

ARCHAEOLOGY, LATE-QUATERNARY LANDSCAPE EVOLUTION, AND
ENVIRONMENTAL CHANGE IN THE UPPER DRIFTWOOD CREEK BASIN, BARBER
COUNTY, KANSAS

By

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Nicholas V. Kessler

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ABSTRACT

This study focused on valley fills in the upper Driftwood Creek basin, a 3rd order drainage network in south-central Kansas to determine the geologic potential for stratified cultural material and to reconstruct a record of Late-Quaternary environmental change. A suite of radiocarbon ages provide a numerical chronology for landscape evolution, and $\delta^{13}\text{C}$ values of soil carbon provide a record of paleo-environmental change. The results generally conform to existing conceptual models for landscape evolution and paleo-environmental change on the Central Plains. Late-Wisconsinan alluvium, rarely found in the valleys of small streams east of the High Plains, is found beneath T-2 terrace remnants and alluvial fans in the upper Driftwood Creek valley. Early and mid-Holocene deposits are present beneath alluvial fans high in the drainage network, and late-Holocene alluvium is stored beneath T-1 terraces. Buried soils recorded within these alluvial fills are high probability targets for locating stratified cultural material. $\delta^{13}\text{C}$ values of soil carbon indicate that the transition from a C_3 to a C_4 dominated plant community began after ca. 14,000 ^{14}C yr B.P. in the study area. The isotopically heaviest $\delta^{13}\text{C}$ values occur after ca. 6,700 ^{14}C yr B.P. in the study area, indicating a generally warm, dry middle Holocene.

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CHAPTER I

INTRODUCTION

This investigation focused on late-Quaternary landscape evolution and paleo-environments of the upper Driftwood Creek basin in south-central Kansas. The purpose of this study was to assess the geologic potential for stratified cultural material in small stream valleys in the region and to reconstruct paleoenvironmental changes that may have affected human economies and settlement. Patterns of landscape evolution are well understood for small ($<5^{\text{th}}$ order) and large ($\geq 5^{\text{th}}$ order) stream valleys in the eastern and western Great Plains. However, small stream valleys in the Plains Border Region are less well documented. Therefore, the objectives of this study were to (1) identify and describe landform sediment assemblages including buried soils in the upper Driftwood Creek basin, (2) determine the spatial and temporal pattern of erosion, sedimentation, and landscape stability in the study area to facilitate preparation of a geoarchaeological model, and (3) infer late-Quaternary environmental changes from stable carbon isotope ratios of soil organic carbon and from the soil-stratigraphic record.

The results generally conform to existing conceptual models for landscape evolution and paleo-environmental change on the Central Plains. Late-Wisconsin alluvium, rarely found in the valley fills of small streams east of the High Plains, is found in remnant T-2 terrace fills and in alluvial fans in the upper Driftwood Creek valley. Early and mid-Holocene deposits are present in alluvial fans high in the drainage network, and late-Holocene alluvium is present in the fills of T-1 terraces. $\delta^{13}\text{C}$ values of soil carbon indicate that the transition from a C_3 to a C_4 dominated plant community began after ca. 14,000 ^{14}C yr B.P. in the study area. The isotopically heaviest $\delta^{13}\text{C}$ values occur after ca. 6,700 ^{14}C yr B.P. in the study area, indicating a generally warm, dry middle Holocene.

The patterns of landscape evolution and the isotopic record of environmental change presented in this study have implications for archaeological interpretations of early and mid-Holocene cultural change in the region. While millennial-scale environmental changes may have driven gradual shifts in settlement and subsistence, spatial and temporal patterns of erosion and sedimentation also help explain the rarity of recorded Archaic-aged sites in the region.

The remainder of this thesis is organized as follows. Chapter II discusses the physiography, geology, vegetation, and climate of the study area. Chapter III summarizes previous paleoenvironmental, geomorphic, and archaeological research in the area, and Chapter IV focuses on field and laboratory methods. Chapter V details the results of this study. Chapter VI concludes by discussing the geoarchaeology and paleoenvironments of the upper Driftwood Creek basin, as well the implications for the archaeological record. Chapter VII summarizes the objectives, results, and conclusions of the study.

CHAPTER II

STUDY AREA

Geographic Setting

Driftwood Creek is a small stream in south-central Kansas and northwest Oklahoma. This study focuses on the upper portion of the drainage above Hardtner, Kansas in the Red Hills physiographic province. Upper Driftwood Creek drains roughly 55 km² above Hardtner, KS, and is a 3rd order intermittent stream. The valley is around 3 km wide near Hardtner and narrows to less than 1 km at the Blunk Ranch and Sterling Ranch study sites. The Red Hills, also called the Gyp-Hills, Cimarron Breaks, and Ogallala Breaks, are easily recognized by their rugged badlands topography (Carter 1991; Dodge 1977; Johnson and Park 1996; Mandel 2006a), and are situated in the southeastern portion of the Plains Border Region (Figure 1). The Plains Border Region extends from southern Nebraska to northwestern Oklahoma and is demarcated by the westward advancing, highly dissected, eastern margin of the High Plains (Thornbury 1965).

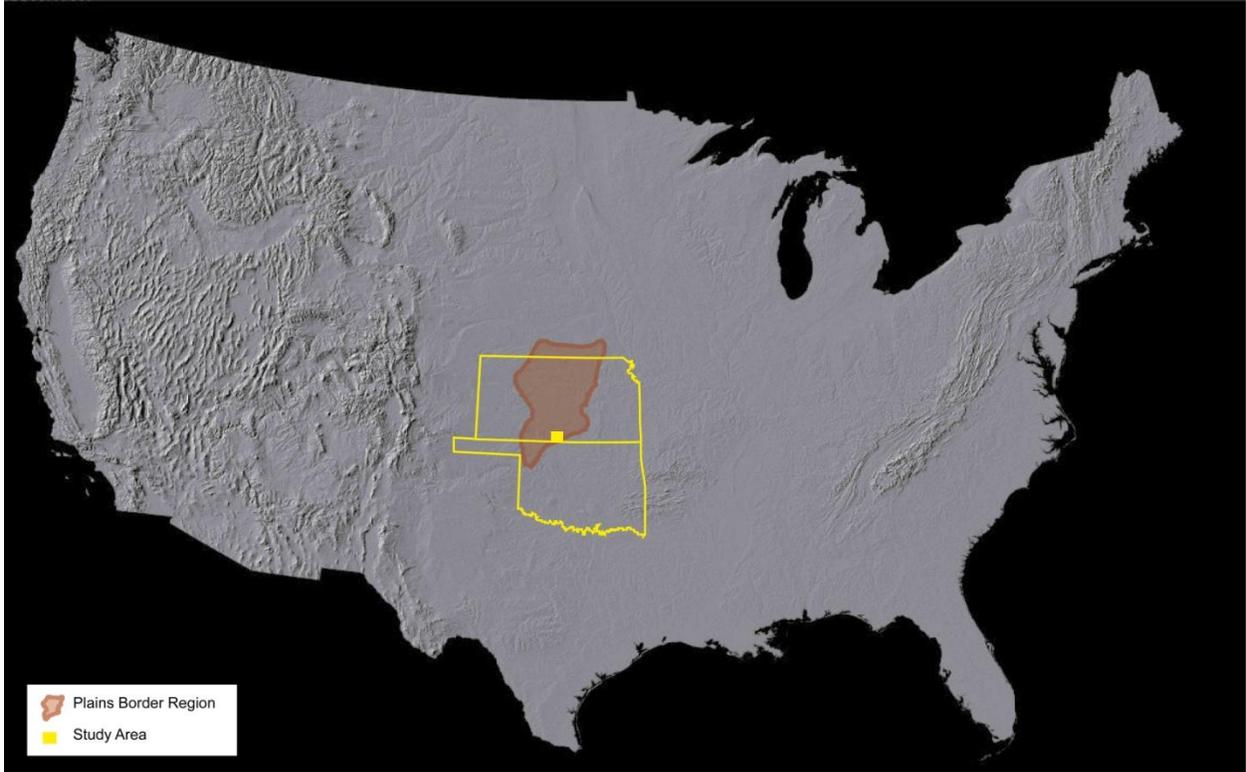


Figure 1. Location of the study area and the Plains Border Region.

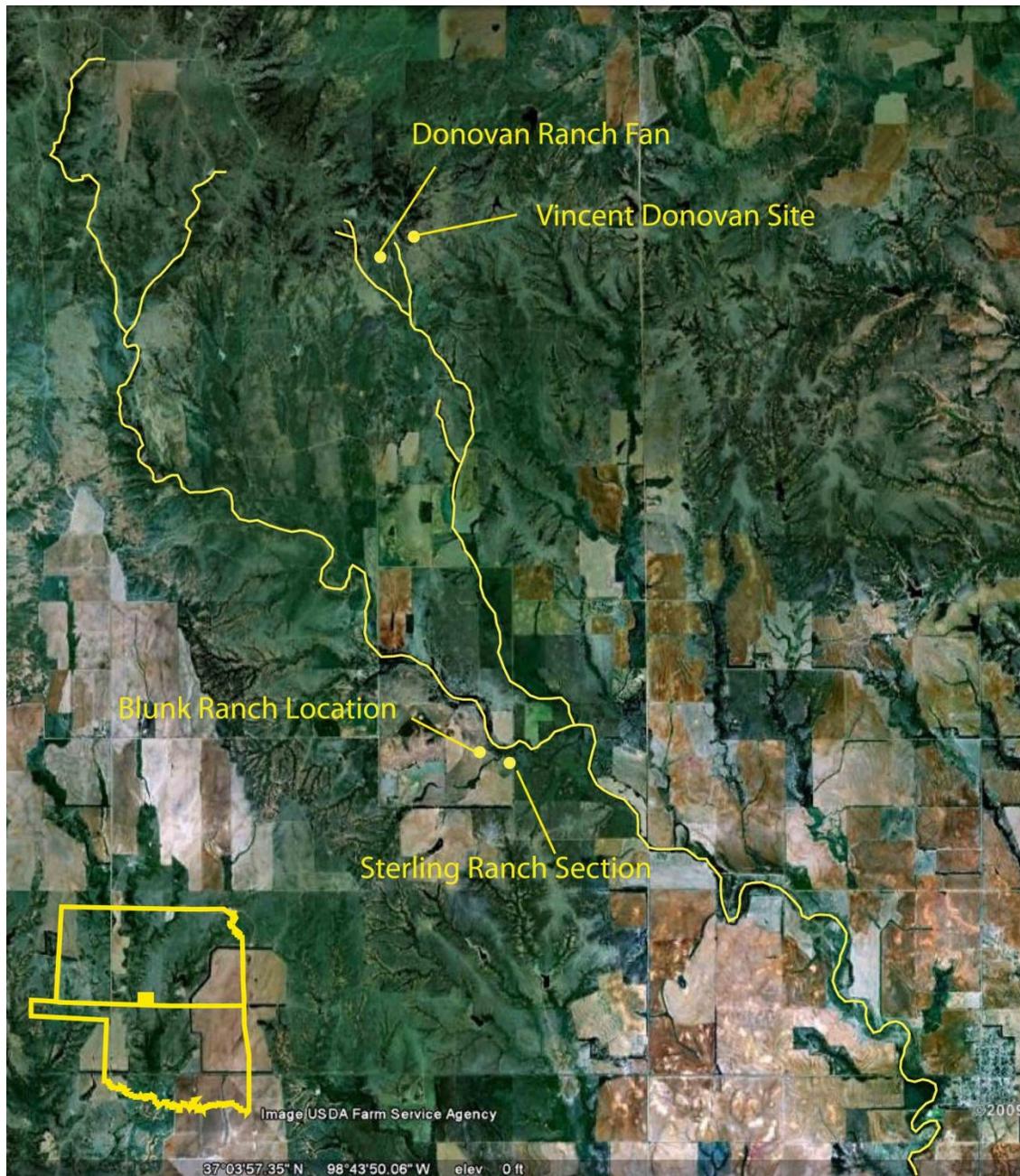


Figure 2. Location of study sites on the upper Driftwood Creek basin.

Geology and Soils

Unconsolidated sediments of the Neogene-age Ogallala Group, Meade Group, and Sanborn Group overlie Permian and Cretaceous bedrock throughout the High Plains and Plains Border in south-west and south-central Kansas as well as north-western Oklahoma (Carter 1991).

Several volcanic ash deposits, including Lava Creek B (~0.68 m.a.), Bishop (~0.76 m.a.), Tsankawi (~0.88 m.a.), Guaje (~1.46 m.a.), and Huckleberry Creek (~1.99 m.a.) have been identified in the southern Plains Border Region and constitute important time-marker beds for the early to middle Pleistocene (Ward 1991). Pleistocene alluvial deposits cap the western-most scarps forming the eastern edge of the High Plains in Comanche, Barber, and Kingman counties. Secondary scarps and buttes are capped by resistant sandstone and gypsum. Pediments flanking these scarps and buttes were produced by geomorphic processes during the late Pleistocene (Frye and Leonard 1952). The upper reaches of Driftwood Creek and its tributaries, like many streams in the region, dissect these surfaces to create draws and steep-sided arroyos.

Lithic resources used as tool-stone by Native Americans in historic and prehistoric times within the general study area include cobbles of opaline sandstone and quartzite associated with the Ogallala Formation. Upper Permian, Day Creek silicified dolomite occurs in outcrops, with recorded prehistoric quarries as close as Clark County, Kansas. In addition, outcrops of Cretaceous-age quartzites also occur immediately northwest of the Red Hills (Stein 2006).

Soils are important components in geoarchaeological research, especially in alluvial settings (Ferring 1992; Mandel and Bettis 2001; Holliday 2004). Soils can be used to reconstruct site formation processes, estimate ages of sites, and provide geomorphic and environmental context to archaeological material. Surface soils mapped by the U.S. Department of Agriculture and published in soil surveys and online provide clues about the relative age and origin of landform sediment assemblages.

Within the Southern Plains Border Region, soils have formed in alluvium, colluvium, and eolian parent materials, though soils developed in loess are not as common here as farther west on the High Plains (Carter 1991). In the immediate study area around the upper reaches of

Driftwood Creek, soils are mainly formed in old and recent alluvium, weathered sandstone, gypsum, and shale red beds (Dodge 1977). The main soil series mapped around the upper reaches of Driftwood Creek are the Albion, Shellabarger, Vernon, Kingfisher, Quinlan, Woodward, Grant, Attica, Clairemont, and Port (Dodge 1977).

Climate

The modern climate of south-central Kansas is distinctly continental with hot summers and cold winters. At Medicine Lodge, Kansas, the mean monthly temperatures range from 33.1°F in January to 81.3°F in July. Mean annual precipitation is 65.5 cm with most precipitation falling during summer months (High Plains Regional Climate Center 2006). The south-central portion of Kansas has the longest growing season in the State, but long droughts lasting several years can seriously affect vegetation.

Most regional precipitation occurs in the form of localized, intense thunderstorms during the late spring and early summer, originating as small storms on the Rocky Mountain Front Range lifted by the differential heating of the ground surface (Forman et al. 2001). As these air masses drift eastward, they encounter low level, moist, easterly air flowing off the backside of the Bermuda High, which moves air from the Gulf of Mexico into the interior of North America. The conditions necessary for heavier and more widespread precipitation during this time are enhanced by a southerly shift and intensification of the Jet Stream which encourages the flow of warm Pacific air responsible for enhancing cyclo-genesis and the relative positioning of a ridge aloft in the southwestern U.S. that helps bring Gulf moisture into the Great Plains (Forman et al. 2001).

Periods of aridity on the Great Plains and western U.S. are produced in part by cool sea surface temperatures in the Pacific that create a La Niña effect (Cook 2004; Cook et al. 2008;

Forman et al. 2001; Woodhouse 2004). La Niña conditions in the Pacific weaken the southwesterly flow of air into the interior of North America and reduce warm season precipitation on the Great Plains (Forman et al. 2001). Cool Pacific sea surface temperatures correlate with prolonged periods of severe aridity in the Great Plains and Western U.S. over the last millennium.

Vegetation

The vegetation of Barber County consists of mixed grass prairie (Küchler 1974). The south-western half of the county is bluestem-grama grassland, and the northeastern half is Cedar Hills prairie. Küchler (1974) noted that the bluestem-grama prairie boundary is very sensitive to fluctuations in precipitation and can shift east and west with alternating dry and wet periods. The dominant natural vegetation within the study area include big bluestem (*Andropogon gerardi*), little bluestem (*Andropogon scoparius*), blue grama (*Blouteloua gracilius*), and eastern red cedar (*Juniperus virginiana*) (Küchler 1974; Mandel 2006a). Sand hill plum (*Prunus americana*) and sumac (*Rhus glabra*) are common on upland prairie and pastures. Sand bar willow (*Salix exigua*), black willow (*Salix nigra*), and eastern cottonwood (*Populus deltoids*) are common riparian tree species within the study area.

CHAPTER III

PREVIOUS RESEARCH

Late-Quaternary Paleo-Environments and Landscape Evolution

Geoarchaeologists use soil stratigraphy and geomorphology to assist archaeological research in a number of ways including: 1) to strategically search for archaeological sites and predict the probability of their preservation in various landform sediment assemblages, 2) to estimate the age of archaeological sites located during survey, 3) to reconstruct site formation histories and assess the stratigraphic integrity of cultural deposits, and 4) to reconstruct the environmental context of archaeological sites (Frederick 2001; Mandel and Bettis 2001). Temporal and spatial patterns of erosion, sedimentation, and stability in fluvial systems control the distribution and visibility of the archaeological record within valley landscapes (Bettis and Benn 1984; Mandel 1995, 2006b; Ferring 1995; Bettis and Mandel 2002; Rapp and Hill 2006). Geoarchaeological research focusing on late-Quaternary landscape evolution in stream valleys provides a framework for evaluating the effects of fluvial processes on the archaeological record, predicting where cultural materials have been removed or preserved, as well as providing proxy data for late-Quaternary environmental change. In addition to landscape-scale or valley-wide studies, geoarchaeologists can place cultural deposits in geologic context at the scale of the archaeological site and provide information crucial for reconstructing site formation processes necessary for making meaningful archaeological interpretations.

Understanding the relationship between climate change, landscape evolution, and human behavior is important to archaeologists (Butzer 1982; Brown 1997; Roberts 1998; Dincauze 2000; Bell and Walker 2005; Rapp and Hill 2006). On the Great Plains, changes in temperature and patterns of precipitation strongly influence the distribution of plants and animals, and climate

is a driving force of change in the regional archaeological and paleontological record. Changes at least partly linked to the environment by archaeologists include the extinction of North American megafauna at the end of the Pleistocene (Martin 1973; Beck 1996; Brook and Powman 2002; Faith and Surovell 2009); reorganizations of settlement patterns and subsistence strategies, as well as the possible abandonment of portions of the Great Plains during the mid-Holocene (Meltzer 1999); and the relatively abrupt abandonment of the southern and western Great Plains by agricultural villagers at approximately 550 yr B.P (Drass 1998; Vehik 2002; Brosowske and Bevitt 2006). However, explanations for social, demographic, and economic changes linked to the environment are often vague, hampered by incomplete temporal and spatial coverage of paleo-environmental records. Geoarchaeological research can provide environmental proxy evidence which can be utilized to test hypotheses linking changes in climate with change recorded in the archaeological record.

A number of studies have focused on late-Quaternary paleo-environments (Arbogast 1995; Bement et al. 2007; Fredlund 1995; Olson and Porter 2002) and landscape evolution (Mandel 1994, 2008) in the region. Johnson and Park (1996) and Mandel (2006a) provided an overview of late Quaternary paleo-environments for the Central Plains and Kansas. Mandel (2006b) presented an overview of landscape evolution in Kansas with information pertinent to the south-central portion of the state. Hall (1990) reviewed late-Quaternary environmental change and landscape evolution for the Southern and Osage Plains. Mandel (2006b, 2008), Mandel and Hofman (2006), and Mandel et al. (2004) discussed the preservation of early Holocene deposits within draws on the High Plains of western Kansas.

In the Cimarron Bend area of southwest Kansas and at the Bull Creek site in the Oklahoma Panhandle, the plant community during the late Pleistocene and early Holocene was

dominated by cool season C₃ grasses, trees, and shrubs (Bement et al. 2007; Olsen and Porter 2002), indicating higher annual precipitation on the Plains. During this period, slow alluviation was accompanied by soil formation in the Cimarron Bend (Olsen and Porter 2002), the Pike Ranch locality (Mandel 2006b), and the Adams Ranch alluvial fan (Mandel 2006b). To the north of the study area, in the Cheyenne Bottoms of central Kansas, pollen and soil stratigraphic evidence indicate that grasslands were fully developed by the very early Holocene, and the stratigraphic record indicates landscape stability and soil formation at that time (Fredlund 1995).

During the mid-Holocene, warm season C₄ grasses dominate the plant communities in southwest Kansas and the Oklahoma Panhandle, as conditions become warmer and drier (Bement et al. 2007; Olsen and Porter 2002). This was a time of relative landscape instability, and buried soils dating to this period are rare in alluvial chronologies for the region (Mandel 2006b). Roughly synchronous with the record in southwest Kansas and the Oklahoma Panhandle, conditions became drier and water levels dropped in the marshlands of the Cheyenne Bottoms, followed by increased precipitation during the late-Holocene (Fredlund 1995). C₄ grasses continued to dominate plant communities in southwest Kansas during the late-Holocene, but with evidence of increased precipitation and landscape stability in stream valleys and alluvial fans (Mandel 2006b; Olsen and Porter 2002).

