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Paleo-environmental reconstruction and bio-stratigraphy, Oklahoma Panhandle, USA

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Abstract

Worldwide, the period between 12,000 and 9000 radiocarbon years before present (RCYBP) witnessed the shift from glacial to post-glacial times and marks the transition from the Pleistocene to the Holocene. On the southern Plains of North America this period is marked by rapidly changing climatic conditions, shifting flora and faunal associations, and cultural adaptations. A recently discovered locality along Bull Creek, Oklahoma Panhandle, provides the opportunity to study the environmental context of changing megafauna presence during this transition. The paleo-environment is reconstructed from sediment particle size distribution, stable carbon isotope, pollen, and phytolith analyses from the Bull Creek site, and compared with the megafaunal biostratigraphy in this area.

1. Introduction

Mammoths became scarce and then disappeared on the southern Plains of North America sometime during the Late Pleistocene/early Holocene transition, a period of environmental reversals and heightened human exploitation (Graham and Lundelius, 1984; Martin and Klein, 1984). Whether this extinction was due to the changing environment with its attendant plant, water, and temperature fluctuations (Grayson, 1991; Grayson and Meltzer, 2002) or due to the hunting pressure exerted by people of the Clovis culture (Martin and Klein, 1984; Martin, 2005) is critical to an understanding of this transitional period. The Bull Creek site in the Oklahoma Panhandle presents the opportunity to address the environmental side of this debate through the analysis of soils, sediment particle size distributions, stable carbon isotopes, pollen, and phytoliths. The objectives of this study are to: (1) combine the results of these various analyses into a bio- and chronostratigraphic column and (2) reconstruct the terminal Pleistocene and early Holocene environment for the Bull Creek area of the Southern Plains.

2. The Bull Creek site

The study site lies within the Great Plains of North America, at the boundary of the High Plains and the Plains Border (Curtis and Ham, 1979). The Beaver (North Canadian) River flows west to east through the area locally known as the Oklahoma Panhandle (Fig. 1). Bull Creek is a short (18 km) ephemeral tributary of the Beaver River, exposing several profiles (Carter and Bement, 2004). These profiles were produced by incised valley bottom gullies and lateral migration of Bull Creek. Undifferentiated Permian rocks including the Dog Creek Shale, Whitehorse Group, Cloud Chief Formation, and Quartermaster Formation underlie Bull Creek and crop out along gully walls (Gustavson et al., 1991). These rocks consist of red shale and red to pink fine-grained sandstone, containing thin stringers of gypsum. The Ogallala Formation lies above Permian rocks within interfluves but is absent in Bull Creek profiles where Late Pleistocene and Holocene deposits directly overlie Permian rock (Fig. 2). The Bull Creek site and most of the Oklahoma Panhandle today are a shortgrass prairie dominated by buffalo grass (*Buchloe dactyloides*) and blue grama (*Bouteloua gracilis*) (Clements, 1916; Bruner, 1931; Weaver and Albertson, 1956). The region is semi-arid, with a mean annual precipitation of 500 mm, a mean annual air temperature of 14 °C, and mean monthly pan evaporation in July of 380 mm. Precipitation

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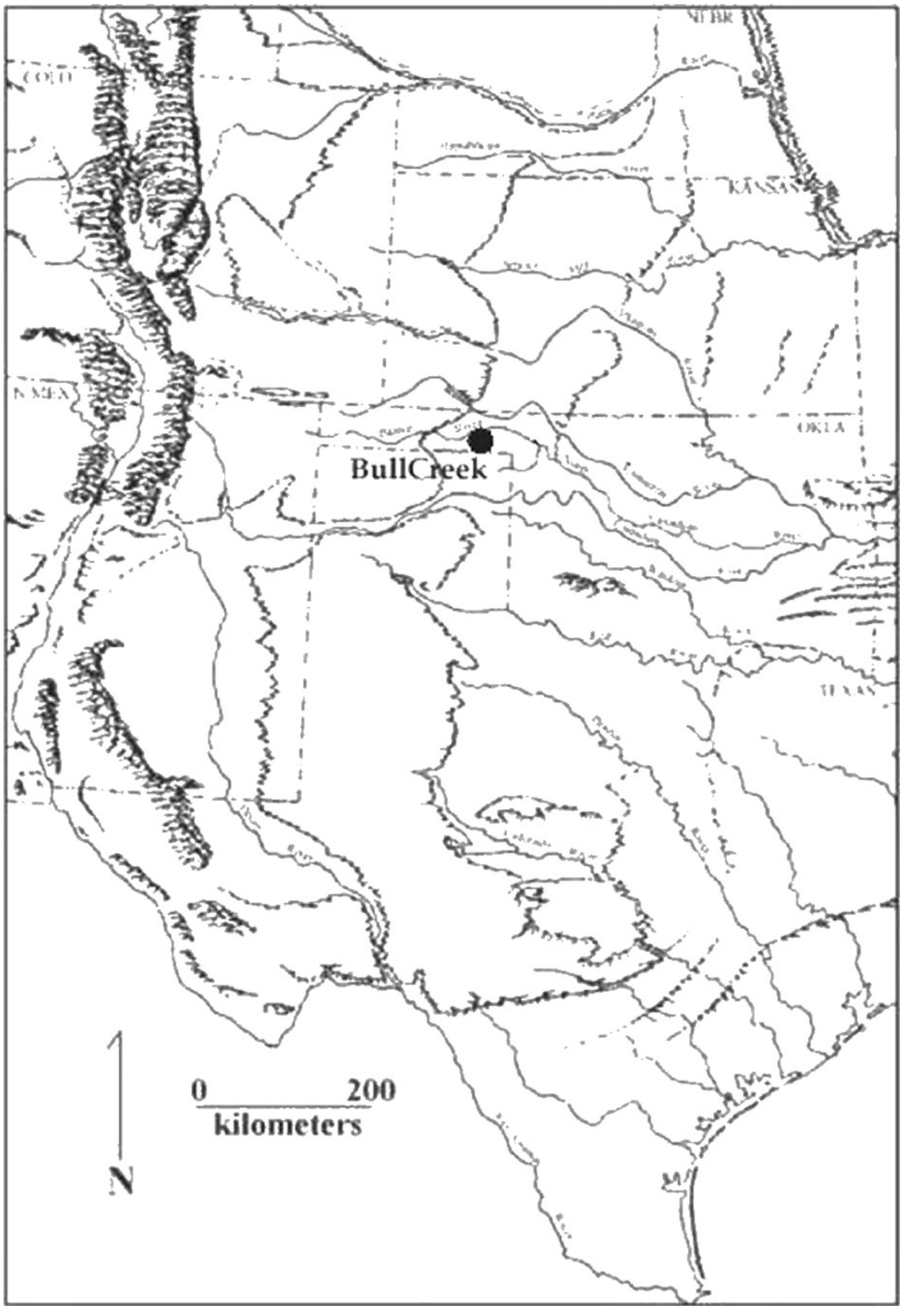

Fig. 1. The Bull Creek site is located in western Beaver County in the Oklahoma Panhandle.

