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Folsom Drought and Episodic Drying on the Southern High Plains from 10,900–10,200 ^{14}C yr B.P.

Vance T. Holliday

Department of Geography, 550 N. Park Street, University of Wisconsin, Madison, Wisconsin 53706

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The paleoenvironments of late Pleistocene and early Holocene time on the Southern High Plains have been studied for decades, but regionally extensive or long-term, easily recoverable proxy climate indicators are difficult to find. The stratigraphy of valley fill and upland eolian deposits and stable-carbon isotope data, in addition to geographically limited paleontological data, now provide clues to the environment during this time, which includes the earliest, or Paleoindian period (~11,200–8000 ^{14}C yr B.P.) of human occupation. During the Clovis occupation (~11,200–10,900 ^{14}C yr B.P.), valleys contained perennial streams. This was followed in Folsom time (10,900–10,200 ^{14}C yr B.P.) by an abrupt change to lakes and ponds (with water levels fluctuating between several meters depth and no surface water) and marshes and accumulation of sheet sands on uplands, starting the earliest phase of construction of the regional dune fields. These changing conditions indicate a shift from relatively wetter to relatively drier conditions with episodic drought. Stable-C isotopes further indicate that warming characterized the Clovis–Folsom transition. During the rest of the Paleoindian period the environment was relatively cool but fluctuated between wetter and drier conditions with an overall trend toward drying that resulted in further enlargement of the dune fields and culminated in the warm, dry Altithermal beginning ~8000 ^{14}C yr B.P. Clovis time probably was the wettest of any Paleoindian period in terms of runoff and spring discharge. The Folsom period was drier and was the earliest episode of regional wind erosion and eolian deposition and may have been the warmest of Paleoindian times. Evidence of a previously hypothesized "Clovis drought" in this region is sparse.

Key Words: **Southern High Plains; Paleoindian; Clovis; Folsom; drought.**

INTRODUCTION

The late-glacial and early postglacial environmental record of the Great Plains has long been the focus of research by Quaternary scientists. This paper presents data and interpretations for terminal Pleistocene and early Holocene environments on the Southern High Plains that both refine and contrast with previous interpretations. In particular, evidence is presented that significant characteristics of the late Holocene/modern environment of the Great Plains appeared during the Paleoindian occupation.

The broad outlines of the environments during the Paleoindian occupation of the Southern High Plains emerged from interdisciplinary archaeological work conducted in the 1930s, 1940s, and 1950s in New Mexico and Texas (e.g., Howard, 1935; Sellards, 1952; Sellards and Evans, 1960). Few paleoenvironmental details were forthcoming, but all investigators agreed that terminal Pleistocene and earliest Holocene times were generally "wetter" or "more moist" and probably cooler than today, followed by warmer and drier conditions, although Sellards (1952, p. 152) and Sellards and Evans (1960) raised the possibility of several wet–dry cycles during Paleoindian times.

In the late 1950s and early 1960s studies of late Quaternary environments focused on the evidence, largely from pollen, for coniferous forest on the Southern High Plains during a cool, wet interval at the close of the Pleistocene, coeval with some of the Paleoindian occupations (Wendorf, 1961, 1970; Wendorf and Hester, 1975). These interpretations were routinely cited in the literature until the 1980s (Holliday, 1987a) and still show up in archaeological discussions (e.g., Boldurian, 1990; Fiedel, 1999), although more recent research provided data that contrasted with those of the High Plains Paleoecology Project and cast considerable doubt on the reliability of the earlier pollen interpretations (Johnson, 1986, 1987a; Bryant and Schoenwetter, 1987; Holliday, 1987a, 1995a, 1997a; Hall, 1995; Hall and Valastro, 1995).

In contrast to the earlier interest in evidence for a "cool and wet forest," much recent research has focused on indicators of drought and aridity both in Paleoindian and in post-Paleoindian times (Holliday, 1989, 1997a; Haynes, 1991, 1993; Meltzer, 1991, 1995, 1999). In particular, some evidence was put forward suggesting drought conditions during the Clovis (earliest Paleoindian) occupation of the region (ca. 11,200–10,900 ^{14}C yr B.P.) (Haynes, 1991, 1993).

This paper deals with the issue of drought during the Paleoindian period. Drought is defined most broadly as below-average precipitation for an extended period of time, causing a serious hydrological imbalance (Felch, 1978, pp. 25–26; Rogers and Armbruster, 1990, pp. 126). Put another way, drought

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represents a temporary moisture deficit in relation to average precipitation (Mainguet, 1999, p. 24). Drought is a temporary condition and is not confined to arid or semiarid regions. Aridity, in contrast, is a long-term climatic condition that can be defined in relation to annual precipitation and potential evapotranspiration (e.g., Mainguet, 1999, p. 25). Paleoindian environments on the Southern High Plains may never have been arid, but could have been prone to drought.

SETTING AND METHODS

The Southern High Plains subregion of the Great Plains is a vast plateau covering approximately 130,000 km^2 (Fig. 1). This semiarid landscape has a virtually featureless, constructional surface, formed by deposition of widespread and thick eolian sediments during the Quaternary (Holliday, 1995b; Holliday and Gustavson, 1991). Low topographic relief on the High Plains is provided by thousands of small lake basins (“playas”); about a dozen dry valleys (“draws”) that are tributaries of the Red, Brazos, and Colorado rivers to the east; and eolian sand, including sheet sands, dune fields, and lunettes (dunes that fringe the downwind margin of some playas) (Fig. 1). The playas, draws, and dunes are the sites of preserved (and usually stratified) late Quaternary sediments, soils, and *in situ* archaeological sites (Hester, 1975; Holliday, 1995b, 1997a).

Reconstructing the history and impact of past climatic changes on the Great Plains has sometimes proven difficult because long-term, high-resolution records, such as tree rings and speleothems, are not available anywhere in the region. Moreover, the semiarid climate of the Southern High Plains inhibits preservation of regionally extensive and easily recoverable paleoenvironmental indicators such as pollen (Bryant and Schoenwetter, 1987; Holliday, 1987a; Bryant *et al.*, 1994; Hall and Valastro, 1995). Nevertheless, the well-preserved stratigraphic record of late Quaternary sediments and soils can provide valuable clues to the regional paleoenvironments and environmental change (Haynes, 1975, 1995; Holliday, 1995a,b, 1997a). In particular, eolian sediments on the Great Plains are key indicators of minimal vegetation cover and wind erosion resulting from aridity (Forman *et al.*, 1992, 1995; Muhs and Maat, 1993; Muhs *et al.*, 1997). Soils formed in the eolian strata mark periods of more abundant vegetation and landscape stability due to relatively moist conditions following aridity. Late Quaternary eolian deposits modified by pedogenesis are found in the draws and dunes throughout much of the Southern High Plains and thus can be used to infer past aridity.