Cultural History

Four cultural periods are considered in this study: Pre-Clovis (>11,500 ¹⁴C yr B.P.), Paleoindian (11,500-8,500 ¹⁴C yr B.P.), Archaic (8,500-2,000 ¹⁴C yr B.P.), and Ceramic (<2,000 ¹⁴C yr B.P.). These divisions are based on subsistence activities and settlement patterns, as well as functional and stylistic differences in technology (Kay 1998; Wood 1998). Many of the temporal boundaries are conveniences used to construct a conceptual model for predicting the

geologic potential for the preservation of prehistoric cultural material in valley landscapes. Also, it is important to outline the adaptations characteristic of each cultural period in order to predict how the Driftwood Creek basin would have been utilized by people prehistorically and where sites are likely to occur.

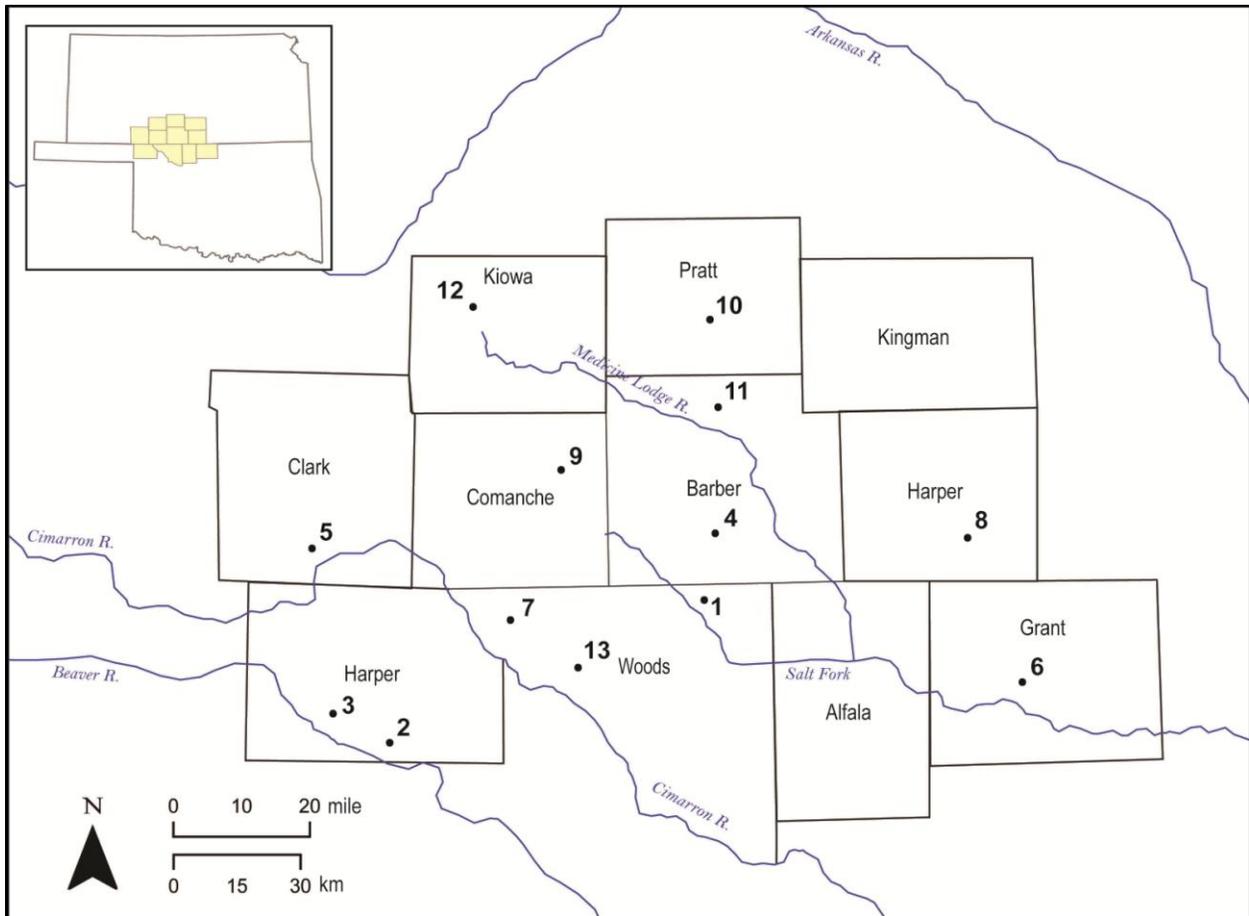


Figure 3. Location of archaeological sites discussed in the text: (1) Burnham, (2) Jake Bluff, Cooper, (3) Waugh, (4) Vincent Donovan, (5) Gardiner, (6) Hunter, (7) Wardrop, (8) Anthony, Hallman, Harper, (9) Bell, Booth, (10) Pratt, (11) Lemon Ranch, (12) Nichols Ranch, and (13) Shadid.

Pre-Clovis

Pre-Clovis refers to any archaeological remains dated earlier than the accepted range for the Clovis techno-complex. Because of the paucity of recorded sites pre-dating Clovis, little is

known about the people of this time period. Therefore, geoarchaeological research that can help locate and verify the integrity of these sites is especially important. The nearby Burnham site (Figure 3) in Woods County, Oklahoma has been dated to pre-Last Glacial Maxima, probably more than 30,000 ^{14}C yr B.P. This site has yielded the remains of a variety of extinct Pleistocene megafauna, including *Bison chaneyi*, in association with flakes and broken cobbles of Day Creek chert and Ogallala quartzite in spring deposits (Wyckoff et al. 2003). Paleoenvironmental evidence gleaned from fossil gastropods indicates that the environment was colder and drier than today (Wyckoff et al. 2003). However, the evidence for pre-Clovis occupation at Burnham is equivocal due to bioturbation caused by extensive crawfish burrowing.

Paleoindian

The Paleoindian period on the Great Plains refers to a basically nomadic hunter-gatherer life-way, which in the immediate region is represented by the late-Pleistocene Clovis and Folsom techno-complexes, as well as the early-Holocene Allen techno-complex (Hofman and Graham 1998). Paleoindian sites are classically characterized by distinctive fluted and un-fluted lanceolate projectile point/knives and, in this region, are often associated with arroyo trap bison kills. Geographically dispersed stone sources, including Edwards chert, Alibates silicified dolomite, Hartville chert, White River Group chalcedonies, and Smoky Hill silicified chalk are common in Paleoindian lithic assemblages, and suggest wide ranging travel and/or extensive trading networks. Paleoindian groups may have passed through the Plains Border Region on their way to and from productive bison hunting grounds on the High Plains, camping on high interfluves (Hofman 1996; Thurmond and Wyckoff 1999).

The Vincent-Donovan site is the only recorded archaeological site within the Upper Driftwood Creek basin (Figure 3). The site is situated on a remnant terrace adjacent to a dry

tributary of Driftwood Creek. After a Folsom point base was reported to the Kansas State Archaeologist by John Vincent, excavations at the site were conducted by the University of Kansas during the summers of 2003 and 2008. Additional diagnostic Folsom artifacts were found in sub-surface and eroded contexts and are mostly contained within a thin A horizon developed in late Pleistocene alluvium capping the landform. These artifacts include a thin end-scraper, and a probable Folsom channel flake, as well as a number of other chipped stone tools and debitage made from local and exotic materials. Although the exact nature of the site remains unclear, it may represent the remnants of a Folsom camp, perhaps associated with an as yet undiscovered bison kill.

Other Folsom sites in the region include the Waugh site, an arroyo bison kill and associated camp in Harper County, Oklahoma dating to ca. 10,400 ^{14}C yr B.P. (Hill and Hofman 1997; Hofman 1991; 2006), and the Cooper site, another arroyo bison kill in Harper County dating to ca. 10,000 ^{14}C yr B.P (Figure 3; Bement 1999; Bement and Carter 2006). Clovis is represented in the Plains Border Region by the Jake Bluff site in Harper County, Oklahoma. It is an arroyo bison kill site, notable for its relatively late date: 10,763 \pm 43 ^{14}C yr B.P. (Figure 3; Bement and Carter 2006; 2010).

The Late Paleoindian period is represented in the region by the Gardiner site to the west of the study area in Clark County, Kansas. At the Gardiner a bison bone bed and an Allen projectile point fragment were found eroding from a pipeline excavation cut into ancient gully fill. Bison bone from the site yielded a radiocarbon age of 8650 ^{14}C yr B.P. and is comparable to other dated Allen sites in the region (Asher 2008; Hofman 2010).

Archaic

The lower boundary of the Archaic period on the Great Plains is indistinct and not marked by any abrupt change in life-way, and the upper boundary is marked by the appearance of pottery making. The Archaic period has been arbitrarily subdivided into early (ca. 8,500 to 6,500 ^{14}C yr B.P.), middle (ca. 6,500 to 4,500 ^{14}C yr B.P.), and late (ca. 4,500 to 2,500 ^{14}C yr B.P.) (Kay 1998). In the Central and Southern Plains, Archaic settlement patterns present evidence for focused foraging on seasonally abundant food resources and communal bison hunting. This subsistence strategy is probably not significantly different from preceding periods, though in the Late Archaic, evidence for small scale horticulture emerges in the eastern Plains (Kay 1998). The Archaic is not well represented within the whole Plains Border Region, possibly because of shifts in land use and population densities during the middle Holocene in response to lower landscape carrying capacities during the Altithermal. Alternatively, geomorphic patterns may have removed or deeply buried middle Holocene cultural deposits (Artz 1995; Bettis and Mandel 2002; Ferring 1995; Mandel 1994, 1995, 2006b). In Oklahoma, however, Thurmond and Wyckoff (1997) documented Early Archaic Calf Creek complex artifacts at the Hunter site in Grant County as well as at the Wardrop site in Woods County (Figure 3).

Ceramic

The Ceramic period in south-central Kansas is marked by changes in technology and settlement patterns. Pottery becomes common, settlements are more permanent, and agriculture contributes to the subsistence of Great Plains populations before ca. A.D. 1000. The Ceramic period is commonly subdivided into the early (ca. 2,500 to 1,000 ^{14}C yr B.P.), middle (ca. 1,000 to 550 ^{14}C yr B.P.), and late (ca. 550 to 150 ^{14}C yr B.P. or A.D. 1450 to 1800). Early-Ceramic refers to Plains Woodland sites. Regionally, the Keith phase is representative of this period,

identifiable by cord roughened pottery and large to medium corner-notched dart points, scallorn type corner-notched arrow points, or small triangular projectile points. Subsistence is characterized as broad spectrum and probably included a variety of plants and animals (Johnson and Johnson 1998). However, the southern limit of Keith phase sites is currently the Arkansas River, and little is known about the Early Ceramic in the south-central and southern Plains. Early Ceramic groups probably utilized the Red Hills as people did for thousands of years prior, as hunting grounds and as connections geographically and ecologically transitional to the High Plains and Central Lowlands.

In the surrounding region, Middle and Late Ceramic Plains Village sites are more numerous than earlier periods, suggesting higher population densities. Plains Village sites in the region encompass the Smoky Hill phase of the Central Plains Tradition, the Bluff Creek and Pratt complexes, the Odessa phase, and the later Great Bend aspect (Berger 2003; Brosowske and Bevitt 2006; Drass 1998; Ranney 1994). Village sites generally consist of the remnants of a few houses, refuse-filled storage pits, and occasional burials. These settlements probably represent dispersed extended family groups practicing a broad based subsistence economy focused on corn agriculture and bison hunting (Brosowske and Bevitt 2006).

No Ceramic period occupations have been recorded within the Upper Driftwood Creek basin, but nearby sites include the Armstrong, Hallman, and Anthony sites less than 100 km to the east on Bluff Creek in Harper County, Kansas and are assigned to the Bluff Creek complex (Figure 3; Berger 2003; Brosowske and Bevitt 2006; Drass 1998). The Bluff Creek complex probably dates to ca. A.D. 1200 and is concentrated within Bluff Creek valley in Harper County. Bluff Creek houses are identified by low ovoid mounds and measure around 25m². They resemble Central Plains Tradition lodges and contain a centrally located hearth with storage pits

located in and outside houses (Brosowske and Bevitt 2006). Based on evidence from the Armstrong, Hallman, and Anthony sites, subsistence involved agriculture and bison hunting as indicated by charred maize kernels and cobs, bison scapula hoes, digging sticks, and faunal assemblages dominated by bison with contributions from a very wide range of smaller terrestrial, aquatic, and avian species. Bluff Creek material culture resembles the general Plains Village pattern. Washita style projectile points, plano-convex scrapers, and diamond-shaped beveled knives and flake drills dominate toolkits. Ceramics tend to be highly varied but are typically cord marked globular vessels with rare decoration. Human remains have been found in the form of complete burials (at the Anthony site), and as partial burials associated with numerous hackberry, bone, and shell beads at the Hallman, Anthony, and Armstrong sites (Brosowske and Bevitt 2006).

To the north of the study area around Pratt, Kansas in the Ninnescah River valley, is a cluster of sites dating to the thirteenth and fourteenth centuries A.D. that have been assigned to the Pratt complex. The Lemon Ranch site (14BA401), approximately 25 km south of Pratt on Elm Creek, a tributary of the Medicine Lodge River, may be affiliated with the Pratt complex (Figure 3; Ranney 1994; Brosowske and Bevitt 2006). Pratt complex houses are round to ovoid structures with centrally located hearths and cylindrical and bell shaped refuse-filled storage pits. Subsistence probably centered on agriculture and bison hunting. Material culture is similar to that described for Bluff Creek. The Lemon Ranch locality contains a single complete child burial in a bell shaped pit as well as a skull and femur fragments of an adult recovered in disturbed contexts (Brosowske and Bevitt 2006). The presence of a small amount of exotic tool stone (Alibates and Smoky Hill silicified chalk) and pottery suggest limited contact with more

distant groups such as villagers from the Southwest, Southern Plains, and Central Plains (Brosowske and Bevitt 2006).

A number of other Ceramic-aged sites have been recorded in the region that have yet to be assigned to any previously mentioned techno-complex. These include most notably: Bell and Booth in Comanche County, Kansas; Nichols Ranch in Kiowa County, Kansas; and Shadid in Woods County, Oklahoma (Figure 3) (Drass 1998; Brosowske and Bevitt 2006). Generally, these sites appear similar in terms of their material culture, settlement patterns, and subsistence to other Middle Ceramic village complexes, though their chronologies are not certain (Brosowske and Bevitt 2006).

CHAPTER IV

RESEARCH METHODS

The objectives of this study were to (1) identify and describe landform sediment assemblages including buried soils in the upper Driftwood Creek basin, (2) determine the spatial and temporal pattern of erosion, sedimentation, and landscape stability in the study area to facilitate preparation of a geoarchaeological model, and (3) infer late-Quaternary environmental changes from stable carbon isotope ratios of soil organic carbon and from the soil-stratigraphic record. To accomplish the first two objectives field methods for this study follow those used in previous geoarchaeological investigations on the Central Plains. Laboratory methods for stable carbon isotope analysis aimed at accomplishing the third objective follow those established in the literature and by personnel at the Kansas Geological Survey and the Keck Paleoenvironmental and Environmental Stable Isotope Laboratory (KPESIL), University of Kansas.

Field Methods

Four locations were selected for detailed study with the following criteria in mind. First an attempt was made to find locations where thick deposits of late-Quaternary sediments are exposed beneath alluvial landforms in the Upper Driftwood Creek basin. Second, locations with buried soils and/or exposed cultural material were preferred. Buried soils are useful for stratigraphic subdivision and correlation, their magnitude of development can provide clues about past environmental conditions and the length of landscape stability, and soil organic matter can be radiocarbon dated to provide an approximate numerical age. Temporally diagnostic artifacts can provide relative ages for sediments, while bone and charcoal can yield radiocarbon ages.

After cleaning each soil profile with a shovel to remove effects of modern weathering, soils and sediments were described using standard terminology and procedures described by Birkeland (1999) and Holliday (2004). A trailer-mounted Giddings Hydraulic Soil Probe was used at one location to collect two soil cores. These cores were wrapped in plastic and aluminum foil, transported to the Kansas Geological Survey, described, photographed, and sampled for radiocarbon and $\delta^{13}\text{C}$ analysis. Texture, structure, boundary characteristic, and Munsell matrix color were described. Root channels, krotovinas, clay films, mottling, pores, worm burrows, clasts, and concretions were recorded when present. When applicable, carbonate morphology was described according to Birkeland's (1999) scheme. After soils were identified, they were numbered consecutively, beginning with Soil 1, the modern surface soil, at the top of the profile. The suffix "b" identifies buried soils and in cases when more than one was present they were numbered consecutively from the top of the section downward with the number following the "b." For example, in the case of three superimposed buried A horizons, the soils would number Ab1, Ab2, Ab3 from top to bottom.

The stages of soil development were described with informal terms following Birkeland (1999) and Holliday (2004). A "very weakly expressed" soil denotes an A-C profile, a "weakly expressed" soil denotes an A-Bw or A-Bk profile, a "moderately expressed" soil equates roughly to a moderate A-Bt or A-Bk profile, and a "strongly expressed" soil equates roughly to a strong A-Bt or A-Btk profile. Certain easily observable pedogenic features are time dependent at a Holocene time-scale, though rates of development can vary significantly based on other soil forming factors such as geomorphic position, parent material, and climate (Birkeland 1999; Holliday 2004). A horizons can form in decades and mollic epipedons require a minimum of ca. 100 years to form. Cambic (Bw) horizons can form in several centuries to a millennium. Calcic

(Bk) horizons can form in as little as ca. 200 years, and argillic (Bt) horizons require a minimum of ca. 3,500 years to reach a thickness of 100 cm with at least a 4% increase in illuvial clays, though minimally expressed Bt horizons can form in as little as ca. 500 years (Birkland 1999; Holliday 2004). Therefore, a very weakly expressed soil may represent less than 100 years of landscape stability, a weakly expressed soil represents at least ca. 200-1,000 years of landscape stability, a moderately expressed soil represents at least ca. 500-4,000 years of landscape stability, and a strongly expressed soil will require at least several millennia of landscape stability. These terms are difficult to apply to buried soils in certain situations because some pedogenic process may continue to affect a soil after burial. For example, the presence of illuvial clays or carbonates in a welded soil may be the product of pedogenesis of the overlying soil. As a result, these terms were only applied to surface soils, or buried soils which were separated by distinct horizons of minimally altered sediment.

Laboratory Methods

Radiocarbon Dating

Twelve AMS radiocarbon ages were determined on soil organic matter (SOM) samples, and one age was determined on bone collagen at the Illinois State Geological Survey Isotope Laboratory. Samples were taken preferentially from the upper 10-15 cm of buried A horizons, but the lower portions of buried A horizons as well as buried B horizons were dated as well. SOM is derived from living plants and animals, dead and decomposing biomass, simple organic compounds (e.g. cellulose and lignin), and complex organic compounds (humus) (Holliday 2004). During pedogenesis, carbon inputs accumulate on the soil surface, are decomposed to form humus, and translocated down the soil profile. Biomass and simple organic compounds decompose relatively rapidly but humus can persist in a soil for thousands of years. Because

humus is the most durable organic compound in the soil, it is the component which is dated by radiocarbon in bulk SOM usually after decalcification to remove inorganic carbon. A radiocarbon age determined on SOM of a surface soil reflects a mixture of old and new carbon from multiple sources and states of synthesis and gives a mean residence time (MRT) of this carbon which usually decreases down the profile (Birkland 1999). A radiocarbon age determined on SOM from a buried soil gives the MRT of the carbon prior to burial plus the time elapsed since burial (Holliday 2004). Ignoring potential contamination, a radiocarbon age determination on the SOM of a buried soil will provide a minimum age for the end of deposition of that soil's parent material and a maximum age for burial. SOM from the uppermost A horizon of a surface soil is usually a few decades old, therefore a radiocarbon age determination on SOM from a buried A horizon can provide a reasonable estimate for the time of burial. Also, since older pedogenic carbon in a soil is stored lower in the profile where it has been translocated downward, SOM from the lower portion of an A horizon or a B horizon provide a better limiting age for the beginning of landscape stability and pedogenesis.

There are many sources of contamination when dating buried soils by radiocarbon (Holliday 2004). Young carbon derived from roots or introduced by burrowing animals can bias or even overwhelm older carbon stored in subsurface horizons or buried soils. Mobile humic acids can be translocated into buried soils from overlying horizons and bias age determinations especially in well drained settings and/or in situations where soil welding has occurred. Older detrital carbon can be deposited by colluvial, alluvial, and eolian processes with a soil's parent material and cause a radiocarbon age to appear older than it would have otherwise. However, when wood charcoal is not available for dating, reliable radiocarbon ages can be obtained from SOM, especially in dry environments, by careful sampling from fresh exposures (Mandel 2008).