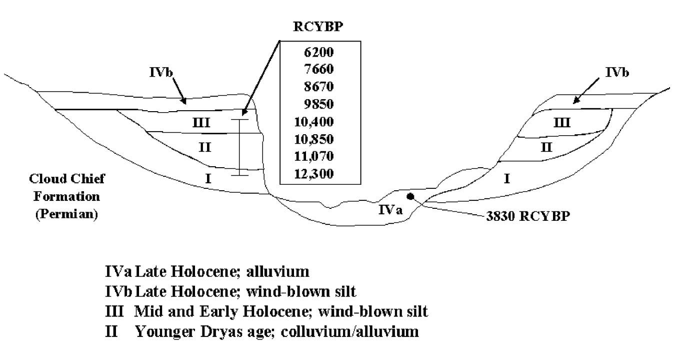

Fig. 2. This schematic profile of Bull Creek reflects several locations along the drainage.

amounts vary widely from year to year and from area to area (Johnson and Duchon, 1995). Spring and summer thunderstorms provide most of the precipitation.

Low order drainages in the Oklahoma Panhandle continually cut into and erode the margins of the High Plains, creating the Plains Border. Perhaps guided by surface expressions of deep, underground dissolution of salt and variation in the resistance of sandstone, caliche, and gypsum, these drainages connected the uplands to the Beaver River (Frye, 1942; Gustavson and Finley, 1985). One such drainage on the right or southern side of the Beaver River is Bull Creek. Its course defines a minor dendritic pattern of first, second, and third order streams.

Contained in this drainage basin are remnants of sediments deposited from Late Pleistocene through historic times. The oldest deposits occur at the base of the Bull Creek site (34BV176) profile (Table 1). The Bull Creek site is approximately 9 km above the confluence of Bull Creek with the Beaver River and 9 km below its head cut into the High Plains. Bounded by Permian bedrock on the south, a first-order drainage on the east, and the main stem of Bull Creek on the west and north, this alluvial terrace remnant is approximately 2 ha. Downcutting of the Bull Creek valley and meandering of the Bull Creek channel truncated deposits, leaving a 6 m high profile (Table 1). Exposed in this profile are sediments attributed to alluvial, eolian, and gully erosional processes. Also contained in the sediments are remains of prehistoric human camps and megafauna which initially drew attention to this site. Chipping debris from stone tool manufacture and broken bison bones were exposed in the cutbank face and in slump deposits at its base. Sediments enveloping the cultural material at a depth of 2.5 m below surface provided the first radiocarbon date of 10, 850 ± 210 RCYBP (Beta-180546) for this site. A second cultural level contained in the upper 15 cm of the site is attributed to Late Archaic cultures (2000–3000 years old) based on projectile point morphology from sites in similar settings in this region (Bement and Brosowske, 2001).

The profile with accompanying radiocarbon series describes deposits of late Pleistocene and early Holocene age, a time when horse, camel, and mammoth were becoming extinct on the southern Plains of North America. To investigate the possible preservation of paleo-environmental proxies in these deposits, the site profile was described and sampled in detail. These samples are the source of all data presented in the remainder of this article. Results of analyses in ascending order of specialization include: (1) particle size analysis to describe deposition; (2) stable carbon isotope analysis to define broad plant community composition; (3) pollen analysis to identify plants within communities of the region; and (4) phytolith analysis to isolate the grass component of the various plant communities. General trends from these analyses are discussed in the context of the temporal distribution of megafaunal remains.

Table 1
Bull Creek site (34BV176) sediment samples

Unit	Sample	Depth (mbs)	Soil	C14 date
III Loess	50–52	0–0.25	A	
	48–49	0.46	Ab	
	46–47	0.65	Akb2	6200 ± 90 (Beta-191039)
	43–45	0.97	Akb3	7660 ± 80 (Beta-184850)
	38–42	1.44	ABkb3	8670 ± 90 (Beta-191040)
II Colluvium/ Alluvium	35–37	1.71	2Akb4	9850 ± 90 (Beta-184851)
	32–34	1.99	2Bkb4	
	29–31	2.3	2Ab5	10,400 ± 120 (Beta-184852)
	27–28	2.46	2Ab6	10,850 ± 210 (Beta-180546)
	26	2.62	2Bwb6	
	24–25	2.79	2Akb7	10,350 ± 210 (Beta-184853)
	23	2.89	2Bkb7	
	21–22	3.07	2Akb8	11,070 ± 60 (Beta-184854)
	19–20	3.51	2ACb8	
I Alluvium	16–18	3.62	3C1b8	
	14–15	3.86	3C2b8	
	10–13	4.22	3C3b8	
	4–9	4.73	3C4b8	
	1–3	5.15	3C5b8	
Bedrock			R	

3. Methods

An inset approximately 1 m deep was cut into the modern Bull Creek wall to remove surface contaminants (Fig. 3). The exposed sediments were described following Schoeneberger et al. (2002). Fifty-two 1-l samples were taken in 10 cm increments beginning at the base (bedrock contact) of the profile (Table 1). Samples did not cross soil or sedimentologic boundaries (Carter and Bement, 2004). Samples were subdivided for analysis and half of each sample was curated for additional analyses as needed. Particle size analysis followed the procedures outlined by Gee and Bauder (1986) and was performed under the

Fig. 3. This photograph documents the Bull Creek site profile after completion of sampling.