Independent verification of the paleoenvironmental inferences drawn from the stratigraphic record comes largely from stable-carbon isotopes, which have emerged as one of the few datable proxies of paleovegetation in semiarid regions like the Southern High Plains. Carbon isotopes in organic matter can be utilized in a wide variety of late Quaternary sediments throughout much of the Southern High Plains (Holliday, 1995a, 1997b). To minimize the variables in their interpretation, however, only isotopic data from playa fill and lunette sediments are compared and interpreted. In the draws, rapidly changing depositional environments during the Paleoindian period inhibit meaningful interpretations for this time interval (Holliday, 1995a). Other proxy indicators of past environments (employed by previous investigators) include phytoliths and remains of invertebrate and vertebrate faunas (Stock and Bode, 1936; Wendorf, 1961; Lundelius, 1972; Slaughter, 1975; Wendorf and Hester, 1975; Johnson, 1986, 1987b; Bozarth, 1995; Neck, 1995; Winsborough, 1995). Most of these methods, while successful, have been used on a more geographically restricted basis.

Age control for the eolian deposits and soils is provided by radiocarbon ages or by archaeological correlation. Most radiocarbon ages were determined for samples collected from A horizons of buried soils in valley fills (Holliday, 1995a) and lunettes (Holliday, 1997b) or from lacustrine or palustrine muds in the valley fill (Holliday, 1995a) or playas (Holliday *et al.*, 1996) (Table 1). Samples collected from the top of a buried A horizon provide a maximum age for overlying sediments (Holliday *et al.*, 1983, 1985; Haas *et al.*, 1986; Holliday, 1995a; Martin and Johnson, 1995). Many of the Paleoindian artifact types found in association with eolian deposits in both the dunes and the draws are relatively well dated and serve as reliable age indicators. The principal artifact types (and their age ranges in uncalibrated ^{14}C yr B.P.) are Clovis (11,200–10,900), Folsom and Midland (10,900–10,200), Plainview and Milnesand (10,500–9500), Hell Gap (~10,000–9500), and Firstview (9400–8300) or late Paleoindian (10,000–8000) (Frison, 1991; Haynes, 1992, 1993; Haynes *et al.*, 1992; Holliday, 1997a; Holliday *et al.*, 1999).

STRATIGRAPHIC EVIDENCE

The best-documented stratigraphic evidence for environmental change in the latest Pleistocene and early Holocene comes from the draws and sand dunes. In the valleys, Clovis-age alluvial deposits are overlain by Folsom-age lacustrine and palustrine sediments at the Clovis, Lubbock Lake, and Mustang Spring sites (Fig. 1) (Cotter, 1937; Sellards, 1952; Sellards and Evans, 1960; Green, 1962; Haynes and Agogino, 1966; Haynes, 1975, 1995; Stafford, 1981; Holliday, 1985, 1995a; Meltzer, 1991). The contact between these deposits is abrupt but generally conformable. It dates to ~11,000 ^{14}C yr B.P. at Clovis and Lubbock Lake, but is mid-Folsom-age ($>\sim$10,200 ^{14}C yr B.P.) at Mustang Spring. Additional evidence for Folsom-age lacustrine or palustrine conditions following (undated) alluviation is reported for the Tolk, Anderson Basin No. 2, Davis, Lubbock Landfill, and Progress sites on Blackwater Draw, Edmonson site on Running Water Draw, and Mustang Spring and Wroe sites on Mustang Draw (Fig. 1) (Table 3 in Holliday, 1995a). Lacustrine sedimentation shifted to palustrine conditions rather abruptly at most sites, based on stratigraphic evidence, but the timing of the change ranged