Stable Carbon Isotopes

Due to differences between C₃ and C₄ plant photosynthetic pathways, stable carbon isotope ratios of SOM from buried soils can record vegetation changes at the millennial time-scale (Boutton et al. 1999; Feggestad et al. 2007; Follett et al. 2004; Leavitt et al. 2008; Nordt et al. 2008; von Fischer et al. 2007). C₃ plants follow the Calvin-Benson photosynthetic pathway, which uses the photosynthetic enzyme rubisco carboxylase to fix carbon from atmospheric CO₂. The Calvin-Benson pathway produces a three-carbon molecule and entails the greatest ¹³C discrimination resulting in δ¹³C values averaging about -27 per mil. C₄ plants follow the Hatch-Slack photosynthetic pathway using PEP-carboxylase to fix carbon, producing a four-carbon molecule. The Hatch-Slack pathway entails smaller overall ¹³C discrimination, and C₄ plants produce δ¹³C values averaging about -13 per mil (Bowen 1990; Farquhar et al. 1989). The majority of plants, including trees, shrubs, and cool-season grasses follow the C₃ photosynthetic pathway, while warm season grasses follow the C₄ photosynthetic pathway. The A horizons of Great Plains soils rapidly integrate organic matter from plants growing on the land surface, and will preserve δ¹³C signals without significant diagenetic or pedogenic alteration (von Fischer et al. 2008). This fact, combined with the lack of overlap between the δ¹³C end-members of C₃ and C₄ plants, allow δ¹³C values from soil organic carbon to be used as a paleoecological proxy.

In general, the proportion of C₄ grass species of Great Plains grasslands increases in a southerly direction (von Fischer et al. 2008: Figure 1). This is probably due in most part to differences in summer climate (von Fischer et al. 2008). The differential productivity of C₃ and C₄ plants along environmental gradients has been interpreted as a result of carbon loss during photorespiration which is temperature dependent (Ehleringer et al. 1997). The C₄ metabolic pathway minimizes photorespiration resulting in greater relative productivity than C₃ plants at

higher temperatures. Physiological models predict that above $\sim 22^{\circ}\text{C}$ C_4 monocots will have a higher net carbon assimilation rate and be at a competitive advantage relative to C_3 monocots (Ehleringer et al. 1997). Other studies have suggested that the seasonality of precipitation is an important determinant for the relative productivity of C_3 and C_4 plants. For example, the shift to summer season monsoonal precipitation is argued to have played a dominant role in the origin and expansion of C_4 grasslands during the latest Miocene in East and Southwest Asia (Pagani et al. 1999; Quade and Cerling 1995; Quade et al. 1989; Zhisheng et al. 2005). In a large scale quantitative study of the variation of grassland composition and $\delta^{13}\text{C}$ values of SOM at native prairie sites on the Great Plains, a combination of the average July high temperature and total summer precipitation correlated positively and significantly with $\delta^{13}\text{C}$ values in SOM and best predicted the proportion of C_4 grasses on the land surface (von Fischer et al. 2008). Laboratory and field experimental evidence confirms that the timing of water availability with seasonal variations in temperature optima for C_3 and C_4 photosynthesis is crucial in determining the relative productivity of C_3/C_4 grasses (Niu et al. 2005; Shim et al. n.d.). Thus $\delta^{13}\text{C}$ values from buried SOM is not an unambiguous indicator of a single climatic variable on the Great Plains, but is instead a result of complex and variable seasonal patterns of temperature and rainfall.

Thirty three samples from the study area were selected for $\delta^{13}\text{C}$ analysis. The samples came from the Donovan Ranch Fan soil profile, Cores 1 and 2 at the Blunk Locality, and the Sterling Section soil profile. Sampling was subjective, though each buried soil present in a particular profile or core was sampled. Special consideration was given to buried A horizons and levels from which AMS dates were derived. A horizons are important because they represent the epipedons of former stable land surfaces, and barring contamination, the $\delta^{13}\text{C}$ values of these horizons reflect the average of the total carbon inputs over the course of pedogenesis until burial.

All samples were pre-treated using standard methods appropriate for the determination of $\delta^{13}\text{C}$ in SOM following Haj et al. (unpublished lab manual, Kansas Geological Survey). Samples were oven dried at 45°C and homogenized with a ceramic mortar and pestle. About 1 g of sample was then decalcified with 7.5ml of 0.5N hydrochloric acid solution, rinsed in 40 mL of distilled water till a neutral pH was obtained, and oven dried at 45°C. Decalcified samples were then pulverized with a synthetic ruby mortar and pestle and transferred to glass vials. $\delta^{13}\text{C}$ values were determined via flash combustion in a Costech ECS4010 element analyzer coupled with a ThermoFinnigan MAT253 isotope ratio mass spectrometer at the Keck Paleoenvironmental and Environmental Stable Isotope Laboratory (KPESIL), University of Kansas. Raw $^{13}\text{C}/^{12}\text{C}$ ratios were calibrated against a curve generated from international standards including dogfish muscle (DORM-2) from the National Research Council of Canada, ANU sucrose (NIST 8542), IAEA-600 caffeine, and graphite (USGS-24), and are reported relative to VPDB and in standard per mil (‰) notation, calculated as:

$$\text{‰} = (R_{\text{sample}}/R_{\text{standard}} - 1) \times 1000 \quad (1)$$

The above mentioned calibration curve yielded an R^2 value of .9997, and quality control was monitored with Montana soil and a calibrated yeast and typically yields an error less than $\pm 0.22\%$ (KPESIL, University of Kansas).

CHAPTER V

RESULTS

This chapter presents the results of the investigations at each study location. First the geographic location, geomorphic setting, and soil stratigraphy of each LSA are detailed. Then the alluvial chronology at each location, based on numerical (Table 1) and relative ages and soil development are presented. Next, the results of $\delta^{13}\text{C}$ analysis are presented. The implications of these results for the geoarchaeology and paleo-environments of the Upper Driftwood Creek basin are discussed in Chapter VI.

Vincent-Donovan site (14BA308, areas A and D)

Area A of 14BA308 is on a remnant terrace of an unnamed intermittent tributary of Driftwood Creek approximately 4 km upstream from its junction with Driftwood Creek and roughly 11 km northwest of Hardtner, KS (Figures 2, 4, and 5). The draw is deeply incised at this location, exposing 2.20 m of late-Quaternary deposits above highly weathered Permian shale and gypsum. Diagnostic Folsom artifacts recovered *in situ* and eroding from upper the 35 cm of the soil profile provide a minimum age for the late-Quaternary deposits capping the landform.

Area D of 14BA308 is approximately 200 m northwest of area A. Area D is situated on a footslope below a high Pleistocene terrace of Driftwood Creek (Figure 2, 4, and 6). A bison humerus was exposed in a 0.55 m thick section of alluvium. When excavated, the humerus was found to articulate to a bison radius and ulna and adjacent to a bison 3rd phalanx and radialcarpal. These bones were collected for radiocarbon dating (Table 1).

Location	Geomorphology	Sample depth (cm)	Material assayed	¹⁴ C yr B.P.	2 σ cal B.P. age range ¹	Median age cal B.P.	δ ¹³ C (‰)	Lab Number ²
14BA308 area D	Paleo-arroyo	50-55	Collagen	280±20	288-429	360	-9.0	ISGS-A1365
Blunk Ranch core 1	T-1 terrace	330-345	SOM	1240±20	1,083-1,263	1,201	-17.8	ISGS-A1359
Blunk Ranch core 2	Alluvial fan	382-397	SOM	9915±30	11,241-11,392	11,298	-18.2	ISGS-A1360
Blunk Ranch core 2	Alluvial fan	615-630	SOM	11475±35	13,240-13,440	13,335	-15.5	ISGS-A1358
Blunk Ranch core 2	Alluvial fan	690-705	SOM	10670±30	12,550-12,679	12,607	-14.9	ISGS-A1361
Blunk Ranch Section	T-1 terrace	173-183	SOM	1430±15	1,300-1,348	1,323	-14.6	ISGS-A1346
Donovan Ranch Fan	Alluvial fan	110-120	SOM	4455±20	4,973-5,278	5,128	-15.1	ISGS-A1348
Donovan Ranch Fan	Alluvial fan	132-142	SOM	6760±25	7,579-7,662	7,613	-16.0	ISGS-A1347
Donovan Ranch Fan	Alluvial fan	247-257	SOM	7635±25	8,383-8,509	8,418	-19.9	ISGS-A1356
Sterling Section	T-2 terrace	228-238	SOM	10590±35	12,426-12,642	12,561	-17.6	ISGS-A1357
Sterling Section	T-2 terrace	298-308	SOM	10715±30	12,560-12,710	12,627	-16.6	ISGS-A1350
Sterling Section	T-2 terrace	358-368	SOM	11745±35	13,437-13,741	13,591	-15.9	ISGS-A1345
Sterling Section	T-2 terrace	419-429	SOM	14280±45	17,036-17,665	17,363	-21.9	ISGS-A1349

¹ Calibration to calendar years using Calib Rev 6.0 Radiocarbon Calibration Program using calibration dataset IntCal09 (Stuiver et al. 1993)

² Samples analyzed at the Illinois State Geological Survey

Table 1. List of radiocarbon ages reported in the text.

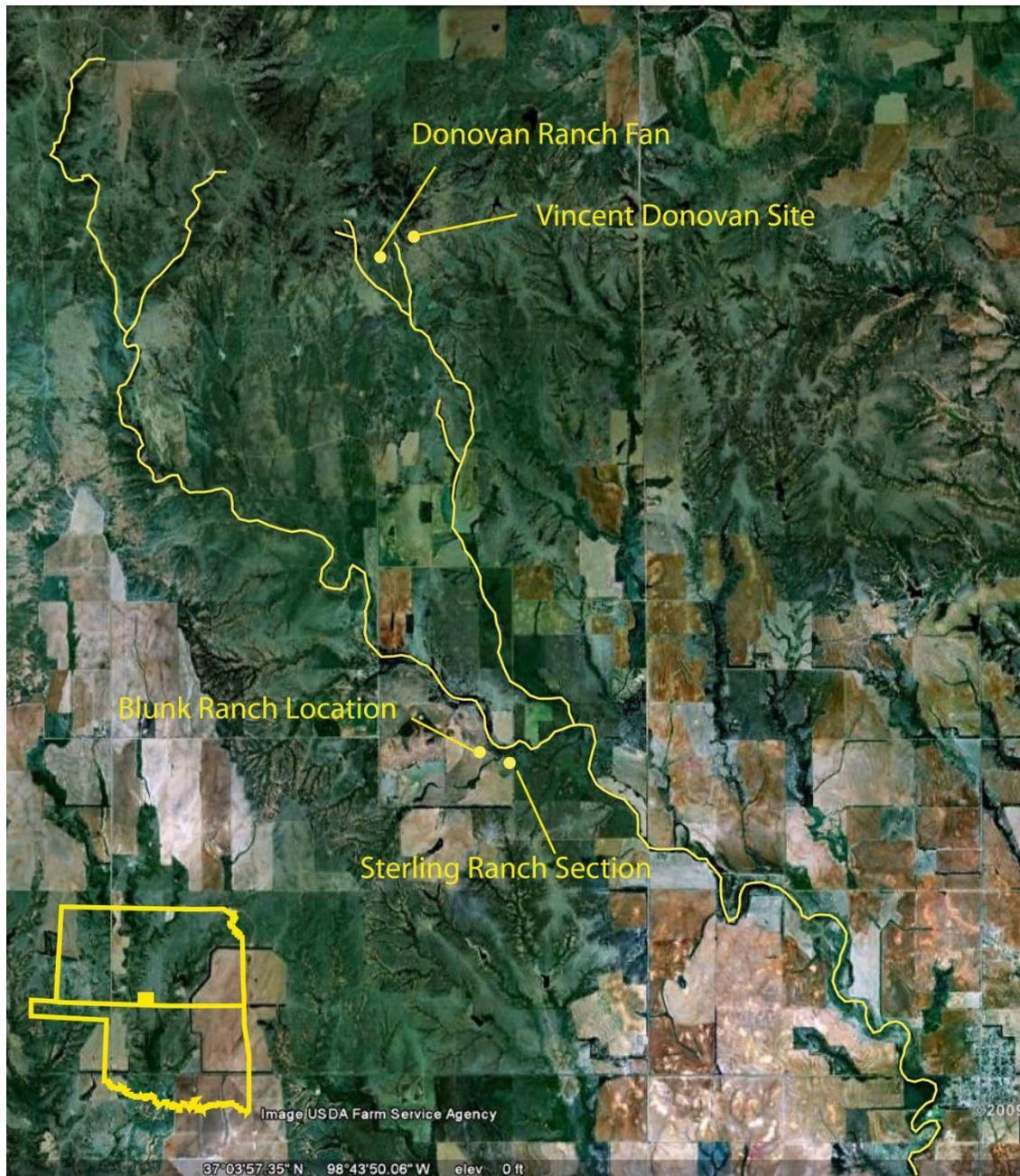


Figure 3. Location of study sites on the upper Driftwood Creek basin.

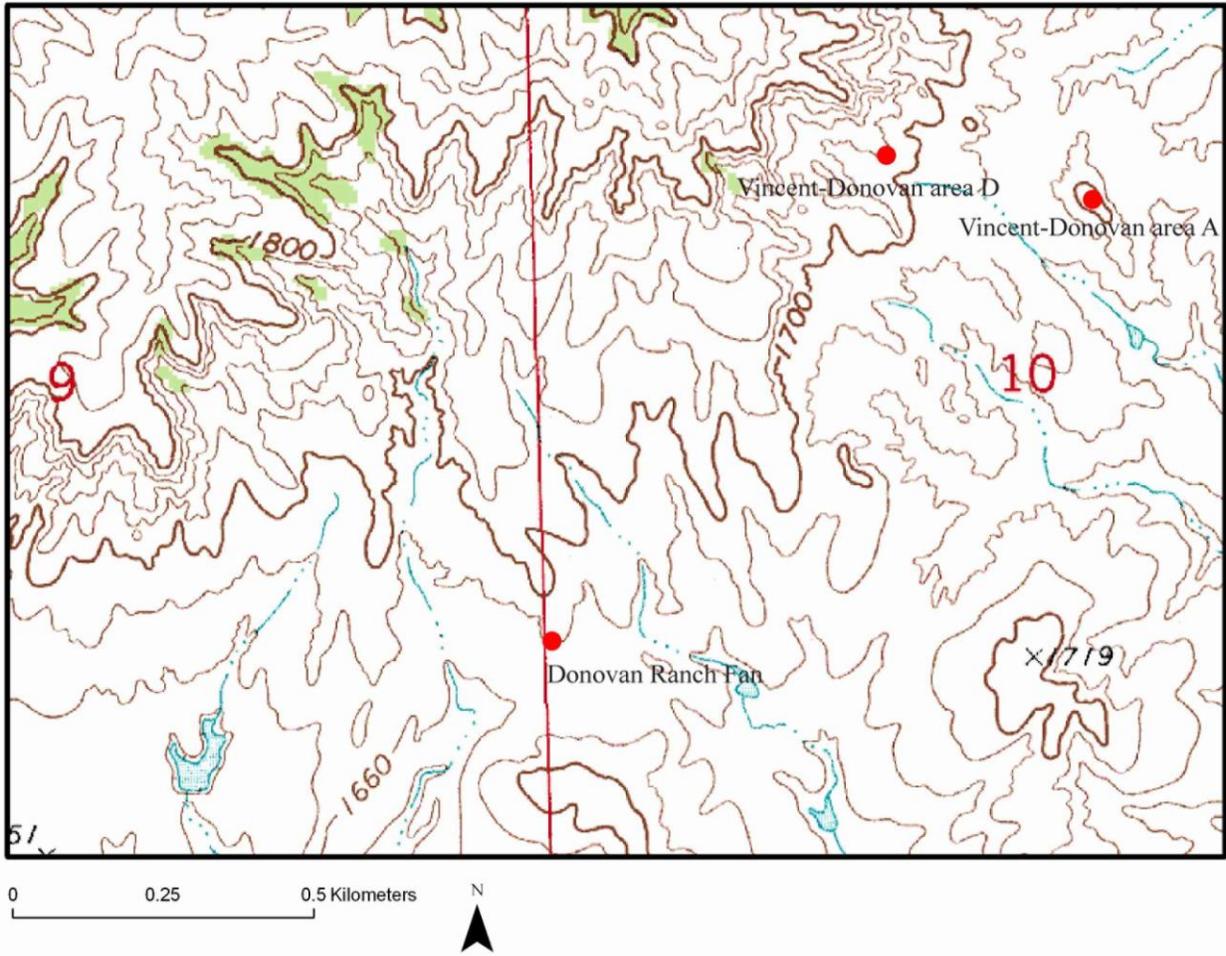


Figure4. Location of the Vincent-Donovan site and the Donovan Ranch Fan.



Figure 5. The terrace remnant and soil profile at area A of the Vincent-Donovan site. View is to the north.



Figure 6. Area D at the Vincent-Donovan site. View is to the northwest.

Stratigraphy

The deposits at area A consist of strong brown (7.5YR 4.5/6, dry) to dark brown (7.5YR 3.5/4, dry) fine-grained and sandy alluvium interbedded with coarse sand and gravel (Table 2 in Appendix A and Table 7). The surface soil (Soil 1) has a moderately developed A-AB-Bw-BC profile. No buried soils occur in the section.

Sediments at area D consists of strong brown (7.5YR 4/5) fine-grained alluvium (Table 3 in Appendix A and Figure 8). Soil 1 has a very weakly developed A-AC profile. The AC horizons have prismatic structure produced by the clay rich alluvium, and there are distinct (7.5YR 3/3) nearly continuous flood coats, resembling clay films, on ped faces.

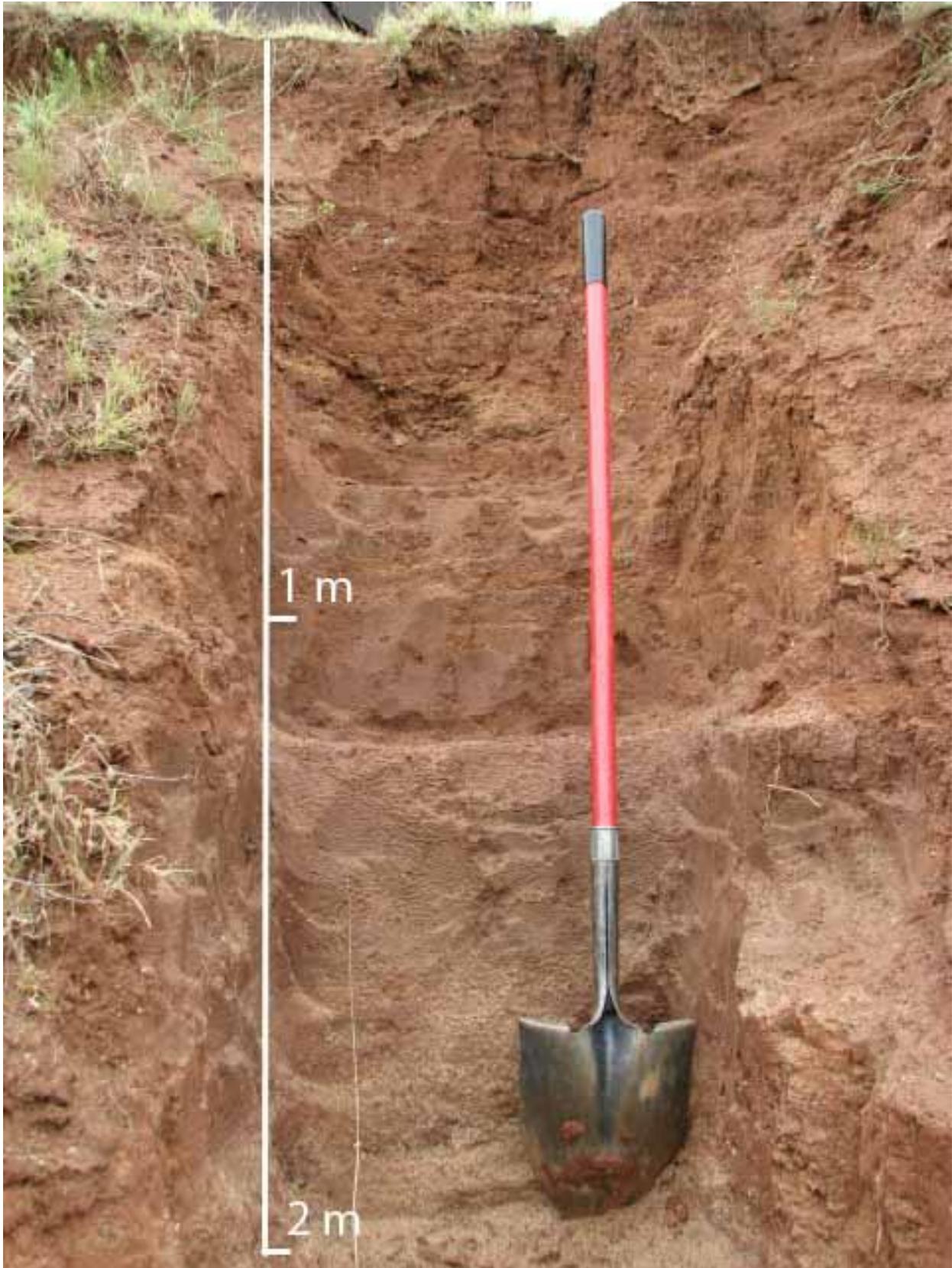


Figure 7. Soil profile at area A of the Vincent-Donovan cite. View is to the northeast.



