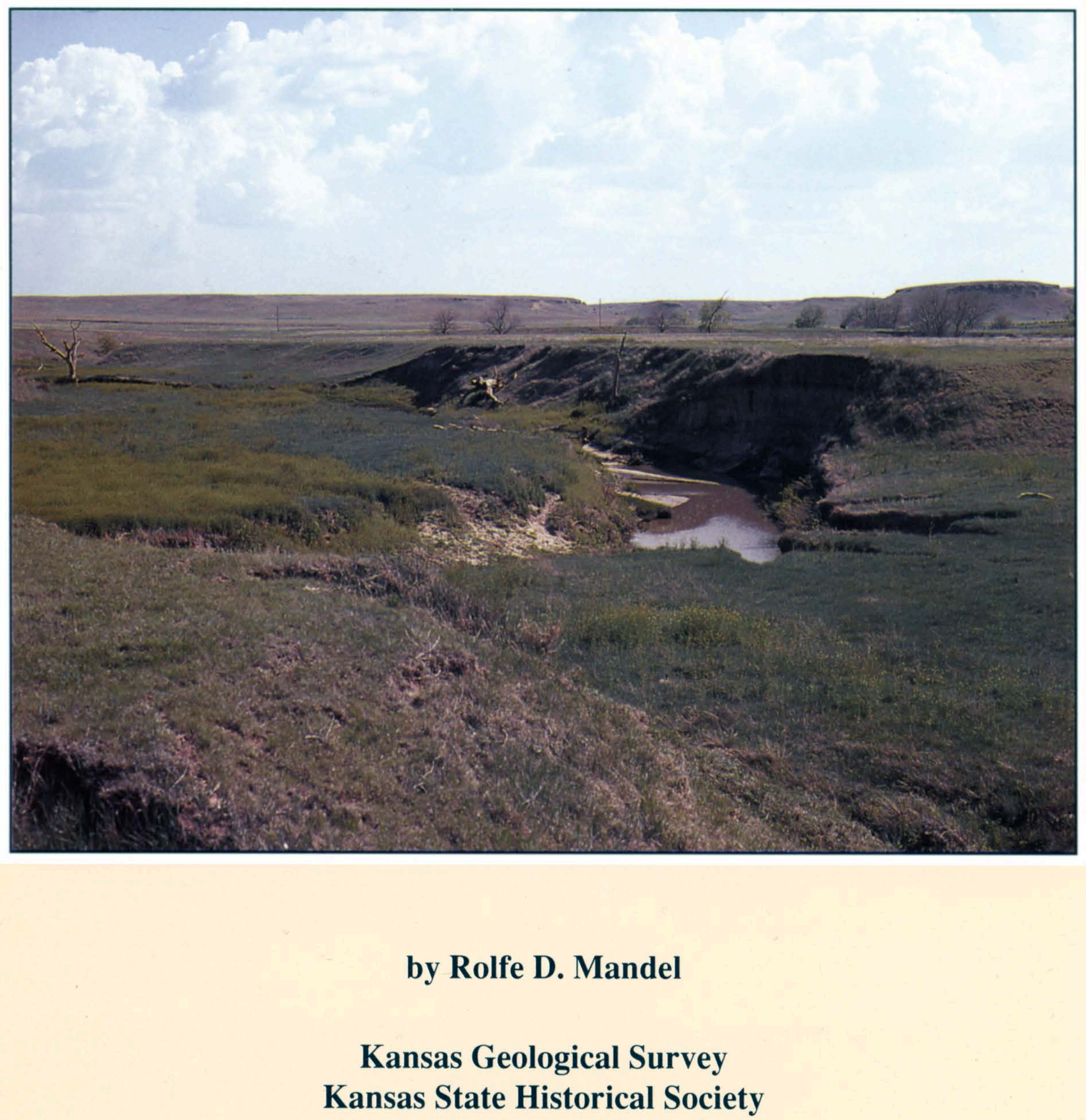
Holocene landscape evolution in the Pawnee River valley, southwestern Kansas



by Rolfe D. Mandel

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Contents

Tables

Figures

Abstract A basinwide study of terraces, Holocene alluvial fills, and soils was conducted in the valley of the Pawnee River, a tributary of the Arkansas River that drains nearly 4,000 km^2 in southwestern Kansas. By focusing on all levels of the drainage hierarchy, I was able to evaluate the similarities among drainage elements composing the basin and the differences in stratigraphy and chronology that occur in various parts of the basin. This information was used to infer causes of Holocene erosion, alluviation, and landscape stability and to define their temporal and spatial relationships in the Pawnee River basin.

Only one terrace (T-1) is present in the upper and middle reaches of small streams (less than fifth-order), but remnants of a slightly higher terrace (T-2) occur in lower reaches of fourth-order streams near their confluences with the Pawnee River. The bulk of the valley fill underlying the T-1 terrace aggraded between 2,800 and 1,000 yr B.P. Most of the alluvium beneath the T-2 terrace accumulated between 10,000 and 5,000 yr B.P.

Three terraces, numbered consecutively upward from T-1, are present in the valley bottoms of large streams (greater than fourth-order). The modern floodplain (T-0) is the lowest surface; the T-2 and T-3 surfaces are Pleistocene terraces, and the T-1 terrace is the surface of Holocene valley fill. Radiocarbon assays suggest that the upper 8–9 m (26–30 ft) of the T-1 fill aggraded between ca. 10,500 and 1,600 yr B.P. Aggradation of the adjacent T-0 fill was underway by 1,000–500 yr B.P.

Radiocarbon ages determined on humates from multiple buried paleosols in valley fill of large streams suggest that the period 10,000–5,000 yr B.P. was punctuated by several episodes of floodplain stability and soil development. However, Holocene valley fills in the Pawnee River basin are devoid of any evidence of soil development between 7,000 and 5,000 yr B.P. Radiocarbon assays suggest that soil development was underway by at least 5,000 yr B.P. on floodplains in large valleys. Two discrete periods of paleosol development were detected in large valleys: one at 2,750–2,600 yr B.P. and another at 2,000–1,600 yr B.P. The older of these two episodes partially coincides with the soil-forming period dated to 2,800–2,000 yr B.P. in small valleys. However, the most recent episode of paleosol development in large valleys (2,000–1,600 yr B.P.) precedes the beginning of the major soil-forming period dated to 1,350–1,000 yr B.P. in small valleys. Hence episodes of late Holocene deposition appear to have been time transgressive throughout the entire extent of the drainage network.

Radiocarbon assays indicate that Holocene erosion and alluviation as well as periods of net transport and storage of sediment were diachronous throughout the Pawnee River basin but were roughly synchronous in similar-sized streams of the drainage network. Early, middle, and late Holocene alluvium is stored in valley fill of large streams, but only late Holocene deposits are present in valley bottoms of small streams.

Although valley erosion and alluviation may have several causes, major bioclimatic changes explain the pattern of Holocene fluvial activity detected in the stratigraphic record in the Pawnee River basin. Reduced vegetative cover combined with infrequent but intense rainfalls during the warm Altithermal (8,000–5,000 yr B.P.) favored erosion and net transport of sediment in small valleys. As mean annual precipitation increased during the late Holocene, vegetation recovered and erosion rates decreased, promoting sediment storage in small valleys.

The Holocene record of entrenchment, alluviation, and soil formation in the Pawnee River valley generally agrees with alluvial chronologies for valleys elsewhere in the Great Plains and Midwest. Detailed correlation between river basins cannot be done at this time, however, because of a lack of sufficient detail from adjacent areas.

Introduction

This study examines late Quaternary landscapes in the Pawnee River basin of southwestern Kansas (fig. 1). Before this investigation, limited geomorphologic research had been conducted in the Pawnee River system, but no systematic studies of late Quaternary landscapes had been undertaken in any drainage basin in southwestern Kansas. Hence little was known about the temporal and spatial relationships of Holocene erosion, alluviation, and landscape stability in the region. The lack of well-dated basinwide alluvial stratigraphic studies precluded evaluation of the driving forces behind landscape evolution in southwestern Kansas. By combining intensive and extensive absolute dating with a basinwide alluvial stratigraphic investigation, I have determined some of the controls and behavior of the Pawnee River fluvial system during the Holocene.

Goals and objectives of the research

The goals of this study are to infer causes of Holocene erosion, alluviation, and landscape stability and to define their temporal and spatial relationships in the Pawnee River drainage system. The three specific objectives of the research are (1) to determine the number of alluvial terraces in the valleys of the Pawnee River and its tributaries, (2) to establish the relative and absolute ages of terrace fills, and (3) to construct an alluvial chronology for the Pawnee River system and then compare it with other known Holocene alluvial sequences in the Midwest.

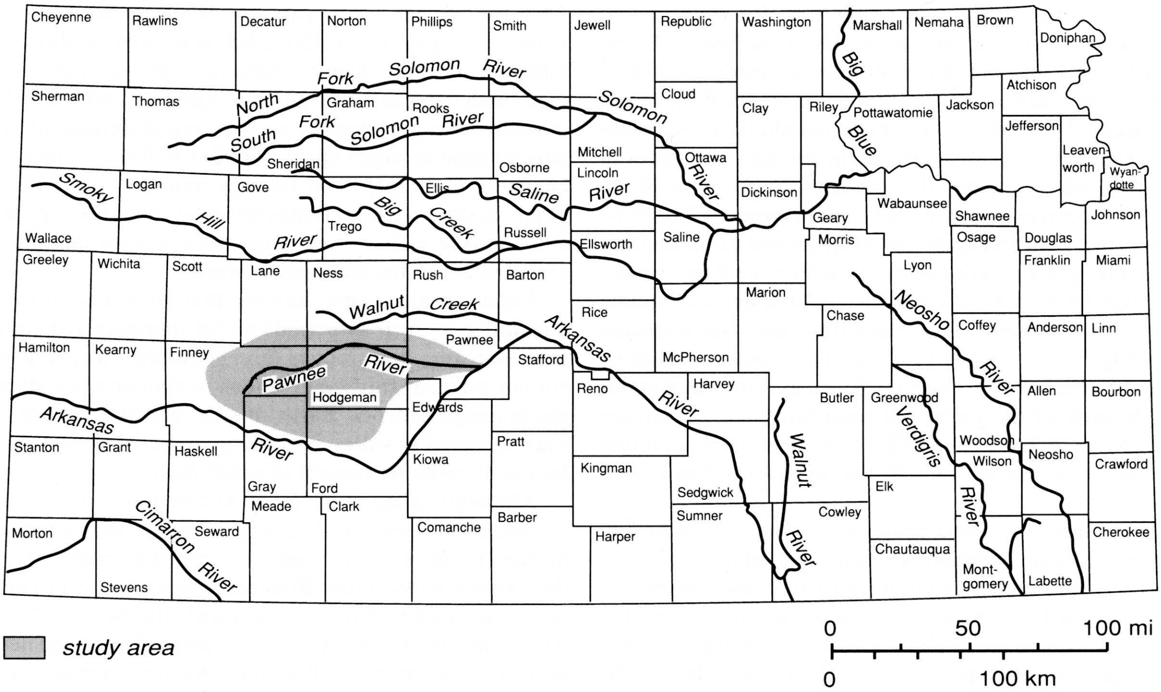

Figure 1. Location of Pawnee River basin (adapted from Kansas Geological Survey base map).

Significance of the research

This study is significant for several reasons. First, it contributes to our understanding of Holocene fluvial geomorphology and alluvial stratigraphy in the Midwest. Although a number of studies have provided information about the Pliocene and Pleistocene stratigraphy of southwestern Kansas [e.g., Smith (1940), Frye and Hibbard (1941), Frye et al. (1943), Frye (1945, 1948), and Frye and Leonard (1952)], little is known about Holocene alluvial landscapes in the region. Second, this study indirectly provides new information about rates of soil genesis in semiarid to dry subhumid environments. The time required for diagnostic horizons to form in soils of the Midwest is not clearly understood (Guccione, 1982; Birkeland, 1984, p. 205–209). This study provides extensive time control for alluvial fills and buried soils in the Pawnee River valley, permitting an approximation of pedogenic rates for modern and ancient alluvial soils. Finally, the research is important to understanding the archeology of the Midwest. Locating prehistoric cultural material in a rapidly evolving alluvial landscape is determined by the ability to analyze and understand the landscape and the processes that created it. By focusing on the extent and timing of erosion, alluviation, and landscape stability in the Pawnee River drainage system, this study should facilitate the discovery of cultural deposits.

Origin of the research problem

The problem of identifying causal factors of erosion, alluviation, and landscape stability in stream systems has been debated by Quaternary scientists since the nineteenth century. Before 1890 the development of nearly all alluvial terraces was attributed to movements of the Earth's crust [e.g., Dana (1864), Foster and Topley (1865), Lyell (1865), Home (1875), Whitaker (1880), and Hull (1878)]. Soon afterward, alluvial terraces were considered products of climatic variations (Gilbert, 1900; Johnson, 1901; Davis, 1902). Davis (1902), for example, suggested that a change of climate from humid to arid would lead to aggradation and steepening of stream gradients and that a change of climate from arid to humid would lead to trenching and a reduction in stream gradients. Later, Huntington (1914, p. 32) hypothesized that valley alluviation in arid and semiarid regions occurred during dry episodes, when vegetative cover was minimal and sediment yields were high. He suggested that a shift to a wetter climate would improve vegetative cover, reduce sediment load, and cause channel entrenchment. On the other hand, Bryan (1928) argued that channel entrenchment in the Southwest was associated with episodes of drought. He suggested that sparse vegetative cover during dry periods initiated channel entrenchment, which migrated upstream. Summaries of subsequent refinements of these hypotheses have been presented by Antevs (1952), Tuan (1966), and Cooke and Reeves (1976).

Hypotheses favoring climate as the primary cause of aggradation and degradation in river systems persist in recent literature. According to Knox (1983, p. 38), alluvial chronologies indicate that climatic changes and concomitant vegetational changes have contributed significantly to widespread synchronous episodes of aggradation and degradation. Although many researchers have focused on the possible contributions of climate as a cause of aggradation or degradation in river systems [e.g., Baker and Penteado-Orellana (1977), Knox (1972), Hall (1977a), Knox et al. (1981), Brakenridge (1981), and May (1986)], there is no consensus on the cause-and-effect relationships involved (Leopold, 1976; Patton and Schumm, 1981).

Schumm (1977, p. 74–81) pointed out that aggradation and degradation may also be related to a complex response of the fluvial system as thresholds intrinsic to the system are crossed. Patton and Schumm (1981) suggested that channel cutting and filling are a natural sequence of events by which sediment is episodically transported out of a drainage system. They concluded that, although major components of an alluvial chronology reflect major climatic changes, details of a chronology may reflect only episodic cut-and-fill processes.

Major valley fill sequences have not been absolutely dated in sufficient detail to resolve the controversy over causal factors of erosion, alluviation, and landscape stability. As more detailed alluvial stratigraphic studies are reported, it becomes obvious that the record is complex (Knox, 1983, figs. 3–9). This complexity may be a result of both the external and internal controls of the fluvial system.

Alluvial stratigraphy has been studied at a number of localities in the Midwest; some studies focused on specific sites (Ahler, 1976; Schmits, 1980), some on valley reaches (Bettis and Benn, 1984; Mandel, 1988a,b; Mandel et al., 1985), and others on entire drainage basins (Brice, 1964; Thompson and Bettis, 1980; Bettis and Hoyer, 1986; Bettis and Littke, 1987). Many of these studies have yielded stratigraphic information that may be used to reconstruct Holocene alluvial chronologies. Episodes of fluvial activity that produced terrace systems and alluvial fans in midwestern stream valleys are outlined in fig. 2.

Several observations can be made from examination of fig. 2. Although there is not an episode-to-episode correlation between any of the valleys, a general pattern is evident. Some valleys show major changes in fluvial activity approximately 10,500–10,000, 8,500–7,500, 4,500–3,000, 2,000–1,500, and 1,000–500 years ago. These ages correspond roughly to the end of the Late Glacial episode, the onset of the Atlantic episode, the end of the Sub-Boreal episode, the beginning of the Scandic episode, and the end of the Neo-Atlantic episode, respectively [see Bryson et al. (1970)]. In many cases it is apparent that different types of fluvial activity were occurring at the same time at different locations. For example, stream entrenchment occurred in the Des Moines valley of central Iowa between 10,000 and 8,000 yr B.P. (Bettis and Hoyer, 1986) while alluviation was taking place in the Perche and Hinkson river valleys of south-central Missouri (Mandel et al., 1985). In other cases similar geomorphic processes were underway at the same time in different drainage systems. For example, major alluvial fan development appears to be an early and middle Holocene phenomenon across the entire Midwest (Bettis et al., 1984). Alluvial fans stabilized between 3,000 and 2,000 yr B.P., and soils developed on their surfaces during the late Holocene. Geomorphic evidence from terrace fills also indicates a shift from aggradation to landscape stability and soil formation at 3,000–2,000 yr B.P. in the Midwest (Schmits, 1980; Artz, 1983, 1985; Mandel, 1985; Mandel et al., 1985; Johnson and Martin, 1987).

Detailed geomorphic research in portions of the Midwest indicates exceptions to these overall patterns of fluvial activity. The timing of a specific downcutting or alluviation episode may not have been the same in all portions of a drainage network. Likewise, certain types of deposition or erosional activity may have been concentrated in specific portions of a drainage system (Bettis and Benn, 1984). For example, in central and western Iowa alluvial fans were developing at the mouths of tributaries in major river valleys while erosion was occurring in the tributary valleys (Thompson and Bettis, 1980; Bettis and Hoyer, 1986). Deposits dating from the early and middle Holocene (8,500–4,500 yr B.P.) are found in alluvial fans of central Iowa, but middle Holocene deposits are not present in the small tributary valleys that were the sediment sources for the fans. The absence of middle Holocene alluvial deposits in tributary valleys may be due to high erosion rates and large sediment yields in these small drainage basins during that period.

Despite variations in the timing and nature of depositional processes, it is evident that the Midwest witnessed rough synchroneity of fluvial events during the Holocene. Many authors [e.g., Walker (1966), Knox (1972, 1976, 1985), Baker and Penteado-Orellana (1977), Brakenridge (1981), and Wendland (1982)] have suggested that climatic change is the underlying cause of the episodes of fluvial activity that produced the terrace systems in the region. There is no question that major climatic changes have affected erosional and depositional events, but examination of Holocene alluvial chronologies does not support the hypothesis that each depositional and erosional event occurred in response to one simultaneous external change, such as climate. Also, as noted in the previous discussion, the number, magnitude, and duration of erosional and depositional events varied not only

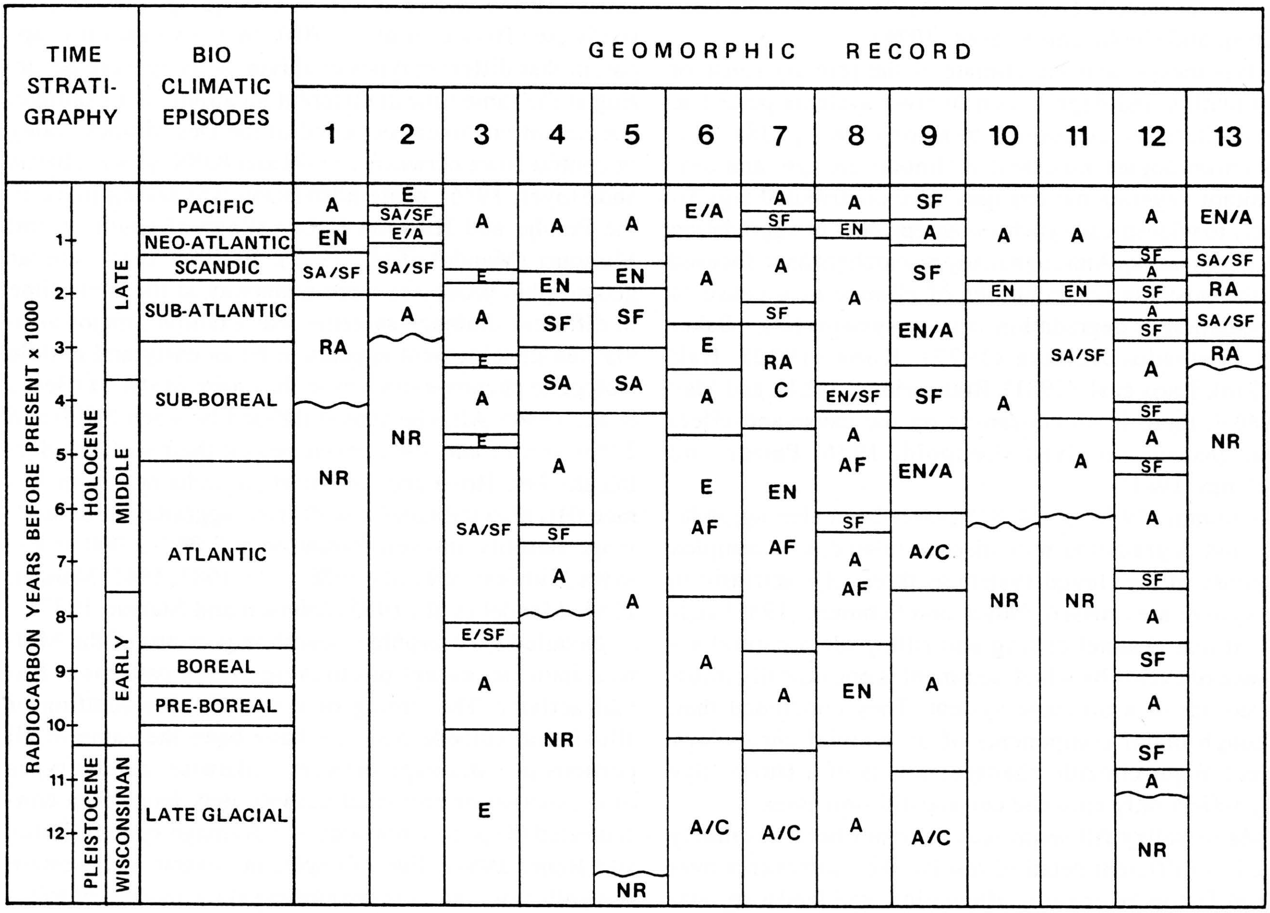

Figure 2. Alluvial episodes in Midwestern stream systems during the Holocene and late Pleistocene. A, alluviation; SA, slow alluviation; FA, fast alluviation; EN, entrenchment; E, erosion; AF, alluvial fan development; C, colluviation; SF, soil formation. (1) Northeastern Oklahoma, small valleys (Artz, 1985, 1988); (2) southwestern Oklahoma, small valleys (Ferring, 1986); (3) central Nebraska, large valley (May, 1986); (4) northwestern Missouri, large valley (Mandel, 1985); (5) north-central Missouri, large valley (Mandel et al., 1985); (6) west-central Missouri, large valley (Brakenridge, 1981); (7) western Iowa, small valleys (Thompson and Bettis, 1980); (8) central Iowa, large valley (Bettis and Hoyer, 1986); (9) southwestern Wisconsin, large valleys (Knox et al., 1981); (10) northeastern Kansas, large valley (Schmits, 1980); (11) south-central Kansas, large valley (Artz, 1983); (12) eastern Kansas, large valley (Johnson and Martin, 1987); (13) southwestern Kansas, small valleys (Mandel, 1988a).

from valley to valley in the Midwest but also within the same valleys. Thus fluvial events were not in phase everywhere, and it is apparent that some erosional and depositional episodes did not occur in response to a single external control. Part of the complexity of the midwestern fluvial record may be the consequence of tectonism, base-level changes, vegetation disturbance, or simply a valley gradient exceeding a threshold value (Schumm, 1977, p. 77–84, 100–104). Furthermore, any one of these extrinsic or intrinsic changes in a drainage network can trigger a complex response, such as a sequence of incision and alluviation, then modest incision downstream (Schumm, 1977, p. 74–77). Incision, therefore, may be episodic in response to a single change external to the fluvial system (Womack and Schumm, 1977).

To better understand stream response to intrinsic and extrinsic variables and the relationship with alluvial stratigraphy, one must carefully examine alluvial deposits and buried soils and radiocarbon-date them throughout the entire extent of drainage basins. Although some

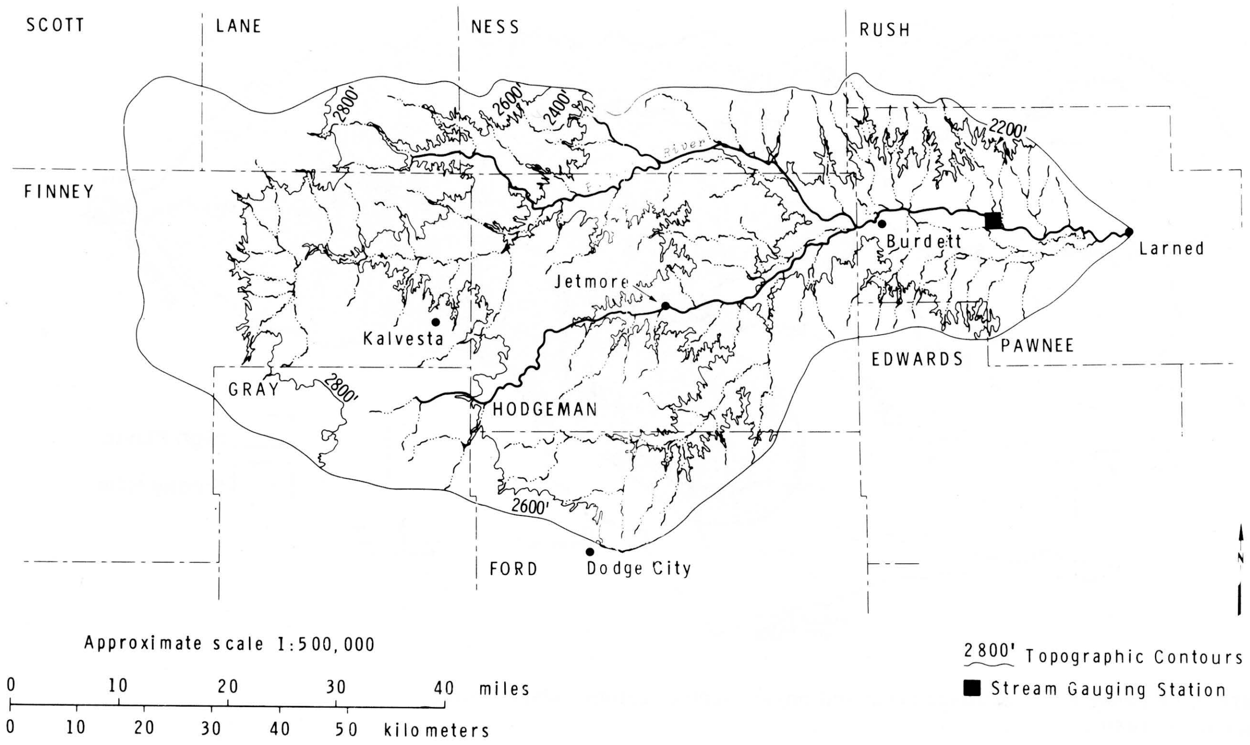

Figure 3. Pawnee River basin and county boundaries and relief [from Sophocleous (1980)].

studies have covered entire basins [e.g., Thompson and Bettis (1980), Bettis and Littke (1987), and Mandel et al. (1991)], most studies have focused only on large valleys *or* small valleys [e.g., Brice (1964), Brakenridge (1981), and Hall (1982)]. The latter approach precludes an evaluation of both the linkages among various drainage elements composing a basin and the differences in stratigraphy and chronology that might be found in various parts of a basin. As Johnson and Martin (1987) pointed out, basinwide data are needed before the response of stream systems can be understood to the point where extrinsic and intrinsic parameters and time-transgressive elements can be sorted out. Toward this end, in the present study I focus on all levels of the Pawnee River drainage hierarchy, a large basin with many tributaries and extending from semiarid to dry subhumid environments.

Study area

Selection of the study area

The Pawnee River valley of southwestern Kansas was chosen for study primarily because it lies on a precipitation gradient from subhumid central Kansas to semiarid extreme western Kansas. This is important because climatic changes are most easily detected along climatic gradients (Birkeland, 1984, p. 305) and because changes between subhumid and semiarid climates produce great variability in runoff and sediment yield from hill slopes (Langbein and Schumm, 1958; Knox, 1972, 1983). The Pawnee River also was selected for study because of the numerous streambank exposures throughout the upper and middle reaches of the drainage basin. Many of these exposures provide opportunities to examine alluvial stratigraphic sequences to depths exceeding 6 m (20 ft).

Location and physiography

The study area includes the Pawnee River basin in Edwards, Finney, Gray, Hodgeman, Ford, Ness, Lane, Pawnee, Rush, and Scott counties in southwestern Kansas (fig. 3). The sites actually investigated were confined

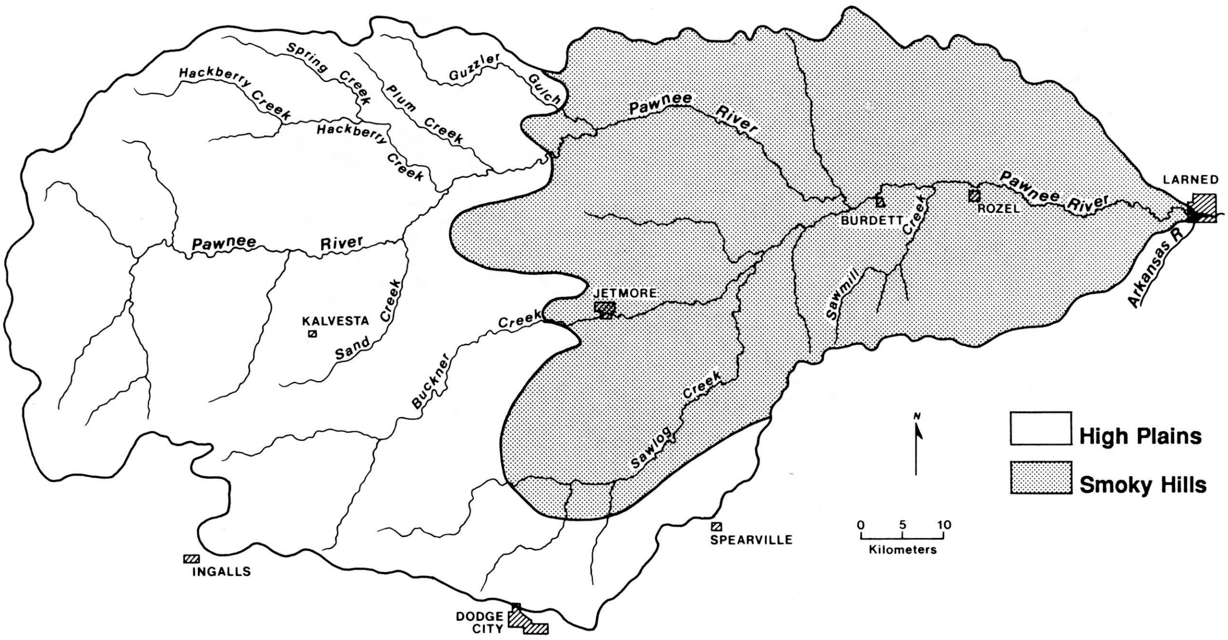

Figure 4. Pawnee River drainage basin and physiographic regions [adapted from Schoewe (1949)].

to floodplains and terraces in valley bottoms of the Pawnee River and its tributaries.

The Pawnee River originates in the High Plains section of the Great Plains physiographic province (Fenneman, 1931) (fig. 4). The river flows eastward through the extreme southwestern portion of the Smoky Hills physiographic subprovince before it joins the Arkansas River.

In the headwater area of the Pawnee River the topography of the High Plains generally is flat. The High Plains surface gradually slopes eastward at a rate of about 1.5 m/km (8 ft/mi) (Frye and Leonard, 1952, p. 201). Shallow, undrained depressions, with diameters ranging from a few meters to several kilometers, are scattered across upland areas of the High Plains (Frye, 1950). Most of these depressions are less than 3 m (10 ft) deep, although some larger ones have depths of 15–20 m (49–66 ft).

The Pawnee River valley is 1–2 km (0.6–1.2 mi) wide, and the level of the floodplain is 20–30 m (66–98 ft) below the High Plains surface in the extreme western portion of the drainage system. However, the valley becomes much wider and deeper along the eastern margin of the High Plains. Sections of the valley bottom in Ness and Hodgeman counties are as great as 6.5 km (10 mi) wide, and the floodplain is 40–60 m (130–200 ft) below the upland surface.

Because the major drainage of the area is toward the east, the stream divides trend and slope eastward. The southern flanks of the divides slope gently to the Pawnee River and its major tributaries, but the northern flanks have short, steep slopes. The Pawnee River flows through a deep, wide valley as it crosses the Smoky Hills. The valley is flanked by pediments (Frye and Leonard, 1952, p. 203), and erosion of the Niobrara Chalk has produced high, flat-topped buttes and mesas in some locations. There is as much as 75 m (250 ft) of relief in this portion of the drainage basin.

As the Pawnee River enters the Arkansas River valley, the landscape becomes an undulating plain with little relief. Thick deposits of alluvial sands and gravels underlie the broad valley floor of the Arkansas River. In some areas winds have swept the sands into low rolling dunes (Frye and Leonard, 1952, p. 141; Merriam, 1963, p. 164).

Hydrology

The Pawnee River is a long, fairly wide west-east-trending drainage system (fig. 5). The Pawnee River and its tributaries drain an area of approximately 3,975 km^2 (1,535 mi^2) into the Arkansas River. Principal tributaries of the Pawnee River are Hackberry, Buckner, and Sawlog creeks (fig. 5).

The discharge of the Pawnee River has been measured by the U.S. Geological Survey near Burdett and Rozel, Kansas, since October 1, 1981, and April 24, 1924, respectively. The average discharge of the Pawnee River for an eight-year period (1981–1989) near Burdett was

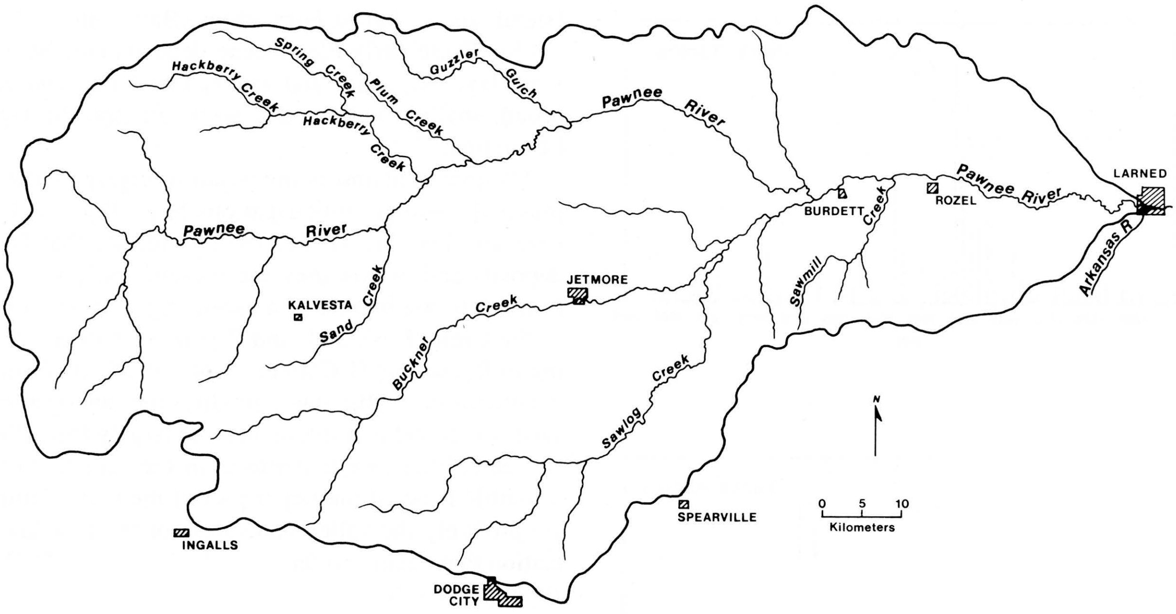

Figure 5. Pawnee River drainage basin and major tributaries.

3.6 cubic feet per second (cfs) (fig. 6); the maximum discharge for this period of record was 1,550 cfs on July 6, 1987 (U.S. Geological Survey, 1990). No flow was recorded for most days at the Burdett gaging station. The average discharge of the Pawnee River for a 61-year period (1928–1989) near Rozel was 68.9 cfs (fig. 6); the maximum discharge for this period of record was 16,300 cfs on July 28, 1958 (U.S. Geological Survey, 1990). The Rozel gaging station recorded lengthy periods of no stream flow for most years.

Residents along the middle and lower reaches of the Pawnee River reported that, before the development of pump irrigation in the 1930's, the river flowed continuously. Subsequently, wells along the Pawnee River valley have lowered the water table of the alluvial aquifer below the river bed. Hence water moves from the stream to the aquifer during periods of streamflow resulting from precipitation (Jenkins and Pabst, 1977). In addition, pumping along the valley intercepts ground water that would have moved toward the stream, thereby resulting in depletion of base flow. The discharge of the Pawnee River also has been reduced by surface-water diversions for irrigation and by the construction of erosion-control dams across many small tributaries.

Geology

Southwestern Kansas, including the area of the Pawnee River drainage system, is located on a platformlike extension of a large craton that forms the Central Stable Region of North America (fig. 7). This situation has persisted since the end of the Precambrian, and only a thin mantle of sedimentary rock covers the basement complex (Merriam, 1963, p. 179). The Precambrian basement complex actually is a buried extension of the Canadian Shield (Eardley, 1951).

The Pawnee River drainage system is within the Western Kansas basin, which is a major structural feature of the central Great Plains (fig. 8). This basin is approximately 160 km (100 mi) wide and 350 km (220 mi) long and extends into southern Nebraska. The Western Kansas basin is a broad syncline that formed during the Mesozoic in the area of the Hugoton embayment (Merriam, 1963, p. 183). The downwarp plunges gently northward between the area of the Central Kansas uplift, the Cambridge arch to the east, and the Las Animas arch to the west. Merriam (1963, p. 183) suggested that the basin was a result of Cretaceous tilting to the northwest into the Denver basin in eastern Colorado and southwestern Nebraska.

The surface bedrock in the study area is sedimentary in origin, primarily consisting of limestone, chalk, shale, and sandstone. All these surface rocks are Cretaceous in age, and they are exposed only in outcrops along major stream valleys. Rocks of Early Cretaceous age crop out in the eastern and southeastern portions of the Pawnee River basin. The Lower Cretaceous Series is composed of the Cheyenne Sandstone, the Kiowa Shale, and the Dakota Formation (fig. 9). These formations largely consist of interbedded shales, siltstones, mudstones, and sandstones (Merriam, 1963).

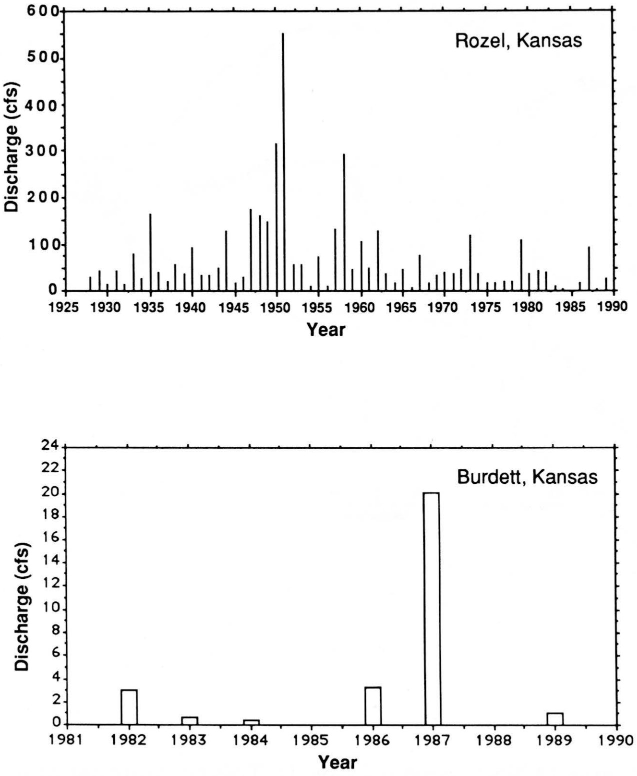

Figure 6. Hydrographs for the Pawnee River at Rozel and Burdett, Kansas (U.S. Geological Survey, 1990).

The Upper Cretaceous Series in southwestern Kansas primarily consists of marine shales and limestones (Merriam, 1963). The formations in this series include the Graneros Shale, the Greenhorn Limestone, the Carlile Shale, and the Niobrara Chalk (fig. 9). These formations crop out in stream valleys throughout the study area (fig. 10).

The surface bedrock in the High Plains section of the study area is mantled by the Pliocene-age Ogallala Formation at many localities (fig. 10). The Ogallala Formation ranges from several centimeters to more than 300 m (980 ft) in thickness (Gutentag et al., 1981). This formation consists of alluvial gravel, sand, silt, and clay and is largely unconsolidated. However, the Ogallala is cemented by calcium carbonate into "mortar beds" at some localities (Frye et al., 1956). The sediment making up the Ogallala deposits was derived from erosion of older rocks to the west, chiefly from the flanks of the Rocky Mountains, and of local bedrock (Frye and Leonard, 1952, p. 181). Clasts primarily consist of feldspar, quartz, granite, and fragments of other igneous and metamorphic rocks.

In some areas of the Pawnee River basin, especially in Ness and Hodgeman counties, the Ogallala Formation is mantled by deposits of the Holdrege, Fullerton, Grand Island, and/or Sappa Formations (Bayne and O'Conner, 1968). These early Pleistocene deposits consist of alluvial clay, silt, sand, and gravel that filled and capped broad, shallow valleys that were cut into the Ogallala Formation.

My own field observations and stratigraphic data from previous geologic investigations [e.g., Frye (1945) and Frye and Leonard (1951, 1952)] indicate that Ogallala deposits and, where they are present, early Pleistocene formations are mantled (in ascending order) by deposits of the Crete, Loveland, and Peoria formations. According to Bayne and O'Conner (1968), the Crete Formation is composed of Illinoian-age silt, sand, and gravel. The sand and gravel is alluvium derived largely from Pliocene and early Pleistocene deposits in the region. Silts that resemble loess in the upper part of the Crete Formation are probably the valley equivalent of the Loveland Formation that occurs on the uplands (Bayne and O'Conner, 1968, p. 66–67).

The Loveland Formation in southwestern Kansas consists of yellowish-brown Illinoian-age loess with minor amounts of alluvium (Bayne and O'Conner, 1968). The texture of the loess ranges from silt loam to very fine sandy loam, and it generally is calcareous. There is a strong brown to reddish-yellow paleosol developed at the top of the Loveland Formation. Frye and Leonard (1951; 1952, p. 119) considered this paleosol a Sangamon soil. The paleosol is truncated down to or into the B horizon. Evidence of truncation is the absence of an A horizon in all sections and a concentration of fine, rounded quartz pebbles at the top of the paleo–B horizon at some localities (Gamble, 1988).

The Peoria formation mantles the truncated paleosol at the top of the Loveland Formation or occurs directly above Cretaceous bedrock, Tertiary deposits, or early Pleistocene deposits. The Peoria formation is composed of brown to pale-brown Wisconsinan-age loess (Bayne and O'Conner, 1968). The texture of the Peoria in the study area generally ranges from loam to light silty clay loam, and it tends to become gritty in its lower part (Gamble, 1988). The Peoria loess is highly calcareous and often contains many soft calcium carbonate concretions. Modern surface soils are developed in the upper part of the Peoria formation.

Large volumes of Quaternary alluvium are stored in valley bottoms of the Pawnee River and its major tributaries (Sophocleous, 1980). Valley cross sections prepared by Fishel (1952) indicate that alluvial fill in the lower two-thirds of the drainage system is as thick as 50 m (164 ft) in some areas. The large volume of alluvium in the main valley of the Pawnee River also is indicated by the great saturated thickness of the alluvial aquifer (fig. 11). Little is known, however, about the absolute age of the Quaternary deposits composing the valley fill of the Pawnee River.

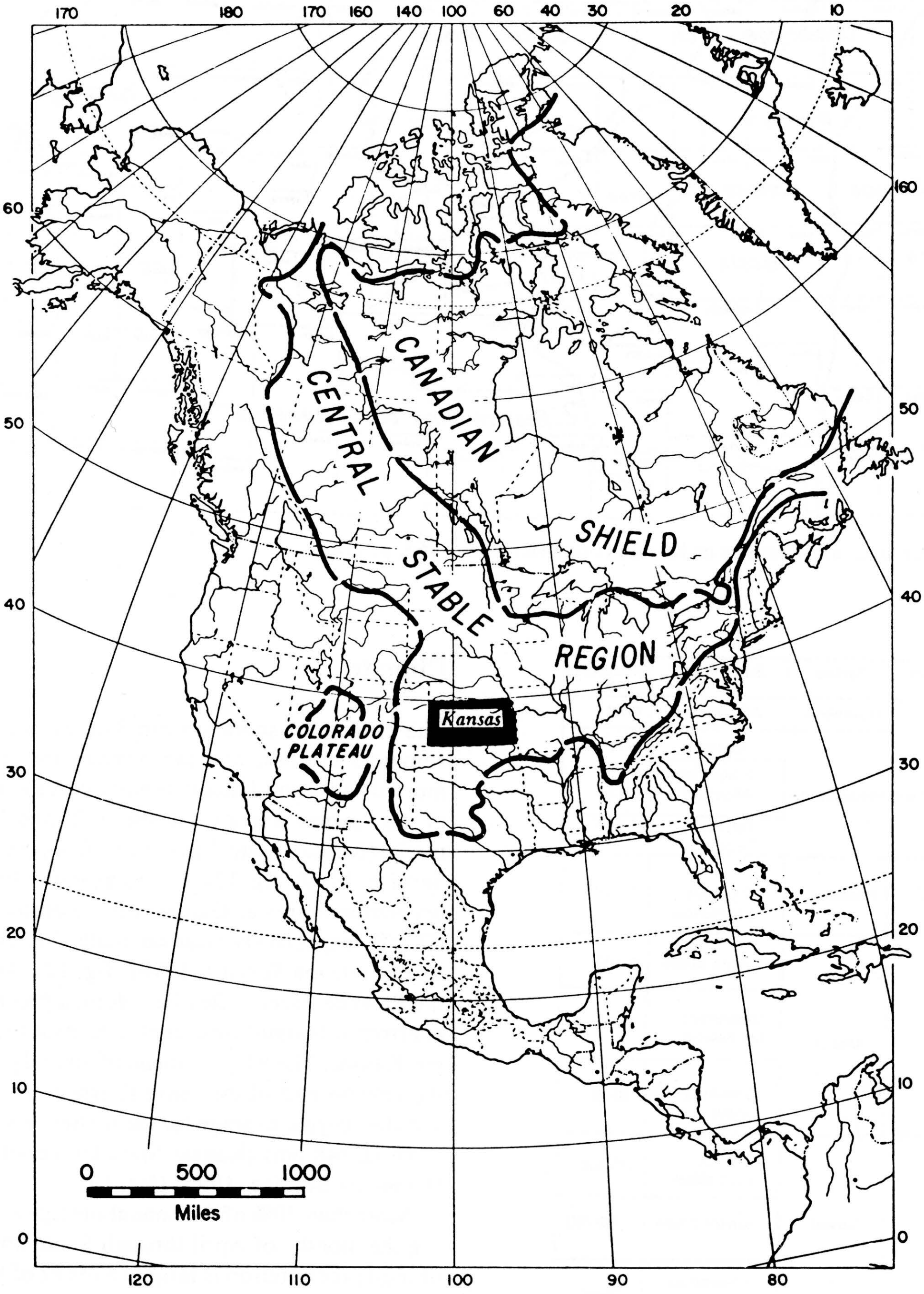

Figure 7. Relationship of Kansas to the Canadian Shield and Central Stable Region [from Merriam (1963, p. 14)].

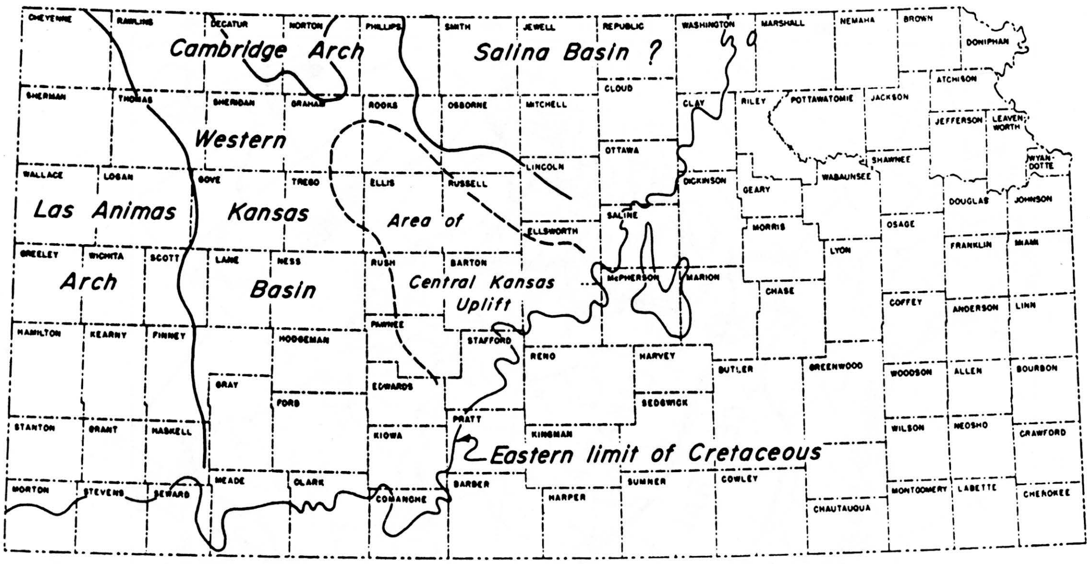

Figure 8. Major structural features of Kansas [from Merriam (1963, p. 178)].

System	Series	Subdivision	Thickness (ft)
Quaternary	Holocene	Alluvium	0-60
	Pleistocene	Loess	0-10
		Floodplain Alluvium	0-135
		Terrace Deposits	0-150
Tertiary	Pliocene	Ogallala Formation	0-100
Cretaceous	Upper	Carlile Shale	0-100
		Greenhorn Limestone	0-125
		Graneros Shale	20-36
	Lower	Dakota Formation	20-300
		Kiowa Shale	100-200
		Cheyenne Sandstone	15-50

Figure 9. Geologic column for southwestern Kansas [adapted from Sophocleous (1980)].

Climate

The climate of southwestern Kansas is continental; the summers are hot, and the winters are cold. The mean monthly July and January temperatures at the eastern end of the Pawnee River basin are 80.2° and 30.4°F, respectively (Kansas State University, Cooperative Extension Service, 1990) (fig. 12). The mean monthly July and January temperatures at Garden City, Kansas, are 80.0° and 27.5°F, respectively (Kansas State University, Cooperative Extension Service, 1990) (fig. 12). As noted earlier, the Pawnee River valley lies along a precipitation gradient from subhumid west-central Kansas to semiarid western Kansas. The 81-year mean of annual precipitation for the eastern end of the basin (Larned) is 23 in. (60 cm), and the 40-year average for the western end (Garden City) is 18 in. (48 cm) (Kansas State University, Cooperative Extension Service, 1990) (fig, 13) .

More than 70% of the annual precipitation occurs during the months of April through September. This period of high precipitation is largely a result of frontal activity. Maritime polar (mP) and continental polar (cP) air masses that flow into southwestern Kansas during late spring and early summer often converge with warm, moist maritime tropical (mT) air flowing north from the Gulf of Mexico. The overrunning of mP and cP air by warmer mT air often produces intense rainfalls of short duration along the zone of convergence. Convectional thunderstorms during the late summer months also can produce heavy rainfalls.

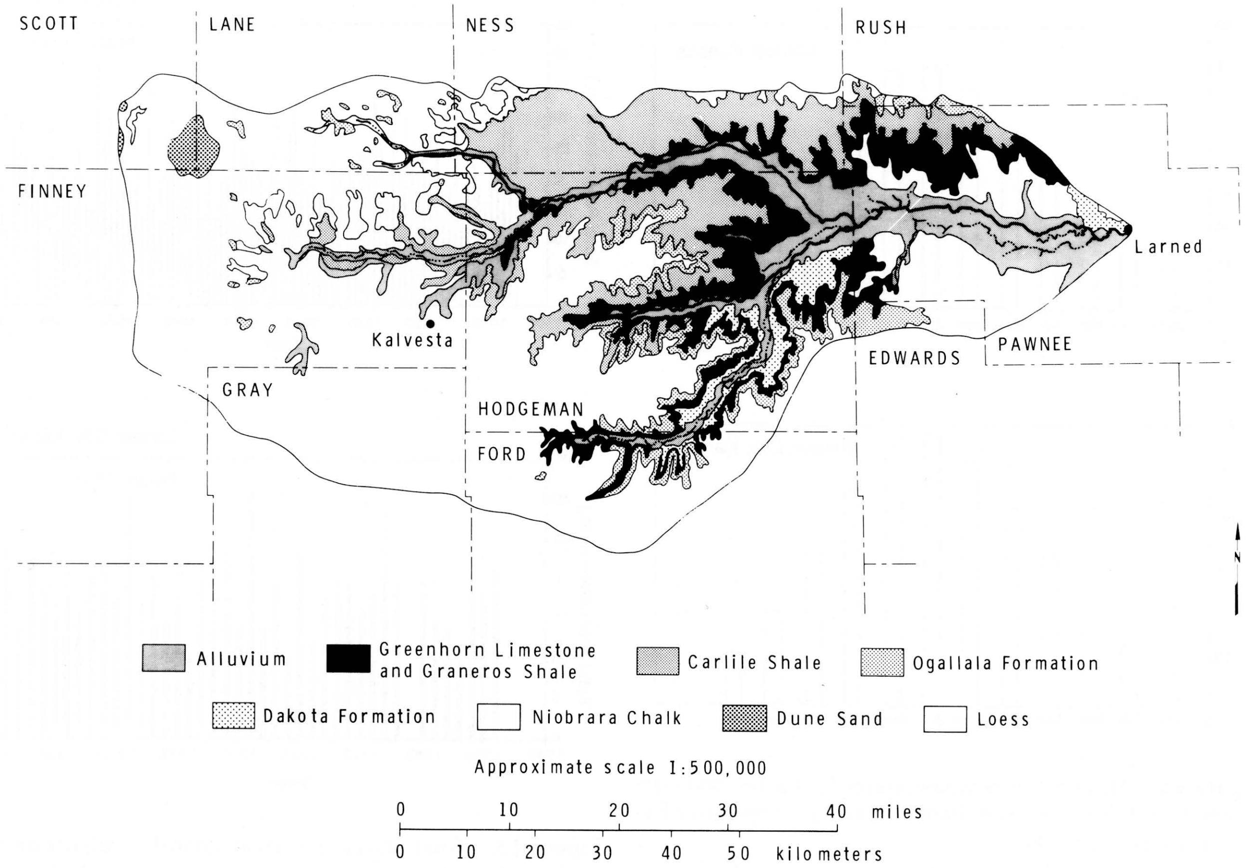

Figure 10. Surface geology of the Pawnee River basin [from Sophocleous (1980)].

