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Buried paleoindian-age landscapes in stream valleys of the central plains, USA ☆

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ABSTRACT

A systematic study of late-Quaternary landscape evolution in the Central Plains documented widespread, deeply buried paleosols that represent Paleoindian-age landscapes in terrace fills of large streams (>5th order), in alluvial fans, and in draws in areas of western Kansas with a thick loess mantle. Alluvial stratigraphic sections were investigated along a steep bio-climatic gradient extending from the moist-subhumid forest-prairie border of the east-central Plains to the dry-subhumid and semi-arid shortgrass prairie of the west-central Plains. Radiocarbon ages indicate that most large streams were characterized by slow aggradation accompanied by cumulic soil development from ca. 11,500 to 10,000 ^{14}C yr B.P. In the valleys of some large streams, such as the Ninnescah and Saline rivers, these processes continued into the early Holocene. The soil-stratigraphic record in the draws of western Kansas indicates slow aggradation punctuated by episodes of landscape stability and pedogenesis beginning as early as ca. 13,300 ^{14}C yr B.P. and spanning the Pleistocene–Holocene boundary. The development record of alluvial fans in western Kansas is similar to the record in the draws; slow aggradation was punctuated by multiple episodes of soil development between ca. 13,000 and 9000 ^{14}C yr B.P. In eastern Kansas and Nebraska, development of alluvial fans was common during the early and middle Holocene, but evidence shows fan development as early as ca. 11,300 ^{14}C yr B.P. Buried soils dating between ca. 12,600 and 9000 ^{14}C yr B.P. were documented in fans throughout the region.

In stream valleys across the Central Plains, rapid alluviation after ca. 9000 ^{14}C yr B.P. resulted in deeply buried soils that may harbor Paleoindian cultural deposits. Hence, the paucity of recorded stratified Paleoindian sites in the Central Plains is probably related to poor visibility (i.e., deep burial in alluvial deposits) instead of limited human occupation in the region during the terminal Pleistocene and early Holocene. The thick, dark, cumulic A horizons of soils, representing buried Paleoindian-age landscapes, are targets for future archaeological surveys.

1. Introduction

The emergence of archaeological geology, or geoarchaeology, in North America is strongly linked to Paleoindian studies in the Great Plains (Holliday, 2000a,b; Mandel, 2000a)[a]. These studies began in the mid to late 1920s with the discoveries at the Folsom site in New Mexico, but it was work at the Clovis site (New Mexico) during the1930s that established a tradition of integrating geoscientific investigations with Paleoindian research (Holliday, 1997, p. 1). This tradition has persisted into the twenty-first century, and geoarchaeology continues to play a significant role in analysis of early sites in the Great Plains. Geoscientific methods also have been used to develop predictive models for locating stratified late Wisconsin and early Holocene cultural deposits in the region (e.g., Mandel, 1992, 1994; Mandel et al., 2004).

The open grasslands of the midcontinent have yielded some of the most important Paleoindian sites in the Western Hemisphere (Holliday, 1997, p. 1; Hofman and Graham, 1998; Stanford, 1999; Holliday and Mandel, 2006). Although material remains of Paleoindians have been discovered throughout the Great Plains, many of the sites with buried, *in situ*, and, in many cases, stratified occupations, such as Clovis, Plainview, Lubbock Lake, Lindenmeir, Hell Gap, Scottsbluff, Olsen-Chubbuck, Lime Creek, Dutton, Lange-Ferguson, and Agate Basin, are found on the High Plains (Holliday and Mandel, 2006). The Southern High Plains of Texas and New Mexico and the Western High Plains of Colorado and Wyoming have especially high concentrations of recorded early sites (Holliday, 2000a; Albanese, 2000). This pattern, however, does not hold up in the Central Plains. Despite the numerous finds of Paleoindian projectile points on uplands and in streambed contexts across this region, few *in situ* camp and kill sites predating 9000 ^{14}C yr B.P. have been documented in Kansas and Nebraska (Hofman, 1996; Blackmar and Hofman, 2006). The dearth of recorded, stratified early sites is especially apparent on the High Plains of western Kansas, a region that should have been attractive to the early human inhabitants of North America considering the archaeological

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☆ In the Central Plains, the Paleoindian period dates to 11,500 to 9000 ^{14}C yr B.P. and is divided into Early Paleoindian (11,500–10,900 ^{14}C yr B.P.), Middle Paleoindian (10,900–10,500 ^{14}C yr B.P.), and Late Paleoindian (10,500–9000 ^{14}C yr B.P.).

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record on the High Plains in neighboring areas (Blackmar and Hofman, 2006).

The paucity of recorded Paleoindian sites in the Central Plains is partly a result of insufficient archaeological investigation in the region. Although many archaeological surveys have been conducted in eastern Kansas and Nebraska, especially in association with reservoir and highway construction projects, most involved only shallow shovel testing and/or surface survey; deep subsurface exploration was not common until after 1980 (Mandel, 2000b). Few systematic archaeological surveys have been conducted in sparsely populated central and western Kansas and Nebraska, and only a few involved deep testing.

A recent study by Mandel and others (2004) suggests that the low number of recorded Paleoindian sites on the High Plains of northwestern Kansas is not just a result of insufficient surveying, but a product of the filtering effects of geomorphic processes on the regional archaeological record. Specifically, the geomorphic settings and associated micro-environments that would have been most attractive to the early residents of the High Plains—stream valleys and playas—also were zones of episodic sedimentation and soil development during the terminal Pleistocene and early Holocene (ca. 12,000–9000 ^{14}C yr B.P.) (Mandel, 1995, 2006a). Consequently, Paleoindian-age landscapes that may harbor *in situ* cultural deposits are deeply buried and are rarely detected using traditional archaeological survey techniques.

The primary goal of this study was to determine if late-Quaternary landscape evolution has affected the distribution and detection of Paleoindian sites in stream valleys across the Central Plains. The following question was specifically addressed: Are buried soils representing Paleoindian-age landscapes preserved in stream valleys throughout the region, and if so, where in drainage networks are they likely to occur? To answer this question, it was necessary to assess temporal and spatial patterns of late-Quaternary erosion, sedimentation, and landscape stability in drainage basins. This was accomplished through a systematic, multi-year investigation of late-Quaternary alluvial fills in the valleys of low- and high-order streams across the Central Plains. The soil stratigraphy, lithostratigraphy, and chronostratigraphy of the fills were defined. Given the focus of this study, emphasis was placed on reconstructing landscape evolution in stream valleys during the Pleistocene–Holocene transition. Because the study was designed to provide a geoarchaeological model, it also was important to consider how erosion and sedimentation may have affected Paleoindian-age alluvial landscapes throughout the Holocene.

Results from this research provide a basis for determining whether alluvial deposits and associated soils of certain ages are systematically preserved in stream systems. From an archaeological perspective, it is reasonable to assume that sites predating 9000 ^{14}C yr B.P. will be found only where geologic deposits are old enough to contain them. A corollary is that where sufficiently thick alluvial deposits post-dating 9000 ^{14}C yr B.P. are present, evidence of these sites will not be found on the modern land surface.

Buried alluvial soils represent former surfaces of floodplains, terraces, or alluvial fans that were stable long enough to develop recognizable soil profile characteristics (Mandel and Bettis, 2001;

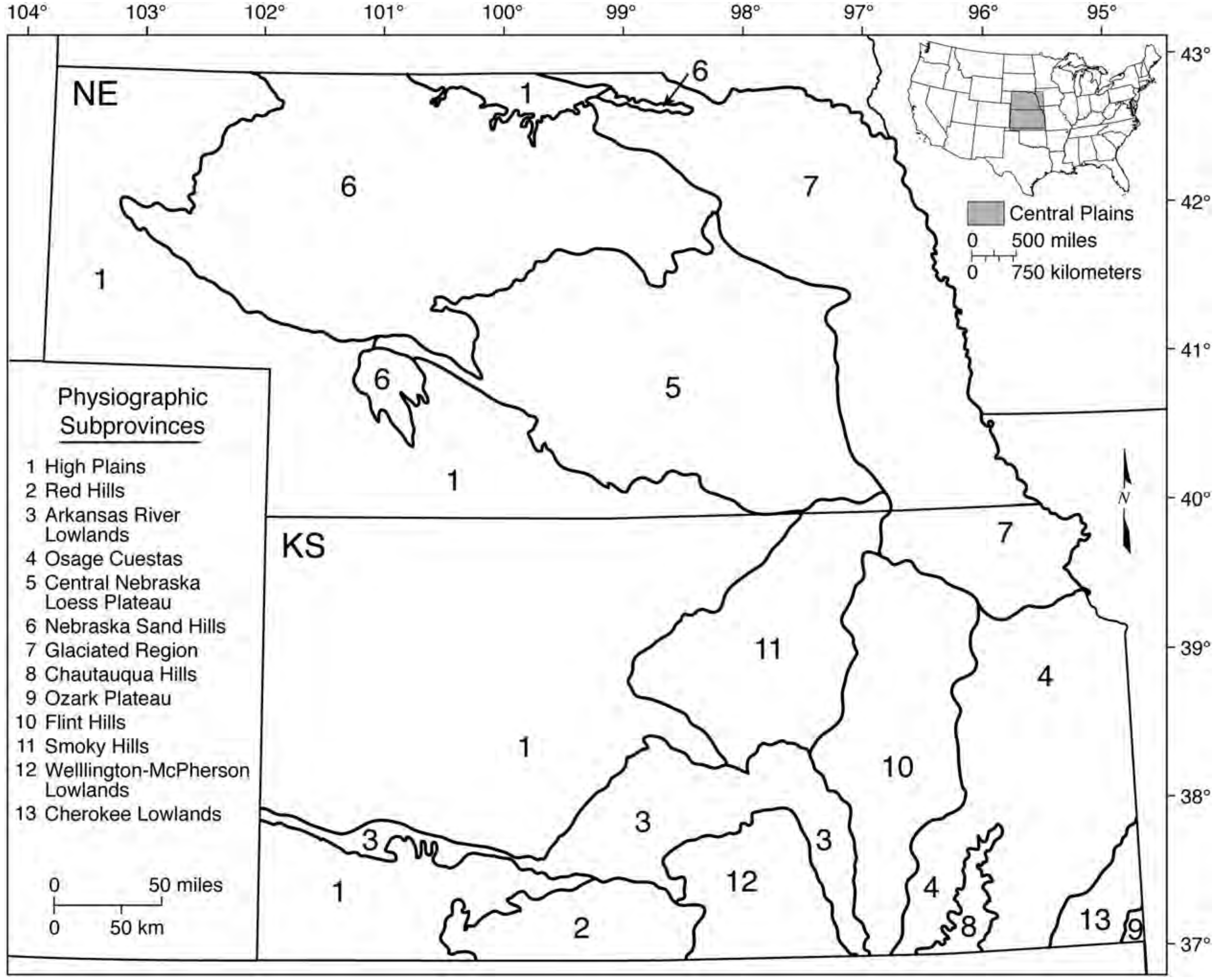

Fig. 1. The study area spans most of the Central Plains of Kansas and Nebraska, a region of the U.S. interior that includes portions of the Great Plains, Central Lowlands, and Glaciated Central Lowlands, and is divided into 13 physiographic subprovinces. Adapted from Wilson (1978, Fig. 8) and U.S. Environmental Protection Agency (2003).

Holliday, 2004). The presence or absence of buried soils, especially buried A horizons, is important in evaluating the potential for archaeological site-preservation (Mandel, 1992; Mandel and Bettis, 2001). As Hoyer (1980) pointed out, if the probability of human use of a particular landscape position was equal for each year, it follows that the surfaces that remained exposed for the longest time would represent those with the highest probability for containing cultural materials. Buried soils identified in the present study represent these surfaces, and evidence for human occupation would most likely be associated with them. Buried alluvial soils dating to the Pleistocene–Holocene transition have especially high geologic potential for containing Paleoindian cultural deposits. Therefore, locating these soils was a major objective of this study.

2. Study area

2.1. Physiography and geology

The Central Plains region of North America extends from northern Nebraska south through Kansas and barely into northern Oklahoma (Fig. 1). This region includes portions of Fenneman's (1931) Great Plains, Central Lowlands, and Glaciated Central Lowlands physiographic provinces. The term "Central Plains" is informal but is often used in the literature for this part of the U.S.

Most of the Central Plains region is within the Great Plains physiographic province. Seven physiographic subprovinces of the Great Plains are represented in the Central Plains: the High Plains, Nebraska Sand Hills, Loess Plains, Smoky Hills, Arkansas River Lowlands, Red Hills, and Wellington-McPherson Lowlands (Fig. 1). The topography of the High Plains in western Kansas and Nebraska is monotonously flat; local relief ranges between about 5 and 15 m. This region is mantled by deposits of Peoria, Gilman Canyon, and Loveland loess with a combined thickness of 3–5 m (Frye and Leonard, 1952; Welch and Hale, 1987). In many areas, the loess overlies thick deposits of Pleistocene and/or Pliocene alluvium. The Sand Hills, located in north-central and west-central Nebraska, is a region of grass-covered sand dunes that occupies about 50,000 km^2; it is the largest sand dune area in the Western Hemisphere.

Immediately south and east of the Sand Hills is an extensive loess-mantled landscape. The dissected Loess Plains dominate central and south-central Nebraska and extend south into northwestern and north-central Kansas. The loess sheet is 9–18 m thick throughout much of this region, and exceeds 30 m in some areas between the Platte River and Sand Hills.

The Smoky Hills region in central and east-central Kansas consists of a broad belt of hills formed by the dissection of Cretaceous and Permian sedimentary rocks (Merriam, 1963). To the south of the Smoky Hills lie the Arkansas River Lowlands, a wide alluvial plain that parallels the Arkansas River throughout the Central Plains. Thick deposits of Quaternary sand and gravel compose the valley fill of the Arkansas River, and portions of the alluvial plain are covered with sand dunes.

The Red Hills region is an area of deeply dissected, red, Permian-age shale, sandstone, and siltstone extending from south-central Kansas into north-central Oklahoma (Swineford, 1955). To the east of the Red Hills are the Wellington Lowlands, a rolling landscape underlain by Permian-age siltstone, sandstone, salt deposits, and gypsum. The McPherson Lowlands form a north-south trending region immediately east of the Arkansas River in McPherson, Harvey, Rice, and Sedgwick counties, Kansas. This broad, flat, alluvial plain is underlain by thick deposits of Pleistocene sand and gravel referred to as the "Equus Beds" (Frye and Leonard, 1952). Thick deposits of Pleistocene loess and, in some locations, volcanic ash mantles the alluvium.

