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 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.

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 occupations, such as Clovis, Plainview, Lubbock Lake, Lindenmeir, Hell Gap, Scottshuff, 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

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). 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 the 1930s 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).

In the Central Plains, the Paleoindian period dates to 11,500 to 9000 $^{14}$C yr B.P. and is divided into Early Paleoindian (11,500–10,500 $^{14}$C yr B.P.), Middle Paleoindian (10,500–10,000 $^{14}$C yr B.P.), and Late Paleoindian (10,500–9000 $^{14}$C yr B.P.).

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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 14C 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 14C 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 14C 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;
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 Pleistocene sand and gravel referred to as the Arkose and/or Florissant alluvium. The Smoky Hills, located in north-central and west-central Nebraska, is a region of grass-covered sand dunes that occupies about 50,000 km²; 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 “Equis 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 northeastern 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 rainfall 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 Holland, 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; 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; 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 Hulet, 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

<table>
<thead>
<tr>
<th>Stream/study site</th>
<th>Locality</th>
<th>Material assayed</th>
<th>Sample depth (m)</th>
<th>δ¹³C (‰)</th>
<th>δ¹⁴C (yr. B.P.)</th>
<th>Cal age (yr. B.P.)</th>
<th>Median cal age (yr. B.P.)</th>
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<tr>
<td>Hendrick Section</td>
<td>32 SOM ²</td>
<td>3.00–3.10</td>
<td>–20.2</td>
<td>10,060±70</td>
<td>12,100–11,217</td>
<td>11,602</td>
<td>ISGS-4701</td>
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<td>Saline River</td>
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<td>Daugherly Section</td>
<td>15 SOM</td>
<td>3.90–4.00</td>
<td>–18.7</td>
<td>9910±70</td>
<td>11,979–10,877</td>
<td>11,343</td>
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<td>Dalaney Section</td>
<td>16 SOM</td>
<td>3.95–4.05</td>
<td>–17.8</td>
<td>10,330±70</td>
<td>12,698–11,983</td>
<td>12,695</td>
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<td>Smoky Hill River</td>
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<td>Clemence Section</td>
<td>14 SOM</td>
<td>2.70–2.80</td>
<td>–15.9</td>
<td>10,010±120</td>
<td>12,562–10,775</td>
<td>11,552</td>
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<td>Clausen Site</td>
<td>4 SOM</td>
<td>Charcoal</td>
<td>7.95–8.00</td>
<td>8800±150</td>
<td>10,606–9,126</td>
<td>9865</td>
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<td>Enns Ranch Section</td>
<td>1 SOM</td>
<td>Charcoal</td>
<td>8.35–8.40</td>
<td>9225±30</td>
<td>10,554–10,247</td>
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<td>Satanta Section</td>
<td>27 SOM</td>
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<td>8.37–8.40</td>
<td>9225±35</td>
<td>10,564–10,244</td>
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<td>Bonner Springs</td>
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<td>6.80–6.95</td>
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<td>10,810±80</td>
<td>12,385–13,099</td>
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<td>Leach Section 2</td>
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<td>2.78–2.88</td>
<td>NR</td>
<td>11,210±80</td>
<td>13,356–12,866</td>
<td>13,309</td>
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<td>Salina Section</td>
<td>27 SOM</td>
<td>Charcoal</td>
<td>8.58–8.65</td>
<td>NR</td>
<td>9440±90</td>
<td>11,180–10,266</td>
<td>10,700</td>
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<td>Cimarron River</td>
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<td>Note 1 SOM</td>
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<td>10,430±130</td>
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<td>Evidman Section</td>
<td>8 SOM</td>
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<td>6.14–6.24</td>
<td>171</td>
<td>9740±70</td>
<td>11,609–10,683</td>
<td>11,112</td>
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<td>Kassack Section</td>
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<td>7.03–7.13</td>
<td>16.7</td>
<td>10,540±90</td>
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<td><strong>Powell Site</strong></td>
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<td>1.65–1.75</td>
<td>16.1</td>
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<td>10,703–9915</td>
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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 sand sage-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 bone and charcoal. This approach was taken because wood and radiocarbon dating soil organic matter (SOM), and in a few instances soil, at the top of the profile on the Saline River. At Hendrick (Locality 32, Fig. 2), the top of a prominent, dark gray paleosol (Soil 3) with Ak-Bkssb2-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 1 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 Paleindian 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-AKb-BKt-BFC 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). This paleosol has a well-expressed Ak-AKb-BKt-BFC 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.
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 14C yr B.P. An episode of rapid sedimentation some time between ca. 9900 and 8200 14C yr B.P. buried Soil 4. The early Holocene floodplain was stable again by ca. 8200 14C 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 tallgrass 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-Csk 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. 2. Map of the Central Plains with locations of sites discussed in the text. Each locality is identified by name in Table 1.
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 14C 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
ca. 8800 14C 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 14C 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. 4. At the Clemance Section (Locality 14) 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 14C 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).
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 14C 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 14C 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 14C 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 14C 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 14C yr B.P. (May, 1986).