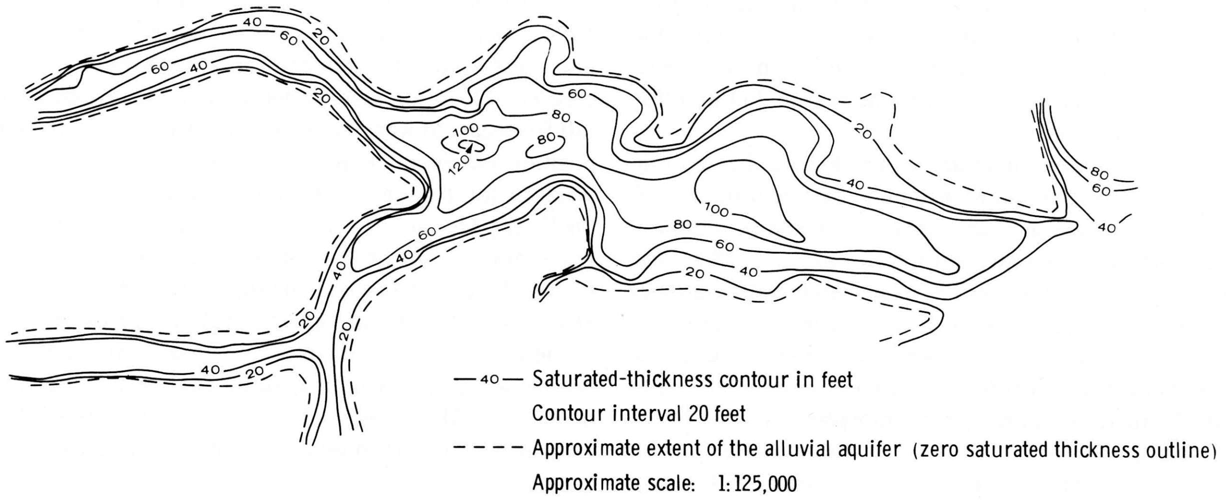

Figure 11. Saturated thickness of valley fill in the central and eastern portions of the Pawnee River basin, 1945–1947 [from Sophocleous (1980)].

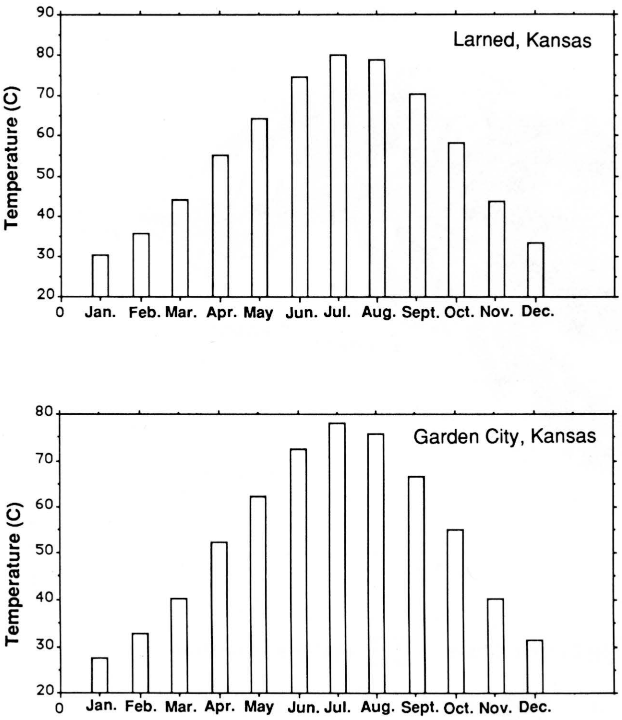

Figure 12. Mean monthly temperatures for Larned and Garden City, Kansas (Kansas State University, Cooperative Extension Service, 1990).

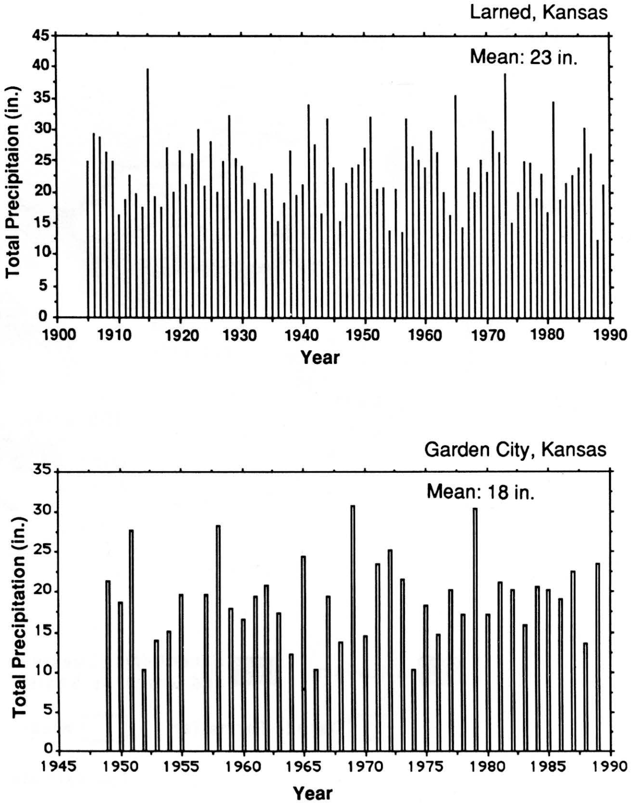

Figure 13. Total annual and mean annual precipitation for Larned and Garden City, Kansas (Kansas State University, Cooperative Extension Service, 1990).

The winter weather patterns in southwestern Kansas generally are unfavorable for high precipitation. The region is dominated by dry westerly and northerly air flow from December to the end of February. Cyclonic frontal cells associated with invading Pacific air masses periodically bring heavy snowfall to the region, but monthly averages rarely exceed 10 cm (4 in.).

Weather patterns in southwestern Kansas have a tendency to produce frequent droughts. Severe droughts afflict the region about every 20 years, extending semiarid conditions eastward into central Kansas (Bark, 1961). The most severe droughts seem to occur during alternate dry periods (Borchert, 1971, p. 2–6). Borchert (1950) suggested that drought occurs when the strong westerlies of winter persist into spring and summer. Intensification of westerly air flow in the upper atmosphere has the effect of blocking the northward penetration of moist Gulf air into the midcontinent (Bryson and Hare, 1974, p. 4), thereby promoting drought.

Vegetation

The study area is within the Interior Grasslands region of North America. Although this region once was regarded as a vast, homogeneous grassland, Kuchler (1964, 1967, 1974) identified several distinct north-south-trending grassland associations in central North America. The increase in elevation and the decrease in mean annual rainfall from east to west have a strong influence on the composition and overall appearance of these associations. The western limit of the Interior Grasslands is bounded by the Rocky Mountains. Abutting the mountains is the short-grass prairie, which extends eastward across the High Plains of western Kansas. The short-grass prairie is gradually replaced by mixed-grass prairie at the eastern edge of the High Plains. There is a transition from mixed-grass prairie to tall-grass prairie along the western boundary of the Flint Hills region. The tall-grass prairie stretches eastward to its boundary with the Eastern Deciduous Forest.

The western quarter of the Pawnee River valley is within the short-grass prairie (fig. 14). Uplands in this area are dominated by blue grama (*Bouteloua gracilis*) and buffalo grass (*Buchloe dactyloides*). Hairy grama (*Bouteloua hirsuta*) takes over on rocky outcrops, and topographic breaks are often enriched with little bluestem (*Andropogon scoparius*) and other medium-tall grasses

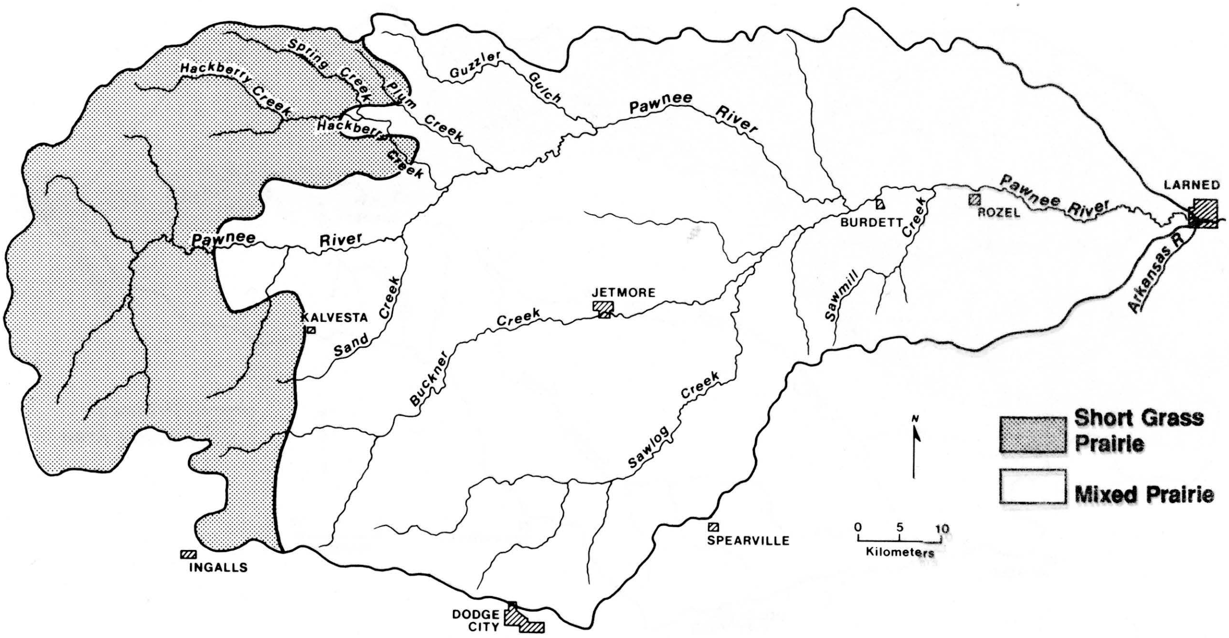

Figure 14. Generalized vegetation map of the Pawnee River basin [adapted from Kuchler (1974)].

(Kuchler, 1967, p. 396). Tall grasses, such as big bluestem (*A. gerardi*), are common in depressions and along floodplains during moist years. Freshwater marshes are dominated by forbs and sedges, including prairie cordgrass (*Spartina pectinata*) and prairie bullrush (*Scirpus paludosus*).

Forested areas are rare in short-grass prairies, except along rivers and on escarpments and other topographic breaks. Riparian forests are dominated by cottonwood (*Populus deltoides*) and willow (*Salix* spp.). These trees are widely spaced in the beds of most intermittent streams. The understory may consist of grasses, including blue grama, buffalo grass, and sand dropseed (*Sporobolus heterolepis*). Where grasses are few or absent, sunflower (*Helianthus* spp.), chenopods (*Chenopodium* spp.), Russian thistle (*Salsola pestifer*), and other weeds often form the lower story of vegetation.

The eastern three-quarters of the study area is within the mixed-grass prairie of the Interior Grasslands (fig. 14). This prairie forms a north-south-trending band through west-central Kansas and extends westward on the breaks in the dissected parts of the High Plains. The mixed-grass prairie consists of graminoids and forbs, often with two distinct layers: one of low-growing grasses and one of medium-tall grasses and forbs (Kuchler 1974, p. 591). The vegetation is characterized by a mixture of tall and short grasses, with the dominant species being big and little bluestem, sideoats grama (*Bouteloua curtipendula*), and blue grama. Other common components include western wheatgrass (*Agropyron smithii*), June grass (*Koeleria pyramidata*), panic grass (*Panicum scribnerianum*), and red three-awn (*Aristida longiseta*).

The wooded areas in the mixed-grass prairie have more species of trees than those in the short-grass prairie to the west. Cottonwood, willow, juniper (*Juniperus virginiana*), burr oak (*Quercus macrocarpa*), and hackberry (*Celtis occidentalis*) are widely spaced along streams and rivers, and few herbs are present in the understory.

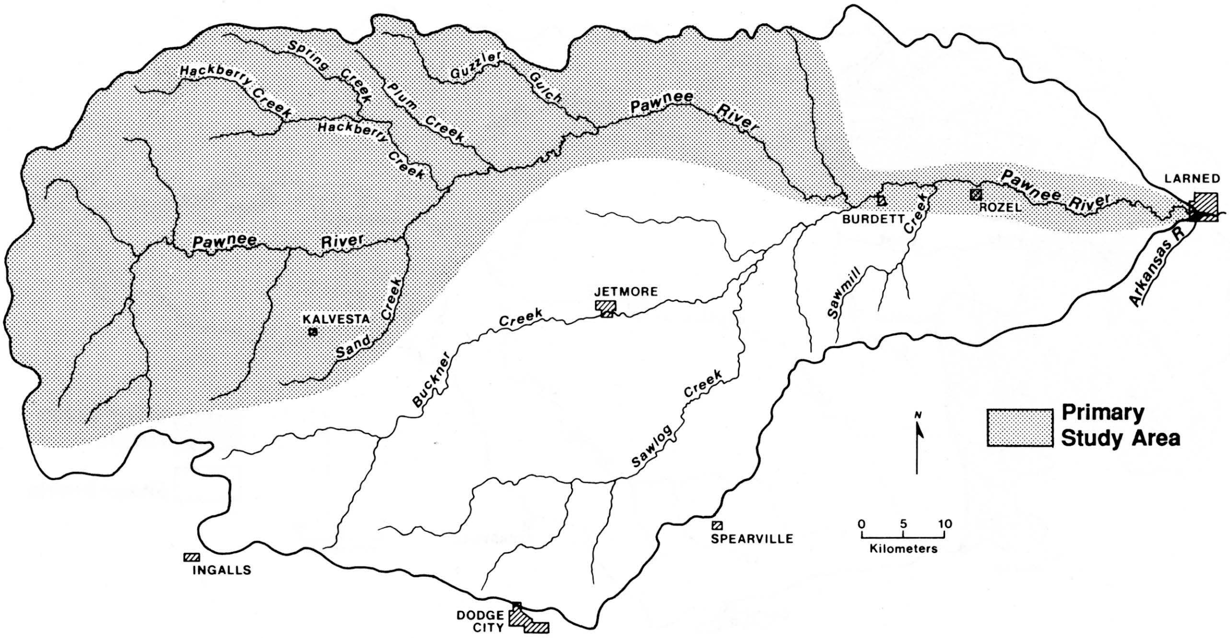

Figure 15. Primary study area within the Pawnee River basin.

Research methods

Data requirements

Because there have been no previous geomorphologic investigations of the Pawnee River valley, I had to acquire data concerning alluvial landforms, stratigraphy, sedimentology, and chronology from field and laboratory studies. There were several sources of existing data that proved useful, including bulletins and reports published by the Kansas Geological Survey, soil surveys prepared by the U.S. Department of Agriculture Soil Conservation Service (SCS), unpublished water-well logs held by private companies, and streamflow observations recorded by the U.S. Geological Survey. In addition, landscape data were gleaned from the U.S. Geological Survey 7.5-minute topographic maps and 1:5,000-scale stereographic air photos supplied by the SCS. Also, useful historical data were obtained from local landowners, including information about flooding, lateral migration of stream channels, and gullying.

Strahler's (1964) drainage classification system was used to determine stream orders on the 7.5-minute topographic maps. Only those drainage elements shown as dashed or solid blue lines on the maps were rank-ordered.

Field and laboratory methods

The field investigation initially involved reconnaissance of the primary study area (fig. 15). At this early stage of the study landforms identified on topographic maps and air photos were field-checked. The stages in the selection of individual geomorphic study sites were as follows. First, the locations of stream cutbanks that expose buried cultural deposits or deep stratigraphic sequences in terrace fills were recorded. Emphasis was placed on locating buried cultural deposits because they often yield material for relative and numerical [carbon-14 (^{14}C)] dating. Second, cutbanks that clearly show stratigraphic relationships of alluvial fills in first-order through sixth-order stream valleys within the primary study area were selected for detailed description, sampling, and radiocarbon dating. In addition, alluvial stratigraphic sequences were examined at several locations outside the primary study area for comparison. This field strategy concentrated on the large area of the Pawnee River drainage system, yet it provided an opportunity to construct detailed alluvial stratigraphic records for subbasins that vary in size.

In addition to examining stream cutbanks, I examined alluvial deposits by coring with a Giddings Hydraulic Soil Probe. Cores were taken along cross-valley transects in the lower, middle, and upper reaches of the Pawnee River drainage system. Most of the transects extended away from stream cutbanks that were selected for detailed analyses. Cores were used to determine the character, depth, and extent of deposits underlying the various landforms in the Pawnee River valley and to establish spatial relationships between the fills. Cores were especially

Table 1. Stages of carbonate morphology for nongravelly sediment

Stage	Properties
I	Few filaments or coatings on sand grains; <10% calcium carbonate
I+	Filaments are common
II	Few to common nodules; matrix between nodules is slightly whitened by calcium carbonate (15–50% by area) that occurs as veinlets and filaments; some matrix can be noncalcareous; 10–15% calcium carbonate in whole sample, 15–75% in nodules
II+	Common nodules; 50–90% of matrix is whitened; 15% calcium carbonate in whole sample
III	Many nodules; calcium carbonate coats so many grains that over 90% of horizon is white; carbonate-rich layers more common in upper part; about 20% calcium carbonate
III+	Most grains coated with calcium carbonate; most pores plugged; >40% calcium carbonate
IV	Upper part of K horizon is nearly pure cemented calcium carbonate (75–90% calcium carbonate) and has a weak platy structure because of weakly expressed laminar depositional layers of calcium carbonate; rest of horizon is plugged with calcium carbonate (50–75% calcium carbonate)
V	Laminar layer and platy structure strongly expressed; incipient brecciation and pisolith formation (thin multiple layers of calcium carbonate surrounding particles)
VI	Brecciation, recementation, and pisoliths common

Source: Birkeland (1984, table A-4).

useful for tracing disconformities and buried soils along cross-valley transects. In most cases undisturbed continuous cores, either 5.0 or 7.6 cm (2.0 or 3.0 in.) in diameter, were taken down to the base of alluvial fills. Cores were taken as deep as possible in several locations where the bedrock could not be reached with the probe. After briefly describing the cores in the field, I placed the cores in PVC tubes for transport to the laboratory for detailed analyses.

Cross sections of the stream valleys were constructed for study sites from 7.5-minute topographic maps. In addition, valley-bottom cross sections were surveyed with a hand level, measuring rod, and fiberglass tape. The cross sections were used in the field in conjunction with enlarged 7.5-minute topographic maps of each study site to map the spatial extent of landforms. The resulting field maps provided information on the relative degree of preservation of both the terraces and the underlying valley fill.

Surfaces of alluvial landforms were numbered consecutively from stream level upward, with the modern floodplain designated T-0, the first terrace T-1, and the highest terrace T-3. At some places along the Pawnee River and its tributaries, the modern floodplain is a complex consisting of two surfaces separated by a short scarp. In this case the lowest floodplain surface was designated as T-0a and the slightly higher one as T-0b.

Soils exposed in cores and stream cutbanks were described using standard U.S. Department of Agriculture terminology and procedures (Soil Survey Staff, 1990). Each soil horizon was described in terms of its texture, Munsell matrix color and mottling, structure, and boundaries. When present, root channels, clay films, matrix carbonate, and ferromanganese concretions were described. Reaction of soils to 10% HCl was noted, and stages of carbonate morphology (Table 1) were defined according to the classification scheme of Birkeland (1984). In addition, sedimentary features preserved in C horizons of some soils were examined to help reconstruct depositional histories.

Soil and sediment samples were collected from two cutbanks to determine particle-size distribution and calcium carbonate equivalent. Soils were sampled by horizon using standard U.S. Department of Agriculture procedures (Soil Conservation Service, 1984). Alluvial units were systematically sampled at intervals that depended on their thickness (Krumbein and Graybill, 1965). Particle-size distribution was determined using the pipette method (Soil Conservation Service, 1984, p. 15–17) and dry-sieving of sand. The Chittick gasometric method (Dreimanis, 1962) was used to determine calcium carbonate equivalent.

Charcoal, bone, and bulk soil samples were submitted to the University of Texas Radiocarbon Laboratory for

^{14}C analysis. All samples were pretreated by the radiocarbon laboratory to remove roots and calcium carbonate.

Radiocarbon ages determined on humates are mean residence times for all organic carbon in the soil samples (Campbell et al., 1967). Although mean residence time does not provide the absolute age of a buried soil, it does give a minimum age for the period of soil development, and it provides a limiting age on the overlying material (Geyh et al., 1975; Scharpenseel, 1975; Birkeland, 1984, p. 150; Haas et al., 1986).

Stratigraphic framework

A bipartite stratigraphic nomenclature is used in this study. Stratigraphic designations are informal and include stratigraphic units and soils. At all research localities in the study area, the boundaries of stratigraphic units are marked by the upper boundary of surface soils or buried paleosols. However, not all buried paleosols served as boundaries for stratigraphic units. Instead, only those with morphologically well-expressed horizons were selected. Not only do the better developed soils indicate longer periods of relative stability (disconformities) separating periods of aggradation, but they also are easily traced along longitudinal and cross-valley transects. Thin, weakly developed buried soils observed in some exposures were not observed in other exposures of the same fill in a stream valley; that is, they were not laterally traceable; hence these soils were not used as boundaries for stratigraphic units. Roman numerals designate the stratigraphic units, beginning with I at the top of a section. The individual units are site specific and do not always represent the same deposits at different localities.

Stratigraphic units recognized in this study are similar to allostratigraphic units of the North American Stratigraphic Code. Allostratigraphic units are mappable stratified bodies of sedimentary rock or sediments whose boundaries are laterally traceable disconformities (North American Commission on Stratigraphic Nomenclature, 1983). The system used in the present study is not as rigid as that of the North American Stratigraphic Code, yet it effectively places bodies of sediment into a stratigraphic framework.

Soils were included in the stratigraphic framework of each vertical section described in the study area. Soils are important to the subdivision of Quaternary sediments, whether the soils are at the present land surface or buried (Birkeland, 1984, p. 325). After soils were identified and described, they were numbered consecutively, beginning with 1, the modern soil, at the top of the section.

Identification of buried soils

The identification of buried soils in late Quaternary valley fill was crucial to inferring intervals of floodplain stability in the Pawnee River basin. However, recognition of buried paleosols was complicated by (1) truncation of soils by erosion before burial, (2) diagenesis of soil horizons after burial, and (3) deposition of organic- and/or clay-rich alluvium that was not subsequently modified by soil genesis. Therefore several criteria were used to differentiate buried soils from unmodified alluvium. These criteria are [after May (1986)]:

1. Color. Modern A horizons in southwestern Kansas tend to have a moist Munsell (1975) value of 4.0 or less and a chroma of 3.0 or less. In the present study buried A horizons must meet these criteria. Also, the dry value or chroma of a buried A horizon must be less than that of the overlying or underlying soil horizon or sediment.
2. Lower boundary. The lower boundary of a modern soil generally is clear, gradual, or diffuse, whereas depositional units that have not been altered by pedogenesis have an abrupt lower boundary. Hence the lower boundary of a buried soil cannot be abrupt.
3. Structure. The bonding together of individual soil particles produces structure. Individual aggregates, or peds, are classified into several types on the basis of shape (i.e., granular, blocky, columnar, and prismatic). Buried paleosols must therefore show evidence of structure. However, this criterion cannot be used alone to differentiate buried soils from depositional units. Flood drapes often are composed of high proportions of clay that are rich in 2:1-layered silicate minerals. The shrinking and swelling of these clays gives the alluvial deposits an angular-blocky structure.
4. Clay films. Clay films lining ped surfaces or voids are good evidence of clay illuviation and B horizon development in modern soils. Hence detection of clay films with a hand lens was a criterion used to identify buried paleosols, especially truncated paleo–Bt horizons. Like structure, this criterion cannot be used alone to differentiate paleosols from alluvial deposits. Pressure faces on aggregates of clay-rich alluvium closely resemble clay films when viewed with a hand lens.
5. Evidence of bioturbation. Modern soils generally have evidence of bioturbation. This evidence may consist of krotovinas, worm casts, or root channels. Thus buried paleosols should show some evidence of bioturbation.
6. Lateral extent. True soils are laterally extensive and are not restricted to particular landforms. They can cross lithologic discontinuities and, in valleys, can be traced from abandoned channels to natural levees and from terraces onto valleyside slopes. Thus a buried soil

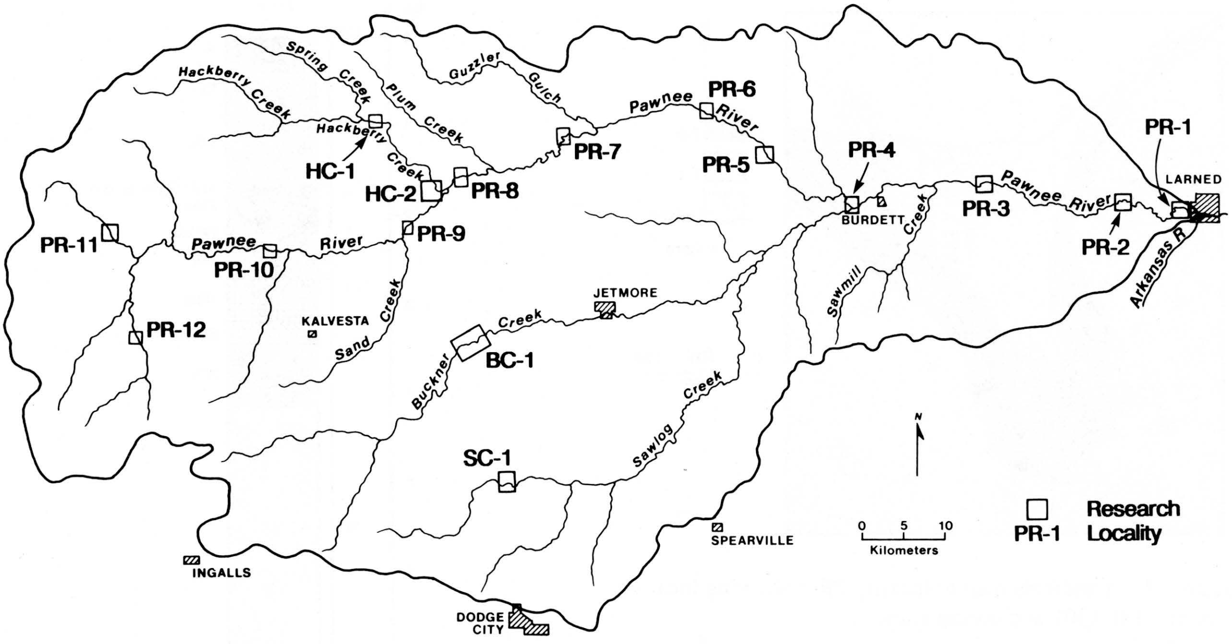

Figure 16. Pawnee River basin and localities where detailed soil-stratigraphic investigations were conducted.

can be mapped in three dimensions over varying topography, whereas a depositional unit is restricted to a particular landform.

The terms *soil* and *deposit* should not be confused. The term *soil* is often used by engineers to represent any deposit of unconsolidated rock material (regolith). Archeologists also commonly use this term when referring to the medium from which artifacts are recovered. In this study, *deposit* refers to a package of sediment, and *soil* refers to the zones within a deposit that have been altered by soil-forming processes.

Geomorphic and stratigraphic investigations

In this section I present the geomorphic and alluvial-stratigraphic information gathered at 16 localities in the study area (fig. 16). First, results of investigations are presented for localities in the main valley of the Pawnee River, beginning at the east end of the basin (PR-1 through PR-10). This discussion is followed by descriptions of the geomorphology and alluvial stratigraphy at localities in small valleys in the study area. Geomorphic and alluvial-stratigraphic data collected from large and small valleys are compared in the next section.

Large valleys

Locality PR-1 Locality PR-1 is situated in the Pawnee River valley, 1.5 km (0.93 mi) upstream from the confluence of that river with the Arkansas River (fig. 16). The Pawnee River is a sixth-order stream and has a gradient of 0.62 m/km (3.3 ft/mi) at this locality. The valley floor is 2.3 km (1.4 mi) wide and is bordered by a steep bedrock valley wall to the north. A low, broad ridge separates the Pawnee River valley from the Arkansas River valley to the south.

Two landforms compose the valley floor at locality PR-1: a narrow modern floodplain (T-0) and a low, broad terrace (T-1) (fig. 17). A 3-m-high (10-ft-high) scarp separates the T-0 and T-1 surfaces. T-1 is a paired terrace, and its broad, flat surface forms most of the valley floor.

Subsurface investigations at locality PR-1 focused on T-1 fill of the Pawnee River at the Lewis site (14PA307) (fig. 17). This site, which was initially referred to as the Larned site (Monger, 1970), is a large multicomponent Late Prehistoric village situated in the neck of a narrow meander bend of the Pawnee River (Ranney, 1988). Five

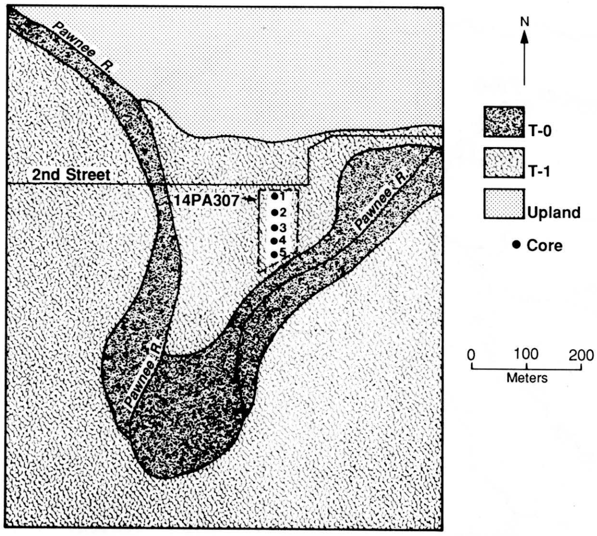

Figure 17. Landform map of locality PR-1 showing location of site 14PA307 and coring sites.

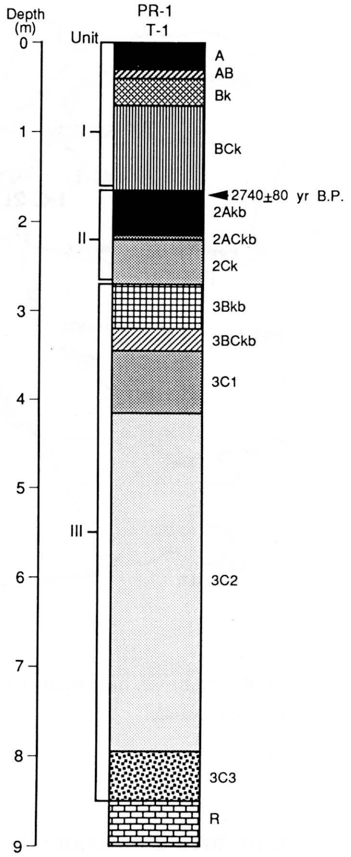

Figure 18. Soil stratigraphy observed in core 1 (T-1 fill) at locality PR-1.

cores were taken along a 120-m (400-ft) transect extending from 2d Street south to the Pawnee River (fig. 17). Core 3, which is the longest of the five cores, reached bedrock at a depth of 8.53 m (28 ft) below the T-1 surface. This core was used to prepare a detailed description of the alluvial stratigraphy at site 14PA307 (see appendix table A.1). In addition, a soil sample was collected from a buried paleosol for radiocarbon dating.

Three stratigraphic units and two buried paleosols were identified beneath the T-1 surface at site 14PA307 (fig. 18). The lowest unit (unit III) is 5.96 m (19.6 ft) thick and consists of fine- and coarse-grained alluvium. Sand and gravel composing the lower 4.34 m (14.2 ft) of unit III grade upward to silt loam and silty clay. Soil 3 is developed in the fine-grained alluvium at the top of unit III. This paleosol has Bk–BCk–C horizonation; the A horizon apparently was stripped off by erosion before burial. The 3Bkb horizon is 53 cm (1.7 ft) thick and is a brown (10YR 5/3, dry) silty clay. There are many distinct threads of calcium carbonate (stage I+) in the 3Bkb horizon, and the paleosolum has moderate fine and medium subangular-blocky structure.

Unit II is 1.15 m (3.77 ft) thick and is composed of loamy fine sand at its base that grades upward to silt loam. A paleosol (soil 2) with Ak–ACk horizonation is developed at the top of this alluvial unit. The 2Akb horizon is 60 cm (2.0 ft) thick and is dark-grayish-brown (10YR 4/2, dry). Films and threads of calcium carbonate are common (stage I+) in the 2Akb and 2ACkb horizons but do not continue down into the 2C horizon.

The upper stratigraphic unit (unit I) is 1.70 m (5.58 ft) thick and is composed of alluvium that fines upward from loam to silt loam. A Haplustoll (soil 1) with A–Bk–BCk horizonation is developed at the top of unit I. The A horizon of this modern surface soil is 33 cm (1.1 ft) thick and is not completely leached of calcium carbonate based on reaction to HCl. The Bk horizon (Bk1 + Bk2) is only 37 cm (1.2 ft) thick and has fairly weak structural development and carbonate morphology (stage I+).

Based on the paleosol record, aggradation was interrupted by two soil-forming intervals before final stabilization of the T-1 surface. Soil 3 at the top of unit III has a well-developed Bk horizon indicative of a relatively long period of landscape stability. Soil 2 at the top of unit II, however, lacks a B horizon, and its overthickened A horizon suggests that pedogenesis accompanied slow aggradation. Humates from the upper 20 cm (0.66 ft) of soil 2 yielded a radiocarbon age of 2,740 ± 80 yr B.P. Hence the episode of floodplain stability indicated by soil 2 dates back to at least ca. 2,740 yr B.P., and unit I aggraded sometime after that.

The modern soil at the top of unit I developed when sedimentation ceased or dramatically slowed on the T-1 surface. The presence of six separate cultural horizons

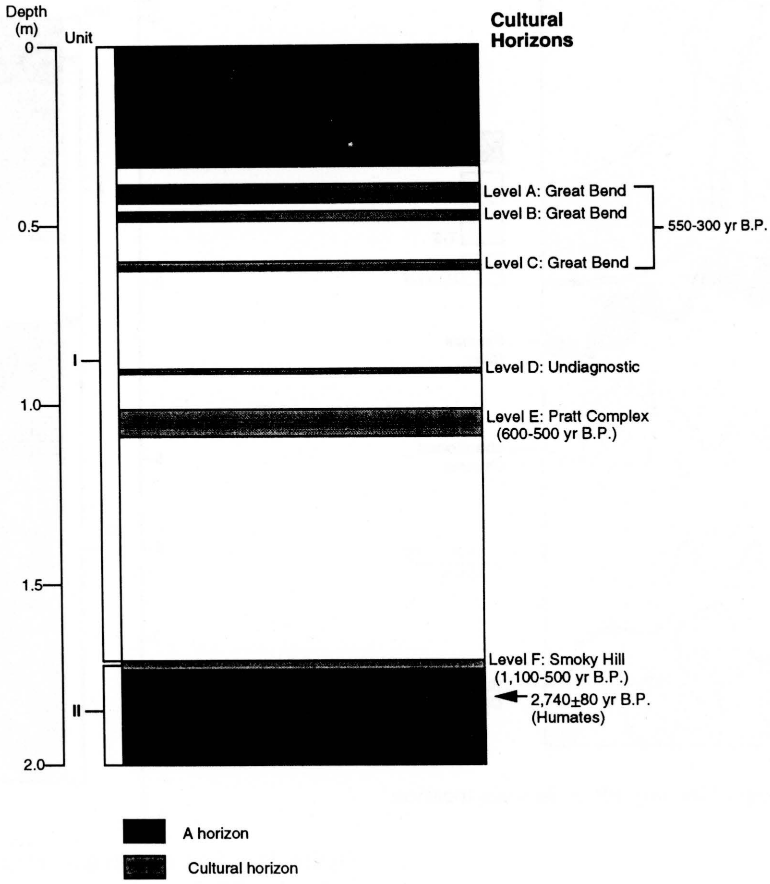

Figure 19. Cultural horizons at site 14PA307 at locality PR-1.

(levels A–F, fig. 19) in the upper 1.72 m (5.64 ft) of the T-1 fill indicates that sedimentation was sporadic after ca. 2,700 yr B.P. The lowest cultural horizon (level F) is 1.67–1.72 m (5.48–5.64 ft) below the T-1 surface and contains Smoky Hill pottery and projectile points (Ranney, 1988). Based on radiocarbon assays from other localities in Kansas, the Smoky Hill variant spans the period 1,100–500 yr B.P. (Brown and Simmons, 1987, p. XVIII-10). Level E is 1.02–1.11 m (3.35–3.64 ft) below the T-1 surface and represents the Pratt complex (ca. 600–500 yr B.P.). Level D is a thin layer of undiagnostic artifacts, 0.90–0.93 m (2.95–3.05 ft) below the T-1 surface. Great Bend cultural components are represented in levels A, B, and C, 0.38–0.42 m (1.25–1.38 ft), 0.46–0.49 m (1.51–1.61 ft), and 0.60–0.63 m (1.97–2.07 ft) below the T-1 surface, respectively (Ranney, 1988). Radiocarbon assays and cross-dating place the Great Bend aspect between ca. 550 and 300 yr B.P. (Brown and Simmons, 1987, p. XVI-10). Hence the upper 38 cm (1.3 ft) of the T-1 fill at site 14PA307 accumulated sometime after ca. 550–300 yr B.P.

Locality PR-2 Locality PR-2 is situated in the Pawnee River valley, 11 km (6.8 mi) upstream from the confluence of that river with the Arkansas River (fig. 16). The Pawnee River in this area is a sixth-order stream with a gradient of 0.75 m/km (4.0 ft/mi). The valley is asymmetric: north-facing slopes are steep but south-facing slopes are much gentler. The valley floor is 8 km (5 mi) wide and is composed of three landforms: a modern floodplain (T-0), a low terrace (T-1), and a high terrace (T-3) (fig. 20). An intermediate terrace (T-2) observed in the middle reaches of the Pawnee River was not detected at locality PR-2. The T-0 surface is 30–75 m (98–246 ft) wide and is separated from the T-1 surface by a steep 4-m-high (13-ft-high) scarp. T-1 is a paired terrace, and its broad, flat surface dominates the valley floor. A gently sloping 3-m-high (10-ft-high) scarp separates the T-1 surface from the T-3 terrace. T-3 is a paired terrace with a fairly broad, gently sloping surface.

Two former channels of the Pawnee River traverse the T-1 terrace south of the modern channel (fig. 20). The northernmost of these two abandoned channels has been greatly modified by land-leveling operations of farmers

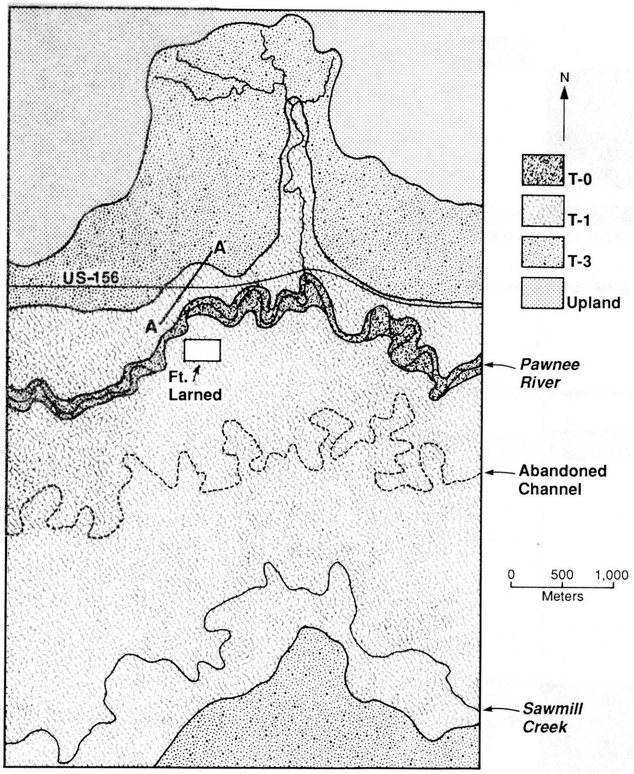

Figure 20. Landform map of locality PR-2 showing location of cores and auger holes.

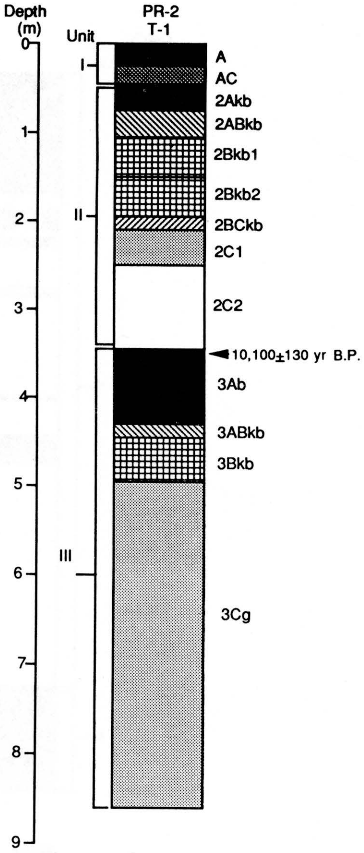

Figure 21. Soil stratigraphy observed in core 1 (T-1 fill) at locality PR-2.

and no longer carries runoff. The southernmost channel, however, is occupied by Sawmill Creek, which is an intermittent stream. Avulsions and concomitant channel abandonment by the Pawnee River are discussed later.

Subsurface investigations at locality PR-2 focused on valley fill beneath the T-1 and T-3 terraces. A series of cores and auger holes were drilled along a southwest to northeast transect (A–A′ in fig. 20). The first core hole (core 1) was drilled on the T-1 terrace north of the Pawnee River between Fort Larned and US–156 (fig. 20). Unfortunately, a high water table prevented coring to bedrock. However, a continuous 8.53-m-long (28.0-ft-long) core of T-1 fill was successfully recovered. In addition, an 8.75-m-long (28.7-ft-long) core (core 2) was taken from T-3 fill immediately north of US–156, and four auger holes were drilled along the transect between cores 1 and 2. The cores were described, and a soil sample was collected from core 1 for radiocarbon dating.

Three stratigraphic units and two buried paleosols were identified beneath the T-1 surface at the core 1 site (fig. 21). The lowest unit (unit III) is at least 5.08 m (16.7 ft) thick and is composed of fine-loamy and clayey alluvium (see appendix table A.2). A paleosol (soil 3) with an A–Bk profile is developed at the top of unit III. The 3Ab horizon is 89 cm (2.9 ft) thick and is a dark-grayish-brown (10YR 4/2, dry) silty clay loam. There is no evidence of secondary carbonates within the 3Ab horizon, and the matrix is noncalcareous. Humates from the upper 10 cm (0.33 ft) of this overthickened A horizon yielded a radiocarbon age of 10,100 ± 130 yr B.P. The underlying 3Bkb is 45 cm (1.5 ft) thick and is a light-yellowish-brown (2.5Y 6/4, dry) silty clay. Although secondary carbonates (stage II) are common in the 3Bkb horizon, the soil matrix is noncalcareous. The underlying 3Cgb horizon is massive and consists of alluvium with silty clay loam texture. A high water table has produced strong gleying in the 3Cgb horizon.

The second unit (unit II) is 2.84 m (9.32 ft) thick and is composed of fine-grained alluvium. A paleosol (soil 2) with Ak–Bk horizonation is developed at the top of unit II. The 2Akb horizon is 25 cm (0.82 ft) thick and is a dark-grayish-brown (10YR 4/2, dry) light silty clay loam. Carbonate morphology is weak in the 2Akb horizon, barely meeting the criteria for stage I development. The underlying 2Bkb horizon (2Bkb1 + 2Bkb2) is 94 cm (3.1 ft) thick and is a brown (10YR 4/3, dry) heavy silty clay loam. It is characterized by medium subangular-blocky structure and stage II carbonate morphology. However, there is little evidence of clay illuviation in the 2Bkb horizon. Silty, stratified alluvium composes the lower 1.33 m (4.36 ft) of unit II.

A 61-cm-thick (2.0-ft-thick) surface deposit (unit I) of fine-silty alluvium mantles soil 2. The modern surface soil (soil 1) at the top of unit I is a Haplustoll with a weakly developed Ap–AC profile. The Ap horizon is 20 cm (0.66 ft) thick and is a dark-grayish-brown (10YR 4/2, dry) light silty clay loam. The underlying AC horizon consists of brown (10YR 5/3, dry) calcareous silt loam.

Based on the mean residence time for organic carbon at the top of soil 3 (ca. 10,100 yr B.P.), alluvium composing the upper 3.45 m (11.3 ft) of the T-1 fill at locality PR-2 was deposited during the Holocene. At least one major episode of landscape stability and soil formation (soil 2) occurred after ca. 10,100 yr B.P. Soil 2, which has a moderately developed A–Bk profile, was buried beneath overbank alluvium (unit I). Although the time of burial is unknown, extremely weak soil development at the top of unit I suggests that this deposit is Historic in age.

Soil 2 strongly resembles the surface soil (soil 1) at site 14PA307 at locality PR-1. Hence soil 1 at locality PR-1 may occur as a buried paleosol (soil 2 at locality PR-2) where it has been mantled by Historic overbank deposits. However, additional absolute time control is needed before these soils can be correlated over such great distances.

Core 2 at locality PR-2 was taken from T-3 fill at a location 205 m (673 ft) northeast of core 1 (fig. 20). This second core revealed three stratigraphic units and two buried paleosols beneath the T-3 surface (fig. 22). The lowest unit (unit III) is at least 1.43 m (4.69 ft) thick and is composed of loamy sediment. A paleosol (soil 3) with a thick carbonate-rich Bk horizon is developed at the top of unit III (see appendix table A.3); the A horizon was stripped off by erosion before burial. The 3Bkb horizon is yellowish brown (10YR 5/4, dry) and has medium subangular-blocky structure. Approximately 15% of the matrix has been whitened by calcium carbonate, and soft carbonate masses are common (stage II) in this paleosol.

Soil 3 is mantled by a 4.32-m-thick (14.2-ft-thick) unit of alluvium (unit II). Loamy fine sand at the bottom of unit II grades upward to silty clay loam at the top of the unit. A truncated Bt horizon (soil 2) is developed in the upper 1.65 m (5.41 ft) of unit II. The 2Btb horizon (2Bt1 + 2Bt2) is 1.83 m (6.00 ft) thick and is a reddish-yellow (7.5YR 6/6, dry) to brownish-yellow (10YR 5/6, dry) silty clay loam. Clay illuviation is indicated by distinct clay flows on vertical ped faces in the 2Btb1 and 2Btb2 horizons. The matrix is noncalcareous, and there is no evidence of secondary carbonates. Based on its color and morphology, soil 2 appears to be the product of a strong weathering environment and/or a long episode of pedogenesis.

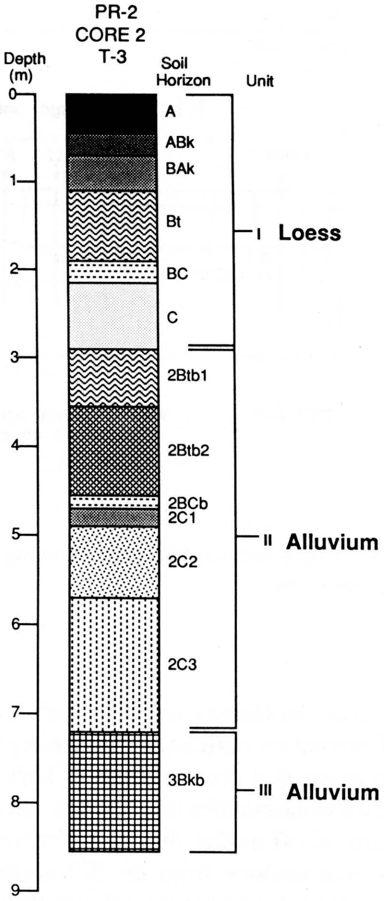

Figure 22. Soil stratigraphy observed in core 2 (T-3 fill) at locality PR-2.

The upper stratigraphic unit (unit I) is 2.92 m (9.58 ft) thick and is composed of pale-brown (10YR 6/3, dry) to light-yellowish-brown (10YR 6/4, dry) massive silt loam. The surface soil at the top of unit I is an Argiustoll (Mollisol) with A–BAk–Btk–Bk–BCk horizonation. The A horizon is 42 cm (1.4 ft) thick and is brown (10YR 5/3, dry) to grayish brown (10YR 5/2, dry). The A horizon is leached of calcium carbonate, secondary carbonates (stage I+) are present in the BAk horizon and continue down into the BCk horizon. The argillic horizon (Btk1 + Btk2) is 1.19 m (3.90 ft) thick and is a brown (10YR 5/3, dry) silty clay loam. This soil is somewhat characteristic of the Harney series on 1–3% slopes. The Harney silt loam is developed in Peoria loess throughout much of western Kansas (Soil Conservation Service, 1986) and has been mapped on the T-3 terrace at locality PR-2 [see Dodge and Roth (1978, sheet 27)]. However, the presence of carbonates within the argillic horizon is

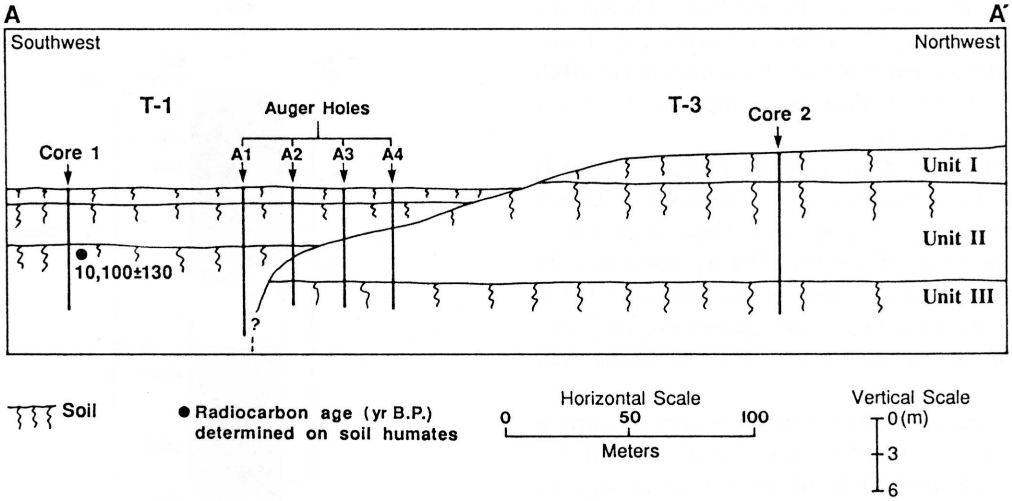

Figure 23. Cross-sectional diagram showing stratigraphic relationship between T-3 and T-1 deposits.

not typical of the Harney soil. The carbonates must be a result of secondary enrichment following the episode of clay illuviation that produced the Bt horizon. The exact origin of these carbonates is unknown, but they may have come from runoff and/or dust fall. Tertiary and Quaternary deposits upslope from the T-3 surface are rich in calcium carbonate; hence runoff and throughflow from higher positions in the valley landscape are likely to be charged with carbonates. Also, carbonate-rich dust from local and western sources may have been deposited on the T-3 surface during the Holocene. According to Twiss (1983), dust currently is deposited at a rate of 371,600 $kg/km^2/yr$ (436,500 $lb/mi^2/yr$) in western Kansas.

Four auger holes were drilled along a transect between cores 1 and 2 to determine stratigraphic relations between T-1 and T-3 deposits. The results of this investigation indicate that T-1 fill is inset above T-3 fill near the scarp that separates the two terraces (fig. 23). The 2Btkb horizon (soil 2) observed in the T-3 fill crops out at the base of the scarp and was detected below the T-1 fill near the boundary between the T-1 and T-3 terraces.

Although the absolute age of the alluvium composing T-3 fill is unknown, the alluvium was deposited sometime before 10,240 ± 120 yr B.P., which is the oldest radiocarbon age determined on soil humates from the T-1 fill. Also, if unit I is Peoria loess, aggradation of the underlying T-3 fill must predate the late Wisconsinan.

Locality PR-3 Locality PR-3 is situated in the Pawnee River valley, 28 km (17 mi) upstream from the confluence of that river with the Arkansas River (fig. 16). The Pawnee River is a sixth-order stream and has a gradient of 0.76 m/km (4.0 ft/mi) at this locality. The valley floor is 6.5 km (4.0 mi) wide and is composed of three landforms: a narrow floodplain (T-0), a low broad terrace (T-1), and a high terrace (T-3) (fig. 24). An intermediate terrace (T-2) observed at locality PR-8 in the middle Pawnee River valley was not detected at locality PR-3. The T-0 surface is 30–75 m (98–250 ft) wide and is separated from T-1 by a 4-m-high (13-ft-high) scarp. T-1 is a paired terrace, and its broad, flat surface dominates the valley bottom. A distinct 4.5-m-high (15-ft-high) scarp separates the T-1 surface from the T-3 surface. As was the case downstream at locality PR-2, T-3 is a paired terrace with a fairly broad, gently sloping surface.

