QUATERNARY RESEARCH 31, 74–82 (1989)

Middle Holocene Drought on the Southern High Plains

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Received May 12, 1988

The climate of the Southern High Plains during the middle Holocene is indicated by data from a variety of sources. Stratigraphic, geomorphic, and pedologic research at six localities in draws, several dune sites, and one playa-lake basin show that widespread eolian erosion and sedimentation began in some areas by 9000 yr B.P. and culminated 6000–4500 yr B.P., probably because of warmer, drier conditions that reduced the vegetative cover. Archaeological investigations at three sites provide evidence for the excavation of wells at this time, apparently because of a declining water table. Studies of a few vertebrate and invertebrate faunas also indicate warming and drying in the middle Holocene. Climate models and very limited isotopic data from *Bison* bone suggest that summers in the middle Holocene were warmer than present, with reduced effective precipitation. All lines of evidence indicate that the Southern High Plains was subjected to prolonged drought in the middle Holocene with a maximum between 6500 and 4500 yr B.P., conforming climatically and chronologically to the Altithermal.

INTRODUCTION

The concept of a warm, dry climate in the western United States in the middle Holocene (ca. 7500–5000 yr B.P.) gained scientific prominence with the definition of the "Altithermal" by Antevs (1948, 1955). These interpretations have been debated by palynologists, paleoclimatologists, geologists and geomorphologists, and archaeologists since they were proposed (Martin, 1963; Martin and Mehringer, 1965; Reeves, 1973; Hassan, 1984; Hall, 1985; McKinnon and Stuart, 1987). Recently developed models of late-Quaternary atmospheric circulation at the subcontinental scale support the argument that the interior of North America was warmer and had less effective precipitation in the middle Holocene (Davis, 1984; Kutzbach and Guetter, 1986), but these models are of insufficient resolution to allow analyses at the scale of individual physiographic sections as defined by Fenneman (1931). One of the reasons for the debate over the Altithermal is the lack of substantive data from well-defined geographic regions.

In order to identify a discrete, regional climatic event, research must be focused on specific time intervals in specific areas. This paper presents evidence from the Southern High Plains for climatic warming and reduced effective precipitation in the middle Holocene, the Altithermal as classically envisioned climatically and chronologically. Antevs (1955) was the first formally to propose regional, middle-Holocene drought for the Southern High Plains, based on evidence from Evans and Meade (1945), Evans (1951), and Judson (1953), but did so in the absence of firm age control and very limited geologic data. The interpretations in this paper are based primarily on more recent geomorphic and stratigraphic data from a number of dated localities throughout the region, with a variety of supporting evidence from paleontology and archaeology.

The Southern High Plains of northwestern Texas and eastern New Mexico is an extensive plateau (~130,000 km^2) with a semi-arid continental climate. It has a virtually featureless, constructional surface modified locally by several dune fields, thousands of small basins with ephemeral lakes or playas locally associated with lunettes, and several northwest–southeast-trending dry valleys or draws (Holli-

0033-5894/89 $3.00

day, 1985a) (Fig. 1). The evidence for the Holocene history of the area comes from late Quaternary sediment found in the draws and playas, and from Holocene dunes. Climatic conditions of the latest Pleistocene were characterized by higher effective precipitation relative to today, based on the presence of fluvial and lacustrine sediments in the draws (Haynes, 1975; Stafford, 1981; Holliday, 1985a, b, c, d, 1986; Meltzer and Collins, 1987) and data from paleontology (Wendorf and Hester, 1975; Johnson, 1986, 1987; Pierce, 1987), with a gradual trend toward drying and increased seasonality extending into the early Holocene (Wendorf and Hester, 1975; Holliday, 1985b, c, d; Johnson, 1986, 1987; Pierce, 1987). This trend culminated in the middle Holocene with conditions warmer and drier than today, as documented by geologic, paleontologic, and archaeologic evidence described below.

GEOMORPHIC EVIDENCE

The strongest evidence used to characterize the middle-Holocene climate of the Southern High Plains is from geomorphic data (Fig. 2). The draws have yielded a large proportion of these data on late-Quaternary environments of the region. Most of the sites are in the central portion of the Southern High Plains and include Lubbock Lake on lower Yellowhouse Draw, the BFI Landfill on lower Blackwa-