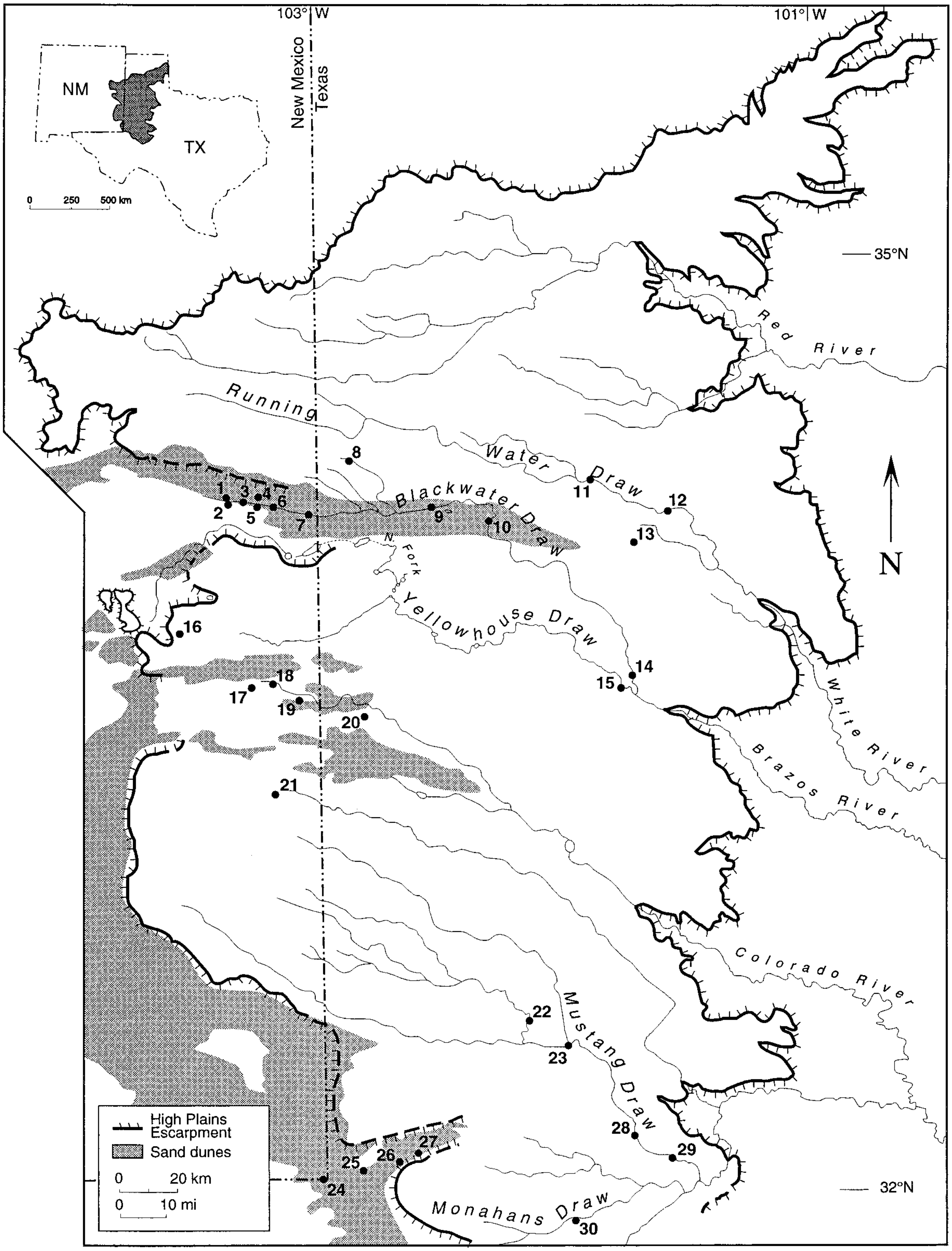

FIG. 1. Map of the Southern High Plains showing the location of the dune fields of the region, drainages, and localities with evidence of late Pleistocene/early Holocene eolian sediments, including Paleoindian archaeological sites (Fig. 2) (1 = Bethel, 2 = Barber, 3 = Burns, 4 = Clovis, 5 = Carbody, 6 = Anderson Basin No. 2, 10 = Marks Beach, 12 = Plainview, 14 = Lubbock Landfill, 15 = Lubbock Lake, 16 = Elida, 17 = Ro-16, 18 = Williamson and Milnesand, 21 = Tatum, 22 = Seminole-Rose, 23 = Carley-Archer, 24 = Winkler-1, 25 = Shifting Sands, 26 = Bedford Ranch, 27 = Wyche Ranch, 30 = Midland); other draw localities (from Holliday, 1995a) (7 = Davis, 8 = Progress, 9 = Tolk, 11 = Edmonson, 28 = Mustang Spring, 29 = Wroe); and lunettes (from Holliday, 1997b) (13 = Texzona, 15 = Lubbock Lake, 19 = Little Bluitt and Bluitt Cemetery, 20 = Bently West). Inset shows the location of the Southern High Plains in Texas and New Mexico.

TABLE 1
Radiocarbon Ages and Stable-C Isotopes from Lunettes[a] and Playas[b]

Lunette			Playa		
Age (^{14}C yr B.P.)	Lab No.	δ^{13}C (‰)	Age (^{14}C yr B.P.)	Lab No.	δ^{13}C (‰)
Bently West			Boyd		
7965 ± 170	A-7868	−21.1	5450 ± 165	SMU-2539	−19.8
19,340 + 825/−745	A-7867	−16.9	Brown		
Bluit Cemetery			7770 ± 210	SMU-2538	−19.7
7880 + 185/−180	A-6904	−17.9	Clovis		
21,865 ± 305	A-6903	−12.3	21,140 ± 470	SMU-2533	−19.1
Bluit Refinery			Elida		
13,730 ± 130	A-6454	−8.4	3215 + 355/−340	A-7435.1	−17.0
14,740 ± 120	A-6453	−7.3	3475 ± 100	A-7436	−20.6
15,150 ± 150	A-6455	−16.6	4720 + 325/−315	A-7437	−21.5
16,210 + 510/−480	A-6910	−18.0	Finney		
21,540 ± 220	A-6456	−16.2	30,200 ± 810	SMU-2681	−23.4
Little Bluit			Jorde		
10,660 + 245/−235	A-6916	−10.5	16,590 + 510/−480	A-6901	−19.4
Lupton West			Lupton East		
24,410 + 1280/−1100	A-6911	−9.5	17,440 ± 840	SMU-2235	−16.8
Peterson			Ryan		
1000 ± 85	A-6908	−14.1	9220 ± 220	SMU-2448	−15.9
19,320 + 750/−690	A-6909	−15.7	10,650 ± 120	SMU-2447	−16.2
Poverty Hill			San Jon		
13,800 ± 90	A-6457	−19.7	3600 + 205/−200	A-7440.1	−18.8
Shepard			7570 + 115/−110	A-7865	−20.0
3110 ± 45	A-6445	−14.4	8360 + 210/−205	A-7864	−22.6
5500 ± 65	A-6446	−16.1	11,450 ± 300	A-7438	−27.3
15,040 ± 200	A-6447	−22.2	12,510 ± 230	A-7439	−28.5
Texzona			13,145 + 315/−305	A-7866	−27.7
8030 ± 65	A-6448	−16.3	Seminole-Rose		
9470 ± 70	A-6452	−20.6	16,310 ± 230	SMU-2342	−15.4
11,670 ± 80	A-6449	−14.2	Truett		
Tobosa Ranch			6665 ± 190	SMU-2537	−16.3
450 ±30	A-6913	−17.0			
755 ± 35	A-6912	−17.8			
14,940 ± 240	A-6914	−13.0			

[a] Radiocarbon ages and isotope data from Holliday, 1997b.
[b] Radiocarbon ages from Holliday *et al.*, 1996.

between 10,500 and 9000 ^{14}C yr B.P. (Holliday, 1995a). Stratigraphic and paleontologic evidence also shows that there were several significant fluctuations of water levels (shifting between several meters depth and no standing water) during accumulation of the lacustrine sediments at a number of localities between 11,000 and 8500 ^{14}C yr B.P., including at least two Folsom-period low stands (Holliday, 1995a; Winsborough, 1995).