The two abandoned channels of the Pawnee River observed at locality PR-2 also cross locality PR-3 (fig. 24). Both channels are cut into T-1 fill, and the southernmost channel is occupied by one of two area streams called Sawmill Creek.

The subsurface investigation at locality PR-3 focused on valley fill beneath the T-1 surface. Alluvial deposits and a buried soil are exposed in a trench silo that was excavated into T-1 fill on the southern side of the valley floor (fig. 24). In addition to examining the soil stratigraphy exposed along the walls of the trench (fig. 25), I recovered a 2.1-m-long (6.9-ft-long) core below the floor of the trench with the Giddings Hydraulic Probe. A detailed description of the west wall of the trench was combined with that of the core (see appendix table A.4). This study site is referred to as the Elmore trench.

Three stratigraphic units and two buried soils were identified beneath the T-1 surface at the Elmore trench (fig. 26). The lowest unit (unit III) is at least 1.09 m (3.6 ft) thick and is composed of fine-grained sediment. A paleosol (soil 3) with a Bt horizon is developed at the top of unit III; the A horizon was removed by erosion before burial. The 3Btb1 horizon is reddish yellow (7.5YR 6/6, dry) and has a silty-clay texture. Discontinuous clay films were detected on vertical and horizontal ped faces throughout the paleosolum. The soil matrix is noncalcareous, and no secondary carbonates were observed in the 3Btb1 and 3Btb2 horizons.

Unit II is 2.52 m (8.27 ft) thick and is composed of stratified and massive loamy and clayey alluvium. A paleosol (soil 2) with Ak–Bk horizonation is developed at the top of unit II (fig. 25B). The 2Akb horizon is 30 cm (1 ft) thick and is a dark-grayish-brown (10YR 4/2, dry) light silty clay loam. Carbonate morphology is weak in the 2Akb horizon (stage I), but it becomes better developed with increasing depth in the paleosolum. The 2Bkb horizon (2Bkb1 + 2Bkb2) is 78 cm (2.6 ft) thick and is a brown (10YR 5/3, dry) silty clay. There is fine and medium subangular-blocky structure within the 2Bkb horizon, and distinct films, threads, and soft masses of calcium carbonate (stage II) occur throughout this horizon. Alluvium composing the lower 80 cm (2.6 ft) of unit II (2C1 and 2C2 horizons) consists of finely laminated sandy loam, loam, silt loam, silty clay loam, and silty clay.

The upper unit (unit I) is 45 cm (1.5 ft) thick and is composed of fine-grained alluvium. The modern surface soil at the top of unit I is a Haplustoll with a weakly developed A–AC profile. The A horizon is 24 cm (0.79 ft) thick and is a grayish-brown (10YR 5/2, dry) silt loam. Thin, faint beds of calcareous silt loam compose the underlying AC horizon.

Cores taken along a transect of the T-1 terrace reveal that unit I thins and eventually disappears southward, away from the Elmore trench silo. Hence soil 2 at the top of unit II is the surface soil where unit I is absent.

Humates from the upper 20 cm (0.66 ft) of soil 2 yielded a radiocarbon age of 2,600 ± 80 yr B.P. Therefore alluvium composing unit II accumulated before ca. 2,600 yr B.P., and unit I aggraded sometime later. The weakly developed A–AC profile of soil 1 suggests that unit I is very young. Although no Historic artifacts were discovered in unit I, the landowner reported that this silty deposit has yielded square nails and colored glass at nearby locations (George Elmore, personal communication, 1988). The age of the reddish truncated Bt horizon (soil 3) at the top of unit III is unknown, but it strongly resembles soil 2 developed in T-3 fill at locality PR-2. The presence of this paleosol beneath the T-1 surface at locality PR-3 was not unexpected, given the closeness of the Elmore trench to the scarp separating the T-1 and T-3 surfaces. As noted earlier, subsurface investigations at locality PR-2 determined that the T-1 fill truncates the T-3 fill near the boundary between these two terraces (see fig. 23). If that is the case at the Elmore trench, soil 3 may be the same truncated paleosol observed beneath Peoria loess on the T-3 terrace. Hence soil 3 and the alluvium into which it is developed may predate the late Wisconsinan.

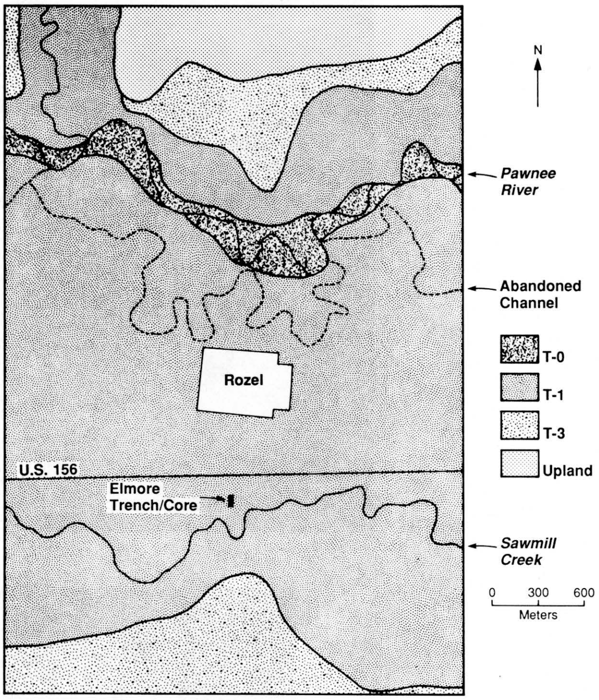

Figure 24. Landform map of locality PR-3 showing location of Elmore trench.

Other similarities exist between the soil stratigraphy at localities PR-3 and PR-2. Specifically, the A–Bk profile of soil 2 developed in T-1 fill at locality PR-3 is nearly identical with the A–Bk profile of soil 2 developed in T-1 fill at locality PR-2. Also, at both sites soil 2 is mantled by a relatively thin deposit of loamy alluvium (unit I) with a weakly developed surface soil (A–AC profile). Correlations between localities PR-3 and PR-2 must be considered tentative, however, in the absence of supporting radiocarbon ages.

Locality PR-4 Locality PR-4 is situated at the confluence of Buckner Creek and the Pawnee River (fig. 16). The valley floor is 6.5 km (4.0 mi) wide and is composed of three landforms: a modern floodplain (T-0), a low terrace (T-1), and a high terrace (T-3) (fig. 27). Again, the intermediate terrace (T-2) was not observed in this portion of the Pawnee River valley. The T-0 surface is 20–50 m (66–164 ft) wide and is separated from the T-1 surface by a steep 4-m-high (13-ft-high) scarp. The broad paired surface of the T-1 terrace dominates the valley floor and is separated from the adjacent T-3 terrace by a moderately sloping 3-m-high (10-ft-high) scarp. T-3 is a paired terrace with a fairly broad, gently sloping surface.

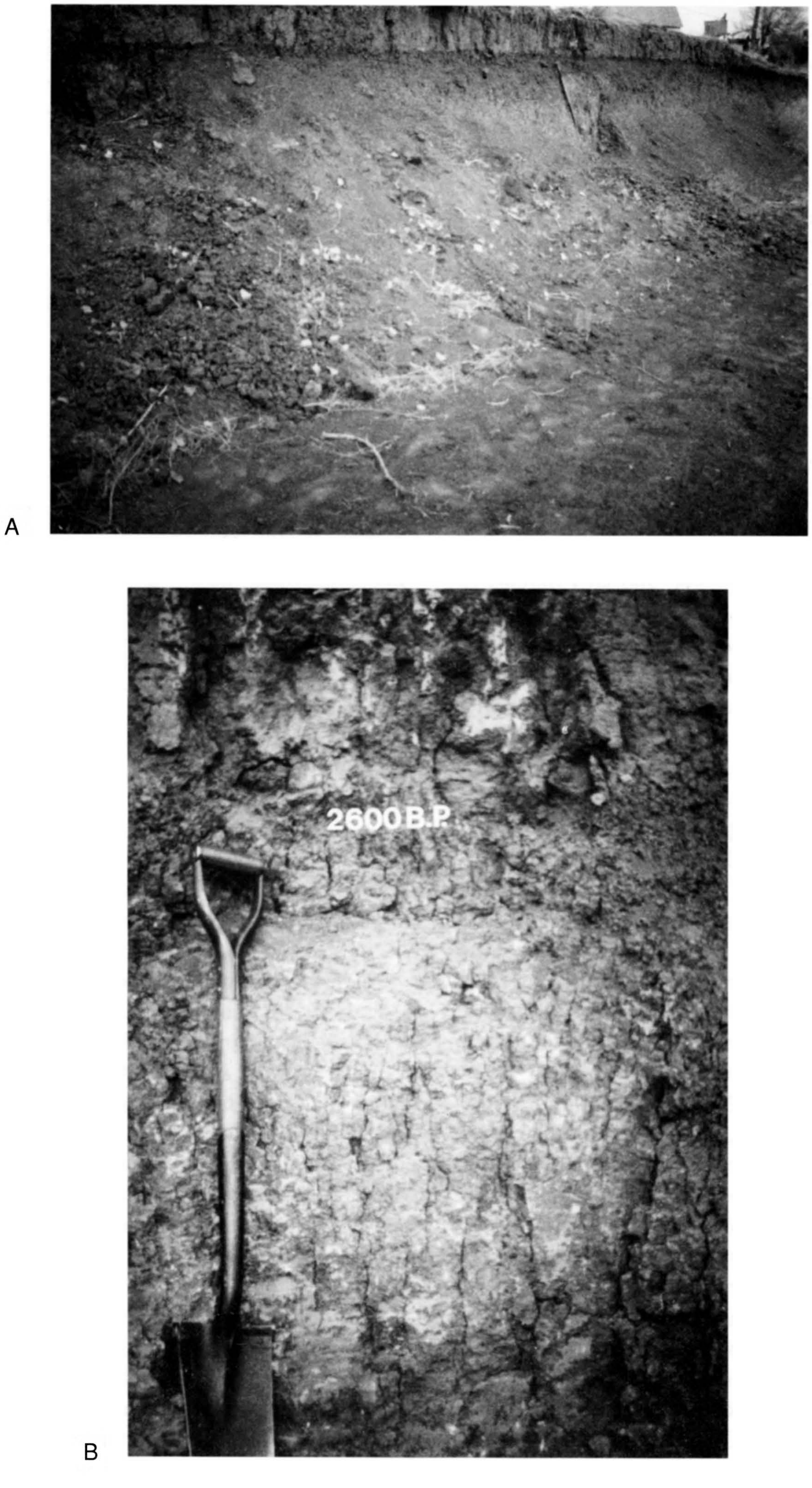

Figure 25. (A) Elmore trench and (B) close-up of T-1 fill exposed in the wall of the silo. The radiocarbon age was determined on humates from the upper 20 cm of the 2Ab horizon. Note the secondary carbonates and structural development in the 2Bkb horizon.

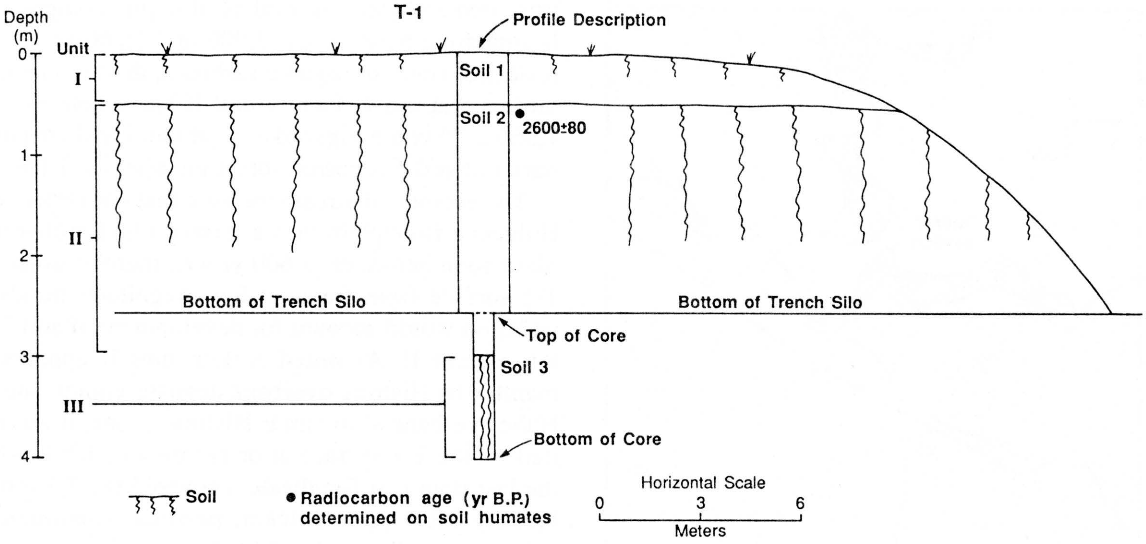

Figure 26. Elmore trench and core showing stratigraphic units, soils, and radiocarbon age.

Both Buckner Creek and the Pawnee River have migrated laterally, cutting into T-1 fill that separates the two streams near their confluence (fig. 27). An 8.5-m-high (28-ft-high) cutbank located along Buckner Creek about 300 m (1,000 ft) upstream from its junction with the Pawnee River provided an opportunity to study a thick section of the T-1 fill (fig. 28). This cutbank exposure, designated as the Rucker section, is described in appendix table A.5, and three soil samples were collected for radiocarbon dating.

Four stratigraphic units and three buried paleosols have been identified in the Rucker section (fig. 29). The lowest stratigraphic unit (unit IV) is at least 2.56 m (8.40 ft) thick and is composed of fine-loamy alluvium. A truncated paleosol (soil 4) is developed at the top of unit IV. Soil 4 has a 40-cm-thick (1.3-ft-thick) Btk horizon above a BCk horizon; the A horizon was stripped off by erosion before burial. The 4Btkb horizon is yellowish brown (10YR 5/4, dry) and is a silty clay loam. Although relatively few clay flows were observed on ped faces in the 4Btkb horizon, many films and threads of calcium carbonate (stage I+) are present in soil 4. Humates from the upper 20 cm (0.66 ft) of soil 4 yielded a radiocarbon age of 9,320 ± 120 yr B.P.

Unit III overlies unit IV except where the former was stripped off by erosion at the west end of the section (fig. 29). Unit III is 1.2 m (3.9 ft) thick and is composed of fine-loamy alluvium. Soil 3 is developed at the top of unit III (fig. 29) and, like soil 4, is a truncated paleosol. The A horizon of soil 3 was removed by erosion, leaving a profile with Bk–Btk–BCk horizonation. The thick, strongly developed paleosolum of soil 3 stands out in the section (fig. 30). Soil colors range from yellowish brown (10YR 5/4, dry) in the 3Bkb horizon to brown (10YR 5/2, dry) in the 3Btkb horizon. The 3Bkb and 3Btkb horizons are characterized by silty clay loam texture, fine and medium subangular-blocky structure, and stage II carbonate morphology. Also, distinct clay films were observed on ped faces in the 3Btkb horizon. Humates from the upper 20 cm (0.66 ft) of soil 3 yielded a radiocarbon age of 7,900 ± 160 yr B.P.

Unit II mantles unit III across the eastern two-thirds of the section and overlies unit IV at the western end (fig. 29). Unit II is about 3.4 m (11 ft) thick and consists of stratified silt loam and fine sandy loam. Soil 2, which is developed at the top of unit II, has a dark A horizon above an ACk horizon (fig. 31). The 2Ab horizon is 40 cm (1.3 ft) thick, dark gray (10YR 4/1, dry), and leached of carbonates. A radiocarbon age of 1,660 ± 70 yr B.P. was determined on humates from the upper 20 cm (0.66 ft) of this horizon. The 2C horizons are pale brown (10YR 6/3, dry) to very pale brown (10YR 7/3, dry) and show little evidence of secondary calcium carbonate accumulation. However, alluvium composing the lower 3 m of unit II is calcareous, based on reaction to HCl. Horizontal bedding is clearly visible throughout the 2C2 horizon (fig. 31B), with strata <5 mm (<0.2 in.) thick collectively making up larger beds 1–10 cm (0.4–4 in.) thick.

Unit II is mantled by unit I, except where gullying has removed the latter (fig. 29). Unit I is 1.05 m (3.4 ft) thick and is composed of stratified fine-grained alluvium. The modern surface soil (soil 1) at the top of unit I is a

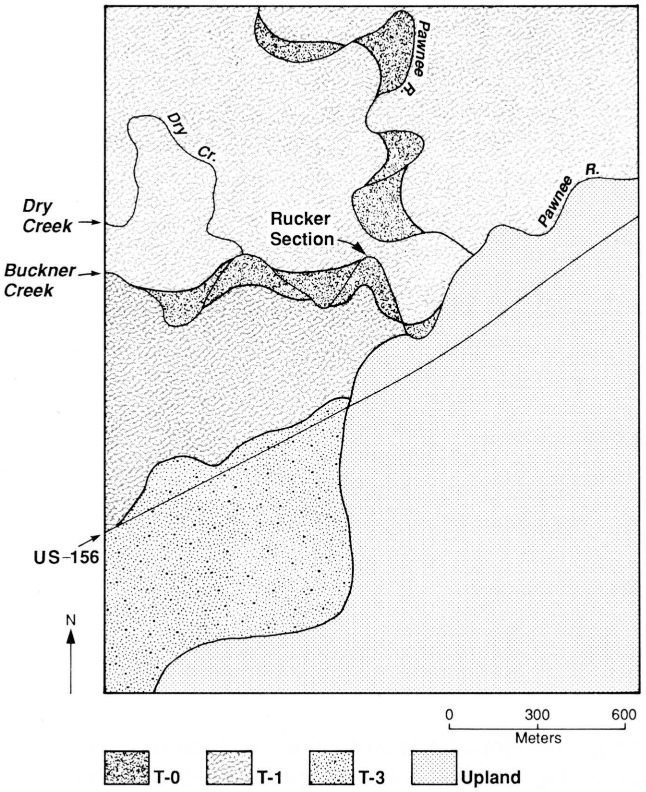

Figure 27. Landform map of locality PR-4 showing the location of the Rucker section.

Haplustoll (Mollisol) with A–ACk horizonation (fig. 31A). The A horizon is 38 cm (1.2 ft) thick and is a dark-grayish-brown (10YR 4/2, dry) to grayish-brown (10YR 5/2, dry) silt loam. The C horizon displays prominent bedding, with texture of strata ranging from silty clay loam to very fine sandy loam. Preservation of bedding at shallow depths combined with weak surface-soil development suggests that unit I is young. Altogether, the physical properties of unit I are characteristic of Historic alluvium. However, the absolute age of this unit is unknown.

Mean residence times determined on organic carbon from buried soils at the Rucker section provide a chronologic framework for Holocene aggradation, erosion, and landscape stability at locality PR-4. Specifically, unit IV aggraded sometime before 9,320 ± 120 yr B.P., which is the radiocarbon age of humates from soil 4 at the top of this unit. Soil 4 was truncated and subsequently mantled by alluvium composing unit III sometime after ca. 9,320 yr B.P. but before ca. 7,900 yr B.P. Development of soil 3 at the top of unit III was underway by at least 7,900 ± 160 yr B.P. This paleosol was truncated and then mantled by alluvium composing unit II sometime between ca. 7,900 and 1,660 yr B.P. Mean residence time for organic carbon at the top of soil 2 indicates that the surface of unit II was stable by at least 1,660 ± 70 yr B.P. Aggradation of unit I and concomitant burial of soil 2 occurred sometime after ca. 1,660 yr B.P.

The episode of stream incision that converted the late Holocene floodplain into a terrace (T-1) probably took place soon before ca. 1,600 yr B.P., thereby isolating the T-1 surface from frequent low-magnitude floods. This isolation would account for development of soil 2 at the top of unit II. As noted earlier, unit II appears to be mantled by Historic overbank deposits composing unit I. If the overbank alluvium is Historic in age, it was deposited on the T-1 surface at or before A.D. 1951, which is the last time that floodwaters covered the T-1 terrace at locality PR-4 (Don Rucker, personal communication, 1988). According to local landowners, both the Pawnee River and Buckner Creek have been downcutting since about A.D. 1970.

Locality PR-5 Locality PR-5 is situated in the Pawnee River valley, 51 km (32 mi) upstream from the confluence of that stream with the Arkansas River (fig. 16). The Pawnee River is a fifth-order stream with a gradient of 1.52 m/km (8.03 ft/mi) at this locality. The valley trends northwest-southeast, and its floor is 2.4 km (1.5 mi) wide. Four landforms compose the valley floor at locality PR-5: a modern floodplain (T-0), a low terrace (T-1), an intermediate terrace (T-2), and a high terrace (T-3) (fig. 32). The T-0 surface is 30–100 m (100–330 ft) wide and is separated from the adjacent T-1 surface by a steep 4-m-high (13-ft-high) scarp. T-1 is a paired terrace, and its broad, flat surface dominates the valley floor. A gently sloping 2-m-high (7-ft-high) scarp separates the T-1 surface from the T-2 surface. The T-2 terrace also is a paired surface, but it is relatively narrow compared to the T-1 terrace (fig. 32). A moderately sloping 3-m-high (10-ft-high) scarp separates the T-2 surface from the T-3 surface. The T-3 terrace has a gently sloping surface that merges with the valley walls.

A 35-m-long (115-ft-long) trench silo (Burdett trench) extends from the base of the T-0/T-1 scarp back into the T-1 fill (fig. 33). The trench, which is 3.50 m (11.5 ft) deep at its north end, provided an opportunity to examine a relatively thick section of T-1 fill. In addition, a core was taken from the bottom of the trench (north end) to a depth of 4.25 m (13.9 ft). Altogether, 7.75 vertical meters (25.4 ft) of T-1 fill (core + trench wall) were examined and described at the Burdett locality. Also, a single soil sample was collected for radiocarbon dating.

In addition to examining the T-1 fill, I inspected alluvial deposits and soils beneath the T-0 surface in a cutbank

Figure 28. Rucker section at locality PR-4.

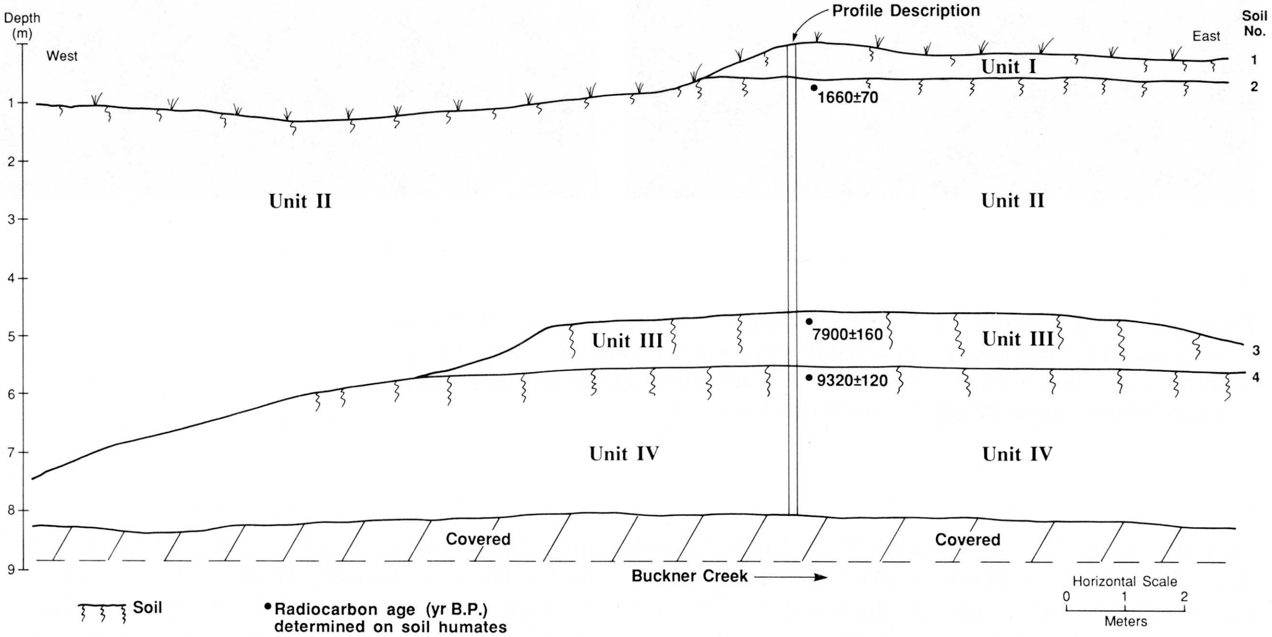

Figure 29. Cross-sectional diagram of the Rucker section showing stratigraphic units, soils, and radiocarbon ages.

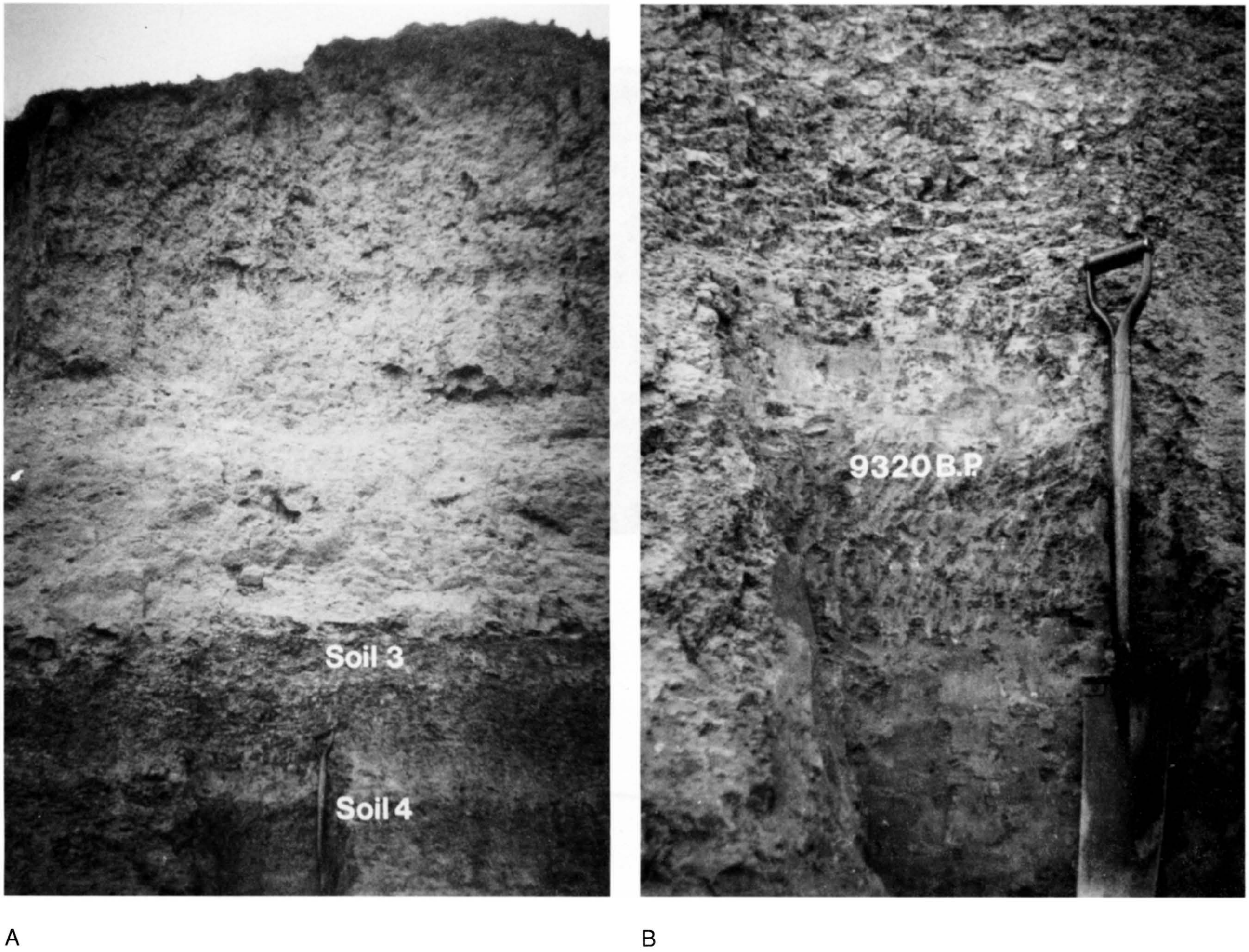

Figure 30. Rucker section. (A) Soils 3 and 4 at the base of the exposure. (B) Strong structural development in the truncated Bt horizon of soil 3 and moderate development in the truncated Bt horizon of soil 4. Radiocarbon ages determined on humates from the upper 20 cm of these buried soils.

exposure 40 m (131 ft) southeast of the Burdett trench (fig. 32). Also, two cores were taken from T-0 fill at locations between the cutbank and the trench (fig. 32). The cores were used to determine whether or not T-0 is an erosional surface cut into T-1 fill, that is, a fillstrath terrace.

Three stratigraphic units and three buried paleosols were identified below the T-1 surface at the Burdett trench (fig. 33). The lowest stratigraphic unit (unit III) is at least 2.83 m (9.28 ft) thick and consists of calcareous fine-grained alluvium. Sandy loam composing the lower 55 cm (1.8 ft) of the core grades upward to silt loam. A paleosol (soil 4) with Bk1–Bk2–BCk–C horizonation is developed at the top of unit III (see appendix table A.6); the A horizon apparently was removed by erosion before burial. The 4Bkb horizon (4Bkb1 + 4Bkb2) is 66 cm (2.2 ft) thick and is a brown (10YR 5/3, dry) silty clay loam. There are many films and threads of calcium carbonate (stage I+) throughout the 4Bkb horizon. Evidence of secondary carbonates is absent below the 4BCk horizon, but alluvium composing the C horizons of soil 4 appears to be calcareous based on reaction to HCl. The 4C1 and 4C2 horizons are massive in structure and have silt loam texture. The alluvium coarsens downward to fine sandy loam in the 4C3 horizon, and bedding is preserved from the top of the 4C3 horizon to the bottom of the core.

Unit II is 2.76 m (9.06 ft) thick and is composed of calcareous fine-grained alluvium. A paleosol (soil 3) with

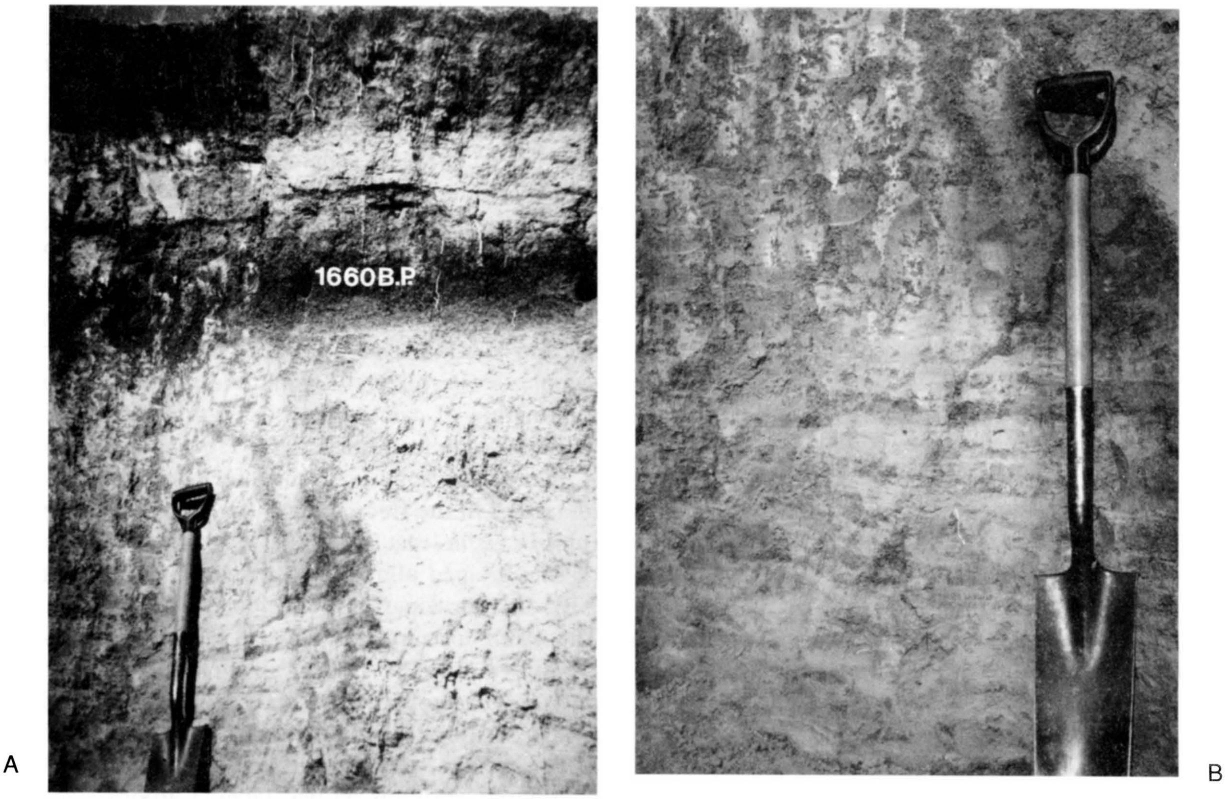

Figure 31. Upper portion of the Rucker section. (A) Soils 1 and 2 developed at the top of units I and II, respectively. Radiocarbon age determined on humates from the upper 20 cm of soil 2. (B) Horizontal bedding in unit II below the 2Ab horizon.

A–Bw–BC horizonation is developed at the top of unit II. The 3Ab horizon is 44 cm (1.4 ft) thick and is a very dark grayish brown (10YR 3/2, dry) silt loam. No secondary carbonates were observed in the 3Ab horizon, and its matrix is noncalcareous. Humates from the upper 20 cm (0.66 ft) of the 3Ab horizon yielded a radiocarbon age of 1,850 ± 80 yr B.P.

A thin, weakly developed cambic (Bw) horizon is present in soil 3. The 3Bwb horizon is 25 cm (0.82 ft) thick and is a yellowish-brown (10YR 5/4, dry) silt loam. Although no secondary carbonates were observed in the 3Bwb horizon, its matrix is calcareous. Soil 3 dips southward toward the edge of the T-1/T-0 scarp (fig. 33).

The upper unit (unit I) of the T-1 fill is 2.76 m (9.06 ft) thick and is composed of calcareous fine-grained alluvium. Thin horizontal beds of silty clay loam, silt loam, loam, and fine sandy loam make up the lower 1.91 m (6.27 ft) of unit I. The remainder of this unit consists of silt loam that has been slightly altered by pedogenesis. A thin, faint buried soil (soil 2) with A–C horizonation was detected in the upper 85 cm (2.8 ft) of unit I (fig. 33). The 2Ab horizon is only 22 cm (0.72 ft) thick and has weak, fine, granular structure. The modern surface soil (soil 1) at the top of unit I also is weakly developed. Soil 1 is characterized by a 12-cm-thick (0.39-ft-thick) Ap horizon above an AC horizon.

Based on the radiocarbon age of humates from the upper 20 cm (0.66 ft) of soil 3, unit I aggraded sometime after ca. 1,850 yr B.P. The weakly developed soils and well-preserved bedding in unit I suggest that it is composed of Historic alluvium. Alluvium composing units II and III accumulated sometime before ca. 1,850 yr B.P.

As noted earlier, valley fill beneath the T-0 surface is exposed in a cutbank 40 m (131 ft) southeast of the Burdett trench. The section, which is 2.6 m (8.5 ft) thick and nearly 4 m (13 ft) long, has been examined and described (see appendix table A.7).

Two stratigraphic units and one buried soil were observed in the upper 2.60 m (8.53 ft) of the T-0 fill. The lowest stratigraphic unit (unit II) is at least 1.55 m (5.09 ft) thick and is composed of calcareous fine-grained alluvium. A thin paleosol (soil 2) with A–AC–C hori-

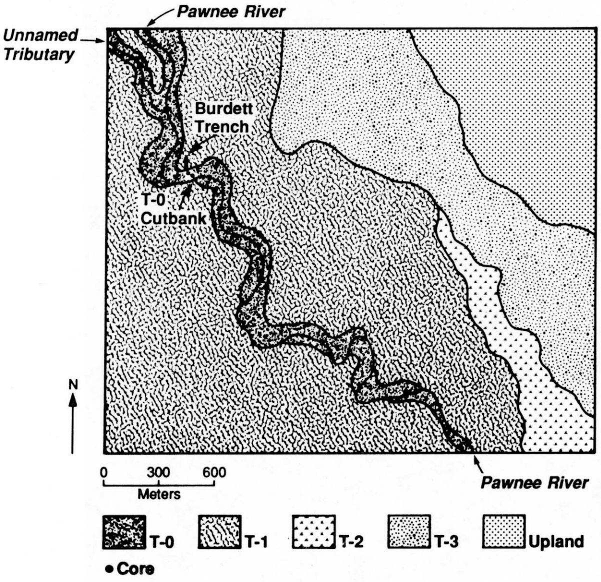

Figure 32. Landform map of locality PR-5 showing location of Burdett trench, T-0 cutbank, and cores.

zonation is developed at the top of unit II. The 2Ab horizon is 35 cm (1.1 ft) thick and is a dark-grayish-brown (10YR 4/2, dry) silt loam. The fill is massive below the 2ACb horizon, and thin beds of clayey and loamy alluvium are common in the 2C horizon.

Unit I is 1.05 m (3.4 ft) thick and also is composed of calcareous fine-grained alluvium. The modern surface soil (soil 1) at the top of this unit is a Haplustoll with A–AC–C horizonation. The A horizon is 25 cm (0.82 ft) thick and is a grayish-brown (10YR 5/2, dry) silt loam. The AC horizon is 30 cm (0.98 ft) thick and is a light-brownish-gray (10YR 6/2, dry) silt loam. Thin faint beds of loam, silt loam, and silty clay loam were observed in the lower 30 cm (0.98 ft) of the C horizon.

Two cores were taken from the T-0 fill to determine its stratigraphic relationship to the T-1 fill. Based on evidence from these cores, the T-0 fill is laterally inset against the T-1 fill (fig. 33). Hence the modern floodplain is not an erosional surface cut across the T-1 fill.

Locality PR-6 Locality PR-6 is situated in the Pawnee River valley, 61 km (38 mi) upstream from the confluence of that river with the Arkansas River (fig. 16). At this locality the Pawnee River is a fifth-order stream with a gradient of 1.25 m/km (6.6 ft/mi). The valley floor is 3.2 km (2.0 mi) wide and is composed of four landforms: the modern floodplain (T-0), a low terrace (T-1), an intermediate terrace (T-2), and a high terrace (T-3) (fig. 34). The modern floodplain is 20–150 m (66–490 ft) wide and is separated from the T-1 surface by a 4-m-high (13-ft-high) scarp. T-1 is a paired terrace, and its broad, flat surface is separated from the T-2 surface by a 1.5-m-high (4.9-ft-high) scarp. The broad, flat surface of the T-2 terrace dominates the valley floor at locality PR-6 (fig. 34). This paired terrace is separated from the T-3 surface by a gently sloping 2-m-high (7-ft-high) scarp.

Subsurface investigations at locality PR-6 focused on T-1 fill exposed in several cutbanks along the Pawnee River. A representative cutbank, referred to as the Foos section, was selected for detailed study (fig. 35). The Foos section is described in appendix table A.8, and soil samples were collected for particle-size analysis and determination of calcium carbonate content. In addition, three soil samples were collected for radiocarbon dating.

Four stratigraphic units and three buried paleosols were identified in the Foos section (fig. 36). The lowest unit (unit IV) is at least 94 cm (3.1 ft) thick and is composed of fine-grained alluvium. A paleosol (soil 4) with Ak–ABk–Btk horizonation is developed at the top of this unit. The 4Akb horizon is 54 cm (1.8 ft) thick and is a grayish-brown (10YR 5/2, dry) silty clay loam. The 4Btkb horizon is a brown (10YR 5/3, dry) silty clay. There is moderate, fine, subangular-blocky structure within the 4Btkb horizon, and clay illuviation is indicated by discontinuous argillans on ped faces. Carbonate morphology is weak (stage I) in the 4Akb and 4Btkb horizons. Although a few calcium carbonate films, threads, and concretions were observed in soil 4, carbonate content is relatively low, ranging from 2.5% to 4.1% (table 2).

Unit III is 2.26 m (7.41 ft) thick and is composed of calcareous fine-grained alluvium. Loam interbedded with fine sandy loam composes the lower 69 cm (2.3 ft) of unit III. This stratified alluvium grades upward to massive silty clay loam composing the upper 1.15 m (3.77 ft) of the unit. A paleosol (soil 3) with A–Bk–C horizonation is developed at the top of unit III. The 3Ab horizon is 30 cm (0.98 ft) thick and dark grayish brown (10YR 4/2, dry). Carbonate content increases from 2.2% in the 3Ab horizon to 6.2% in the 3Bkb1 horizon (table 2). Films and threads of calcium carbonate in the 3ABkb horizon (stage I+) extend down into the 3Bkb horizon. The 3Bkb horizon (3Bkb1 + 3Bkb2) is 70 cm (2.3 ft) thick and is a pale-brown (10YR 6/3, dry) silty clay loam. Bedding is faint in the lower 10 cm (0.32 ft) of the 3BCkb horizon but becomes distinct down through the 3C horizon.

Unit II is 65 cm (2.1 ft) thick and also is composed of calcareous fine-grained alluvium. The alluvium fines upward from silt loam in the lower half of the unit to silty clay in the upper half. A thin paleosol (soil 2) with A–AC horizonation is developed at the top of unit II. The 2Ab horizon is 36 cm (1.2 ft) thick and grayish brown (10YR 5/2, dry). There is no evidence of clay illuviation or secondary carbonates in soil 2.

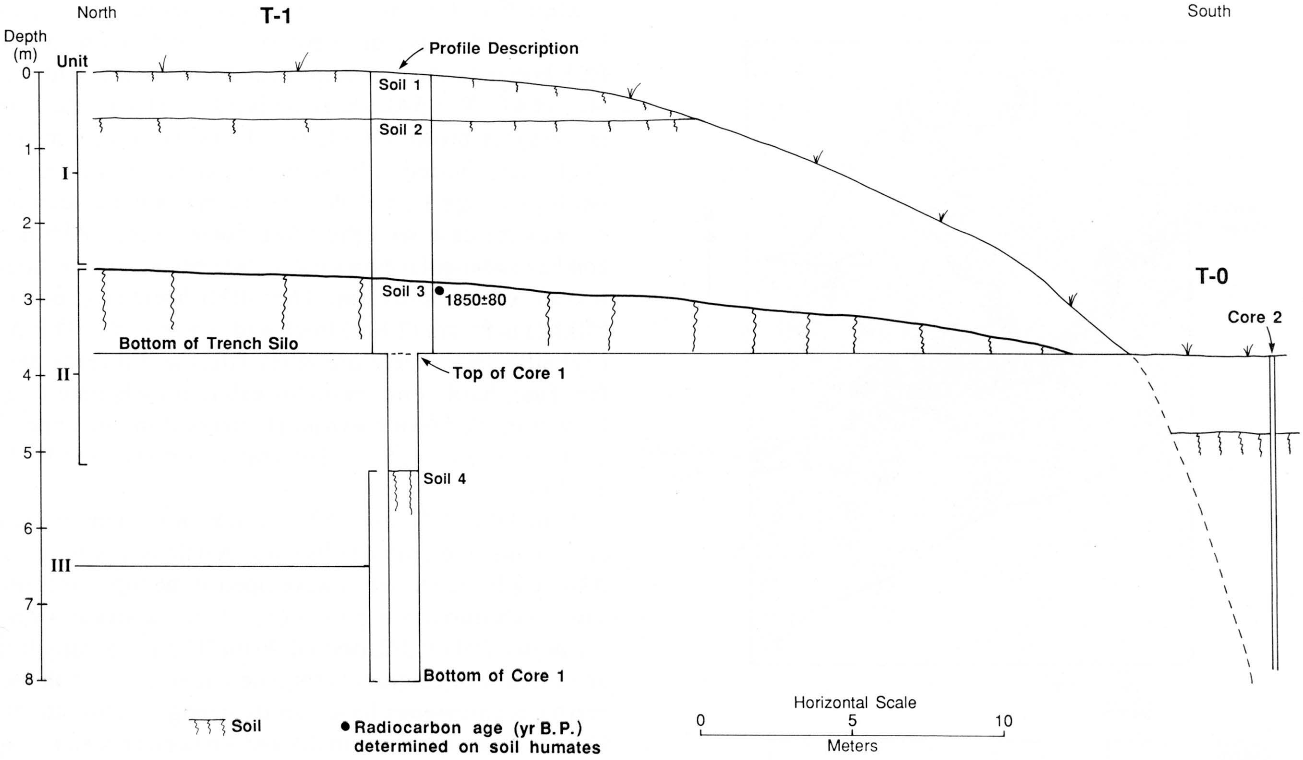

Figure 33. Cross-sectional diagram of T-1 and T-0 fill at locality PR-5. Stratigraphic information was gleaned from cores, a cutbank exposure, and the Burdett trench.

Unit I is 60 cm (2.0 ft) thick and is composed of calcareous loamy alluvium. The modern surface soil developed at the top of unit I is a thin Haplustoll (soil 1) with A–AC horizonation. The A horizon is 20 cm (0.66 ft) thick and is a grayish-brown (10YR 5/2, dry) loam. Bedding is preserved at a depth of only 40 cm (1.3 ft) below the land surface, and there is no evidence of clay illuviation or secondary carbonate accumulation in soil 1. Weak pedogenic modification of unit I suggests that it is young (Historic?).

Mean residence times determined on organic carbon from buried paleosols at section 14NS316 are interpreted as the minimum ages of these soils; hence they provide maximum and/or minimum ages for T-1 deposits. Humates from the upper 20 cm (0.66 ft) of soils 4, 3, and 2 yielded radiocarbon ages of 7,150 ± 110, 4,350 ± 50, and 2,050 ± 80 yr B.P., respectively (fig. 36). Hence unit IV is at least ca. 7,150 years old, and unit III aggraded sometime between ca. 7,150 and 4,350 yr B.P. Sediment composing unit II accumulated sometime after ca. 4,300 yr B.P. but before ca. 2,000 yr B.P. Unit I aggraded sometime after ca. 2,000 yr B.P.

Locality PR-7 Locality PR-7 is situated in the Pawnee River valley, 80 km (50 mi) upstream from the confluence of that river with the Arkansas River (fig. 16). The Pawnee River is a fifth-order stream and has a gradient of 2.1 m/km (11 ft/mi) at this locality. The valley floor is 3.6 km (2.2 mi) wide and is composed of four landforms: a modern floodplain (T-0), a low terrace (T-1), an intermediate terrace (T-2), and a high terrace (T-3) (fig. 37). The T-0 surface is 20–50 m (66–160 ft) wide and is separated from the T-1 surface by a steep 5-m-high (16-ft-high) scarp (fig. 38). T-1 is a paired terrace, and its broad, flat surface composes most of the valley floor (fig. 37). Remnants of the T-2 terrace occur on both sides of the valley floor in the western half of locality PR-7. Where the T-2 terrace is preserved, its surface is separated from the T-1 terrace by a 2-m-high (7-ft-high) scarp. Also, a 2-m-high (7-ft-high) scarp separates the T-2 terrace from the T-3 terrace where both terraces occur. Remnants of the T-3 terrace are scattered along the margins of the valley floor (fig. 37).

A 9.9-m-thick (32-ft-thick) section of T-1 fill is exposed in a steep cutbank along the Pawnee River at locality PR-7 (fig. 39). This cutbank, referred to as the

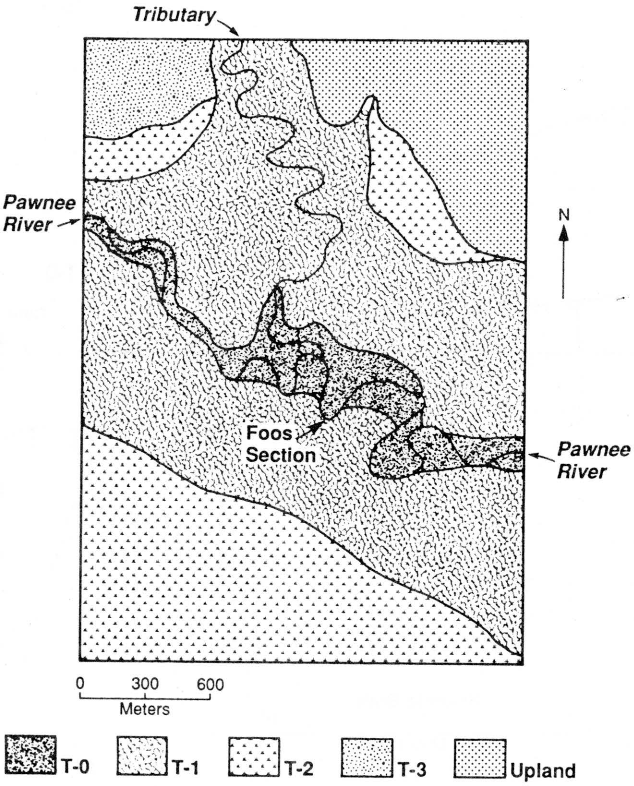

Figure 34. Landform map of locality PR-6 showing location of Foos section.

McCreight section, is described in appendix table A.9, and two soil samples were collected for radiocarbon dating.

Six stratigraphic units and five buried soils have been identified in the McCreight section (fig. 40). The lowest stratigraphic unit (unit VI) is at least 2.07 m (6.79 ft) thick and is composed of calcareous fine-grained alluvium. A paleosol (soil 6) with Ak–Bk–Ck horizonation is developed at the top of unit VI (figs. 40 and 41). The 6Akb horizon is 30 cm (0.98 ft) thick and is a brown (10YR 4/3, dry) silty clay loam. Films and threads of carbonate are common (stage I+), and the heavy texture of alluvium at the top of unit VI has imparted subangular-blocky structure within this former surface horizon.

The 6Bkb horizon is 61 cm (2.0 ft) thick and is a brown (10YR 5/4, dry) silty clay. This horizon has medium subangular-blocky structure and many carbonate films and threads and few fine, soft carbonate masses (stage II). Films and threads of calcium carbonate (stage I+) are also present in the 6BCkb and 6Ck horizons. The 6Ck horizon consists of pale-brown (10YR 6/3, dry) stratified silty clay loam.

Unit V is 1.30 m (4.27 ft) thick and is composed of fine-grained alluvium. A paleosol (soil 5) with Ak–Bk–BCk horizonation is developed at the top of this unit (figs. 40 and 41). The 5Akb horizon is 55 cm (1.8 ft) thick and is a grayish-brown (10YR 5/2, dry) silty clay loam. This thick, dark buried A horizon has weak carbonate morphology (stage I), and the soil matrix is noncalcareous. As was the case with the 6Akb horizon, the 5Akb horizon has subangular-blocky structure because of the heavy texture of the alluvium. The 5Bkb horizon (5Bkb1 + 5Bkb2) is 85 cm (2.8 ft) thick and is a brown (10YR 5/3, dry) silty clay. There are many films and threads and a few fine, hard concretions of calcium carbonate (stage II) within the 5Bkb horizon. Humates from the upper 20 cm (0.66 ft) of soil 5 yielded a radiocarbon age of 10,240 ± 120 yr B.P.

Unit IV is 1.32 m (4.33 ft) thick and is composed of calcareous fine-grained alluvium. A paleosol (soil 4) with Ak–ACk horizonation is developed at the top of this unit. The 4Akb horizon is 55 cm (1.8 ft) thick and is a grayish-brown (10YR 5/2, dry) silt loam. There are many films and threads of calcium carbonate (stage I+), and the soil matrix is calcareous based on its strong reaction to HCl. Carbonate morphology in the 4ACkb horizon also is stage I+.

A paleochannel is cut into units IV and V (figs. 39 and 40). This channel is filled with very pale brown (10YR 7/3, dry) fine sandy loam and loamy fine sand (unit IIIb). The channel fill and unit IV are mantled by a 1.68-m-thick (5.51-ft-thick) stratum (unit IIIa) of fine-grained alluvium (fig. 40). A paleosol (soil 3) with Ak–ACk–Ck horizonation is developed at the top of unit IIIa. The 3Akb horizon is 47 cm (1.5 ft) thick and is a brown (10YR 4/3, dry) silt loam. Carbonate morphology is weak (stage I) in the 3Akb horizon but becomes better developed (stage II) in the 3ACkb horizon. Humates from the upper 20 cm (0.66 ft) of the 3Akb horizon yielded a radiocarbon age of 7,720 ± 110 yr B.P.

Unit II is 1.40 m (4.59 ft) thick and is composed of calcareous fine-grained alluvium. A paleosol (soil 2) with Ak–ACk–C horizonation is developed at the top of this unit. The 2Akb horizon is 35 cm (1.1 ft) thick and is a brown (10YR 4/3, dry) silt loam. Carbonate morphology is weak (stage I) in soil 2, and the soil matrix is moderately calcareous based on its reaction to HCl. The lower 80 cm (2.6 ft) of unit II (2C horizon) consists of stratified vertical-accretion deposits. In the 2C horizon, dark-brown strata of silty clay and silty clay loam are separated by pale-brown strata of silt loam and very fine sandy loam.

Unit I is 1.90 m (6.23 ft) thick and also is composed of calcareous fine-grained alluvium. The modern surface soil (soil 1) at the top of unit I has a moderately devel-

Figure 35. Foos section at locality PR-6.

oped A–ABk–Bk–BCk–C profile. The A horizon is 55 cm (1.8 ft) thick and is a brown (10YR 5/3, dry) to dark-grayish-brown (10YR 4/2, dry) silt loam. No secondary carbonates were observed in the A horizon, but the soil matrix is calcareous based on its strong reaction to HCl. A few films and threads of calcium carbonate (stage I) appear in the ABk horizon, and carbonate morphology increases to stage II in the Bk horizon. The Bk horizon is 49 cm (1.6 ft) thick and is a brown (10YR 5/3, dry) silty clay loam. There is medium subangular-blocky structure in the Bk horizon, and secondary carbonates occur as films, threads, and fine soft and hard concretions (stage II). Carbonate morphology weakens in the BCk horizon and does not exceed stage I in the underlying C horizon. The C horizon is massive and is composed of calcareous silt loam.