The Central Lowlands is a region of low relief that includes much of southeastern Kansas and northeast Oklahoma. Four physiographic subprovinces of the Central Lowlands are within the Central Plains: the Flint Hills, Osage Cuestas, Chautauqua Hills, and Cherokee Lowlands (Fig. 1). The Flint Hills trend north-south through east-central Kansas and extreme northeastern Oklahoma. Differential erosion of westward-dipping shales and cherty limestones has created a landscape that resembles steplike benches.

The Osage Cuestas region is a large area south of the Kansas River, east of the Flint Hills, and west of the Ozark Plateau. The cuestas are formed by differential erosion of Pennsylvanian- and Permian-age limestone and shale. Extending northward into the Osage Cuestas from the Oklahoma–Kansas border are the gently rolling Chautauqua Hills, a region where erosion of thick strata of Pennsylvanian-age sandstone formed a series of low hills that are in sharp contrast with the cuesta-form ridges of the surrounding region.

The Cherokee Lowlands are confined to the extreme southeastern corner of Kansas and northeastern corner of Oklahoma. This region is a nearly flat, featureless erosional plain underlain by soft Pennsylvanian-age shale and sandstone.

The Glaciated Central Lowlands region is a dissected drift plain that includes the eastern quarter of Nebraska and the northeastern corner of Kansas (Fig. 1). A continental ice sheet covered this region during the Pre-Illinoian glacial stages (>0.5 ma). The advance of the ice sheet scoured stream valleys and leveled cuesta-form uplands throughout the drift plain (Frye and Leonard, 1952; Aber, 1991).

2.2. Climate

The Central Plains has a continental climate characterized by a large annual temperature range. A distinct east-to-west precipitation gradient exists, with mean annual precipitation ranging from about 100 cm at the eastern edge of the region to less than 40 cm along the western edge. The region receives approximately 75% of its precipitation from April through September, largely as a result of frontal activity. Pacific and polar air masses that flow into the Central Plains during spring and summer usually converge with warm, moist maritime-tropical air flowing north from the Gulf of Mexico. The collision of these air masses often produces intense rainfalls of short duration along the zone of convergence. Periodic intensification of westerly (zonal) airflow, however, prevents moist Gulf air from penetrating the Central Plains. This condition and the development of strong anticyclonic (high-pressure) activity in the upper atmosphere over the midcontinent tend to promote drought in the region (Borchert, 1950; Bryson and Hare, 1974, p. 4; Namias, 1982, 1983; COHMAP, 1988; Laird et al., 1996; Smith and Hollander, 1999). Recent studies have shown that severe drought in North America fits into a pattern that has zonal symmetry, as demonstrated by Hoerling and Kumar (2003), and also hemispheric symmetry (Schubert et al., 2004a,b; Seager et al., 2005; Cook et al., 2007). Specifically, persistent droughts over most of North America, including the Great Plains, appear to be related to persistent cool sea surface temperatures (SST) associated with La Niña in the eastern tropical Pacific Ocean (Schubert et al., 2004a,b; Seager et al., 2005; Seager, 2007).

Severe droughts have afflicted the Central Plains roughly every 20 years during the period of record, causing dramatic changes in the composition of grassland communities and significant (>75%) losses of vegetative cover (Albertson and Weaver, 1942; Albertson and Tomanek, 1965; Tomanek and Hulett, 1970; Borchert, 1971; Frison, 1978, p. 25). Strong evidence also exists for Holocene "megadroughts" of unprecedented severity and duration (hundreds of years), unlike any experienced by modern societies in North America (Laird et al., 1996; Woodhouse and Overpeck, 1998; Cook et al., 2004, 2007; Miao et al., 2007). These protracted droughts caused major perturbations among plant communities in the midcontinent (Grimm, 2001; Clark et al., 2002; Nelson et al., 2004; Brown et al., 2005) and probably had considerable impact on prehistoric people in the Central Plains.

2.3. Vegetation

The Central Plains are within the Interior Grasslands region of North America. Küchler (1964) identified several distinct north-south

Table 1
Radiocarbon ages from buried Paleoindian-age alluvial soils in the Central Great Plains

Stream/study site	Locality[a]	Material assayed	Sample depth (m)	δ^{13}C (‰)	^{14}C age (yr. B.P.)	Cal age[b] (yr. B.P.)	Median cal age (yr. B.P.)	Lab. no.
High order streams								
N. Fork Solomon R.								
Hendrick Section	32	SOM[c]	3.00–3.10	−20.2	10,060 ± 70	12,100–11,217	11,602	ISGS-4701
	32	SOM	5.00–5.10	−20.9	11,350 ± 70	13,470–12,937	13,224	ISGS-4704
Saline River								
Daugherty Section	15	SOM	3.90–4.00	−18.7	9910 ± 70	11,979–10,877	11,343	ISGS-4781
	15	SOM	5.85–5.95	−20.4	10,660 ± 100	12,986–11,983	12,695	ISGS-4779
Dalaney Section	16	SOM	3.95–4.05	−17.8	10,330 ± 70	12,698–11,506	12,177	ISGS-5219
Smoky Hill River								
Clemance Section	14	SOM	2.70–2.80	−15.9	10,010 ± 120	12,562–10,775	11,552	A-11418
	14	SOM	3.75–3.85	−17.7	10,330 ± 95	12,757–11,404	12,179	A-11419
	14	SOM	5.20–5.30	−20.9	11,270 ± 90	13,460–12,863	13,159	A-11420
Mill Creek								
Claussen Site	4	Charcoal	7.95–8.00	−24.2	8800 ± 150	10,606–9126	9866	ISGS-4684
	4	Charcoal	8.35–8.40	−25.5	9225 ± 30	10,554–10,247	10,385	ISGS-A0479
	4	Charcoal	8.37–8.40	−24.8	9225 ± 35	10,564–10244	10,611	ISGS-A0480
Little Blue River								
Site 25TY30	38	SOM	4.10–4.20	−18.6	8830 ± 110	10,489–9446	9906	TX-7830
Morrison Section	44	SOM	7.00–7.15	−17.1	10,340 ± 100	12,777–11,404	12,156	ISGS-6121
Kansas River								
Bonner Springs	1	SOM	6.80–6.95	NR[d]	8940 ± 90[e]	10,485–9548	10,033	DIC-3210
	1	SOM	8.80	NR	10,430 ± 130[f]	12,859–11,393	12,343	Beta-2931
Stranger Creek								
Leach Section 2	48	SOM	6.65–6.75	−17.5	10,810 ± 80	12,385–13,099	12,748	ISGS-4622
Cimarron River								
Satanta Section	27	SOM	2.78–2.88	NR	11,210 ± 80	13,356–12,866	13,109	TX-7668
Crooked Creek								
Enns Ranch Section 1	24	SOM	2.00–2.10	−14.7	10,010 ± 165	12,685–10,609	11,626	A-11384
Pawnee River								
Rucker Section	19	SOM	5.63–5.83	NR	9320 ± 120	11,218–9909	10,568	TX-6396
Core PR-2	18	SOM	3.45–3.70	NR	10,100 ± 130	12,689–10,871	11,695	TX-6374
McCreight Section	20	SOM	6.20–6.40	NR	10,240 ± 120	12,707–11,243	11,974	TX-6391
Hackberry Creek								
Site 14HO316 Section	21	SOM	6.50–6.70	NR	9820 ± 110	12,038–10,588	11,249	TX-6480
High Order Streams								
Chikaskia River								
Claypool Section 1	12	SOM	11.21–11.31	NR	10,800 ± 130	13,239–11,995	12,807	TX-9306
Bluff Creek								
Site 14SR319	13	Charcoal	8.58–8.65	NR	9440 ± 90	11,180–10,266	10,700	TX-9233
Ninnescah River								
KTA Section 1	11	SOM	5.14–5.24	NR	10,810 ± 130	13,250–12,002	12,736	TX-9226
Neosho River								
Site 14CF8 Section	2	SOM	4.50–4.60	NR	10,050 ± 80	12,338–11,184	11,584	TX-8582
Cottonwood River								
Eidman Section	8	SOM	6.14–6.24	−17.1	9740 ± 70[g]	11,609–10,683	11,112	ISGS-5893
Kissack Section	9	SOM	7.03–7.13	−16.7	10,540 ± 90[g]	12,871–11,827	12,458	ISGS-5985
S. Fork Cottonwood R.								
Peterson Section	7	SOM	6.59–6.66	−16.2	10,750 ± 80[g]	13,050–12,189	12,732	ISGS-5990
Draws								
Middle Beaver Creek								
Site 14SN101	35	SOM	1.60–1.70	−16.9	9240 ± 70	11,066–9966	10,438	ISGS-5583
	35	SOM	1.95–2.05	−17.1	9750 ± 70	12,616–10,693	11,130	ISGS-5576
	35	Bone	1.45–1.50	−10.2	10,370 ± 20	12,553–12,052	12,235	CURL-8998
	35	Bone	1.67–1.72	−14.0	10,950 ± 60	13,125–12,777	12,920	CAMS-112741
Site 14SN105	35	Bone	1.48–1.53	−11.5	10,350 ± 20	12,386–12,044	12,206	CURL-9002
	35	Bone	1.55–1.60	−12.0	10,395 ± 45	12,658–11,984	12,292	NZA-27864
Site 14SN106	35	Bone	1.66–1.71	−9.4	10,854 ± 40	12,953–12,740	12,853	NZA-27348
	35	Bone	2.35–2.40	−13.5	11,005 ± 50	13,110–12,830	12,954	CAMS-112742
	35	Bone	2.35–2.40	−8.3	11,085 ± 20	13,089–12,913	13,001	CURL-9009
Little Beaver Creek								
Powell Site	34	SOM	1.65–1.75	−16.1	9160 ± 70	10,703–9915	10,341	ISGS-4421
	34	SOM	1.97–2.02	−17.4	9800 ± 70	11,745–10,738	11,220	ISGS-4428
	34	SOM	2.59–2.69	−19.9	10,800 ± 70	13,120–12,418	12,865	ISGS-4426
Busse Pit Section	33	SOM	1.40–1.50	−17.5	9510 ± 70	11,205–10,426	10,838	ISGS-4671
	33	SOM	2.20–2.30	−16.7	10,060 ± 70	12,100–11,217	11,602	ISGS-4670
Wild Horse Creek								
Gosselin Section	36	SOM	1.50–1.60	−18.6	9030 ± 70	10,542–9697	10,155	ISGS-4793
	36	SOM	3.50–3.60	−17.4	10,500 ± 140	12,925–11,394	12,325	ISGS-4788
	36	SOM	4.55–4.65	−17.5	10,840 ± 90	13,174–12,247	12,824	ISGS-4802
Sand Creek								
Shenkle Section	28	SOM	1.36–1.46	−19.0	9430 ± 95	11,186–10,249	10,686	A-11421
	28	SOM	2.36–2.46	−16.7	10,200 ± 100	12,623–11,248	11,898	A-11423
	28	SOM	1.98–2.08	−15.7	10,500 ± 95	12,852–11,768	12,403	A-11422
	28	SOM	3.24–3.34	−19.1	10,625 ± 75	12,871–12,124	12,683	A-11424
	28	SOM	3.64–3.74	−18.4	11,700 ± 110	14,002–13,153	13,561	A-11425

(continued on next page)

Table 1 (*continued*)

Stream/study site	Locality[a]	Material assayed	Sample depth (m)	δ^{13}C (‰)	^{14}C age (yr. B.P.)	Cal age[b] (yr. B.P.)	Median cal age (yr. B.P.)	Lab. no.
Mattox Draw								
Simshauser Section	30	SOM	1.80–1.90	−20.2	9700±70	11,592–10,587	11,106	ISGS-4643
	30	SOM	2.20–2.30	−18.6	10,130±80	12,374–11,242	11,757	ISGS-4679
	30	SOM	5.50–5.60	−16.7	11,550±100	13,813–13,063	13,400	ISGS-4673
	30	SOM	6.25–6.35	−19.8	13,380±130	16,635–15,146	15,876	ISGS-4672
Sand Creek								
Eder Ranch Section	31	SOM	2.15–2.25	−16.7	9450±70	11,173–10,300	10,702	ISGS-4385
	31	SOM	2.75–2.85	−16.7	9790±70	11,708–10,727	11,212	ISGS-4377
	31	SOM	3.10–3.20	−17.5	10,760±80	13,065–12,238	12,799	ISGS-4380
Enns Draw								
Enns Ranch Section 2	25	SOM	5.27–5.37	−15.9	9055±165	11,150–9473	10,192	A-11387
Otter Creek								
OT-Core 1	17	SOM	1.85–1.95	NR	9540±70	11,223–10,445	10,892	TX-9115
	17	SOM	2.43–2.53	NR	9700±110	11,945–10,415	11,046	TX-9114
Low Order Streams (Excluding Draws)								
Otter Creek								
OT-Core 1 (cont.)	17	SOM	2.92–3.05	NR	9980±70	12,030–11,183	11,528	TX-9116
	17	SOM	3.23–3.35	NR	11,760±90	13,974–13,268	13,612	TX-9111
Keiger Creek								
Cox Ranch Section 1	23	SOM	3.95–4.05	−15.4	10,130±90	12,558–11,213	11,770	A-11095
	23	SOM	4.55–4.65	−15.0	10,460±90	12,836–11,752	12,356	A-11094
Cox Ranch Section 2	23	SOM	2.90–3.00	−15.3	10,090±135	12,686–10,800	11,739	A-11098
Diamond Creek								
Buchman Ranch Sec.	6	SOM	3.10–3.20	−17.7	10,330±90	12,752–11,405	12,149	ISGS-5215
	6	SOM	4.40–4.50	−16.5	10,690±90	12,960–12,081	12,644	ISGS-5211
	6	SOM	5.80–5.90	−18.9	10,760±70	13,024–12,253	12,759	ISGS-5201
Day Creek								
Pike Ranch Section	22	SOM	3.95–4.05	−15.4	10,130±90	12,558–11,213	11,770	A-11095
	22	SOM	4.55–4.65	−15.0	10,460±90	12,836–11,752	12,356	A-11094
Alluvial Fans								
Unnamed Draw								
Busse Ranch Fan	45	SOM	2.55–2.65	−17.4	10,580±70	12,841–12,108	12,540	ISGS-4442
	45	SOM	2.90–3.00	−17.3	11,090±70	13,232–12,840	13,020	ISGS-4443
South Beaver Cr. Valley								
Willems Ranch Fan	46	SOM	2.84–2.94	−16.9	9290±70	10,195–11,069	10,496	ISGS-6162
	46	SOM	4.50–4.60	−16.9	10,390±70	11,764–12,759	12,275	ISGS-6164
	46	SOM	5.05–5.15	−20.1	10,750±70	12,243–12,993	12,748	ISGS-6165
Walnut River Valley								
14CO1 Fan	10	SOM	6.40–6.50	−17.8	11,050±110	13,398–12,418	13,002	TX-9119
Sand Creek Valley								
Banhntge Ranch Fan	29	SOM	2.00–2.10	−16.8	10,695±140	13,190–11,717	12,562	A-11426
Cimarron River Valley								
Adams Ranch Fan	26	SOM	2.90–3.00	−16.3	9015±100	10,643–9551	10,116	A-11388
	26	SOM	4.40–4.50	−15.5	10,215±115	12,675–11,239	11,928	A-11389
Mattox Draw Valley								
Site 14KY102 Fan	30	SOM	1.48–1.58	−17.5	9420±70	11,126–10,288	10,688	ISGS-4676
	30	SOM	3.03–3.13	−16.8	10,170±70	12,377–11,279	11,827	ISGS-4675
Keiger Creek Valley								
Cox Ranch Fan 1	23	SOM	5.00–5.10	−16.0	11,335±95	13,585–12,893	13,216	A-11091
	23	SOM	2.90–3.00	−15.3	10,095±135	12,692–10,805	11,747	A-11098
	23	SOM	3.75–3.85	−15.3	11,500±230	14,746–12,396	13,430	A-11096
Cox Ranch Fan 2	23	SOM	1.45–1.55	−19.3	8870±150	10,749–9142	9962	A-11086
	23	SOM	4.00–4.10	−20.7	9570±200	12,335–9705	10,941	A-11085
Kansas River Valley								
Ft. Riley Fan	5	SOM	2.70–2.80	−19.6	9350±70	11,082–10,236	10,579	ISGS-4335
	5	SOM	3.65–3.75	−16.4	9710±70	11,598–10,594	11,058	ISGS-4323
S. Fork Big Nemaha Valley								
Miles Ranch Fan	37	SOM	3.60–3.70	NR	10,450±120	12,860–11,406	12,292	TX-8944
Elkhorn River Valley								
Site 25DO95 Fan	39	SOM	2.70–2.80	−20.7	9780±90	11,823–10,593	11,193	ISGS-4887
	39	SOM	3.28–3.38	−19.5	9580±80	11,269–10,425	10,907	ISGS-4883
	39	SOM	6.00–6.10	−21.1	11,300±90	13,505–12,875	13,183	ISGS-4894