For the Clovis site proper, Haynes (1991, 1993) proposes that erosional disconformities within the Clovis-age alluvial deposits are indicative of eolian deflation during a "Clovis drought" and that the overlying lacustrine and palustrine deposits represent increased effective moisture following the drought. An alternate interpretation is that the change in sedimentation and the resulting stratigraphic break represents a *decrease* in effective moisture (Holliday, 1995a, 1997a). A similar case was made for the identical stratigraphic sequence at Lubbock Lake (Holliday, 1985). Stafford (1981) and I both interpret the alluvial deposits there as evidence of through-flowing streams resulting from higher runoff and spring discharge. The erosional contacts within the sands at Clovis, interpreted as eolian deflation surfaces by Haynes (1991, 1993), could be from alluvial erosion (cutting-and-filling) or perhaps represent only the earliest phases of dessication and wind erosion. The lacustrine and palustrine deposits represent a hydrologic shift to isolated standing water due to decreased runoff and declining spring discharge. The subsequent shift (~10,000 ^{14}C yr B.P.) from lacustrine (standing water) to palustrine (marshy) conditions is interpreted as evidence for continued drying and lowering of the water table.

Haynes *et al.* (1999) also describe a "well" at the Clovis site and offer it as further evidence of drought conditions during the

Clovis occupation of the site. This writer participated in the 1993 work on the feature. Clearly it is a pit dug by Clovis-age people. Pits can be dug for many reasons, however, and there is no clear evidence that it was a well. In any case, excavation of a well is not necessarily a response to drought. If the pit does represent digging in response to a lowered water table, however, it could represent a short (one season) dry spell. The pit, although interesting, is far from unequivocal evidence for regional drought.

Eolian deposits in the draws are also evidence for drying from Clovis to Folsom and later times. Eolian sediments are a common component of the valley fill in the region, usually as a valley-margin or upland facies (Holliday, 1995a). The oldest dated eolian deposits (based on radiocarbon or artifact associations) in or along the draws are ca. 11,000 ^{14}C yr B.P. or a little younger (i.e., latest Clovis or Folsom age) (Fig. 2). Radiocarbon ages or artifacts recovered from the Burns, Carbody, Marks Beach, Lubbock Landfill, Lubbock Lake, and Seminole Rose sites suggest that additional eolian sedimentation began after 10,000 ^{14}C yr B.P., with substantial accumulation after 9500 ^{14}C yr B.P. (Fig. 2).

Upland eolian sand on the Southern High Plains is found in three west-to-east-trending dune fields (Fig. 1) and in lunettes. The dunes are stratified, and buried soils are common. The dunes typically contain three or four separate eolian units (Green, 1961; Holliday, 1995b, 1997a). The oldest eolian stratum in each of the three dune fields is a layer of sand, deposited as a sand sheet or low-relief dune, usually <1 m thick and with a Bt horizon that rests uncomformably on older noneolian deposits. The dunes have long been known to be rich in archaeological material, particularly Paleoindian remains (Pearce, 1938; Fritz and Fritz, 1940; Polyak and Williams, 1986; Holliday, 1997a). Twelve Paleoindian sites associated with the oldest eolian unit in the dunes were investigated. Sites with Clovis artifacts are rare in this unit; almost all components are younger, with Folsom artifacts being especially common at most sites (Fig. 2). The common association of Folsom and younger artifacts with a sheet sand, as well as the absence of Clovis material, suggests that the oldest layer is Folsom age or younger. An alternative explanation is that these sites simply were not inhabited by Clovis occupants. Evidence that the eolian sheet sands are no older than Folsom age, however, is available from the Clovis site proper. Boldurian (1990), Haynes (1995), and Holliday (1995a) report a Folsom-age upland eolian layer, identical to the one at the other Folsom localities in dunes. No upland Clovis-age eolian deposit with good stratigraphic control is known in the area, although Clovis occupation here was extensive and is well-documented (Hester, 1972). Moreover, no Clovis-age eolian sediments are reported from the uplands of the Southern High Plains.

Lunettes accreted episodically throughout the late Pleistocene and Holocene, indicating fluctuating water levels in the adjacent playas (Holliday, 1997b). Under wet conditions playas did not deflate, the adjacent lunettes were stable, and soils formed, whereas under drier conditions the playas were subject to deflation, which would result in dune sedimentation. Radiocarbon ages from five sites (Fig. 1) show that during the Paleoindian period there were probably several cycles of lunette sedimentation and stability (Holliday, 1997b). The Lubbock Lake lunette contains evidence of at least two cycles of stability–sedimentation–stability: ca. $<12{,}000$ to >8300 ^{14}C yr B.P. and <8300 to >6700 ^{14}C yr B.P. The Little Bluitt lunette accreted sometime before and after ca. 10,600 ^{14}C yr B.P., and both the Bluitt Cemetery and the Bently West lunettes were active shortly before and shortly after ca. 7900 ^{14}C yr B.P. The Texzona lunette went through at least one cycle between $<11{,}600$ and >8000 ^{14}C yr B.P. The data from lunettes do not directly address the issue of Clovis drought vs Folsom drought, but clearly provide evidence of episodic drought during the Paleoindian occupation of the region.

ISOTOPIC INDICATORS

Stable-carbon isotopes (δ^{13}C PDB) in organic matter from the dated A horizons of buried soils in 10 lunettes and from dated lacustrine muds in 11 playas (Table 1) allow inferences to be made regarding past vegetation, and hence past environments, because there is a strong positive correlation between temperature and relative abundance of grasses (Teeri and Stowe, 1976; Kelly *et al.*, 1993, 1998). Plants of C_3 and C_4 photosynthetic pathways are broadly indicative of two distinct environments: C_4 plants are mainly warm-season grasses with δ^{13}C values of -9 to -17 (mean of -13), whereas the C_3 plants include cool season grasses, most aquatic plants, and all trees, with δ^{13}C values of -22 to -32 (mean of -27) (Fig. 3). The trends in late Pleistocene and early Holocene plant communities are best compared with data for "modern" or late Holocene plant communities in playas and lunettes. For lunettes, only three data points are available for the past 1500 years (Fig. 3), but suggest a mix of C_3 and C_4 plant communities. This interpretation is supported by a regional study of isotope values for native prairie (Table 2 in Fredlund and Tieszen, 1997). Only one data point is available for the playa (Fig. 3), also indicative of an isotopically mixed plant community. This is supported by descriptions of the plant communities growing in modern undisturbed playas (Reed, 1930; Rowell, 1971), which indicate a mixed C_3 and C_4 grass community.