Figure 8. Bison bone exposed in alluvium at area D of the Vincent-Donovan site. View is to the north.

Chronology

At area A, alluvium rapidly aggraded sometime before the surface was occupied by Folsom people, or between ca. 10,800-10,200 ^{14}C yr B.P. The subsequent timing of stream incision and landscape stability is uncertain.

Collagen from bison bone (3rd phalanx) recovered *in situ* 50 cm below surface of the exposure in area D (Figure 8) yielded a radiocarbon age of 280 ± 20 ^{14}C yr B.P. (Table 1). This age indicates that alluvium in this section is proto-historic in age.

Donovan Ranch Fan

The Donovan Ranch Fan is a low-gradient alluvial fan on the valley floor of an unnamed, second-order stream roughly 3 km from its confluence with Driftwood Creek (Figure 2 and 4).

The ephemeral feeder stream has incised at this location, exposing 3 m of alluvium overlying weathered bedrock in the west lobe of the fan (Figure 9 and 10).

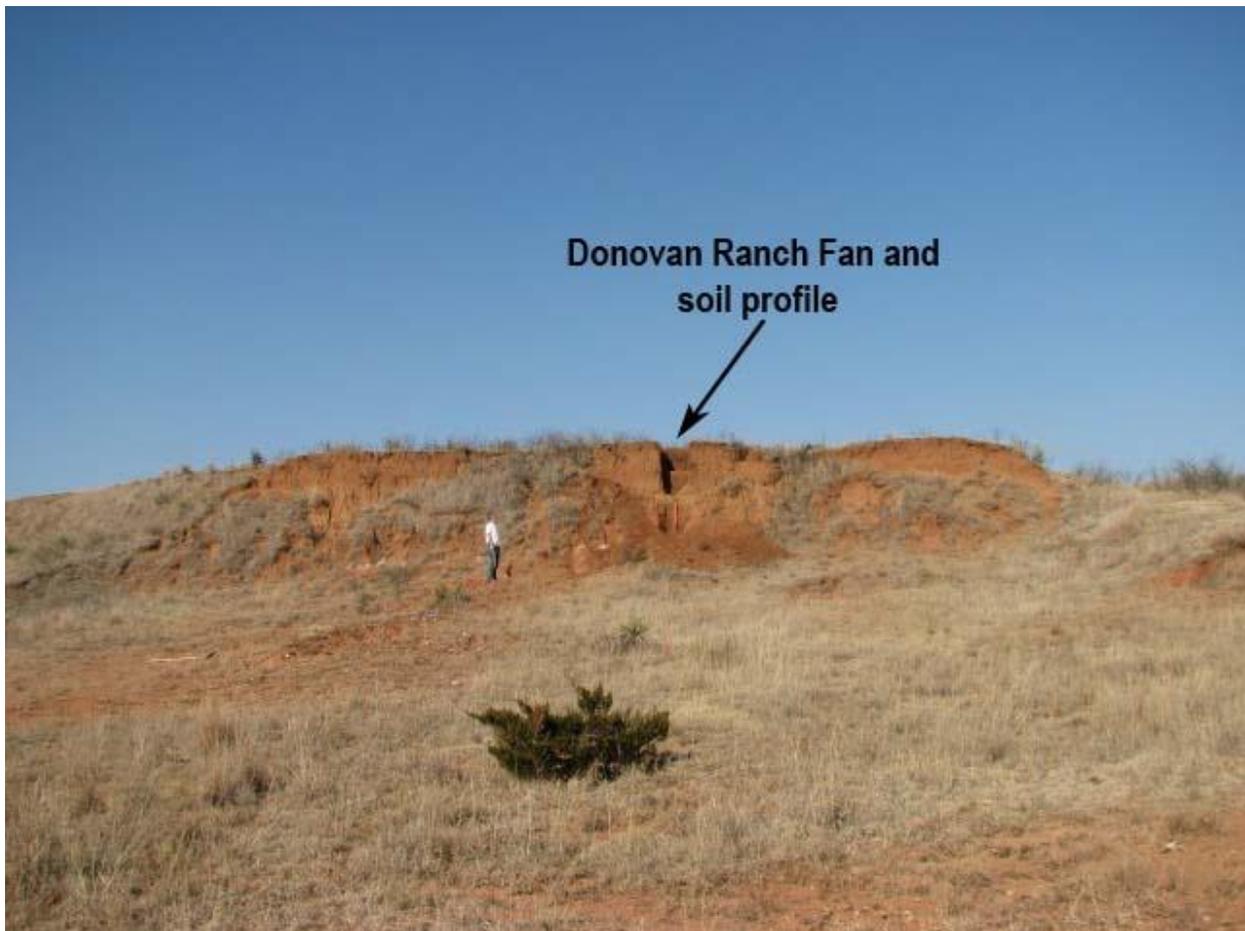


Figure 9. Donovan Ranch Fan and soil profile. View is to the north.

Stratigraphy

At the Donovan Ranch Fan, four soils are formed in brown (7.5YR 5/4) to dark brown (7.5YR 3.5/4) sandy alluvial fan deposits (Table 3 in Appendix A and Figure 10 and 11). The weakly expressed surface soil (Soil 1) has a 110 cm thick A-AB-Bw profile. Soil 1 is welded to Soil 2, which consists of a 22-cm-thick Btk horizon. Soil 2 has been truncated by erosion and is welded to Soil 3, which has a Ak-Bk profile. Soil 4 is truncated and consists of a strongly developed Bt-BCt profile. The top of Soil 4 represents a lithologic discontinuity and was formed

in colluvium consisting of sandy clay loam with abundant pebbles and Permian shale rip-up clasts.

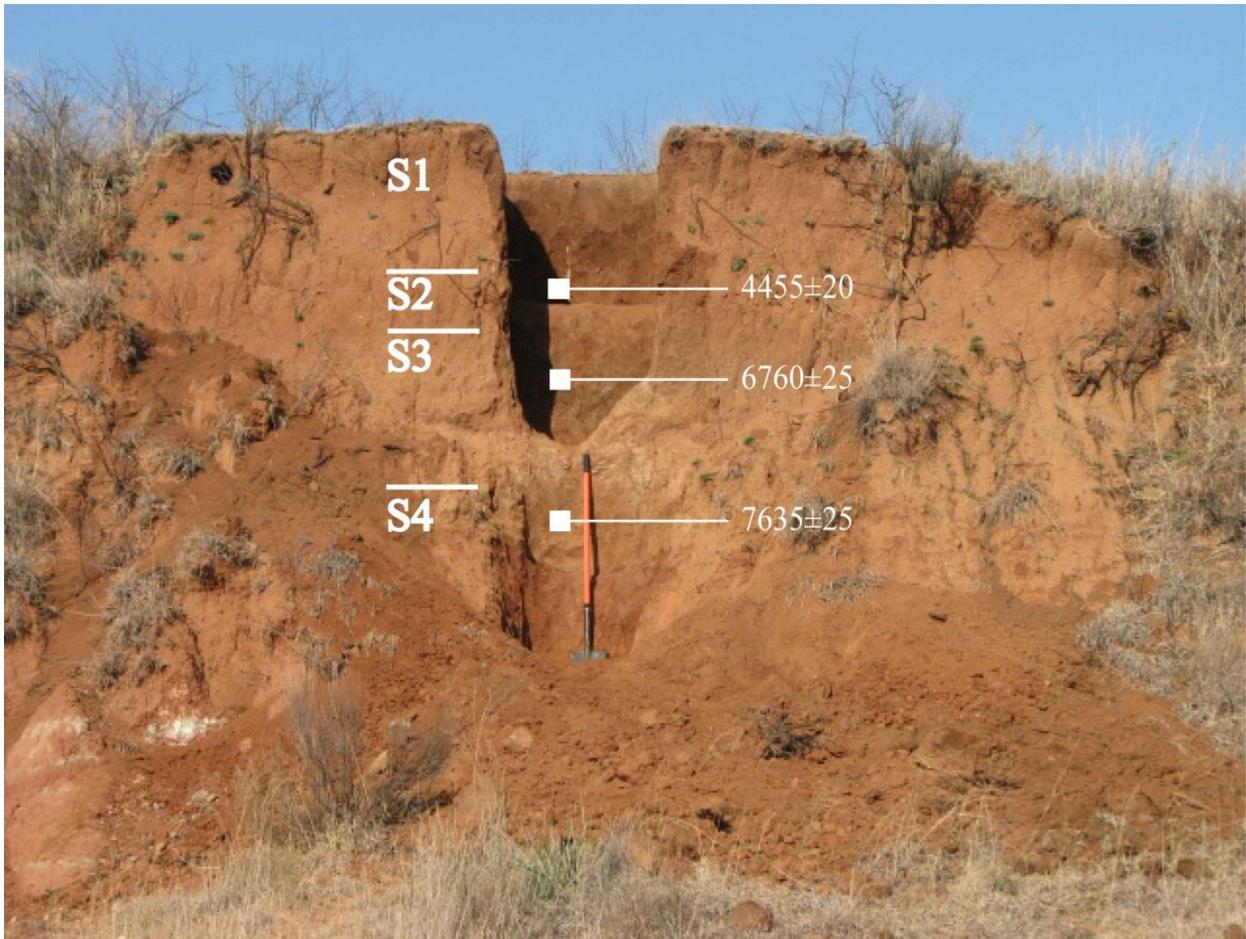


Figure 10. Soil profile and radiocarbon chronology at the Donovan Ranch Fan. Soils are numbered S1-S4. Radiocarbon ages were determined on SOM. View is to the north.

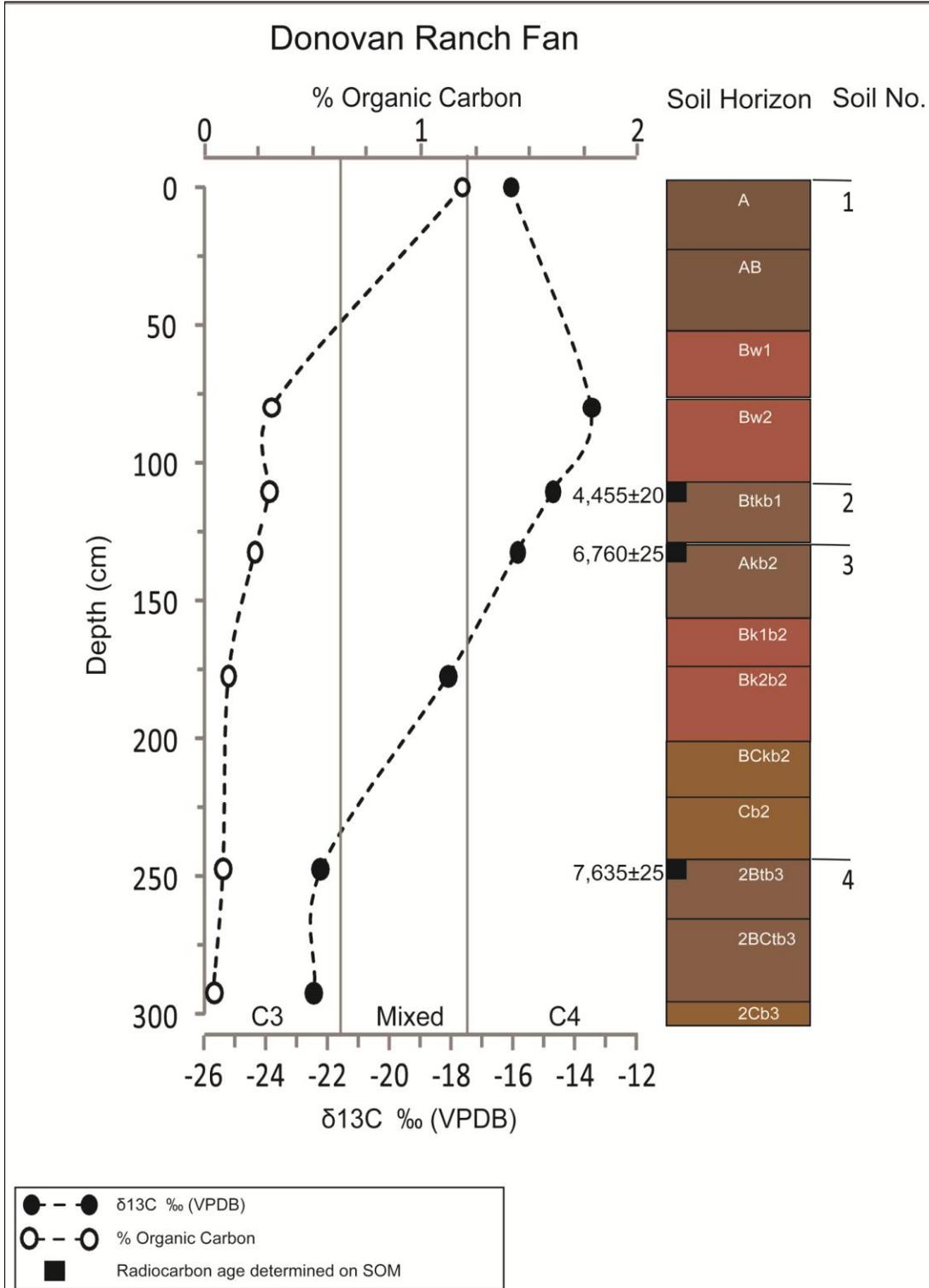


Figure 11. Soil stratigraphy, radiocarbon chronology, and stable carbon isotope ratios at the Donovan Ranch Fan.

Chronology

Three radiocarbon ages determined on SOM provide a numerical chronology for the Donovan Ranch Fan (Figure 10). SOM from the upper 10 cm of Soils 2, 3, and 4 yielded radiocarbon ages of $4,455 \pm 20$, $6,760 \pm 25$, and $7,635 \pm 35$ ^{14}C yr B.P respectively (Table 1).

Stable Carbon Isotopes

At the Donovan Ranch Fan, the $\delta^{13}\text{C}$ values determined on soil carbon decrease by 6 ‰ from Soil 1 to Soil 4 (Figure 11). The $\delta^{13}\text{C}$ values in Soil 4 average 22.35 ‰, and the average $\delta^{13}\text{C}$ value for Soils 2 and 3 is -16.23 ‰, a 6.12 per mil offset. The $\delta^{13}\text{C}$ value of soil carbon in the Bw horizon of Soil 1 is -13.48 ‰, the most isotopically enriched carbon sample in the profile. Soil carbon from the A horizon of Soil 1 has a $\delta^{13}\text{C}$ value of -16.08 ‰ (Figure 10).

Blunk Ranch Location

The Blunk Ranch location is situated on Driftwood Creek approximately 7 km northwest of Hardtner, KS (Figure 2 and 12). The valley floor at this locality consists of three LSAs: a narrow, T-0 floodplain, a low T-1 terrace, and a low, broad alluvial fan.

The lateral migration of Driftwood Creek has exposed 2.51+ m of T-1 fill in a cutbank (Blunk Ranch Section). In this exposure, three buried soils are developed in a valley-axis facies beneath a natural levee. A 5.15-m-long soil core (Core 1) taken on the T-1 surface approximately 40 m southwest of the Blunk Ranch Section revealed a fourth buried soil (Soil 5) (Figure 13). The distal portion of the east lobe of a low gradient alluvial fan was also cored (Figure 14), and this 7.60-m-long core (Core 2) contained four buried soils.

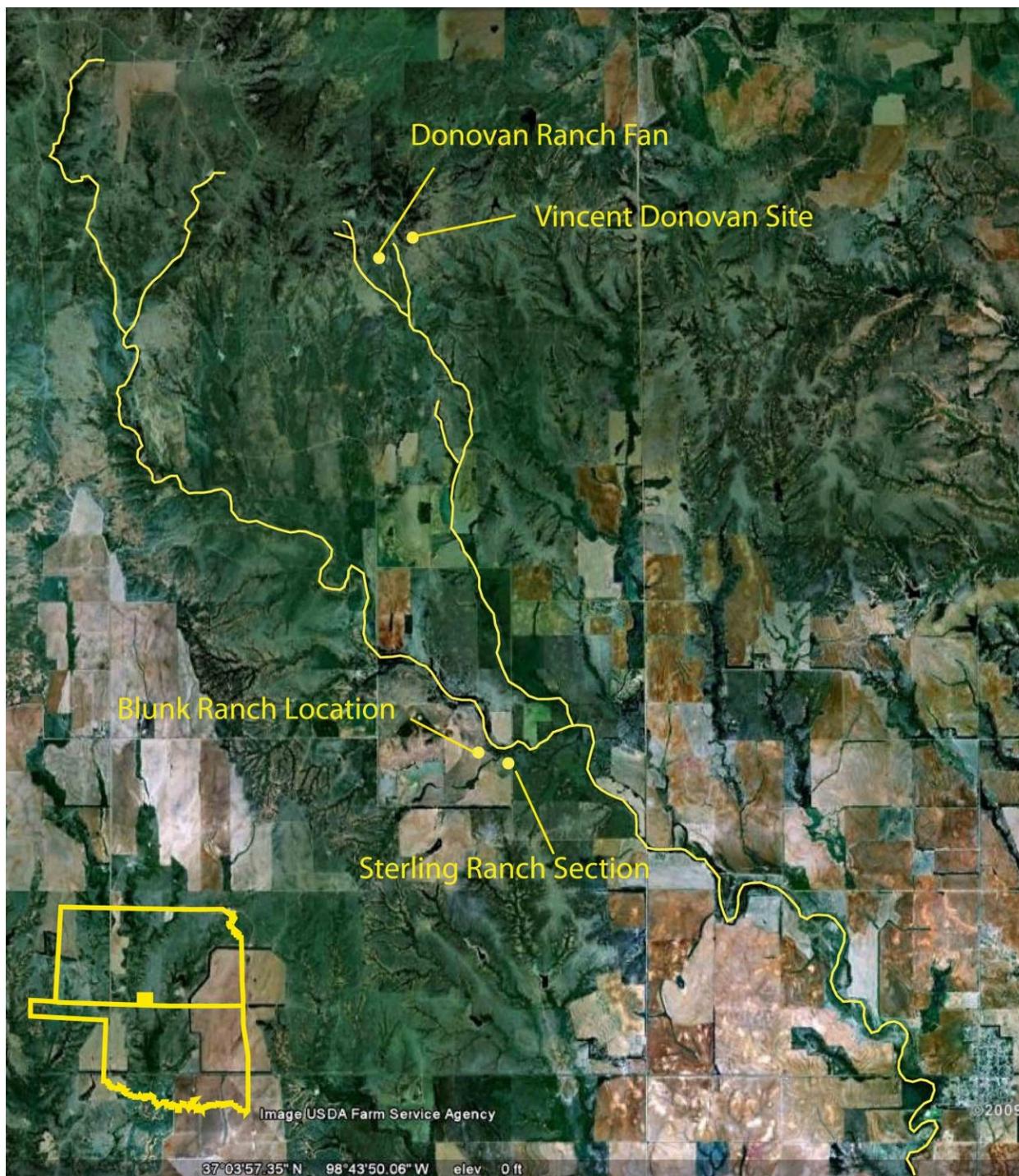


Figure 4. Location of study sites on the upper Driftwood Creek basin.

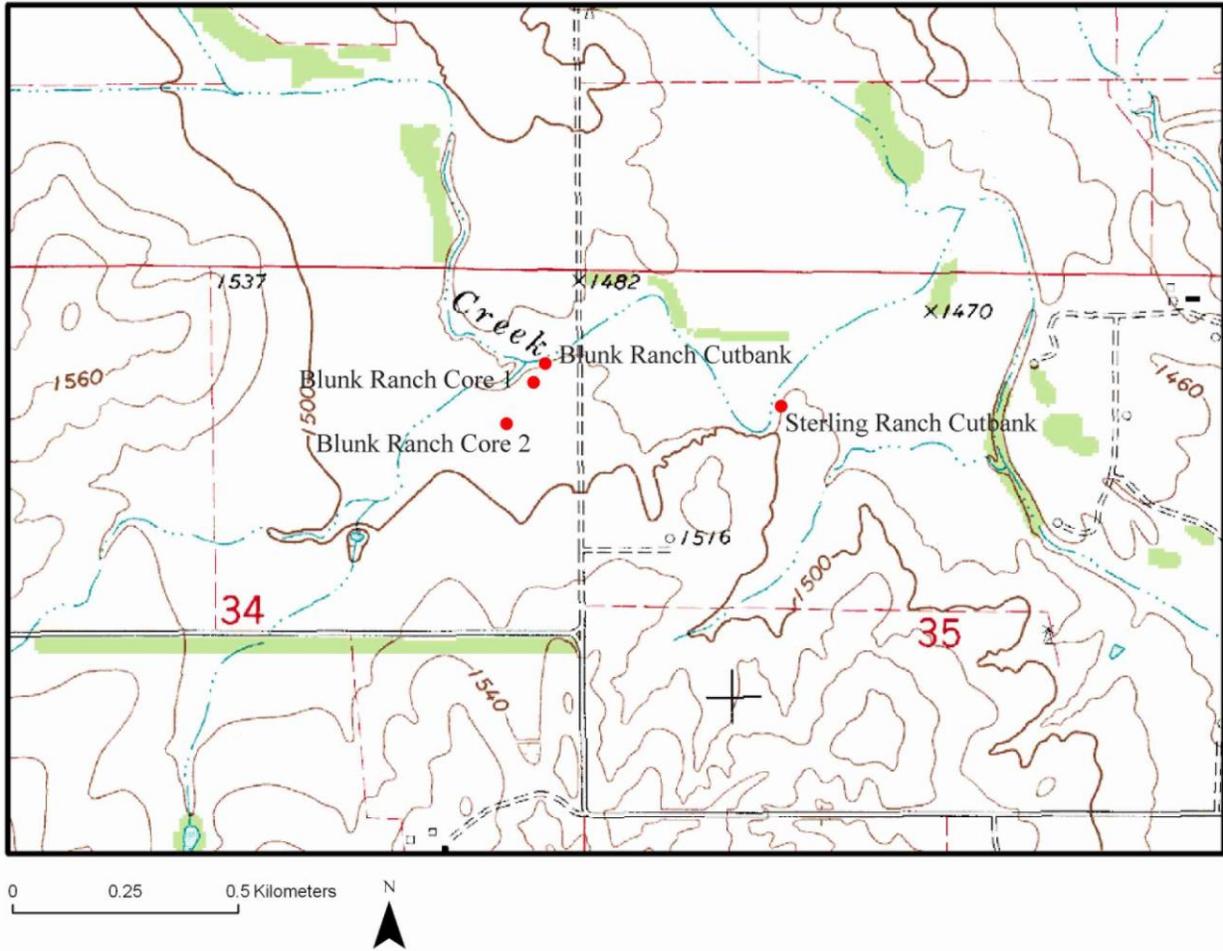


Figure 12. Location of cores 1 and 2 at the Blunk Ranch location and the Sterling Ranch Section.