[a] Keyed to Fig. 2.

[b] Calibration to calendar years was performed with CALIB 5.0 (Stuiver and Reimer, 1993) using calibration dataset intcal04.14c (Reimer et al., 2004).

[c] SOM = Soil organic matter.

[d] NR = Not reported.

[e] Source: Johnson and Martin (1987).

[f] Source: Holien (1982).

[g] Source: Beeton (2007).

trending grassland associations in this region. 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. Short-grass prairie dominated by blue grama (*Bouteloua gracilis*) and buffalo grass (*Buchloë dactyloides*) extends eastward from the foot of the Rocky Mountains in Colorado into Kansas and Nebraska. Short grasses are gradually replaced by mixed-grass prairies along the eastern edge of the High Plains.

In central Kansas, a broad band of mixed prairie dominated by big bluestem (*Andropogon gerardii*), little bluestem (*Andropogon scoparius*), blue grama (*Bouteloua gracilis*), and sideoats grama (*Bouteloua curtipendula)* grades northward into the wheatgrass-bluestem-needlegrass mixed prairie of south-central Nebraska. Where the soils are sandy, the sandsage-bluestem prairies replace the mixed prairies. Sand prairies dominated by bluestem (*Andropogon* sp.), sandreed (*Calamovilfa longifolia*), and switchgrass (*Panicum virgatum*) cover the Sand Hills on the north side of the Platte River in Nebraska and the Great Bend prairie on the south side of the Arkansas River in Kansas.

Mixed-grass prairie is replaced by tall-grass prairie in eastern Kansas and Nebraska. The open tall-grass prairie is dominated by bluestem (*Andropogon* sp.), switchgrass (*Panicum virgatum*), and Indian grass (*Sorghastrum nutans*) and stretches eastward almost to the Missouri River valley. Trees become progressively more prevalent along the eastern fringe of the Central Plains, with oak (*Quercus* sp.), hickory (*Carya* sp.), elm (*Ulmus* sp.), sugar maple (*Acer saccharum*), and black walnut (*Juglans nigra*) dominating wooded areas within the ecotone separating the tall-grass prairie from the eastern deciduous forest.

Gallery forests grow in narrow bands along major streams throughout the Central Plains. These riparian woodlands are dominated by hackberry (*Celtis occidentalis*), cottonwood (*Populus deltoides*), willow (*Salix* sp,), and American elm (*Ulmus americana*).

3. Methods

The field investigation consisted of mapping geomorphic surfaces and landforms and describing and sampling sections of late-Quaternary alluvial fills along the steep bio-climatic gradient extending from the moist-subhumid forest-prairie border of the east-central Plains to the dry-subhumid and semi-arid shortgrass prairie of the west-central Plains. Most of the exposures were natural cutbanks along streams, but a few gravel pits were examined, and a Giddings hydraulic soil probe was used to collect cores at two localities. All sections and cores were described using standard geologic terminology (American Geological Institute, 1982) and soil-stratigraphic nomenclature (Soil Survey Staff, 1993; Birkeland, 1999). After soils were identified and described, they were numbered consecutively, beginning with 1, the modern surface soil, at the top of the profile.

The numerical ages of buried landscapes were determined by radiocarbon dating soil organic matter (SOM), and in a few instances bone and charcoal. This approach was taken because wood and charcoal, preferred material for radiocarbon dating, are scarce in the Central Plains. Although radiocarbon dating of soil carbon can be problematic (Martin and Johnson, 1995; Birkeland, 1999; Holliday, 2004, pp. 178–183), with proper care in sampling and interpretation, SOM can provide accurate age control, especially in drier environments (Holliday et al., 2006). Reliable dating of SOM has been demonstrated in many studies (e.g., May and Holen, 1985, 1993; Haas et al., 1986; Holliday et al., 1994, 1996; Mandel, 1994; Rawling et al., 2003; Mayer and Mahan, 2004). In this study, large (5 to 10 kg) samples were collected from buried soils. The samples were assayed at the University of Texas Radiocarbon Laboratory, the Illinois Geological Survey Isotope Geochemistry Laboratory, and the University of Arizona Isotope Geochemistry Laboratory. The samples underwent standard pretreatment to remove rootlets and calcium carbonate. Radiocarbon ages were determined for the total decalcified soil carbon using the liquid scintillation method, and bone collagen and small charcoal samples were dated by accelerator mass spectrometry (AMS). Radiocarbon ages were corrected for isotopic fractionation and are presented in uncalibrated radiocarbon years before present (^{14}C yr B.P.) in the text, and in uncalibrated and calibrated years (cal yr B.P.) in Table 1.

Fifty-eight soil samples, all from the Willems Ranch alluvial fan, were submitted to the University of Kansas W. M. Keck Paleoenvironmental and Environmental Stable Isotope Laboratory for δ^{13}C analysis of SOM. Soil samples were combusted using a Costech ECS 1040 elemental analyzer. With helium acting as a carrier gas, SOM was converted to CO and CO^2 at temperatures reaching 1800 °C, with excess CO being catalyzed to quantitative CO^2 using a cupric oxide reactor. Excess oxygen used during the combustion phase was consumed through a second reactor comprised of elemental copper. The sample CO^2 was then passed on via the helium stream directly to a Finnigan MAT 253 isotope ratio mass spectrometer for raw δ^{13}C analysis. Final corrected δ^{13}C data were reported versus the VPDB scale by generating a calibration curve from the measurement of primary standards of IAEA-600 (sucrose), USGS-24 (graphite) and ANU (sucrose) from the National Institute of Standards (NIST), and a dogfish muscle from the National Research Council of Canada. A soil standard from NIST (SRM 2711 Montana Soil) and a yeast standard were analyzed as part of quality control measures. Typical R^2 generated by calibration curves are 0.9997 or better.

4. Results

4.1. High-order streams

Terrace fills in the valleys of high-order streams were studied in two major drainage systems: the Kansas and Arkansas River basins. Study sites in the Kansas River basin include localities along the North Fork Solomon, Saline, Smoky Hill, and Little Blue rivers and lower Mill Creek (Fig. 2). The Cimarron, Pawnee, Ninnescah, Chikaskia, Walnut and Neosho rivers, as well as lower Hackberry, Crooked, Day and Bluff creeks, were studied in the Arkansas River basin.

4.1.1. Kansas River basin

The Kansas River basin has a drainage area of 155,000 km^2 that includes the northern half of Kansas and portions of southwestern Nebraska and northeastern Colorado. Unlike the Arkansas River, the headwaters of the Kansas River are confined to the High Plains; they do not extend into the Rocky Mountains.

In the short-grass prairie on the High Plains, two study sites are cutbanks exposing terrace fills of high-order tributaries to Kansas River: the Hendrick section on the North Fork Solomon River, and the Delaney section on the Saline River. At Hendrick (Locality 32, Fig. 2), the top of a prominent, dark gray paleosol (Soil 3) with Ak-Bkss-Bk-BCk horizonation lies 3 m below the surface of the lowest terrace (T-1) of the North Fork Solomon River (Fig. 3). The Akb2 horizon of Soil 3 is 1 m thick and has weak stage I carbonate morphology. This over-thickened, organic-rich (Munsell matrix color 10YR 3/1, moist) horizon is typical of a cumulic soil formed on a floodplain. With cumulic soils, pedogenesis and sedimentation occur simultaneously because the rate of sedimentation is very slow (Birkeland, 1999). In other words, soil development keeps up with sedimentation.

SOM from the upper 10 cm of the Akb2 horizon and lower 10 cm of the Bkssb2 horizon of Soil 3 at Hendrick yielded radiocarbon ages of 10,060 ± 70 and 11,350 ± 70 yr B.P., respectively (Fig. 3). SOM immediately above Soil 3 yielded a radiocarbon age of 6720 ± 80 yr B.P. Based on these ages, Soil 3 represents the surface of a buried Early through Middle Paleoindian landscape.

At the Delaney section on the Saline River (Locality 16, Fig. 2), a thick, prominent dark-gray paleosol also occurs (Soil 5) in the T-1 terrace fill. The top of Soil 5 is nearly 4 m below the T-1 surface (Fig. 3). This paleosol has a well-expressed Ak-ABk-Btk-BC profile. The Akb4 horizon is 1.1 m thick and capped by silty alluvium that accumulated on the floodplain (now a terrace) during the early, middle, and late Holocene.

SOM from the upper and lower 10 cm of the Akb4 horizon of Soil 5 at Delaney yielded radiocarbon ages of 10,330 ± 70 and 12,270 ± 70 yr B.P., respectively (Fig. 3). Hence, Soil 5 represents the surface of an Early Paleoindian-age landscape that was buried by fine-grained floodplain sediments soon after ca. 10,300 ^{14}C yr B.P.

The Solomon and Saline rivers flow east out of the short-grass prairie of the High Plains and cross the mixed-grass prairie of the Smoky Hills

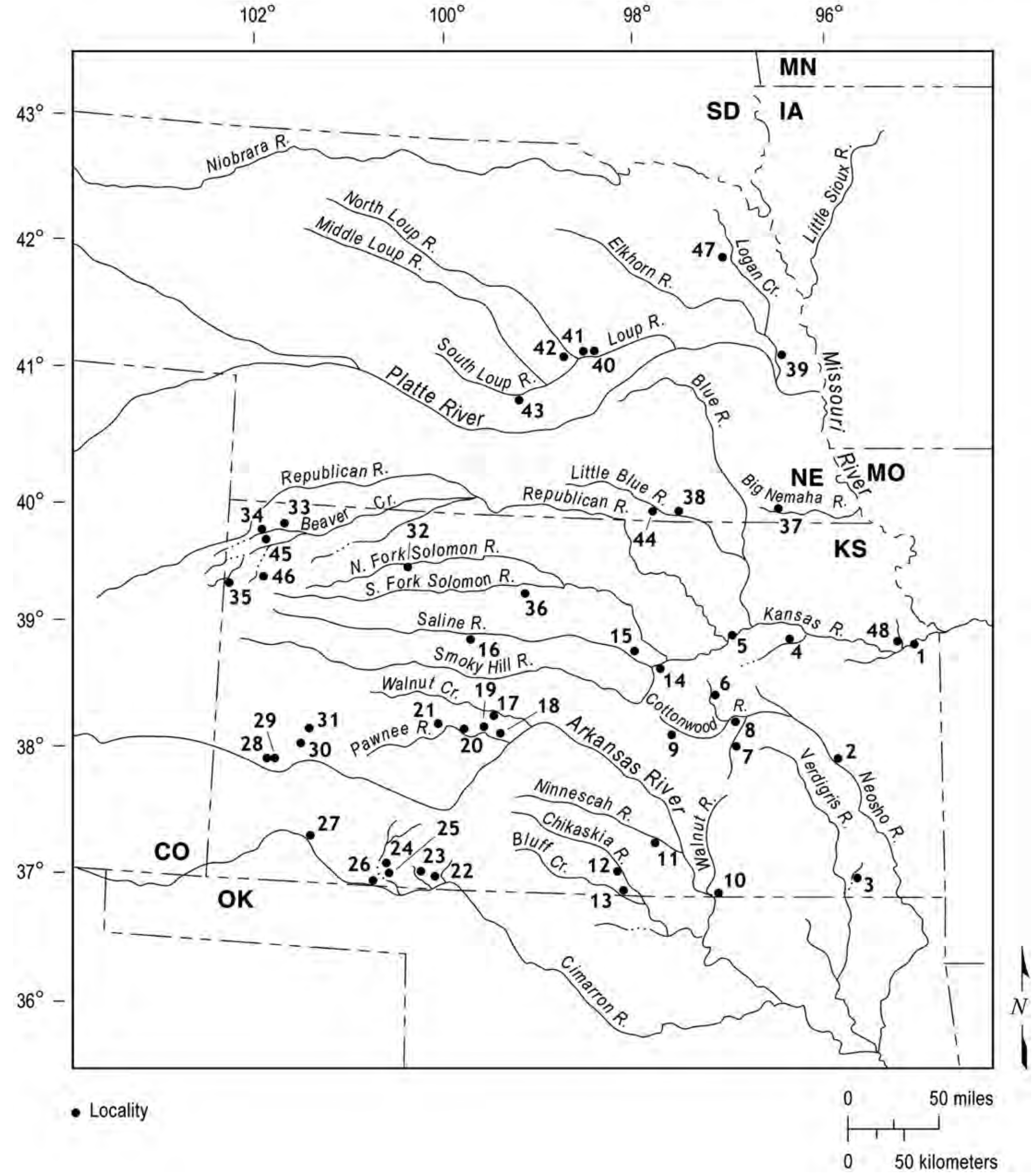

Fig. 2. Map of the Central Plains with locations of sites discussed in the text. Each locality is identified by name in Table 1.

physiographic subprovince before joining the Smoky Hill River in the Flint Hills. One high-order stream locality, the Daugherty section, was investigated in the Smoky Hills of the Kansas River basin (Locality 15, Fig. 2). At Daugherty, a cutbank exposes an 8.5 m-thick package of fine-grained alluvium beneath a broad, low terrace (T-1) spanning most of the valley floor. This section has six buried soils, and the four deepest soils (soils 4-7) form a set of welded, dark gray, cumulic soils, or a pedocomplex (cf. Catt, 1990), at a depth of 3.9–6.9 m (Fig. 3).