Based on mean residence time for organic carbon from the upper 20 cm (0.66 ft) of soil 5, alluvium composing units VI and V accumulated sometime before ca. 10,200 yr B.P. The fine texture of alluvium composing these units is typical of distal floodplain deposits. Aggradation of unit VI was followed by a period of floodplain stability and soil development (soil 6). Renewed alluviation resulted in burial of soil 6 beneath vertical-accretion deposits composing unit V. The floodplain stabilized again at ca. 10,200 yr B.P., which is the radiocarbon age determined on humates from the upper 20 cm (0.66 ft) of soil 5. Soil 5 was buried by alluvium composing unit IV sometime after ca. 10,200 yr B.P. but before ca. 7,720 yr B.P. During this same period, a deep channel was cut into units IV and V, and soil 4 developed at the top of unit IV. Before ca. 7,720 yr B.P. the paleochannel was filled with sandy alluvium composing unit IIIb. Aggradation continued, and fine-grained alluvium composing unit IIIa mantled both the channel fill and soil 4. Mean residence time for organic carbon from the upper 20 cm (0.66 ft) of soil 3 indicates that aggradation of unit IIIb ceased and soil development was underway on the early Holocene floodplain by at least ca. 7,720 yr B.P. Soil 3 was buried by flood deposits composing unit II sometime after ca. 7,720 yr B.P. An episode of landscape stability resulted in the development of soil 2 at the top of unit II. Renewed alluviation and concomitant aggradation of unit I resulted in burial of soil 2. Subsequent downcutting by the Pawnee River isolated the T-1 surface from frequent floods, thereby allowing soil 1 to develop at the top of unit I. The exact timing of this downcutting event is unknown, but temporal data from other localities suggest that it occurred sometime between ca. 2,000 and 500 yr B.P.

Locality PR-8 Locality PR-8 is situated in the Pawnee River valley, 89.5 km (55.6 mi) upstream from the confluence of that river with the Arkansas River (fig. 16). The Pawnee River is a fifth-order stream and has a gradient of 2.3 m/km (12 ft/mi) at this locality. The valley floor is 2.4 km (1.5 mi) wide and is composed of four landforms: a modern floodplain (T-0), a low terrace (T-1), an intermediate terrace (T-2), and a high terrace (T-3) (fig. 42). The T-0 surface is 20–150 m (66–490 ft) wide and is separated from the T-1 surface by a steep 4-m-

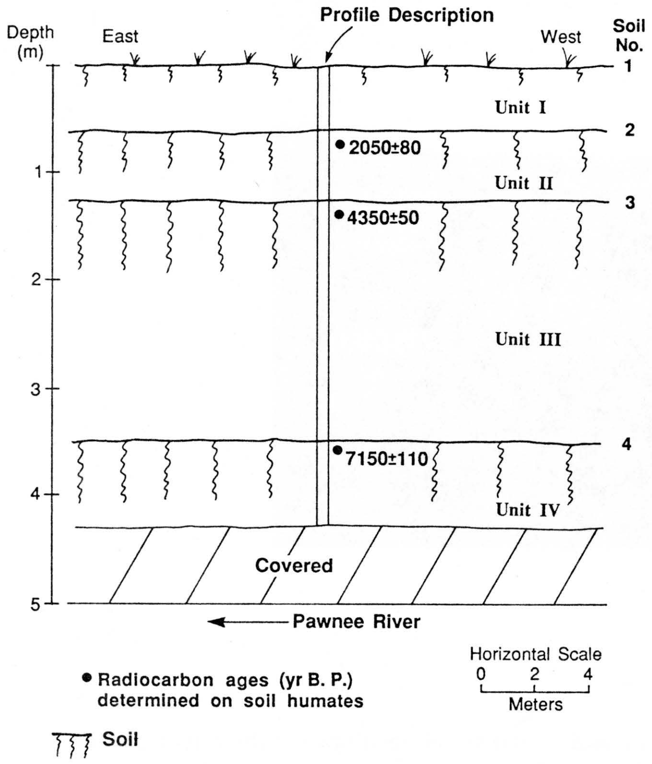

Figure 36. Cross-sectional diagram of the Foos section showing stratigraphic units, buried paleosols, and radiocarbon ages.

high (13-ft-high) scarp. T-1 is a paired terrace, and its broad, flat surface composes most of the valley floor. Remnants of the T-2 terrace occur on both sides of the valley floor in the western half of locality PR-8 but are limited to the northern side in the eastern half. Where the T-2 terrace is present, its surface is separated from the T-1 terrace by a 2-m-high (7-ft-high) scarp. Also, a 2-m-high (7-ft-high) scarp separates the T-2 and T-3 terraces where both terraces are preserved. Remnants of the T-3 terrace are scattered along the margins of the valley floor (fig. 42).

Lateral migration of the Pawnee River at locality PR-8 has created many long, steep cutbanks that expose thick sections of T-1 fill. The T-1 fill also is exposed in several deep trench silos. The stratigraphy observed in the silos and cutbanks is basically the same from one exposure to the next. A paleosol with a thick, dark A horizon is typically buried beneath about 2.5 m (8.2 ft) of loamy alluvium (figs. 43 and 44). The paleosol is developed in fine loamy sediment that grades downward into sandy stratified fill. Although no paleosols were detected below this distinct buried soil, buried soils with weakly expressed A–AC profiles are often developed in the alluvium above it.

A representative cutbank, referred to as the Patchen section, was selected for detailed study of the T-1 fill (fig. 45). The Patchen section is described in appendix table A.10, and a soil sample was recovered for radiocarbon dating.

Two stratigraphic units and four buried soils were identified in the Patchen section (fig. 46).The lowest stratigraphic unit (unit II) is at least 4 m (13 ft) thick. The upper 2.69 m (8.83 ft) of unit II consists of fine-grained calcareous alluvium. Below a depth of 2.69 m, however, the alluvium is sandy. Sedimentary features, including foreset crossbedding and horizontal laminae, were observed in the sandy fill. The alluvium above the stratified sand is massive and fines upward from loam to silt loam.

A paleosol (soil 5) with A–Bw–BCk–C horizonation is developed at the top of unit II (fig. 46). The 5Ab horizon (5Ab1 + 5Ab2) is 46 cm (1.5 ft) thick and is a dark-gray (10YR 4/1, dry) to grayish-brown (10YR 5/2, dry) silt loam. No secondary carbonates were observed in the 2Ab horizon, and the soil matrix is slightly calcareous based on its weak reaction to HCl. Humates from the upper 20 cm (0.66 ft) of soil 5 yielded a radiocarbon age of 1,940 ± 60 yr B.P.

The 5Bwb horizon is 33 cm (1.1 ft) thick and is a yellowish-brown (10YR 5/4, dry) silt loam. This cambic horizon has weak, fine subangular-blocky structure. There is no evidence of secondary carbonates, but the matrix is calcareous.

Unit I is 2.51 m (8.23 ft) thick and is composed of calcareous fine-grained alluvium. Three buried paleosols (soils 2, 3, and 4) were detected in this unit (figs. 45 and 46). All these soils and the modern surface soil (soil 1) at the top of unit I have weakly developed A–AC profiles. The buried A horizons are dark brown (10YR 4/3, dry) and 20–30 cm (0.66–0.98 ft) thick.

Based on the radiocarbon age of humates from soil 5, the underlying alluvium accumulated sometime before ca. 1,900 yr B.P. The late Holocene floodplain of the Pawnee River was relatively stable by at least 1,900 yr B.P., but renewed alluviation resulted in aggradation of unit I and burial of soil 5. Accumulation of sediments composing unit I was interrupted by three episodes of landscape stability and concomitant soil formation. The thin, faint A–AC profiles of soils 2, 3, and 4 suggest that these episodes of stability were of short duration. Also, the weakly developed surface soil at the top of unit I is indicative of a short period of landscape stability. Hence the T-1 surface at locality PR-8 appears to be young.

Locality PR-9 Locality PR-9 is situated in the Pawnee River valley, 99.2 km (61.6 mi) upstream from the confluence of that river with the Arkansas River (fig. 16). The Pawnee River is a fifth-order stream and has a gradient of 2.2 m/km (12 ft/mi) at this locality. The valley

Table 2. Particle-size distribution and calcium carbonate content of sediment samples from the Foos section at locality PR-6

		Particle-size distribution (mm)										
		Sand[a]						Silt				
Depth (cm)	Soil horizon	VC % (0.25–1.0)	C % (0.10–0.5)	M % (2.0–0.25)	F % (0.02–0.10)	VF % (0.05–0.05)	Total % (2.0–0.05)	Fine % (0.02–0.002)	Total % (0.05–0.002)	Total clay % (<0.002)	Texture class[b]	$CaCO_3$ (%)
0–20	A	0.2	1.6	7.6	15.9	12.9	38.2	10.4	43.3	18.5	L	8.3
20–60	AC	0.1	0.4	1.9	20.1	16.4	38.9	9.3	48.7	12.4	L	12.2
60–96	2Ab	0.1	0.0	0.1	0.6	1.2	2.0	35.3	47.5	50.5	SiC	13.3
96–125	2ACb	0.1	0.1	1.2	2.4	7.3	11.1	21.3	64.1	24.8	SiL	6.6
125–155	3Ab	0.2	0.1	0.5	0.9	3.5	5.2	28.2	59.6	35.2	SiCL	2.2
155–170	3ABkb	0.0	0.1	0.3	1.3	3.4	5.1	27.4	58.7	36.2	SiCL	4.7
170–200	3Bkb1	0.0	0.1	0.2	0.6	4.7	5.6	18.8	64.8	29.6	SiCL	6.2
200–240	3Bkb2	0.1	0.2	0.3	0.6	2.4	3.6	24.1	69.1	27.3	SiCL	4.4
240–282	3BCkb	0.1	0.2	0.2	0.5	4.6	5.6	20.0	72.2	22.2	SiL	1.3
282–351	3Ck	0.0	0.1	0.2	4.1	10.3	14.7	19.7	62.0	23.3	SiL	1.2
351–405	4Akb	0.0	0.3	0.3	0.7	1.2	2.5	45.6	57.8	39.7	SiCL	2.5
405–420	4ABkb	0.0	0.1	0.2	0.6	0.6	1.5	48.5	56.4	42.1	SiC	3.9
420–445	4Btkb	0.0	0.1	0.1	0.5	0.5	1.2	51.9	52.1	46.7	SiC	4.1

a. VC, very coarse grained; C, coarse-grained; M, medium-grained; F, fine-grained; VF, very fine grained.

b. L, loam; SiL, silt loam; SiCL, silty clay loam; SL, sandy loam; LS, loamy sand.

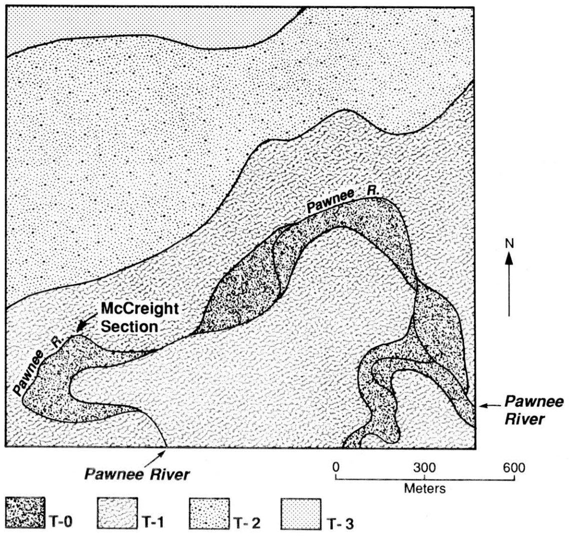

Figure 37. Landform map of locality PR-7 showing the location of the McCreight section.

floor is 3.0 km (1.9 mi) wide and is composed of four landforms: a modern floodplain (T-0), a low terrace (T-1), an intermediate terrace (T-2), and a high terrace (T-3) (fig. 47). The T-0 surface is 120 m (394 ft) wide and is separated from the T-1 surface by a steep 4-m-high (13-ft-high) scarp. T-1 is a paired terrace, and its broad, flat surface dominates the valley floor (fig. 47). Remnants of the T-2 terrace occur on both sides of the valley floor at locality PR-9 and are separated from T-1 by a 2-m-high (7-ft-high) scarp. A 2-m-high (7-ft-high) scarp also separates T-2 from T-3 where both terraces are preserved. The broad, gently sloping surface of the T-3 terrace merges with the valley walls.

The Pawnee River has cut laterally into its modern floodplain at locality PR-9, exposing a long, 2.5-m-thick (8.2-ft-thick) section of T-0 fill. Inspection of the cutbank resulted in the discovery of numerous bones (burned and unburned), potsherds, and chert flakes at a depth of 90–125 cm (3.0–4.10 ft) below the T-0 surface. Probing with a bucket auger revealed that the cultural deposits (site 14HO5) extend far back into the T-0 fill. A portion of the cutbank is described in appendix table A.11, and several pottery fragments were collected for identification.

Two stratigraphic units and one buried soil were observed in the section at site 14HO5 (fig. 48). The lowest stratigraphic unit (unit II) is at least 1.6 m (5.2 ft) thick and is composed of calcareous fine-grained alluvium. A thin paleosol (soil 2) with A–AC–C horizonation is developed at the top of unit II. The 2Ab horizon is 25 cm (0.82 ft) thick and is a dark-grayish-brown (10YR 4/2, dry) silt loam. The underlying alluvium is silty, but there are thin beds of loamy and fine-sandy alluvium in the 2C horizon.

Unit I is 90 m (295 ft) thick and is composed of calcareous silt loam. The modern surface soil (soil 1) at the top of this alluvial unit is a Haplustoll with A–AC–C horizonation. The potsherds recovered from the upper 25 cm (0.82 ft) of the 2Ab horizon were identified as Middle Ceramic (Barry Williams, personal communication, 1988). The Middle Ceramic spans the period 1,000 to 500 yr B.P. Hence unit II is at least 500–1,000 years old, and unit I is less than 500 years old. In addition to providing minimum and maximum ages for stratigraphic units composing T-0 fill, temporal information from site 14HO5 sheds light on the timing of late Holocene entrenchment. Because the T-0 fill had aggraded by ca. 1,000–500 yr B.P., the Pawnee River must have deeply incised its Holocene valley fill, thereby creating the T-1 terrace, sometime before that time.

Locality PR-10 Locality PR-10 is situated in the Pawnee River valley, 115 km (71.4 mi) upstream from the confluence of that river with the Arkansas River (fig. 16). Here, the Pawnee River is a fifth-order stream with a gradient of 1.5 m/km (7.9 ft/mi). The valley floor is 3.2 km (2.0 mi) wide and is composed of three landforms: a narrow modern floodplain (T-0), a low terrace (T-1), and a high terrace (T-3) (fig. 49). The intermediate terrace (T-2) was not observed at locality PR-10.

The Pawnee River has migrated laterally into the T-1 fill at several places at locality PR-10. One of the cutbanks formed by lateral erosion provided an opportunity to examine a 3.4-m-thick (11-ft-thick) section of T-1 fill (fig. 50A). This cutbank exposure, which is referred to as the Fearker section, is described in appendix table A.12, and a soil sample was collected for radiocarbon dating.

Two stratigraphic units and one buried paleosol were identified in the Fearker section (fig. 51). The lowest stratigraphic unit (unit II) is at least 1.98 m (6.50 ft) thick and is composed of calcareous fine-grained alluvium. A dark paleosol (soil 2) with Ak–Bk–BCk horizonation is developed at the top of unit II (fig. 50B). The 2Akb horizon is 53 cm (1.7 ft) thick and is a gray (10YR 5/1, dry) to grayish-brown (10YR 5/2, dry) silt loam. Carbonate threads (stage I) are common in the 2Akb horizon and extend down into the 2Bkb horizon. The 2Bkb horizon is 40 cm (1.3 ft) thick and is a brown (10YR 5/3, dry) silty clay loam. Structural development is relatively weak in the 2Bkb horizon. The underlying 2BCkb and 2Ck horizons have loamy texture, and carbonate morphology is slightly better developed (stage I+) in these horizons. Humates from the upper 20 cm (0.66 ft) of soil 2 yielded a radiocarbon age of 1,710 ± 80 yr B.P.

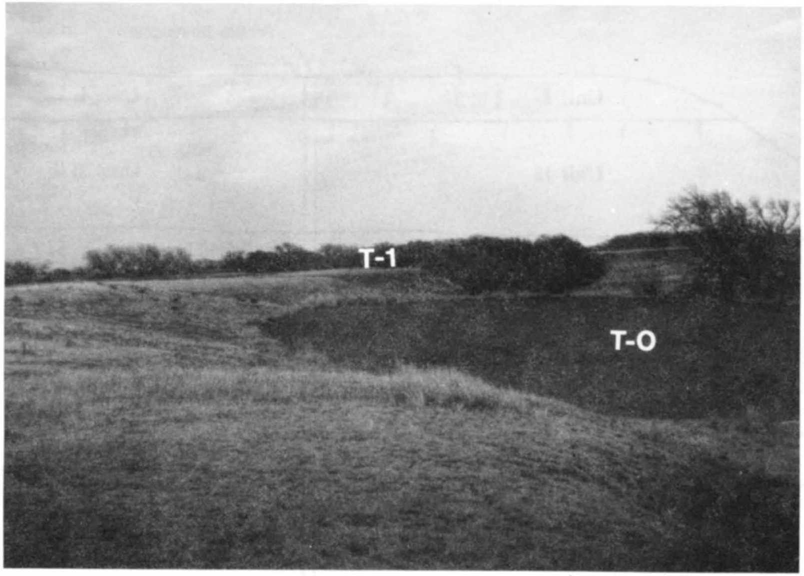

Figure 38. The scarp separating the T-1 and T-0 surfaces at locality PR-7.

Figure 39. McCreight section.

Unit I is 1.42 m (4.66 ft) thick and consists of calcareous fine-grained alluvium. Stratified fine and very fine sandy loam composing the lower 97 cm (3.2 ft) of the unit grades upward to a massive loam. The surface soil (soil 1) at the top of unit I is a Haplustoll with A–AC horizonation. The A horizon is 32 cm (1.0 ft) thick and is a brown (10YR 5/3, dry) loam. The alluvium becomes slightly coarser going from the AC to C1 horizon, and thin horizontal bedding is preserved in the C1 and C2 horizons. Threads of calcium carbonate (stage I) are common in the C2 horizon and extend down into the 2Ab horizon.

Based on the age of humates from soil 2 at the top of unit II, sediment composing unit I accumulated sometime after ca. 1,700 yr B.P. Weak pedogenic alteration of alluvium in unit I suggests that it may be Historic in age.

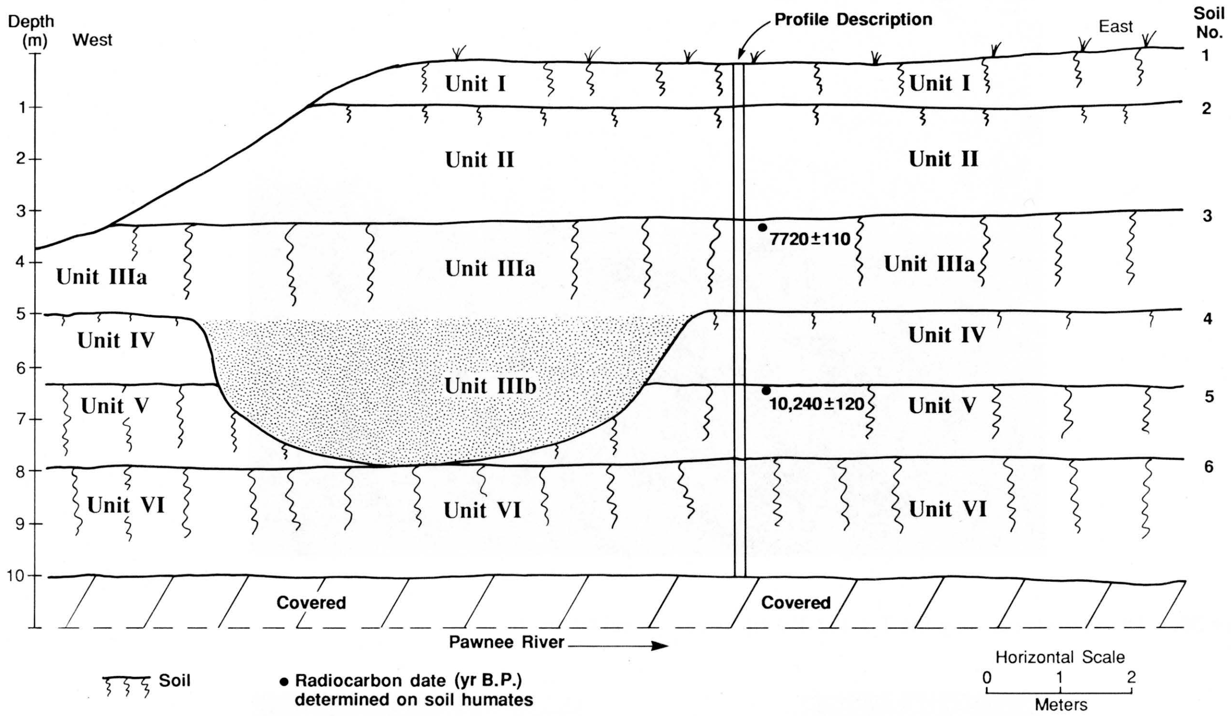

Figure 40. Cross-sectional diagram of the McCreight section showing stratigraphic units, soils, and radiocarbon ages.

Also, the mean residence time of organic carbon from soil 2 indicates that pedogenesis was underway on the late Holocene floodplain by at least ca. 1,700 yr B.P. However, the absolute age of deposits composing unit II is unknown.

The two remaining localities along the main stem of the Pawnee River are examined in the next section. These two localities are in the extreme headwaters of the Pawnee River (fig. 16). Hence they are described as small valleys rather than as large ones.

Small valleys

Locality BC-1 Locality BC-1 is situated in Buckner Creek valley, 46 km (29 mi) upstream from the confluence of that creek with the Pawnee River (fig. 16). Buckner Creek is a fourth-order stream and has a gradient of 3.3 m/km (17 ft/mi) at this locality. The valley trends east-west and is asymmetric, with steep north-facing slopes and gentle south-facing slopes.

The valley floor at locality BC-1 is 50–200 m (164–656 ft) wide and is composed of two landforms: the modern floodplain (T-0) and a low terrace (T-1) (fig. 52). T-1 is a paired terrace throughout most of this locality and is separated from T-0 by a short, steep 3-m-high (10-ft-high) scarp (fig. 53). In some sections of the valley, however, the T-1 terrace has been removed as a result of lateral migration by Buckner Creek. Hence the side slopes of the valley descend to the T-1 surface or merge with the modern floodplain (fig. 52).

Buckner Creek has deeply incised its valley fill, creating many steep cutbanks throughout locality BC-1. A survey of cutbanks resulted in the discovery of site 14HO306 (fig. 52). Buckner Creek migrated into a remnant of the T-1 terrace at site 14HO306, creating a 7.2-m-high (24-ft-high) cutbank that reveals multiple buried paleosols and several prehistoric cultural horizons in the terrace fill (fig. 54). The section at site 14HO306 was selected for study because it appeared to be representative of T-1 fill examined in other sections along Buckner Creek and because it contained stratified archeological materials for radiometric and relative dating.

Three stratigraphic units and five buried paleosols were identified in the section at site 14HO306 (fig. 55). The lowest unit (unit III) is 3.18 m (10.4 ft) thick and consists of gravelly fine sand at its base grading upward to silt loam. A paleosol (soil 6) at the top of unit III has a thick, dark Ak horizon above a thin Bk horizon (see appendix table A.13). The 6Akb horizon (6Akb1 + 6Akb2)

Figure 41. Soils 5 and 6 at the base of the McCreight section. Radiocarbon age determined on humates.

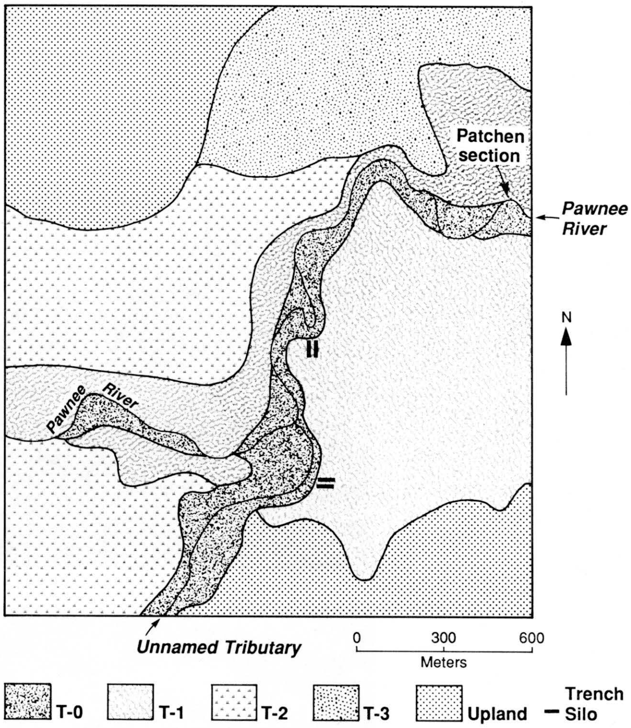

Figure 42. Landform map of locality PR-8 showing the location of the Patchen section.

is 77 cm (2.5 ft) thick and is a dark-grayish-brown (10YR 4/2, dry) to grayish-brown (10YR 5/2, dry) silt loam. Carbonate morphology is weak in the 6Akb horizon (stage I). However, calcium carbonate content steadily increases with depth below the 6Ab1 horizon, reaching a maximum of 8.5% in the 6Ck horizon (table 3). The 6Bkb horizon is 52 cm (1.7 ft) thick and is a brown (10YR 5/3, dry) silt loam. Films and threads of calcium carbonate are common and there are a few small, hard carbonate concretions (stage II) in the 6Bkb horizon.

Cultural materials, including chert flakes, fire-cracked rocks, and burned bones were observed in the upper 15 cm (0.49 ft) and lower 10 cm (0.33 ft) of the 6Akb1 and 6Akb2 horizons, respectively (fig. 55). Although no culturally diagnostic artifacts were recovered from soil 6, charcoal from a hearth 5–10 cm (2–4 in.) beneath the surface of the 6Akb1 horizon yielded a radiocarbon age of 2,620 ± 220 yr B.P. In addition, a radiocarbon age of 2,820 ± 260 yr B.P. was determined on charcoal from a zone of fire-cracked rocks and burned bones 70–75 cm (2.3–2.5 ft) below the surface of the 6Akb1 horizon. The great thickness of soil 6 and the presence of two Late Archaic cultural levels in the 6Akb horizon suggest that soil formation was accompanied by slow aggradation between ca. 2,800 and 2,600 yr B.P. Hence soil 6 appears to be a "cumulative soil" (Nikiforoff, 1949).

Unit II is 2.18 m (7.15 ft) thick and is composed of calcareous loamy alluvium. Soils 5 and 4 are developed in the middle and at the top of unit II, respectively (fig. 55). Soil 5 has a thin, faint Ak–Ck profile that is difficult to trace across the exposure. Soil 4 is characterized by a thick, dark A horizon that clearly stands out in the section (fig. 54). The 4Akb horizon (4Ab + 4Akb) is 61 cm (2.0 ft) thick and has a silt loam texture. Carbonate content steadily increases with depth in soil 4, ranging from 0.4% in the 4Ab horizon to 11.1% in the 4Bkb horizon (table 3). Carbonate morphology reflects this trend, increasing from stage I in the 4Akb horizon to stage II in the 4Bkb horizon. The 4Bkb horizon is 46 cm (1.5 ft) thick and is a brown (10YR 5/3) silt loam. Structural development is weak in the 4Bkb horizon, and there is little evidence of clay illuviation.

Several hearths and lithic artifacts and many burned and unburned bone fragments were observed in soil 4 (figs. 54 and 55). The artifact assemblage included a projectile point characteristic of the Keith variant of the

Figure 43. T-1 fill exposed in cutbanks at locality PR-8. Note the dark buried paleosol (soil 5) in the upper portion of the fill.

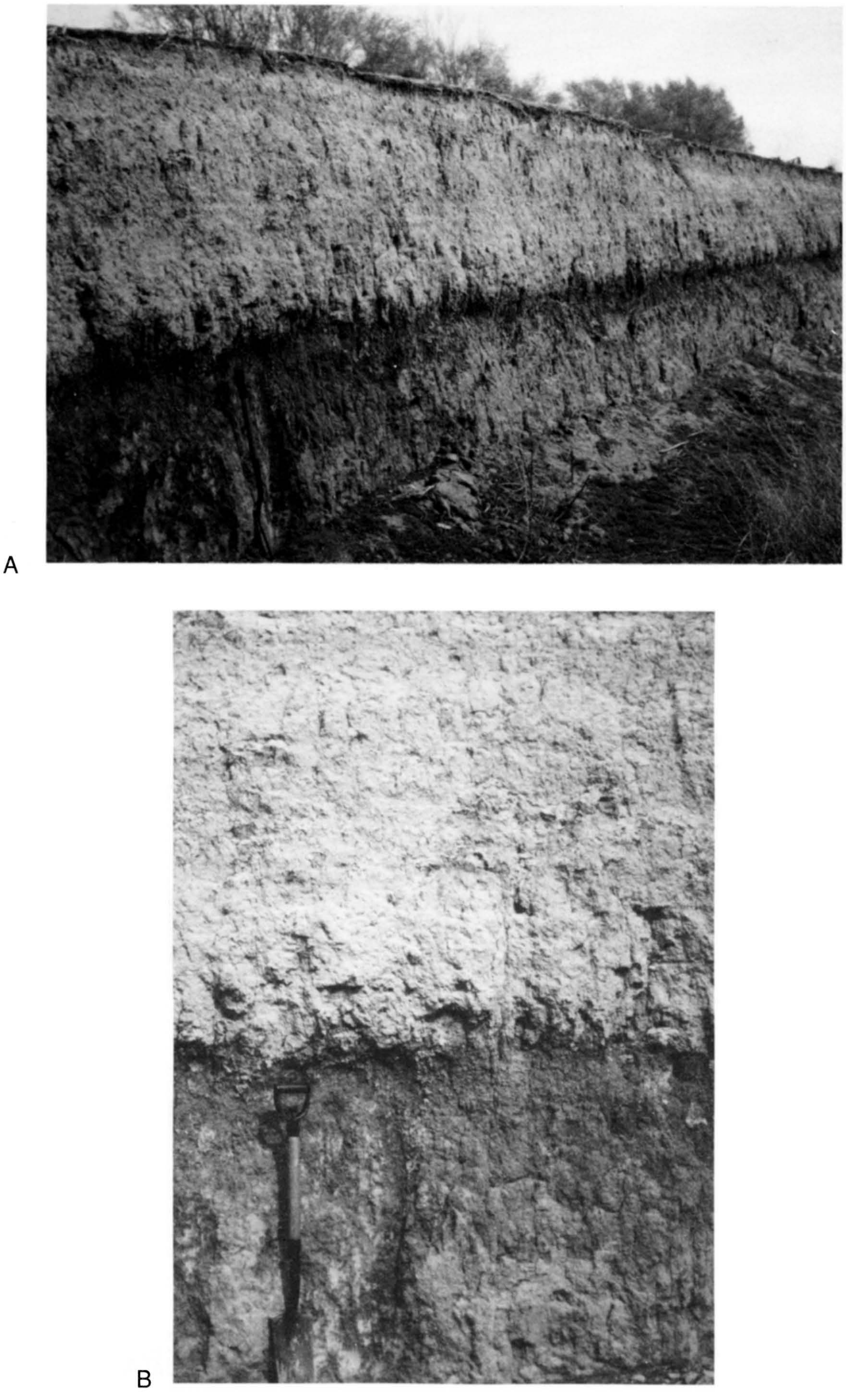

Figure 44. (A) Trench silo cut into T-1 fill. (B) Close-up of soil 5 exposed in the wall of the trench.

Figure 45. Patchen Section at locality PR-8.

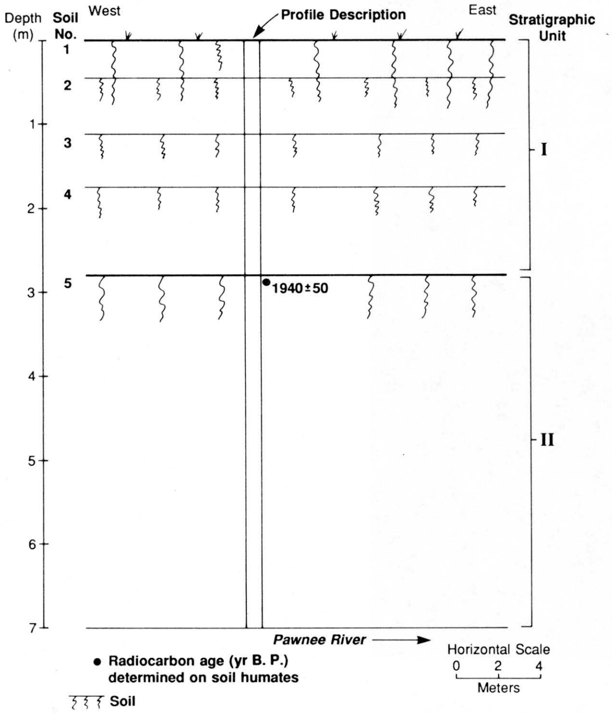

Figure 46. Cross-sectional diagram of the Patchen section showing stratigraphic units, buried soils, and radiocarbon age.

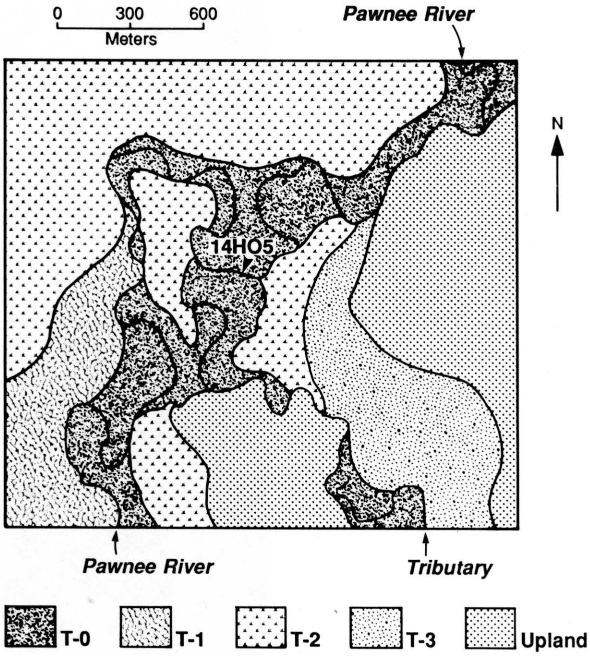

Figure 47. Landform map of locality PR-9 showing the location of site 14HO5.

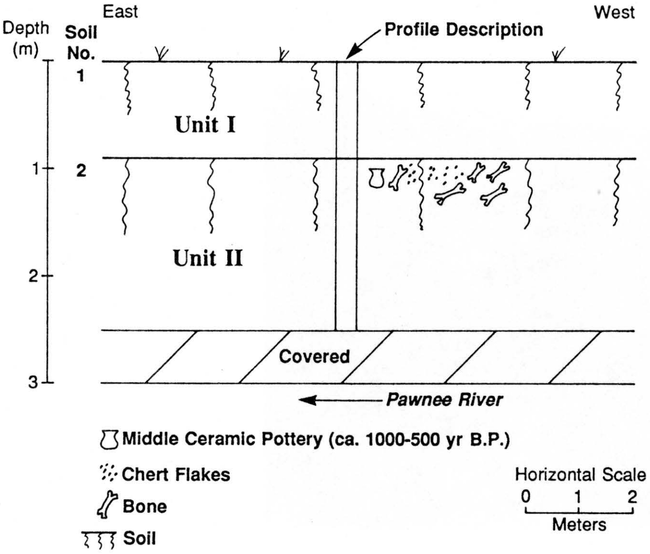

Figure 48. Cross-sectional diagram of the section at site 14HO5 showing stratigraphic units, soils, and cultural horizon.

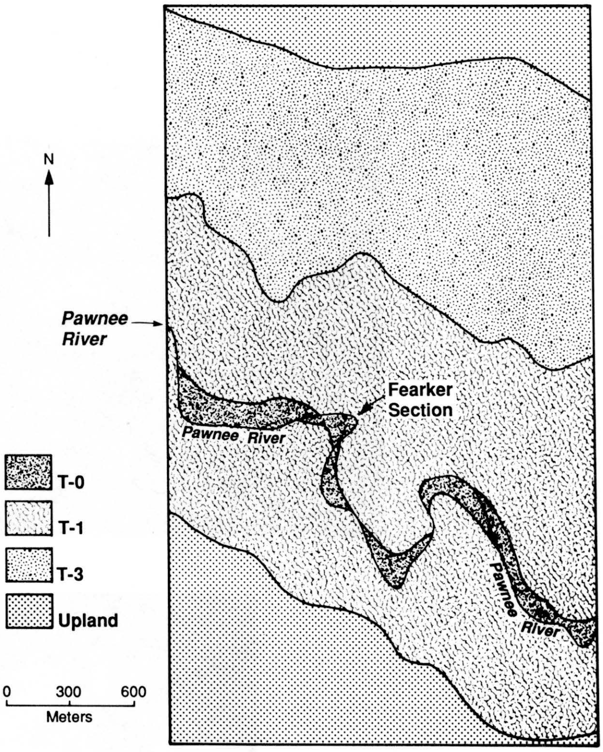

Figure 49. Landform map of locality PR-10 showing the location of the Fearker section.

Plains Woodland period. Radiocarbon assays from the High Plains place the Keith variant from ca. 1,600 to 1,200 yr B.P. (Grange, 1980, p. 126). A radiocarbon age of 1,360 ± 60 yr B.P. determined on humates from the upper 25 cm (0.82 ft) of soil 4 falls within this period.

Unit I, which is at the top of the section, is 1.76 m (5.77 ft) thick and is composed of calcareous fine-grained alluvium. Two paleosols (soils 2 and 3) with thin A horizons are developed in unit I (fig. 55). The Roxbury silt loam, which is developed at the top of unit I, has A–Bk–BCk horizonation. This surface soil is a Haplustoll and is welded into soil 2. Soil welding helps explain the dark zone within the upper 15 cm (0.49 ft) of the Roxbury Bk horizon (see appendix table A.13). The Bk horizon is 40 cm (1.3 ft) thick and is characterized by weak, fine, subangular-blocky structure. Carbonate morphology is weak, reaching a maximum of stage I+ in the Bk horizon.

With the exception of the Roxbury silt loam (soil 1), soils 4 and 6 are morphologically the best expressed soils in the section at site 14HO306. Two dark, overthickened A horizons resembling soils 4 and 6 were observed in cutbank exposures of T-1 fill throughout Buckner Creek valley. Exposures of T-1 fill in many other small valleys in the Pawnee River basin also display two distinct A horizons among the buried soils. In an earlier study I suggested that soils 4 and 6 are stratigraphic markers and informally named them the Buckner Creek and Hackberry Creek paleosols, respectively (Mandel, 1988a). The cutbank exposure at site 14HO306 is designated in the present study as the type section for both of these paleosols.

Two cores were taken from T-1 fill near site 14HO306: core 1 on the east side of Buckner Creek and core 2 on the west side (fig. 52). The stratigraphy observed in these cores indicates that depositional units and buried soils exposed in the cutbank extend laterally away from the modern channel of Buckner Creek (fig. 56). The T-1 fill is inset against bedrock along the margin of the valley floor.

Exposures in gullies reveal that the erosion surfaces cut into bedrock immediately upslope from T-1 terraces are mantled by a thin veneer of well-rounded alluvial gravel (fig. 56). Much of the gravel is siliceous material derived from the Rocky Mountains and was transported across the High Plains by eastward-flowing streams during Tertiary and early Pleistocene times (Frye and Leonard, 1952). The veneer of gravel generally is less than 1.5 m (4.9 ft) thick at locality BC-1, and it has been altered by slope processes, especially gully and rill erosion. Although the absolute age of these coarse-grained

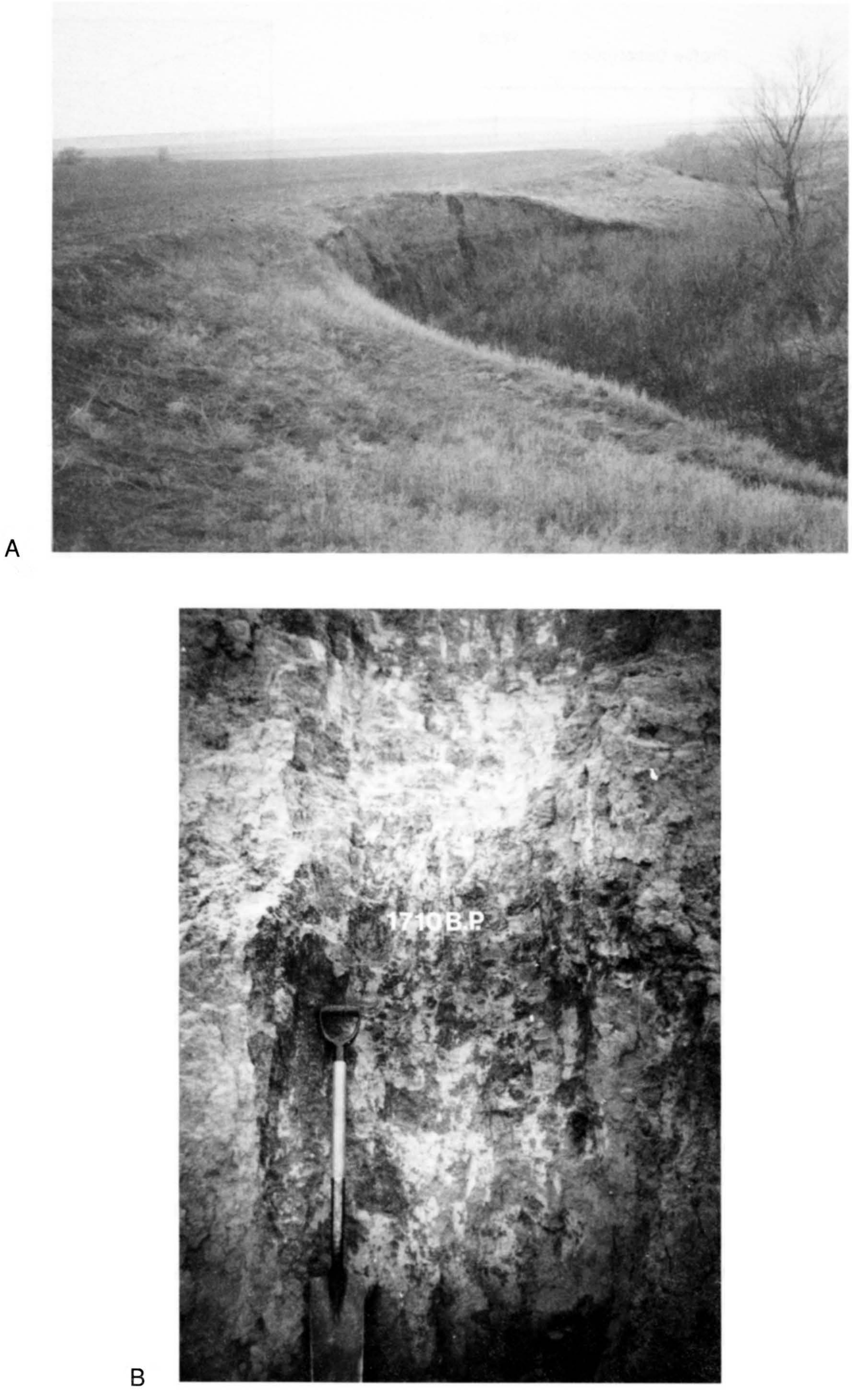

Figure 50. (A) Fearker section at locality PR-10. (B) Close-up of soil 2.

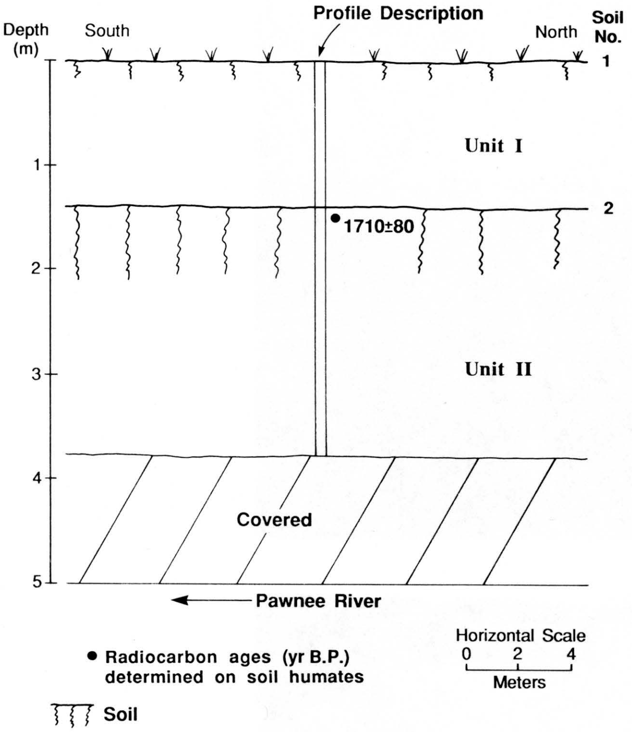

Figure 51. Cross-sectional diagram of the Fearker section showing stratigraphic units, soils, and radiocarbon age.

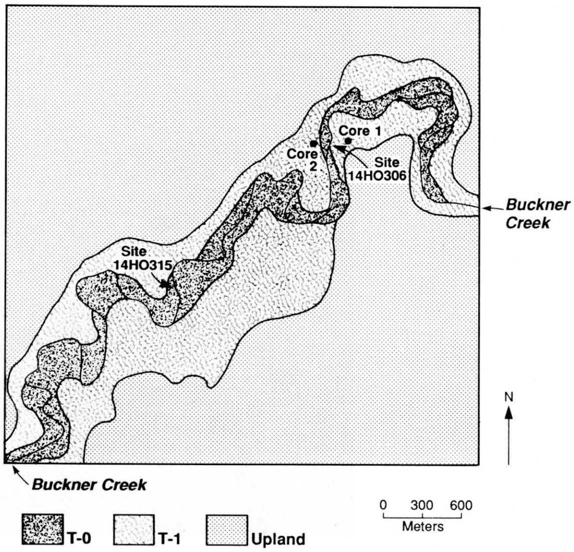

Figure 52. Landform map of locality BC-1 showing locations of sites 14HO306 and 14HO315.

Figure 53. Valley floor of Buckner Creek at locality BC-1. Note the scarp separating the T-0 surface from that of T-1.

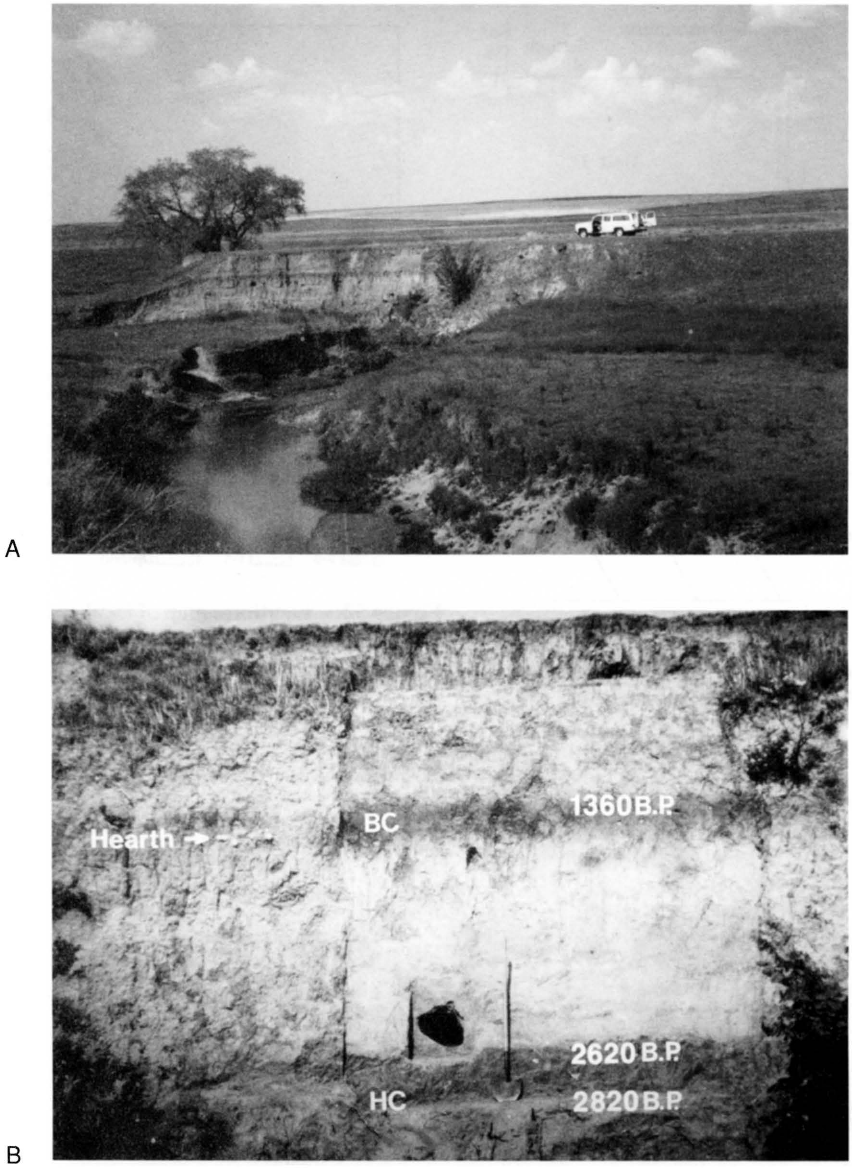

Figure 54. Section at site 14HO306 at locality BC-1. (A) The vehicle is on the T-1 surface. (B) Dark A horizons of the Buckner Creek (BC) and Hackberry Creek (HC) paleosols.

deposits is unknown, concentrations of *Proboscidean* bones on and below their surfaces (fig. 56) suggest that the gravels accumulated during the Pleistocene.

Modern floodplain (T-0) deposits were examined in many cutbanks throughout locality BC-1. These deposits are inset against T-1 fill or bedrock. All sections of T-0 fill exhibit the following characteristics: (1) Bedding is preserved throughout the vertical extent of the fill, except where it has been modified by pedogenesis; (2) the lower portion of the fill is gravelly, whereas the upper portion is loamy; and (3) soils with thin A–C profiles are developed at the top of the fill.

No cultural deposits were detected in the T-0 fill. However, portions of an articulated bison skeleton were found eroding out of T-0 deposits at a cutbank locality (site 14HO315), 2.8 km (1.7 mi) upstream from site 14HO306 (fig. 57). The section at site 14HO315 is described in appendix table A.14. Bison bones were collected for radiocarbon dating.

Two stratigraphic units and one buried paleosol were

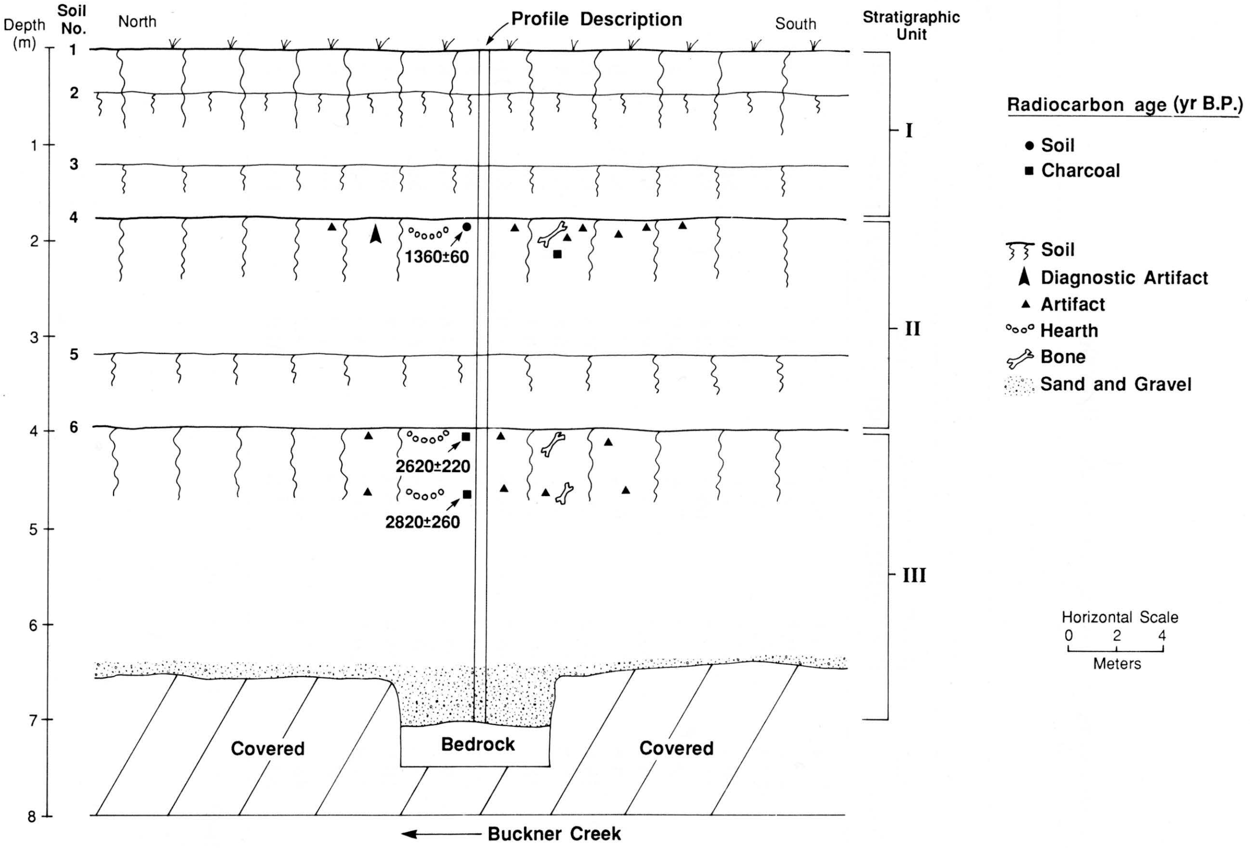

Figure 55. Cross-sectional diagram of section at site 14HO306 showing stratigraphic units, soils, prehistoric cultural horizons, and radiocarbon ages.