The well-drained, exposed lunettes and more poorly drained playa floors are very different settings and each probably contained different vegetation assemblages, precluding meaningful comparison of specific isotopic values. The playa basins also may contain some organic matter washed in from the basin margins, whereas the lunettes probably have a record of *in situ* vegetation. Some organic matter may have been deflated from the basins and redeposited on lunettes, but this would have been during dune accretion and most if not all of the redeposited organic matter would have been oxidized prior to the next

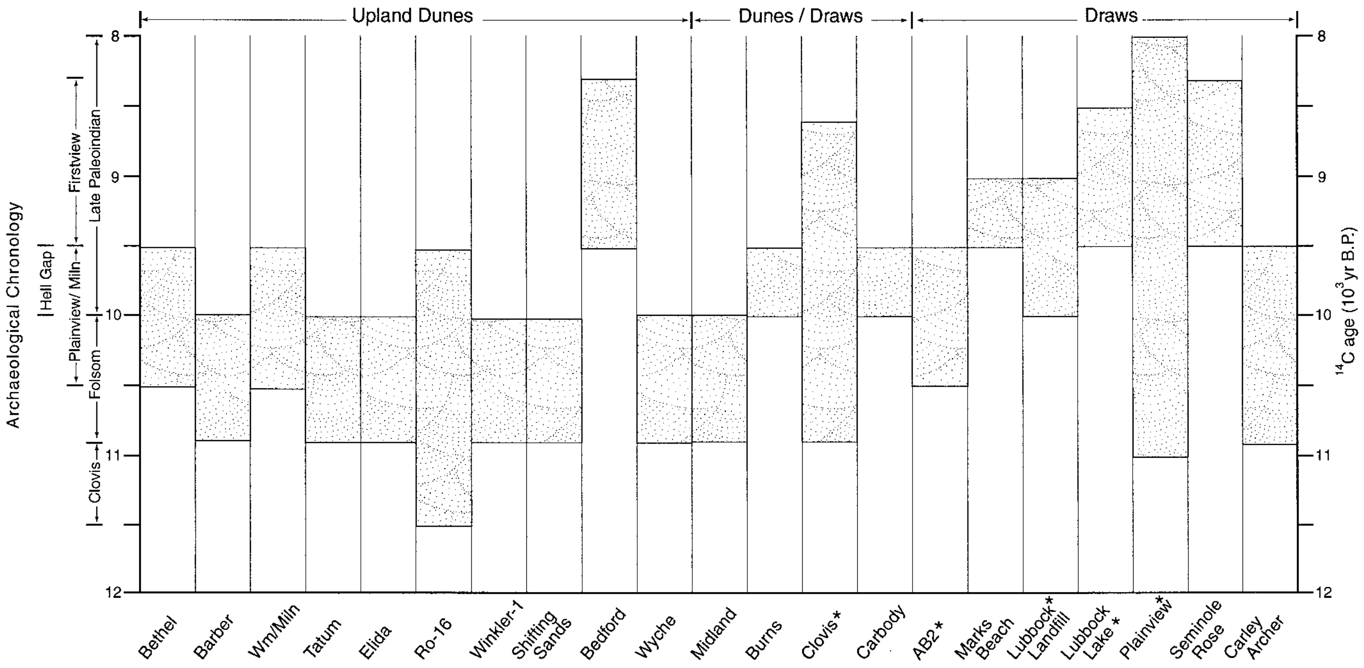

FIG. 2. Archaeological sites on the Southern High Plains (located in Fig. 1) with Paleoindian-age eolian deposits (Wm/Miln = Williamson and Milnesand sites; AB2 = Anderson Basin No. 2). The shading indicates the presence of eolian sediments with associated archaeological material representing a particular time period (vertical axis), although episodes of eolian deposition probably represent much shorter time intervals. Eolian deposits in sites denoted by * have associated radiocarbon ages. The sites are grouped by geomorphic setting. Sites identified as "dune/draw" are in dunes along the margins of draws (Fig. 1). The Paleoindian chronology follows Holliday (1997a), which also contains discussions of all sites. Additional information is available for the following sites: Clovis (Haynes and Agogino, 1966; Haynes, 1975, 1995; Haynes *et al.*, 1999), Lubbock Lake (Stafford, 1981; Holliday, 1985; Johnson, 1987b), Midland (Holliday and Meltzer, 1996), and Plainview (Holliday *et al.*, 1999).

phase of dune stability and soil formation. Comparisons of specific points in time also are difficult owing to the distribution of radiocarbon ages. Substantial changes in vegetation through time due to climate change, however, are apparent in a comparison of broad isotopic trends (Fig. 3).

In the lunettes there was a gradual shift toward lighter (lower) isotopic values from 25,000–15,000 ^{14}C yr B.P. (i.e., from C_4-dominated grass to C_3-dominated grasses). Isotopic values for the period 15,000–8000 ^{14}C yr B.P. are variable, including both heavier and lighter values 15,000–13,000 ^{14}C yr B.P., but generally heavier values 12,000–10,000 ^{14}C yr B.P. (based on only two data points), and a shift back to lighter values 10,000–8000 ^{14}C yr B.P. (also based on only a few data points). At ca. 8000 ^{14}C yr B.P. there was another shift to relatively heavier values. The lunette data show a gradual increase in plants favoring cooler, temperate environments and probably an increase in effective moisture 25,000–15,000 ^{14}C yr B.P. The isotopic variability for the period 15,000–13,000 ^{14}C yr B.P. may be indicative of fluctuating environments, followed by warmer conditions until 10,000 ^{14}C yr B.P. and then a return to a cooler environment until 8000 ^{14}C yr B.P.

The isotope data from the playa sediments for the period ca. 20,000–8000 ^{14}C yr B.P. suggest a marked shift from heavier to lighter values 20,000–12,000 ^{14}C yr B.P., back to heavier values ca. 12,000–9000 ^{14}C yr B.P., and then a return to heavier values 9000–7000 ^{14}C yr B.P. The data points for the late Pleistocene from the playas are broadly similar to those from the lunettes although indicating cooler conditions 14,000–11,000 ^{14}C yr B.P. The two different data sets do not provide the same temporal coverage, but a reasonable interpretation is that vegetation on the floors of playa basins may not have been as sensitive to short-term environmental changes other than decreasing in density during brief dry phases.