SOM from the upper 10 cm of soils 3, 4, and 7 at the Daugherty section yielded radiocarbon ages of 8220±70, 9910±70, and 10,660±100 yr B.P., respectively. Hence, soils 5, 6, and 7 probably represent only a few hundred years of floodplain stability between ca. 10,600 and 9900 ^{14}C yr B.P. An episode of rapid sedimentation some time between ca. 9900 and 8200 ^{14}C yr B.P. buried Soil 4. The early Holocene floodplain was stable again by ca. 8200 ^{14}C yr B.P. (Soil 3). Based on the soil stratigraphy and radiocarbon chronology at Daugherty, stratified Early through Late Paleoindian cultural deposits may be associated with the deeply buried pedocomplex in the T-1 fill of the lower Saline River.

The Saline River joins the Smoky Hill River in the Flint Hills physiographic subprovince of the Great Plains. The Smoky Hill River is among the largest streams in Kansas and flows east through the tall-grass prairie of the Flint Hills. Two high-order stream localities, the Clemance section and the Claussen site, were investigated in the Flint Hills of the Kansas River basin.

The Clemance section (Locality 14, Fig. 2) is a cutbank exposing a 6 m-thick package of fine-grained alluvium beneath the T-1 terrace of the Smoky Hill River (Fig. 4A). In the lower 3 m of the section are three buried soils (soils 2, 3, and 4), all with cumulic properties (Fig. 3). Soil 2 at a depth of 2.70–3.75 is an overthickened A horizon. It is welded to Soil 3, a dark grayish brown paleosol with Ak-Bk-BCk-Cssk horizonation. Soil 4 at a depth of 520–600+ cm has A-Bk horizonation. The Bk horizons in soils 3 and 4 are weakly developed and have only stage I carbonate morphology. Hence, the cumulative process that produced these soils probably was interrupted by short episodes (a few hundred years) of non-deposition. This interpretation is supported by the radiocarbon chronology.

SOM from the upper 10 cm of soils 2, 3, and 4 at the Clemance section yielded radiocarbon ages of 10,010±120, 10,330±95, and

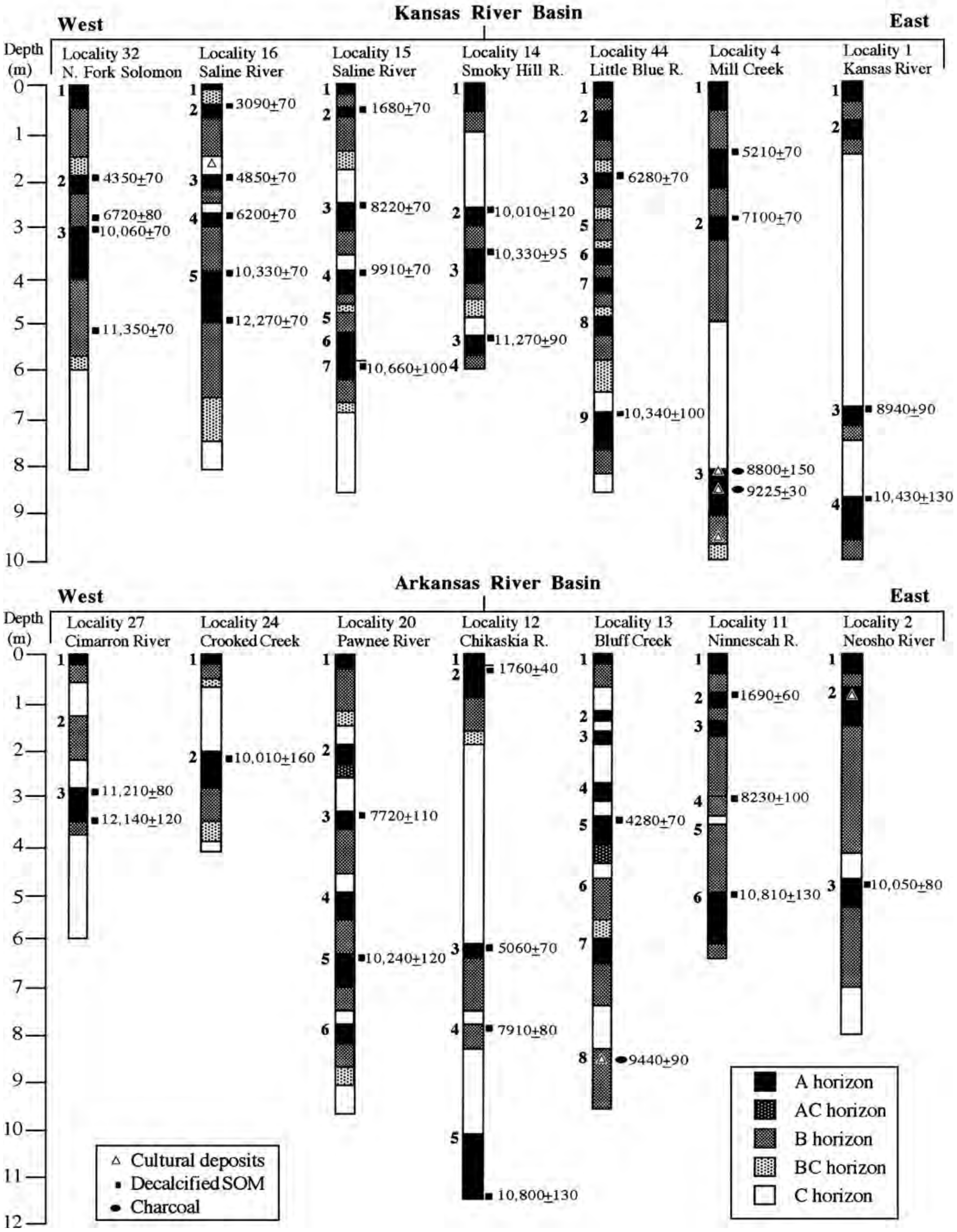

Fig. 3. Examples of soil-stratigraphic sequences in the valleys of high-order streams in the Kansas and Arkansas river basins. Soil numbers are on the left side of the columns. Radiocarbon ages are in uncalibrated years B.P.

11,270±90 yr B.P., respectively (Figs. 3 and 4A). These ages show that on and within Soil 4, Early Paleoindian cultural deposits are possible, and stratified Early through Middle Paleoindian materials may be associated with Soil 3. Soil 2 may harbor stratified Middle through Late Paleoindian cultural deposits. The sequence of buried Paleoindian-age landscapes is mantled by late Holocene alluvium containing Ceramic-period artifacts.

The Claussen site (14WB322) is in the valley of lower Mill Creek (Locality 4, Fig. 2), a major tributary of the Kansas River in northeastern Kansas (Fig. 2). A 10 m-high section of valley fill is exposed in a cutbank at Claussen. Soil 4, which is the deepest of three buried soils in the section, is 8 m below the T-2 terrace of Mill Creek (Fig. 3). This paleosol has a 90 cm-thick cumulic Ak horizon above a Btk horizon.

The archaeological record and radiocarbon chronology indicate that Late Paleoindian people repeatedly occupied the early Holocene floodplain represented by Soil 4 at Claussen (Mandel et al., 2006). Charcoal from a cultural horizon 30–40 cm below the top of Soil 4 yielded an AMS radiocarbon age of 9225±30 yr B.P., and charcoal from a cultural feature in the upper 10 cm of Soil 4 was dated at 8800±150 ^{14}C yr B.P. (Fig. 3). A Dalton projectile point was found in a small mass of soil that fell out of the Akb3 horizon and came to rest at the bottom of the section. Also, a cultural horizon occurs in the lower 10 cm of the Btkb3 horizon, or about 1.9 m below the top of Soil 4, but it is undated and has not yielded culturally diagnostic artifacts. Slow aggradation accompanied by pedogenesis formed the stratified record of human occupation within Soil 4. Rapid aggradation was underway soon after

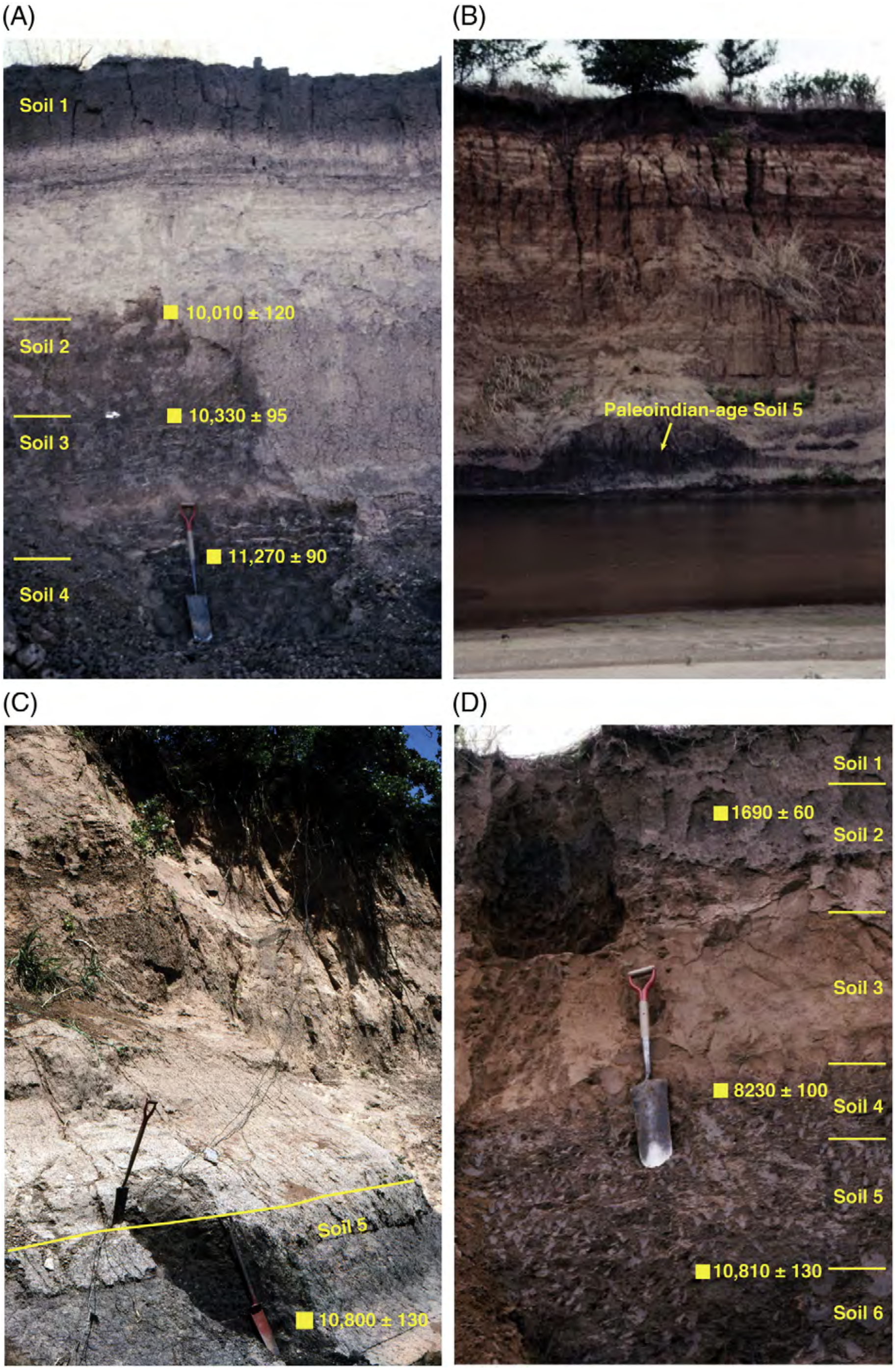

Fig. 4. At the Clemance Section (Locality14) in the Smoky Hill River valley, three buried soils (soils 2, 3 and 4) characterized by thick, cumulic, organic-rich horizons encompass most if not all of the Early through Middle Paleoindian period (ca. 11,500–10,000 ^{14}C yr B.P.), as shown above in (A). Paleoindian-age alluvial paleosols often are at great depths in terrace fills of high-order streams, such as the Chikaskia River, as shown above in (B). These paleosols, like Soil 5 at the bottom of Claypool Section 1 in the Chikaskia River valley, often have black, overthickened A horizons, as shown above in (C). At many localities, such as KTA Section 1 in the Ninnescah River valley, buried Paleoindian-age paleosols are associated with pedocomplexes formed in fine-grained alluvium, as shown above in (D).

ca. 8800 ^{14}C yr B.P. as indicated by a radiocarbon age determined on charcoal from a cultural feature immediately above Soil 4 at the nearby Imthurn site (Mandel et al., 2006). Flood deposits buried the early Holocene landscape, and Late Paleoindian and potentially older cultural components were sealed beneath an 8 m-thick package of early through middle Holocene alluvium at Claussen.