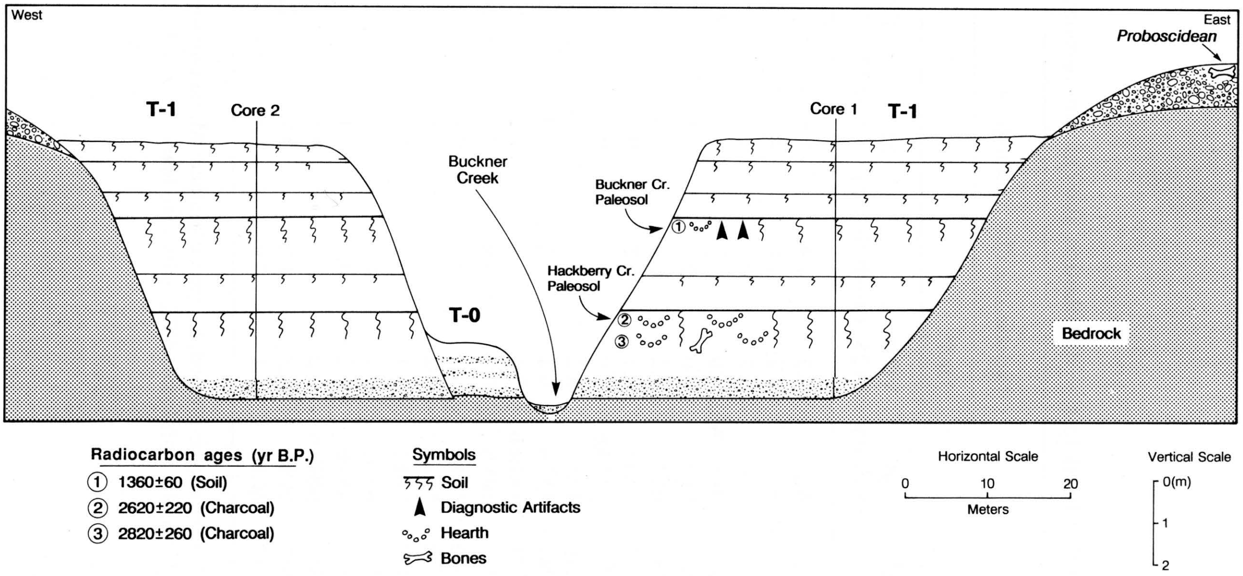

Figure 56. Cross-sectional diagram of Buckner Creek valley at locality BC-1.

Table 3. Particle-size distribution and calcium carbonate content of sediment samples from section at site 14HO306

		Particle-size distribution (mm)										
		Sand[a]						Silt				
Depth (cm)	Soil horizon	VC % (0.25–1.0)	C % (0.10–0.5)	M % (2.0–0.25)	F % (0.02–0.10)	VF % (0.05–0.05)	Total % (2.0–0.05)	Fine % (0.02–0.002)	Total % (0.05–0.002)	Total clay % (<0.002)	Texture class[b]	$CaCO_3$ (%)
0–18	Ap	0.2	1.9	3.5	7.5	9.3	22.4	23.1	66.2	11.4	SiL	0.4
18–38	A	0.2	2.0	4.0	6.6	8.4	21.2	20.3	64.1	14.7	SiL	0.6
38–46	AB	0.2	0.7	2.1	8.4	11.1	22.5	16.5	58.7	18.8	SiL	7.2
46–61	Bk1(2Ab)	0.0	0.2	1.0	2.3	6.7	10.2	27.2	69.1	20.7	SiL	5.5
61–86	Bk2	0.0	0.7	1.1	3.4	6.1	11.3	25.7	66.3	22.4	SiL	6.2
86–119	BCk	0.2	0.2	0.3	2.0	5.7	8.4	16.9	71.6	20.0	SiL	4.7
119–147	3Akb	0.1	0.2	0.5	1.8	4.0	6.6	33.0	74.2	19.2	SiL	4.5
147–176	3ACkb	0.0	0.1	0.5	2.3	5.9	8.8	32.2	63.9	27.3	SiCL	6.4
176–210	4Ab	0.2	2.6	7.2	11.9	7.7	29.6	17.8	49.6	20.8	L	0.4
210–241	4Akb	0.4	2.3	7.7	16.1	10.8	37.3	12.4	45.9	16.8	SiL	5.4
241–271	4ABkb	0.3	1.9	7.4	17.1	11.6	38.3	10.3	45.6	16.1	SiL	9.5
271–317	4Bkb	0.1	0.8	3.6	10.3	11.7	26.5	16.7	51.6	21.9	SiL	11.1
317–345	5Akb	0.3	0.5	0.9	11.0	13.1	25.8	20.2	54.3	19.9	SiL	8.0
345–394	5Ckb	0.4	1.2	1.4	1.3	5.0	9.3	27.3	66.1	24.6	SiL	8.6
394–432	6Ab1	0.4	0.7	1.2	2.7	3.5	8.5	30.9	64.6	26.9	SiL	3.8
432–471	6Ab2	0.4	1.0	2.1	3.4	4.0	10.9	28.9	65.3	23.8	SiL	4.7
471–523	6Bkb	0.2	0.9	3.1	7.3	6.4	17.9	20.1	56.9	25.2	SiL	7.4
523–658	6BCkb	0.2	1.7	4.5	8.4	5.9	20.7	20.7	56.9	22.4	SiL	8.5
658–685	6Cb1	0.3	1.9	3.2	22.3	20.4	48.1	17.9	45.7	6.2	SL	3.7
685–712	6Cb2	2.1	2.9	5.1	37.1	36.2	83.4	15.1	13.6	3.0	LS	2.3

a. VC, very coarse grained; C, coarse-grained; M, medium-grained; F, fine-grained; VF, very fine grained.

b. L, loam; SiL, silt loam; SiCL, silty clay loam; SL, sandy loam; LS, loamy sand.

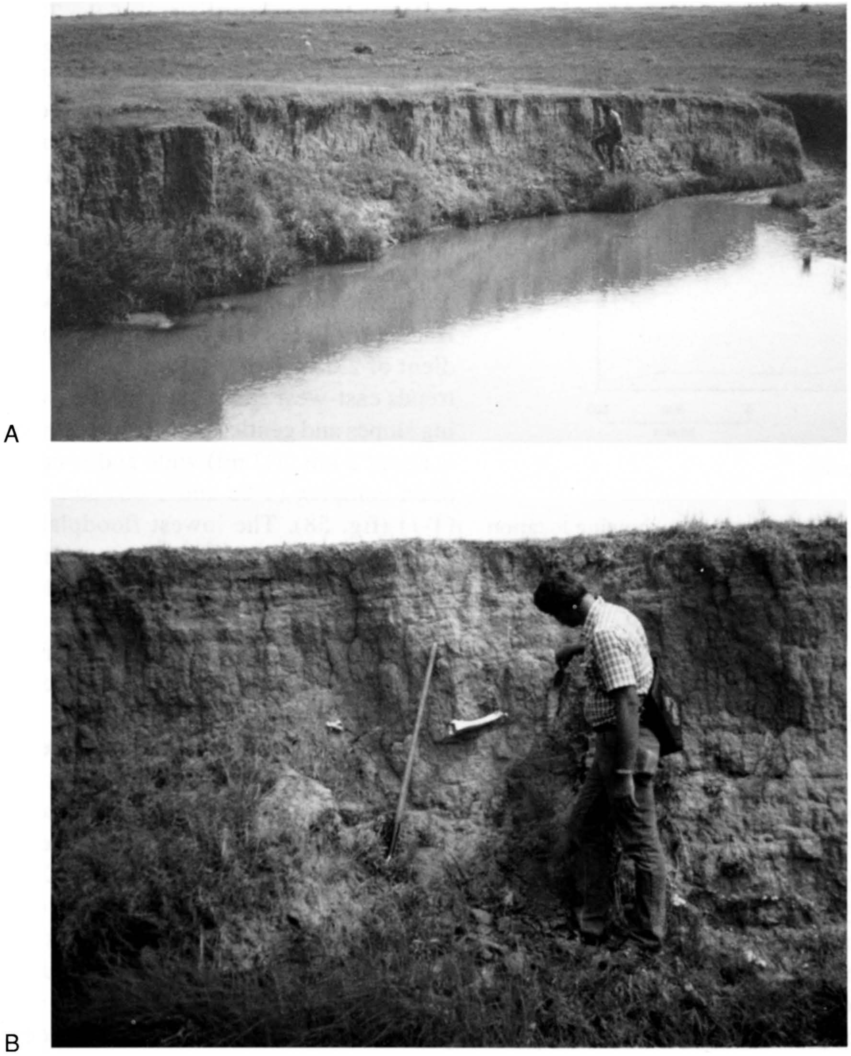

Figure 57. Site 14HO315 at locality BC-1. (A) Cutbank exposure of T-0 fill with uplands in the background. (B) Close-up of the cutbank showing bison bones in a buried A horizon. Note the bedding above the buried soil.

identified in the section at site 14HO306. The lower unit (unit II) is 3.02 m (9.91 ft) thick and is composed of stratified, well-sorted gravels that grade upward to loamy alluvium. A paleosol (soil 2) with Ak–ACk–C horizonation is developed at the top of unit II. The 2Akb horizon is 46 cm (1.5 ft) thick and is a grayish-brown (10YR 5/2) silt loam. Approximately 95% of the gravel in the 2C horizon consists of limestone pebbles, with siliceous rocks composing the rest. The upper 2.3 m (7.5 ft) of the T-0 fill consists of loamy alluvium, and bedding is preserved near the top of this fill (fig. 57B).

The bison skeleton was discovered in the 2ACkb horizon at a depth of 1.10–1.30 m (3.61–4.27 ft) below the T-0 surface (fig. 57B). A tibia, calcaneus, and malleolus were combined and sent to the University of Texas Radiocarbon Laboratory. These bones collectively yielded a radiocarbon age of 1,010 ± 410 yr B.P. (apatite). This represents the only numerical age from T-0 fill in the Pawnee River basin.

Unit I of the T-0 fill is 59 cm (1.9 ft) thick and is composed of calcareous vertical accretion deposits. A Haplustoll with a thin A–C profile is developed in fine-

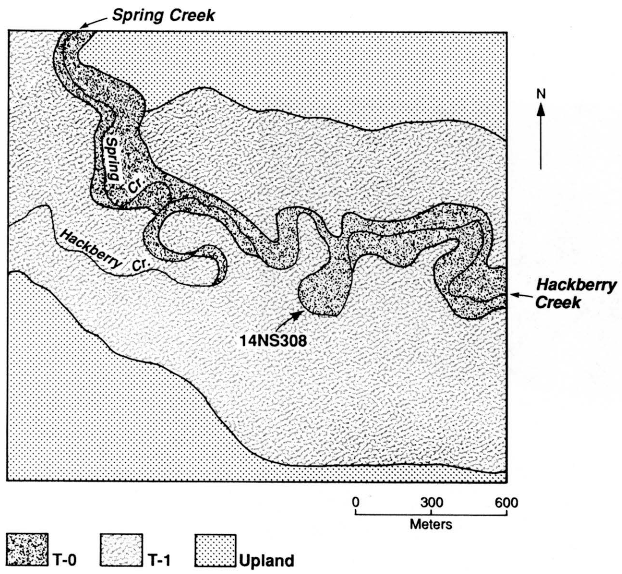

Figure 58. Landform map of locality HC-1 showing location of site 14NS308.

grained, stratified alluvium at the top of unit I (fig. 57B). Organic matter has darkened only the upper 30 cm (0.98 ft) of this surface soil, and there is minimal structural development in the A horizon. Altogether, the morphology of this soil and that of other soils developed at the top of T-0 fill in Buckner Creek valley suggest that the floodplain surfaces are young.

Radiocarbon assays combined with archeological evidence indicate that the bulk of the alluvium stored in the valley bottom of Buckner Creek accumulated during the late Holocene. Specifically, most of the T-1 fill aggraded between ca. 2,800 and 1,360 yr B.P. Aggradation of T-1 fill was punctuated by episodes of floodplain stability and concomitant soil development. Although some of these episodes of stability were relatively short, as indicated by thin, faint A–C profiles among the buried soils developed in T-1 fill, two episodes were longer. These two episodes are represented by the thick, dark Hackberry Creek and Buckner Creek paleosols. Development of the Hackberry Creek paleosol was underway by at least ca. 2,800 yr B.P. and continued to at least ca. 2,600 yr B.P. The Buckner Creek paleosol was forming by at least ca. 1,360 yr B.P., although bounding dates for development of this soil are not available at locality BC-1.

Buckner Creek downcut sometime after ca. 1,360 yr B.P., leaving its late Holocene floodplain as the T-1 terrace. Because the T-1 surface was isolated from frequent floods, a Mollisol with A–Bw horizonation developed at the top of the T-1 fill.

Based on the radiocarbon age of bison bones recovered from the T-0 fill at site 14HO315, the modern floodplain was aggrading by at least ca. 1,000 yr B.P. Weak soil development at the top of the T-0 fill suggests that the floodplain surface is very young, probably postdating Euro-American settlement in the region (ca. A.D. 1830). The absence of prehistoric archeological sites on T-0 surfaces at locality BC-1 and other reaches of Buckner Creek valley supports this hypothesis.

Locality HC-1 Locality HC-1 is situated in Hackberry Creek valley, 9.5 km (5.9 mi) upstream from the confluence of that creek with the Pawnee River (fig. 16). Hackberry Creek is a fourth-order stream and has a gradient of 2.05 m/km (11 ft/mi) at this locality. The valley trends east-west and is asymmetric, with steep north-facing slopes and gentle south-facing slopes. The valley floor is about 2 km (1.2 mi) wide and is composed of a floodplain complex (T-0a and T-0b) and a low, broad terrace (T-1) (fig. 58). The lowest floodplain surface (T-0a) is 20–30 m (66–98 ft) wide and is separated from the next highest surface (T-0b) by a 1.8-m-high (5.9-ft-high) scarp. The T-0b surface is 30–50 m (98–164 ft) wide and is separated from the T-1 surface by a prominent 4-m-high (13-ft-high) scarp. T-1 is a paired terrace, and its broad, flat surface dominates the valley floor.

Hackberry Creek has migrated laterally across its valley floor, cutting into the T-1 fill at site 14NS308 (fig. 58). As a result, the creek has created a 7.5-m-high (25-ft-high) cutbank (fig. 59) that exposes a thick section of alluvium beneath the T-1 surface. Charcoal, bone, fire-cracked rocks, and chert flakes were detected in a deeply buried paleosol within the section at site 14NS308. Hence this site was selected for detailed subsurface investigation to obtain temporal data along with alluvial stratigraphic information. The section is described in appendix table A.15; soil and charcoal samples were collected for radiocarbon dating.

Four stratigraphic units and three buried paleosols were identified in the section at site 14NS308 (fig. 60). The lowest stratigraphic unit (unit IV) is 3.40 m (11.2 ft) thick. Gravelly, sandy, and coarse-loamy fluvial deposits compose the lower half of unit IV, and the upper half consists of fine-grained alluvium. Stratified sand and gravel at the base of unit IV overlies bedrock (fig. 60). This stratified alluvium is calcareous and contains many gastropods and pelecypods. Loamy alluvium above the stratified fill grades upward into silty alluvium at the top of unit IV. The loamy and silty alluvium is calcareous and contains a rich assemblage of gastropods.

Soil 4 at the top of unit IV (fig. 60) has an Ak–Bk profile. The 4Akb horizon is 1.10 m (3.61 ft) thick and is a brown (10YR 5/3, dry) silt loam (fig. 61A). Carbonate morphology is weak (stage I+) in the 4Akb and 4Bkb

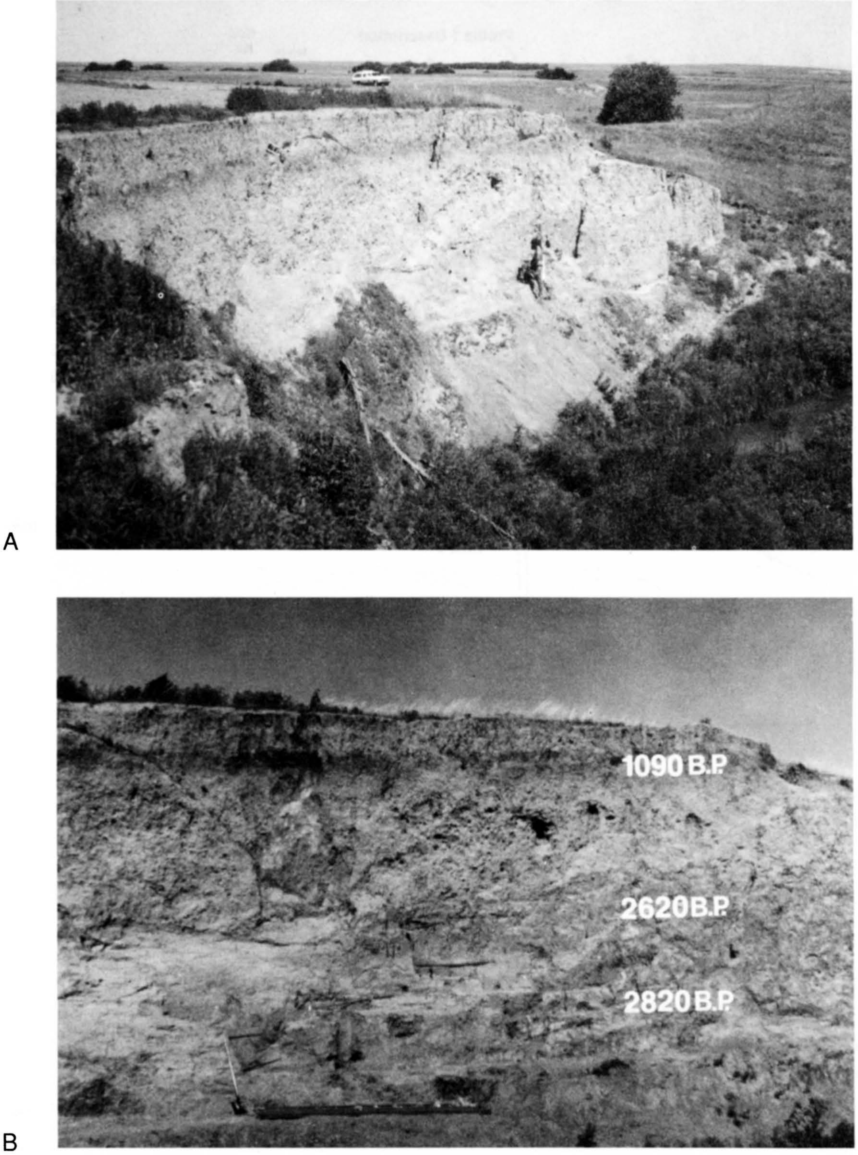

Figure 59. Section at site 14NS308 at locality HC-1. (A) The vehicle is on the T-1 surface. (B) Flags mark prehistoric cultural material in the Hackberry Creek paleosol.

horizons and is slightly better developed (stage II) in the 4Ck1 and 4Ck2 horizons.

Prehistoric cultural materials, including chert flakes and a biface, were observed in the A horizon of soil 4 at site 14NS308 (fig. 60). None of this material, however, was diagnostic of a cultural period. Soil 4 also contains hearths and many bones and bone fragments. A small volume of charcoal [3.0 g (0.0066 lb)] recovered from the surface of the 4Akb1 horizon yielded a radiocarbon age of 2,340 ± 400 yr B.P. Charcoal from a hearth 5–15 cm (2–6 in.) beneath the surface of the 4Akb horizon produced a radiocarbon age of 2,450 ± 90 yr B.P. A third radiocarbon age, 2,680 ± 80 yr B.P., was determined on charcoal from a cultural level 80–100 cm (2.6–3.3 ft) beneath the surface of the 4Akb horizon.

The presence of an overthickened A horizon (soil 4) containing two Late Archaic cultural levels indicates that deposition of alluvium was accompanied by soil formation on the late Holocene floodplain (now the T-1 terrace) of Hackberry Creek. The uniform color and texture

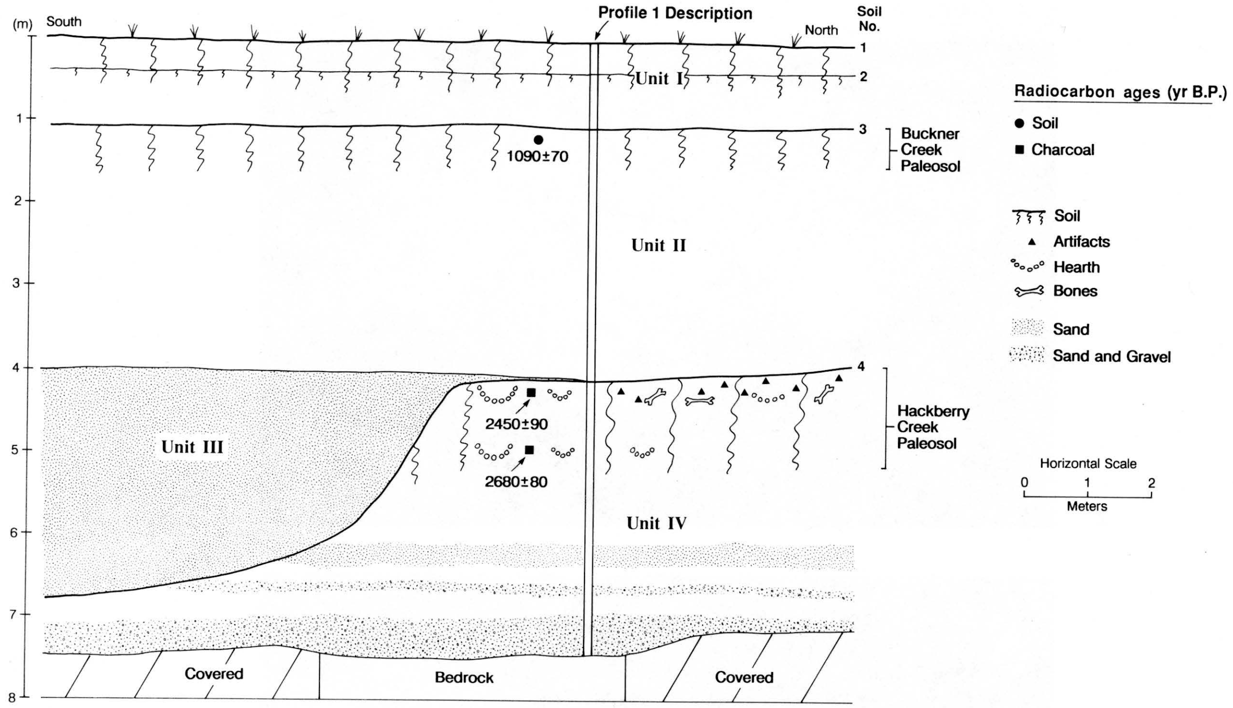

Figure 60. Cross-sectional diagram of section at site 14NS308 showing stratigraphic units, soils, prehistoric cultural horizons, and radiocarbon ages.

of the cumulic A horizon suggests that deposition was gradual and may have occurred without major interruptions from ca. 2,700 to 2,300 yr B.P. Based on its morphological characteristics and the radiocarbon ages, soil 4 is correlated with the Hackberry Creek paleosol at site 14HO306 (type section) in Buckner Creek valley.

At the southern end of the exposure, soil 4 and the underlying alluvium have been deeply incised by a channel (fig. 60). This channel is filled with crossbedded sands containing many gastropods (fig. 61B). The channel fill (unit III) and the Hackberry Creek paleosol are mantled by massive silts composing unit II.

Unit II is 3.08 m (10.1 ft) thick and is composed of calcareous silt loam. A distinct paleosol (soil 3) with A–AB–Bk–Ck horizonation is developed at the top of this alluvial unit. The 3Ab horizon is 44 cm (1.4 ft) thick and dark grayish brown (10YR 4/2, dry). The 3Bkb horizon is 32 cm (1.0 ft) thick and is a pale-brown (10YR 6/3, dry) silt loam with stage I+ carbonate morphology. A radiocarbon age of 1,090 ± 70 yr B.P. was determined on humates from the upper 30 cm (0.98 ft) of the 3Ab horizon.

The upper unit (unit I) is 1.07 m (3.51 ft) thick and is composed of fine-loamy alluvium. The modern surface soil (soil 1) is developed at the top of unit I. This soil is classified as the Roxbury silt loam, a Haplustoll with a thick noncalcareous A horizon above a calcareous Bk horizon. The Bk horizon has light silty clay loam texture, weak subangular-blocky structure, and stage I carbonate morphology.

The Roxbury profile at site 14HO308 represents complex soil development. Based on soil color, the Bk horizon appears to be welded into the A horizon of a buried soil (soil 2) 55–67 cm (1.8–2.2 ft) below the T-1 surface. Despite its relatively shallow depth, organic matter in the A horizon of soil 2 has not been completely oxidized during the course of modern pedogenesis.

The sequence of buried soils exposed in a second section (profile 2) about 50 m (160 ft) downstream from site 14NS308 is similar to profile 1 (fig. 62). However, no cultural materials were detected in profile 2. Absence of these materials provided an opportunity to recover soil samples from soil 4 that were uncontaminated by prehistoric cultural carbon. Radiocarbon ages of 1,950 ± 50 and 2,170 ± 50 yr B.P. were determined on humates from the upper 20 cm (0.66 ft) of the 4Akb1 and 4Akb2 horizons, respectively. The mean residence time for organic carbon and the radiocarbon ages determined on charcoal

Figure 61. (A) Hackberry Creek paleosol exposed in section at site 14NS308. Note the thickness of the A horizon. (B) Eroded surface of the Hackberry Creek paleosol where it has been incised by a former channel of Hackberry Creek. Note the crossbedding in the channel fill.

from the 4Ab1 and 4Ab2 horizons in profile 1 indicate that development of soil 4 was underway by at least ca. 2,700 yr B.P. and continued to as late as ca. 1,950 yr B.P.

Although profile 2 contained no archeological materials, the skeletal remains of a bison were discovered in the AC horizon of soil 3 (fig. 62). Collagen and apatite from a composite sample (femur + pelvis) yielded radiocarbon ages of 1,190 ± 370 and 1,310 ± 130 yr B.P., respectively. These ages slightly predate the radiocarbon age of 1,090 ± 70 yr B.P. determined on humates from the A horizon of soil 3 in profile 1.

Based on the assemblage of radiocarbon ages from site 14HO308, the bulk of the alluvium composing T-1 fill at locality HC-1 was deposited between ca. 2,700 and 1,000 yr B.P. Accumulation of alluvium on the late Holocene floodplain (now the T-1 terrace) occurred primarily through vertical accretion. However, lateral-accretion deposits compose the lower 1.5 m (4.9 ft) of the T-1 fill. Pedogenesis accompanied slow aggradation from ca. 2,680 to 2,450 yr B.P., resulting in the development of a cumulic soil (Hackberry Creek paleosol) with an overthickened A horizon. Mean residence time for organic carbon from the upper 20 cm (0.66 ft) of the Hackberry Creek paleosol indicates that it was still developing as late as ca. 2,000 yr B.P. Sometime after that, a channel was cut into this late Holocene paleosol. The channel was subsequently filled, and renewed alluviation resulted in burial of the Hackberry Creek paleosol. A major portion of the T-1 fill (unit II) aggraded between ca. 2,000 and 1,000 yr B.P. A second major episode of landscape stability is indicated by the Buckner Creek paleosol (soil 3), which developed at the top of unit II. Radiocarbon assays indicate that this soil developed between ca. 1,190 and 1,000 yr B.P. A final episode of T-1 aggradation occurred sometime after ca. 1,000 yr B.P. This period of alluviation resulted in burial of the Buckner Creek paleosol. Deep incision and subsequent accumulation of T-0 fill also occurred sometime after 1,000 yr B.P. However, the exact timing of these last two events is unknown.

Locality HC-2 Locality HC-2 is situated in Hackberry Creek valley, approximately 2 km (1.2 mi) upstream from the confluence of that creek with the Pawnee River (fig. 16). Hackberry Creek is a fourth-order stream and

Figure 62. Profile 2 located about 50 m downstream from site 14NS308. Note the bison bone above and to the right of the shovel.

has a gradient of 1.50 m/km (7.9 ft/mi) at this locality. The valley floor is 0.8 km (0.5 mi) wide and is bordered by moderately sloping valley walls. Three landforms compose the valley bottom: a narrow floodplain (T-0), a low terrace (T-1), and an intermediate terrace (T-2) (fig. 63). The T-0 surface is 50–250 m (164–820 ft) wide and is separated from the adjacent T-1 surface by a prominent 4-m-high (13-ft-high) scarp. Although broad paired surfaces of the T-1 terrace dominate the valley bottom at locality HC-2, there is an extensive remnant of a second terrace (T-2) on the west side of the stream (figs. 63 and 64). This remnant is one of the few occurrences of the T-2 terrace in the lower Hackberry Creek valley; no traces of a T-2 terrace were documented in the middle or upper reaches of Hackberry Creek. The soil-stratigraphic investigations at locality HC-2 focused on deposits underlying the T-2 surface.

Hackberry Creek has migrated laterally across its valley floor, cutting into the T-2 fill at a place designated as site 14HO316 (fig. 63). An 8-m-high (26-ft-high) cutbank at site 14HO316 (fig. 65) exposes a thick section of valley fill beneath the T-2 surface. Coring revealed that bedrock is less than 1 m (0.3 ft) below the base of the cutbank. The complex stratigraphy observed in this cutbank is described in appendix table A.16. Three soil samples were collected for radiocarbon dating.

Four stratigraphic units and eight buried paleosols were identified in the section at site 14HO316 (fig. 66). The lowest unit (unit IV) consists of stratified sand and gravel overlying bedrock. These coarse-grained lateral-accretion deposits grade upward into fine-grained vertical-accretion deposits. A paleosol (soil 9) with Ak–ACk–C horizonation is developed at the top of unit IV. The 9Ak horizon is 20 cm (0.66 ft) thick and is a brown (10YR 4/3, dry) silt loam. Carbonate morphology is weak (stage I) in soil 9, although there are a few large, hard concretions scattered through the silty matrix.

Unit III is composed of fine-grained alluvium with a few discontinuous lenses of small rounded pebbles near its base. A distinct paleosol (soil 8) with Ak–Bk–BCk horizonation is developed at the top of unit III. Soil 8 is the thickest and most strongly developed paleosol in the section. The 8Akb horizon is 40 cm (1.3 ft) thick and is a brown (10YR 3/3, dry) silt loam. There are common films and threads and a few fine, hard concretions of calcium carbonate (stage I+) in the 8Akb horizon. The 8Bkb horizon is 45 cm (1.5 ft) thick and is a brown (10YR 3/3, dry) silty clay loam. There is weak, fine, subangular-blocky structure in the 8Bkb horizon, and carbonate morphology is the same as that in the 8Akb horizon. The underlying Ck horizon consists of brown (10YR 5/3, dry) calcareous loam with massive structure and few thin, discontinuous lenses of well- to subrounded limestone and chert pebbles.

Unit II is 2.06 m (6.76 ft) thick and is largely composed of fine-grained alluvium. Soil 4, which is developed at the top of unit II (fig. 66), has a dark-grayish-brown (10YR 4/2, dry) silt loam A horizon above a brown (10YR 5/4, dry) loam ACk horizon. The 4Akb horizon is 36 cm (1.2 ft) thick and has stage I carbonate morphology. Soils 5, 6, and 7 also are developed in unit II (fig. 66). These three paleosols have thin, faint Ak horizons above ACk horizons. In addition, soil 6 has a thick C horizon composed of laminated silt and very fine sand with a few thin, discontinuous lenses of well- to subrounded calcareous pebbles.

The upper stratigraphic unit (unit I) is 2.45 m (8.04 ft) thick and is composed of fine-grained alluvium. The modern surface soil (soil 1) at the top of unit I is the Hord silty clay loam, a Pachic Haplustoll with a thick, noncalcareous silt loam A horizon above a light silty clay loam Bw horizon. A few films and threads of calcium carbonate (stage I) are present in the underlying Bk horizon and extend down into the BCk horizon. The C horizon is composed of pale-brown (10YR 6/3, dry) silt loam with massive structure and a few thin, discontinuous lenses of very fine sand.

Two buried paleosols (soils 2 and 3) are developed in the lower 90 cm (3.0 ft) of unit I. Both of these paleosols have thin Ak–ACk profiles with weak (stage I) carbonate morphology. The 2Akb and 3Akb horizons are dark-grayish-brown (10YR 5/2, dry) silty clay loams. Sediment composing the 2ACkb and 3ACkb horizons is predominantly silt loam, but there are many thin lenses of very fine sand.

Three radiocarbon ages were determined on soil humates from site 14HO316, one from each of the major paleosols developed in the T-2 fill. Humates from the upper 20 cm (0.66 ft) of soils 4, 8, and 9 yielded ages of 4,970 ± 100, 7,170 ± 120, and 9,820 ± 110 yr B.P., respectively. These ages and the soil-stratigraphic evidence indicate that the bulk of the sediment composing the T-2 fill at site 14HO316 accumulated during the early and middle Holocene.

Although particle-size analyses were not conducted on sediments from site 14HO316, field observations detected a repetitive sequence of deposits beneath the T-2 surface. The deposits generally fine upward from the surface of one paleosol to the top of the next overlying paleosol. It is likely that this sedimentation pattern resulted from episodes of flooding and overbank deposition in Hackberry Creek valley. Runoff and erosion in the tributary basin upstream from Site 14HO316 contributed sediment to floodwaters in the lower reach of the valley. Unstable periods, marked by deposition of floodplain sediments, were followed by periods of stability and soil formation.

Based on the paleosol record, aggradation was interrupted by eight soil-forming intervals before the T-2 surface finally stabilized. However, only soils 1 and 8 have B horizons; the other paleosols have thin A–C profiles that are products of relatively short episodes of landscape stability.

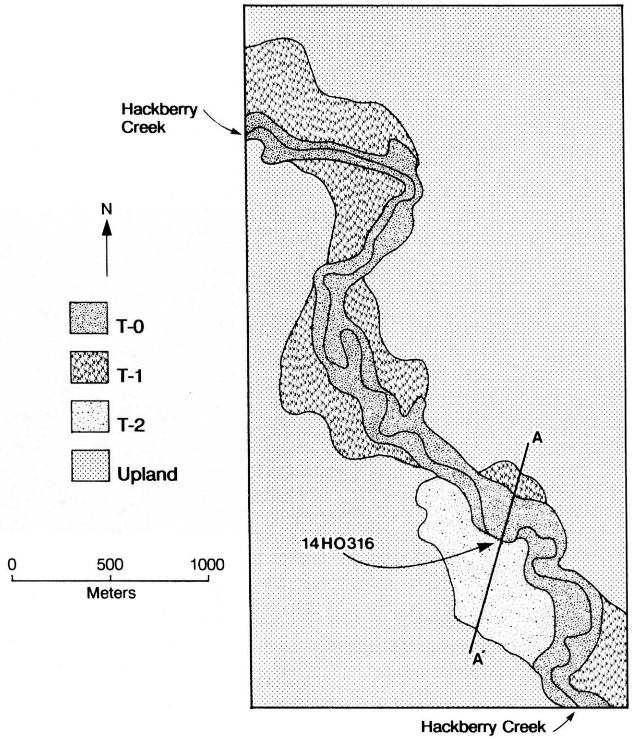

Figure 63. Landform map of locality HC-2 showing location of site 14HO316.

The modern soil at the top of unit I developed when sedimentation ceased on the T-2 surface. Although the exact time of this event is unknown, it occurred sometime after 4,970 ± 100 yr B.P., which is the radiocarbon age determined on organic carbon from soil 4. Radiocarbon ages from T-1 fill in Hackberry Creek indicate that alluviation was underway again by ca. 2,700 yr B.P. Hence the episode of stream incision that left the middle Holocene floodplain as a stable terrace surface (T-2) occurred sometime between ca. 5,000 and 2,700 yr B.P.

Six cores were taken along a cross-valley transect (A–A′, fig. 67) to determine whether different terrace levels might be surfaces cut on T-2 fill (i.e., fillstrath terraces). Also, two of the cores provided information about the lateral extent, depth, and thickness of deposits and buried paleosols beneath the T-2 surface at site 14HO316.

Cores 2 and 3 were taken from T-2 fill near the valley wall and at the midsection of the T-2 terrace, respectively (fig. 67). The soil-stratigraphic sequences observed in these cores indicate that deposits and buried soils exposed in cutbank 14HO316 continue laterally toward the valley wall in a horizontal fashion beneath the T-2 surface. No variability in thickness, physical properties, or depth of paleosols was detected. Hence early and middle Ho-

Figure 64. Hackberry Creek valley at locality HC-2. The T-2 surface is immediately above the cutbank exposure (site 14HO316) in the center of the photo.

locene floodplain surfaces represented by buried paleosols in T-2 fill appear to have been relatively flat.

Based on subsurface information gleaned from core 1 (fig. 67) and gully exposures, the T-2 fill is inset against limestone bedrock. The bedrock is mantled by a thin veneer of limestone gravel, and a 1.5–2.0-m-thick (4.9–6.6-ft-thick) unit of grayish-brown silt overlies the gravel. Although the grayish-brown silt often is referred to as Peoria loess [e.g., Haberman et al. (1973)], it may be colluvium (i.e., reworked loess), given that it occurs at the base of a slope and contains a few pebbles. The stratigraphic relationship of the silty slope deposits to the T-2 surface deposits has not been determined.

Core 5, taken from T-1 fill on the north side of Hackberry Creek (fig. 67), revealed a sequence of deposits and buried paleosols similar to the one observed beneath the T-1 surface at localities HC-1 and BC-1. Two buried soils with thick, dark A horizons are developed in fine-loamy alluvial deposits. A thin, faint paleosol with A–C horizonation is developed in the alluvium between these soils. The uppermost and lowermost buried soils are morphologically similar to the Buckner Creek and Hackberry Creek paleosols, respectively. The soil-stratigraphic sequence observed in core 5 is visible in cutbank exposures of T-1 fill throughout locality HC-2 and along other reaches of Hackberry Creek. At several of these exposures T-1 fill was seen abutting the bedrock valley wall, as shown in fig. 67.

Core 6, taken on sloping uplands adjacent to T-1 (fig. 67), revealed a soil-stratigraphic sequence identical to the one observed in core 1 on the south side of the creek. A 2-m-thick (7-ft-thick) deposit of silty sediment overlies a thin layer of limestone and chert gravel above bedrock.

Modern floodplain (T-0) deposits are inset against T-1 fill on the north side of Hackberry Creek (fig. 67). Core 4 revealed a 1-m-thick (3-ft-thick) cap of fine-textured alluvium above alternating beds of sandy loam, sand, and gravel. The T-0 deposits at this locality are distinct from T-1 and T-2 deposits in that the T-1 material is coarser and much more stratified and does not contain buried paleosols. Also, the T-0 fill is largely composed of lateral-accretion deposits whereas the bulk of T-1 and T-2 alluvium consists of vertical-accretion deposits. Stratigraphic information gleaned from core 5 indicates that beds of sand and gravel below the T-0 surface do not continue beneath the T-1 surface. Hence the T-0 surface does not represent a surface cut into T-1 fill. The presence of an Entisol with a thin A horizon at the top of the T-0 fill indicates that the floodplain surface has not been stable for a long period of time. Altogether, the soil-stratigraphic evidence suggests that alluvium composing the T-0 fill rapidly accumulated and that the modern floodplain is still aggrading.

Locality SC-1 Locality SC-1 is situated in Sawlog Creek valley, approximately 43 km (27 mi) upstream from the confluence of that creek with Buckner Creek (fig. 16). Sawlog Creek is a third-order stream and has a gradient of 2.9 m/km (15 ft/mi) at this locality. The valley trends east-west and is asymmetric, with moderately steep north-

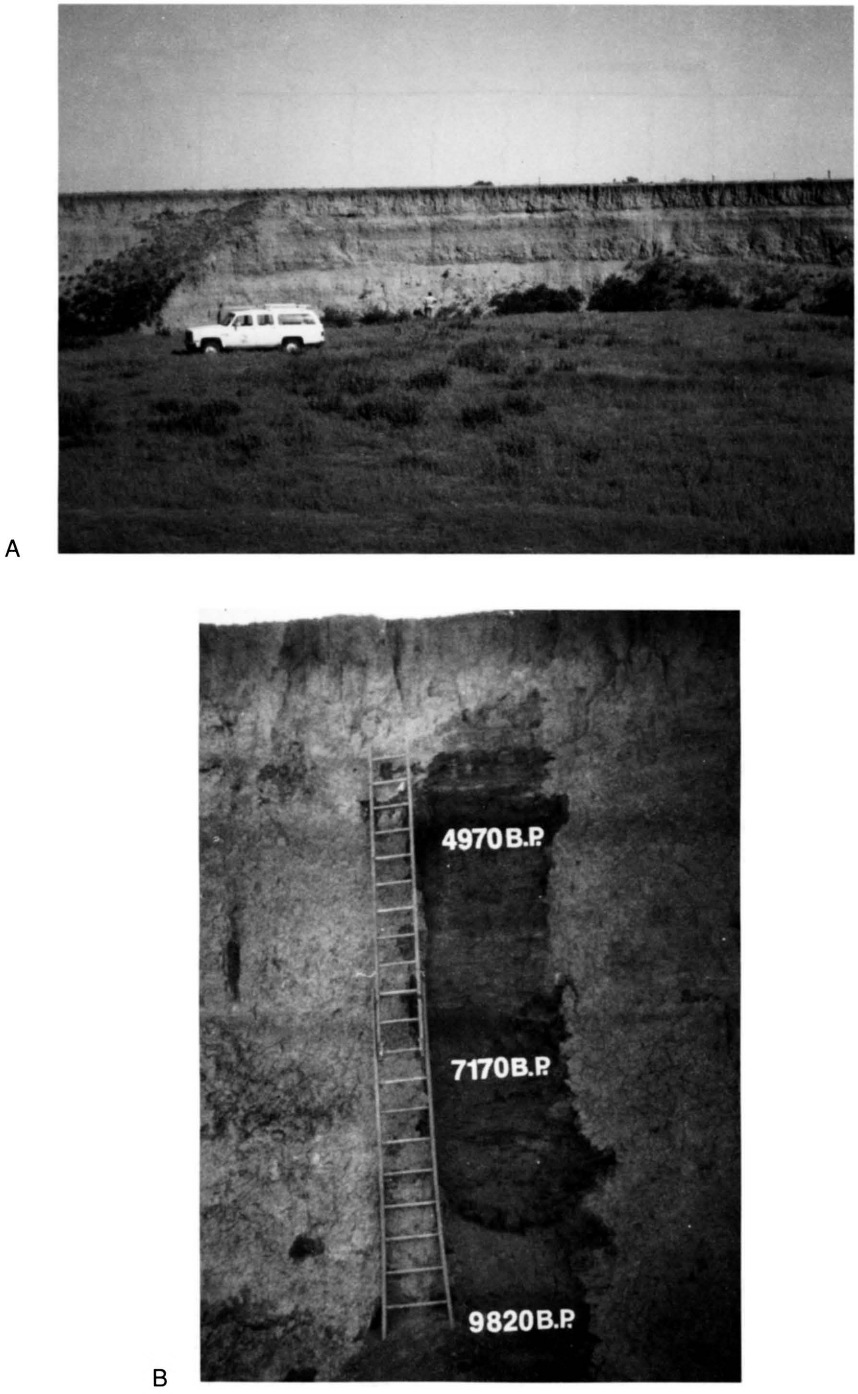

Figure 65. Section at site 14HO316. (A) The vehicle is on the T-0 surface. (B) The distance between each rung of the ladder is 30 cm.

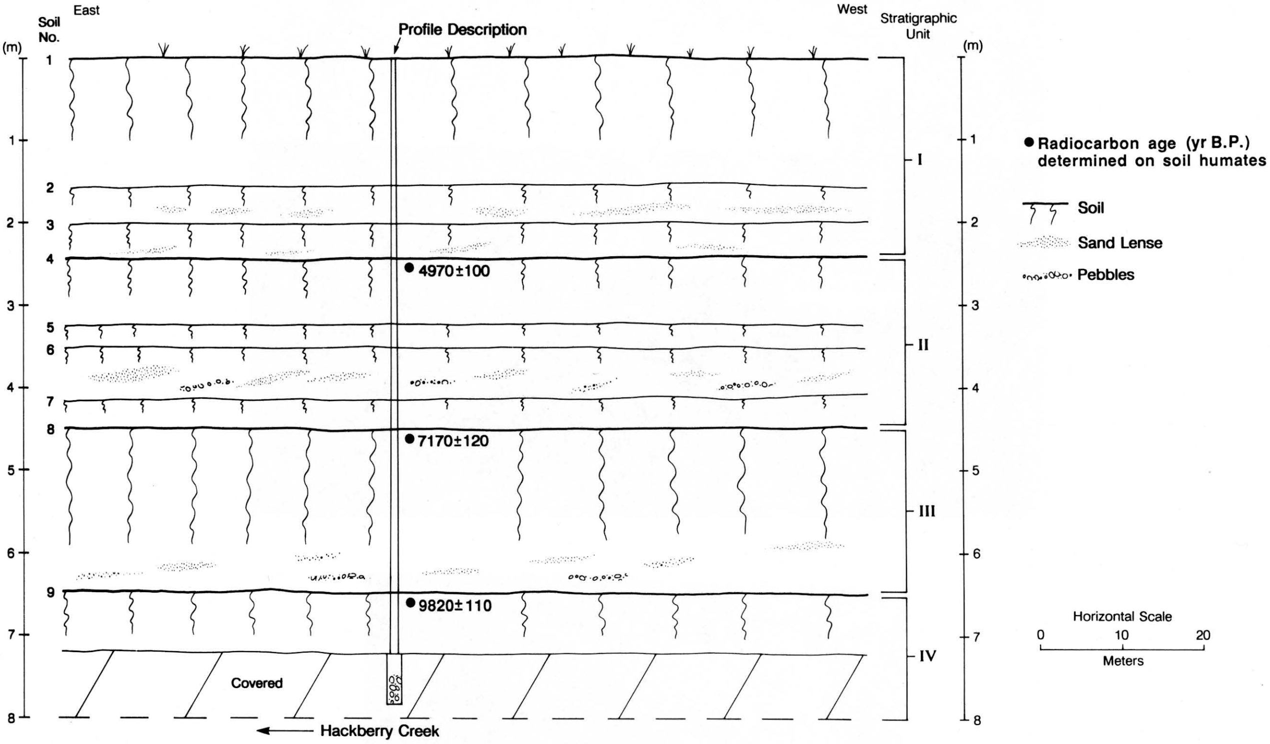

Figure 66. Cross-sectional diagram of section at site 14HO316 showing stratigraphic units, soils, and radiocarbon ages.

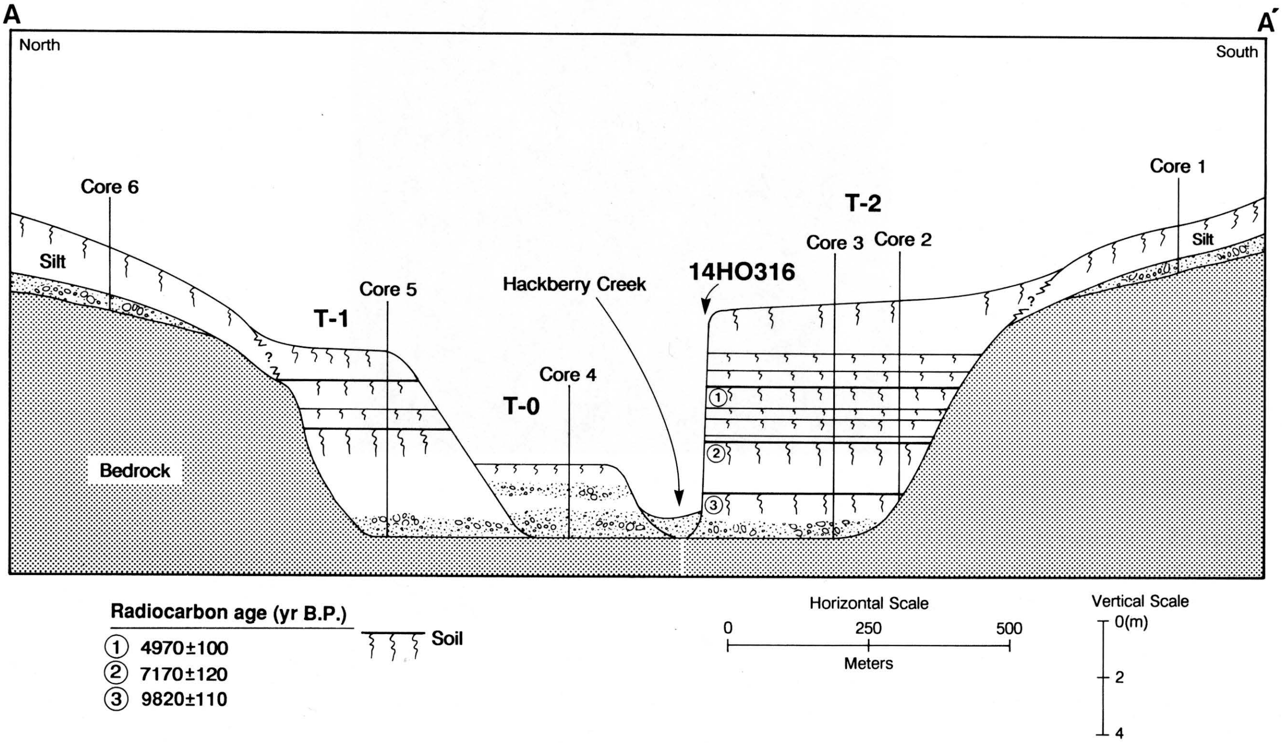

Figure 67. Cross-sectional diagram of Hackberry Creek valley at locality HC-2.

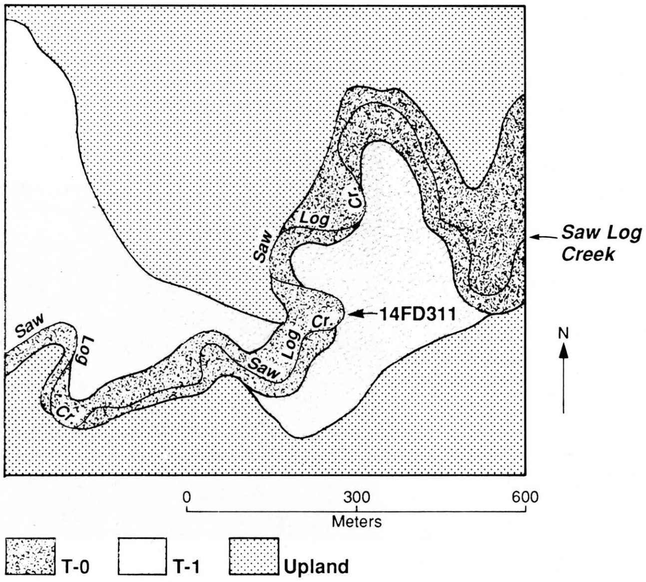

Figure 68. Landform map of locality SC-1 showing location of site 14FD311.

facing slopes and gentle south-facing slopes. The valley floor is 200–400 m (650–1,300 ft) wide and is composed of two landforms: a narrow modern floodplain (T-0) and a broad, low terrace (T-1). The T-0 surface is 20–30 m (66–98 ft) wide and is separated from the adjacent T-1 surface by a 3-m-high (10-ft-high) scarp. T-1 dominates the valley bottom and is a paired surface throughout locality SC-1 (fig. 68).

Lateral migration of Sawlog Creek has created a number of steep cutbanks that expose T-1 fill. One of these cutbanks (site 14FD311) was selected for detailed study at locality SC-1 (figs. 68 and 69). The T-1 fill is 3.65 m (12.0 ft) thick at site 14FD311 and has been described from the terrace surface down to its contact with bedrock (see appendix table A.17). Also, a soil sample was collected from the deepest buried paleosol for radiocarbon dating.

Three stratigraphic units and four buried soils were identified at site 14FD311 (fig. 70). The lowest stratigraphic unit (unit III) is 1.65 m (5.41 ft) thick and overlies limestone. Unit III is largely composed of loamy alluvium. However, the lower portion of the unit consists of alternating beds of gravelly loam and organic-rich silty clay. Individual beds within the lower 95 cm (3.1 ft) of unit III are 5–35 cm (0.2–1.1 ft) thick and have smooth, abrupt boundaries (fig. 69B). Pelecypods are common in this stratified fill, indicating that it was deposited in a channel environment. Fine-loamy alluvium, composing the upper 70 cm (2.3 ft) of unit III, however, is characteristic of vertical-accretion deposits. The surface of unit III gently slopes from east to west (fig. 70).

A distinct paleosol (soil 5) with Ak–ACk horizonation is developed at the top of unit III (figs. 69 and 70). The 5Akb horizon is 64 cm (2.1 ft) thick and is a dark-grayish-brown (10YR 4/2, dry) silt loam. Carbonate morphology increases from stage I in the 5Akb horizon to stage I+ in the ACk horizon. Humates from the upper 20 cm (0.66 ft) of the 5Ab horizon yielded a radiocarbon age of 2,260 ± 80 yr B.P.

Unit II is 1.55 m (5.09 ft) thick and consists of loamy alluvium with a few thin lenses of gravel. Faint bedding is visible in the loamy fill, except where deposits have been modified by pedogenesis. Three paleosols (soils 2, 3, and 4) are developed in unit II (fig. 70). All these soils have thin A–AC profiles, and soils 2 and 3 nearly merge to form a composite profile (figs. 69B and 70).

Unit I at the top of the section (fig. 70) is 45 cm (1.5 ft) thick and is composed of loam in its lower portion, grading upward to silt loam. The modern surface soil (soil 1) at the top of unit I is a Haplustoll with a thin A–C profile.