Figure 13. The T-1 surface at the Blunk Ranch location. View is to the north.



Figure 14. Core 2 being collected on the alluvial fan at the Blunk Ranch location. View is to the southwest.

Stratigraphy

The T-1 fill at the Blunk Ranch location consists of reddish brown (5YR 4/4, dry) to dark grayish brown (7.5YR 4/2, dry), fine-grained vertical accretion deposits (Figure 15 and 16). The soil stratigraphy exposed in the Blunk Ranch Section and in Core 1 exhibit variation typical of a floodplain catena, with stronger soil expression, more compressed profiles, and finer texture away from the channel. The surface soil (Soil 1) has a weakly expressed A-Bw-BC profile in the section, and a weakly expressed Ap-A-Bw profile in Core 1 (Tables 5 and 6 in Appendix A). In the section, soils 2 and 3 have very weakly expressed Ak-ACk profiles. However, in Core 1, Soil 2 has a weakly expressed Ak-Bk profile and Soil 3 has a dark grayish brown overthickened Ak horizon. In Core 1, Soil 4 has a moderately expressed Ak-ABk-Btk-BCK-CBk profile, and is

similar to the profile exposed in the Blunk Ranch Section. However, in the section, Soil 4 is only exposed down to the Btk2b3 horizon. Soil 5, exposed only in Core 1, has a weakly expressed Ay-ABy-BCy profile.

Alluvial fan deposits in Core 2 consist of brown (7.5YR 5/4) to dark brown (7.5YR 3.5/4) fine-grained alluvium (Figure 17). A moderately expressed soil (Soil 1) with an A-AB-Bt-Btk profile has formed on the fan surface and is welded to Soil 2 (Figure 18 and Table 7, appendix A). Soil 2 has a truncated Btk profile and is welded to Soil 3, which has a ABtk-Btk-BCK profile. Soil 4 has a prominent, overthickened Ak horizon overlying a moderately developed Btk-BCK&Bt-C profile. The BCK&Btb3 horizon of Soil 4 contains dark brown clay lamellae (Bt horizon) anastomosing through strong brown silty clay loam matrix (BCK horizon). The clay lamellae are likely illuvial, and given continued pedogenesis, would have merged to form a Bt horizon (see Birkland 1999 pp.113-114). Soil 5 has a prominent, overthickened Ay horizon overlying a ACy horizon. Gypsum, as indicated by the “y” occurs as hard nodules.

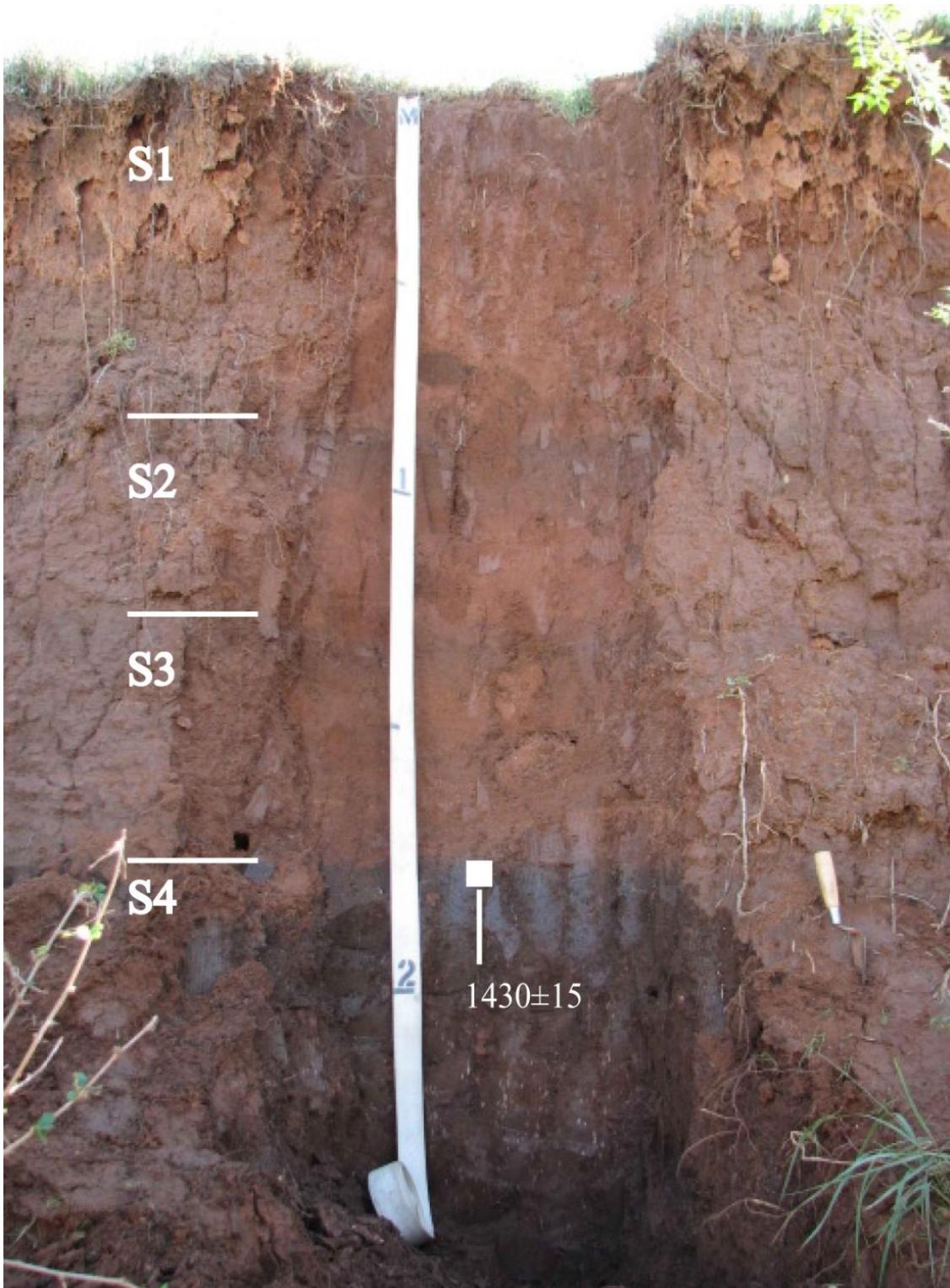


Figure 15. Soil profile and radiocarbon chronology of T-1 terrace fill at the Blunk Ranch section. Soils are numbered from S1-S4. The radiocarbon age was determined on SOM. View is to the south.

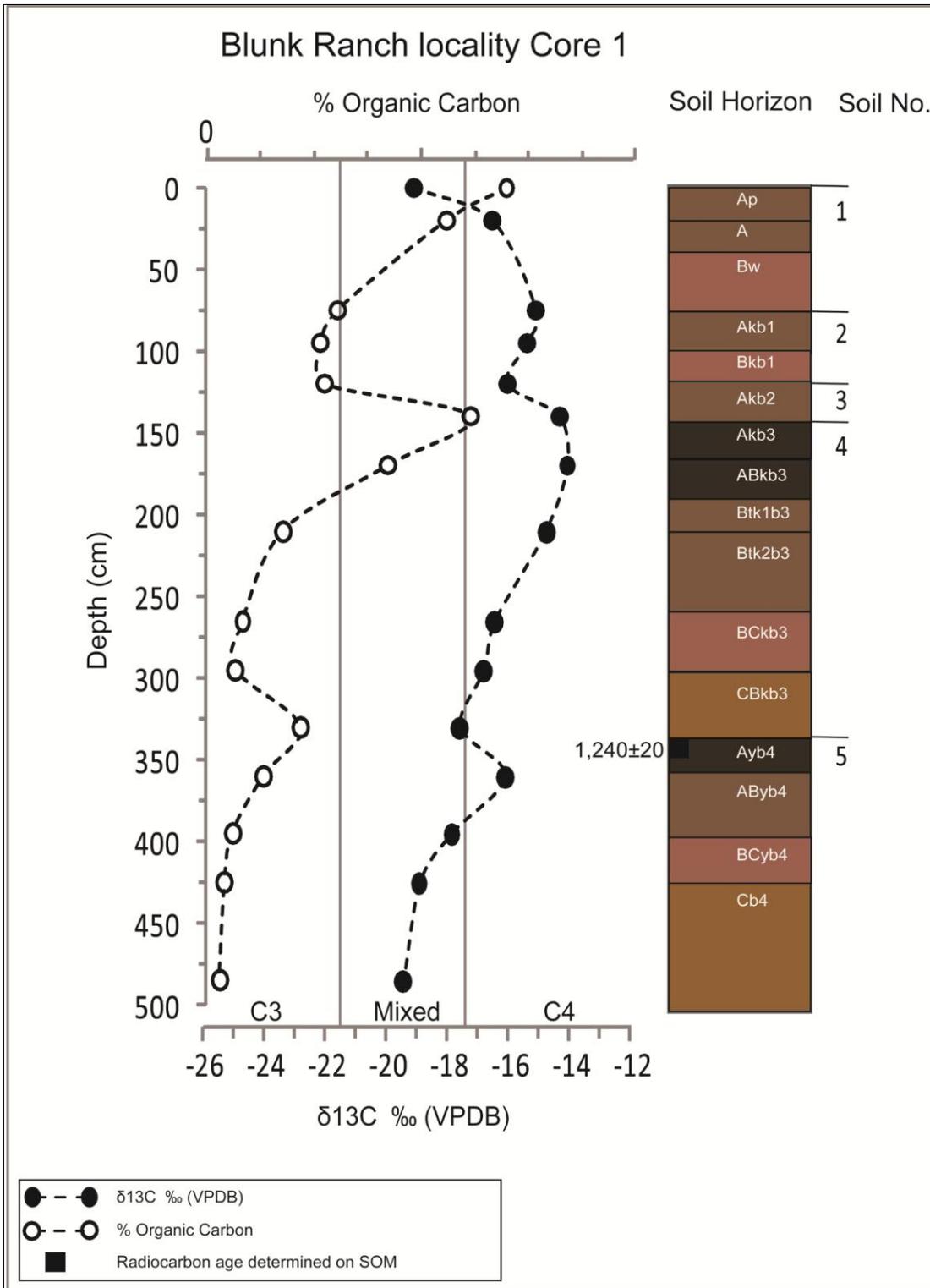


Figure 16. Soil stratigraphy, radiocarbon chronology, and stable carbon isotope ratios of T-1 terrace fill exposed in Core 1 at the Blunk Ranch location.

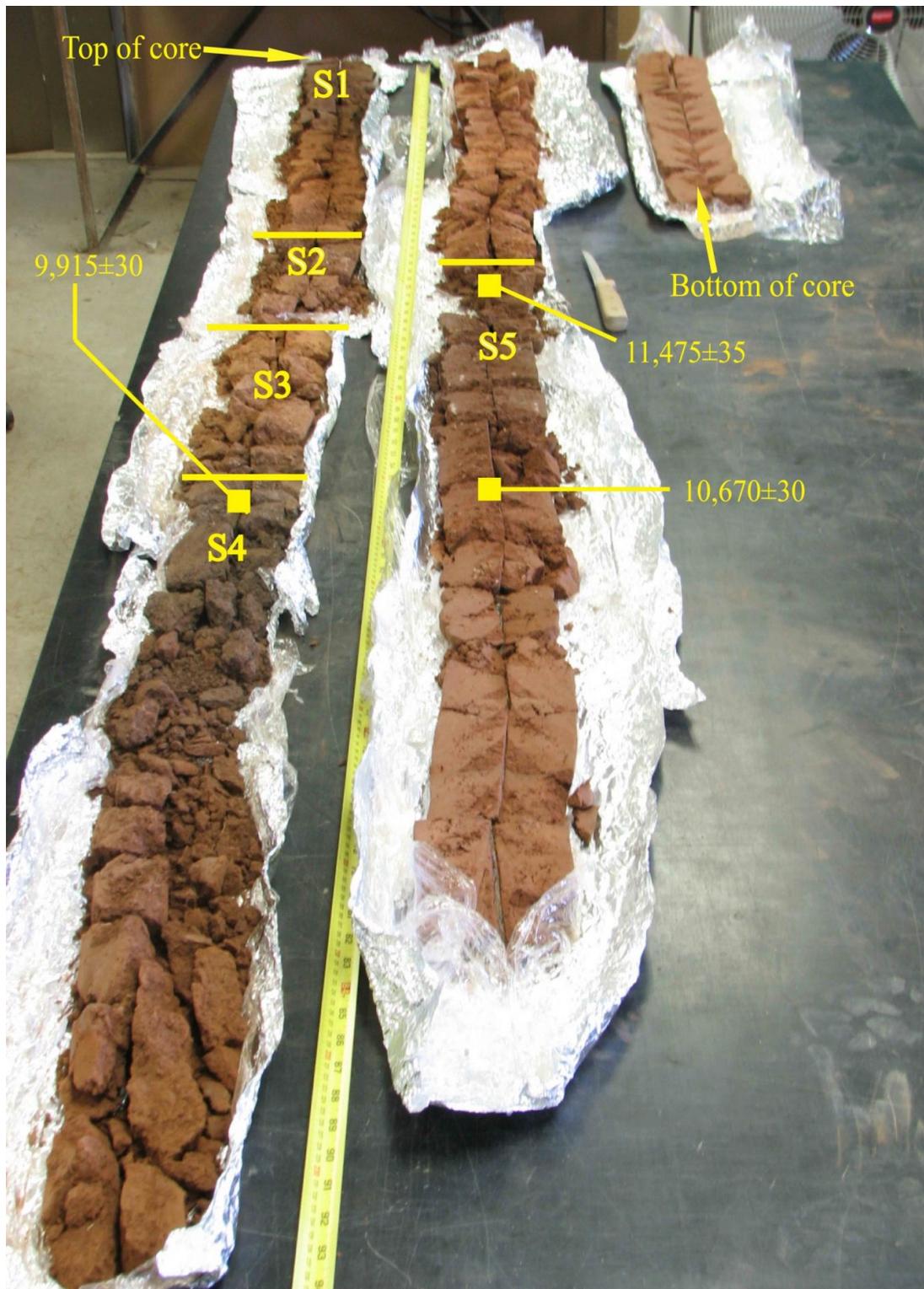


Figure 17. Soil stratigraphy of the alluvial fan at the Blunk Ranch location, Core 2. Soils are numbered S1-S5. Radiocarbon ages were determined on SOM.

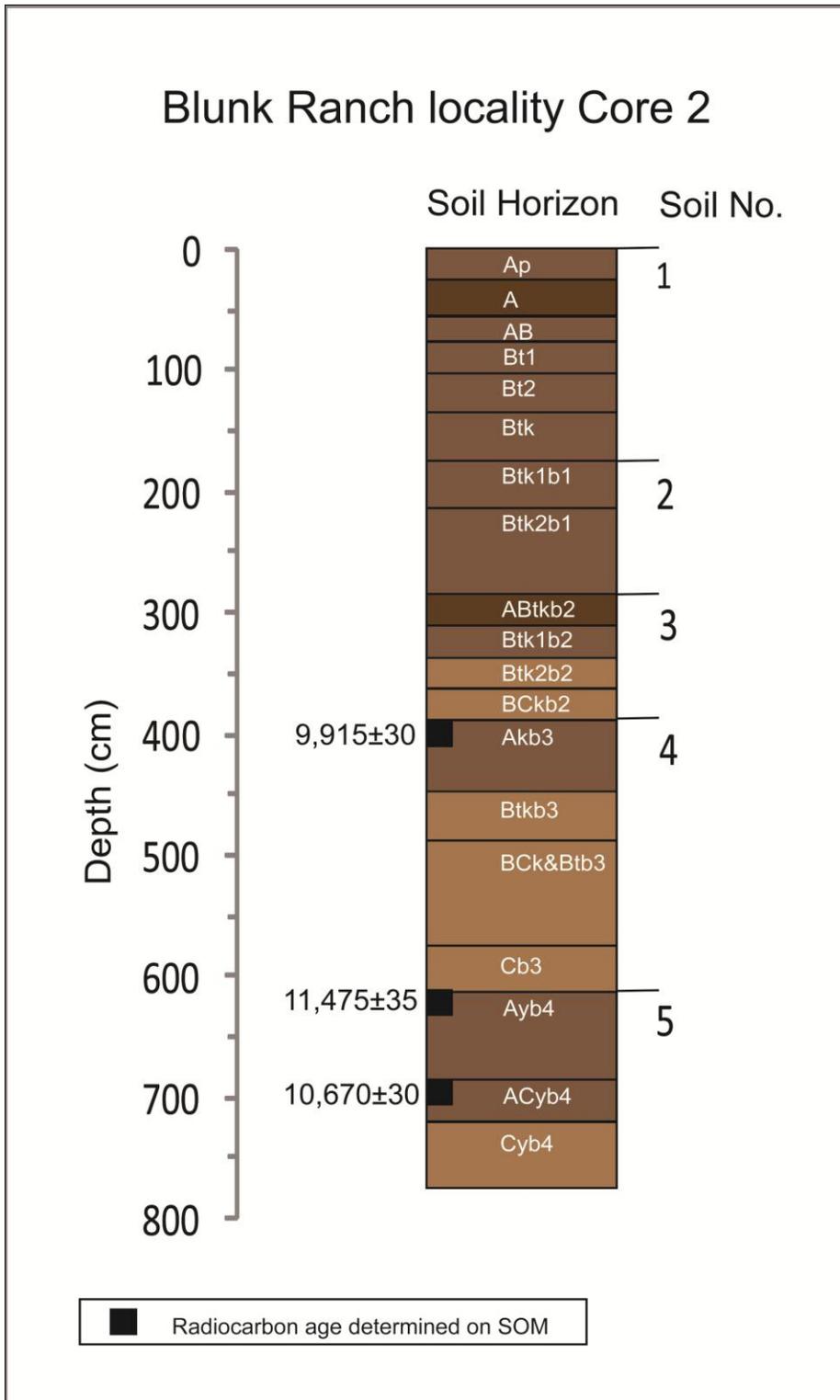


Figure 18. Soil stratigraphy and radiocarbon chronology of the alluvial fan at the Blunk Ranch location, Core 2.

Chronology

Two radiocarbon ages were determined on SOM from buried soils developed in the T-1 fill at the Blunk Ranch location (Table 1, Figures 15 and 16). SOM from the upper 10 cm of Soil 4 exposed in the Blunk Ranch Section yielded an AMS age of $1,430 \pm 15$ ^{14}C yr B.P. SOM from the upper 15 cm of Soil 5 exposed in Core 1 yielded an AMS age of $1,240 \pm 20$ ^{14}C yr B.P. The inversion of ages may be due to the deposition of older detrital carbon with alluvial sediments, or contamination by younger carbon caused by bioturbation or illuviation. However, when the radiocarbon ages were calibrated their standard deviations (2σ) overlapped, indicating that the difference between the ages was not significant, and that the aggradation of alluvium between the formation of soils 5 and 4 was rapid (Table 1).

Three radiocarbon ages were determined on SOM from buried soils developed in the Blunk Ranch Fan (Table 1, Figure 17). SOM from the upper 15 cm soils 4 and 5 yielded radiocarbon ages of $9,915 \pm 30$ and $11,475 \pm 35$ ^{14}C yr B.P., respectively. Also, SOM from the upper 15 cm of the ACy4 horizon of Soil 5 yielded an AMS age of $10,670 \pm 30$ ^{14}C yr B.P. Older detrital carbon from the uplands deposited with alluvial fan fill during the late-Wisconsinan may account for the inversion of AMS ages in Soil 5. If so, then the younger AMS date best estimates the maximum age for the burial of Soil 5.