The data from both lunettes and playas for the period 11,000–7000 ^{14}C yr B.P. show considerable fluctuation in isotopic trends, suggestive of environmental fluctuations between cooler and warmer conditions. The most dramatic shift is the one toward heavier isotopic values 11,000–10,000 ^{14}C yr B.P., indicative of relatively warm conditions during the Folsom occupation. During the preceding Clovis occupation, one data point from a lunette suggests that the warm trend was underway, but the single Clovis-age isotope sample from a playa indicates that cool-season plants persisted. Perhaps lunettes, being well drained and topographically higher than the surrounding terrain, warmed more quickly than playa basins. Alternatively, perhaps the warming trend began with a series of temperature fluctuations during Clovis time. A similar contrast in isotope trends, also based on only one data point each for the two settings, is apparent for the period 10,000–9000 ^{14}C yr B.P. The lunettes either stayed warmer later or the period

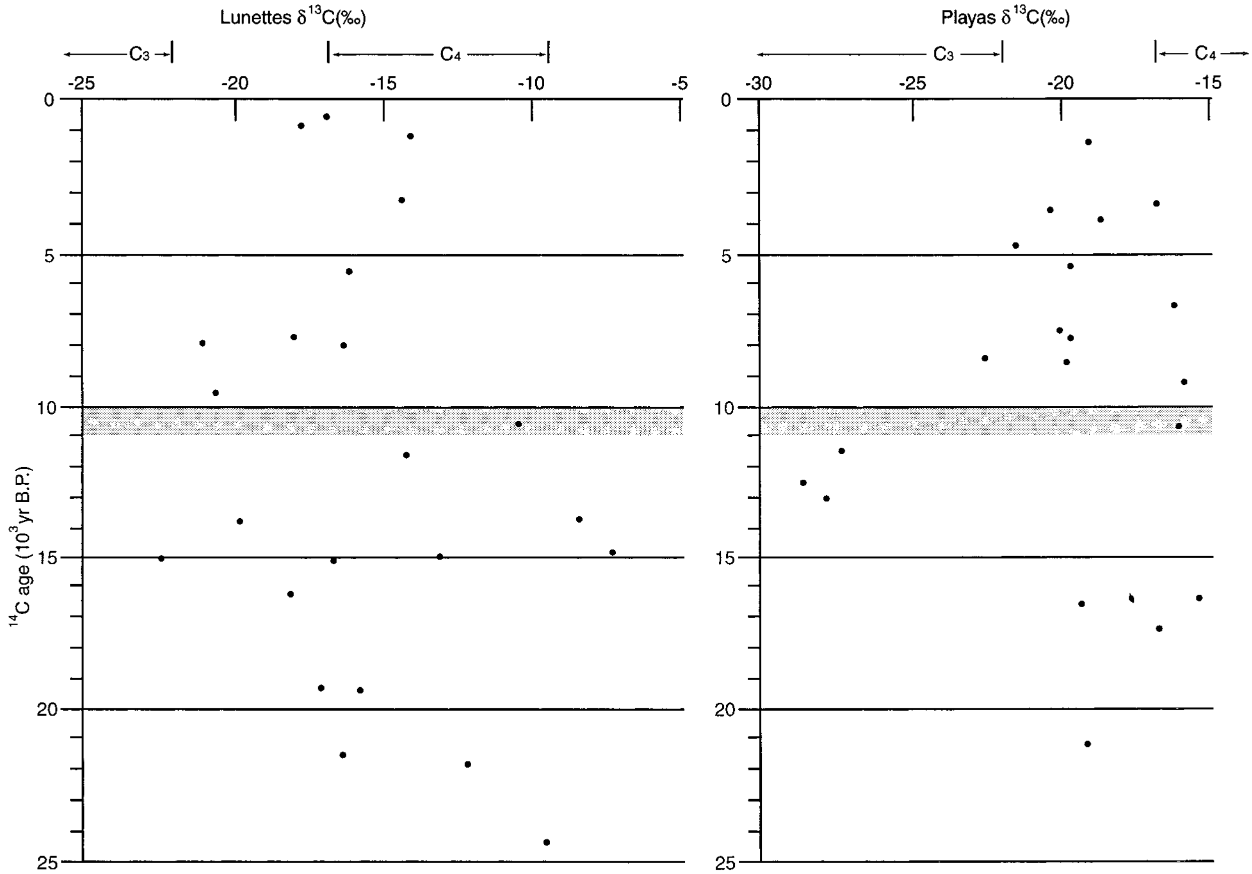

FIG. 3. Values for stable-carbon isotopes from late Pleistocene and early Holocene contexts in lunettes (from Holliday, 1997b) and playas on the Southern High Plains (modified from Fig. 5.3 in Holliday, 1997a). Shading indicates the approximate duration of the Folsom occupation of the Southern High Plains.

witnessed more temperature fluctuations. Relatively cooler conditions apparently existed from 9000–8000 ^{14}C yr B.P. The isotopic data from the lunettes indicates a dramatic shift toward warmer conditions at ca. 8000 ^{14}C yr B.P., almost identical to a trend apparent in isotopic data from late Quaternary valley fills (Holliday, 1995a) that coincides with independent stratigraphic and paleontological evidence of middle Holocene warming and drying (Holliday, 1989, 1995a,b; Johnson, 1987a; Johnson and Holliday, 1986).

The stable-C isotope values also provide additional evidence that the Southern High Plains was not covered by coniferous forest in terminal Pleistocene and early Holocene times (Wendorf, 1961, 1970; Wendorf and Hester, 1975). All trees follow the C_3 photosynthetic pathway and have δ^{13}C values in the range of −24 to −28‰. All of the values for the period 11,000–9000 ^{14}C yr B.P. are heavier and most are not in the C_3 range (Table 1, Fig. 3).

DISCUSSION AND CONCLUSIONS

Lacustrine, palustrine, and eolian sediments, stable-C isotopes, and paleontology indicate that the Southern High Plains was subjected to significant, rapid fluctuations in temperature and moisture in the last millennia of the Pleistocene and early millennia of the Holocene, including the Paleoindian period. The aridity characteristic of the middle and late Holocene first appeared as episodes of drought in the last millennia of the Pleistocene and earliest millennia of the Holocene. The stratigraphic record from dune fields and draws, and to a lesser extent from lunettes, indicates that the region was subjected to several periods of wind erosion and eolian sedimentation between ~11,000 and ~8000 ^{14}C yr B.P., but evidence for drought during Clovis time (~11,200–10,900 ^{14}C yr B.P.) is sparse. Data from stable-C isotopes show that the grass communities shifted between dominantly cool-season and dominantly warm-season species beginning in Clovis time and continuing until ~9000 ^{14}C yr B.P., but with a very strong influence from warm-season grasses during Folsom time and no evidence of boreal forest, as proposed by earlier investigators. The drying, probably linked to warming, destabilized the landscape and resulted in wind erosion and eolian sedimentation. This eolian sedimentation also marked the beginning of construction of the dune fields of the region.