Based on the radiocarbon age of humates from soil 5, the bulk of the sediment composing T-1 fill at locality SC-1 was deposited sometime after ca. 2,260 yr B.P. With the exception of coarse-grained lateral-accretion deposits within the lower meter of the fill, most of the alluvium accumulated through vertical accretion. The paleosol record indicates that T-1 aggradation was interrupted by at least three episodes of landscape stability and concomitant soil formation after ca. 2,260 yr B.P. However, the thin A–C profiles of soils 2, 3, and 4 suggest that these episodes were relatively short. Also, the presence of a weakly developed soil at the top of the T-1 fill suggests that the terrace surface is young.

The overthickened A horizon of soil 5 strongly resembles the Hackberry Creek paleosol at sites 14HO306 and 14NS308. Also, the radiocarbon age of 2,260 ± 80 yr B.P. determined on humates from the upper 20 cm (0.66 ft) of the 5Akb horizon is close to the ages (1,950 ± 50 and 2,170 ± 50 yr B.P.) determined on humates from the Hackberry Creek paleosol at site 14NS308. Hence soil 5 may correlate with the Hackberry Creek paleosol.

Locality PR-11 Locality PR-11 is situated in the valley of an unnamed third-order tributary in the headwater area of the Pawnee River basin (fig. 16). The valley trends north-south, and its floor is about 75 m (250 ft) wide. The stream's gradient is 1.5 m/km (7.9 ft/mi), and there is about 50 m (160 ft) of relief at this locality.

The valley floor of the stream is composed of two landforms: a narrow modern floodplain (T-0) and a low terrace (T-1). The floodplain surface is 15–20 m (66–98 ft) wide and is separated from that of the T-1 terrace by a 3-m-high (10-ft-high) scarp. T-1 is a paired terrace, and its surface dominates the valley floor (fig. 71).

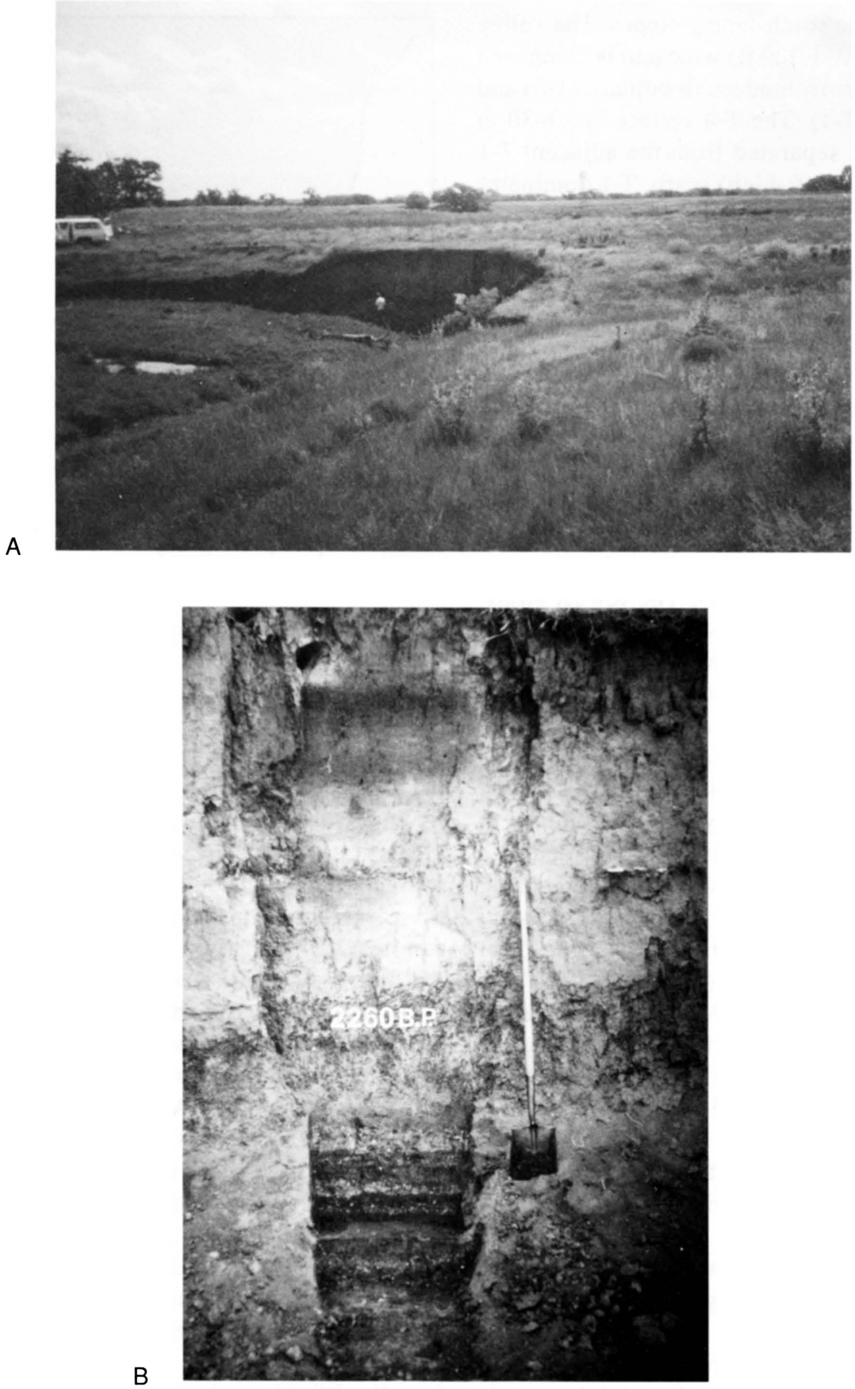

Figure 69. Section at site 14FD311 at locality SC-1. (A) The cutbank exposes fill beneath the T-1 surface. (B) Close-up of the section showing the buried paleosols. Radiocarbon age determined on humates from soil 5. Note the bedding in the lower portion of the section.

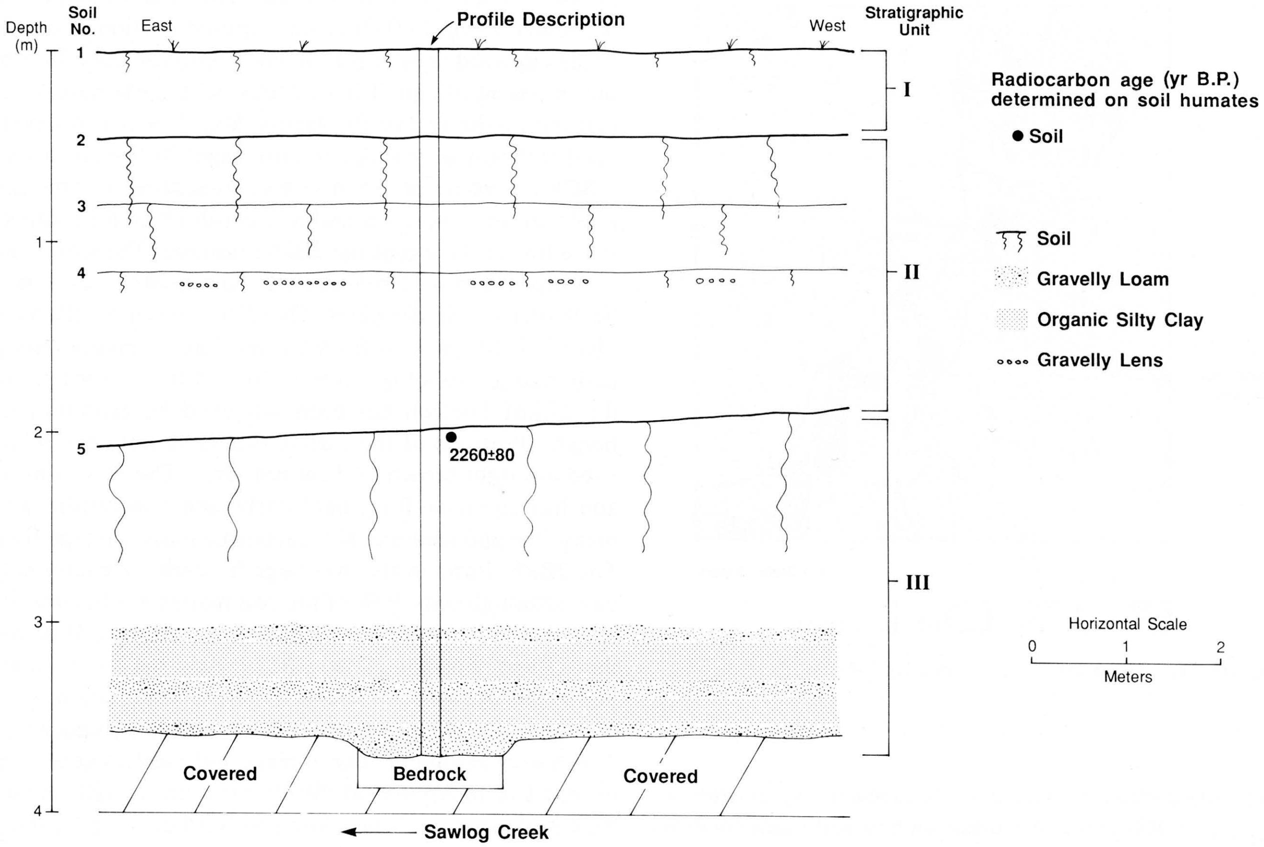

Figure 70. Cross-sectional diagram of section at site 14FD311 showing stratigraphic units, soils, and radiocarbon ages.

The stream has migrated laterally into the T-1 fill at several places at locality PR-11, creating several cutbank exposures. One of these exposures, referred to as the Doll section (figs. 71 and 72), was selected for study. The section is described in appendix table A.18. Two soil samples were collected for radiocarbon dating.

Three stratigraphic units and two buried paleosols were identified beneath the T-1 surface at the Doll section (fig. 73). The lowest unit (unit III) is at least 72 cm (2.4 ft) thick and is composed of fine-grained alluvium. A paleosol (soil 3) with a dark overthickened Ak horizon above a Bk horizon is developed at the top of this unit (fig. 72B). The 3Akb horizon is 61 cm (2.0 ft) thick and is a brown (10YR 3/3) silt loam. Few films and threads of calcium carbonate (stage I) are present in the 3Akb horizon, but they become better developed and more common with increasing depth. The 3Bkb horizon is a brown (10YR 5/3, dry) silt loam with weak fine subangular-blocky structure. Films, threads, and fine soft masses of calcium carbonate (stage I+) are common in the 3Bk horizon.

Unit II is 73 cm (2.4 ft) thick and is composed of calcareous silty alluvium. A paleosol (soil 2) with Ak–Ck horizonation is developed at the top of this unit. The 2Akb horizon is 21 cm (0.69 ft) thick and is a brown (10YR 4/3, dry) silt loam. Carbonate morphology is weak (stage I) throughout soil 2.

The upper unit (unit I) is 120 cm (3.94 ft) thick and is composed of calcareous fine-grained alluvium. The modern surface soil (soil 1) at the top of unit I is a Haplustoll with A–Bw–C horizonation. The A horizon is 26 cm (0.85 ft) thick and is a brown (10YR 5/3, dry) silt loam. Alluvium composing this unit becomes coarser with increasing depth below the A horizon, changing from a loam in the Bw horizon to a fine sandy loam in the C horizon. No secondary carbonates were detected in unit I.

Radiocarbon ages of 1,500 ± 80 and 2,430 ± 90 yr B.P. were determined on humates from the upper 15 cm (0.49 ft) of soils 2 and 3, respectively. These ages are similar to ones determined on materials from the Buckner Creek and Hackberry Creek paleosols, respectively. Based on

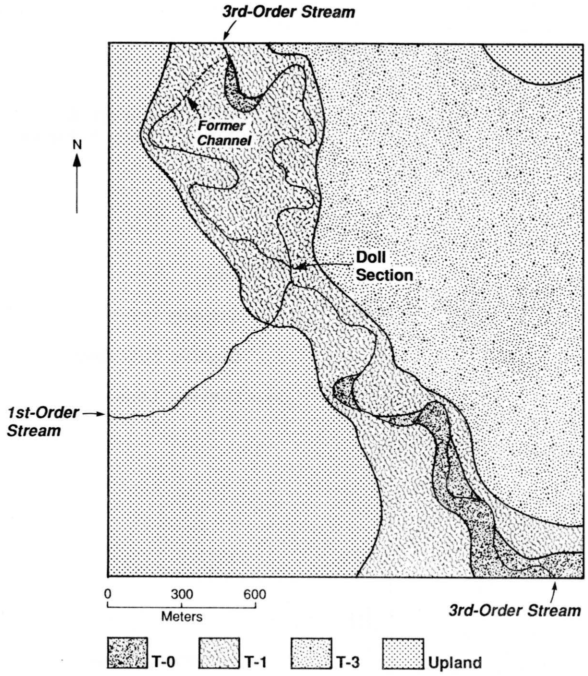

Figure 71. Landform map of locality PR-11.

the radiocarbon assays, unit III aggraded sometime before ca. 2,400 yr B.P. Accumulation of sediment composing unit II occurred after ca. 2,400 yr B.P. but before ca. 1,500 yr B.P. The final episode of T-1 aggradation took place sometime after ca. 1,500 yr B.P.

Locality PR-12 Locality PR-12 is situated in the headwater area of the Pawnee River basin (fig. 16). The Pawnee River is a third-order stream with a gradient of 1.3 m/km (6.9 ft/mi) at this locality. The valley floor is 1.1 km (0.68 mi) wide and is composed of two landforms: a modern floodplain (T-0) and a high terrace (T-3). Lateral erosion by the Pawnee River has apparently removed the T-1 and T-2 fills in this segment of the valley. The floodplain surface ranges from 30 m to 100 m (98–330 ft) in width and is separated from that of the T-3 terrace by a 7-m-high (23-ft-high) scarp. T-3 is a paired terrace, and its broad, gently sloping surface dominates the valley floor (fig. 74).

Although no cutbank exposures were found at locality PR-12, a trench silo provided an opportunity to examine a thick section of T-3 fill (figs. 74 and 75). The trench, which is referred to as the Doll silo, had been excavated into the scarp separating the T-0 surface from the T-3 surface. The soil stratigraphy exposed in the west wall of the trench is described in appendix table A.19 and is illustrated in fig. 76.

Two stratigraphic units and one paleosol were observed beneath the T-3 surface (fig. 76). The lowest stratigraphic unit (unit II) is at least 2.75 m (9.02 ft) thick and is composed of loamy alluvium. Fine sandy loam composing the lower 90 cm (3.0 ft) of the exposed portion of unit II grades upward to silty clay loam. Approximately 70% of the sediment in unit II is siliceous, with carbonate rocks making up the rest of the grains. Soil 2, which is developed at the top of unit II, has a truncated Bk horizon above a BCk horizonation. Evidence of truncation was the absence of an A horizon and a 2-cm-thick (0.8-in.-thick) stone line at the top of the 2Bkb1 horizon. The stone line is composed of well-rounded siliceous pebbles, 2–10 mm (0.08–0.4 in.) in diameter. The 2Bkb horizon (2Bkb1 + 2Bkb2) is 85 cm (2.8 ft) thick and has relatively strong carbonate morphology. About 20% of the soil matrix in the 2Bkb1 horizon has been whitened by calcium carbonate. Portions of the matrix that have not been whitened are light brown (7.5YR 6/4, dry). The 2Bkb1 horizon has common fine, hard carbonate concretions and many fine and medium, soft carbonate masses (stage II+). The 2Bkb2 horizon also has stage II+ carbonate morphology, although only 50% of the soil matrix has been whitened. Carbonate morphology decreases to stage II below the 2Bkb1 horizon. The 2BCkb horizon is a light-yellowish-brown (10YR 6/4, dry) fine sandy loam.

Unit I is 1.45 m (4.76 ft) thick and is composed of fine-loamy sediment. The surface soil (soil 1) at the top of unit I is an Argiustoll (Mollisol) with A–ABk–Btkb–BCk horizonation. The A horizon is 35 cm (1.1 ft) thick and is a brown (10YR 5/3, dry) silt loam. Secondary carbonates appear in the ABk horizon (stage I), but the soil matrix is noneffervescent down to the Btk horizon. The Btk horizon (Btk1 + Btk2) is 68 cm (2.2 ft) thick and is a yellowish-brown (10YR 5/6, dry) to light-brown (7.5YR 6/4, dry) silty clay loam. Moderate fine and medium subangular-blocky structure has developed in the subsoil. Also, discontinuous clay films and carbonate films and threads (stage I+) were observed in the Btk horizon. The underlying BCk horizon is a light-brown (7.5YR 6/4, dry) loam. Carbonate films and threads become thicker and more common in the lower 15 cm (0.49 ft) of soil 1, and the soil matrix is calcareous based on its strong reaction to HCl.

The Finney County Soil Survey (Harner et al., 1965, sheet 56) shows the Richfield soil on the T-3 terrace at locality PR-12. The Richfield soil is developed in Pleistocene loess and is common on uplands throughout southwestern Kansas. Although unit I at the Doll silo appears to be loess, the shallow depth of secondary carbonates is not characteristic of the Richfield soil.

Based on its position in the landscape and the presence of loess on its surface, T-3 appears to be a Pleistocene terrace. The truncated paleosol (soil 2) at the top of unit II is similar to soil 2 at the top of T-3 fill at locality PR-2. The yellowish-brown to reddish color and the strong structure of these soils suggest that they are old.

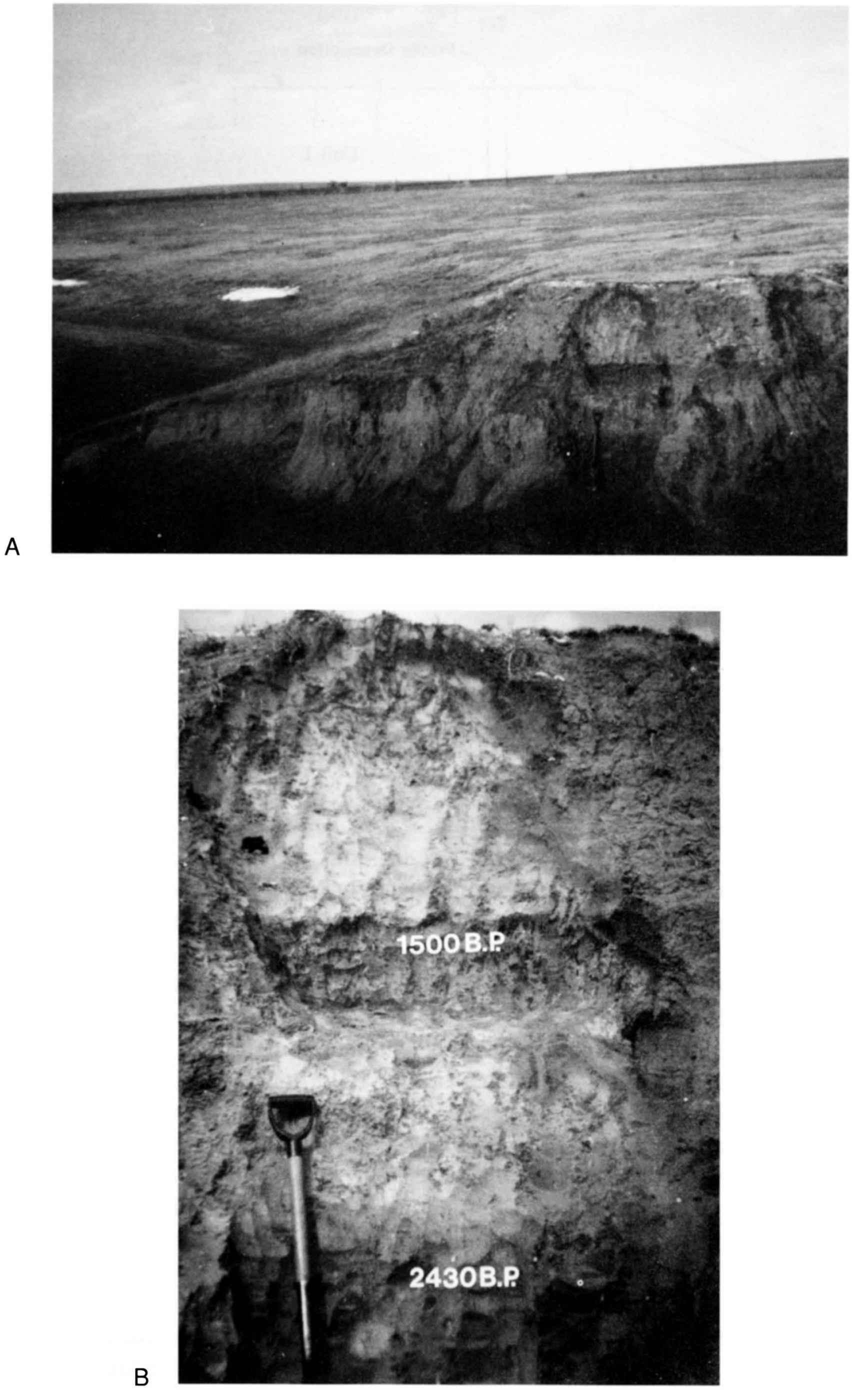

Figure 72. Doll section at locality PR-11. (A) Channel of an unnamed third-order stream at the base of the cutbank. (B) Dark A horizons of soils 2 and 3. Radiocarbon ages determined on humates.

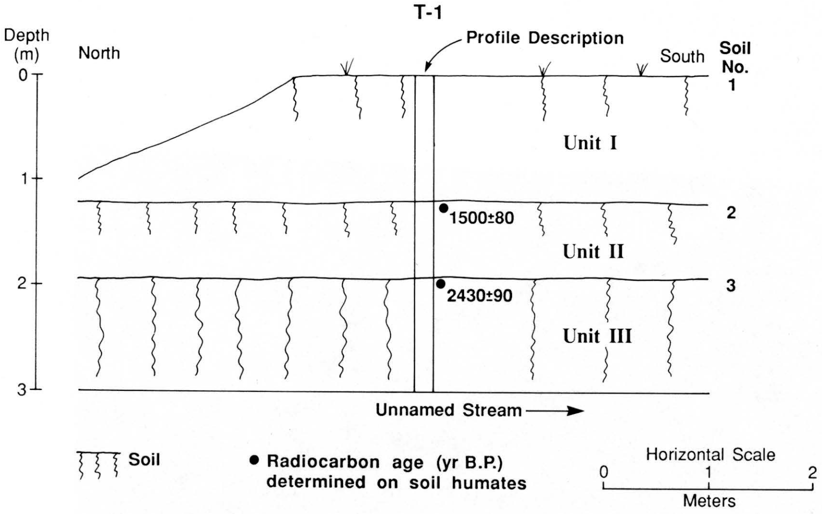

Figure 73. Cross-sectional diagram of the Doll section at locality PR-11 showing stratigraphic units, soils, and radiocarbon ages.

Holocene landscape evolution in the Pawnee River basin

The purposes of this section are to summarize the record of Holocene erosion, alluviation, and landscape stability in the Pawnee River basin and to provide interpretations of that record. First, geomorphic data and stratigraphic records from large and small valleys in the Pawnee River basin are described and compared. Second, a Holocene alluvial chronology of the Pawnee River system is constructed from radiocarbon assays. Third, the Holocene history of the Pawnee River basin is compared with alluvial chronologies of other streams in the Central Plains. Finally, causal factors of Holocene erosion, alluviation, and landscape stability in the Pawnee River basin are considered.

Terraces, valley fills, and soils in the Pawnee River basin

As many as three terraces are present in the valley bottom of the Pawnee River (fig. 77). All these terraces are essentially the original depositional surfaces of valley fills (filltop terraces), although the surface of T-3 fill has been somewhat modified by erosion and loess deposition. T-3, which is the highest terrace, has a broad, gently sloping surface, 7–8 m (23–26 ft) above the modern floodplain. This terrace is paired and nearly continuous along the entire course of the Pawnee River. Limited subsurface investigations revealed a 1–2-m-thick (3–7-ft-thick) deposit of Peoria loess on the T-3 surface. The loess overlies a truncated Bt horizon developed in alluvium. This paleo–Bt horizon is reddish and exhibits strong structural development. Valley fill beneath the truncated paleosol consists of 2–3 m (7–10 ft) of loamy alluvium grading downward into sandy and gravelly deposits.

An intermediate terrace (T-2) occupies a portion of the valley floor in the middle reach of the Pawnee River, but it was not observed in the upper and lower reaches. This terrace is paired in some areas and unpaired in others. The T-2 terrace is a broad, flat surface, 5–6 m (16–20 ft) above the modern floodplain. One cutbank exposure of T-2 fill was briefly examined at locality PR-8, where a 6-m-thick (20-ft-thick) unit of brown and pale-brown massive silty sediment extended from the T-2 surface to the base of the exposure. No buried paleosols were detected in the exposure, and the absolute age of the fill is unknown. However, based on radiocarbon ages determined on humates from deeply buried paleosols in the adjacent T-1 fill, the T-2 fill is older than 10,300 yr B.P.

The lowest terrace (T-1) has a broad, flat surface that dominates the valley floor along nearly all of the Pawnee River. This terrace usually is on both sides of the river and is separated from the modern floodplain by a 3–5-m-high (10–16-ft-high) scarp. Valley fill underlying the T-1 terrace is up to 50 m (160 ft) thick in the middle and lower reaches of the Pawnee River. Deposits composing the lower 20–30 m (65–100 ft) of the fill largely consist of bedded sands and gravels. These coarse-grained lateral-accretion deposits are mantled by thick, fine-grained vertical-accretion deposits.

Buried paleosols are common in the upper 7–10 m (23–33 ft) of the T-1 fill (fig. 78). Most of the buried late Holocene paleosols have A–C or thin A–Bw profiles. A few late Holocene soils with A–Bk profiles were observed in the lower Pawnee River valley; however, the Bk horizons have weak carbonate morphology and show little or no evidence of clay illuviation. In contrast, early and middle Holocene soils usually are strongly developed and have thick clay-rich Bk, Bt, and/or Btk horizons. Also, some of the early and middle Holocene soils were truncated by erosion before burial, and in some cases only their B horizons remain (fig. 78).

The stratigraphic record preserved in T-1 fill indicates that episodes of stream erosion during the early and middle Holocene were separated by periods of alluviation. However, since no ^{14}C datable materials, such as charcoal or wood, were found in T-1 fill, absolute ages of alluvial deposits could not be determined. Instead, relative ages of deposits were inferred from the paleosol record where more than one buried soil was radiocarbon-dated within a section.

Deposits of Historic alluvium, up to 2 m (7 ft) thick, cover much of the T-1 terrace in the middle and lower reaches of the Pawnee River valley. These deposits consist of stratified clays, silts, and very fine sands, and they often contain Historic artifacts. Surface soils developed at the top of Historic fill are Haplustolls with thin A–C profiles. The mantle of Historic alluvium generally becomes thinner with increasing distance from the modern channel of the Pawnee River, and it is usually absent near margins of the valley floor. This factor accounts for soil variability observed along some cross-valley transects. For example, at locality PR-3 a young surface soil with a thin A–C profile is developed in deposits of Historic alluvium on the T-1 terrace. The Historic alluvium mantles a late Holocene soil with an A–Bk profile developed into T-1 fill. This buried late Holocene soil is the surface soil where the mantle of Historic alluvium is absent.

The modern floodplain (T-0) of the Pawnee River is 20–150 m (66–490 ft) wide and 2–3 m (7–10 ft) above the bottom of the river channel. The T-0 fill is composed largely of sandy and gravelly lateral-accretion deposits capped by silty and clayey overbank deposits. Archeological and soil evidence suggests that T-0 surfaces are Late Prehistoric to Historic in age. At site 14HO5 at locality PR-9, Middle Ceramic potsherds were found in a cultural horizon 1 m (3 ft) below the T-0 surface. Hence alluvial deposits above the cultural horizon are no greater than 1,000 years old and may be less than 500 years old. Soils developed at the top of the T-0 fill are Haplustolls with thin A–C profiles; they have not developed long enough to have B horizons. The morphology of these soils suggests that the T-0 surfaces are young.

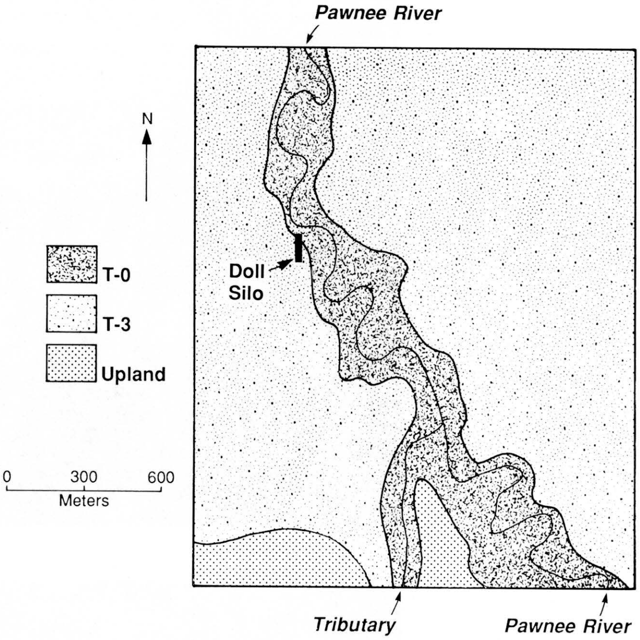

Figure 74. Landform map of locality PR-12 showing location of the Doll silo.

All the tributaries of the Pawnee River are fourth-order or smaller streams. The valley floors of second- and third-order streams are composed of two landforms: a narrow floodplain (T-0) and a low, broad terrace (T-1) (see fig. 77). The T-0/T-1 sequence also characterizes most reaches of fourth-order streams, but a second terrace (T-2) is present near their confluences with the Pawnee River. As was the case in large valleys, all terraces in small valleys are original depositional surfaces of alluvial fills (filltop terraces).

The T-2 terrace is unpaired, and its surface is 6–7 m (20–23 ft) above the modern floodplain. A detailed subsurface investigation of the T-2 fill was conducted at locality HC-2 along lower Hackberry Creek. The T-2 fill at this locality is about 8 m (26 ft) thick and is composed almost entirely of fine-grained overbank alluvium. Eight buried paleosols were identified below the T-2 surface (see fig. 78). Although most of these paleosols are characterized by thin A–C profiles, two have an overthickened A horizon above a C horizon and one has a thick Bk horizon. Based on radiocarbon ages determined on humates from buried paleosols, the bulk of the alluvium beneath the T-2 terrace accumulated during the early and middle Holocene. The modern surface soil at the top of the T-2 fill is a Haplustoll with A–Bw–Bk horizonation.

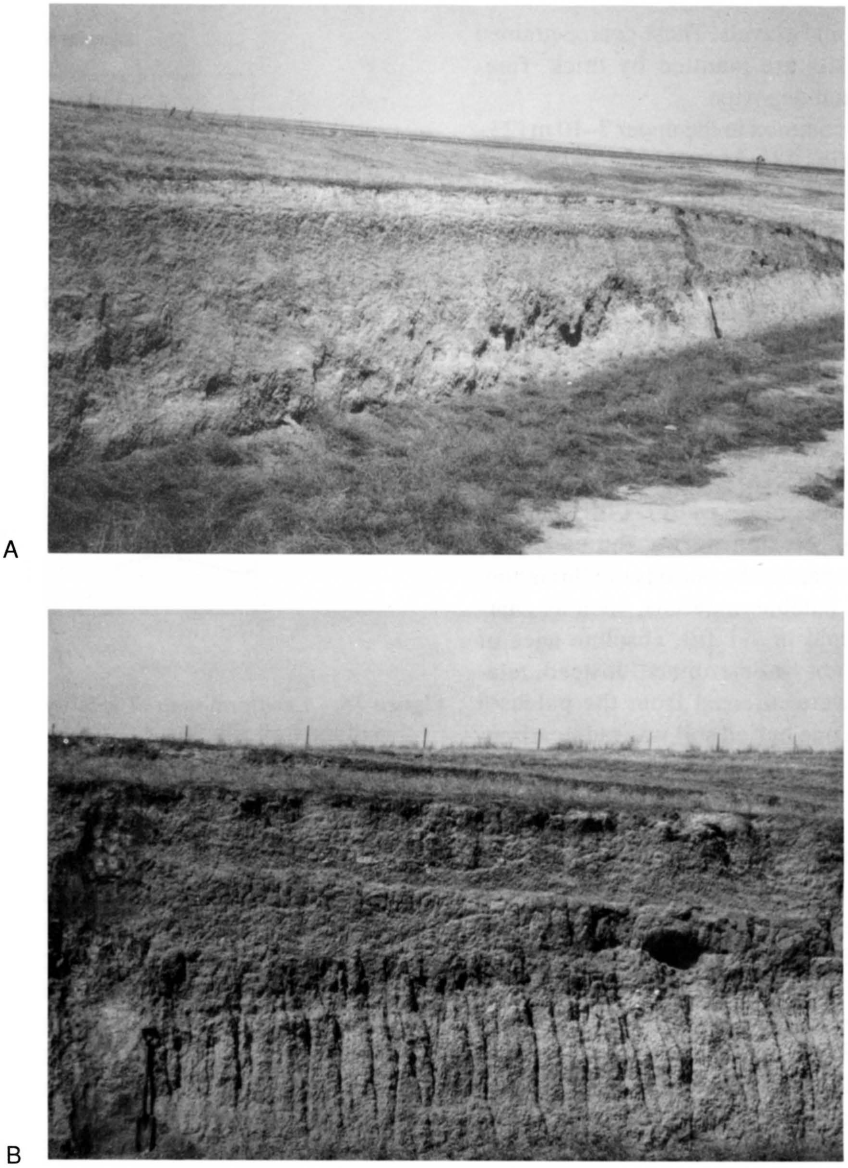

Figure 75. Doll silo. (A) Scarp separating the T-3 surface (left) from the T-0 surface (far upper right). (B) West wall of the ground silo.

The T-1 terrace dominates valley floors of small streams in the Pawnee River basin. T-1 is usually a paired terrace, although it is unpaired in portions of some valleys as a result of lateral stream erosion. The T-1 surface is separated from that of the modern floodplain by a 3–4-m-high (10–13-ft-high) scarp.

Deposits underlying the T-1 terrace were examined at many cutbank exposures, and detailed descriptions of soil stratigraphy were made at localities HC-1, BC-1, SC-1, and PR-11. The T-1 fill generally is 7–8 m (23–26 ft) thick and is composed of thick units of fine-grained overbank alluvium above thin basal deposits of stratified sand and gravel. Radiocarbon assays indicate that the bulk of the alluvium composing T-1 fill accumulated between ca. 2,800 and 1,000 yr B.P.

As many as five buried paleosols were identified in T-1 fill of small valleys (see fig. 78). Most of these paleosols are thin, weakly developed A horizons. However, two paleosols are relatively well developed and can be traced laterally throughout the low-order drainages. These soils were first recognized at site 14HO306 at locality BC-1. The oldest of the two buried soils, informally named the Hackberry Creek paleosol, has a 50–100-cm-thick (1.6–3.3-ft-thick) cumulic A horizon above a thin Bk horizon.

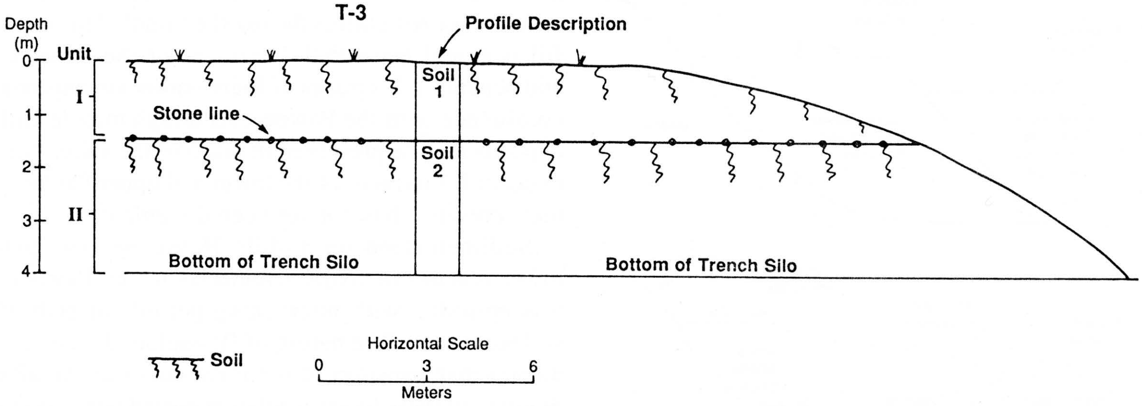

Figure 76. Cross-sectional diagram of the west wall of the Doll silo showing stratigraphic units and soils.

This paleosol usually is developed in loamy alluvium near the base of the T-1 fill. At some localities, such as site 14NS308 (locality HC-1), a deep channel is cut into the Hackberry Creek paleosol and underlying fill. Radiocarbon assays suggest that formation of the Hackberry Creek paleosol began ca. 2,800 yr B.P. and continued until at least 2,000 yr B.P.

A younger buried soil in T-1 fill also has a thick, dark A horizon above a weakly developed Bk horizon. This buried soil, informally named the Buckner Creek paleosol, is developed in silty alluvium near the top of the T-1 fill. Archeological evidence and radiocarbon ages suggest that the Buckner Creek paleosol developed from about 1,350 to at least 1,000 yr B.P.

The Buckner Creek paleosol is mantled by 1–2 m (3–7 ft) of silty alluvium composing the upper portion of the T-1 fill. Surface soils developed at the top of the T-1 fill are Haplustolls with thin A–Bk profiles.

Modern floodplains in small valleys generally are 30–50 m (100–160 ft) wide, although floodplain surfaces are as wide as 100 m (330 ft) in lower reaches of major tributaries. Some streams downcut slightly [1–2 m (3–7 ft)] as they migrated across their valley floors. Consequently, floodplains may consist of several individual levels (T-0 complex) separated by short scarps. These individual levels cannot be traced up or down the valleys with any certainty.

Floodplain (T-0) deposits are inset against T-1 fill or bedrock walls in small valleys. The floodplain fill generally is less than 4 m (13 ft) thick and is composed of 1–2 m (3–7 ft) of fine-grained alluvium above alternating beds of sandy loam, sand, and gravel. Deposits underlying the T-0 surface are distinct from those beneath the T-1 surface in that the former are coarser, much more stratified, and rarely contain buried paleosols. The absolute age of T-0 fill, however, has not been firmly established. Only one radiocarbon age has been determined on materials from T-0 deposits: 1,010 ± 410 yr B.P. on bison bones (apatite) recovered 1 m (3 ft) below the T-0 surface. No prehistoric cultural deposits were discovered on or below the T-0 surface, and Historic materials are common in the upper 1 m (3 ft) of the fill. The presence of Haplustolls with thin A–C profiles developed at the top of the T-0 fill suggests that the floodplain surfaces are young.

A comparison of soil-stratigraphic records from large and small valleys in the Pawnee River basin (see fig. 78) reveals a pattern. Specifically, late Holocene alluvial deposits and buried paleosols are present in both large and small valleys. However, middle and early Holocene deposits and buried paleosols are documented only in the main valley of the Pawnee River and in the lower reaches of major tributaries near their confluence with the Pawnee River.

The morphology of surface soils in valley bottoms of the Pawnee River basin is fairly consistent. With the exception of soils developed in the Peoria loess on the T-3 terrace, all surface soils are weakly developed Haplustolls characterized by A–C, A–Bw, or A–Bk horizonation. The presence of weakly developed soils suggests that the surfaces of most landforms in valley bottoms are relatively young. Radiocarbon ages determined on charcoal, bones, and humates from buried paleosols in large and small valleys indicate that the overlying deposits and hence the modern surface soils often are less than 2,000 years old.

Holocene valley history

Radiocarbon ages combined with age estimates based on temporally diagnostic archeological materials were used

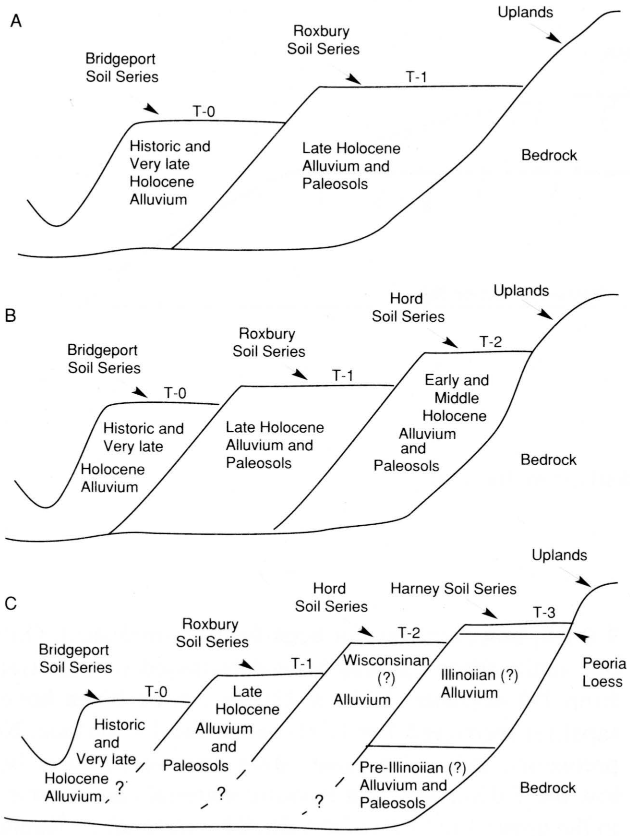

Figure 77. Generalized cross sections of (A) small valleys, (B) lower reaches of fourth-order stream valleys, (C) and large valleys.

to outline the chronology of Holocene landscape evolution in the Pawnee River basin. The ages on which this chronology is based roughly span the Holocene (table 4).

During the early Holocene (ca. 10,500–7,000 yr B.P.), alluviation in large valleys of the Pawnee River basin was punctuated by floodplain stability, soil formation, and erosion. Buried paleosols dating to this period are documented in T-1 fill of the Pawnee River and in T-2 fill of lower Hackberry Creek near its confluence with the Pawnee. Many of these paleosols are deeply truncated, indicating that periods of soil development were followed by episodes of stream erosion.

During the early and middle Holocene, between about 10,000 and 4,000 yr B.P., second- and third-order streams together with the upper and middle reaches of fourth-order streams were characterized by net transport of alluvium, with little or no long-term storage. It is likely that small streams were actively downcutting and lengthening during this period. Sediment transported out of these drainage elements accumulated as valley fill in the middle reach of the Pawnee River and in lower reaches of its major tributaries during the middle Holocene. This fill is stored beneath T-1 terraces of the Pawnee River and beneath T-2 terraces of fourth-order streams near their confluence with the Pawnee. Although middle Holocene deposits may be preserved in much of the valley fill stored beneath T-1 terraces of the lower and upper Pawnee River, their presence has not yet been documented.

Sedimentation on middle Holocene floodplains in lower reaches of major tributaries to the Pawnee River was episodic, with intervening periods of stability and soil formation. The nature of floodplain development indicates that transport of sediment out of the small basins draining to these lower reaches occurred with flood events during the middle Holocene.

A major shift in the locus of sediment storage took place during the late Holocene in the Pawnee River basin. Following the middle Holocene episode of downcutting and lateral erosion, second-order, third-order, and the upper and middle reaches of fourth-order streams, formerly zones of net sediment transport, became zones of sediment storage. Although valley bottoms of small streams experienced cut-and-fill episodes during the late Holocene, net storage of alluvium occurred, as evidenced by preservation of large volumes of late Holocene valley fill beneath T-1 terraces. Sometime around 1,000 yr B.P., small streams downcut, leaving their late Holocene floodplains as T-1 terraces.

Alluviation slowed in the lower, middle, and upper Pawnee River valley by ca. 2,800, 2,000, and 1,500 yr B.P., respectively, allowing soils to develop on the late Holocene floodplain. Also, the lower Pawnee River experienced two major avulsions sometime between 2,000 and 1,000 yr B.P. The timing of these avulsions is inferred from the archeological record. Numerous Plains Woodland sites (ca. 2,000–1,000 yr B.P.) are concentrated along the banks of two abandoned channels on the T-1 terrace between Larned and Burdett, Kansas (Earl Monger, personal communication, 1986). However, no Late Prehistoric sites have been documented near these channels; hence it is likely that the channels did not carry water after ca. 1,000 yr B.P.

The Pawnee River went through a major episode of incision sometime between 2,000 and 500 yr B.P. Deep entrenchment left late Holocene floodplains as T-1 terraces. The timing of this event can also be inferred from the archeological record. Concentrations of Plains Woodland sites along banks of abandoned channels on the T-1 surface suggest that the Pawnee River was at that level sometime between 2,000 and 1,000 yr B.P. However, a buried Middle Ceramic site (ca. 1,000–500 yr B.P.) in T-0 fill (locality PR-9, site 14H05) indicates that the Pawnee River had downcut and that T-0 aggradation was underway before 500 yr B.P. Late Holocene entrenchment and lateral channel migration in the Pawnee River valley re-

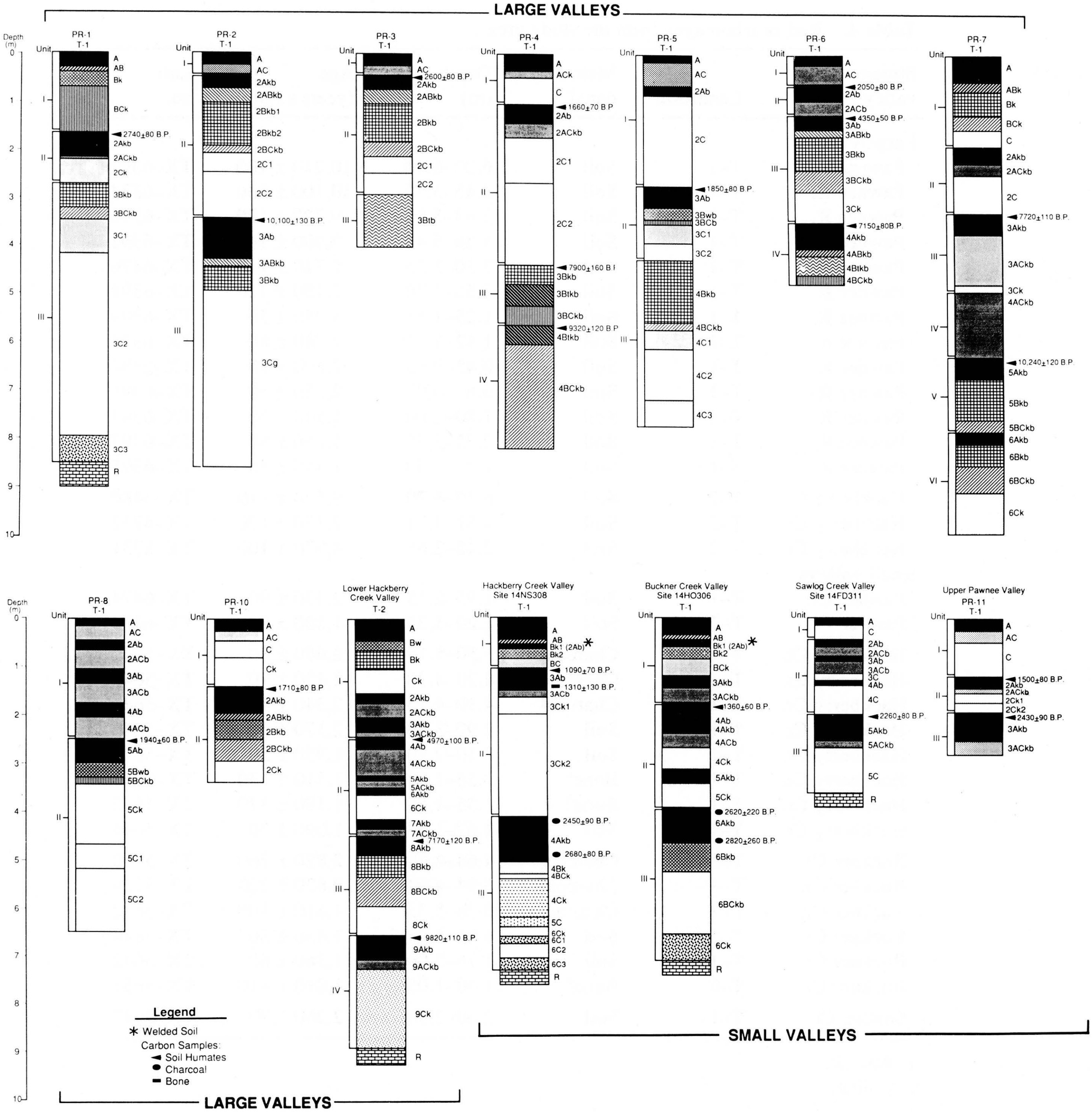

Figure 78. Stratigraphy in large and small valleys of the Pawnee River basin.

worked some deposits stored during the early and middle Holocene.

The drainage network of the Pawnee River appears to have received large volumes of sediment during the Historic period. It is likely that various human activities, such as land clearance and cultivation, increased sediment delivery to all drainage elements. The bulk of the Historic alluvium accumulated on modern floodplains (T-0) in large and small valleys and makes up flood drapes that mantle T-1 terraces in large valleys.

Regional correlation of Holocene alluvial sequences

When the Holocene alluvial record of the Pawnee River basin is compared with those of other stream systems in

Table 4. Radiocarbon ages from the study area

Stream valley	Landform	Material dated	Depth (m)	Age (years B.P.)	Lab no.
Large valleys					
Pawnee R.	T–1	Soil	6.20–6.40	10,240 ± 120	TX-6391
Pawnee R.	T–1	Soil	3.45–3.70	10,100 ± 130	TX-6374
Pawnee R.	T–1	Soil	5.63–5.83	9,320 ± 120	TX-6396
Pawnee R.	T–1	Soil	5.28–5.48	7,900 ± 160	TX-6392
Pawnee R.	T–1	Soil	3.30–3.35	7,720 ± 110	TX-6476
Pawnee R.	T–1	Soil	3.50–3.70	7,150 ± 110	TX-6398
Pawnee R.	T–1	Soil	1.25–1.55	4,350 ± 50	TX-6389
Pawnee R.	T–1	Soil	1.42–1.62	2,740 ± 80	TX-6375
Pawnee R.	T–1	Soil	0.45–0.65	2,600 ± 80	TX-6394
Pawnee R.	T–1	Soil	0.60–0.95	2,050 ± 80	TX-6390
Pawnee R.	T–1	Soil	1.80–2.00	1,940 ± 60	TX-6393
Pawnee R.	T–1	Soil	2.75–2.95	1,850 ± 80	TX-6397
Pawnee R.	T–1	Soil	1.20–1.40	1,710 ± 80	TX-6395
Hackberry Cr.	T–2	Soil	6.50–6.70	9,820 ± 110	TX-6480
Hackberry Cr.	T–2	Soil	4.51–4.71	7,170 ± 120	TX-4732
Hackberry Cr.	T–2	Soil	2.45–2.65	4,970 ± 100	TX-5731
Small valleys					
Pawnee Cr.	T–1	Soil	1.95–2.15	2,430 ± 90	TX-6474
Pawnee Cr.	T–1	Soil	1.20–1.35	1,500 ± 80	TX-6473
Hackberry Cr.	T–1	Charcoal	5.50–5.15	2,680 ± 80	TX-5640
Hackberry Cr.	T–1	Charcoal	4.20–4.30	2,450 ± 90	TX-5641
Hackberry Cr.	T–1	Charcoal	4.10–4.15	2,340 ± 400	TX-5639
Hackberry Cr.	T–1	Soil	2.90–3.30	2,170 ± 50	TX-5645
Hackberry Cr.	T–1	Soil	2.10–2.50	1,950 ± 50	TX-5645
Hackberry Cr.	T–1	Bone[a]	1.55–1.60	1,310 ± 130	TX-5643
Hackberry Cr.	T–1	Bone[b]	1.55–1.60	1,190 ± 370	TX-5643
Hackberry Cr.	T–1	Soil	1.07–1.37	1,090 ± 70	TX-5646
Buckner Cr.	T–1	Charcoal	4.64–4.69	2,820 ± 260	TX-5730
Buckner Cr.	T–1	Charcoal	3.94–4.04	2,620 ± 220	TX-5729
Buckner Cr.	T–1	Charcoal	5.28–5.33	1,610 ± 100	TX-5642
Buckner Cr.	T–1	Soil	4.98–5.28	1,430 ± 50	TX-5644
Buckner Cr.	T–1	Soil	1.76–2.00	1,360 ± 60	TX-5642
Buckner Cr.	T–0	Bone[b]	1.00–1.05	1,010 ± 410	TX-5651
Sawlog Cr.	T–1	Soil	2.00–2.30	2,260 ± 80	TX-5647

a. Apatite.
b. Collagen.

Table 5. Sources of error in radiocarbon dating

Source of error	Description
Sample selection	Inconsistencies in the collection of radiocarbon samples, especially from buried paleosols for humate dates, may lead to misinterpretations of the results. Not all researchers indicate whether the sample was taken from the top, middle, or bottom of a buried A or B horizon. Johnson and Martin (1987, p. 118) reported that up to 1,000 years could exist between ages from the top and bottom of an A horizon.
Contamination	It is difficult to remove all rootlets and other modern intrusive carbon from a sample. Also, materials containing carbonates (e.g., gastropods, bone) are susceptible to contamination by modern carbon because they readily participate in chemical reactions with meteoric and/or ground water (Bradley, 1985).
Fractionation effects	Some plants show evidence of preferential assimilation of ^{14}C to ^{12}C, thereby producing ages that are systematically too young (Bender, 1971). Some assessment of the ^{14}C fractionation effect can be made relatively easily by measuring the ^{13}C content of the sample. However, although some radiocarbon laboratories provide a ^{13}C-corrected age as part of their routine procedure, others provide it only on request.
Variations in the ^{14}C content of the atmospheric reservoir	There are systematic differences between radiocarbon and calender ages because of a changing concentration of radiocarbon within the atmospheric reservoir over time (Ralph and Michael, 1967). As the amount of radiocarbon in the atmosphere increases, the ratio of $^{14}CO_2$ to $^{12}CO_2$ is also increased, which yields an age anomalously too young. Although corrections can be applied to radiocarbon assays to diminish these systematic discrepancies, they can be applied only to ages less than about 6,500 years old (Wendland, 1983).
Variations in laboratory procedures	Different radiocarbon laboratories use different procedures to pretreat and process samples. This factor should be considered when comparing radiocarbon ages reported by more than one laboratory.

the Midwest, there is not an episode-to-episode correlation between any of the records. However, a general pattern is evident in the timing of fluvial events across the region as a whole. This pattern is similar to the one described by Knox (1983) for the Midwest and western Great Plains. Many of the alluvial chronologies used for comparison in the present study, as was the case in Knox's (1983) investigation, are tied to Holocene paleosol records from stream valleys. Buried paleosols in valley fills are readily dated by radiocarbon analysis, and they have long been recognized as indicators of episodic change in stream systems (Johnson and Martin, 1987). Caution must be exercised, however, when comparing radiocarbon ages determined on different materials (e.g., humates, charcoal, and bone) from different soils. Also, there are a number of sources of error in radiocarbon dating that should be considered (table 5).