supervision of Brian Carter at the Department of Plant and Soil Sciences, Oklahoma State University, Stillwater. The Ehleringer Laboratory, Stable Isotope Ratio Facility for Environmental Research (SIRFER) in the Department of Biology, University of Utah, Salt Lake City performed the carbon isotope analysis. Results are reported in parts per mil related to the PDB standard. The Paleo Research Institute, Golden, Colorado, employed a standard chemical extraction technique based on flotation for pollen analysis. Hydrochloric acid (10%) was used to remove calcium carbonates, after which the samples were screened through 150 μm mesh, treated with hexametaphosphate followed by sodium polytungstate. After rinsing the pollen-rich organic fraction, the sample received a short (10–15 min) treatment in hot hydrofluoric acid to remove any remaining inorganic particles and was then acetolated for 3 min to remove any extraneous organic matter. A 500 × light microscope was used to count pollen to a total of 100–203 grains. Pollen aggregates were included in the pollen counts as single grains, and are noted by an "A" on the pollen diagram. Indeterminate pollen, also included in the total pollen count, includes pollen grains that are folded, mutilated, and otherwise distorted beyond recognition. Pollen diagrams, produced using Tilia (developed by Dr. Eric Grimm of the Illinois State Museum) calculates pollen concentrations using the quantity of sample processed (cm^3), the quantity of exotics (spores) added to the sample, the quantity of exotics counted, and the total pollen counted. Phytolith separation and identification followed techniques described in Fredlund (1995) and Fredlund and Tieszen (1994). This technique utilizes chemical flotation procedures employing zinc bromide after removal of carbonates, clays, and organic matter. All radiocarbon dates were obtained from the A horizon total organic matter fraction, after decalcification (Martin and Johnson, 1995, p. 232). These were processed by Beta Analytic Inc., Miami, FL, USA. Results are presented in radiocarbon years before present (RCYBP) after $\delta^{13}C$ adjustment.

4. Analyses and results

4.1. Profile description

In general, the deposits were divided into three depositional units excluding the Permian sandstone of the Cloud Chief formation exposed at the base of the profile. The lowest layers, immediately above the bedrock, are attributed to the alluvial deposition of gravels and sands (Unit I). Deposition shifts to colluvium/alluvium of silt loams with gravel and sand stringers (Unit II). Wind deposited silts form the upper layers of the sequence (Unit III).

Pedogenesis was apparent in the eolian and colluvial/alluvial deposits, but not in the sand and gravels of the lower alluvium (Table 2). The surface soil and three buried soils were defined in the wind-blown silt deposits. An additional five soils were identified in the colluvium/alluvium. Chronological control was provided by radiocarbon dating eight A horizons, ranging from 6200 ± 90 RCYBP (Beta-191039) for the second buried soil located only 50 cm below the modern surface, to 11,070 ± 60 RCYBP (Beta-184854) for the eighth buried soil at a depth of 231 cm below the modern surface (Table 1). One out-of-sequence date of 10,350 ± 210 RCYBP (Beta-184853) was obtained from the seventh buried soil. The reason for the out of sequence date is unknown; however it is suspected that the sample was contaminated with recent material, probably roots. Soil organics can be divided into three fractions for dating: total organic, humic acid, and residue. Attempts using split samples to assess which fraction best reflects the age of a soil have met with inconsistent results (Martin and Johnson, 1995). Whereas the total fraction results are bracketed by the humic acid (more recent) and residue (older) fractions in late Holocene soils, no such pattern emerged in middle Holocene and earlier soils (Martin and Johnson, 1995, p. 236). A similar problem was noted in dating the late Pleistocene-age soils at the Miami mammoth kill site in the Texas Panhandle (Holliday et al., 1994, p. 238). For consistency, all Bull Creek site dates were obtained from the total fraction from A horizons.

4.2. Particle size analyses

Particle size analyses of sediments from the Bull Creek site describe changes in depositional process. The deposits shift from alluvium in the lowest levels to colluvium/alluvium in the mid levels and finally to eolian in the upper levels.

Unit I (samples 1–18) consists of coarse sand and gravel alluvium (Fig. 4). Beginning with Unit II sample 19, finer clasts dominate the deposits, marking a shift from rapid to slower stream flow, and overbank deposits mixed with colluvium. Samples 23 and 24 denote a short-term deposit of wind-blown silts, indicating a brief drying episode. A return to wetter conditions is implied by the subsequent alluvial/colluvial deposition of sands in samples 25–28 dating to 10,850 RCYBP. Similar materials are deposited through sample 31 at which time soil 2Ab5 dated to 10,400 RCYBP developed. Following this, deposits fine upward in Unit II through sample 35. Sample 36 ushers in Unit III which is characterized by wind-blown silts that continue to the top of the profile. Periods of stability are represented in Unit III by the development of soils dated to 9850 RCYBP, 8270 RCYBP, 7660 RCYBP, and 6200 RCYBP. The youngest dated soil indicates a hiatus of deposition on this landscape feature sometime in the last 6200 years.

4.3. Stable carbon isotopes

Stable carbon isotopes provide a measure of the C3/C4 composition of the plant community. Many dicotyledons, especially arboreal and similar woody plants, are classified as C3 although they also include important C4 species. Both C3 and C4 photosyntheses are recognized in grasses

Table 2
Soil profile description for Bull Creek site (34BV176) Beaver County, OK (September 28, 2003)

Horizon	Depth (cm)	Color moist	Structure[a]	Texture[b]	Consistence[c]	Boundary[d]	Effervescence[e]	Special features
A	0–25	7.5YR4/2	2fGr	SiL	Fr	c	ve	Loess (unit III); many, fine and m roots.
Ab	46	7.5YR3/2	2fGr	SiL	fr	g	ve	Loess (unit III); many, fine and in roots.
Akb2	65	10YR3/3	1fSBK	SiL	fr	c	ve	Loess (unit III); many, fine and medium roots; few fine $CaCO_3$ soft bodies in pores.
Akb3	97	10YR3/2	2fSBK	SiL	fr	g	ve	Loess (unit III); many, fine and medium roots; common fine $CaCO_3$ soft bodies in pores.
ABkb3	144	10YR3/3	2mSBK	SiL	fr	g	ve	Loess (unit III); many fine and medium roots; few fine $CaCO_3$ soft bodies in pores.
2Akb4	171	10YR3/2	2mSBK	SiL	fr	c	ve	Colluvium (unit II) few gravels; many fine and medium; roots; common fine $CaCO_3$ soft bodies in pores.
2Bkb4	199	7.5YR3/3	2mSBK	L	fr	c	ve	Colluvium (unit II); 5% gravels; many fine roots; few fine $CaCO_3$ soft bodies in pores.
2Ab5	231	7.5YR3/2	2mSBK	GCoSL	fr	c	ve	Colluvium (unit II); 15% gravels; common fine roots; few fine $CaCO_3$ soft bodies on gravels.
2Ab6	246	7.5YR3/3	1mSBK	SCL	fr	c	ve	Colluvium (unit II); 2% gravels; common fine roots; few fine ($CaCO_3$ soft bodies in pores; few very fine charcoal fragments; bison sacral fragment.
2Bwb6	262	7.5YR4/3	1mSBK	CoSL	fr	c	ve	Colluvium; few gravels; common fine roots; few fine $CaCO_3$ soft bodies on gravels; bison bone and flakes.
2Akb7	279	7.5YR3/4	2mSBK	SiL	fr	c	ve	Colluvium (unit II); few fine roots; common fine $CaCO_3$ soft bodies in pores.
2Bkb7	289	7.5YR4/4	2mSBK	SiL	fr	g	ve	Colluvium (unit II); few co. sands; few fine roots; many fine $CaCO_3$ soft bodies in pores.
2Akb8	307	7.5YR4/3	2mSBK	SiL	fr	g	ve	Colluvium (unit II); few gravels; few fine roots; many fine $CaCO_3$ soft bodies in pores
2ACb8	351	7.5YR3/4	1mSBK	L	fr	a	ve	Colluvium (unit II); few gravels; few fine roots; few fine $CaCO_3$ soft bodies in pores.
3C1b8	362	7.5YR5/3	SG	VGLCoS	vfr	a	e	Alluvium (unit I); 40% gravels; few fine roots; few fine $CaCO_3$ soft bodies on rock fragments.
3C3b8	422	7.5YR4/6	MA	VFSL	fr	a	ve	Alluvium (unit I); few fine roots; common fine $CaCO_3$ soft bodies in pores.
3C4b8	473	7.5YR6/4	SG	LS	vfr	a	ve	Alluvium (unit I); few gravels; few fine roots.
3C5b8	515	5YR6/4	SG	GCoS	l	a	ve	Alluvium (unit I); 30% gravels.
R	615+	2.5YR5/6	MA	—	vfi	—	e	Residuum: permian cloud chief sandstone.