A cutbank exposure at site 25TY30, located on the Little Blue River in the tall-grass prairie of southeastern Nebraska (Locality 38, Fig. 2), is very similar to the section at the Claussen site. At 25TY30, the T-2 terrace comprises most of the valley floor; the T-1 terrace and modern floodplain (T-0) are narrow geomorphic surfaces. Two buried soils were observed in the upper 5 m of the T-2 fill, and the deepest, Soil 3 at 4.10–4.68 m, has a thick, cumulic A horizon above a moderately developed Bw horizon. SOM from the upper 10 cm of Soil 3 yielded a radiocarbon age of 8700±100 yr B.P. A few chert flakes were recorded at the top of Soil 3, but no temporally diagnostic artifacts were found. Based on the ^{14}C age of the SOM, Early Archaic and Late Paleoindian cultural deposits could potentially occur in the upper 10 cm of Soil 3, as well as older archaeological materials within this deeply buried soil.

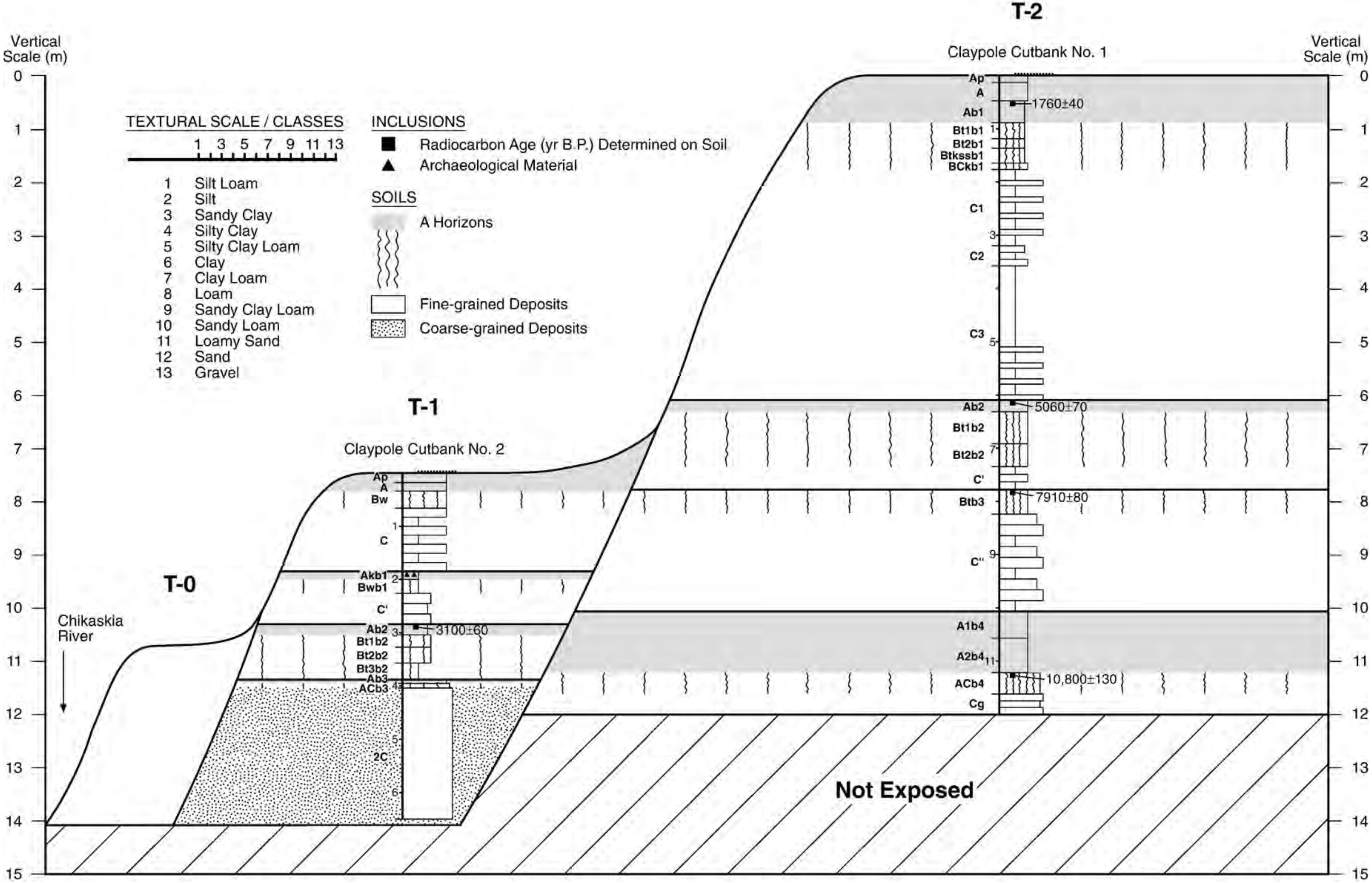

Fig. 5. Cross-section of the valley floor of the Chikaskia River in south-central Kansas.

At Locality 44 about 30 km upstream from Locality 38 (Fig. 2), eight buried soils are exposed in an 8.6 m-thick section of T-2 fill (Fig. 3). SOM from the upper 10 cm of Soil 9 near the bottom of the section yielded a radiocarbon age of 10,340 ± 100 yr B.P.

The easternmost locality in the Kansas River basin that has yielded information about buried terminal Pleistocene and early Holocene soils in terrace fills of a high-order stream is Bonner Springs on the lower Kansas River (Locality 1, Fig. 2). Holien (1982) reported an age of 10,430 ± 130 ^{14}C yr B.P. determined on SOM from the upper 10 cm of a thick, well developed paleosol 8.8 m below the surface of the Newman terrace at Bonner Springs. SOM from the upper 15 cm of a weakly developed paleosol about 2 m above the buried soil dated by Holien yielded an age of 8940±90 ^{14}C yr B.P. (Johnson and Martin, 1987). Soils representing the surfaces of Paleoindian-age landscapes are, therefore, preserved in the Kansas River valley, but they are at great depths.

The soil stratigraphic records of high-order streams in the Kansas River system are remarkably similar to the records of high-order streams in the Loup River basin of central Nebraska, an area that has been intensively studied by May (1986, 1989, 1990). May (1990) reported multiple buried paleosols dating between ca. 11,000 and 9000 ^{14}C yr B.P. in the Elba terrace fill at Cooper's Canyon on the North Loup River (Locality 42, Fig. 2). SOM from buried paleosols developed in Elba terrace fill at the Tibbets and Bruce sites (Localities 40 and 41, Fig. 2) in the Loup River valley yielded radiocarbon ages of ca. 9500 and 9000 ^{14}C yr B.P., respectively (May, 1990). At site 25CU62 in the South Loup River valley, collagen from bison bones 50 cm above a deeply buried alluvial paleosol yielded a radiocarbon age of ca. 9800 ^{14}C yr B.P. (May, 1986).

4.1.2. Arkansas River basin

The Arkansas River drains about 80,585 km^2 north of the Kansas–Oklahoma border and is the largest drainage system in the Central Plains. It originates in the Rocky Mountains and flows east-southeast across the Great Plains before entering the Central Lowlands in northeastern Oklahoma. Because its headwaters are in the Rocky Mountains, the Arkansas River was influenced by alpine hydrogeomorphic controls, including glacial meltwater, during the late Quaternary.

Terrace fills of two high-order streams, the Cimarron River and lower Crooked Creek, were studied in the High Plains portion of the Arkansas River basin. At Locality 27 in the short-grass prairie of southwestern Kansas (Fig. 2), a 6 m-thick section of valley fill underlying the lowest terrace (T-1) of the Cimarron River was studied. A prominent, organic-rich paleosol (Soil 3) with an overthickened Ak horizon and a moderately developed Bk horizon lies 2.78–3.61 m below the T-1 surface (Fig. 3). SOM from the upper 10 cm of the Ak1 and Ak2 horizons of Soil 3 yielded radiocarbon ages of 11,210 ± 80 and 12,140 ± 120 yr B.P., respectively (Mandel and Olson, 1993). Hence, Soil 3 represents a deeply buried Clovis-age geomorphic surface.

About 70 km east of Locality 27 is the Enns Ranch section on lower Crooked Creek (Locality 24, Fig. 2), a tributary of the Cimarron River. Crooked Creek, a 5th-order stream at this study site, flows through the mixed-grass prairie of the High Plains. The valley floor consists of a narrow modern floodplain (T-0) and a broad, low terrace (T-1). A thick, dark-gray cumulic paleosol (Soil 2) with A-Bk-BCk horizonation is 2.00–3.85 m below the T-1 surface. SOM from the upper 10 cm of Soil 2 yielded a radiocarbon age of 10,010 ± 160 yr B.P. (Fig. 3). Based on this age, Soil 3 was a surface soil during Paleoindian time and was buried soon after ca. 10,000 ^{14}C yr B.P.

An intensive study of Holocene landscape evolution was conducted in the Pawnee River basin, the second largest tributary of the Arkansas River in southwestern Kansas (see Mandel, 1994). The headwaters of the Pawnee River are in the short-grass prairie of the High Plains, but most of the main stem of the river crosses the mixed-grass prairie of the Smoky Hills region. Four localities, three in the Pawnee River valley (Localities 18, 19, and 20, Fig. 2) and one in Hackberry Creek valley (Locality 21, Fig. 2) have deeply buried soils dating to the Paleoindian period (Table 1).

Other major tributaries of the Arkansas River that were studied include the Chikaskia, Ninnescah, and Neosho rivers. Also, Bluff Creek, a high-order tributary of the Chikaskia River, was investigated.

The Chikaskia River drains a large portion of south-central Kansas before crossing into northeastern Oklahoma where it joins the Arkansas River. The valley floor of the lower Chikaskia River consists of a narrow modern floodplain (T-0) and two terraces, designated T-1 and T-2 from lowest to highest (Fig. 5). The T-2 terrace is a broad, flat surface that dominates the valley floor. An 11 m-thick section of valley fill underlying the T-2 terrace was studied at Locality 12 in the tall-grass prairie of the Wellington Lowlands (Fig. 2). The most striking feature in the section is a black, overthickened A horizon of a paleosol (Soil 5) at a depth of 10.10–11.20 m (Figs. 4B and C). SOM from the lower 10 cm of the A2b4 horizon of Soil 5 yielded a ^{14}C age of 10,800 ± 130 yr B.P. The Paleoindian-age landscape represented by Soil 5 is mantled by fine-grained Holocene alluvium (Fig. 3).

Bluff Creek, one of the largest tributaries of the Chikaskia River, also flows through the tall-grass prairie of the Wellington Lowlands. The valley floor of lower Bluff Creek consists of a narrow modern floodplain (T-0) and a broad alluvial terrace (T-1). At site 14SR319 (Locality 13, Fig. 2), seven buried soils were identified in a 9.5 m-thick section of T-1 fill (Fig. 3). Soil 8, the deepest of the seven buried soils, is 8.28–9.45+ m below the T-1 surface and represented by a Btss horizon; the A horizon was stripped off by stream erosion prior to burial. Cultural deposits, including chert flakes and bone fragments, were recorded next to three hearth-like features in the upper 20 cm of the Btssb7 horizon of Soil 8. Charcoal from one of these features yielded a ^{14}C age of 9440±90 yr B.P. This age places the cultural deposits into the Late Paleoindian period and indicates that the early Holocene floodplain of Bluff Creek was relatively stable around 9400 ^{14}C yr B.P.

The Ninnescah River basin, adjoining the northern boundary of the Chikaskia River basin, is another major drainage system in the Central Plains-portion of the Arkansas River basin. The Ninnescah trends east-southeast across the tall-grass prairie of the Wellington Lowlands. The valley floor of the lower Ninnescah consists of two narrow geomorphic surfaces, T-0 and T-1, and a broad, flat terrace, T-2, that is 3-4 m above the T-1 surface. At KTA Section 1 (Locality 11, Fig. 2), a 6 m-thick section of T-2 fill is exposed in a cutbank. Five buried soils occur in the section (soils 2-6), and the deepest soils, 5 and 6, form a pedocomplex 3.62 to 6.00+ m below the T-2 surface (Figs. 3 and 4D). Matrix colors range from black to dark gray in this pedocomplex. SOM from the upper 10 cm of soils 4 and 6 yielded ^{14}C ages of 8230 ± 100 and 10,810 ± 130 yr B.P., respectively (Fig. 3). Although the numerical age of Soil 5 is unknown, it probably represents a Paleoindian-age geomorphic surface, as does Soil 6.

Site 14CF8 on the Neosho River (Locality 2, Fig. 2) is the easternmost locality in the Arkansas River basin that has yielded information about buried Paleoindian-age landscapes in terrace fills of a high-order stream. At this site, the Neosho River flows south through the tall-grass prairie of the Osage Cuestas. The valley floor of the Neosho is 4–5 km wide and consists a narrow modern floodplain (T-0) and a broad, flat terrace (T-1). A buried paleosol (Soil 3) 4.50–6.88 m below the T-1 surface at Locality 2 has a thick, organic-rich Btss horizon above a Bt horizon; the A horizon was stripped off by high-energy stream flow that deposited sand and gravel on the truncated Btssb2 horizon. SOM from the upper 10 cm of Soil 3 yielded a ^{14}C age of 10,050 ± 80 yr B.P.

4.2. Low-order streams

In striking contrast to the high-order streams, no traces of buried soils exist nor, for that matter, any alluvium dating to the Paleoindian period in the valleys of most small streams (<5th order) in the Central Plains (Mandel, 1995, 2006b). This alluvium may be absent because of net sediment removal in the middle and upper segments of drainage networks during the early and middle Holocene (Mandel, 1995, 2006a; Bettis and Mandel, 2002). This general pattern of sediment removal in low-order streams, however, has one exception. Thick deposits of alluvium with multiple buried soils dating to the Pleistocene–Holocene transition are stored in the valleys of low-order intermittent streams, or draws (Fig. 6A), in areas of the High Plains with a thick loess mantle (Mandel et al., 2004; Mandel and Hofman, 2006). The loess is a major source of silty alluvium, accounting for the large volume of sediment in the draws.