The timing of Holocene landscape stability and concomitant soil development in the Pawnee River basin is separated into two principal categories: episodes in large valleys and episodes in small valleys (fig. 79). This comparison reveals that, whereas some episodes of landscape stability were basinwide, others were not. The paleosol records for large and small drainage elements in the Pawnee River basin were then compared with records for other drainage systems in the Central Plains (fig. 80).

Within the main valley of the Pawnee River, soil formation was underway by at least 10,300–10,100 yr B.P., based on mean residence time for organic carbon from buried paleosols. This period coincides with the Pleistocene-Holocene transition in the Midwest: a time of major atmospheric circulation shifts that resulted in dramatic hydrologic changes. Deposits and associated soils of such antiquity have been documented at a few localities in the

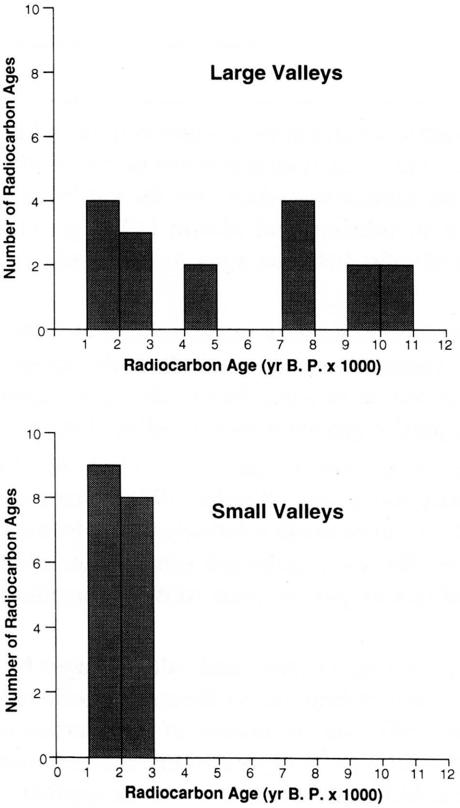

Figure 79. Histograms showing radiocarbon ages determined on humates from buried soils in large and small valleys.

Central Plains, including Cooper's Canyon in central Nebraska (May, 1990), Bonner Springs in northeastern Kansas (Holien, 1982), and Wokanda Lake in north-central Kansas (May, 1993) (fig. 80).

Mean residence time for humates from buried paleosols in large valleys of the Pawnee River suggests that the period 10,000–7,000 yr B.P. was punctuated by episodes of floodplain stability and soil development. A similar pattern of early Holocene soil development is indicated by radiocarbon assays from the Loup River basin of Nebraska and the Walnut and Kansas river valleys of Kansas (fig. 80).

Holocene valley fills in the Pawnee River basin are devoid of any indications of soil development between 7,000 and 5,000 yr B.P. (fig. 80). However, mean residence times for organic carbon from buried paleosols indicate soil formation on large, low-angle alluvial fans in the Smoky Hill River valley at ca. 5,100–5,300 and 5,750 yr B.P. (Mandel, 1992b), partially filling the gap in the middle Holocene paleosol record. Several studies suggest that the middle Holocene was a time of stream-system instability or at least of low potential for strong soil development in the Central Plains (Johnson and Martin, 1987). For example, at the Coffey site in the Big Blue River valley of northeastern Kansas, Schmits (1980) recorded aggradation at ca. 6,300 yr B.P. May (1986) noted that alluvial fill at the Horn site on the South Loup River shows no evidence of soil development, in the form of buried paleosols, from ca. 7,000 to 4,780 yr B.P. Elsewhere in the South Loup River valley, Ahlbrandt et al. (1983) reported 10 radiocarbon ages from organic-rich zones in sandy alluvial fill. None of these dates, however, is within the period 7,000–5,000 yr B.P., suggesting an absence of floodplain stability and/or sufficient biomass for organic enrichment of sediment.

Radiocarbon assays suggest that soil formation was underway by at least 5,000 yr B.P. on floodplains of large valleys in the Pawnee River basin. Corroborative evidence for this episode of landscape stability once again comes from the Kansas and Loup river systems (fig. 80).

The timing of late Holocene floodplain stability and soil formation in the Pawnee River basin shows some variation according to the size of the streams. Radiocarbon assays indicate two discrete periods of paleosol development in large valleys: one at ca. 2,750–2,600 yr B.P. and another at ca. 2,000–1,600 yr B.P. (fig. 80). The older of these two episodes partially coincides with the soil-forming period radiocarbon-dated to ca. 2,800–2,000 yr B.P. in small valleys. However, the most recent episode of paleosol development in large valleys, 2,000–1,600 yr B.P., precedes the beginning of the major soil-forming period dated to 1,350–1,000 yr B.P. in small valleys. Hence late Holocene deposition appears to have been time-transgressive throughout the entire extent of the drainage basin.

Good indications of fluvial stability and soil formation during the late Holocene are found elsewhere in the Midwest, including the Central Plains (fig. 80). Late Holocene paleosols have been documented in the South Loup River valley in central Nebraska (May, 1986, 1989), the Republican River valley in south-central Nebraska (Martin, 1990), and the Smoky Hill River valley in north-central Kansas (Mandel, 1992b). Buried paleosols dating to the late Holocene are common in the valleys of tributaries to the Arkansas River in Kansas, including the Neosho, Verdigris, Fall, and lower Walnut rivers (Mandel, 1992a, 1993a,b).

There are exceptions to the synchronous pattern of fluvial stability and soil development in midwestern stream valleys during the Holocene. For example, an episode of soil development radiocarbon-dated to ca. 600–400 yr B.P. (Delaware Creek paleosol) in small stream valleys in southwestern Oklahoma (Ferring, 1986) has not been documented in the Central Plains. Similarly, a major episode of soil development dated to ca. 6,500–6,000 yr B.P. in the Des Moines River valley (Bettis and Hoyer, 1986) has not been recorded in central or southwestern Kansas.

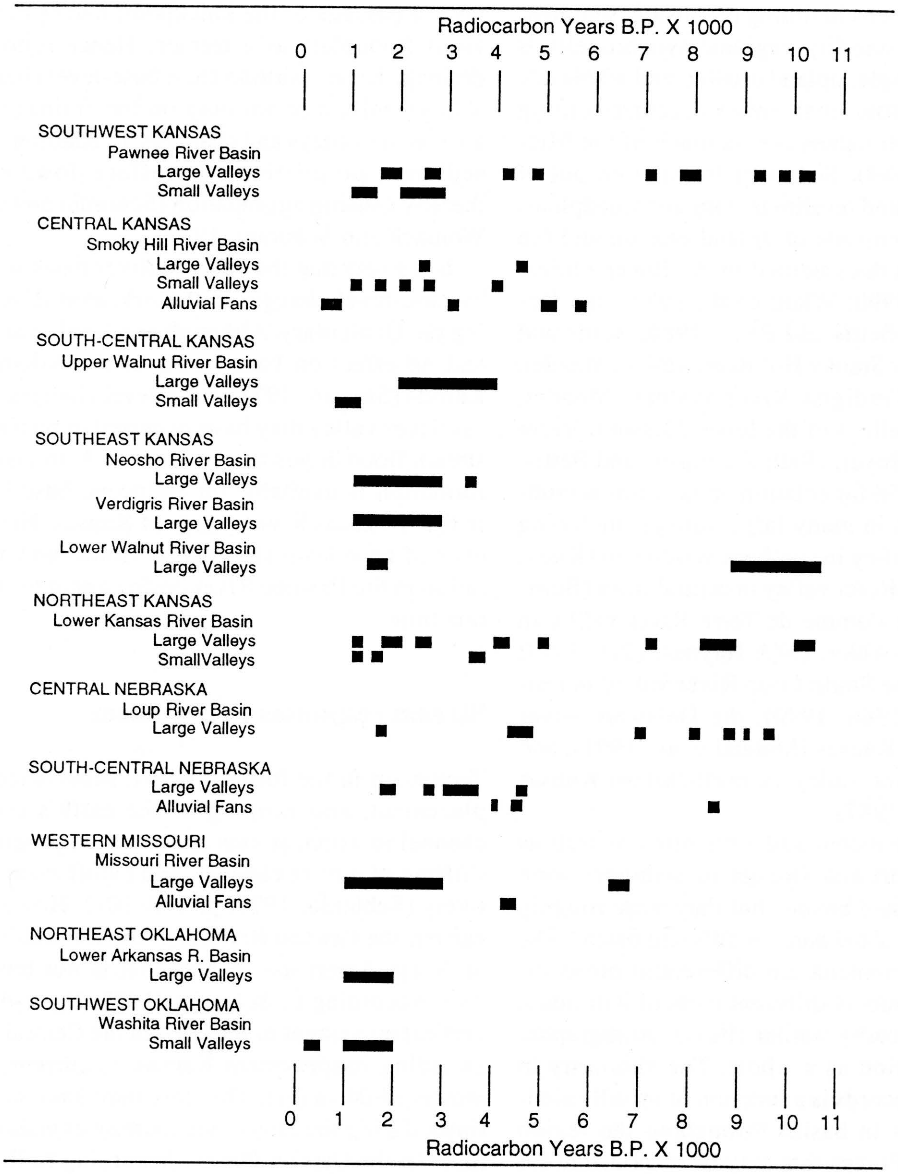

Figure 80. Periods of Holocene floodplain stability and soil formation in the Central Plains. Records are based on radiocarbon assays from the region. Sources: Present study (southwest Kansas); Mandel (1992b) (central Kansas); Artz (1983) and Mandel (1993b) (south-central Kansas); Mandel (1993a,b) (southeast Kansas); Bowman (1985), Johnson and Martin (1987), Mandel (1987), and Mandel et al. (1991) (northeast Kansas); Brice (1964) and May (1986, 1989, 1990) (central Nebraska); Martin (1990) (south-central Nebraska); Mandel (1985) (western Missouri); Artz and Reid (1984) and Hall (1977a–c) (northeast Oklahoma); Hall (1982), Lintz and Hall (1983), and Ferring (1986) (southwest Oklahoma).

Despite some variations in timing of erosion, sedimentation, and landscape stability, regional synchroneity is indisputable. For example, upland erosion and wholesale removal of sediment from small valleys occurred during the early and middle Holocene across much of the Midwest (Bettis et al., 1984). Sediment transported out of small valleys accumulated on alluvial fans and floodplains in large valleys. This episode of upland erosion and fan development has been documented in the lower Illinois River valley (Hajic, 1990; Wiant et al., 1983), the Des Moines River valley (Bettis and Benn, 1984; Bettis and Hoyer, 1986), the lower Smoky Hill River valley (Mandel, 1988b, 1992b), the Verdigris River system (Mandel, 1990a), and in large valleys of the lower Missouri River system (Ahler, 1973; Hoyer, 1980; Thompson and Bettis, 1980; Mandel, 1985). Sedimentation on fans was accompanied by aggradation in many large valleys, including the Wisconsin River valley in southern Wisconsin (Knox, 1972), the Des Moines River valley in central Iowa (Bettis and Hoyer, 1986), the Pomme de Terre River valley in west-central Missouri (Ahler, 1973; Haynes, 1976, 1977; Brakenridge, 1981), the South Loup River valley in central Nebraska (May, 1986, 1990), the Delaware River valley in northeastern Kansas (Mandel et al., 1991), and the lower Kansas River valley in northeastern Kansas (Johnson and Martin, 1987).

In summary, entrenchment and alluviation as well as periods of net transport and storage of sediment were diachronous in individual basins, but they were roughly synchronous in similar-sized parts of different basins. The products of these phenomena are differential preservation of Holocene deposits in different parts of individual drainage basins and broadly similar alluvial stratigraphic records across the region as a whole. The similarity in alluvial stratigraphic records is a function of broadly similar activity of streams in basins throughout the region during the Holocene. Forces that may be responsible for the pattern of Holocene fluvial activity are considered in the following discussion.

Stream responses to base-level changes

Raising and lowering the base level of a drainage basin cause aggradation and incision, respectively (Schumm, 1977, p. 70–74). Considerable attention has been given to the role of base-level changes in terrace formation (Schumm, 1977, p. 13–14, 70–74; Chorley et al., 1984, p. 334–335). Schumm (1977) demonstrated that the lowering of the base level creates a knickpoint in a stream profile that migrates upstream, successively rejuvenating tributaries as it does so. According to Chorley et al. (1984, p. 334), this can be viewed as a "wave of rejuvenation" that advances not only up the main channel but also up tributaries of decreasing rank order. In each valley the passage of the knickpoint leaves the incised previous floodplain as a terrace. Hence rejuvenation of a drainage basin resulting from base-level change has a significant influence not only on the drainage network but also on the valleys and channels. In addition, the increased sediment production may affect downstream areas, thereby causing aggradation (Schumm and Parker, 1973; Womack and Schumm, 1977).

It is likely that the Pawnee River basin was influenced by base-level changes in the Arkansas River valley during the Quaternary. Although sea-level changes probably had no effect on base levels of the Arkansas River in Kansas (Stewart, 1973), base-level changes in the Arkansas River valley may have occurred in response to downstream flood deposition or erosion. Unfortunately, no information is available on Holocene base-level changes in the Arkansas River valley of Kansas. Hence the influence of base-level changes on Holocene landscape evolution in the Pawnee River basin cannot be determined at this time.

Stream responses to tectonism

Tectonism in the form of uplift, subsidence, lateral displacement, and warping of the earth's crust produces channel incision, stream aggradation, progressive lateral shifting of a river channel, and cutoff meanders, respectively (Schumm, 1977, p. 100–101). However, as noted earlier, the Pawnee River is in the Central Stable Region of North America—an area that is not tectonically active. According to Schumm (1977, fig. 2-6), the rate of vertical movement of the crust in the Central Great Plains, including southwestern Kansas, is currently less than 1 mm/yr (0.04 in./yr). This rate may have been greater at times during the Holocene, thereby explaining some terraces in the Central Plains. According to Rogers (1984), dramatic Holocene uplift caused channel trenching and thus terrace formation in the Kansas and Arkansas River valleys of western Kansas.

Geophysical information collected by the Kansas Geological Survey suggests that the rate of uplift in southwestern Kansas was no greater at any time during the Holocene than it is today (Don Steeples, personal communication, 1988). This information combined with the diachronous pattern of Holocene erosion and sedimentation in the Pawnee River basin raises doubts about the role of tectonics in Holocene landscape evolution in the study area.

Stream responses to climatic change

Flowing water provides the energy with which streams erode, transport, and deposit sediment. Hence landscape

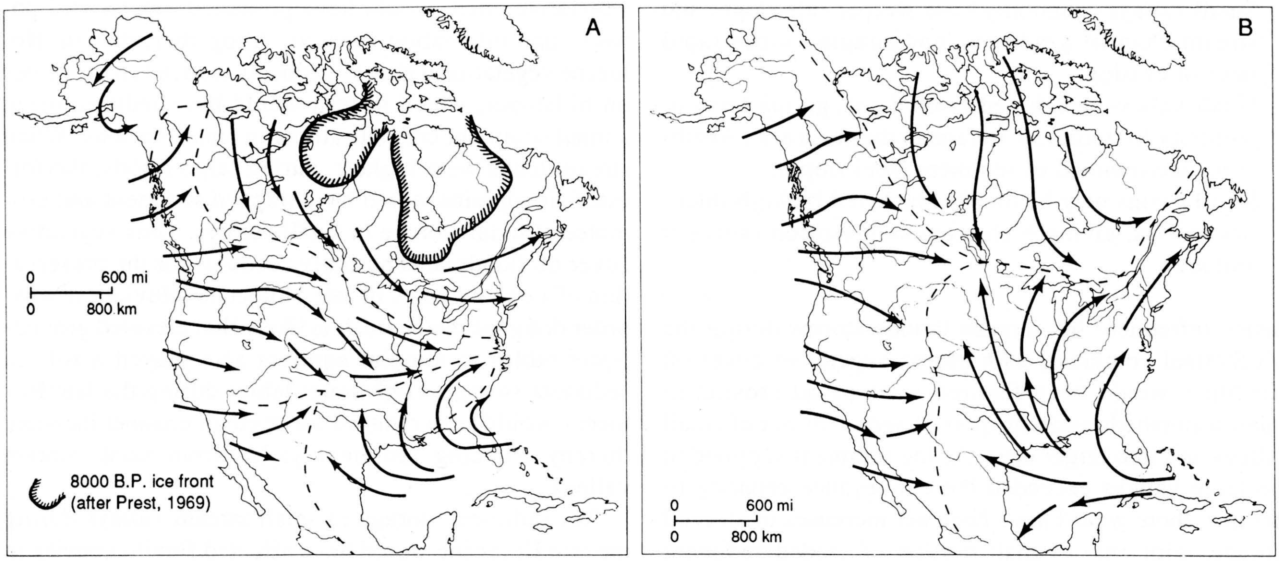

Figure 81. Dominant air-flow patterns in North America during the Holocene. (A) Strong zonal westerly flow during the Altithermal [March resultant surface streamlines (after Bryson and Hare, 1974)]. (B) Meridional flow that has persisted since about 6,000 yr B.P. [June resultant streamlines (after Bryson and Hare, 1974)]. [From Knox (1983).]

evolution in a drainage basin is linked to changes in hydrologic variables affecting stream flow. Hydrologic variables are, in turn, responsive to changes in climate. Also, climate has a significant effect on vegetation density (Schumm, 1977, p. 25–26). The density of vegetative cover, in turn, affects surface runoff and erosion. Hence climatic change must be considered a major factor influencing landscape evolution in any river basin.

The alluvial chronology of the Pawnee River basin and other midwestern stream systems combined with paleoenvironmental data from the region suggests that wholesale removal of sediment from small valleys during the early and middle Holocene was a result of major bioclimatic change. Models of climatic conditions during this period indicate a trend toward warmer and drier conditions, apparently as a result of increased summer insolation (COHMAP Members, 1988) and stronger zonal air flow at the surface (Bryson and Hare, 1974; Kutzbach and Guetter, 1986; Kutzbach, 1987). Strong zonal flow restricted the northward penetration of moist tropical air masses into the Plains (fig. 81), thereby triggering the warm, dry Altithermal climate that prevailed in the Midwest from about 8,000 to 5,000 yr B.P. (Antevs, 1955; Deevey and Flint, 1957; Bryson et al., 1970; Webb and Bryson, 1972). The pollen record from Muscotah Marsh in northeastern Kansas documents an increase in grasses at the expense of trees during the Altithermal (Gruger, 1973). This interval of aridity caused prairies to expand far eastward into Missouri, Iowa, and Illinois (Brush, 1967; Wright, 1968, 1971; Durkee, 1971; King and Allen, 1977; Van Zant, 1979). As tall- and mixed-grass prairies in the Central Plains were replaced by sparser short-grass prairie, hillslopes would have been prone to erosion. It is also likely that frequent fires during this dry period removed ground cover and thereby accelerated erosion on hillslopes. Valley floors also would have been prone to erosion as ground-water levels in alluvial aquifers dropped, allowing streams to deeply incise their valley fill. In addition, the northward retreat of the Laurentide ice sheet during the early Holocene and the sharp north-south temperature gradient at its southern margin probably triggered a change from frequent widespread but gentle rains associated with air-mass fronts to less frequent precipitation but more intense and erosive thunderstorms in the Midwest (Knox, 1983, p. 34).

The net effect of these climatic and vegetative changes would have been high erosion rates and large sediment yields in small streams during the early and middle Holocene (Bettis and Mandel, 1989). As Chorley et al. (1984, p. 53–54) pointed out, sediment delivery ratios are greater for small drainage basins than for larger ones under normal conditions. They attribute this inverse relationship to the following properties of small basins in relation to larger ones:

1. Small valleys commonly have steeper side slopes and stream-channel gradients, encouraging more rapid rates of erosion.
2. Small valleys lack broad floodplains, giving less opportunity for sediment storage in the basin after weathering and removal of sediment from slopes.
3. Small basins may be totally blanketed by high-intensity storms, giving high maximum erosion rates per unit area.

Hence infrequent but intense thunderstorms during the Altithermal combined with sparse vegetative cover on hillslopes would have favored widespread erosion in small watersheds and transport of sediment out of small valleys and into larger ones. As the sediment supplied to the large valleys exceeded the conveyance capacity of streams, there would have been net increases in alluvial storage, with only a small portion of eroded sediment leaving the basin (Phillips, 1987). It is likely that alluviation and storage of sediment occurred both on fans and on floodplains in high-order stream valleys.

The change of atmospheric circulation from frequent zonal dominance during the early and middle Holocene to mixed zonal and meridional dominance during the late Holocene (fig. 81) influenced the regional distribution of vegetative communities and thus the activity of fluvial systems (Knox, 1983, p. 31). The increased frequency of meridional atmospheric circulation after ca. 4,000 yr B.P. is significant because it allowed warm, moist tropical air masses from the Gulf of Mexico to penetrate deep into the central Great Plains. Mean annual precipitation and large floods probably increased significantly because of frequent frontal activity in the collision zone between polar and tropical air masses (Knox, 1983, p. 39). As mean annual precipitation increased during the late Holocene, forests expanded across floodplains and hillslopes in the Midwest (Wright, 1971). Vegetation density increased in upland areas of the Central Plains as short-grass prairies were replaced by mixed- and tall-grass prairies. Denser vegetative cover would have promoted greater soil porosity and infiltration capacity. Altogether, the late Holocene vegetational change probably reduced erosion rates on hillslopes, which in turn would have reduced mean annual sediment concentrations in small streams. When stream loads were highest, during large floods, the forested floodplains would have trapped sediment and promoted alluvial storage in small valleys. Thus vegetative cover on floodplains partially accounts for the preservation of large volumes of late Holocene alluvium in low-order drainage elements. It is likely that elevated groundwater tables in alluvial aquifers also played a role in sediment storage. High water tables during the late Holocene would have reduced the depth of channel incision, thereby reducing sediment yields from small stream valleys.

Net sediment storage in small stream valleys during the late Holocene would have affected fluvial activity in large valleys. Because conveyance capacities of high-order streams were no longer satisfied by sediment imposed from tributaries, entrenchment and lateral channel migration into floodplain deposits of large valleys probably enhanced sediment loads in this part of the fluvial system.

There is no question that major bioclimatic changes affected Holocene landscape evolution in stream valleys of the Midwest, including the Great Plains. The development of alluvial fans during the early and middle Holocene is a case in point. However, when basinwide Holocene alluvial chronologies are examined, it is apparent that each erosional and depositional event did not occur in response to one external change, such as climate. Also, the number, magnitude, and duration of erosional and depositional events varied not only from valley to valley in the Midwest but also from area to area in the same basin. Thus fluvial events were not in phase everywhere, suggesting that some episodes of erosion, deposition, and landscape stability did not occur in response to a single external control.

Summary and conclusions

The foregoing discussion described the nature of valley landscapes in the Pawnee River basin of southwestern Kansas and focused on the stratigraphy and chronology of alluvial deposits composing landform-sediment assemblages in different drainage elements of the basin. Here, I summarize the findings and make recommendations for future research in the Central Plains.

Landforms and valley fill

Three terraces were identified in the large valley (greater than fourth-order) of the Pawnee River. These terraces are designated, from lowest to highest, T-1, T-2, and T-3. Radiocarbon assays indicate that most of the Holocene valley fill underlies the T-1 terrace. Alluvium beneath the

T-2 and T-3 terraces is thought to be Wisconsinan and Illinoian in age, respectively, though no absolute ages are available for these landform-sediment assemblages.

A modern floodplain (T-0) borders the Pawnee River throughout most of its course. The presence of weakly developed floodplain soils and buried Late Prehistoric cultural materials suggests that deposits underlying the T-0 surface are less than 1,000 years old.

The valley floors of second- and third-order streams in the Pawnee River basin are composed of two landforms: a narrow floodplain (T-0) and a low terrace (T-1). This sequence of landforms also is documented in the middle and upper reaches of fourth-order streams. Radiocarbon assays indicate that most of the alluvium composing the T-1 fill accumulated between ca. 2,800 and 2,000 yr B.P.; no early or middle Holocene valley fill is documented beneath these terraces.

A second terrace (T-2) was observed on valley floors of fourth-order streams near their confluence with the Pawnee River. Radiocarbon assays indicate that most of the alluvium composing the T-2 fill accumulated between ca. 9,000 and 5,000 yr B.P.

Holocene history

Temporal data, both absolute and relative, were used to reconstruct the Holocene history of the Pawnee River basin. During the early Holocene, alluviation in large valleys was punctuated by floodplain stability, soil formation, and erosion. However, the early Holocene record of small streams is unknown because no fill dating to that period has been found. During the middle Holocene, aggradation continued in large valleys, but there is no evidence of soil formation between ca. 7,000 and 5,000 yr B.P. Small streams (second- and third-order) and the upper and middle reaches of fourth-order streams were characterized by net transport of alluvium during the middle Holocene. However, a major shift in the focus of sediment storage took place during the late Holocene. Small streams, formerly zones of net sediment transport, became zones of net sediment storage. This period of alluviation in small valleys was punctuated by episodes of landscape stability and soil formation. Two major periods of floodplain stability and soil formation were documented: one at ca. 2,800–2,000 yr B.P. and another at ca. 1,350–1,000 yr B.P.

Alluviation slowed in the lower, middle, and upper Pawnee River valley by ca. 2,800, 2,000, and 1,500 yr B.P., respectively, allowing soils to develop on the late Holocene floodplain. The Pawnee River downcut sometime between 2,000 and 500 yr B.P., leaving the late Holocene floodplain as a terrace (T-1). This wave of late Holocene incision spread into small valleys at about 1,000 yr B.P., also creating a T-1 terrace.

The entire network of the Pawnee River received large volumes of sediment during the past 1,000 years, especially during the Historic Period. This sediment is stored beneath modern floodplains in large and small valleys. Also, Historic alluvium mantles portions of T-1 terraces in the main valley of the Pawnee River.

The Holocene alluvial chronology of the Pawnee River basin corresponds to the record of climatic change for the Central Plains. In general, early and middle Holocene erosion in small valleys accompanied by alluviation in large valleys corresponds to regional warming and drying (Altithermal). Increased sediment storage in small valleys during the late Holocene was in phase with a shift to wetter conditions. Deep entrenchment in large and small valleys sometime around 1,000 yr B.P. may be related to a short episode of warm, dry conditions documented elsewhere in the Great Plains [see Hall (1990)].

The Holocene stratigraphic record of the Pawnee River is similar to records of other streams in the Central Plains. This similarity is attributed to broadly similar activity of streams throughout the Plains during the Holocene. Major climatic changes appear to be the cause of the synchronous patterns of fluvial activity detected in the stratigraphic records of streams in the regions. However, extrinsic and intrinsic factors in the fluvial system interact to produce periods of stability and instability that may be detected in the stratigraphic record of one stream but not in the record of another stream in the same basin.

Directions for future research

Archeological research The preceding discussion noted that alluvial deposits of certain ages are differentially but systematically preserved in various drainage elements of the Pawnee River basin. This information combined with geomorphic and soil-stratigraphic data can be used to direct future archeological research in the region. For example, the results of this study make it possible to predict where buried materials for each cultural period are likely to occur in the drainage network (table 6). The potential is based on the presence or absence of Holocene deposits and buried paleosols in the different drainage elements of the basins [after Bettis and Benn (1984, p. 22)].

The geologic potential for buried prehistoric deposits older than Plains Village in T-0 deposits of large and small valleys in the study area is considered low to nonexistent (table 6). Archeological evidence suggests that most of the fill beneath modern floodplains in the region is less than 1,000 years old, and no paleosols were found at

Table 6. Geologic potentials for buried archeological deposits in the study area[a]

Cultural period	Large valleys T-0	Large valleys T-1	Large valleys T-2[b]	Small valleys T-0	Small valleys T-1
Paleo-Indian (>10,000 yr B.P.)	–	+++	+++	–	–
Early Archaic (10,000–6,000 yr B.P.)	–	+++	+++	–	–
Middle Archaic (6,000–4,000 yr B.P.)	–	+++	+++	–	–
Late Archaic (4,000–2,000 yr B.P.)	+	+++	++	–	+++
Plains Woodland (2,000–1,000 yr B.P.)	+	+++	+	+	+++
Plains Village (1,000–500 yr B.P.)	++	+++	–	++	++
Proto-Historic (500–150 yr B.P.)	+++	+++	–	+++	+
Historic (<150 yr B.P.)	+++	+++	–	+++	+

a. +, low potential; ++, moderate potential; +++, high potential; –, impossible.

b. Applies only to T-2 terraces in lower reaches of fourth-order streams near their confluence with the Pawnee River.

depths of more than 50 cm (1.6 ft) below the T-0 surface. Also, preservation of sedimentary features throughout most of the T-0 fill indicates rapid deposition. Altogether these lines of evidence suggest that buried prehistoric sites probably are rare in T-0 deposits, and sites that do occur are likely to be Plains Village and Proto-Historic occupations. There is high potential, however, for Historic sites and artifacts below the surfaces of modern floodplains.

There is high potential for buried archeological deposits dating to all cultural periods in T-1 fill of the Pawnee River valley. Paleo-Indian and Early Archaic sites are likely to be associated with buried early Holocene soils documented 3.5–7.0 m (11–23 ft) beneath the T-1 surface. Also, Middle Archaic materials may occur at the top of these buried soils. Late Archaic and younger cultural deposits are likely to be associated with buried late Holocene soils documented at many localities in the Pawnee River valley. Most of these late Holocene soils are beneath Historic alluvium that mantles large areas of the T-1 terrace.

Alluvial deposits and paleosols beneath T-1 terraces in small valleys are likely to contain Late Archaic and Plains Woodland sites, but no Middle Archaic or older sites are associated with T-1 fills. Only late Holocene deposits are stored in T-1 fill of second- and third-order streams, precluding an early archeological record. Deep entrenchment of small streams in the Pawnee River basin isolated T-1 surfaces from Historic floods and concomitant sedimentation. Hence Historic and Late Prehistoric cultural deposits should be present on these surfaces in small valleys. This has been confirmed by a recent archeological survey in small valleys of the Pawnee River basin (Timberlake, 1988).

The geologic potential for buried archeological deposits in valley fill underlying T-2 terraces of the Pawnee River is unknown because the age of the fill has not been determined. However, T-2 fill in the lower reaches of fourth-order tributaries to the Pawnee River contains early and middle Holocene deposits and paleosols; therefore it may contain materials dating from the Paleo-Indian through the Late Archaic period.

If the time-space distribution of alluvial deposits in the study areas holds true for other drainage basins of the Great Plains, it may explain the paucity of Archaic and Paleo-Indian sites in the region. In large valleys most of the archeological record may be deeply buried in early through late Holocene terrace fills. In small valleys erosion during the early and middle Holocene probably removed most of the early sites, and aggradation during the late Holocene and Historic Period favored deep burial of Late Archaic and younger sites. Also, surfaces of landforms that dominate valley bottoms throughout the drainage systems are geologically young, often postdating 2,000 yr B.P. Hence apparent gaps in the archeological record may be a result of (1) deep burial of sites, (2) removal of deposits that contain sites, and (3) young surfaces dominating valley landscapes.

Pedologic research Soil data gleaned from the present study provide a basis for future pedologic research in the region. For example, radiocarbon ages can be used to determine rates of soil genesis in dry-subhumid and semi-arid regions of the Central Plains. Also, morphologic properties of buried Holocene soils raise interesting questions about soil-forming factors. For example, why do early and middle Holocene soils in the Pawnee River valley generally have strongly developed Bt and/or Btk horizons, whereas most late Holocene buried soils are characterized by weakly developed A–C, A–Bw, or A–Bk profiles? Preliminary results suggest that such variability in Holocene soils may be related to preconditioning of parent materials (Mandel, 1990b). However, additional study is needed to isolate the effects of parent materials from those of time and climate on soil morphology.

Paleoenvironmental research Most of what has been stated here about Holocene paleoenvironments of the study region was inferred from data gathered elsewhere in the Central Plains. However, there is great potential for collecting paleoenvironmental data in the Pawnee River basin. For example, stratified archeological deposits in late Holocene valley fill of Buckner and Hackberry creeks contain large- and small-mammal bones. Different faunal assemblages detected in different cultural horizons may reflect environmental changes during the late Holocene.

Gastropods and pelecypods also are common in Holocene valley fill of the Pawnee River and its tributaries. Preliminary examination of these invertebrate fauna revealed that there is great potential for paleoenvironmental reconstruction based on changes in taxa from one stratigraphic unit to the next (Raymond Neck, personal communication, 1988).

In addition to examining faunal assemblages in the Holocene fills, an effort should be made to recover pollen and opal phytoliths from Holocene buried soils in the Pawnee River basin. Paleobotanic information combined with the available temporal data would be invaluable to a reconstruction of the region's late Quaternary environments.

Appendix: Soil profile descriptions

Table A.1. Description of core 3 at site 14PA307 at locality PR-1

Location: Pawnee County, KS; NENE sec. 6, R. 16 W., T. 22 S.
Landscape position: T-1 terrace
Slope: <1%
Vegetation: alfalfa

Depth (cm)	Soil horizon	Unit	Description
0–20	Ap	I	Brown (10YR 4/3) silt loam, very dark grayish-brown (10YR 3/2) moist; weak fine granular structure; friable; many fine roots; strong effervescence; clear boundary.
20–33	A	I	Very dark gray (10YR 3/1) silt loam, very dark grayish-brown (10YR 3/2) moist; weak medium and fine granular structure; friable; many fine roots; weak effervescence; gradual boundary.
33–43	AB	I	Brown (10YR 4/3) silt loam, dark-brown (10YR 3/3) moist; weak medium granular structure; friable; common fine roots; strong effervescence; gradual boundary.
43–58	Bk1	I	Brown (10YR 4/3) light silty clay loam, dark-brown (10YR 3/3) moist; weak medium subangular blocky structure parting to fine granular structure; friable; common threads of calcium carbonate; common fine pores; few earthworm casts; few fine roots; few bone fragments at 45 cm; strong effervescence; gradual boundary.
58–80	Bk2	I	Brown (10YR 5/3) loam, brown (10YR 4/3) moist; weak fine subangular blocky structure parting to fine granular structure; friable; common threads and films of calcium carbonate; many fine pores; many earthworm casts; few bone fragments at 60–63 cm; strong effervescence; gradual boundary.
80–170	BCk	I	Pale-brown (10YR 6/3) loam, brown (10YR 4/3) moist; weak medium granular structure to massive; friable; common threads and films of calcium carbonate; many fine pores; many earthworm casts; few fine roots; strong effervescence; abrupt boundary.
170–220	2Akb	II	Dark-grayish-brown (10YR 5/2) silt loam, very dark grayish-brown (10YR 3/2) moist; weak fine granular structure; friable; many prominent films and threads of calcium carbonate; common fine pores; common flecks of charcoal; strong effervescence; gradual boundary.
220–226	2ACkb	II	Grayish-brown (10YR 5/2) fine sandy loam, dark-brown (10YR 3/3) moist; weak very fine granular structure; very friable; common threads of calcium carbonate; common fine pores; strong effervescence; gradual boundary.
226–275	2Ck	II	Grayish-brown (10YR 5/2) loamy fine sand, dark-brown (10YR 3/3) moist; massive; soft; common fine threads of calcium carbonate; common fine pores; strong effervescence; abrupt boundary.
275–328	3Bkb	III	Brown (10YR 5/3) silty clay, dark-brown (10YR 3/3) moist; moderate fine and medium subangular blocky structure; firm; many prominent threads of calcium carbonate; common fine pores; common earthworm casts; strong effervescence; gradual boundary.
328–352	3BCkb	III	Brown (10YR 5/3) silty clay loam, brown (10YR 4/3) moist; weak fine subangular blocky structure; firm; many films and threads of calcium carbonate; many fine pores; common earthworm casts; strong effervescence; gradual boundary.
352–419	3C1	III	Pale-brown (10YR 6/3) laminated silt and very fine sand, brown (10YR 4/3) moist; common fine distinct dark-yellowish-brown (10YR 4/6) and yellowish-brown (10YR 5/8) mottles; massive; soft, friable; few fine pores; weak effervescence; abrupt boundary.
419–792	3C2	III	Light-yellowish-brown (10YR 6/4) medium sand, yellowish-brown (10YR 5/4) moist; single-grained; loose; noneffervescent; abrupt boundary.

Table A.1 (continued)

Depth (cm)	Soil horizon	Unit	Description
792–853	3Cg	III	Grayish-brown (2.5Y 4/2) sand and gravel in clayey matrix, very dark grayish-brown (2.5Y 3/2) moist; massive; firm; weak effervescence; abrupt boundary.
853	4R	–	Dakota Sandstone.

Table A.2. Description of core 1 at locality PR-2

Location: Pawnee County, KS; NWNW sec. 32, R. 17 W. ,T. 21 S.
Landscape position: T-1 terrace
Slope: <1%
Vegetation: native grasses

Depth (cm)	Soil horizon	Unit	Description
0–20	Ap	I	Dark-grayish-brown (10YR 4/2) light silty clay loam, very dark brown (10YR 2/2) moist; weak fine granular structure; friable; common fine roots; weak effervescence; clear smooth boundary.
20–61	AC	I	Brown (10YR 5/3) to grayish-brown (10YR 5/2) silt loam, dark-grayish-brown (10YR 4/2) moist; weak fine granular structure; friable; common fine roots; many earthworm casts; strong effervescence; abrupt boundary.
61–86	2Akb	II	Dark-grayish-brown (10YR 4/2) light silty clay loam, very dark grayish-brown (10YR 3/2) moist; weak medium and fine granular structure; friable; few fine roots; few films of calcium carbonate; common earthworm casts; strong effervescence; gradual boundary.
86–96	2ABkb	II	Dark-grayish-brown (10YR 4/2) light silty clay loam, very dark grayish-brown (10YR 3/2) moist; weak fine subangular blocky structure; friable; few fine roots; common films and threads of calcium carbonate; few earthworm casts; matrix has weak effervescence; gradual smooth boundary.
96–142	2Bkb1	II	Brown (10YR 4/3) heavy silty clay loam, dark-brown (10YR 3/3) moist; weak medium subangular blocky structure; friable; few fine roots; common films and threads of calcium carbonate along ped faces; few fine hard calcium carbonate concretions; common fine pores; common pressure faces; matrix is noneffervescent; gradual boundary.
142–190	2Bkb2	II	Brown (10YR 4/3) heavy silty clay loam, dark-brown (10YR 3/3) moist; weak medium subangular blocky structure; friable; many prominent films of calcium carbonate; common fine irregular soft masses of carbonate; few fine hard carbonate nodules; common fine pores; common pressure faces; matrix is noneffervescent; gradual boundary.
190–212	2BCkb	II	Brown (10YR 4/3) silty clay loam, dark-brown (10YR 3/3) moist; weak fine subangular blocky structure; friable; common films and threads and few fine hard concretions of calcium carbonate; common pressure faces; common fine pores; matrix is noneffervescent; gradual boundary.
212–292	2C1	II	Pale-brown (10YR 6/3) and brown (10YR 5/3) laminated silt loam, brown (10YR 4/3) and dark-brown (10YR 3/3) moist; massive; friable; few fine pores; weak effervescence; gradual boundary.
292–345	2C2	II	Brown (10YR 5/3) silt loam, dark-brown (10YR 3/3) moist; massive; friable; few pale-brown (10YR 6/3) lenses (<3 mm thick) of silt; few fine pores; noneffervescent; abrupt boundary.
345–434	3Ab	III	Dark-grayish-brown (10YR 4/2) silty clay loam, very dark brown (10YR 2/2) moist; weak medium and fine granular structure; friable; few fine pores; noneffervescent; gradual boundary.
434–447	3ABkb	III	Brown (10YR 4/3) silty clay loam, dark-brown (10YR 3/3) moist; weak medium granular and fine subangular blocky structure; friable; common films and threads of calcium carbonate; few fine pores; moderate effervescence; gradual boundary.
447–492	3Bkb	III	Light-yellowish-brown (2.5Y 6/4) silty clay, light-olive-brown (2.5Y 5/4) moist; few fine faint olive-yellow (2.5Y 6/6) and strong brown (7.5YR 5/8) mottles; moderate medium and fine subangular blocky structure; firm; many prominent films and threads and common soft irregular masses of calcium

Table A.2 (continued)

Depth (cm)	Soil horizon	Unit	Description
			carbonate; few fine pores; few pressure faces; matrix is noneffervescent; gradual boundary.
492–853+	3Cg	III	Grayish-brown (2.5Y 5/2) silty clay loam, dark-grayish-brown (2.5Y 3/2) moist; few fine faint olive-yellow (2.5Y 6/6) and strong brown (7.5YR 5/8) mottles; massive; firm; few fine pores; weak effervescence.

Table A.3. Description of core 2 at locality PR-2

Location: Pawnee County, KS; SWSE sec. 29, R. 17 W., T. 21 S.
Landscape position: T-3 terrace
Slope: 1%
Vegetation: wheat stubble

Depth (cm)	Soil horizon	Unit	Description
0–20	Ap	I	Brown (10YR 5/3) silt loam, very dark grayish-brown (10YR 3/2) moist; weak fine granular structure; slightly hard, friable; many fine roots; many fine pores; noneffervescent; abrupt boundary.
20–42	A	I	Grayish-brown (10YR 5/2) silt loam, very dark grayish-brown (10YR 3/2) moist; moderate fine and medium granular structure; slightly hard, friable; many fine roots; many fine pores; noneffervescent; gradual boundary.
42–71	BAk	I	Grayish-brown (10YR 5/2) heavy silt loam, very dark grayish-brown (10YR 3/2) moist; moderate coarse columnar parting to moderate fine subangular blocky structure; hard, firm; common fine roots; common fine pores; common films and threads of calcium carbonate; common fine irregular soft masses of calcium carbonate; strong effervescence; gradual boundary.
71–109	Btk1	I	Brown (10YR 5/3) silty clay loam, dark-brown (10YR 3/3) moist; common medium distinct grayish-brown (10YR 5/2) mottles; moderate medium subangular blocky structure; hard, firm; few fine roots; common fine pores; few threads of calcium carbonate; few fine irregular soft masses of calcium carbonate; matrix is noneffervescent; gradual boundary.
109–190	Btk2	I	Brown (10YR 5/3) light silty clay loam, very dark brown (10YR 3/3) moist; moderate medium subangular blocky structure; hard, firm; common fine pores; few threads of calcium carbonate; many distinct discontinuous very dark grayish-brown (10YR 3/2) clay films on vertical ped faces and in pores; matrix is noneffervescent; gradual boundary.
190–215	Bk	I	Pale-brown (10YR 6/3) to brown (10YR 5/3) silt loam, brown (10YR 5/3) moist; common fine faint light-yellowish-brown (10YR 6/4) mottles; weak fine subangular blocky structure; hard, firm; few threads of calcium carbonate; many fine pores; matrix is noneffervescent; gradual boundary.
215–292	BCk	I	Light-yellowish-brown (10YR 6/4) silt loam, brown (10YR 5/3) moist; massive; slightly hard, friable; many fine pores; few threads of calcium carbonate; common black (10YR 2/1) stains along root channels; matrix is noneffervescent; abrupt boundary.
292–355	2Btb1	II	Reddish-yellow (7.5YR 6/6) heavy silty clay loam, strong brown (7.5YR 4/6) moist; moderate medium subangular blocky structure; very hard, very firm; common fine pores; common prominent discontinuous dark-brown (7.5YR 3/2) clay flows on vertical ped faces and in pores; few black (10YR 2/1) stains in pores; noneffervescent; gradual boundary.
355–457	2Btb2	II	Brownish-yellow (10YR 6/6) silty clay loam, yellowish-brown (10YR 5/6) moist; moderate fine and medium subangular blocky structure; hard, firm; many fine pores; few clay flows as above; few black stains as above; noneffervescent; gradual boundary.
457–469	2BCb	II	Light-yellowish-brown (10YR 6/4) loam, dark-yellowish-brown (10YR 4/4) moist; weak fine subangular blocky structure; hard, firm; common fine pores; noneffervescent; gradual boundary.
469–490	2C1	II	Light-yellowish-brown (10YR 6/4) fine sandy loam, dark-yellowish-brown (10YR 4/4) moist; massive; slightly hard, friable; few fine pores; noneffervescent; gradual boundary.

Table A.3 (continued)

Depth (cm)	Soil horizon	Unit	Description
490–571	2C2	II	Light-yellowish-brown (10YR 6/4) loamy fine sand, dark-yellowish-brown (10YR 4/4) moist; massive; soft, friable; few fine pores; noneffervescent; clear boundary.
571–722	2C3	II	Yellowish-brown (10YR 5/4) silt loam, dark-yellowish (10YR 4/4) moist; massive; slightly hard, friable; few fine pores; noneffervescent; clear boundary.
722–865+	3Bkb	III	Yellowish-brown (10YR 5/4) silty clay loam, dark-yellowish-brown (10YR 4/4) moist; moderate medium subangular blocky structure; hard, firm; common films and threads of calcium carbonate; many fine irregular soft masses of calcium carbonate; few fine pores; matrix is noneffervescent.

Table A.4. Description of Elmore trench and core at locality PR-3

Location: Pawnee County, KS; NWNW sec. 34, R. 19 W., T. 21 S.
Landscape position: T-1 terrace
Slope: <1%
Vegetation: native grasses

Depth (cm)	Soil horizon	Unit	Description
0–10	Ap	I	Dark-grayish-brown (10YR 4/2) silt loam, very dark gray (10YR 3/1) moist; weak fine granular structure; slightly hard, friable; common fine roots; many fine pores; noneffervescent; clear smooth boundary.
10–24	A	I	Grayish-brown (10YR 5/2) silt loam, very dark grayish-brown (10YR 3/2) moist; weak fine granular structure; slightly hard, friable; common fine roots; common fine pores; noneffervescent; gradual smooth boundary.
24–45	AC	I	Grayish-brown (10YR 5/2) silt loam, dark-grayish-brown (10YR 4/2) moist; weak very fine granular structure to massive; faint lamination; slightly hard, friable; few fine roots; few fine pores; few earthworm casts; abrupt smooth boundary.
45–75	2Akb	II	Dark-grayish-brown (10YR 4/2) light silty clay loam, very dark grayish-brown (10YR 3/2) moist; weak fine and medium granular structure; slightly hard, friable; few fine roots; few fine pores; few earthworm casts; few films and threads of calcium carbonate; weak effervescence; gradual smooth boundary.
75–105	2ABkb	II	Dark-grayish-brown (10YR 4/2) light silty clay loam, very dark grayish-brown (10YR 3/2) moist; weak fine subangular blocky structure; hard, friable; few fine roots; few fine pores; common films and threads of calcium carbonate; strong effervescence; gradual smooth boundary.
105–142	2Bkb1	II	Brown (10YR 5/3) silty clay, dark-brown (10YR 3/3) moist; moderate medium subangular blocky structure; hard, firm; few fine roots, few fine pores; many films and threads of calcium carbonate; strong effervescence; gradual smooth boundary.
142–183	2Bkb2	II	Brown (10YR 5/3) silty clay, brown (10YR 4/3) moist; moderate medium subangular blocky structure; very hard, firm; few very fine roots; few fine pores; common films and threads of calcium carbonate; common fine irregular soft masses of calcium carbonate; strong effervescence; gradual smooth boundary.
183–216	2BCkb	II	Brown (10YR 5/3) loam, brown (10YR 4/3) moist; weak fine subangular blocky structure; hard, friable; few fine pores; common films and threads of calcium carbonate; few fine irregular soft masses of calcium carbonate; strong effervescence; gradual boundary.
216–251	2C1	II	Brown (10YR 5/3) to yellowish-brown (10YR 5/4) loam, brown (10YR 4/3) moist; massive with faint bedding; soft, friable; common fine pores; few fine threads of calcium carbonate; strong effervescence; gradual boundary.
251–296	2C2	II	Laminated brown (10YR 5/3), very dark grayish-brown (10YR 3/2), very dark brown (10YR 2/2), pale-brown (10YR 6/3), grayish-brown (10YR 5/2), light-yellowish-brown (10YR 6/4), brownish-yellow (10YR 6/6), yellowish-brown (10YR 5/4–5/6), and dark-brown (7.5YR 3/4) silty clay, silty clay loam, silt loam, loam, and fine sandy loam; soft, friable; moderate effervescence; clear smooth boundary.
296–338	Btb1	III	Reddish-yellow (7.5YR 6/6) silty clay, brown (7.5YR 5/4) to yellowish-brown moist; common fine and medium distinct dark-grayish-brown (10YR 4/2) and dark-gray (10YR 4/1) mottles; few fine distinct reddish-yellow (10YR 6/6) mottles; moderate fine subangular blocky structure; hard, firm; few discontinuous clay films on ped faces; few fine pores; noneffervescent; clear boundary.

Table A.4 (continued)

Depth (cm)	Soil horizon	Unit	Description
338–405+	3Btb2	III	Brown (7.5YR 5/4) to yellowish-brown (10YR 5/4) silty clay loam, dark-yellowish-brown (10YR 4/4) moist; moderate fine subangular blocky structure; hard, firm; few discontinuous clay films on ped faces; common fine pores; noneffervescent.

Table A.5. Description of Rucker section at locality PR-4

Location: Pawnee County, KS; SWNW sec. 31, R. 20 W., T. 21 S.
Landscape position: T-1 terrace
Slope: <1%
Vegetation: native grasses

Depth (cm)	Soil horizon	Unit	Description
0–27	Ap	I	Dark-grayish-brown (10YR 4/2) silt loam, very dark grayish-brown (10YR 3/2) moist; weak fine granular structure; slightly hard, friable; many fine roots; common fine pores; weak effervescence; clear smooth boundary.
27–38	A	I	Grayish-brown (10YR 5/2) silt loam, very dark grayish-brown (10YR 3/2) moist; weak fine granular structure; slightly hard, friable; many fine roots; common fine pores; few fine flecks of calcium carbonate; strong effervescence; clear smooth boundary.
38–48	ACk	I	Grayish-brown (10YR 5/2) to brown (10YR 5/3) silt loam, dark-grayish-brown (10YR 4/2) moist; weak very fine granular structure; slightly hard, friable; many fine roots; common fine pores; few fine flecks of calcium carbonate; strong effervescence; gradual smooth boundary.
48–105	C	I	Laminated light-grayish-brown (10YR 6/2), grayish-brown (10YR 5/2), dark-grayish-brown (10YR 4/2), and very dark grayish-brown (10YR 3/2) silty clay loam, silt loam, and very fine sandy loam; individual strata are <2 mm thick; slightly hard, friable; common fine roots; few fine pores; strong effervescence; abrupt smooth boundary.
105–145	2Ab	II	Dark-gray (10YR 4/1) silt loam, very dark gray (10YR 3/1) moist; weak fine granular structure; slightly hard, friable; common fine roots; few fine pores; few earthworm casts; noneffervescent; gradual smooth boundary.
145–175	2ACkb	II	Brown (10YR 5/3) silt loam, brown (10YR 4/3) moist; common fine faint grayish-brown (10YR 5/2) mottles; weak fine granular structure; slightly hard, friable; few fine roots, few fine pores; few threads of calcium carbonate; violent effervescence; gradual smooth boundary.
175–273	2C1	II	Pale-brown (10YR 6/3) silt loam, brown (10YR 5/3–4/3) moist; weak fine granular structure; hard, friable; few fine roots; common fine pores; violent effervescence; gradual smooth boundary.
273–441	2C2	II	Very pale brown (10YR 7/3) and pale-brown (10YR 6/3) silt loam and very fine sandy loam; stratified; soft, friable; individual strata are <1 to 5 cm thick; few fine roots, few fine pores; violent effervescence; gradual smooth boundary.
441–482	3Bkb	III	Yellowish-brown (10YR 5/4) silty clay loam, dark-yellowish-brown (10YR 4/4) moist; common fine and medium distinct brown (10YR 5/3) and grayish-brown (10YR 5/2) mottles; moderate fine and medium subangular blocky structure; hard, friable; many films and threads of calcium carbonate; few fine hard calcium carbonate concretions; strong effervescence; diffuse boundary.
482–528	3Btkb	III	Brown (10YR 5/2) heavy silty clay loam, dark-brown (10YR 3/3) moist; moderate medium subangular blocky structure; hard, firm; few fine pores; common films and threads of calcium carbonate; few fine hard calcium carbonate concretions; common discontinuous clay films on ped faces; weak effervescence; gradual smooth boundary.
528–564	3BCkb	III	Brown (10YR 5/3) silty clay loam, brown (10YR 4/3) moist; moderate fine subangular blocky structure; slightly hard, friable; few fine pores; few films and threads of calcium carbonate; weak effervescence; gradual smooth boundary.
564–604	4Btkb	IV	Yellowish-brown (10YR 5/4) silty clay loam, dark-yellowish-brown (10YR 4/4) moist; moderate fine subangular blocky structure; hard, firm; few dark-brown (10YR 3/3) clay flows on vertical faces; common films and threads of calcium carbonate; few fine pores; strong effervescence; gradual smooth boundary.

Table A.5 (continued)

Depth (cm)	Soil horizon	Unit	Description
604–720+	4BCkb	IV	Yellowish-brown (10YR 5/4) light silty clay loam, dark-yellowish-brown (10YR 4/4) moist; massive; soft, friable; common fine pores; common films and threads of calcium carbonate; strong effervescence.