[a]Structure: 1—weak; 2—moderate; f—fine; m—medium; GR—granular; SBK—subangular blocky; MA—massive; SG—single grain.
[b]Texture: VF—very fine; S—sand; SI—silt; L—loam; Co—coarse; G—gravelly.
[c]Consistency: v—very; fr—friable; l—loose; fi—firm.
[d]Boundary: c—clear; g—gradual; a—abrupt.
[e]Effervescence: ve—violent; e—moderate.

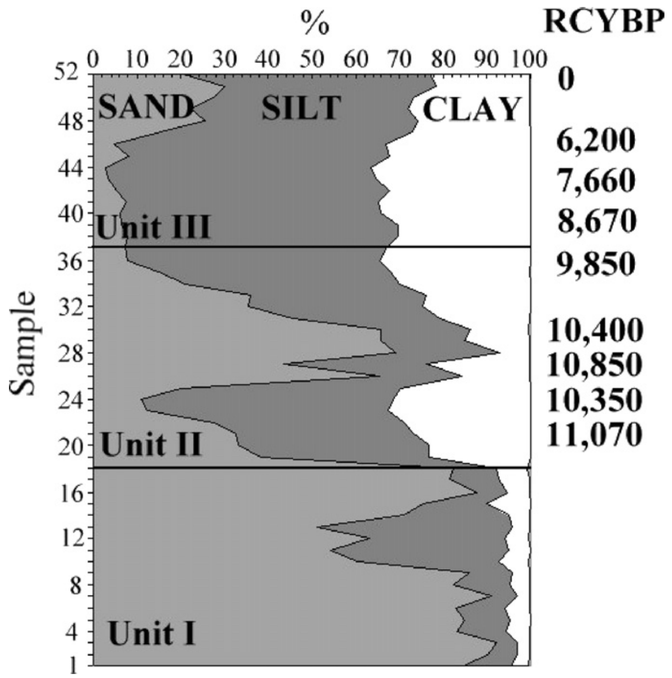

Fig. 4. Particle size distribution at the Bull Creek site documents the change from alluvial to colluvial/alluvial to eolian deposition.

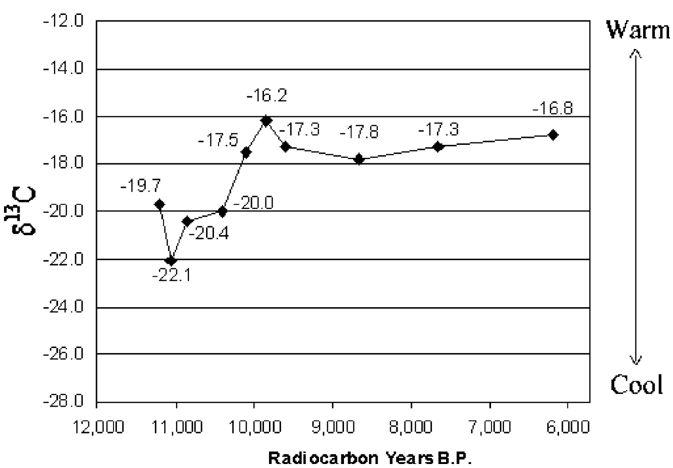

Fig. 5. Stable carbon isotope results indicate a dramatic shift to cooler temperatures by 11,000 RCYBP followed by an abrupt warm up by 10,000 RCYBP and a gradual warming trend to mid-Holocene times.

and stable carbon isotopes are widely used to interpret grassland composition. However, with stable carbon isotopes, all plant matter deposited within the soil contributes to the sample, not just the grasses. Preliminary stable carbon isotope analysis of 10 samples defines shifts in the floral communities over time (Fig. 5). More negative values indicate C3 plants, while less negative values indicate an increase in C4 plants (Nordt et al., 1994; Boutton, 1996; Johnson and Willey, 2000). At Bull Creek, stable carbon isotopes document C3 dominated plant communities before 11,000 RCYBP. A marked trend toward more evenly distributed C3/C4 plant communities is represented by samples between 11,000 and 10,000 RCYBP. A slight rebound to more C3 plants by 8700 RCYBP is followed by a slight trend toward increased C4 plants through the middle Holocene.

4.4. Pollen analysis

The analysis of 34 pollen samples (19 through 52), taken at 10 cm intervals, are discussed in order from oldest to youngest. Problems of interpreting pollen from alluvium generally relate to issues of pollen preservation and discontinuous deposition (Schoenwetter and Eddy, 1964; Hall, 1995). Pollen preservation in the Bull Creek samples varied from good to fair. In general, pollen concentrations tended to become greater with the decreasing age of the sediments sampled, with a low of 26 grains per cubic centimeter in the lowest sample analyzed and a high of over 100,000 gr/cm^3 in the youngest sample. Because pine pollen quantities observed in the modern surface sample can be attributed to blown in pollen from distant sources, similar quantities in other samples are likewise attributed to these distant sources (Hoyt, 2000, p. 66).

