst*
Woods, Cynthia A., *clerk*
Yewell, Andrea, *secretary*
Young, David P., *hydrologist*

William C. Johnson SURFICIAL GEOLOGY AND STRATIGRAPHY OF PHILLIPS COUNTY, KANSAS Kansas Geological Survey 1993

Kansas Geological Survey
The University of Kansas
1930 Constant Avenue
Campus West
Lawrence, Kansas 66047