The earliest and best-documented phase of marked regional drying and widespread eolian sedimentation occurred between 10,900 and 10,200 ^{14}C yr B.P. and was largely coincident with the Folsom occupation of the region. Evidence for sand sheets dating to this time is found throughout the western portion of the Southern High Plains. The draws also began to undergo a marked hydrologic change from flowing water to standing water. This hydrologic shift in the draws evolved over more than a millennium (11,000–9500 ^{14}C yr B.P.) and produced an asynchronous stratigraphic record (Holliday, 1995a). This change was first manifested sedimentologicaly at three major springs (Clovis, Lubbock Lake, and Mustang Spring) at or just after 11,000 ^{14}C yr B.P. with an abrupt change from alluviation to lacustrine sedimentation. Eolian sediments also began to accumulate in some reaches of the draws during the 11,000–10,000 ^{14}C yr B.P. interval. The stable-C isotopes also provide evidence, albeit limited, of a shift to warmer conditions at this time. Several more phases of drying followed the Folsom period, but they are not as well dated or as apparent stratigraphically. There was probably one between 10,000 and 9000 ^{14}C yr B.P. and another around or after 9000 ^{14}C yr B.P. Limited stable-C data suggest that there was a shift to relatively cooler conditions during all or part of the period 10,000–8000 ^{14}C yr B.P. At ca. 8000 ^{14}C yr B.P. the entire region was subjected to the warmer and drier conditions that characterized the middle Holocene "Altithermal" period.

Paleobiological studies at several localities in the region provide further clues to the shifting environments of the Paleoindian period. The microvertebrate record from Lubbock Lake clearly shows a significant ecological change at 11,000 ^{14}C yr B.P., with cooler, wetter conditions in Clovis time shifting to relatively warmer, drier, and more seasonal conditions in Folsom time (Johnson, 1986, 1987a,c). Molluscs (Neck, 1995), and particularly diatoms (Winsborough, 1995), from a number of draw localities provide evidence of fluctuating ponds and marshes between 11,000 and 8000 ^{14}C yr B.P. The chronometric resolution of these records is low, but the diatoms suggest a period of higher water and possibly moister conditions sometime between 10,500 and 9500 ^{14}C yr B.P., perhaps separating the Folsom and earliest post-Folsom episode of regional dessication.

The drought conditions on the Southern High Plains during the Folsom occupation are not comparable to aridity of the middle Holocene or the droughts of historic time. Drought and aridity are not synonymous terms. In a relative sense, however (and drought is a relative condition), drought prevailed during the Folsom and subsequent late Paleoindian time compared to conditions during the earlier Clovis period. Water was flowing in most draws until ~11,000 ^{14}C yr B.P. At that time the hydrology of the draws began to change; lakes, ponds, and marshes abruptly replaced streams. At least twice during Folsom time lakes with water several meters deep disappeared from the draws and temporarily were replaced with shallow ponds or marshes. Beginning ~10,000 ^{14}C yr B.P., the lakes and ponds began to fall permanently, leaving marshes. On the uplands, sand sheets began to form beginning ~10,900 ^{14}C yr B.P. and spread episodically until the early Holocene, when they evolved into dune fields. In the draws, these pulses of eolian sediment interfinger with the lacustrine and palustrine deposits.

The recognition of drought episodes during the early human occupation of the Southern High Plains raises the issue of human adaptation to the changing environment. The archaeological record at this point provides some clues. Most of the intensively studied Folsom sites in the region with *in situ* features are kill/butchering locales (Holliday, 1997a). These features include bone beds at the Lubbock Lake and Clovis archaeological sites found within diatomite (Hester, 1972; Holliday, 1985; Johnson, 1987b) and formed during marshy, low-water phases (butchering would be unlikely in standing water). Therefore, the drought conditions apparently did not impact bison populations significantly. Likewise, human predation of bison, which occurred prior to, throughout, and after this period, appears to be unaffected by the local climatic shifts. However, the high archaeological visibility of bison remains may mask the fact that additional resources were incorporated into the diet in response to archaeologically undetectable fluctuations in bison numbers. Overall, archaeological evidence does not suggest a major decline in human population or resources during drought episodes of the Folsom period.

The potential lack of an obvious adaptive response to drought may be related to the intensity and duration of this drought. Conditions were only temporarily drier, but water was still available. This was not a drought of the magnitude of the middle Holocene "Altithermal" when groups responded to the disappearance of surface water by digging wells, broadening the diet to include more plant resources, and even abandoning local areas (Johnson and Holliday, 1986; Meltzer, 1995, 1999). Moreover, given that Folsom Paleoindian groups were among the earliest occupants of the region, their population density may have been relatively low and the demand for resources was not as great as that during the Holocene.

Interpretations of Paleoindian environments on the Southern High Plains have evolved considerably since they were first proposed more than 60 years ago. A recent revision of these interpretations is Haynes' (1991, 1993) proposal for a Clovis drought, followed by a return to cooler, wetter conditions in Folsom time. A reasonable assumption to follow from this hypothesis is that evidence for a regional drought on the Southern High Plains should be manifested by Clovis-age eolian deposits. The Clovis Drought hypothesis is based on stratigraphic data from the southwestern United States, including two localities on the Southern High Plains: the Clovis and Miami archaeological sites. The stratigraphic interpretations at Clovis are equivocal, however, as discussed above, and the eolian layer at Miami actually predates the Clovis level (Holliday *et al.*, 1994; Holliday, 1997a). The geochronology and stratigraphy of the Midland site were reinvestigated and substantially revised (Holliday and Meltzer, 1996). The site is typical of other draw localities in the region, containing evidence for reduced discharge from pre-Folsom through Folsom time (Holliday, 1995a). There is no evidence for Clovis-age wind deflation or eolian sedimentation. Moreover, archaeological sites in the region with Clovis artifacts and Clovis-age sediments typically are associated with depositional environments characteristic of wetter conditions (e.g., perennial streams, alluviation, and more energetic spring discharge) compared to Folsom-age and younger sediments characterized by depositional environments associated with relatively drier conditions (e.g., standing water or absence of surface water altogether, lower spring discharge or seeps, and eolian sedimentation). Clovis time, in all probability, was the "wettest" of any Paleoindian period, at least in terms of runoff and spring discharge. The Folsom period, in contrast, was the earliest episode of regional wind erosion and eolian deposition and may have been the warmest of Paleoindian times.