Samples 1 through 18 consist of coarse sands and gravels not conducive to pollen preservation. None of these samples were tested for pollen. Samples 19 and 20 were recovered from stratum 2ACb8, predating 11,070 ± 60 RCYBP (Fig. 6). The pollen record from these samples contained the highest percentages of *Artemisia* pollen in the study, indicating that the period before 11,070 was possibly a sage scrubland. Relatively low frequencies of *Pinus* and *Juniperus* pollen, representing pines and junipers, suggest that these trees grew at some distance from the site. *Juglans* pollen was noted in sample 19, indicating the presence of walnut trees, perhaps as part of the local riparian community. Recovery of *Salix* pollen in both samples indicates the presence of willow, probably growing in the riparian vegetation community along Bull Creek. Recovery of *Typha angustifolia*-type pollen indicates that cattails also grew along Bull Creek. In addition to the high frequency of *Artemisia* pollen, Poaceae and High-spine Asteraceae pollen frequencies were elevated, indicating that grasses and members of the sunflower family were well represented in the local plant community. Given the high rate of deposition in the lower portion of the profile, it is likely that the two samples older than 11,070 ± 60 RCYBP do not precede that date by a long period of time.

Samples 21 and 22 were collected from stratum 2Akb8, dated to 11,070 ± 60 RCYBP. *Juniperus* pollen was present in sample 21 in low frequencies, but was very poorly represented in sample 22, suggesting a possible decline in the juniper trees during the deposition of this stratum. *Artemisia* pollen shows a decline in frequency over the same period, while High-spine Asteraceae increased. The changes in the *Artemisia*/High-spine Asteraceae frequencies might reflect a transition toward a community with more rabbitbrush and less sagebrush.

Sample 23 was collected from stratum 2Bkb7 and dates between 10,800 and 11,070 RCYBP. There is a significant

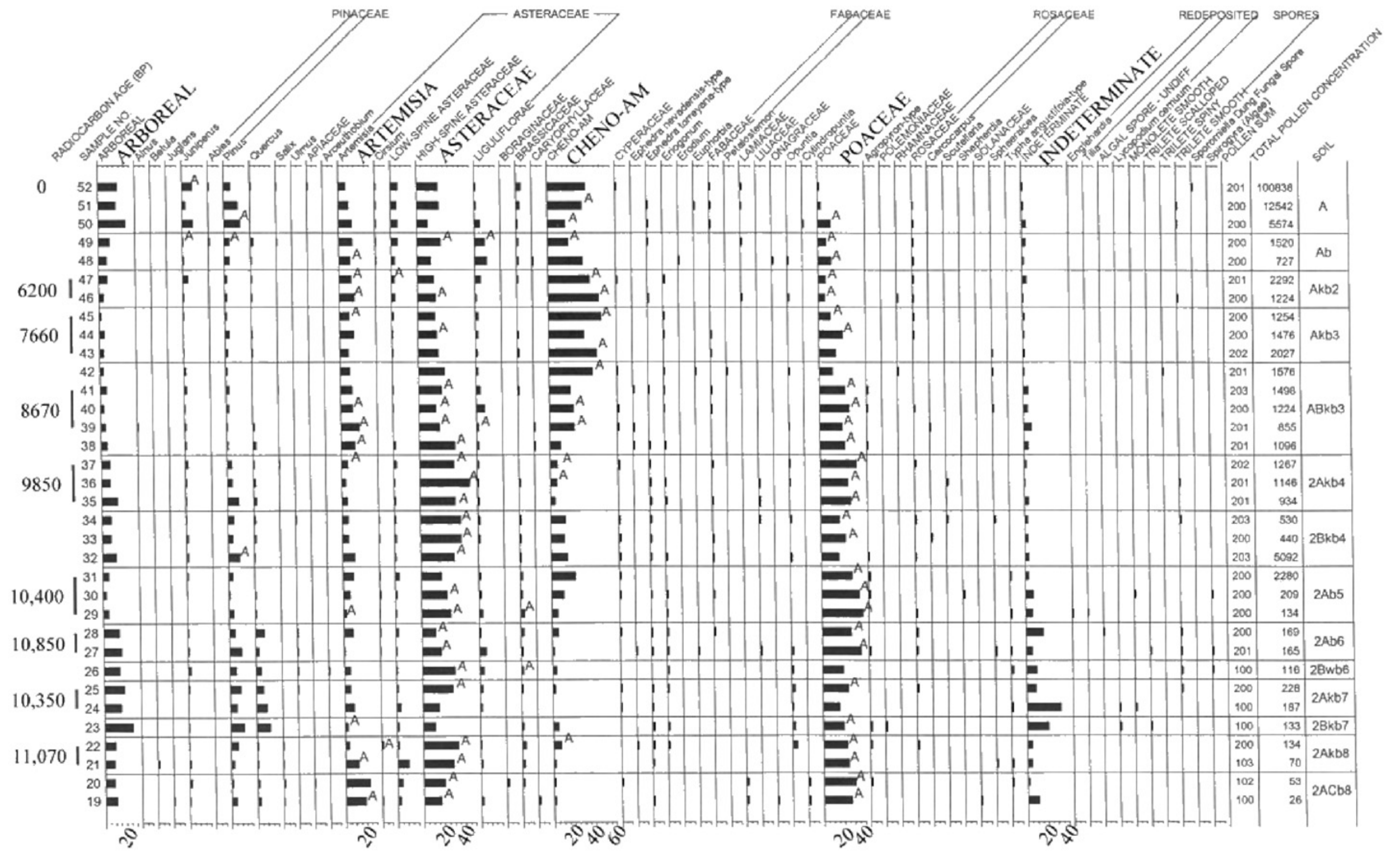

Fig. 6. Several major shifts in plant community composition are displayed in this pollen diagram from the Bull Creek site. The overall low percentage of indeterminate pollen grains indicates preservation is good to fair in these deposits.

difference in the vegetation suggested by the pollen signatures of this sample compared to the underlying 2Akb8 soil. Frequencies of arboreal pollen types are considerably higher compared to non-arboreal types. Indeterminate pollen was noted in a relatively high frequency, suggesting an increase in oxidizing agents or perhaps mechanical abrasion, a situation often attributed with differential pollen preservation favoring arboreal species. Pollen concentration is roughly double the older samples, and the apparent plant community as indicated by the pollen profile, is different. The High-spine Asteraceae pollen frequency is considerably lower than in previous samples, perhaps indicating a drying of the environment. Based on the evident changes in the plant community, it appears that there was some climatic instability between 11,070 BP and the deposition of these sediments.