The draws lie high in the drainage networks, and the Holocene and late-Pleistocene alluvial fills stored in the draws are inset into late Pleistocene loess and older Neogene deposits. In most draws, the valley floor consists of a narrow modern floodplain (T-0) and two

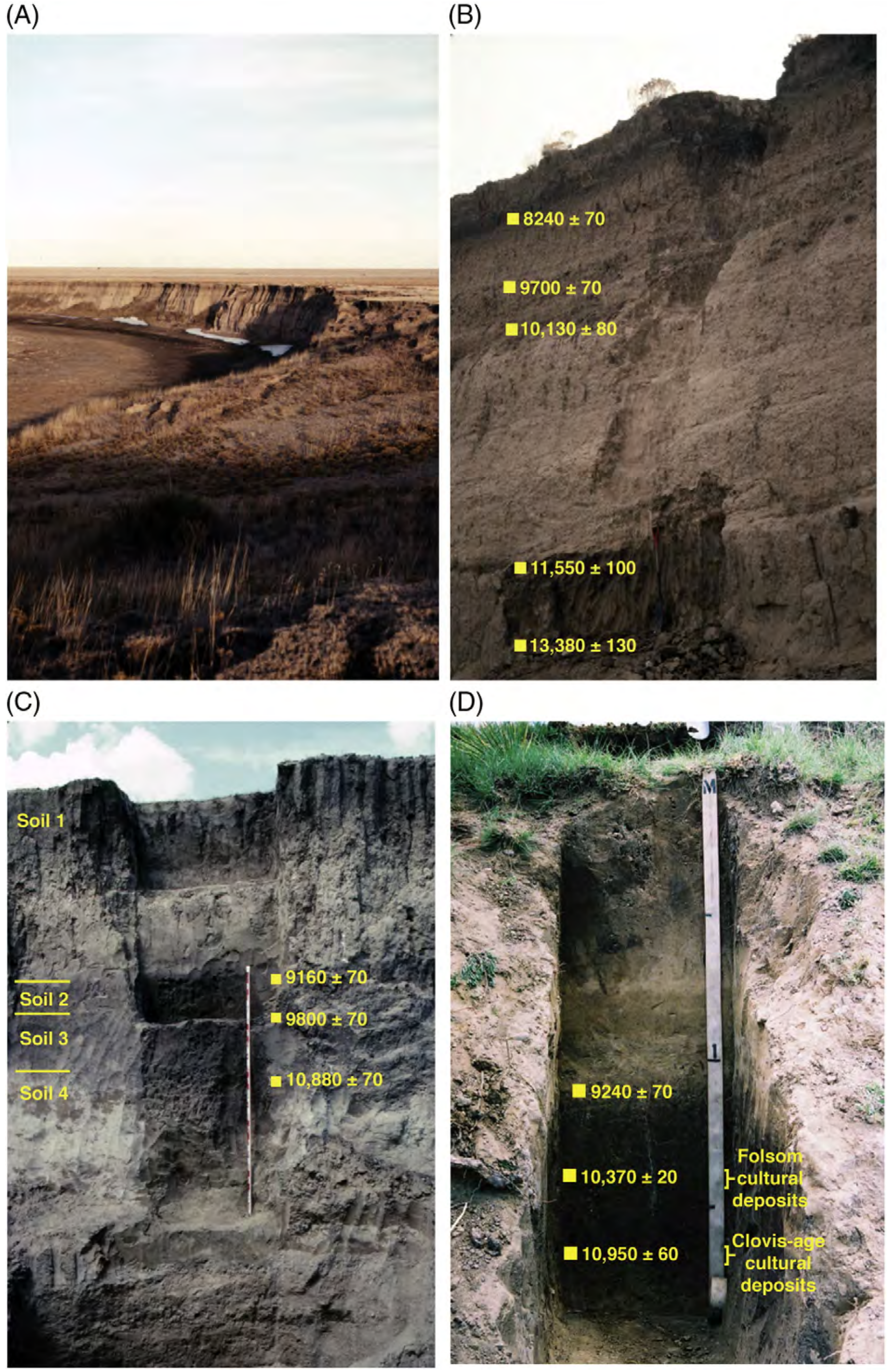

Fig. 6. Large volumes of terminal Pleistocene and early Holocene alluvium are stored in dry valleys, or draws, on the High Plains of western Kansas, as shown above in (A). During the Pleistocene–Holocene transition, alluviation in these intermittent streams was punctuated by soil development, a pattern observed at many of the study sites, including the Simshauser Section (Locality 30) in Mattox Draw, as shown above in (B). Also, pedocomplexes comprised of buried Paleoindian-age soils are common in draws. A good example is the Powell Section (Locality 34) in Little Beaver Creek, as shown above in (C). However, a single buried paleosol with a cumulative profile, such as the one containing stratified Clovis-age and Folsom cultural deposits at Kanorado (Locality 35) may encompass most of the Paleoindian period, as shown above in (D).

terraces, designated T-1 and T-2 from lowest to highest (Fig. 7). Late Holocene alluvium beneath the T-1 terrace is laterally inset against a thick package of terminal Pleistocene and early Holocene alluvium comprising the T-2 fill. The T-2 surface dominates the valley floor, and the underlying alluvium is inset against the Ogallala Formation, which is the local "bedrock" of the High Plains.

Waves of entrenchment post-dating the Pleistocene–Holocene transition did not extend into the draws until the late Holocene, generally after ca. 3000 B.P. Consequently, insufficient time was available for complete removal of the vast quantity of terminal Pleistocene and early Holocene alluvium stored in the draws.

The soil-stratigraphic record preserved in the draws indicates gradual aggradation punctuated by episodes of landscape stability and soil development beginning as early ca. 13,300 ^{14}C yr B.P. and continuing into the early Holocene (Figs. 6B and C). However, most of the radiocarbon ages determined on SOM and other materials from buried soils in the draws range between ca. 11,000 and 9000 yr B.P. (Fig. 8 and Table 1). A good example is the Kanorado locality, a cluster of three archaeological sites (14SN101, 14SN105, and 14SH106) in upper Middle Beaver Creek valley on the High Plains of northwestern Kansas (Locality 35, Fig. 2).

At Kanorado, a prominent buried paleosol (Soil 3) with a thick, organic-rich Ak horizon and a moderately developed Bk horizon is 1.30–1.70 m below the surface of the T-1 terrace (Figs. 6D and 8). SOM from the upper 10 cm of the Ak1b2 horizon and lower 10 cm of the Ak2b2 horizon yielded radiocarbon ages of 9240±70 and 9750±70 yr B.P., respectively (Table 1). Collagen extracted from bison bones associated with a Folsom component in the lower 20–30 cm of the Ak1b2 horizon yielded AMS ^{14}C ages ranging from 10,350±20 to 10,395±45 yr B.P., and AMS radiocarbon ages determined on collagen from bones associated with a cultural component in the upper 10 cm of the Bk1b2 horizon range from 10,950±60 to11,085±20 yr B.P. (Table 1). Based on this record, gradual sedimentation accompanied by soil development occurred on the former floodplain (now the T-1 terrace) of Middle Beaver Creek from ca. 11,000 to 9200 ^{14}C yr B.P. Rapid alluviation, underway soon after ca. 9200 ^{14}C yr B.P., resulted in deep burial of the Paleoindian-age landscape.

The soil-stratigraphic records of other draws on the High Plains of western Kansas generally resemble the record at Kanorado: slow alluviation accompanied by soil development from ca. 11,000 to 9000 ^{14}C yr B.P. In many of the draws, however, this period of cumulic soil development is represented by pedocomplexes instead of a single buried paleosol (Fig. 8). Furthermore, soil development was underway as early as 11,700 ^{14}C yr B.P. on the valley floors of Sand Creek (Locality 28) and Otter Creek (Locality 17), and a pedocomplex also formed between ca. 13,500 and 11,500 ^{14}C yr B.P. on the valley floor of Mattox Draw (Locality 30) (Figs. 6B and 8). Regardless of some differences in the timing of soil development among the draws, it is apparent that these segments of drainage networks were major zones of sediment storage and cumulic soil development during the Pleistocene–Holocene transition. Buried paleosols, representing the surfaces of Paleoindian-age landscapes, are common in the draws and have yielded stratified Early Paleoindian cultural deposits (e.g., Kanorado locality).

Among the nearly 100 localities investigated in the valleys of low-order streams that are not draws, only three study sites have alluvium and cumulic soils dating to the Pleistocene–Holocene transition: localities 22, 23, and 6 (Fig. 2). Localities 22 and 23 are in the valleys of Day and Keiger creeks, respectively. These two small tributaries of the Cimarron River are in the mixed-grass prairie of the Cherokee Lowlands. In both valleys, SOM from a thick, dark-gray buried paleosol developed in fine-grained terrace fill yielded ^{14}C ages ranging between 10,000 and10,500 ^{14}C yr B.P. (Table 1).

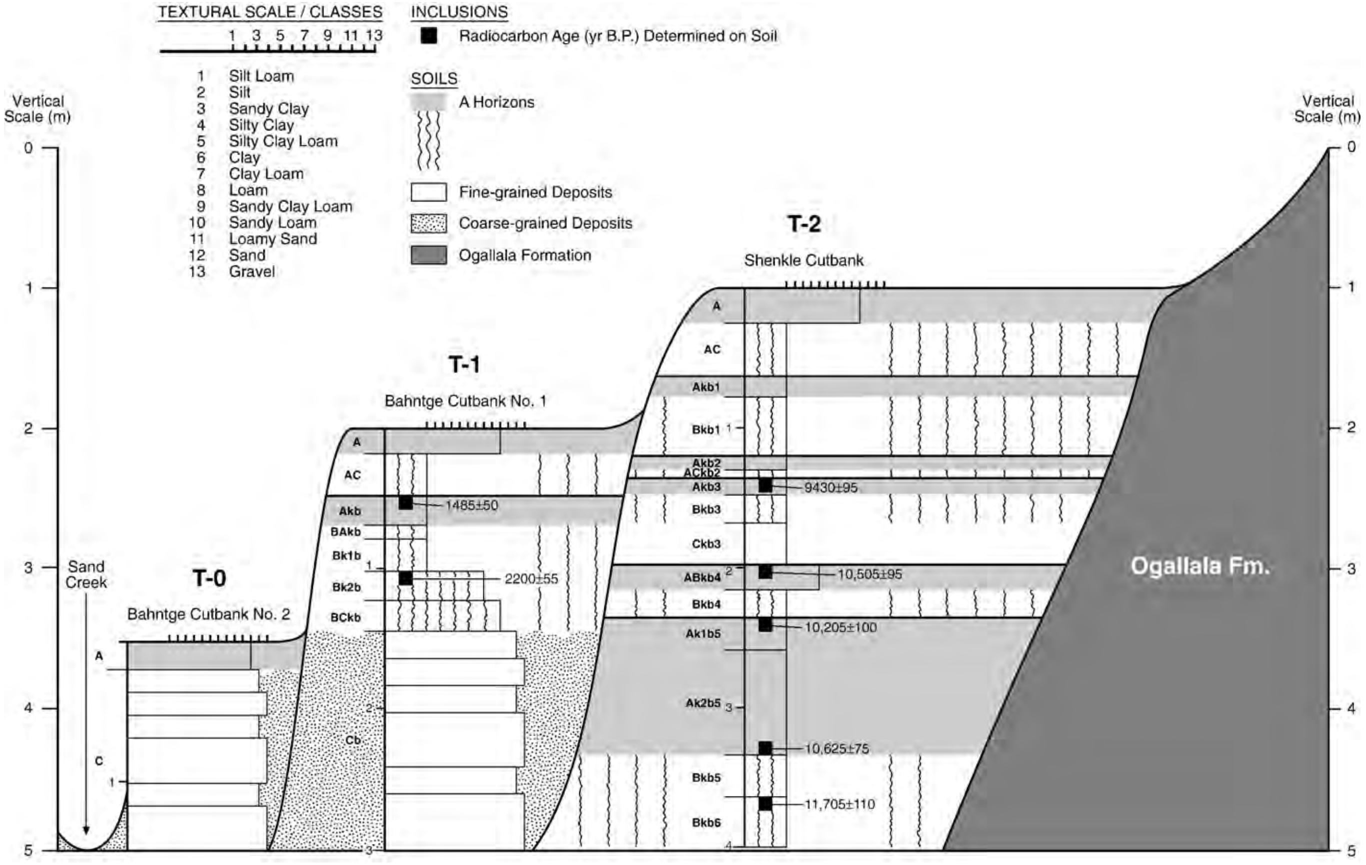

Fig. 7. Cross-section of the valley floor of Sand Creek valley, a typical draw on the High Plains of western Kansas.

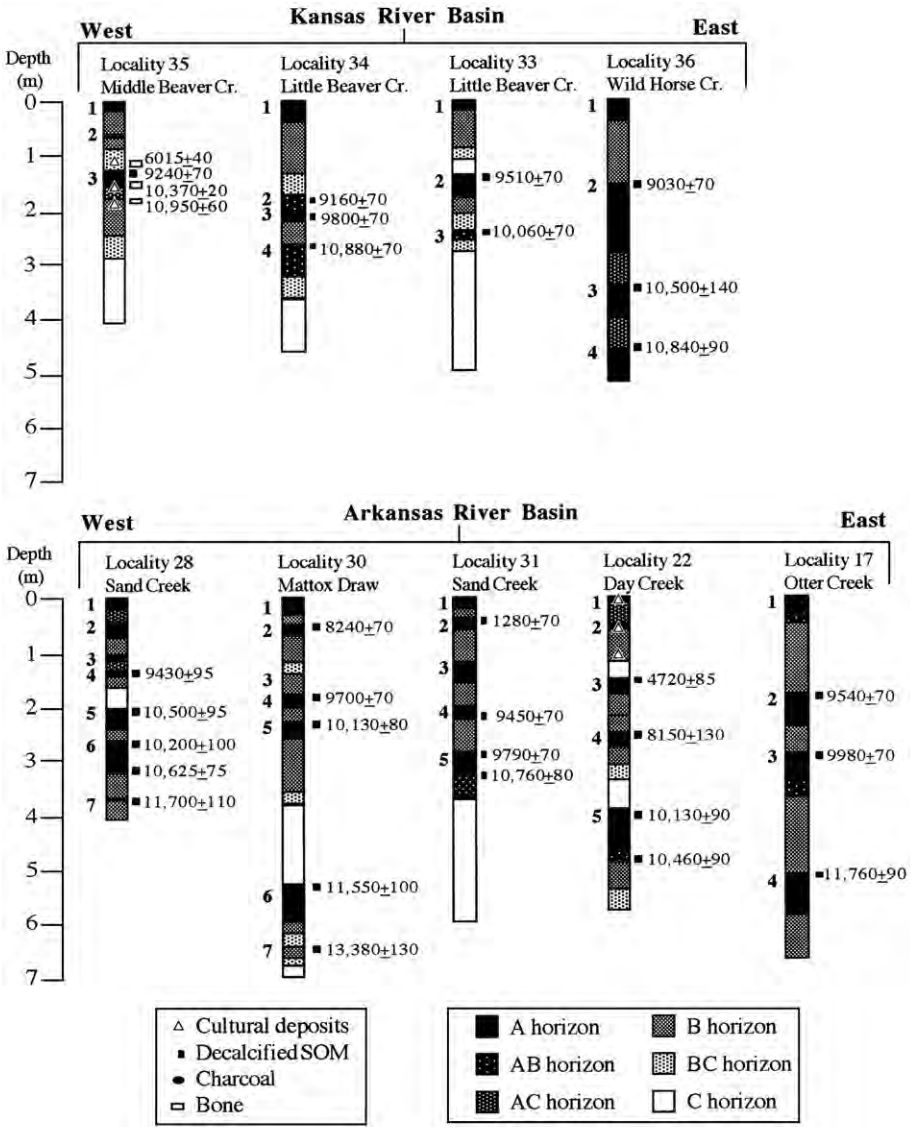

Fig. 8. Examples of soil-stratigraphic sequences in the valleys of draws in the Kansas and Arkansas river basins. Soil numbers are on the left side of the columns. Radiocarbon ages are in uncalibrated years B.P.