4.1.2. Arkansas River basin

The Arkansas River drains about 80,585 km² 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 an 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 14C 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, Ninneschau, 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 14C 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 14RS319 (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 14C 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 14C yr B.P.

The Ninneschau 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 Ninneschau trends east-southeast across the tall-grass prairie of the Wellington Lowlands. The valley floor of the lower Ninneschau 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 14C ages of 8230±100 and 10,810±130 yr B.P., respectively (Mandel and Olson, 1993). The Paleoindian-age landscape represented by Soil 5 is mantled by fine-grained Holocene alluvium, 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 of 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 14C 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).
terrace, 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 as 13,300 $^{14}$C yr B.P. and continuing into the early Holocene (Figs. 6A and 7). 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 to 11,085±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 lower-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 and 10,500 $^{14}$C yr B.P. (Table 1).
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 \(^{14}C\) yr 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 (site 14LT351) 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...
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 14C 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 14C 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 14C 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
were underway as early as ca. 13,400 14C yr B.P. in some alluvial formation of discernable stable surfaces within the pedocomplexes. Cumulization periodically slowed or completely ceased, resulting in the settings, 11,000 14C yr B.P. (Table 1), alluvial settings of the Central Plains were relatively stable mantled High Plains. These soils are common in late Wisconsin and early Holocene alluvium representing the entire Paleoindian period. In most steam valleys, thickened A horizons formed between ca. 11,500 and 9000 14C 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 14C 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 overthickened A horizons formed between ca. 11,500 and 9000 14C 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 14C yr B.P. in some alluvial settings, 11,000–10,000 14C 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) Chron-ozone, 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 13C 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 δ13C 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 δ13C values in the record at the Willems Ranch fan and suggest that a mixed C3/C4 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 δ13C 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 C4 plants. This shift most likely represents a trend towards warmer and probably drier conditions by ca. 10,400 14C yr B.P. The timing of the shift is based on a radiocarbon age of 10,390±70 14C yr B.P. determined on SOM from the upper 10 cm of the YD paleosol. Although δ13C values fluctuate after ca. 10,400 14C yr B.P., the general trend during the early and middle Holocene is one of more C4 plant biomass production at the Willems Ranch locality. An especially strong C4 signal occurs throughout the upper 1 m of the fan and suggests maximum warming and aridification after ca. 6500 14C 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 14C yr B.P. (Fredlund, 1995). At site 14RY6176, an alluvial fan in northeast Kansas (Locality 5, Fig. 2), the δ13C values of soil organic carbon indicate an increase in the relative abundance of C4 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,
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, $\delta^{13}C$ values of SOM in playas and lunettes increase between ca. 11,000 and 10,000 $^14C$ 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
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 14C 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 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 14C 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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