Samples 24 and 25 were recovered from the 2Akb7 horizon. The arboreal pollen includes *Ulmus* (elm) and *Juniperus* (juniper). *Artemisia* pollen was observed in low frequencies indicating local growth of sagebrush or one of the low-growing members of the genus *Artemisia*. The High-spine Asteraceae pollen frequency had begun a return to higher frequencies and Liguliflorae pollen was observed in the sample. High-spine Asteraceae pollen could indicate many different members of the sunflower family with a variety of environmental tolerances, but Liguliflorae pollen indicates members of the chicory tribe of the Asteraceae, which is usually associated with moderately to mostly moist conditions. Poor representation of Cheno-Am pollen in these samples very likely indicates readily available moisture.

Sample 26 was recovered from stratum 2Bwb6, the B horizon of the sixth buried soil, which was dated to 10,850 $\pm$ 210 RCYBP. The arboreal pollen frequency continued to be elevated in this stratum, but was lower than that observed in the underlying soil. The upswing in High-spine Asteraceae and Liguliflorae pollen, as well as the occurrence of *Typha* pollen, suggests continued and possibly increasingly moist conditions.

Samples 27 and 28 were collected from stratum 2Ab6; the A horizon of the sixth buried soil. The pollen signature of these two samples suggests a change in vegetation during the deposition of this layer. The lower sample, 27, exhibits a spike in the Poaceae pollen frequency, reflecting better representation on the landscape of grasses, while sample 28 contains higher frequencies of *Artemisia* and *Quercus* pollen, representing more sagebrush and oaks. This vegetational change is probably the result of warming temperatures in the area. Additional observations about these samples include the decrease in the frequency of High-spine Asteraceae and Liguliflorae pollen and the slight increase in the frequency in Brassicaceae and Cheno-Am pollen types. These changes in frequency indicate a vegetation community becoming adapted to drying conditions, even though water was still readily available.

Samples 29–31 were collected from the 2Ab5 stratum, dated to 10,400 $\pm$ 120 RCYBP. Cheno-Am frequencies increase upward through the stratum, and Poaceae pollen amounts are relatively high throughout the unit. The *Artemisia* pollen frequency, like that for Cheno-Ams, increases upward through the stratum, suggesting that the landscape was more open, with sagebrush, grasses, and members of the goosefoot family and/or amaranth growing in the area. The increase in shrubby plants suggests increased dryness or a reduction in the water balance index.

Samples 32, 33 and 34 were collected from stratum 2Bkb4 dating between 10,400 and 9800 BP. The pollen record indicates few junipers and oaks and rare elms in the local woodland. High-spine Asteraceae pollen is the dominant type observed in the sample, probably representing shrubby members of the sunflower family. Relatively low frequencies of Poaceae pollen and continued elevated percentages of Cheno-Am pollen suggest continuing dryer conditions and presence of pigweed as part of the shrubby Cheno-Am population.

Samples 35–37 were taken from the 9850 $\pm$ 90 RCYBP 2Ab4. *Artemisia* and Cheno-Am pollen frequencies are uniformly low in the samples, while High-spine Asteraceae and Poaceae pollen frequencies are high, suggesting a grassland. This stratum is the upper layer of colluvial deposits.

Samples 38–42 were extracted from the Abkb3 and contain a record of a changing vegetation community. A bulk radiocarbon date on sediment corresponding to samples 39–41 returned an age of 8670 $\pm$ 90 RCYBP. Sample 38 contains a pollen signature dominated by High-spine Asteraceae pollen with *Artemisia*, and Poaceae well-represented and low percentages of Cheno-Am pollen noted. The three middle samples, 39–41, appear very similar to one another. These samples contain moderate frequencies of *Artemisia*, High-spine Asteraceae and Cheno-Am pollen and higher frequencies of Poaceae pollen, suggesting a return to grasslands. The upper sample in the stratum, 42, contains smaller frequencies of *Artemisia* and Poaceae pollen, but larger High-spine Asteraceae and very large frequencies of Cheno-Am pollen.

The pollen signature from samples 43–45 from the 7660 $\pm$ 80 RCYBP Akb3 horizon is fairly uniform throughout, containing moderate *Artemisia*, High-spine Asteraceae, and Poaceae pollen, and dominated by high frequencies of Cheno-Am pollen. This signature indicates a grassland with exposed ground and mixed sagebrush and probably shrubby members of the goosefoot family.

Samples 46 and 47 from the 6200 $\pm$ 90 RCYBP stratum Akb2 show a continued moderate representation by *Artemisia* and High-spine Asteraceae pollen, low frequencies of Poaceae pollen, and slight increases in Low-spine Asteraceae, Liguliflorae, and *Juniperus* pollen. Cheno-Am pollen is the dominant type noted in the stratum. The slight increases in Low-spine Asteraceae and Liguliflorae pollen might reflect more effective moisture, a migration of the stream edge closer to the sampling locus or perhaps widening of the floodplain, or the in-migration of more mesic members of these plant groups into the plant community.

Samples 48 and 49 from stratum Ab shows a slight increase in *Quercus*, Brassicaceae, and Poaceae pollen frequencies, stable levels of *Artemisia*, significant increases in High-spine Asteraceae and Liguliflorae pollen frequencies, and a drop in Cheno-Am pollen. Though there is, as yet, no date for this stratum, the pollen signature implies one of the more mesic periods between 6200 BP and today.

The modern A horizon (samples 50–52) contains a record of a local vegetation return to a more wooded riparian community with a significant portion of the pollen coming from trees. This is likely the result of a combination of 19th and 20th century fire suppression. *Juniperus* pollen is noted in moderate frequencies, with *Quercus* and *Salix* present in very low quantities. *Artemisia* pollen declines in frequency upward through the stratum, suggesting increasingly less sagebrush in the area approaching the modern surface. Low-spine Asteraceae pollen increases in frequency in this stratum, suggesting more ragweed, cocklebur, or sumpweed in the local plant community. Liguliflorae pollen decreases, and Cheno-Am pollen increases in frequency, signaling at least a change in vegetation along the creek and perhaps also dryer conditions. Despite the perception of the area as a grassland, Poaceae pollen declines in the modern A horizon, while Cheno-Ams are better represented.

The pollen results document three general shifts in the plant communities contributing to the Bull Creek site deposits. The first shift is around 11,070 RCYBP when high *Artemisia* (sagebrush) counts are replaced by increasing high spine Asteraceae counts. Poaceae pollen counts remain high during this shift to apparently drier conditions. Samples dating to 10,850 and 10,400 RCYBP indicate grasslands dominate the area accompanied by a second shift to very high levels of high spine Asteraceae species. High spine Asteraceae species suggest the presence of mudflats or the seasonal reduction in precipitation. At the beginning of the Holocene (ca. 9850 RCYBP), conditions dry even further. High spine Asteraceae pollen counts decline as Cheno-Am pollen counts increase. This third shift is accompanied by a general decline in the contribution of Poaceae pollen, suggesting a thinning of the grasslands. A resurgence of *Artemisia* pollen suggests winter moisture increases compared to the previous periods. This trend continues through deposits dating to 6200 RCYBP, culminating in the conditions documented for the modern surface of short grass prairie.