Stable Carbon Isotopes

$\delta^{13}\text{C}$ values determined on soil carbon from T-1 terrace fill in Core 1 at the Blunk Ranch location decrease by 2.91 ‰ from the surface soil (Soil 1) to Soil 5 (Figure 16). $\delta^{13}\text{C}$ values in Soil 5 average -18.06 ‰. The average $\delta^{13}\text{C}$ value for soils 4, 3, and 2 range from -15.02 ‰ to -16.13 ‰, an average offset of 2.49 ‰ from Soil 5. The $\delta^{13}\text{C}$ values from Soil 1 average -17.91 ‰, but recent cultivation in alfalfa (a C_3 plant) has resulted in soil carbon that is isotopically

depleted in the epipedon of Soil 1. The $\delta^{13}\text{C}$ value for the modern native prairie soil is probably closer to the -15.33 ‰ average obtained from the Ak horizon of Soil 2, which is comparable to $\delta^{13}\text{C}$ values for the surface soil at other grassland sites (Donovan Ranch Fan and the Sterling Ranch Section) in the study area.

UDC-5: Sterling Ranch Section

The Sterling Ranch Section is a remnant T-2 terrace inset against the valley wall of Driftwood Creek approximately 8 km northwest of Hardtner, Kansas (Figures 2 and 12). At the Sterling Ranch Section, lateral migration and incision of Driftwood Creek has exposed a 4.9-m-package of alluvial fill in a cutbank (Figure 19).

Stratigraphy

The T-2 terrace fill in the Sterling Ranch Section consists of brown (7.5YR 5/3 to 4/3, dry) to dark brown (7.5YR3/3, dry), generally fine-grained vertical accretion deposits. Four welded soils forming a pedocomplex are developed in this fill (Table 8 in Appendix A and Figures 20 and 21). A moderately expressed soil (Soil 1) with an A-Bk-Btk profile has formed on the terrace surface. Soil 1 is welded to Soil 2, which has a truncated Btk-Bk profile. Soil 3 has a cummulic Atk-Btk profile. The Atk horizon of Soil 3 has distinct, discontinuous, dark brown clay films on ped faces. Soil 4 has an Ak-Btky-Btyg profile. The Btyg horizons of Soil 4 have dark bluish grey (10B 4/1, dry) mottles and coatings on ped faces and macro-pores. These features were produced by wet reducing conditions during aggradation and pedogenesis in a flood-basin/backwater environment. Reduced colors persist long after burial, and uniformly blue or grey colors indicate saturation under high water tables with little fluctuation (Holliday 2004). Soluble materials, including carbonates (stage I+ morphology) and few, very fine to medium concretions of gypsum, are present in Soil 4 and post-date the wet, reducing conditions.



Figure 19. T-2 fill exposed in a cutbank at the Sterling Ranch locality. View is to the east.

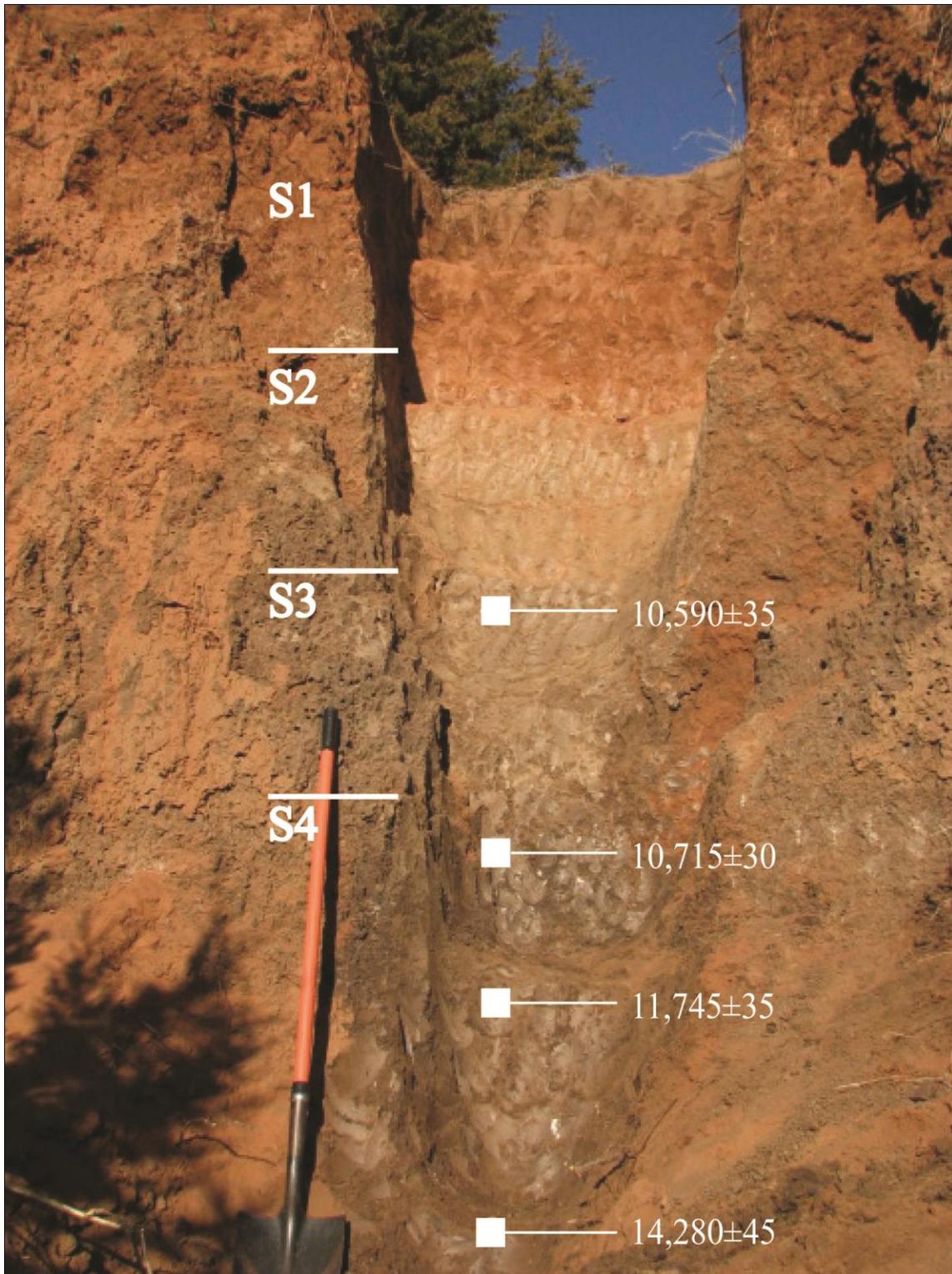


Figure 20. Soil profile and radiocarbon chronology of T-2 terrace fill at the Sterling Ranch Section. The soils are numbered S1-S4. Radiocarbon ages were determined on SOM. View is to the east.

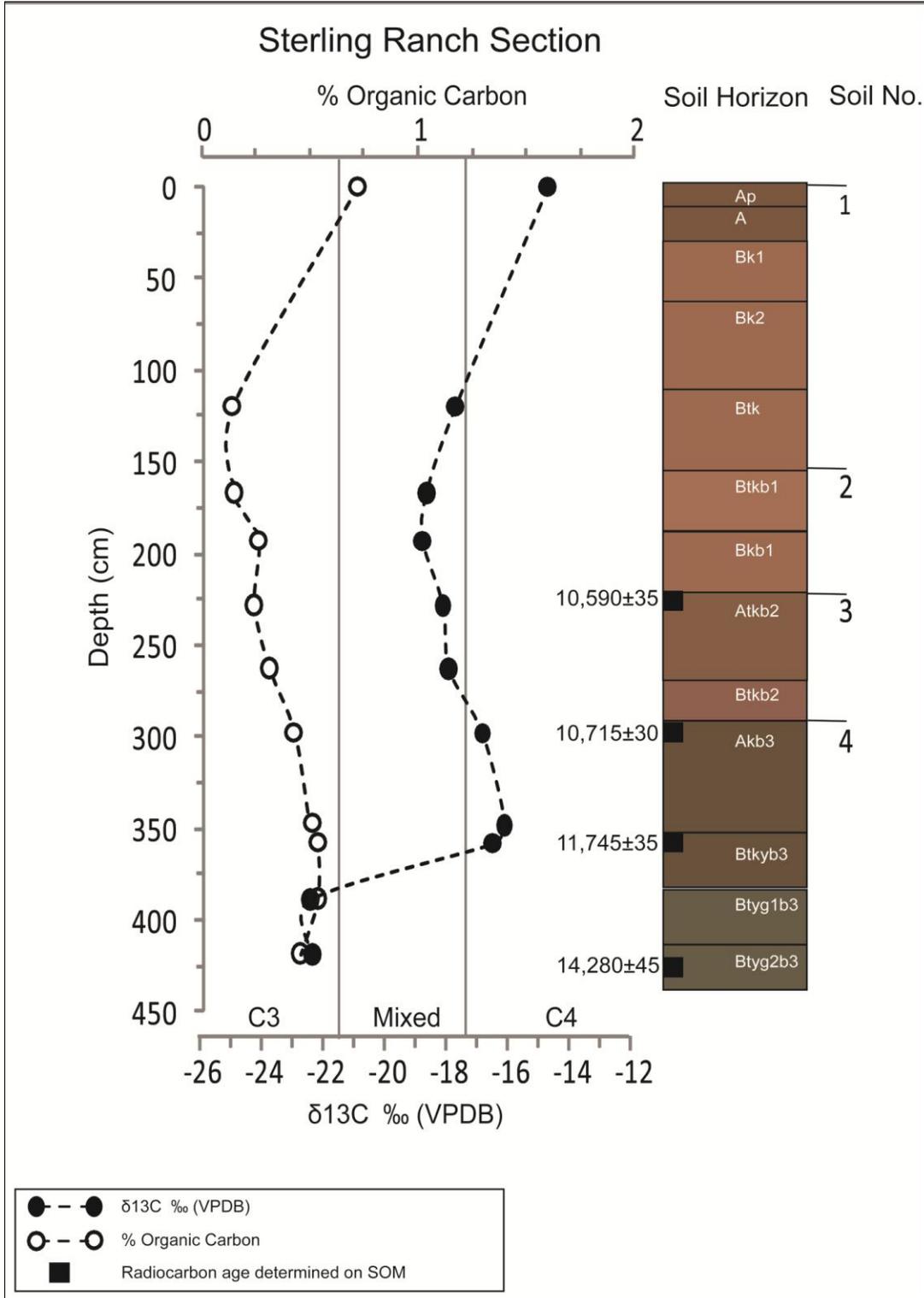


Figure 21. Soil stratigraphy, radiocarbon chronology, and stable carbon isotope ratios of T-2 terrace fill at the Sterling Ranch Section.

Chronology

Four radiocarbon ages were determined on SOM from T-2 terrace fill at the Sterling Ranch Section (Table 1, Figure 20). SOM from the upper 10 cm of the Akb3, Btkyb3, Btyg2b3 horizons of Soil 4 yielded radiocarbon ages of $10,715 \pm 30$, $11,745 \pm 35$, and $14,280 \pm 45$ ^{14}C yr B.P., respectively. SOM from the upper 10 Soil 3 yielded a radiocarbon age of $10,590 \pm 35$ ^{14}C yr B.P.

Stable Carbon Isotope Ratios

The $\delta^{13}\text{C}$ values determined on soil carbon from the Sterling Ranch Section decreased by 7.64 ‰ from the surface soil (Soil 1) to Soil 4 (Figure 21). The $\delta^{13}\text{C}$ values in Soil 4 averaged -18.74 ‰ and increased from -22.46 ‰ in the Btyg2b3 horizon 4.19 m below the terrace surface to -16.94 ‰ in the Akb3 horizon 2.28 m below surface, a 5.52 ‰ offset. $\delta^{13}\text{C}$ values in Soil 3 averaged -18.13 ‰, and $\delta^{13}\text{C}$ values in Soil 2 averaged -18.82 ‰. Soil carbon in the A horizon of Soil 1 had a $\delta^{13}\text{C}$ value of -14.82 ‰, the most isotopically enriched sample in the profile.

CHAPTER VI

CONCLUSIONS

Patterns of landscape evolution are well documented for small ($<5^{\text{th}}$ order) and large ($\geq 5^{\text{th}}$ order) stream valleys in the eastern and western Great Plains of Kansas. Many studies have provided important regional records of late-Quaternary environmental change and have helped explain the distribution of archaeological sites in valley landscapes. However, few such studies have been conducted in the Plains Border Region, along the eastern edge of the High Plains in Kansas. Therefore, this study focused on late-Quaternary valley fills in the upper Driftwood Creek basin, a 3^{rd} order drainage network in south-central Kansas. Radiocarbon ages determined on SOM from buried soils provide a numerical chronology for landscape evolution, and $\delta^{13}\text{C}$ values of soil carbon provide a record of paleoenvironmental change. This information was used to determine the geoarchaeological potential for buried cultural material in terrace fills and alluvial fans within small stream valleys in the southern Plains Border Region (Table 9). Also, $\delta^{13}\text{C}$ values from SOM provide a millennial time-scale reconstruction of paleoenvironmental change over the last 14,000 years (Table 9). The patterns of erosion, sedimentation, and landscape stability as well as changes in climate and vegetation inferred from the $\delta^{13}\text{C}$ values of SOM are relevant to discussions of prehistoric human economies and settlement patterns in Plains Border Region. This is especially true for the early and middle Holocene, and so these results will be discussed in terms of their relevance to explanations for the paucity of recorded Archaic Period sites in the region.

Table 9. The geologic potential for stratified cultural material in the upper Driftwood Creek basin, as well as a summary of paleoenvironments inferred from stable carbon isotope ratios of SOM in the study area.

Alluvial Landform Sediment Assemblage	Cultural Period					
	Pre-Clovis (>11,500)	Paleoindian (11,500– 8,500)	Early Archaic (8,500– 6,000)	Middle Archaic (6,000– 4,000)	Late Archaic (4,000– 2,000)	Ceramic (>2,000)
T-2	++	++	+	+	+	–
T-1	–	–	–	–	+	++
Fans	+	++	++	++	+	–
Paleo-Environment	Cooler; transition from C ₃ to C ₄ /mixed plant community	C ₄ /mixed plant community	C ₃ plant community?	Warmer; C ₄ grasses dominate	Warmer; C ₄ grasses dominate	C ₄ grassland similar to the present

Symbols: ++ high potential, + low potential, – not possible.

Ages for cultural periods are uncalibrated ¹⁴C yr B.P.

Paleo-environments of the Upper Driftwood Creek Basin

Based on $\delta^{13}\text{C}$ values from the Sterling Ranch Section, a predominantly C₃ plant community was in place at ca. 14,200 ¹⁴C yr B.P. indicating cooler than present temperatures and more available moisture during the cool growing seasons. This C₃ plant community gave way to a more C₄ dominated grassland by ca. 11,700 ¹⁴C yr B.P. which persisted until ca. 10,600 ¹⁴C yr B.P. when a mixed C₃/C₄ grassland emerged. The isotopic enrichment of soil carbon between ca. 14,200 ¹⁴C yr B.P. and 10,600 ¹⁴C yr B.P. indicates a general warming and drying trend through the late-Pleistocene, and is generally consistent with results from a paleoenvironmental study in the Oklahoma Panhandle (Bement et al. 2008) and the Cimarron Bend area of southwestern Kansas (Olsen and Porter 2002).

Based on $\delta^{13}\text{C}$ values from the Donovan Ranch Fan, a predominantly C₃ plant community was in place at ca. 7,600 ¹⁴C yr B.P. Depleted $\delta^{13}\text{C}$ values are documented for roughly the same period on the Southern Plains in dunes (Holliday 1997), in loess sections on the Central Plains

(Miao et al. 2007), and in lake sediments on the Northern Plains (Clark et al. 2002). These values may be due to an increase in shrubs prior to ca. 8,000 B.P. caused by an overall decrease in vegetative cover during the early Holocene (Holliday 2004). By ca. 6,700 ¹⁴C yr B.P. C₄ grassland was in place, and has persisted to the present. However, δ¹³C values at and after ca. 4,500 ¹⁴C yr B.P. are more enriched than modern values, indicating a greater proportion of C₄ grasses on the landscape during that time. The isotopic record from the the Donovan Ranch Fan is similar to other paleoecological records from the Great Plains and points to mid-Holocene warming (e.g., Fredlund 1995; Holliday 1997; Baker et al. 2000; Clark et al. 2002; Follett 2004; Forman et al. 2001; Miao et al. 2007; Bement et al. 2008; Mandel 2008).

Based on δ¹³C values from the Blunk Ranch location, a mixed C₃/C₄ plant community was in place during the late Holocene before ca. 1,200 ¹⁴C yr B.P. After, 1,200 ¹⁴C yr B.P. a C₄ dominated grassland appeared and has remained in place. A drier climatic interval beginning ca. 1,000 ¹⁴C yr B.P. has been suggested by other research in the region (Hall 1990). However, the isotopic enrichment of soil carbon after ca 1,200 ¹⁴C yr B.P. at the Blunk Ranch location is relatively small, and the resolution of the δ¹³C data currently make sub-millennial time-scale trends impossible to distinguish.

Geoarchaeology of the Upper Driftwood Creek Basin

Alluvial Terraces

At the Sterling Ranch Section, beginning before ca. 14,200 ¹⁴C yr B.P., slow floodplain aggradation was accompanied by cumulic soil formation (soils 3 and 4). The long term, slow accretion of organic-rich backwater deposits is especially apparent in Soil 4 with its darker color, and the presence of reduced features indicating a saturated environment at this location during the late Wisconsin. Subsequent erosion resulted in the truncation of Soil 2. Based on previous

studies of Holocene landscape evolution in the Central Plains (Mandel 1994, 1995; 2006b; 2007; Baker et al. 2000; Bettis and Mandel 2002), pulses of erosion caused by channel incision and migration likely began sometime after ca. 9,000 ¹⁴C yr B.P. and may have persisted until ca. 4,500 ¹⁴C yr B.P. Based on the magnitude of surface soil development, the T-2 terrace has probably been stable for at least 4,000 years.

The geologic potential for buried Pre-Clovis and Paleoindian-aged cultural material is high beneath remnant T-2 terraces in the upper Driftwood Creek valley. The cumelic A horizons of soils 4 and 3 in the Sterling Ranch Section represent slowly aggrading alluvial surfaces and are archaeologically significant because they can preserve intact features as well as their stratigraphic relationships (see Mandel and Bettis 2001; Holiday 2004; Mandel 2008). While the marshy, poorly-drained flood-basin setting indicated by the Btyg horizons of Soil 4 may have been an important location for foraging activities, it may not have been suitable as a habitation site during times when water tables were elevated. Nevertheless, the relatively stable landscapes represented by soils 3 and 4 in the T-2 fill of Driftwood Creek are high probability targets for archaeological investigations in the region. The geologic potential for the preservation of cultural material post-dating ca. 10,600 ¹⁴C yr B.P. is uncertain.

In Area A of the Vincent-Donovan site, alluvium rapidly aggraded sometime before the terrace surface was occupied by Folsom people between ca. 10,800-10,200 ¹⁴C yr B.P. Then, between the late Wisconsin and the present, artifacts at the site were buried as deep as 35 cm below surface, and the draw next to the site incised into Permian bedrock, forming what is now a high terrace remnant. Folsom artifacts may have been buried by alluvium after they were deposited. However, based on their position in the weakly developed surface soil, the artifacts may have been exposed to multiple cycles of erosion that inhibited soil development over the

course of the Holocene before being buried at shallow depths through bioturbation. If that is the case, artifacts in area A are in an eroded context and may be mixed with chipped stone debitage of different ages. Alternatively, the surface soil may represent a recently exhumed paleosol containing *in situ* Folsom cultural deposits. In order to better understand the context of artifacts in area A, as well as the evolutionary history of similar terrace remnants in the region, more research is needed. Detailed lithic study, including refitting and the analysis of artifact weathering patterns, could address the relationship between buried and surface artifacts at area A. Also, the numerical age of alluvial deposits at area A and in similar terrace fills must be determined in order to better assess the stratigraphic context for such sites. Nevertheless, the presence of Folsom artifacts at the Vincent-Donovan site demonstrates that Paleoindian people frequented the area and that sites of this age may still be preserved in the upper reaches of Driftwood Creek valley.

At the Blunk Ranch location, T-1 fill began aggrading on the valley floor sometime before ca. 1,400 to 1,200 ¹⁴C yr B.P. The longest period of landscape stability and pedogenesis (more than ca. 500 years) is represented by Soil 4, which has a moderately expressed Ak-Btk profile. This period ended with the deposition of 1.40 m of alluvium. Aggradation after ca. 1,400 to 1,200 ¹⁴C yr B.P. was punctuated by brief episodes of landscape stability resulting in the formation of weakly developed soils represented by multistory A-C or A-Bw profiles in axial floodplain facies, and A-Bk profiles or overthickened A horizons in more distal floodplain facies.