Table A.6. Description of Burdett trench and core at locality PR-5

Location: Hodgeman County, KS; NWNW sec. 7, R. 21 W., T. 21 S.
Landscape position: T-1 terrace
Slope: <1%
Vegetation: native grasses

Depth (cm)	Soil horizon	Unit	Description
0–12	Ap	I	Brown (10YR 4/3) silt loam, dark-brown (10YR 3/3) moist; weak fine granular structure; friable; common fine roots; weak effervescence; clear smooth boundary.
12–63	AC	I	Brown (10YR 5/3) silt loam, brown (10YR 4/3) moist; weak very fine granular structure; friable; common fine roots; faint thin bedding in lower 20 cm; strong effervescence; abrupt smooth boundary.
63–85	2Ab	I	Brown (10YR 4/3) silt loam, dark-brown (10YR 3/3) moist; weak fine granular structure; friable; common fine roots; strong effervescence; gradual smooth boundary.
85–276	2C	I	Stratified dark-grayish-brown (10YR 4/2) silty clay loam, grayish-brown (10YR 5/2) silt loam, brown (10YR 5/3) loam, and pale-brown (10YR 6/3) fine sandy loam; individual beds are 2–15 mm thick; massive; friable; few fine roots; strong effervescence; abrupt boundary.
276–320	3Ab	II	Very dark grayish-brown (10YR 3/2) silt loam, very dark brown (10YR 2/2) moist; moderate fine granular structure; hard, friable; common fine and medium pores; common very fine white noncalcareous flecks; few earthworm casts; noneffervescent; gradual smooth boundary.
320–345	3Bwb	II	Yellowish-brown (10YR 5/4) heavy silt loam, brown (10YR 4/3) moist; common fine faint brown (10YR 5/3) mottles; moderate fine subangular blocky parting to fine granular structure; hard, friable; common fine and few medium pores; few earthworm casts; moderate effervescence; gradual smooth boundary.
345–350	3BCb	II	Pale-brown (10YR 6/3) to brown (10YR 5/3) silt loam, brown (10YR 5/3) moist; moderate fine granular structure; hard, friable; common fine and few medium pores; few earthworm casts; strong effervescence; gradual smooth boundary.
350–397	3C1	II	Pale-brown (10YR 6/3) to brown (10YR 5/3) loam, brown (10YR 5/3) moist; massive; soft, friable; many fine and few medium pores; violent effervescence; clear boundary.
397–429	3C2	II	Pale-yellow (2.5Y 7/4) to light-yellowish-brown (2.5Y 6/4) loam, brown (10YR 5/3) to yellowish-brown (10YR 5/4) moist; massive; soft, friable; many fine pores; abrupt boundary.
429–523	4Bkb1	III	Brown (10YR 5/3) silty clay loam, brown (10YR 4/3) moist; weak fine subangular blocky structure; hard, friable; common pale-brown (10YR 6/3) silt coatings on ped faces; many films and threads of calcium carbonate; many fine pores; strong effervescence; gradual boundary.
523–558	4Bkb2	III	Brown (10YR 5/3) to yellowish-brown (10YR 5/4) silty clay loam, brown (10YR 4/3) moist; moderate fine subangular blocky structure; hard, friable; common fine and medium pores; many films and threads of calcium carbonate; strong effervescence; gradual boundary.
558–575	4BCkb	III	Pale-brown (10YR 6/3) silt loam, brown (10YR 5/3) moist; common medium distinct brown (10YR 5/3) mottles; moderate fine subangular blocky structure; hard, friable; common fine pores; common films and threads of calcium carbonate; violent effervescence; gradual boundary.
575–616	4C1	III	Pale-brown (10YR 6/3) to light-yellowish-brown (2.5Y 6/4) silt loam, yellowish-brown (10YR 5/4) moist; massive; soft, friable; few fine pores; violent effervescence; gradual boundary.

Table A.6 (continued)

Depth (cm)	Soil horizon	Unit	Description
616–720	4C2	III	Light-yellowish-brown (2.5Y 6/4–10YR 6/4) silt loam, yellowish-brown (10YR 5/4) moist; massive; soft, friable; few fine pores; violent effervescence; clear boundary.
720–775	4Ck	III	Very pale brown (10YR 7/4) to pale-yellow (2.5Y 7/4) fine sandy loam, yellowish-brown (10YR 7/4) moist; laminated; soft, friable; few fine pores; few fine threads of calcium carbonate; violent effervescence.

Table A.7. Description of T-0 section at locality PR-5

Location: Hodgeman County, KS; NWNW sec. 7, R. 21 W., T. 21 S.
Landscape position: T-0 floodplain
Slope: <1%
Vegetation: riparian forest

Depth (cm)	Soil horizon	Unit	Description
0–25	A	I	Grayish-brown (10YR 5/2) silt loam, very dark grayish-brown (10YR 3/2) moist; weak fine granular structure; slightly hard, friable; many fine roots; common worm casts; moderate effervescence; gradual smooth boundary.
25–55	AC	I	Light-brownish-gray (10YR 6/2) silt loam, dark-grayish-brown (10YR 4/2) moist; weak fine granular structure; slightly hard, friable; common fine roots; few worm casts; strong effervescence; gradual smooth boundary.
55–105	C	I	Light-brownish-gray (10YR 6/2) silt loam, dark-grayish-brown (10YR 4/2) moist; massive; soft, friable; common thin beds of loam, silt loam, and silty clay loam in lower 30 cm of horizon; common fine roots; strong effervescence; abrupt smooth boundary.
105–140	2Ab	II	Dark-grayish-brown (10YR 4/2) silt loam, very dark grayish-brown (10YR 3/2) moist; weak fine granular structure; slightly hard, friable; common fine roots; moderate effervescence; gradual smooth boundary.
140–165	2ACb	II	Grayish-brown (10YR 5/2) silt loam, dark-grayish-brown (10YR 4/2) moist; weak very fine granular structure; slightly hard, friable; few fine roots; strong effervescence; gradual smooth boundary.
165–260	2C	II	Laminated light-grayish-brown (10YR 6/2) loam, grayish-brown (10YR 5/2) silt loam, brown (10YR 5/3) silty clay loam, and pale-brown (10YR 6/3) silty clay; massive; soft, friable; few fine roots; strong effervescence.

Table A.8. Description of Foos section at locality PR-6

Location: Ness County, KS; NENW sec. 28, R. 22 W., T. 20 S.
Landscape position: T-1 terrace
Slope: <1%
Vegetation: native grasses

Depth (cm)	Soil horizon	Unit	Description
0–20	A	I	Grayish-brown (10YR 5/2) loam, very dark grayish-brown (10YR 3/2) moist; weak fine granular structure; very friable; many fine roots; violent effervescence; gradual smooth boundary.
20–60	AC	I	Light-brownish-gray (10YR 6/2) loam, grayish-brown (10YR 4/2) moist; weak very fine granular structure; very friable; common fine roots; common fine pores; many earthworm casts; violent effervescence; abrupt smooth boundary.
60–96	2Ab	II	Grayish-brown (10YR 5/2) silty clay, very dark grayish-brown (10YR 3/2) moist; moderate fine granular structure; hard, friable; common fine roots; violent effervescence; gradual smooth boundary.
96–125	2ACb	II	Light-brownish-gray (10YR 6/2) silt loam, grayish-brown (10YR 4/2) moist; weak very fine granular structure; hard, friable; few fine roots; few fine pores; violent effervescence; abrupt smooth boundary.
125–155	3Ab	III	Dark-grayish-brown (10YR 4/2) silty clay loam, very dark grayish-brown (10YR 3/2) moist; moderate medium and coarse granular structure; slightly hard, friable; few fine roots; weak effervescence; gradual smooth boundary.
155–170	3ABkb	III	Grayish-brown (10YR 5/2) silty clay loam, dark-grayish-brown (10YR 4/2) moist; moderate fine subangular blocky structure; hard, firm; few fine roots; few fine pores; common films and threads of calcium carbonate; strong effervescence; gradual smooth boundary.
170–200	3Bkb1	III	Pale-brown (10YR 6/3) to brown (10YR 5/3) silty clay loam, brown (10YR 4/3) moist; moderate medium subangular blocky structure; very hard, firm; few fine pores; many films and threads of calcium carbonate; few fine irregular soft masses of carbonate; strong effervescence; gradual smooth boundary.
200–240	3Bkb2	III	Pale-brown (10YR 6/3) silty clay loam, brown (10YR 4/3) moist; moderate medium subangular blocky structure; very hard, firm; common fine pores; many films and threads of calcium carbonate; few fine irregular soft masses of calcium carbonate; strong effervescence; gradual smooth boundary.
240–282	3BCkb	III	Brown (10YR 5/3) silt loam, brown (10YR 4/3) moist; moderate fine subangular blocky structure; very hard, firm; common fine pores; common films and threads of calcium carbonate; strong effervescence; gradual smooth boundary.
282–351	3Ck	III	Brown (10YR 5/3) and pale-brown (10YR 6/3) silt loam, brown (10YR 5/3) moist; stratified; common thin (<10 mm thick) strata of fine sandy loam; hard, friable; common fine pores; few threads of calcium carbonate; moderate effervescence; abrupt boundary.
351–405	4Akb	IV	Grayish-brown (10YR 5/2) silty clay loam, dark-grayish-brown (10YR 4/2) moist; moderate medium granular structure; friable; few fine pores; few fine threads of calcium carbonate; matrix is noneffervescent; gradual smooth boundary.
405–420	4ABkb	IV	Grayish-brown (10YR 5/2) silty clay loam, dark-grayish-brown (10YR 4/2) moist; moderate fine subangular blocky structure; firm; common fine pores; few fine threads of calcium carbonate; matrix is noneffervescent; gradual smooth boundary.
420–470	4Btkb	IV	Brown (10YR 5/3) silty clay, brown (10YR 4/3) moist; moderate fine subangular blocky structure; firm; common fine pores; few films and threads of calcium carbonate; few fine hard carbonate concretions; few discontinuous clay films on ped faces; moderate effervescence.

Table A.9. Description of McCreight section at locality PR-7

Location: Pawnee County, KS; SWSW sec. 35, R. 24 W., T. 20 S.
Landscape position: T-1 terrace
Slope: <1%
Vegetation: crops

Depth (cm)	Soil horizon	Unit	Description
0–27	Ap	I	Brown (10YR 5/3) silt loam, dark-brown (10YR 3/3) moist; weak fine granular structure; slightly hard, friable; common fine roots; weak effervescence; clear smooth boundary.
27–55	A	I	Dark-grayish-brown (10YR 4/2) to dark-gray (10YR 4/1) silt loam, very dark grayish-brown (10YR 3/2) moist; moderate medium granular structure; slightly hard, friable; common fine roots; common earthworm casts; common fine pores; strong effervescence; gradual smooth boundary.
55–75	ABk	I	Brown (10YR 5/3) silty clay loam, dark-brown (10YR 3/3) moist; moderate medium and fine subangular blocky structure; hard, friable; few fine roots; common fine pores; few films and threads of calcium carbonate; strong effervescence; gradual boundary.
75–124	Bk	I	Brown (10YR 5/3) heavy silty clay loam, brown (10YR 4/3) moist; moderate medium subangular blocky structure; hard, friable; common films, threads, and fine soft masses of calcium carbonate; few fine hard carbonate concretions; few fine roots; common fine pores; strong effervescence; gradual smooth boundary.
124–153	BCk	I	Brown (10YR 5/3) light silty clay loam, brown (10YR 4/3) moist; moderate fine subangular blocky structure; hard, friable; common films and threads and few soft masses of calcium carbonate; few fine, hard carbonate concretions; few fine roots; common fine pores; strong effervescence; gradual smooth boundary.
153–190	C	I	Pale-brown (10YR 6/3) to brown (10YR 5/3) silt loam, brown (10YR 4/3) moist; massive; hard, friable; common fine pores; few fine threads of calcium carbonate; strong effervescence; abrupt smooth boundary.
190–225	2Akb	II	Brown (10YR 4/3) silt loam, dark-brown (10YR 3/3) moist; moderate medium granular structure; hard, friable; common fine pores; few fine threads of calcium carbonate; weak effervescence; gradual smooth boundary.
225–250	2ACkb	II	Brown (10YR 5/3) silt loam, dark-brown (10YR 3/3) moist; moderate fine granular structure; hard, friable; common fine pores; few fine threads of calcium carbonate; moderate effervescence; gradual smooth boundary.
250–330	2C	II	Brown (10YR 5/3) silty clay and pale brown (10YR 6/3) silt loam and very fine sandy loam; stratified; hard, friable; strong effervescence; abrupt smooth boundary.
330–377	3Akb	IIIa	Brown (10YR 4/3) silt loam, dark-brown (10YR 3/3) moist; moderate fine and medium granular structure; hard, friable; common fine pores; few fine threads of calcium carbonate; moderate effervescence; gradual smooth boundary.
377–480	3ACkb	IIIa	Brown (10YR 5/3) to pale-brown (10YR 6/3) silt loam, brown (10YR 4/3) moist; weak fine granular structure; hard, friable; many fine pores; many films and threads of calcium carbonate; few fine soft carbonate masses; strong effervescence; gradual smooth boundary.
480–498	3Ck	IIIa	Pale-brown (10YR 6/3) silt loam, brown (10YR 5/3) to yellowish-brown (10YR 5/4) moist; massive; hard, friable; many fine pores; secondary carbonates as above; strong effervescence; abrupt smooth boundary.
498–553	4Akb	IV	Grayish-brown (10YR 5/2) silt loam, dark-grayish-brown (10YR 4/2) moist; massive to weak fine granular structure; hard, friable; many fine pores; many films and threads of calcium carbonate; few fine soft carbonate masses; violent effervescence; gradual smooth boundary.

Table A.9 (continued)

Depth (cm)	Soil horizon	Unit	Description
553–630	4ACkb	IV	Light-grayish-brown (10YR 6/2) silt loam, grayish-brown (10YR 5/2) to dark-grayish-brown (10YR 4/2) moist; massive to weak fine granular structure; hard, friable; many fine pores; many films and threads of calcium carbonate; few fine soft carbonate masses; strong effervescence; abrupt smooth boundary.
630–675	5Akb	V	Grayish-brown (10YR 5/2) to brown (10YR 5/3) heavy silty clay loam, dark-grayish-brown (10YR 4/2) moist; moderate fine and medium subangular blocky structure; very hard, firm; common fine pores; few fine threads of calcium carbonate; matrix is noneffervescent; gradual smooth boundary.
675–705	5Bkb1	V	Brown (10YR 5/3) silty clay, brown (10YR 4/3) moist; moderate medium subangular blocky structure; very hard, firm; common fine pores; many films and threads of calcium carbonate; few fine hard carbonate masses; strong effervescence; gradual smooth boundary.
705–760	5Bkb2	V	Brown (10YR 5/3) silty clay, brown (10YR 4/3) moist; moderate fine subangular blocky structure; very hard, firm; common fine pores; secondary carbonates as above; strong effervescence; gradual smooth boundary.
760–783	5BCkb	V	Pale-brown (10YR 6/3) silty clay loam, brown (10YR 5/3–4/3) moist; moderate fine subangular blocky structure parting to granular structure; hard, friable; common fine pores; common films and threads of calcium carbonate; few fine soft carbonate masses; strong effervescence; abrupt smooth boundary.
783–813	6Akb	VI	Brown (10YR 4/3) heavy silty clay loam, dark-brown (10YR 3/3) moist; moderate fine subangular blocky structure; hard, firm; common fine pores; many films and threads of calcium carbonate; strong effervescence; gradual smooth boundary.
813–874	6Bkb	VI	Brown (10YR 5/3) silty clay, brown (10YR 4/3) moist; moderate medium subangular blocky structure; hard, firm; common fine pores; many films and threads of calcium carbonate; few fine soft calcium carbonate masses; strong effervescence; gradual smooth boundary.
874–910	6BCkb	VI	Light-brownish-gray (10YR 6/2) silty clay loam, brown (10YR 4/3) moist; weak fine subangular blocky structure; hard, firm; common fine pores; common films and threads of calcium carbonate; few fine soft calcium carbonate masses; strong effervescence, gradual smooth boundary.
910–990+	6Ck	VI	Pale-brown (10YR 6/3) to brown (10YR 5/3) silty clay loam, brown (10YR 4/3) moist; massive; faint lamination; hard, firm; common fine pores; common films and threads of calcium carbonate; strong effervescence.

Table A.10. Description of Patchen section at locality PR-8

Location: Hodgeman County, KS; SWNW sec. 16, R. 25 W., T. 21 S.
Landscape position: T-1 terrace
Slope: <1%
Vegetation: native grasses

Depth (cm)	Soil horizon	Unit	Description
0–15	Ap	I	Brown (10YR 4/3) silt loam, dark-brown (10YR 3/3) moist; weak fine granular structure; friable; common fine roots; weak effervescence; clear smooth boundary.
15–46	AC	I	Brown (10YR 5/3) silt loam, dark-brown (10YR 3/3) moist; weak very fine granular structure; friable; common fine roots; strong effervescence; abrupt smooth boundary.
46–64	2Ab	I	Brown (10YR 4/3) silt loam, dark-brown (10YR 3/3) moist; weak fine granular structure; friable; common fine roots; strong effervescence; gradual smooth boundary.
64–111	2ACb	I	Brown (10YR 4/3) silt loam, dark-brown (10YR 3/3) moist; weak very fine granular structure; friable; common fine roots; common earthworm casts; strong effervescence; abrupt smooth boundary.
111–136	3Ab	I	Brown (10YR 4/3) silt loam, brown (10YR 3/3) moist; weak fine granular structure; friable; common fine roots; strong effervescence; gradual smooth boundary.
136–175	3ACb	I	Brown (10YR 5/3) silt loam, brown (10YR 3/3) moist; weak very fine granular structure; friable; common fine roots; strong effervescence; few fine pores; abrupt smooth boundary.
175–205	4Ab	I	Brown (10YR 4/3) silt loam, brown (10YR 3/3) moist; weak fine granular structure; friable; common fine roots; strong effervescence; gradual smooth boundary.
205–251	4ACb	I	Brown (10YR 5/3) silt loam, brown (10YR 4/3) moist; weak very fine granular structure; faint lamination; friable; few fine roots; common fine pores; strong effervescence; abrupt smooth boundary.
251–280	5Ab1	II	Dark-gray (10YR 4/1) silt loam, black (10YR 2/1) moist; moderate fine granular structure; slightly hard, friable; few fine roots; common gastropods; weak effervescence; gradual smooth boundary.
280–297	5Ab2	I	Grayish-brown (10YR 5/2) silt loam, very dark grayish-brown (10YR 3/2) moist; moderate fine granular structure; slightly hard, friable; few fine roots; few gastropods; weak effervescence; gradual smooth boundary.
297–330	5Bwb	II	Brown (10YR 5/3) to yellowish-brown (10YR 5/4) silt loam, brown (10YR 4/3) moist; weak fine subangular blocky structure; slightly hard, friable; few fine roots; common very fine pores; moderate effervescence; gradual smooth boundary.
330–345	5BCkb	II	Yellowish-brown (10YR 5/4) silt loam, dark-yellowish-brown (10YR 4/4) moist; weak fine granular structure; slightly hard, friable; few fine roots; common fine pores; few fine threads of calcium carbonate; strong effervescence; gradual smooth boundary.
345–470	5Ck	II	Pale-brown (10YR 6/3) silt loam, brown (10YR 5/4) moist; massive; soft, friable; common fine pores; very few fine threads of calcium carbonate; violent effervescence; gradual smooth boundary.
470–520	5C1	II	Pale-brown (10YR 6/3) to very pale brown (10YR 7/3) loam, brown (10YR 5/3) moist; massive; soft, friable; few fine pores; violent effervescence; clear smooth boundary.
520–650+	5C2	II	Pale-brown (10YR 6/3) fine, medium, and coarse sand, brown (10YR 5/4) moist; stratified; some crossbedding; single grain, loose; ≈80% siliceous grains by volume; moderate effervescence.

Table A.11. Description of section at site 14HO5 at locality PR-9

Location: Hodgeman County, KS; NENE sec. 3, R. 26 W., T. 22 S.
Elevation: 725.4 m (2,380 ft)
Landscape position: T-0 floodplain
Slope: <1%
Vegetation: riparian forest

Depth (cm)	Soil horizon	Unit	Description
0–30	A	I	Grayish-brown (10YR 5/2) silt loam, very dark grayish-brown (10YR 3/2) moist; weak fine granular structure; slightly hard, friable; many fine roots; common worm casts; moderate effervescence; gradual smooth boundary.
30–75	AC	I	Light-brownish-gray (10YR 6/2) silt loam, dark-grayish-brown (10YR 4/2) moist; weak fine granular structure; slightly hard, friable; common fine roots; few worm casts; strong effervescence; gradual smooth boundary.
75–90	C	I	Light-brownish-gray (10YR 6/2) silt loam, dark-grayish-brown (10YR 4/2) moist; massive; soft, friable; common fine roots; strong effervescence; abrupt smooth boundary.
90–115	2Ab	II	Dark-grayish-brown (10YR 4/2) silt loam, very dark grayish-brown (10YR 3/2) moist; weak fine granular structure; slightly hard, friable; common fine roots; common bones and bone fragments, chert flakes, and pottery shards; moderate effervescence; gradual smooth boundary.
115–160	2ACb	II	Grayish-brown (10YR 5/2) silt loam, dark-grayish-brown (10YR 4/2) moist; weak very fine granular structure; slightly hard, friable; few fine roots; strong effervescence; gradual smooth boundary.
160–250	2C	II	Stratified light-grayish-brown (10YR 6/2) loam, grayish-brown (10YR 5/2) fine sandy loam, and pale-brown (10YR 6/3) silty clay; massive; soft, friable; few fine roots; strong effervescence.

Table A.12. Description of Fearker section at locality PR-10

Location: Finney County, KS; NESE sec. 12, R. 28 W., T. 22 S.
Landscape position: T-1 terrace
Slope: <1%
Vegetation: crops

Depth (cm)	Soil horizon	Unit	Description
0–20	Ap	I	Brown (10YR 5/3) loam, dark-brown (10YR 3/3) moist; weak fine granular structure; slightly hard, friable; common fine roots; strong effervescence; clear smooth boundary.
20–32	A	I	Brown (10YR 5/3) loam, dark-brown (10YR 3/3) moist; weak fine granular structure; slightly hard, friable; common fine roots; common fine pores; many earthworm casts; violent effervescence; gradual smooth boundary.
32–45	AC	I	Brown (10YR 5/3) to pale-brown (10YR 6/3) loam, brown (10YR 5/3) moist; moderate fine granular structure; hard, friable; common fine roots; common fine pores; common earthworm casts; violent effervescence; gradual boundary.
45–80	C	I	Pale-brown (10YR 6/3) fine sandy loam, brown (10YR 5/3) moist; faint horizontal bedding with individual beds <2 mm thick; hard, friable; few fine roots; common fine pores; few earthworm casts; violent effervescence; clear smooth boundary.
80–142	Ck	I	Pale-brown (10YR 6/3) very fine sandy loam and silt loam, brown (10YR 5/3) moist; stratified, with individual beds <2 mm thick; slightly hard, friable; few fine roots; common fine pores; few threads of calcium carbonate; violent effervescence; abrupt smooth boundary.
142–195	2Akb	II	Gray (10YR 5/1) to grayish-brown (10YR 5/2) silt loam, very dark gray (10YR 3/1) moist; moderate fine granular structure; slightly hard, friable; few fine and medium roots; common fine pores; few earthworm casts; common threads of calcium carbonate; strong effervescence; gradual smooth boundary.
195–210	2ABkb	II	Grayish-brown (10YR 5/2) silty clay loam, very dark grayish-brown (10YR 3/2) moist; weak fine subangular blocky structure; few faint medium-brown (10YR 5/3) mottles; gritty; few fine roots; common fine pores; common threads of calcium carbonate; strong effervescence; gradual smooth boundary.
210–250	2Bkb	II	Brown (10YR 5/3) silty clay loam, brown (10YR 4/3) moist; gritty; weak fine and medium subangular blocky structure; hard, firm; few dark-grayish-brown (10YR 4/2) coatings on ped faces; common fine pores; common threads of calcium carbonate; strong effervescence; gradual smooth boundary.
250–295	2BCkb	II	Brown (10YR 5/3) to pale-brown (10YR 6/3) loam, brown (10YR 4/3) moist; weak fine and medium subangular blocky structure; hard, firm; common fine pores; common films and threads of calcium carbonate; violent effervescence; gradual smooth boundary.
295–340	2Ck	II	Pale-brown (10YR 6/3) loam, brown (10YR 5/3) moist; massive; hard, friable; common fine pores; many films and threads of calcium carbonate; violent effervescence.

Table A.13. Description of section at site 14HO306 (locality BC-1) in Buckner Creek valley

Location: Hodgeman County, KS; SWNE sec. 16, R. 25 W., T. 23 S.
Landscape position: T-1 terrace
Slope: <1%
Vegetation: native grasses

Depth (cm)	Soil horizon	Unit	Description
0–18	Ap	I	Brown (10YR 4/3) silt loam, very dark grayish-brown (10YR 3/2) moist; weak medium granular structure; slightly hard, friable; common fine roots; common fine pores; noneffervescent; gradual smooth boundary.
18–38	A	I	Grayish-brown (10YR 5/2) silt loam, very dark grayish-brown (10YR 3/2) moist; moderate medium granular structure; slightly hard, friable; common fine roots; common fine pores; few earthworm casts; moderate effervescence; gradual smooth boundary.
38–46	AB	I	Grayish-brown (10YR 5/2) silt loam, brown (10YR 4/3) moist; moderate medium granular structure; slightly hard, friable when moist; few pale-brown (10YR 6/3) silt coatings on ped faces; few fine roots; common fine pores; moderate effervescence; clear smooth boundary.
46–61	Bk1 (2Ab)[a]	I	Dark-brown (10YR 3/3) silt loam, dark-grayish-brown (10YR 3/2) moist; weak medium columnar parting to weak fine subangular blocky structure; hard, friable; common pale-brown (10YR 6/2) silt coatings on ped faces; few fine roots; common fine pores; few threads and films of calcium carbonate; strong effervescence.
61–86	Bk2	I	Grayish-brown (10YR 5/2) silt loam, brown (10YR 4/3) moist; moderate medium columnar parting to moderate medium granular structure; hard, friable; common pale-brown (10YR 6/3) silt coatings on ped faces; few fine roots; common fine pores; common films and threads of calcium carbonate; strong effervescence; gradual smooth boundary.
86–119	BCk	I	Grayish-brown (10YR 5/2) silt loam, brown (10YR 4/3) moist; weak medium and fine granular structure; very hard when dry, friable when moist; common fine pores; common films and threads of calcium carbonate; strong effervescence; abrupt smooth boundary.
119–147	3Akb	I	Grayish-brown to dark-grayish-brown (10YR 5/2 – 4/2) silt loam, dark-grayish-brown (10YR 4/2) moist; weak medium granular structure; hard, friable; common fine pores; common films and threads of calcium carbonate; strong effervescence; gradual smooth boundary.
147–176	3ACkb	I	Grayish-brown (10YR 5/2) silty clay loam, dark-grayish-brown (10YR 4/2) moist; weak fine and medium granular structure; hard, friable; common fine pores; common films and threads calcium carbonate; strong effervescence; abrupt smooth boundary.
176–210	4Ab	II	Dark-gray (10YR 4/1) loam, very dark gray (10YR 3/1) moist; moderate medium granular structure; hard when dry, friable when moist; common fine pores; few flecks of charcoal; few chert flakes and burned rocks; few gastropods; noneffervescent; gradual smooth boundary.
210–241	4Akb	II	Dark-grayish-brown (10YR 4/2) silt loam, very dark grayish-brown (10YR 3/2) moist; moderate medium granular structure; hard, friable; common fine pores; few films and threads of calcium carbonate; few flecks of charcoal; few chert flakes and burned rocks; few gastropods; strong effervescence; gradual smooth boundary.
241–271	4ABkb	II	Brown (10YR 5/3) silt loam, dark-grayish-brown (10YR 4/2) moist; weak fine subangular-blocky structure; hard, friable; common fine pores; common grayish-brown (10YR 5/2) coatings on ped faces; few films and threads of calcium carbonate; few gastropods; strong effervescence; gradual smooth boundary.

Depth (cm)	Soil horizon	Unit	Description
271–317	4Bkb	II	Pale-brown (10YR 6/3) silt loam, brown (10YR 5/3) moist; weak fine subangular-blocky structure; hard, friable; many fine pores; common films and threads of calcium carbonate; few fine hard concretions of calcium carbonate; violent effervescence; abrupt smooth boundary.
317–345	5Akb	II	Grayish-brown (10YR 5/2) silt loam, dark-brown (10YR 3/3) moist; weak fine granular structure; hard, friable; common fine pores; common films and threads of calcium carbonate; few fine soft calcium carbonate concretions; strong effervescence; gradual smooth boundary.
345–394	5Ck	II	Pale-brown (10YR 6/3) silt loam, brown (10YR 5/3) moist; massive with faint lamination; hard, friable; common fine pores; many films and threads of calcium carbonate; strong effervescence; abrupt smooth boundary.
394–432	6Akb1	III	Dark-grayish-brown (10YR 4/2) silt loam, very dark grayish-brown (10YR 3/2) moist; moderate medium granular structure; hard, friable; many fine pores; common films and threads of calcium carbonate; many flecks of charcoal; common bone fragments and burned rocks; few chert flakes; strong effervescence; gradual smooth boundary.
432–471	6Akb2	III	Grayish-brown (10YR 5/2) silt loam, dark-grayish-brown (10YR 4/2) moist; moderate medium granular structure; hard, friable; common fine pores; common films and threads of calcium carbonate; few gastropods; common flecks of charcoal, bone fragments, and burned rocks in lower 10 cm of horizon; strong effervescence; gradual smooth boundary.
471–523	6Bkb	III	Brown (10YR 5/3) silt loam, dark-brown (10YR 4/3) moist; weak fine granular structure; hard, friable; common fine pores; common films and threads of calcium carbonate; few fine hard calcium carbonate concretions; violent effervescence; gradual smooth boundary.
523–658	6BCkb	III	Pale-brown (10YR 6/3) silt loam, brown (10YR 4/3) moist; massive with faint bedding; hard, friable; common fine pores; common films and threads of calcium carbonate; few fine hard concretions of calcium carbonate; violent effervescence; gradual smooth boundary.
658–712	6Ck	III	Brown (10YR 5/3) gravelly fine sand grading upward to fine sandy loam, brown (10YR 4/3) moist; massive with faint bedding in the upper 25 cm; hard, friable; few fine pores; few films and threads of calcium carbonate; strong effervescence; irregular boundary.
712+	7R	–	Limestone.

a. Welded soil.

Table A.14. Description of section at site 14HO315 at locality BC-1

Location: Hodgeman County, KS; NWNW sec. 20, R. 25 W., T. 23 S.
Landscape position: T-0 floodplain
Slope: <1%
Vegetation: native grasses

Depth (cm)	Soil horizon	Unit	Description
0–30	A	I	Dark-grayish-brown (10YR 4/2) silt loam, very dark grayish-brown (10YR 3/2) moist; weak fine granular structure; slightly hard, friable; many fine roots; few worm casts; weak effervescence below 10 cm; gradual smooth boundary.
30–42	AC	I	Grayish-brown (10YR 5/2) silt loam, dark-grayish-brown (10YR 4/2) moist; weak fine granular structure; slightly hard, friable; common fine roots; faint bedding; strong effervescence; clear smooth boundary.
42–59	Ck	I	Light-brownish-gray (10YR 6/2), pale-brown (10YR 6/3), and grayish-brown (10YR 5/2) silt loam; stratified; few thin lenses (<2 mm thick) of very pale brown (10YR 7/3) fine sandy loam; slightly hard, friable; few fine roots; few fine pores; few threads of calcium carbonate; strong effervescence; abrupt smooth boundary.
59–105	2Akb	II	Grayish-brown (10YR 5/2) silt loam, dark-grayish-brown (10YR 4/2) moist; moderate fine and medium granular structure; hard, friable; few fine roots; common fine pores; few films and threads of calcium carbonate; strong effervescence; abrupt smooth boundary.
105–230	2ACkb	II	Grayish-brown (10YR 5/2) loam, dark-grayish-brown (10YR 4/2) moist; moderate fine granular structure; hard, friable; few fine roots; few fine threads of calcium carbonate; strong effervescence; gradual smooth boundary.
230–361	2C	II	Grayish-brown (10YR 5/2) gravelly loam, dark-grayish-brown (10YR 4/2) moist; stratified; loamy matrix is slightly hard and friable; pebbles compose 80% of sediment in horizon; strong effervescence; irregular boundary.
361+	3R	–	Limestone.

Table A.15. Description of section 1 at site 14NS308 at locality HC-1

Location: Ness County, KS; NESE sec. 29, R. 26 W., T. 20 S.
Landscape position: T-1 terrace
Slope: <1%
Vegetation: wheat

Depth (cm)	Soil horizon	Unit	Description
0–15	Ap	I	Grayish-brown (10YR 5/2) silt loam, brown (10YR 4/3) moist; weak medium granular structure; slightly hard, friable; common fine roots; moderate effervescence; gradual smooth boundary.
15–48	A	I	Grayish-brown (10YR 5/2) silt loam, very dark grayish-brown (10YR 3/2) moist; moderate medium granular structure; slightly hard, friable; common fine roots; common fine pores; common earthworm casts; moderate effervescence; gradual smooth boundary.
48–55	AB	I	Grayish-brown (10YR 5/2) silt loam, brown (10YR 4/3) moist; moderate medium granular structure; slightly hard, friable; few pale-brown (10YR 6/3) silt coatings on ped faces; few fine roots; common fine pores; moderate effervescence; clear smooth boundary.
55–67	Bk1 (2Ab)[a]	I	Dark-grayish-brown (10YR 4/2) light silty clay loam, very dark grayish-brown (10YR 3/2) moist; moderate medium columnar parting to moderate subangular blocky structure; hard, friable; common pale-brown (10YR 6/3) silt coatings on ped of calcium carbonate; strong effervescence; gradual smooth boundary.
67–85	Bk2	I	Brown (10YR 4/3) light silty clay loam, dark-brown (10YR 3/3) moist; moderate medium columnar parting to moderate medium subangular blocky structure; hard, friable; common pale-brown (10YR 6/3) silt coatings on ped faces; few fine roots; common fine pores; few threads of calcium carbonate; strong effervescence; gradual smooth boundary.
85–107	BC	I	Pale-brown (10YR 6/3) silt loam, brown (10YR 4/3) moist; moderate medium columnar parting to moderate medium subangular blocky structure; hard, friable; common fine pores; strong effervescence; abrupt smooth boundary.
107–151	3Ab	II	Dark-grayish-brown (10YR 4/2) silt loam, very dark grayish-brown (10YR 3/2) moist; moderate medium granular structure; hard, friable; few fine roots; common fine pores; strong effervescence; gradual smooth boundary.
151–168	3ABb	II	Pale-brown (10YR 6/3) silt loam, grayish-brown (10YR 5/2) moist; moderate medium granular structure; hard, friable; common fine pores; strong effervescence; gradual smooth boundary.
168–200	3Bkb	II	Pale-brown (10YR 6/3) silt loam, brown (10YR 5/3) moist; massive; very hard, friable; common fine pores; common films and threads of calcium carbonate; violent effervescence; gradual smooth boundary.
200–415	3Ck	II	Very pale brown (10YR 7/3) silt loam, brown (10YR 5/3) moist; massive; very hard, friable; common fine pores; common films and threads of calcium carbonate; violent effervescence; abrupt smooth boundary.
415–455	4Akb1	IV	Grayish-brown (10YR 5/2) silt loam, very dark grayish-brown (10YR 3/2) moist; moderate medium granular structure; hard, friable; common fine pores; common fine threads of calcium carbonate; common flecks of charcoal; common gastropods; prehistoric cultural materials and bones concentrated in upper 15 cm; strong effervescence; gradual smooth boundary.
455–510	4Akb2	IV	Brown (10YR 5/3) silt loam, brown (10YR 4/3) moist; moderate medium granular structure; hard, friable; common fine pores; common films and fine threads of calcium carbonate; common flecks of charcoal; common gastropods; prehistoric cultural materials concentrated in lower 30 cm of horizon; strong effervescence; gradual smooth boundary.

Table A.15 (continued)

Depth (cm)	Soil horizon	Unit	Description
510–532	4Bk	IV	Pale-brown (10YR 6/3) silt loam, brown (10YR 4/3) moist; moderate fine subangular blocky structure; hard, friable; common fine pores; common threads of calcium carbonate; many hard, tubular and irregularly shaped calcium carbonate concretions, 0.25–0.50 cm in diameter; common gastropods and pelecypods; violent effervescence; gradual smooth boundary.
532–545	4BCk	IV	Very pale brown (10YR 7/3) silt loam, brown (10YR 4/3) moist; weak fine subangular blocky structure; very hard, friable; common fine pores; common threads of calcium carbonate; many hard, tubular and irregularly shaped calcium carbonate concretions, 0.50–2.50 cm in diameter; common gastropods and pelecypods; violent effervescence; gradual smooth boundary.
545–628	4Ck	IV	Very pale brown (10YR 7/3) loam, brown (10YR 4/3) moist; massive; very hard, friable; common fine pores; common films of calcium carbonate; common gastropods and pelecypods; violent effervescence; abrupt smooth boundary.
628–645	5C	IV	Brown (10YR 5/3) loamy fine sand, brown (10YR 4/3) moist; single grain; soft, loose; prominent crossbedding; many gastropods and pelecypods; strong effervescence; abrupt boundary.
645–662	6Ck	IV	Pale-brown (10YR 6/3) fine sandy loam, brown (10YR 4/3) moist; massive; hard, friable; common films and threads of calcium carbonate; common fine pores; common gastropods; violent effervescence; abrupt smooth boundary.
662–670	6C1	IV	Pale-brown (10YR 6/3) to light-brownish-gray (10YR 6/2) gravelly sandy loam, brown (10YR 4/3) moist; single grain, loose; few films of calcium carbonate; many gastropods; violent effervescence; abrupt smooth boundary.
670–713	6C2	IV	Pale-brown (10YR 6/3) fine sandy loam, brown (10YR 5/3) moist; massive; hard, friable; common films of calcium carbonate; few fine pores; many gastropods; violent effervescence; abrupt smooth boundary.
713–734	6C3	IV	Light-brownish-gray (10YR 6/2) very gravelly loamy sand, grayish-brown (10YR 5/2) moist; massive to single grain, loose; few fine films of calcium carbonate; violent effervescence; irregular boundary.
734+	7R	–	Limestone.

a. Welded soil.

Table A.16. Description of section at site 14HO316 (locality HC-2) in Hackberry Creek valley

Location: Hodgeman County, KS; SESE sec. 13, R. 26 W., T. 21 S.
Landscape position: T-2 terrace
Slope: <1%
Vegetation: native grasses

Depth (cm)	Soil horizon	Unit	Description
0–12	Ap	I	Grayish-brown (10YR 4/2) silt loam, dark-grayish-brown (10YR 3/2) moist; weak fine granular structure; very friable; many fine roots; noneffervescent; clear smooth boundary.
12–43	A	I	Dark-brown (10YR 3/3) silt loam, very dark grayish-brown (10YR 3/2) moist; weak medium granular structure; very friable; common fine roots; common earthworm casts; noneffervescent; gradual smooth boundary.
43–65	Bw	I	Brown (10YR 5/3) light silty clay loam, brown (10YR 4/3) moist; moderate coarse subangular blocky parting to medium granular structure; friable; few fine and medium roots; common earthworm casts; common fine and few medium pores; noneffervescent; gradual smooth boundary.
65–103	Bk	I	Pale-brown (10YR 6/3) light silty clay loam, brown (10YR 4/3) moist; moderate coarse subangular blocky parting to medium granular structure; friable; common films and threads of calcium carbonate; few fine and medium roots; common earthworm casts; common fine pores, strong effervescence; gradual smooth boundary.
103–155	Ck	I	Pale-brown (10YR 6/3) silt loam, brown (10YR 5/3) moist; massive; hard when dry, firm when moist; common thin lenses of very fine sand; few fine roots; common threads of calcium carbonate; common fine pores; strong effervescence; abrupt smooth boundary.
155–176	2Akb	I	Dark-grayish-brown (10YR 4/2) silty clay loam, very dark grayish-brown (10YR 3/2) moist; moderate medium and fine granular structure; friable; few fine roots; common films and threads of calcium carbonate; common fine pores; strong effervescence; gradual smooth boundary.
176–207	2ACkb	I	Grayish-brown (10YR 5/2) silt loam, dark-grayish-brown (10YR 4/2) moist; moderate fine granular structure; friable; few fine threads of calcium carbonate, many fine and medium pores; common lenses of very fine sand; strong effervescence; abrupt smooth boundary.
207–233	3Akb	I	Dark-grayish-brown (10YR 4/2) silt loam, very dark grayish-brown (10YR 3/2) moist; weak fine granular structure; friable; few fine threads of calcium carbonate; many fine pores; strong effervescence; gradual smooth boundary.
233–245	3ACkb	I	Brown (10YR 4/3) loam, dark-brown (10YR 3/3) moist; weak fine granular structure; friable; few fine threads of calcium carbonate; common fine pores; many faint lenses of very fine sand; strong effervescence; abrupt smooth boundary.
245–271	4Akb	II	Dark-grayish-brown (10YR 3/2) silt loam, very dark grayish-brown (10YR 3/2) moist; weak medium and fine granular structure; friable; few threads and flecks of calcium carbonate; many fine pores; strong effervescence; gradual smooth boundary.
271–323	4ACkb	II	Brown (10YR 5/3) silt loam, dark-brown (10YR 3/3) moist; weak fine granular structure; few films and threads of calcium carbonate; many fine pores; strong effervescence; abrupt smooth boundary.
323–335	5Akb	II	Brown (10YR 4/3) silt loam, dark-brown (10YR 3/3) moist; weak fine granular structure; slightly hard when dry, friable when moist; common threads of calcium carbonate; few fine pores; strong effervescence; gradual smooth boundary.

Table A.16 (continued)

Depth (cm)	Soil horizon	Unit	Description
335–349	5ACkb	II	Brown (10YR 5/3) loam, dark-brown (10YR 3/3) moist; weak fine granular structure; slightly hard when dry, friable when moist; common threads of calcium carbonate; many fine pores; strong effervescence; abrupt smooth boundary.
349–365	6Akb	II	Brown (10YR 4/3) loam, dark-brown (10YR 3/3) moist; weak fine granular structure; friable; common threads and flecks of calcium carbonate; many fine pores; strong effervescence; gradual smooth boundary.
365–417	6Ck	II	Brown (10YR 5/3 and 4/3) finely stratified loam and very fine sand, dark-brown (10YR 3/3) moist; soft; many fine pores; few films of calcium carbonate in pores; many thin discontinuous lenses of fine and medium sand; common discontinuous lenses of well- to subrounded pebbles; strong effervescence; abrupt smooth boundary.
417–432	7Akb	II	Brown (10YR 4/3) silt loam, brown (10YR 3/3) moist; weak fine granular structure; friable; few fine threads of calcium carbonate; common fine pores; strong effervescence; gradual smooth boundary.
432–451	7ACkb	II	Brown (10YR 5/3) loam, dark-brown (10YR 3/3) moist; weak fine granular structure; friable; common fine threads of calcium carbonate; common fine pores; strong effervescence; abrupt smooth boundary.
451–491	8Akb	II	Brown (10YR 4/3) silt loam, dark-brown (10YR 3/3) moist; weak fine granular structure; friable; common films and threads and few fine hard concretions of calcium carbonate; many fine pores; strong effervescence; gradual smooth boundary.
491–536	8Bkb	III	Brown (10YR 4/3) silty clay loam, dark-brown (10YR 3/3) moist; weak fine subangular blocky parting to fine and medium granular structure; firm; common films and threads and few fine hard concretions of calcium carbonate; many fine pores; strong effervescence; gradual smooth boundary.
536–595	8BCkb	III	Brown (10YR 5/3) silt loam, dark-brown (10YR 3/3) moist; weak fine granular structure; friable; common threads and few fine hard concretions of calcium carbonate; many fine pores; strong effervescence; gradual smooth boundary.
595–654	8Ck	III	Brown (10YR 5/3) loam, brown (10YR 4/3) moist; weak fine granular structure; friable; common small and few large hard calcium carbonate concretions; many fine pores; strong effervescence; abrupt smooth boundary.
654–704	9Akb	IV	Brown (10YR 4/3) heavy silt loam, dark-brown (10YR 3/3) moist; weak fine granular structure; friable; few fine threads and large hard concretions of calcium carbonate; many fine pores; strong effervescence; gradual smooth boundary.
704–724	9ACkb	IV	Brown (10YR 5/3) loam, brown (10YR 4/3) moist; weak fine granular structure; friable; few thin threads and large hard concretions of calcium carbonate; many fine pores; strong effervescence; gradual smooth boundary.
724–805	9Ck	IV	Brown (10YR 5/3) loam grading downward into sandy loam, sand, and gravel, brown (10YR 4/3) moist; massive; friable; few large hard concretions of calcium carbonate; weak effervescence.

Table A.17. Description of section at site 14FD311 in Sawlog Creek valley

Location: Ford County, KS; SESE sec. 2, R. 25 W., T. 25 S.
Landscape position: T-1 terrace
Slope: <1%
Vegetation: native grasses

Depth (cm)	Soil horizon	Unit	Description
0–15	A	I	Grayish-brown (10YR 4/2) silt loam, dark-grayish-brown (10YR 4/2) moist; weak fine granular structure; friable; many fine roots; moderate effervescence; gradual smooth boundary.
15–45	C	I	Brown (10YR 5/3) loam, brown (10YR 4/3) moist; weak fine granular structure; slightly hard, friable; few fine roots; strong effervescence; abrupt smooth boundary.
45–60	2Ab	II	Grayish-brown (10YR 5/2) silt loam, dark-grayish-brown (10YR 4/2) moist; weak very fine granular structure; slightly hard, friable; few fine roots; few fine pores; strong effervescence; gradual smooth boundary.
60–82	ACb	II	Brown (10YR 5/3) silt loam, brown (10YR 4/3) moist; weak very fine granular structure; slightly hard when dry, friable when moist; few fine roots; few fine pores; strong effervescence; clear smooth boundary.
82–91	3Ab	II	Grayish-brown (10YR 5/2) silt loam, dark-grayish-brown (10YR 5/2) moist; weak fine granular structure; slightly hard, friable; few fine roots; few fine pores; strong effervescence; gradual smooth boundary.
91–115	3ACb	II	Brown (10YR 5/3) silt loam, brown (10YR 4/3) moist; weak very fine granular structure; slightly hard, friable; few fine roots; few fine pores; strong effervescence; gradual smooth boundary.
115–127	3Cb	II	Stratified brown (10YR 5/3) silt loam and loam, brown (10YR 4/3) moist; slightly hard, friable; few fine roots; few fine pores; strong effervescence; clear smooth boundary.
127–142	4Ab	II	Grayish-brown (10YR 5/2) loam, dark-grayish-brown (10YR 4/2) moist; weak very fine granular structure; slightly hard, friable; few fine roots; few fine pores; gravel lens at a depth of 135–140 cm; strong effervescence; gradual smooth boundary.
142–200	4C	II	Laminated brown (10YR 5/3) and pale-brown (10YR 6/3) loam and very fine sandy loam, brown (10YR 4/3) moist; massive; slightly hard, friable; few fine pores; few fine roots; strong effervescence; abrupt wavy boundary.
200–264	5Akb	III	Dark-grayish-brown (10YR 4/2) loam, very dark grayish-brown (10YR 3/2) moist; moderate medium granular structure; hard, friable; few films and threads of calcium carbonate; many gastropods; moderate effervescence; gradual smooth boundary.
264–270	5ACkb	III	Grayish-brown (10YR 5/2) loam, dark-grayish-brown (10YR 4/2) moist; weak fine granular structure; slightly hard, friable; common films and few threads of calcium carbonate; many gastropods; strong effervescence; gradual smooth boundary.
270–365	5C	III	Stratified coarse and fine alluvium; very dark grayish-brown (10YR 3/2) strata of silt loam and silty clay loam alternating with dark-grayish-brown (10YR 4/2) and grayish-brown (10YR 5/2) strata of gravelly sand and sandy loam; common flecks of calcium carbonate; many gastropods and pelecypods; strong effervescence; irregular boundary.
365+	6R	–	Limestone.

Table A.18. Description of Doll section at locality PR-11

Location: Finney County, KS; SWNW sec. 6, R. 29 W., T. 22 S.
Landscape position: T-1 terrace
Slope: <1%
Vegetation: native grasses

Depth (cm)	Soil horizon	Unit	Description
0–26	A	I	Brown (10YR 5/3) silt loam, dark-brown (10YR 3/3) moist; weak fine granular structure; friable; common fine roots; strong effervescence; gradual smooth boundary.
26–60	Bw	I	Pale-brown (10YR 6/3) loam, brown (10YR 5/3) moist; weak fine subangular blocky structure; friable; common fine and medium pores; many earthworm casts; common fine roots; violent effervescence; gradual smooth boundary.
60–120	C	I	Pale-brown (10YR 6/3) fine sandy loam; brown (10YR 5/3) moist; massive; slightly hard, friable; few fine and medium pores; few earthworm casts; common fine roots; violent effervescence; abrupt smooth boundary.
120–141	2Akb	II	Brown (10YR 5/3) silt loam, dark-brown (10YR 3/3) moist; moderate fine granular structure; hard, friable; common fine pores; few earthworm casts; pale-brown (10YR 6/3) fine sandy loam in krotovinas; few fine roots; few fine threads of calcium carbonate; strong effervescence.
141–149	2ABkb	II	Light-grayish-brown (10YR 6/2) to pale-brown (10YR 6/3) silt loam; weak fine subangular blocky structure; slightly hard, friable; many fine pores; few fine roots; few fine threads and films of calcium carbonate; hard, friable; strong effervescence; gradual smooth boundary.
149–175	2Bkb	II	Pale-brown (10YR 6/3) to light-yellowish-brown (10YR 6/4) silt loam, brown (10YR 5/3) moist; weak fine subangular blocky structure; hard, friable; common fine and medium pores; few fine roots; few films and threads of calcium carbonate; violent effervescence; gradual smooth boundary.
175–193	2BCkb	II	Pale-brown (10YR 6/3) to very pale brown (10R 7/3) silt loam; massive; hard, friable; common fine and medium pores; few fine roots; few films and threads of calcium carbonate; few fine soft carbonate masses; violent effervescence; abrupt smooth boundary.
193–254	3Akb	III	Brown (10YR 5/3) silt loam, dark-brown (10YR 3/3) moist; moderate fine and medium granular structure; hard, friable; many fine pores; few fine roots; common films and threads of calcium carbonate; few fine soft carbonate masses; few large krotovinas filled with pale-brown (10YR 6/3) silt loam; strong effervescence; gradual smooth boundary.
254–265	3Bkb	III	Brown (10YR 5/3) silt loam, brown (10YR 4/3) moist; weak fine subangular blocky structure; few fine roots; common fine and medium pores; common films, threads, and fine soft masses of calcium carbonate; violent effervescence.

Table A.19. Description of Doll silo at locality PR-12

Location: Finney County, KS; NESE sec. 8, R. 29 W., T. 23 S.
Landscape position: T-3 terrace
Slope: 1%
Vegetation: crops

Depth (cm)	Soil horizon	Unit	Description
0–25	Ap	I	Brown (10YR 5/3) silt loam, brown (10YR 4/3) moist; weak fine granular structure; slightly hard, friable; common fine roots; weak effervescence; clear smooth boundary.
25–35	A	I	Brown (10YR 5/3) silt loam, dark-brown (10YR 3/3) moist; moderate medium granular structure; slightly hard, friable; common fine roots; common earthworm casts; noneffervescent; gradual smooth boundary.
35–68	ABk	I	Yellowish-brown (10YR 5/4) heavy silt loam, dark-yellowish-brown (10YR 4/4) moist; common medium faint reddish-yellow (7.5YR 6/6) mottles; moderate fine subangular blocky structure; slightly hard, friable; common earthworm casts; common fine roots; few medium pores; few films of calcium carbonate; matrix is noneffervescent; gradual smooth boundary.
68–103	Btk1	I	Yellowish-brown (10YR 5/6) light silty clay loam, dark-yellowish-brown (10YR 4/6) moist; common medium faint reddish-yellow (7.5YR 6/6) mottles; moderate fine subangular blocky structure; slightly hard, friable; few earthworm casts; few fine roots; common fine and few medium pores; few discontinuous clay films; common films and threads of calcium carbonate; strong effervescence; gradual smooth boundary.
103–130	Btk2	I	Light-brown (7.5YR 6/4) silty clay loam, strong brown (7.5YR 4/6) moist; common medium faint reddish-yellow (7.5YR 6/6) mottles; moderate medium subangular blocky structure; slightly hard, friable; few fine roots; common fine and few medium pores; few discontinuous clay films; common films and threads of calcium carbonate; strong effervescence; gradual smooth boundary.
130–145	BCk	I	Light-brown (7.5YR 6/4) loam, strong brown (7.5YR 4/6) moist; common medium faint reddish-yellow (7.5YR 6/6) mottles; moderate fine subangular blocky structure; hard, friable; few fine roots; common fine pores; many films and threads of calcium carbonate; strong effervescence; abrupt smooth boundary.
145–190	2Bkb1	II	Light-yellowish-brown (7.5YR 6/4) silty clay loam, pink (7.5YR 7/4) moist; moderate medium subangular blocky structure; hard, firm; 85% of matrix is whitened by calcium carbonate; common fine hard carbonate concretions; common fine and medium soft calcium carbonate masses; rounded siliceous pebbles form a stone line at top of horizon; few thin lenses of siliceous pebbles within horizon; few fine pores; violent effervescence; gradual smooth boundary.
190–230	2Bkb2	II	Light-yellowish-brown (10YR 6/4) loam, brown (7.5YR 5/4) moist; common medium distinct reddish-yellow (7.5YR 6/8) mottles; moderate medium subangular blocky structure; hard, firm; 50% of matrix is whitened by calcium carbonate; many films and threads of calcium carbonate; common fine hard carbonate concretions; common fine and medium soft calcium carbonate masses; violent effervescence; gradual smooth boundary.
230–320+	2BCkb	II	Light-brown (10YR 6/4) fine sandy loam, brown (7.5YR 5/4) moist; moderate fine subangular blocky structure; hard, firm; common films and threads of calcium carbonate; few fine hard carbonate concretions; few soft carbonate masses; violent effervescence.

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Index

Kansas Geological Survey, The University of Kansas

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Bulletin 236
1994

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