4.5. Phytoliths

Comparing phytolith assemblages from selected surface and buried soil produce notable differences (Fig. 7). The late Pleistocene/early Holocene (10,000–11,000 RCYPB) phytolith assemblages indicate a mixed-grass prairie with a probable dominance of western wheatgrass (*Elymus smithii*) or similar Pooideae grasses (e.g., *Elymus canadensis* and *Koeleria pyramindata*) followed by notable amounts of Chloridoideae grasses. Variable but small percentages of

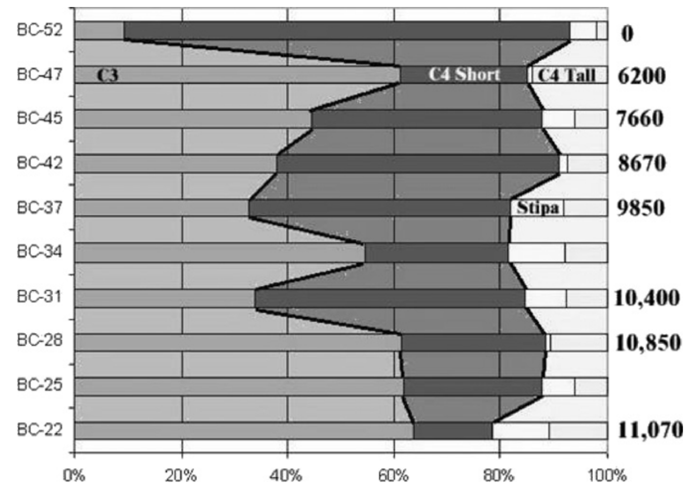

Fig. 7. Phytolith distributions at the Bull Creek site document shifts in grassland composition over time.

Stipa-type, simple lobate, and Panicoid-type phytoliths indicate that the late Pleistocene/early Holocene also contain some warm season (C4) grasses (e.g., *Andropogen geradii* and *Andropogen scoparius*) and cool season grasses (C3) (e.g., *Danthonia spicata* and *Stipa leucotricha*). The buried soil phytolith assemblages indicate a mixture of C3 and C4 grasses with a tendency toward a higher occurrence of C4 grasses during the early Holocene (8500–10,000 RCYBP) compared to the later middle Holocene or the late Pleistocene. The C4 phytoliths in the 8500–10,000 RCYPB time period contain a relatively high percentage of C4 (warm, dry) Chloridoideae phytoliths compared to other buried assemblages. Also, this period is marked by a relatively low percentage of Pooideae phytolith forms which further support the interpretation of a relatively warm and dry environment. The middle Holocene phytolith assemblage, as highlighted by sample #47 (6,200 RCYBP), is similar to the late Pleistocene/early Holocene except for a very low percentage of Stipa-type and a relatively high percentage of Panicoid-type. This middle Holocene mixed-grass phytolith assemblage suggests a return to moist conditions following the drier early Holocene (approximately 8000–9000 RCYPB). The phytolith assemblage of the surface soil indicates a dominance of saddle morphotypes as expected from the buffalo grass (*Buchloe dactyloides*) dominated prairie currently at the site. *Buchloe dactyloides* and other Chloridoideae (*Boutloua gracilis* and *Bouteloua hirsuta*) grasses prefer warm semi-arid regions similar to the Oklahoma Panhandle. The surface phytolith assemblage is unique when compared to buried soils that suggest the environmental conditions during the late Pleistocene and early Holocene were cooler and wetter than present.

The phytolith data indicate grassland composition in the Bull Creek site area varied from a dominance of C3 cool grasses around 11,000 RCYBP, to a preponderance of C4 short grasses, indicating warmer temperatures, today. Periods when C4 short grasses out-contributed C3 grasses include 10,400 RCYBP, 9850 RCYBP and 8670 RCYBP. A significant reversal is noted at 6200 RCYBP when C3 cool grasses dominate C4 short grasses, indicating a return to cooler temperatures. This is supported by an increase in C4 tall grasses, suggesting an increase in moisture accompanied the cooler temperatures.

4.6. Fauna

The distribution of faunal remains in the sediment units described for Bull Creek and adjacent streams reflects systematic sampling procedures at two localities (Dalquest and Baskin, 1992), two prehistoric sites (Bement and Carter, 2005a), and isolated finds reported by local collectors. Mammoth, horse, camel, and bison remains were collected from Unit I deposits in Bull, Fulton, and Elm creeks. Mammoth (*Mammuthus columbi*) tooth fragments, camel (*Camelops* sp.) phalanx, bison (*Bison antiquus*) astragalus, and horse (*Equus* sp.) teeth were recovered from sediments dating between 11,000 and 14,000 years ago in Elm Creek (Dalquest and Baskin, 1992, p. 17). Accompanying these megafaunal remains were the remains of smaller animals with extra-local distributions, including the water shrew (*Sorex palustris*), chipmunk (*Tamias striatus*), Franklin's ground squirrel (*Spermophilus franklinii*) and others still common in the local area, including black-tailed prairie dog (*Cynomys ludovicianus*), 13-lined ground squirrel (*Spermophilus tridecemlineatus*), Plains pocket gopher (*Geomys bursarius*), and wood rat (*Neotoma* cf. *micropus*).

In the Bull Creek drainage, the remains of mammoth, horse, camel, and bison were found in Unit I deposits dating prior to 11,000 RCYBP. In particular, a cervical vertebra from *Camelops* cf. *hesternus* eroded from the base of the sampled sequence at the Bull Creek site. A mammoth tusk fragment was retrieved from the Unit I deposits 2 km downstream and a mammoth tooth fragment and horse tooth eroded from Unit I deposits upstream from the Bull Creek site. Bison remains including a femur and tibia are exposed in Unit I deposits along the bank containing site 34BV177 approximately 1 km upstream of the Bull Creek site. A third mammoth tooth fragment was recovered from Unit I deposits in neighboring Fulton Creek.