A broadly similar stratigraphic and paleoenvironmental record for the period 12,000–8000 ^{14}C yr B.P. is apparent elsewhere on the Great Plains. Some Paleoindian-age eolian deposition is documented in western Oklahoma (Thurmond and Wyckoff, 1998). On the Colorado Piedmont and High Plains of eastern Colorado, Clovis artifacts are reported in association with alluvium or indicators of high-water-table conditions (e.g., Holliday, 1987b; Reider, 1990; McFaul *et al.*, 1994; Haynes *et al.*, 1998). Some younger occupations are also associated with these conditions, especially along the South Platte River (McFaul *et al.*, 1994; Haynes *et al.*, 1998), but beginning with the Folsom period, Paleoindian sites are increasingly associated with eolian deposits (e.g., Roberts, 1937; Malde, 1960; Agogino and Parrish, 1971; Reider, 1990; McFaul *et al.*, 1994). Some of the extensive sheet sands and dune sands in eastern Colorado probably were emplaced ca. 11,000 ^{14}C yr B.P., and locally eolian deposition may have continued until 9000 ^{14}C yr B.P. (Madole, 1995; Muhs *et al.*, 1996). Loess was also deposited in eastern Colorado between ~11,000 and 9000 ^{14}C yr B.P. under warming conditions (Muhs *et al.*, in press). Farther east, a component of the Nebraska Sand Hills probably formed between 11,000 and 10,000 ^{14}C yr B.P. (Swinehart, 1989; Loope *et al.*, 1995; May *et al.*, 1995; Muhs *et al.*, 1999). High-resolution paleobotanical or paleontological records for the terminal Pleistocene and early Holocene on the Great Plains are rare, but Fredlund and Tieszen (1997), using isotope and phytolith analyses, show that the Black Hills region underwent rapid warming between 11,000 and 9000 ^{14}C yr B.P.

The paleoclimatic significance of some of the eolian deposits on the Central Plains and Rolling Plains is difficult to assess, however. Many of the localities are near major drainages which probably provided an abundant supply of sand (e.g., the South Platte and Red rivers) (e.g., Muhs *et al.*, 1996, p. 147) or are located in proximity to extensive sand sources (e.g., the Ogallala Formation in western Oklahoma) (Thurmond and Wyckoff, 1998). However, regional aridity almost certainly accounted for sediment movement in some of the large dune fields (Muhs *et al.*, 1996, Muhs *et al.*, 1999).

Several archaeological sites on or along the fringes of the northern High Plains (Lindenmeier, CO, Hell Gap, WY, and Lange-Ferguson, SD) are mentioned in support of the Clovis Drought hypothesis (Haynes, 1993, p. 231–232). They all contain evidence of Clovis-age erosion (interpreted as an indicator of aridity) followed by formation of a Folsom-age "wet meadow soil" (interpreted as a return to more stable wetter conditions). The interpretations are equivocal. The Clovis-age erosion could be the result of wetter conditions and increased runoff followed by drier Folsom-age conditions with marshes forming where water once flowed. Or the erosion and stability could represent a geomorphic cycle unrelated to climate or induced by environmental instability in Clovis or pre-Clovis time.

In other areas of the eastern Great Plains, evidence suggests that during the last millennia of the Pleistocene and the early millennia of the Holocene the landscape was stable and experiencing pedogenesis and that environmental conditions were generally cooler and moister than today, although they were gradually warming and drying (Martin, 1993; Humphrey and Ferring, 1994; Nordt *et al.*, 1994; Valero-Garcés *et al.*, 1997). Forman *et al.* (1995, p. 46), drawing on various lines of evidence, emphatically state that "eolian activity ceased in the mid-continental U.S. between ca. 12,000 and 9000 [^{14}C] yr B.P." This generalization, however, is based on a very limited number of localities studied in eastern Colorado and conflicts with other studies in that area and western Nebraska (Swinehart, 1989; Loope *et al.*, 1995; Madole, 1995; Muhs *et al.*, 1996, 1999, in press).

Rapid climatic oscillations apparently coincided with the collapse of the last Pleistocene ice sheets (Dansgaard *et al.*, 1989; Stuiver *et al.*, 1995), but most of the evidence for these climate shifts comes from high latitudes or the western and eastern margins of North America (e.g., Allen and Anderson, 1993; Benson *et al.*, 1997; Yu and Eicher, 1998). The data presented in this paper are the first from the Great Plains to suggest that this mid-latitude, continental region was also subjected to rapid fluctuations in climate in late-glacial times. In particular, the eolian activity documented for 10,900–10,200 ^{14}C yr B.P. on the Southern High Plains coincided with the Younger Dryas climate episode, the subject of much discussion in recent Quaternary paleoclimate literature (e.g., Berger, 1990; Broecker, 1992, 1995; Mayewski *et al.*, 1993; Anderson, 1997). How the Younger Dryas affected the Great Plains, if at all, is far from clear, however. Although the Folsom-age eolian activity coincides in time with the Younger Dryas, the Folsom period was probably drier (and warmer?) than the preceding Clovis period or the succeeding late Paleoindian period. As yet, no evidence has been found of Younger Dryas-style cooling on the Southern High Plains 11,000–10,000 ^{14}C yr B.P.

The stratigraphic and isotopic data refine the chronology of late Pleistocene and early Holocene environmental change on the Southern High Plains and contradict some previous reconstructions, particularly the ideas for a Clovis-age drought and a Folsom-age boreal forest. The environmental conditions in the region during the Paleoindian occupation clearly were unlike any other time in the late Pleistocene or in the Holocene. The final millennia of the Pleistocene became significantly warmer and drier than the preceding part of the late Pleistocene and probably triggered shifts in vegetation that destabilized the sandy substrate and led to formation of three dune fields. This drought was the first step in late Quaternary desiccation of the Southern High Plains which culminated, in the middle Holocene, with the most severe aridity in the geologic record of the region.

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