The geologic potential for buried Ceramic-aged cultural material is high within T-1 fill in the upper Driftwood Creek valley. On the Central Plains, cultural features such as hearths and mussel-shell middens are commonly found buried in stratified late-Holocene terrace fills and are

often associated with buried A horizons (Holliday 2004; Mandel and Bettis 2001; Mandel 2006b). The Ak horizon of Soil 4 represents a stable floodplain surface during the longest period of landscape stability in the soil-stratigraphic record for the T-1 fill. The buried A horizons of soils 2, 3, and 5 represent brief episodes of landscape stability and may preserve intact cultural deposits from discreet occupations of the floodplain surface due to their rapid burial. Based on the radiocarbon ages, soil-stratigraphy, and the degree of surface-soil development cultural materials above Soil 4 are unlikely to be older than Late Ceramic.

Alluvial Fans

Alluvial fans began developing sometime before ca. 10,700 ¹⁴C yr B.P. along the margin of the Driftwood Creek valley, and before ca. 7,600 ¹⁴C yr B.P. at the mouths of low-order tributaries high the drainage network of Driftwood Creek. At the Blunk Ranch Fan, located on the valley margin of Driftwood Creek, Late-Wisconsinan aggradation was punctuated by at least two episodes of landscape stability resulting in the formation of soils 4 and 5. Slow aggradation of very fine-grained alluvial fan deposits allowed the formation of the cummulic, very weakly expressed Soil 5. Aggradation after ca. 10,700 ¹⁴C yr B.P. buried Soil 5 but eventually slowed enough to allow the formation of the overthickened Akb3 horizon of Soil 4 by 9,900 ¹⁴C yr B.P. After ca. 9,900 ¹⁴C yr B.P., aggradation resumed with at least two episodes of landscape stability and soil development, resulting in the formation of the moderately expressed soils 3 and 2. Soil 2 was truncated by erosion probably during the Holocene.

Aggradation of the Donovan Ranch Fan, located at the mouth of a low-order tributary to Driftwood Creek, began sometime before ca. 7,600 ¹⁴C yr B.P. based on a radiocarbon age from Soil 4. Pedogenesis on the stable Donovan Ranch Fan surface was interrupted sometime after ca. 7,600 ¹⁴C yr B.P. by erosion, which truncated Soil 4. Erosion was followed by aggradation

before ca. 6,700 ¹⁴C yr B.P. and pedogenesis (Soil 3). After ca. 6,700 ¹⁴C yr B.P., aggradation resumed and was followed by landscape stability and pedogenesis (Soil 2). The formation of Soil 2 ended sometime after ca. 4,500 ¹⁴C yr B.P. with erosion followed by the aggradation of the upper 1 m of fan fill.

Alluvial fans have attracted people throughout prehistory because they are often situated between upland and valley settings and represent topographic highs on a valley floor (Mandel and Bettis 2001; Holliday 2004). During the terminal Pleistocene the Blunk Ranch Fan would have been a stable, well drained surface with close access to a perennial water source, upland resources, and clear views of the valley. As previously discussed for the Sterling Ranch Section, cummulic A horizon are targets for archaeological surveys because they represent gradually aggrading surfaces with the potential to accumulate and preserve the remains of previous occupations. Thus, the geologic potential for buried Paleoindian-aged cultural material is high in alluvial fans in the upper Driftwood Creek valley. However, sites dating to this period are probably deeply buried and difficult to locate by standard archaeological survey techniques.

Alluvial fans in the upper reaches of Driftwood Creek may contain Early, Middle, and Late Archaic cultural deposits in stratified contexts. Presently, multiple perennial springs surround the Donovan Ranch Fan. These water sources were probably available during the drier mid-Holocene (Wood 2002) and the area may have drawn Archaic period hunters seeking to trap and kill bison in the many arroyos and small canyons in the upper Driftwood Creek basin. However, erosion events after ca. 7,600 and 4,500 ¹⁴C yr B.P. removed an unknown quantity of alluvium from the fan surface along with any archaeological deposits contained in it. The buried Ak horizon of Soil 3 dating to the Early Archaic may have the highest potential for preserving cultural material because it represents a stable landscape not truncated by erosion. The geologic

potential for buried Paleoindian cultural deposits is uncertain, since the age of deposits below the radiocarbon dated portion of Soil 4 is unknown. Ceramic-aged fan deposits could be preserved in the upper portions of these alluvial fans, though the late-Holocene chronology is uncertain as well. Based on the presence of a weakly expressed surface soil, cultural material deposited on the modern stable surface of the Donovan Ranch Fan will probably date no earlier than the middle-Ceramic.

Implications for the Archaeological Record of the Early and Middle Holocene

Recorded archaeological sites dating to the early and middle Holocene are rare in the archaeological record of the Plains Border Region, as well as the Central and Southern Great Plains as a whole. Explanations have invoked shifts in land use, reduced population densities, and abandonment of the region in response to lower landscape carrying capacities during the warm, dry Altithermal. Also, some researchers have suggested that geomorphic processes removed or obscured the middle Holocene archaeological record in valley landscapes (Mandel 1995; Meltzer 1999; Bettis and Mandel 2002; Sheehan 2002; McBrinn 2010). The results of this study have implications regarding interpretations of the paucity of Archaic Period sites in the region. First, $\delta^{13}\text{C}$ values from SOM at the Blunk Ranch Fan indicate millennial-scale environmental changes that may have affected human land-use and subsistence patterns. Specifically, by altering the productivity and structure of plant communities, middle-Holocene climatic changes would have directly affected bison populations, and therefore hunter-gatherers in the region. While these environmental changes may have driven gradual shifts in settlement and subsistence, patterns of erosion and sedimentation also help explain the paucity of recorded Archaic-aged sites in the region. Erosion associated with middle Holocene landscape instability

has likely removed some deposits dating to the early and middle Holocene from the Driftwood Creek valley.

Seasonal movements of hunter-gatherers on the Great Plains during the early and middle Holocene were likely structured around the availability, abundance, and condition of bison (Hofman 1996; Meltzer 1999). Changes in the composition of grasslands driven by millennial-scale climate change may have altered patterns in bison behavior by affecting the seasonal abundance and quality of forage. Isotopically depleted $\delta^{13}\text{C}$ values from the Donovan Ranch Fan indicate a possible increase in shrubs and a decrease in warm season grasses around ca. 7,600 ^{14}C yr B.P. due to increased aridity, especially during the summers, as well as an overall reduction of vegetative cover (Clark et al. 2002; Holliday 2004). However, by ca. 6,700 ^{14}C yr B.P., C_4 grasses dominate the plant community indicating warmer and dryer conditions than today with a seasonal distribution of precipitation similar to the present. A relative decrease in grasses and an increase in shrubs around 7,600 ^{14}C yr B.P. would have reduced the quality and abundance of forage available to bison in the area, since bison graze very little on shrubs even when they are plentiful, such as in semi-arid shrub-steppe vegetation communities (Van Vuren 1984). At the regional scale, an overall less productive landscape may have resulted in the expansion of hunter-gatherer diet breadth and a more intensive, longer-term utilization of resource patches to accommodate the reduced numbers or condition of top-ranked prey species such as bison (Meltzer 1999; Sheehan 2002; Garvey 2008). After 6,700 ^{14}C yr B.P. the increased proportion of C_4 grasses may have reduced the quality of forage during the spring and fall. This is important because C_3 grasses have higher levels of crude protein than C_4 grasses and are critical to bison during the calving season (mid-April), as well as after the rut (mid-July to August) when weight gain before winter is crucial (Schwartz and Ellis 1981; Plumb and Dodd 1993). In addition, the

smaller proportion of C₃ grasses on the Great Plains generally during the mid-Holocene has been correlated to the rapid reduction in bison body size, which has been interpreted as an evolutionary response to reduced forage quality (Hill et al. 2008). Also, the increased proportion of warm season grasses in the area would have resulted in abundant summer forage, and may have allowed larger congregations of bison during the mid-summer than in previous times.

Middle Holocene paleo-environmental records do not indicate a uniformly warm and dry climate, and it is likely that the Central Great Plains remained populated during much of the middle Holocene (Meltzer 1999). Therefore, while the results of this study suggest that millennial-scale environmental changes could have affected settlement patterns of hunter-gatherers over the course of the early and middle Holocene, this factor alone does not explain the paucity of recorded Archaic-aged sites in the region. In the Driftwood Creek valley, spatial and temporal patterns of erosion and sedimentation have resulted in the net removal of middle Holocene deposits and have reduced the probability of finding buried *in situ* cultural material from this period. This fits the generalized model for landscape evolution for small streams in the Central Plains as a whole and helps explain why so few Archaic-aged sites have been recorded in the region (Mandel 1995; 2006b; Bettis and Mandel 2002). However, middle Holocene deposits were recorded beneath the Donovan-Ranch Fan at the mouth of a low-order tributary high in the drainage network of Driftwood Creek. The fan began aggrading before ca. 7,600 ¹⁴C yr B.P., probably in response to a reduction in vegetative cover which caused large-scale erosion on the uplands and delivery of sediment to the valley floor. Aggradation continued until after ca. 4,500 ¹⁴C yr B.P. Three buried soils, two of which have been truncated by erosion, indicate that the aggradation of the fan was punctuated by periods of landscape stability followed by instability and erosion. Because alluvial fans were zones of net sediment storage during the early and

middle Holocene (Mandel 1995; 2006b) they should be targets for when searching for stratified Archaic cultural material in the region.

CHAPTER VII

SUMMARY

The purpose of this study was to assess the geologic potential for stratified cultural material in small stream valleys in the region and to reconstruct paleoenvironmental changes that may have affected human economies and settlement patterns. AMS ^{14}C ages determined on SOM from stratigraphic sections and cores provide a numerical chronology for the evolution of late-Quaternary alluvial landform sediment assemblages. In addition, an isotopic record of paleoecological change spanning 14,000 ^{14}C years was reconstructed from $\delta^{13}\text{C}$ values determined on pedogenic carbon at the study sites.

The T-2 fill of upper Driftwood Creek consists of 4.3+ m of fine-grained vertical accretion deposits that began aggrading sometime before ca. 14,200 ^{14}C yr B.P. Slow aggradation during the late Wisconsin was accompanied by soil development until ca. 10,600 ^{14}C yr B.P., resulting in the formation of two welded cumulic soils. These soils are buried beneath 2.28 m of alluvium. There is evidence for reduction of the lowermost buried soil, indicating saturation under higher than present water tables. Sometime during the Holocene, Driftwood Creek incised, thereby abandoning the late-Wisconsinan floodplain (now the T-2 terrace).

The T-1 fill consists of 5.1+ m of fine-grained vertical accretion deposits that began aggrading before ca. 1,400 ^{14}C yr B.P. Late-Holocene aggradation was punctuated by multiple brief episodes of landscape stability and pedogenesis, resulting in the formation of four weakly developed soils. Alluvium dating to the mid-Holocene was not recorded in the terrace fills of Driftwood Creek, probably due to erosion associated with landscape instability after ca. 9,000 ^{14}C yr B.P.

Along the margin of the valley floor of the Driftwood Creek, there is evidence for the development of alluvial fans beginning before ca. 10,700 ¹⁴C yr B.P. At the Blunk Ranch Fan, aggradation was punctuated by two episodes of cumulic soil formation between ca. 10,700 ¹⁴C yr B.P. and soon after ca. 9,900 ¹⁴C yr B.P. Along the margin of the valley floor of a low-order tributary to Driftwood Creek, the Donovan Ranch Fan began aggrading sometime before ca. 7,600 ¹⁴C yr B.P. Three buried soils indicate that the aggradation of the fan was punctuated by periods of landscape stability before 7,600, 6,700 and 4,500 ¹⁴C yr B.P. followed by instability and erosion.

Based on $\delta^{13}\text{C}$ values from the study area, a predominantly C₃ plant community was in place at ca. 14,200 ¹⁴C yr B.P. By ca. 11,700 ¹⁴C yr B.P. C₄ grassland persisted, and remained in place until ca. 10,600 ¹⁴C yr B.P. when a mixed C₃/C₄ plant community emerged. By ca. 7,600 ¹⁴C yr B.P. a C₃ plant community dominated in the study area, but by ca. 6,700 ¹⁴C yr B.P., C₄ grassland was in place and has persisted to the present. The isotopic enrichment of soil carbon between ca. 14,200 ¹⁴C yr B.P. and 10,600 ¹⁴C yr B.P., and after ca. 6,700 ¹⁴C yr B.P. indicates a general warming and drying trend through the late Wisconsin and again during the mid-Holocene; this is broadly consistent with other regional paleoenvironmental records.

Buried late-Wisconsinan landscapes represented by overthickened A horizons are preserved beneath alluvial fans and remnant T-2 terraces. These soils are targets for archaeological surveys in the region and could have intact stratified pre-Clovis and Paleoindian-aged cultural deposits. Buried early and mid-Holocene landscapes are preserved in alluvial fans in the upper reaches of low-order drainage networks and could contain stratified Archaic-aged cultural deposits. Buried late-Holocene landscapes were identified beneath the T-1 terraces and

represent relatively brief episodes of landscape stability that could contain stratified Ceramic-aged cultural material.

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APPENDIX A

Table 2. Description of soil profile at 14BA308 area A

Depth (cm)	Soil Horizon	Description
0-12	A	Dark brown (7.5YR 3.5/4) loam to very fine sandy loam, dark brown (7.5Y R3/4) moist; weak fine granular structure; soft, very friable; common pebbles; many fine to very fine roots; few worm casts and open worm burrows; common fine to very fine pores; smooth gradual boundary.
12-24	AB	Brown (7.5YR 4/4) very fine sandy loam, dark brown (7.5YR 3/4) moist; weak fine subangular blocky structure parting to weak medium to fine granular; slightly hard, friable; common pebbles; many fine roots; many granules, few worm casts and open worm burrows; common fine and few medium pores; gradual smooth boundary.
24-38	Bw1	Brown (7.5YR 4/4) fine sandy loam, dark brown (7.5YR 3.5/4) moist; weak fine subangular blocky structure parting to weak fine granular; slightly hard, friable; common fine pebbles; common fine and very fine roots; common granules; few worm casts and open worm burrows; common fine pores, few medium pores; gradual smooth boundary
38-59	Bw2	Brown (7.5YR 4/4) fine sandy loam, dark brown (7.5YR 3.5/4) moist; weak medium prismatic structure parting to weak fine subangular blocky; slightly hard, friable; common fine to medium pebbles; few fine angular cobbles; common fine roots, few very fine roots; many granules; few worm casts and open worm burrows; common fine and few medium pores; gradual smooth boundary.
59-82	BC	Strong brown (7.5YR 4/6) fine sandy loam, dark brown (7.5YR 3/4) moist; light brown (5YR 6/4) sand lens, reddish yellow (5YR 6/6) moist; very weak fine prismatic structure, parting to very weak fine subangular blocky; slightly hard, friable; common fine to medium pebbles; few lenses of fine subrounded cobbles; few fine roots; few worm casts and open worm burrows; common fine and few medium pores; faint bedding; gradual smooth boundary.

82-100	C1	Strong brown (7.5YR 4/6) stratified sand and gravel, dark brown (7.5YR 3.5/4) moist; light brown (5YR 6/4) sand lenses, reddish yellow (5YR 6/6) moist; single grain; loose; few fine and very fine roots; few worm casts and open worm burrows; few macropores; abrupt smooth boundary.
100-130	C2	Strong brown (7.5YR 4/6) clay loam, dark brown (7.5YR 3/4) moist; massive; hard; few fine roots; many fine to very fine pores; very faint bedding; abrupt smooth boundary.
130-143	C3	Strong brown (7.5YR 4/6) stratified sand interbedded with clay loam, dark brown (7.5YR 3/4) moist; sand beds: single grain; loose; clay loam: massive; hard(dry), firm(moist); few lenses of gravel; few very fine roots; many fine and very fine pores in clay loam beds; abrupt smooth boundary.
143-220+	C4	Strong brown (7.5YR4/6) stratified clay loam interbedded with loamy fine sand, dark brown (7.5YR3/4) moist; massive; hard, firm; common lenses of gravel, fine pebbles, and shale rip up clasts; few very fine roots; many fine and very fine pores in clay loam; common fine to very fine pores in loamy fine sand.

Table 3. Description of soil profile at 14BA308 area D

Depth (cm)	Soil Horizon	Description
0-11	A	Brown (7.5YR 4/4) silty clay loam, dark brown (7.5YR 3/3.5) moist; weak fine subangular blocky structure parting to moderate fine and medium granular; hard, friable; very few fine pebbles; many fine to very fine roots; few worm casts and open worm burrows; few fine and very fine pores; gradual smooth boundary.
11-25	AC1	Brown (7.5YR 4/4) silty clay loam, dark brown (7.5YR 3/4) moist; moderate medium prismatic structure parting to moderate fine subangular blocky; very hard, firm; common dark brown (7.5YR 3/3) distinct nearly continuous flood coats on surfaces of ped faces; few very fine pebbles; few granules; common fine and very fine roots; few worm casts and open worm burrows; few fine and very fine pores; gradual smooth boundary.
25-55+	AC2	Brown (7.5YR 4/4) silty clay loam, dark brown (7.5YR 3/4) moist; moderate medium prismatic structure parting to moderate fine subangular blocky; very hard, firm; common dark brown (7.5YR 3/3) distinct nearly continuous flood coats on surfaces of ped faces, frequency decreasing with depth; few very fine pebbles; few granules; common fine to very fine roots; few worm casts and open worm burrows; few fine to very fine pores.

Table 4. Description of soil profile at the Donovan Fan

Depth (cm)	Soil Horizon	Description
0-35	A	Brown (7.5YR 4/3.5), fine sandy loam, dark brown (7.5YR 3/3) moist; weak fine to medium subangular blocky structure parting to weak fine granular; slightly hard, friable; very few fine pores; many fine and medium roots, few coarse roots; few open worm burrows and casts; common pebbles; gradual smooth boundary.
35-64	AB	Brown (7.5YR 4/4), fine sandy loam, dark brown (7.5YR 3/4) moist; weak fine granular structure parting to weak very fine granular; soft, friable; few fine to medium pores; many fine and medium roots, few coarse roots; few open worm burrows and worm casts; common pebbles; gradual smooth boundary.
64-80	Bw1	Brown (7.5YR 4/4), fine sandy loam, dark brown (7.5YR 3/4) moist; weak fine subangular blocky structure parting to weak fine granular; soft, friable; few fine to medium pores; common fine roots and very few coarse roots; few open worm burrows and worm casts; common pebbles; gradual smooth boundary.
80-110	Bw2	Brown (7.5YR 4/4), fine sandy loam, dark brown (7.5YR 3/4) moist; weak medium subangular blocky structure parting to weak fine granular; slightly hard, friable; few fine pores; very few open worm burrows and worm casts; few fine and medium roots; common pebbles; clear smooth boundary.
110-132	Btkb1	Brown (7.5YR 4/4), fine sandy clay loam dark brown (7.5YR 3/4) moist; moderate medium prismatic structure parting to weak fine to medium subangular blocky; hard, friable; common faint discontinuous dark brown (7.5YR 3/3) clay films on ped faces; few thin threads, films, and flecks of CaCO ₃ ; common fine and medium pores; very few open worm burrows, common closed worm burrows and worm casts; common fine and medium roots; many pebbles and few cobbles; clear smooth boundary.

132-157	Akb2	Dark brown (7.5YR 3.5/4), coarse sandy loam, dark brown (7.5YR 3/2) moist; moderate medium prismatic structure parting to moderate fine to medium subangular blocky; hard, firm; few fine and medium pores; few open and closed worm burrows and worm casts; few fine and coarse roots; many pebbles; abrupt smooth boundary.
157-177	Bk1b2	Brown (7.5YR 5/4), fine to coarse sandy loam, brown (7.5YR 4/4) moist; weak medium subangular blocky structure parting to weak fine subangular blocky; hard, firm; very few fine threads and few films of CaCO ₃ ; common fine pores; few fine and medium roots; many pebbles and few cobbles; gradual smooth boundary.
177-202	Bk2b2	Brown (7.5YR 5/4), coarse sandy loam, brown (7.5YR 4/4) moist; moderate medium subangular blocky structure parting to moderate fine subangular blocky; very hard, very firm; common fine threads, films, and flecks of CaCO ₃ ; many fine and medium pores; very few fine and medium roots; many pebbles and common cobbles; gradual smooth boundary.
202-222	BCkb2	Brown (7.5YR 5/4), coarse sandy loam, brown (7.5YR 4/4) moist; weak fine to medium subangular blocky structure parting to very fine subangular blocky; hard, firm; common flecks, few fine threads and films of CaCO ₃ ; common fine pores; few fine roots; many pebbles and few cobbles; gradual smooth boundary.
222-247	Cb2	Brown (7.5YR 5/4), coarse sandy loam, brown (7.5YR 4/4) moist; massive; hard, friable; few fine pores; many pebbles and few cobbles; faint bedding; abrupt smooth boundary.
247-267	2Btb3	Brown (7.5YR 4/4), very fine sandy clay loam, dark brown (7.5YR 3/4) moist; strong coarse prismatic structure parting to moderate medium prismatic; hard, firm; common distinct discontinuous dark brown (7.5YR 3/3) clay films on ped faces; few fine and medium pores; very few fine roots; many pebbles and shale rip-up clasts; clear smooth boundary.