Megafauna remains in Unit II deposits include bison remains (ribs and vertebrae) in the 10,850 RCYBP cultural deposits at the Bull Creek site and at the 9000-year-old cultural deposit at 34BV178 in neighboring Fulton Creek. The size of these bison remains compare favorably to specimens identified as *Bison antiquus* at the Clovis age Jake Bluff site and Folsom age Cooper site, both in neighboring Harper County, Oklahoma (Bement and Carter, 2005b; Bement, 1999).

Bison remains consistent in size with *Bison bison* have been found in Unit III deposits along Fulton Creek and in Unit IV deposits along Bull Creek at site 34BV182 located 0.5 km downstream from the Bull Creek site.

5. Discussion

Reconstructing the environment of the southern Plains region of North America during the late Pleistocene/early Holocene megafauna extinction (11,000 to 10,000 RCYBP) is a formidable task. This time period witnessed the extinction of up to 34 mammalian genera and a cultural shift from Clovis mammoth hunters to the Folsom bison hunters. The scarcity of preserved pollen in samples within the Plains region has led researchers to explore other environmental proxy datasets, including particle size distribution, stable carbon isotopes, and phytolith analysis. Most studies rely on one or two datasets. This study relates the results from at least four datasets developed from a single stratigraphic column from the Bull Creek site in the Oklahoma Panhandle.

Pollen preservation at the Bull Creek site stands in stark contrast to reviews of late Pleistocene/early Holocene southern Plains pollen analyses that conclude preservation is poor to non-existent (Hall, 1995; Hall and Valastro Jr., 1995). Exceptions include pollen indicating a grassland prairie found at the 11,000-year-old Domebo Clovis mammoth kill site in west central Oklahoma (Wilson, 1966) and in 13,000-year-old deposits at the Aubrey site in north Texas (Hall, 2001). Similarly, pollen from the 11,800-year-old deposits at Ferndale Bog in eastern Oklahoma depicts a grassland (Bryant and Holloway, 1985). Early Holocene age pollen from the Cheyenne Bottoms in central Kansas is dominated by Cheno-Am types suggesting a lowland mudflat vegetation and a fully developed grassland on the uplands by 10,500 years ago (Fredlund, 1995, p. 77).

At the Bull Creek site, specific vegetation, as noted in the pollen record, implies a change from a landscape supporting an open mesic sage scrubland mixed with hardwoods (walnut, oak, elm, and willow) with an understory of mixed grasses, shrubs, and a variety of the sunflower family prior to 11,000 RCYBP, to one containing more oaks and grassy clearings with a mix of grass, shrubs, weedy forbs, and prickly pear cactus. Vegetation at 11,000 RCYBP was relatively dense. Cattails and willow grew along Bull Creek. The timing of this shift is supported by the stable carbon isotope results that place the coldest conditions immediately prior to 11,000 RCYBP (Fig. 8). The phytolith data likewise support a cool, moist period when the grasses were dominated by C3 species. Mammoths are still a part of the faunal assemblage.

A brief period between 11,070 and 10,850 RCYBP is marked by eolian deposition, degraded pollen recovery, and the out-of-sequence radiocarbon date. This silt deposit may suggest the drying of the landscape. However, the negative $\delta^{13}C$ value indicates the continued dominance of C3 (cool season) plant species. The phytoliths indicate the grassland composition during this time contains increasing levels of C4 species.

By 10,850 RCYBP open grasslands dominate the landscape. Phytoliths suggest the grassland community includes an increase in the seasonally available C4 short chloridoid

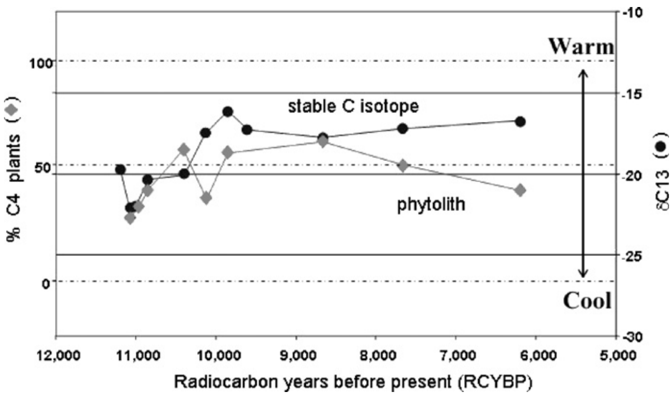

Fig. 8. Combined stable carbon isotope and phytolith results, converted to %C4 for ease of comparison, document temperature and/or precipitation shifts in the Bull Creek environment.

grasses. This is further supported by less negative δ^{13}C values. These results reflect drier conditions than that seen in the preceding period. Bison are the largest animal on the landscape during this time.

The transition from this vegetation regime to the next began about 8670 RCYBP with declines in oak, a slight increase in sagebrush and an increase in Cheno-Ams. Wind deposition replaces colluvial/alluvial processes and by 7660 RCYBP there were few oaks, a stable amount of sagebrush, increasing Cheno-Ams, and declining quantities of grass. Stable carbon isotope values continue the trend toward less negative values, reflecting the warming and drying of the landscape. Phytolith data, however describe decreasing C4 short chloridoid grasses in favor of more C3 grasses. The panicoid tall grasses remain the same. Although the δ^{13}C data appear at odds with the phytolith data, this may simply imply that the C4 component on the landscape is found in the Cheno-Ams rather than the grasses. The increase in Cheno-Ams, as indicated by the pollen, may indicate an increase in pioneering C4 Cheno-Ams (e.g. *Suadea suffrutescens* and *Amaranthus retroflexus*). By mid-Holocene times, the Bull Creek area is well on its way to dry conditions similar to those described for the Altithermal (Antevs, 1955) and supported by paleoenvironmental reconstructions to the south (Holliday, 1995) and north (Baker et al., 2000) of the study area. The Bull Creek environmental record is either compressed or truncated between approximately 6200 RCYBP and the present.

6. Conclusion

Against this environmental backdrop, mammoth, bison, horse, and camel remains are found in the late Pleistocene age deposits. Mammoth, horse, and camel become scarce by 11,000 RCYBP as the environment warms and dries, and only bison are found in the area by 10,850 RCYBP as these environmental trends continue into the mid-Holocene.

Bull Creek joins a growing number of southern Plains environmental studies, including Burnham (Wyckoff et al., 2003), Lubbock Lake (Holliday, 1995; Johnson, 1995), Nall (LaBelle et al., 2003), Folsom (Meltzer et al., 2002; Meltzer, 2006), Clovis (Haynes, 1995; Wendorf and Hester, 1975) and Aubrey (Ferring, 2001), to name a few. Comparisons between these studies will undoubtedly highlight areas of convergence and divergence in environmental reconstructions, providing fruitful avenues for future investigations.

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