The Buchman Ranch Section (Locality 6) is in upper Diamond Creek, a tributary of the Cottonwood River in the tall-grass prairie of the Flint Hills. SOM from a pedocomplex of cumulic soils 3.10 to 6.00 m below the T-1 terrace yielded ^{14}C ages ranging from ca. 10,300 to 10,800 yr B.P.

4.3. Alluvial fans

Based on previous studies, ca. 9000 to 6000 ^{14}C B.P. was a major period of alluvial fan development in the Central Plains of North America (e.g., Mandel, 1995, 2006a; Bettis and Mandel, 2002). For example, in Big Hill Creek valley in southeastern Kansas (Locality 3, Fig. 2), development of the Stigenwalt alluvial fan (site14LT351) began ca. 8800 ^{14}C yr B.P. and ended soon after ca. 7400 ^{14}C yr B.P. (Mandel, 1990). At the Logan Creek site in northeastern Nebraska (Locality 46, Fig. 2), radiocarbon ages determined on charcoal from stratified cultural deposits in an alluvial fan indicate that most of the sediment composing the fan accumulated between ca. 7300 and 6000 ^{14}C yr B.P. (Mandel, 1995). Strong evidence indicates that large, low-angle fans formed in the Smoky Hill River valley of central Kansas during the Altithermal climatic episode, with most of the sediment accumulating between ca. 6000–5000 ^{14}C yr B.P (Mandel, 1992). The results of the present study, however, indicate that alluvial-fan development was underway before ca. 9000 ^{14}C yr B.P. and spanned the Pleistocene–Holocene transition at a number of localities in the Central Plains.

The nature of alluvial-fan development between ca. 11,500 and 9000 ^{14}C yr B.P. was remarkably similar to the mode of alluviation in draws and high-order stream valley during that period; sedimentation was gradual and accompanied by soil formation. At the Adams Ranch Fan in the Cimarron River valley of dry-subhumid southwestern Kansas (Locality 26, Fig. 2), slow aggradation was accompanied by three episodes of pedogenesis between ca. 13,000 to 9000 ^{14}C yr B.P. These episodes are represented by buried paleosols with thick, cumulic profiles (Figs. 9A and 10). Further west, in the semi-arid short-grass prairie of the High Plains, the Simshauser Fan (site 14KY102) (Locality 30, Fig. 2) began to form in Mattox Draw during the Pleistocene–Holocene transition. Three buried soils are exposed in the 4.5 m-thick section at Simshauser (Fig. 10), and Soil 4, the deepest paleosol, has an over-thickened, cumulic A horizon. SOM from the upper 10 cm of Soil 4 yielded a ^{14}C age of 10,170 ± 70 yr B.P., and bison bone and chipped-stone artifacts likely representing a Folsom component were recorded in the lower 10 cm of this paleosol (Mandel and Hofman, 2006). A ^{14}C age of

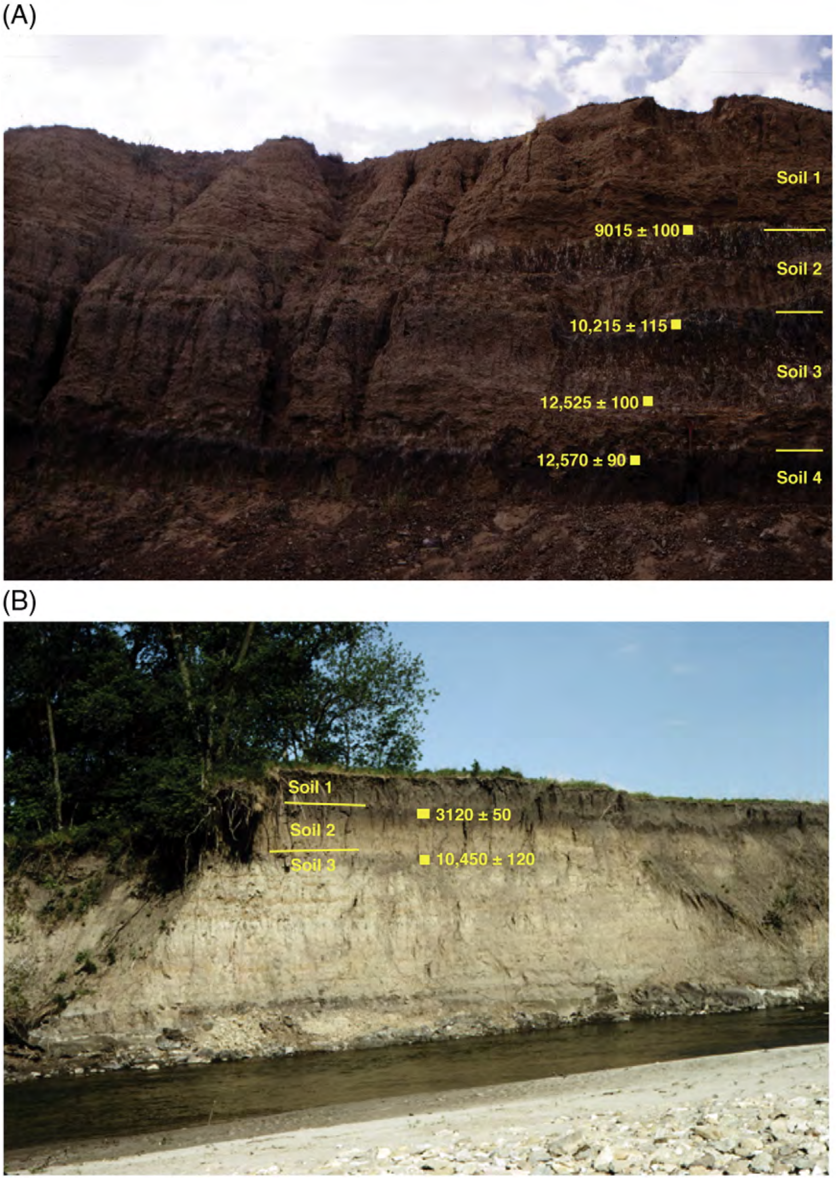

Fig. 9. Multiple buried soils encompassing the Pleistocene–Holocene transition and representing different phases of the Paleoindian period are common in alluvial fans in the short-grass prairie of western Kansas. A good example is the Adams Ranch Fan (Locality 26), as shown above in (A). In some cases, such as the Miles Ranch Fan (Locality 37) in the tall-grass prairie of southeastern Nebraska, a single buried paleosol represents the Paleoindian period, as shown above in (B).

9420±70 yr B.P. determined on SOM from the upper 10 cm of Soil 2, which also contains cultural deposits, indicates that cumulic soil development continued into the early Holocene at the Simshauser Fan.

At site 14CO1 in the southern Flint Hills of south-central Kansas (Locality 10, Fig. 2), a thick, organic-rich paleosol (Soil 2) with A-Bk-Btk horizonation was observed over 6 m below the surface of a large, low-angle alluvial fan in the Walnut River valley (Fig. 10). SOM from the upper 10 cm of the paleosol (Soil 2) yielded a ^{14}C age of 11,050±110 yr B.P., indicating the presence of a deeply buried Early-Paleoindian-age fan surface. By comparison, at site 14RY6175 (Locality 5) in the northern Flint Hills of eastern Kansas (Fig. 2), a prominent buried paleosol (Soil 2), also with A-Bk-Btk horizonation, was recorded 2.70–3.50+ m below the surface of a large alluvial fan in the Kansas River valley. SOM from the upper 10 cm of Soil 2, however, yielded a ^{14}C age of 9350±70 yr B.P. (Fig. 10). Although Soil 2 at 14RY6175 is younger than Soil 2 at 14CO1, it represents cumulic soil formation on the fan during the Paleoindian period. Furthermore, cultural deposits were recorded in Soil 2 (Mandel,1999), and subsequent archaeological excavations at 14RY6175 yielded 206 artifacts from this paleosol (Sherman and Johnson, 2006). Sherman and Johnson (2006) also reported AMS ^{14}C ages ranging from 9450±50 to 10,350±55 yr B.P. (uncalibrated), all determined on SOM from Soil 2.

Two alluvial fans were studied in the tall-grass prairie of the glaciated Central Lowlands: the Miles Ranch Fan in southeastern Nebraska (Locality 37) and the Appleby Fan in eastern Nebraska (Locality 39) (Fig. 2). The Miles Ranch Fan is at the mouth of an unnamed, intermittent stream draining into the South Fork Big Nemaha River. A 12 m-thick section of alluvium underlying the mid-section of the fan is exposed in a stream bank (Fig. 9B). Soil 3, the deepest of two buried paleosols in the section, has a thick, dark-gray A horizon and a moderately developed Bk horizon. SOM from the upper 10 cm of Soil 3 yielded a radiocarbon age of 10,450±120 yr B.P. (Fig. 9B and 10).

The Appleby Fan is in the Elkhorn River valley and also formed at the mouth of a small, unnamed, intermittent stream. A core collected from the mid-section of the fan revealed a complex sequence of buried soils (Fig. 10). Soil 6, the deepest buried paleosol, is 6 m below the surface and developed in late-Wisconsin loess. SOM from the upper 10 cm of the A

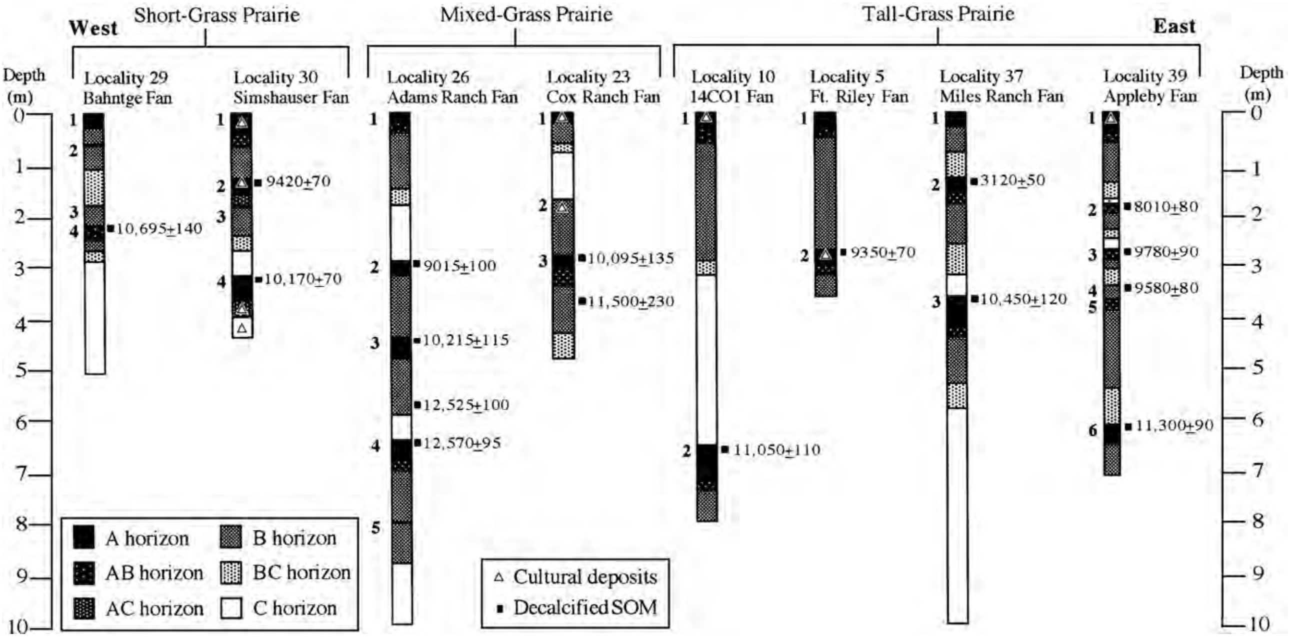

Fig. 10. Examples of soil-stratigraphic sequences in alluvial fans of the Central Plains. Soil numbers are on the left side of the columns. Radiocarbon ages are in uncalibrated years B.P.

horizon of Soil 6 yielded a ^{14}C age of 11,300±90 yr B.P. A pedocomplex consisting of soils 3, 4, and 5 formed in fan deposits above Soil 6. Radiocarbon ages determined on SOM indicate that the peodocomplex formed between ca. 11,300 and 9700 ^{14}C yr B.P. (Fig. 10), spanning much of the Paleoindian period.

5. Discussion and conclusions

The results of this study indicate that buried alluvial soils representing Paleoindian-age landscapes are ubiquitous in the Central Plains, a large region with considerable physiographic and bioclimatic diversity. These soils are common in late Wisconsin and early Holocene alluvium stored beneath terraces in valleys of high-order streams throughout the region. They also occur in alluvial fans at the mouths of intermittent streams, and beneath terraces in the valleys of draws on the loess-mantled High Plains.