267-292	BCtb3	Brown (7.5YR 5/4), very fine sandy clay loam, brown (7.5YR 4/4) moist; weak fine to medium subangular blocky structure parting to weak very fine subangular blocky; hard, friable; few faint discontinuous brown (7.5YR 4/4) clay films on ped faces; many fine roots; common medium pores; abrupt smooth boundary.
292+	Cb3	Brown (7.5YR 5/4), coarse sandy loam, brown (7.5YR 4/4) moist; stratified; massive; slightly hard, firm; few fine and medium pores; very few fine roots.

Table 5. Description of soil profile at the Blunk Ranch Section

Depth (cm)	Soil Horizon	Description
0-23	A	Strong brown (7.5YR 4/6) silt loam, dark brown (7.5YR 3/4) moist; weak fine granular structure; soft, very friable; many fine and very fine roots; common worm casts and open worm burrows; common fine and very fine pores; gradual smooth boundary.
23-63	Bw	Strong brown (7.5YR 4/6) silt loam, dark brown (7.5YR 3/4) moist; very weak fine subangular blocky structure parting to very weak very fine subangular blocky; soft, very friable; common fine and very fine roots, few medium roots; common worm casts and open worm burrows; common fine and very fine pores; gradual smooth boundary.
63-85	BC	Strong brown (7.5YR 4/6) silt loam, dark brown (7.5YR 3/4) moist; weakly stratified; very weak very fine subangular blocky structure; soft, very friable; bed of fine pebbles at 65-67cm; common fine and very fine roots; common worm casts and open worm burrows; common krotovinas 10-12 cm in diameter filled with silt loam from above; many fine and very fine pores; faint bedding clear irregular boundary.
85-101	Akb1	Strong brown (7.5YR 4/6) silt loam, dark brown (7.5YR 3/3.5) moist; weak fine subangular blocky structure parting to weak fine granular; soft, friable; common films and fine threads of CaCO ₃ ; common fine and very fine roots; few worm casts and open worm burrows; many very fine pores; gradual smooth boundary.
101-130	ACkb1	Strong brown (7.5YR 4/6) very fine sandy loam, dark brown (7.5YR 3/4) moist; very weak very fine subangular blocky structure parting to weak very fine granular; soft, very friable; common fine threads and films of CaCO ₃ ; common fine and very fine roots; few worm casts and open worm burrows; common krotovinas 10-12cm in diameter; common fine and very fine pores; faint bedding; clear smooth boundary.

- 130-145 Akb2 Strong brown (7.5YR 4/6) silt loam, dark brown (7.5YR 3/4) moist; weak very fine subangular blocky structure parting to weak fine granular; soft, very friable; common fine threads and films of CaCO₃; common fine and very fine roots; few worm casts and open worm burrows; common fine and very fine pores; gradual smooth boundary.
- 145-173 ACkb2 Strong brown (7.5YR 4/6) coarse silt loam, dark brown (7.5YR 3/4) moist; very weak fine subangular blocky structure parting to weak fine granular; soft, friable; common films and fine threads of CaCO₃; common fine and very fine roots; few worm casts and open worm burrows; many fine and very fine pores; faint bedding; abrupt smooth boundary.
- 173-199 Akb3 Dark brown (7.5YR 3/4) silt loam, very dark brown (7.5YR 2/2) moist; weak fine subangular blocky structure parting to moderate fine granular; slightly hard, friable; common fine films and medium threads of CaCO₃; common very fine and few fine roots; common worm and ants burrows filled with silt loam from above; many very fine pores; gradual smooth boundary.
- 199-207 ABkb3 Dark brown (7.5YR 3/4) silt loam, dark brown (7.5YR 3/2) moist; weak fine subangular blocky structure parting to moderate medium coarse granular; slightly hard, friable; common fine films and medium threads of CaCO₃; few fine roots; common worm casts and open worm burrows; common fine and very fine pores; gradual smooth boundary.
- 207-231 Btk1b3 Dark brown (7.5YR 4/4) silty clay loam, dark brown (7.5YR 3/4) moist; moderate subangular blocky structure parting to moderate fine subangular blocky; hard, firm; common distinct discontinuous dark brown (7.5YR 3/4) thin clay films on ped faces; common encrusted threads of CaCO₃, few fine soft CaCO₃ concretions, and few slightly hard CaCO₃ risoliths; few very fine roots; very few worm casts and open worm burrows; many fine and very fine pores; gradual smooth boundary.

231-
251+ Btk2b3 Dark brown (7.5YR 4/4) silty clay loam, dark brown (7.5YR 3/4) moist; weak medium subangular blocky structure parting to weak fine subangular blocky; hard, firm; few thin distinct dark brown (7.5YR 3/4) clay films on ped faces; common encrusted threads of CaCO₃, few fine soft CaCO₃ concretions, and few slightly hard CaCO₃ risoliths; few very fine roots; very few worm casts and open worm burrows; few very fine pores.

Table 6. Description of soil Core 1 at the Blunk Ranch location

Depth (cm)	Soil Horizon	Description
0-20	Ap	Brown (7.5YR 4/3), silt loam, dark brown (7.5YR 3/3) moist; weak fine granular structure parting to very fine granular; slightly hard, friable; common open worm burrows and casts; common very fine to fine roots; very few very fine and fine pores.
20-35	A	Brown (7.5YR 4/3), silt loam, dark brown (7.5YR 3/2) moist; weak fine granular structure parting to weak very fine granular; slightly hard, friable; common open worm burrows and casts; common very fine and fine roots; many very fine and common fine pores.
35-75	Bw	Brown (7.5YR 4/4), silt loam, dark brown (7.5YR 3.5/4) moist; weak fine subangular blocky structure; slightly hard, friable; few dark brown (7.5YR 3/4) thin faint discontinuous clay films on ped faces; common open worm burrows and casts; very few very fine and fine roots; common fine to medium pores.
75-100	Akb1	Brown (7.5YR 4/3), silt loam, dark brown (7.5YR 3/3) moist; weak medium subangular blocky structure parting to moderate medium and fine granular; slightly hard, friable; common films and fine threads and very few soft concretions of CaCO ₃ ; common open worm burrows and casts; few fine roots; common very fine and fine pores and few medium pores.
100-120	Bkb1	Brown (7.5YR 4/3), silt loam, dark brown (7.5YR 3.5/3) moist; weak medium subangular blocky structure parting to weak fine subangular blocky; slightly hard, friable; few dark brown (7.5YR 3/4) faint discontinuous clay films on ped faces; few fine threads of CaCO ₃ ; very few open worm burrows and casts; very few very fine roots; common fine and medium pores.
120-140	Akb2	Brown (7.5YR 4/2), silt loam, dark brown (7.5YR 3.5/3) moist; weak medium subangular blocky structure parting to weak fine subangular blocky; slightly hard, friable; common fine threads and films of CaCO ₃ ; very few open worm burrows and casts; very few very fine roots; common fine and medium pores.

140-170	Akb3	Brown (7.5YR 4/2), silt loam, dark brown (7.5YR 3/2) moist; weak fine subangular blocky structure parting to moderate medium to coarse granular; loose, friable; common fine threads and films of CaCO ₃ ; common very fine to fine pores; few fine roots; common very fine and fine pores.
170-185	ABkb3	Brown (7.5YR 4/3), silt loam, dark brown (7.5YR 3/3) moist; weak fine subangular blocky structure parting to moderate medium to coarse granular; loose, friable; very few fine threads and films of CaCO ₃ ; few fine roots; common very fine and fine pores.
185-210	Btk1b3	Brown (7.5YR 4/3), silty clay loam, dark brown (7.5YR 3/3) moist; moderate medium subangular prismatic structure parting to moderate fine subangular blocky; slightly hard, friable; few distinct discontinuous dark brown (7.5YR 3/3) clay films on ped faces; very few flecks of CaCO ₃ ; few fine roots; few fine and very few medium pores.
210-265	Btk2b3	Brown (7.5YR 4/4), silty clay loam, dark brown (7.5YR 3/4) moist; moderate coarse prismatic structure parting to moderate medium to fine subangular blocky; hard, firm; few faint discontinuous dark brown (7.5YR 3/3) clay films on ped faces; very few fine flecks and hard concretions of CaCO ₃ ; few fine and very fine roots; common very fine and fine pores and very few medium pores.
265-295	BCkb3	Reddish brown (5YR 4/4), silty clay loam, reddish brown (7.5YR 3/4) moist; very weak fine subangular blocky structure parting to very weak very fine subangular blocky; soft, friable; very few flecks of CaCO ₃ ; very few very fine and fine roots; faint bedding; common fine and medium pores.
295-330	CBkb3	Reddish brown (5YR 4/4), silt loam, dark brown (7.5YR 3/4) moist; massive; loose, very friable; common fine soft concretions of CaCO ₃ ; few fine roots; common fine and medium pores.
330-365	Ayb4	Brown (7.5YR 4/3), silt loam, dark brown (7.5YR 3/3) moist; weak fine subangular blocky structure parting to weak fine granular; soft, friable; few fine and medium soft concretions of gypsum; few closed worm burrows; very few fine roots; few fine and medium pores.

- 365-405 AByb4 Brown (7.5YR 4/4), silt loam, dark brown (7.5YR 3/4) moist; weak fine subangular blocky structure parting to weak fine granular; soft, friable; very few fine and medium soft concretions of gypsum; very few fine roots; very few fine pores.
- 405-415 BCyb4 Brown (7.5YR 4/4), silt loam, dark brown (7.5YR 3/4) moist; weak fine granular structure parting to weak very fine granular; soft, friable; very few fine to medium soft concretions of gypsum; very few fine roots; very few fine pores.
- 415-515 Cb4 Reddish brown (5YR 5/4), silt loam, reddish brown (5YR 4/4) moist; massive; soft, very friable; very few very fine roots; very few fine pores.
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Table 7. Description of soil Core 2 at the Blunk Ranch locality

Depth (cm)	Soil Horizon	Description
0-25	Ap	Brown (7.5YR 4/3), silt loam, dark brown (7.5YR 3/3) moist; weak fine granular structure; loose, friable; common fine and very fine roots; few open worm burrows and worm casts; few fine and medium pores.
25-45	A	Dark brown (7.5YR 3/3), silt loam, very dark brown (10YR 2/1) moist; weak medium granular structure parting to weak fine granular; loose, friable; few common very fine and fine roots; few open worm burrows and worm casts; few fine and medium pores.
45-60	AB	Brown (7.5YR 4/4), silt loam, dark brown (7.5YR 3/4) moist; weak fine subangular blocky structure parting to fine granular; loose, friable; few fine roots; very few open worm burrows and worm casts; few fine pores.
60-110	Bt1	Brown (7.5YR 4/4), silty clay loam, dark brown (7.5YR 3/4) moist; moderate medium subangular blocky structure parting to weak very fine subangular blocky; hard, firm; common distinct discontinuous dark brown (7.5YR 3/4) clay films on ped faces; few very fine and fine roots; very few open worm burrows and worm casts; few very fine pores.
110-135	Bt2	Brown (7.5YR 4/4), silty clay loam, dark brown (7.5YR 3/4) moist; moderate medium subangular blocky structure parting to moderate fine subangular blocky; hard, firm; common distinct discontinuous dark brown (7.5YR 3/4) clay films on ped faces; very few very fine and fine roots; very few open worm burrows and worm casts; few fine pores.
135-175	Btk	Brown (7.5YR 4/4), silty clay loam, dark brown (7.5YR 3/4) moist; weak medium prismatic structure parting to weak fine subangular blocky; hard, firm; common distinct discontinuous dark brown (7.5YR 3/3) clay films on ped faces; many fine threads and few films of CaCO ₃ ; few fine roots; very few open worm burrows and worm casts; few very fine and fine pores.

- 175-210 Btk1b1 Brown (7.5YR 4/4), silty clay loam, dark brown (7.5YR 3/4) moist; moderate medium prismatic structure parting to moderate fine subangular blocky; hard, firm; common distinct continuous dark brown (7.5YR 3/3) clay films on ped faces; many films and common fine hard concretions of CaCO₃; very few very fine and fine roots; very few open worm burrows and worm casts; common very fine and medium pores.
- 210-290 Btk2b1 Brown (7.5YR 4/4), silty clay loam, dark brown (7.5YR 3/4) moist; moderate medium prismatic structure parting to moderate medium subangular blocky; hard, firm; common faint discontinuous dark brown (7.5YR 3/3) clay films on ped faces; few fine threads, films, and fine concretions of CaCO₃; very few open and few closed worm burrows and worm casts; few fine roots; few fine and common medium pores.
- 290-315 ABtkb2 Dark brown (7.5YR 3/4), silty clay loam, dark brown (7.5YR 3/3) moist; moderate medium prismatic structure parting to moderate fine subangular blocky; hard, firm; common distinct discontinuous dark brown (7.5YR 3/3) clay films on ped faces; few threads and films and few very fine concretions of CaCO₃; very few very fine and fine roots; common fine and many medium pores.
- 315-330 Btk1b2 Brown (7.5YR 4/4), silty clay loam, dark brown (7.5YR 3/4) moist; moderate medium prismatic structure parting to moderate fine subangular blocky; hard, firm; common distinct discontinuous dark brown (7.5YR 3/3) clay films on ped faces; few fine films and threads and few very fine concretions of CaCO₃; very few very fine to fine roots; few fine and medium pores.
- 330-355 Btk2b2 Dark brown (7.5YR 3/4), silty clay loam, dark brown (7.5YR 3/4) moist; weak medium prismatic structure parting to moderate fine subangular blocky; hard, firm; common distinct discontinuous dark brown (7.5YR 3/3) clay films on ped faces; few fine films and threads and few very fine concretions of CaCO₃; very few very fine and fine roots; few fine and medium pores.
- 355-382 BCkb2 Strong brown (7.5YR 4/6), silt loam, dark brown (7.5YR 3/4) moist; weak medium prismatic structure parting to weak fine subangular blocky; slightly hard, friable; few fine films and threads and few very fine concretions of CaCO₃; few very fine and fine roots; very faint bedding; common fine and few medium pores.

382-455	Akb3	Brown (7.5YR 4/3), silt loam, dark brown (7.5YR 3/2) moist; weak fine subangular blocky structure parting to moderate medium to coarse granular; hard, firm; very few fine films and threads of CaCO ₃ ; few very fine and fine roots; few very fine and medium pores.
455-490	Btkb3	Strong brown (7.5YR 4/6), silty clay loam, dark brown (7.5YR 3/4) moist; moderate medium prismatic structure parting to weak fine subangular blocky; hard, firm; few distinct discontinuous dark brown (7.5YR 4/4) clay films on ped faces; very few fine films and threads, and fine flecks of CaCO ₃ ; very few closed worm burrows; very few fine roots; few very fine and medium pores.
490-580	BCK&Btb3	The BCK matrix is strong brown (7.5YR 4/6), silty clay loam, dark brown (7.5YR 3/4) moist, and the Bt matrix (lamellae) is dark brown (7.5YR 4/4) clay; BCK matrix has weak medium subangular blocky structure parting to very weak fine subangular blocky; slightly hard, friable; Bt matrix is hard, firm; the BCK matrix contains few fine flecks of CaCO ₃ ; very few fine to medium roots; very few fine and medium pores.
580-615	Cb3	Strong brown (7.5YR 4/6), silty clay, dark brown (7.5YR 3/4) moist; massive; soft, friable, very few very fine and fine roots; laminated; common very fine and fine pores.
615-690	Ayb4	Brown (7.5YR 4/3), silty clay loam, dark brown (7.5YR 3/2) moist; weak fine subangular blocky structure parting to weak fine granular; slightly hard, firm; common fine hard and soft concretions of gypsum; very few closed worm burrows; very few fine roots; many very fine and fine pores.
690-715	ACyb4	Brown (7.5YR 4/3), silty clay loam, dark brown (7.5YR 3/3) moist; weak very fine subangular blocky structure parting to weak fine granular; hard, firm; very few fine hard and soft concretions of gypsum; very few fine pores.
715-760+	Cyb4	Brown (7.5YR 4/4), silty clay, dark brown (7.5YR 3/4) moist; massive; hard, firm; very few fine hard and soft concretions of gypsum; very few fine pores.

Table 8. Description of soil profile at the Sterling Section

Depth (cm)	Soil Horizon	Description
0-15	Ap	Brown (7.5YR 4/3), silty loam, dark brown (7.5YR 3/3) moist; very weak fine granular structure; slightly hard, friable; common open worm burrows and many worm casts; many fine roots and common medium roots, few coarse roots; ; few fine pores; clear smooth boundary.
15-30	A	Brown (7.5YR 4/3), silty loam, dark brown (7.5YR 3/3) moist; very weak fine subangular blocky structure parting to very weak fine granular; slightly hard, friable; common open worm burrows and many worm casts; many fine roots and common medium roots, and few coarse roots; common fine and medium pores; gradual smooth boundary.
30-60	Bk1	Brown (7.5YR 4/4), silty clay loam, dark brown (7.5YR 3/4) moist; weak fine subangular blocky structure; slightly hard, friable; common fine films and threads of CaCO ₃ ; common open worm burrows and many worm casts; many fine roots, common medium roots and few coarse roots; many fine and medium pores; gradual smooth boundary.
60-120	Bk2	Brown (7.5YR 4/4), silty clay loam, dark brown (7.5YR 3/4) moist; weak medium subangular blocky structure parting to weak fine granular; hard, friable; few fine films, threads, and fine soft concretions of CaCO ₃ ; common fine to medium pores; few closed worm burrows and worm casts; common fine roots, few medium and coarse roots; gradual smooth boundary.
120-163	Btk	Strong brown (7.5YR 4/6), silty clay loam, dark brown (7.5YR 3/4) moist; weak medium subangular blocky structure parting to weak fine subangular blocky; hard, friable; common distinct discontinuous dark brown (7.5YR 3/3) clay films on ped faces; few fine films, threads, and soft concretions of CaCO ₃ ; few closed worm burrows and worm casts; few fine and medium roots; ; common fine and medium pores; clear smooth boundary.
163-193	Btkb1	Brown (7.5YR 4/4), silty clay loam, dark brown (7.5YR 3/4) moist; moderate medium to coarse subangular blocky structure parting to moderate fine subangular blocky; slightly hard, friable; common distinct discontinuous dark brown (7.5YR 3/3) clay films on pedfaces; common fine films, threads, and fine concretions of CaCO ₃ ; few medium roots; common fine and medium pores; gradual smooth boundary.

- 193-228 Bkb1 Brown (7.5YR 4/4), silty clay loam, dark brown (7.5YR 3/4) moist; weak fine prismatic structure parting to weak fine subangular blocky; slightly hard, friable; very few fine films, threads, and soft concretions of CaCO₃; few open worm burrows and worm casts; few medium and very few fine roots; common fine and medium pores; gradual smooth boundary.
- 228-273 Atkb2 Brown (7.5YR 4/4), silty clay loam, brown (7.5YR 3/4) moist, weak fine and medium prismatic structure parting to weak fine subangular blocky; slightly hard, firm; few distinct discontinuous dark brown (7.5YR 3/3) clay films on ped faces; few fine films, threads, and soft concretions of CaCO₃; very few fine roots; common fine and few medium pores; gradual smooth boundary.
- 273-298 Btkb2 Brown (7.5YR 5/4), silty clay loam, dark brown (7.5YR 4/4) moist; moderate medium and coarse subangular blocky structure parting to moderate fine subangular blocky; hard, firm; few distinct discontinuous dark brown (7.5YR 3/3) clay films on ped faces; very few fine films, threads, and fine soft concretions of CaCO₃; very few fine and few medium roots; common fine and few medium pores; clear smooth boundary.
- 298-358 Akb3 Brown (7.5YR 4/3), silty clay loam, dark brown (7.5YR 3/3) moist; moderate medium prismatic structure parting to moderate medium to fine granular; hard, firm; very few fine threads of CaCO₃; many fine and medium pores; gradual smooth boundary.
- 358-389 Btkyb3 Brown (7.5YR 4/3), clay loam, dark brown (7.5YR 3/3) moist; strong medium and coarse prismatic structure parting to moderate fine to very fine subangular blocky; hard, firm; common distinct continuous dark brown (7.5YR 3/2) clay films; very few fine threads of CaCO₃; very few very fine concretions of gypsum; very few fine roots; many very fine and fine pores and common medium pores; gradual smooth boundary
- 389-419 Btyg1b3 Brown (10YR 5/3), clay loam, dark brown (10YR 3/3) moist; moderate fine prismatic structure parting to moderate fine subangular blocky; hard, firm; common distinct continuous very dark grayish brown (10YR 3/2) clay films on ped faces; few very fine and medium concretions of gypsum; many dark bluish grey (10B 4/1) redox features consisting of mottles and coatings on macro-pores; few fine and medium pores; gradual smooth boundary.

419+ Btyg2b3 Brown (10YR 5/3), clay loam, dark brown (10YR 3/3) moist; moderate medium subangular blocky structure parting to moderate fine granular; hard, firm; common distinct continuous very dark grayish brown (10YR 3/2) clay films on ped faces; common very fine and medium concretions of gypsum; many dark bluish grey (10B4/1) redox features consisting of mottles and coatings on macro-pores; few fine and medium pores.