Based on soil stratigraphic records and a suite of nearly 90 ^{14}C ages (Table 1), alluvial settings of the Central Plains were relatively stable during the Pleistocene–Holocene transition. No evidence exists for high-magnitude floods that would have rapidly deposited large volumes of fine-grained sediment on floodplains during this period. Instead, small quantities of alluvium were gradually deposited, allowing soil development to keep pace with alluviation. The result was "upbuilding" or cumulization of soils, a process that also occurred on alluvial fans during this period.

In the valleys of some streams, such as the Chikaskia River and Middle Beaver Creek, cumulization during the Pleistocene–Holocene transition resulted in the development of a thick, organic-rich soil representing the entire Paleoindian period. In most steam valleys, however, pedocomplexes consisting of two or more soils with over-thickened A horizons formed between ca. 11,500 and 9000 ^{14}C yr B.P. These pedocomplexes are products of fluctuating rates of alluviation. Cumulization periodically slowed or completely ceased, resulting in the formation of discernable stable surfaces within the pedocomplexes.

Although landscape stability and concomitant soil development were underway as early as ca. 13,400 ^{14}C yr B.P. in some alluvial settings, 11,000–10,000 ^{14}C yr B.P. (12,900–11,500 cal. yr B.P.) appears to encompass a major episode of quasi-stability, characterized by cumulative soil development in stream valleys throughout the region. This episode coincides with the Younger Dryas (YD) Chronozone, a period of cooler climate compared to the preceding Allerød interstadial (Broecker et al., 1989; Alley et al., 1993; Mayewski et al., 1993).

Analysis of the stable ^{13}C isotope from SOM of paleosols at the Willems Ranch alluvial fan on the High Plains of northwest Kansas (Locality 46, Fig. 2) was used to assess vegetative change during the YD and into the middle Holocene. The temporal changes in vegetation at this locality likely were in response to regional climatic change.

The Willems Ranch fan is at the mouth of an ephemeral, first-order stream that delivers sediment to the valley floor of South Beaver Creek (Fig. 11A). A prominent YD paleosol with a thick, dark gray, cumulic A horizon is developed in the lower 1.5 m of the fan (Fig. 11B). The δ^{13}C values determined on organic carbon from all but the upper 10 cm of the YD paleosol range between −22.7‰ and −19.5‰. These are the most depleted δ^{13}C values in the record at the Willems Ranch fan and suggest that a mixed C_3/C_4 plant community dominated the local ecosystem during most of the YD (Fig. 12). Also, the values suggest that the YD was the coldest climatic episode during the entire period of fan development. The δ^{13}C values become significantly heavier, however, in the upper 20 cm of the YD soil (−17.7–17.4‰), indicating an increase in the carbon contribution of C_4 plants. This shift most likely represents a trend towards warmer and probably drier conditions by ca. 10,400 ^{14}C yr B.P. The timing of the shift is based on a radiocarbon age of 10,390±70 ^{14}C yr B.P. determined on SOM from the upper 10 cm of the YD paleosol. Although δ^{13}C values fluctuate after ca. 10,400 ^{14}C yr B.P., the general trend during the early and middle Holocene is one of more C_4 plant biomass production at the Willems Ranch locality. An especially strong C_4 signal occurs throughout the upper 1 m of the fan and suggests maximum warming and aridification after ca. 6500 ^{14}C yr B.P.

The trend towards warmer and drier conditions in the latter half of the YD and continuing into the early Holocene has been detected at other localities in the Central Plains. For example, at Cheyenne Bottoms, a large depression in central Kansas, the pollen record suggests that grasslands had fully developed by 10,500 ^{14}C yr B.P. (Fredlund, 1995). At site 14RY6176, an alluvial fan in northeast Kansas (Locality 5, Fig. 2), the δ^{13}C values of soil organic carbon indicate an increase in the relative abundance of C_4 vegetation during the YD, and, presumably, increased aridity (Sherman and Johnson, 2006). Most of the evidence for YD climatic fluctuations, however, has been gleaned from speleothem,

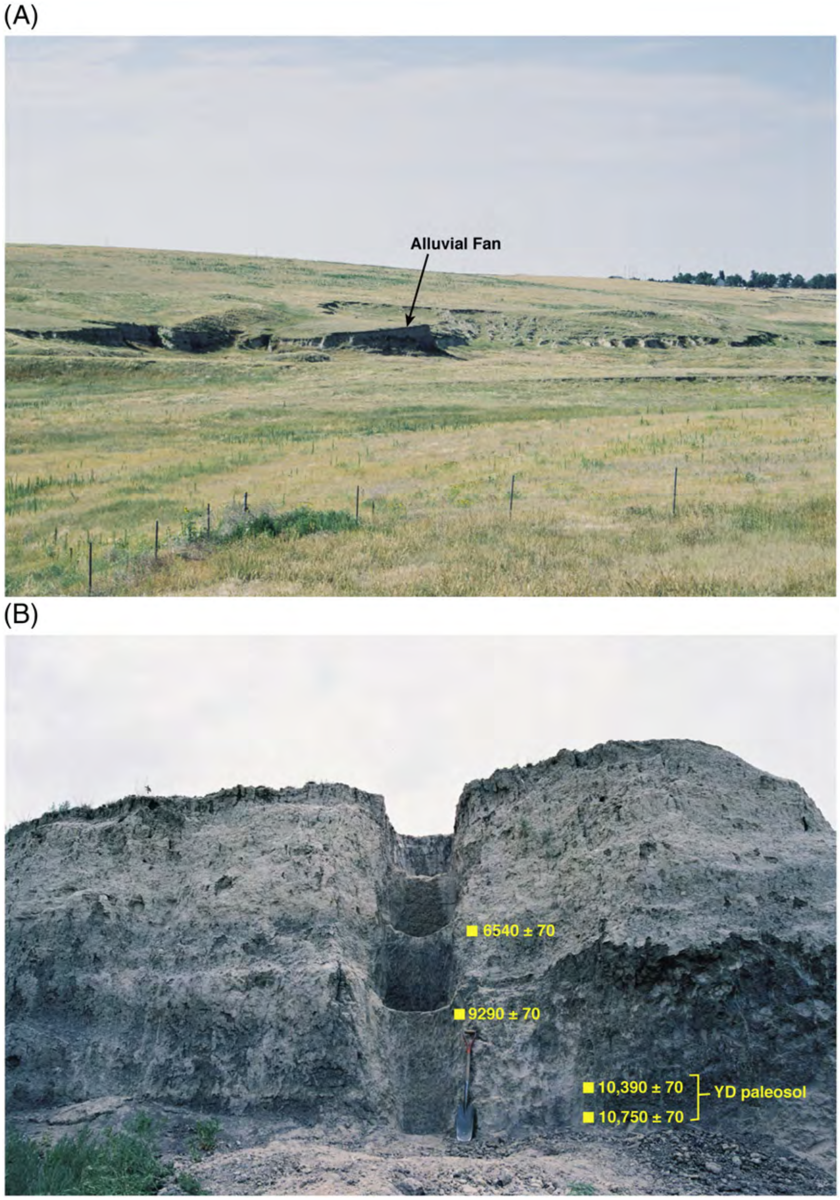

Fig. 11. The Willems Ranch alluvial fan formed at the mouth of an ephemeral, first-order stream that delivers sediment to valley floor of South Beaver Creek (Locality 46 in Fig. 2), as shown above in (A). The YD paleosol is developed in the lower 1.5 m of the fan, as shown above in (B).

pollen, and stable carbon isotope records in areas bordering the Central Plains. This evidence points to progressive aridification during the YD. For example, in the Southern High Plains, δ^{13}C values of SOM in playas and lunettes increase between ca. 11,000 and 10,000 ^{14}C yr B.P. and suggests significant expansion of C_4 vegetation in response to drier conditions (Holliday, 2000b). During this same period, widespread dune activation occurred along with a shift from flowing streams to isolated pools of standing water (Holliday, 2000b). Stable carbon isotope records from southwest Missouri also indicate expansion of C_4 grasses during the YD (Letts, 2003; Wozniak et al., 2005), a likely response to an increase in regional aridity.

A reduction in moisture, which seems to have characterized the YD in the mid-continent, cannot by itself account for the thick, organic-rich alluvial soils that formed during this period. The ubiquitous cumulative soils, representing Paleoindian-age alluvial landscapes, typically have overthickened A horizons and organic-rich B horizons that are products of either *in situ* organic-matter accumulation during periods of slow alluviation, gradual deposition of organic-rich alluvium, or a combination of both processes. Regardless of the dominant process of soil melanization, alluviation did not cease during the YD. Instead, the rate of alluviation slowed and allowed thick, organic-rich soil horizons to form. If mean annual precipitation declined but extreme rainfall events periodically occurred during the YD, cumulative soil profiles would not be present in floodplain or fan deposits dating to that period. High-magnitude floods produced by excessive rainfall favor rapid deposition instead of soil cumulization on floodplains and alluvial fans.

Perhaps strong zonal airflow at the surface restricted the northward penetration of moist Gulf air masses into the Central Plains during the Pleistocene–Holocene transition. This would have created atmospheric conditions unfavorable for the development of powerful, flood-generating mid-latitude cyclones. Weak Pacific storms depleted of Gulf moisture may have generated enough rainfall and associated runoff to promote alluviation in streams, but at a slow rate, thereby allowing cumulative soils to develop.

The early Holocene was a time of major bioclimatic change in the mid-continent (Grüger, 1973; COHMAP, 1988; Kutzbach et al., 1993; Bartlein et al., 1998; Baker et al., 2000; Johnson and Willey, 2000; Clark et al., 2001; Grimm et al., 2001; Mandel, 2006b). The northward

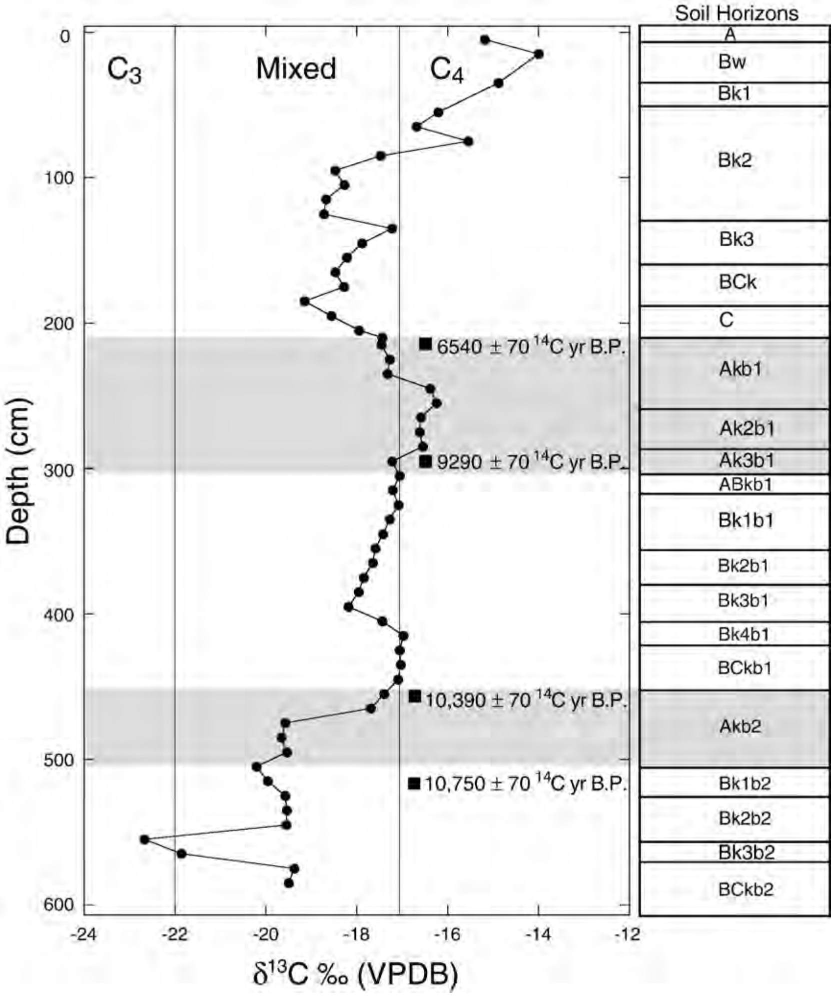

Fig. 12. δ^{13} C values verses depth and stratigraphy in the section at the Willems Ranch alluvial fan.

retreat of the Laurentide ice sheet and sharp north-south temperature gradient at its southern margin probably triggered a change from frequent widespread but gentle rainfall associated with Pacific air-mass fronts to less frequent but more intense and erosive thunderstorms in the mid-continent (Knox, 1983, p. 34). Uplands would have been prone to erosion as tall- and mixed-grass prairies in the Central Plains were replaced by sparser short-grass prairie during the Altithermal climatic episode, a period of warmer and drier conditions that prevailed from about 8000 to 5000 ^{14}C yr B.P. (Kutzbach, 1987; Mandel, 2006b). It is also likely that frequent fires during this period removed ground cover and thereby accelerated erosion on hillslopes (Mandel, 1995). The net effect of these early- through mid-Holocene climatic and vegetative changes would have been high rates of erosion and large sediment yields from uplands. Runoff transported the sediment to streams, where it was deposited on alluvial fans and floodplains, resulting in deep burial of Paleoindian-age landscapes.

As shown in this study, alluvial paleosols representing portions of Paleoindian-age landscapes often lie at depths of 3-5 m and are at greater depths in many stream valleys. From an archaeological perspective, this presents a dilemma. Although terrace fills and alluvial fans with buried Paleoindian-age soils could contain stratified cultural deposits, with limited or no exposure of the buried soils, detecting Paleoindian cultural deposits in these soils is problematic. Also, buried Paleoindian-age landscapes are not preserved throughout drainage networks. Excluding draws on the High Plains, buried soils dating to 11,500-9000 ^{14}C yr B.P. rarely occur in the valleys of small and intermediate streams (Mandel, 2006a). Entrenchment and lateral migration of stream channels during the middle Holocene removed terminal Pleistocene and early Holocene alluvium in those valleys (Mandel, 1995, 2006a). Hence, the paucity of recorded Paleoindian sites in the Central Plains may be more related to lack of visibility (i.e., they are deeply buried) and removal by channel erosion than to low human population densities in the region during the Pleistocene–Holocene transition.

The thick, dark, cumulic A horizons of alluvial paleosols representing buried Paleoindian-age landscapes are prominent stratigraphic markers that can be targeted in archaeological surveys that use deep exploration methods, such as coring, trenching, and stream-bank inspection. This soil-stratigraphic approach has great potential for shedding new light on the early archaeological record of the Central Plains.

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