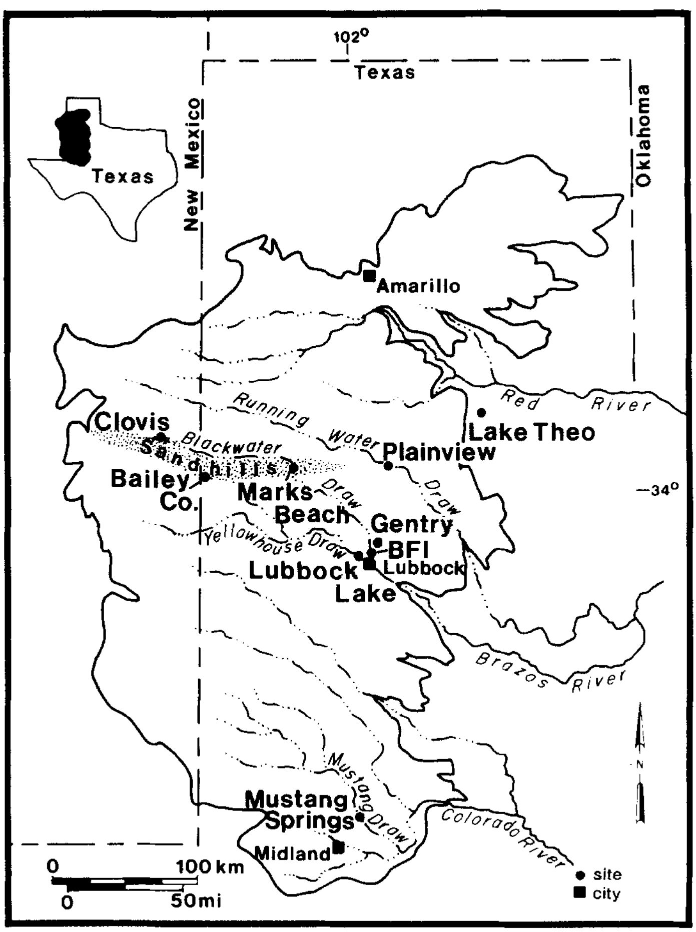

FIG. 1. Map of the Southern High Plains with locations of principal cities and rivers, draws and sites mentioned in the text. Inset is a map of Texas with the location of the Southern High Plains.

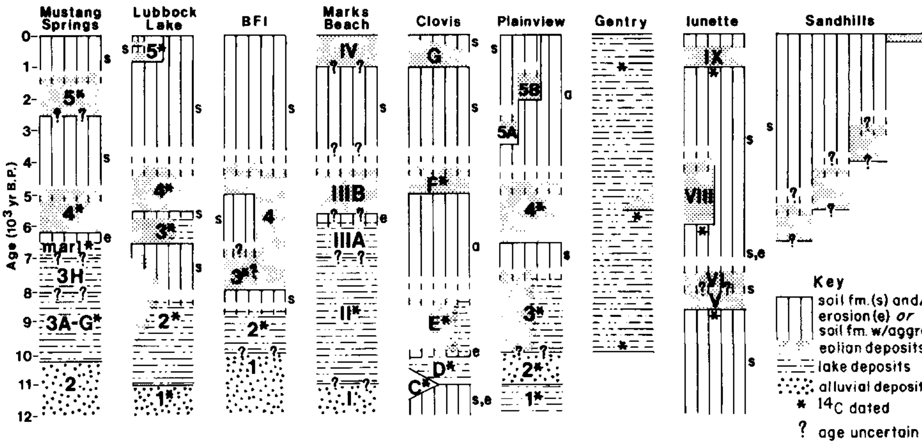

FIG. 2. Correlation chart of all dated late-Quaternary stratigraphic sequences on the Southern High Plains with evidence of middle-Holocene eolian deposition. The letters and numbers within the patterns in each column refer to the stratigraphic terminology reported for each site.

ter Draw, Marks Beach on middle Blackwater Draw, the Clovis site (Blackwater Locality No. 1) and other localities on upper Blackwater Draw, and the Plainview site on middle Running Water Draw (Fig. 1). In the extreme southern portion of the region data are available from Mustang Springs on Mustang Draw (Fig. 1).

Lubbock Lake (Fig. 1) is the most intensively investigated and best-dated late-Quaternary locality on the Southern High Plains (Holliday, 1985b; Johnson, 1987). The middle-Holocene geologic record is largely one of eolian sedimentation (Fig. 2). Sandy windblown deposits (in stratum 2) began accumulating in the draw by 9000 yr B.P., but were concentrated in two pulses, between ca. 6300 and >5000 yr B.P. (in stratum 3) and from ca. 5000 to ca. 4500 yr B.P. (in stratum 4). Along the axis of the draw stratum 2 has a noncalcareous lacustrine facies with diatomite and abundant secondary silica and stratum 3 has a paludal marl facies. Between the deposition of strata 3 and 4 was a period of landscape stability, and along the valley axis a resurgence of spring activity is represented by erosion, then deposition, of alluvial sands and marsh clays. After deposition of stratum 4, most of the rest of the Holocene was a time of landscape stability and soil formation in the eolian parent material. This middle-Holocene stratigraphic sequence is continuous downstream from Lubbock Lake for at least 14 km (Stafford, 1981).

The BFI Landfill contains eolian sediment of middle-Holocene age (stratum 4) (Holliday, 1985a) (Figs. 1 and 2). Along the valley axis this material buries calcareous marsh sediment (stratum 2, lithologically similar to the lacustrine facies of stratum 3 at Lubbock Lake), which contains organic matter at the top that yielded a radiocarbon age of 8130 ± 50 yr B.P. (SMU-1675). On the valley margin, stratum 4 buries a calcareous eolian deposit (stratum 3) with organic material at the top dated to 5125 ± 95 yr B.P. (SI-5495). In stratum 4 at the BFI site, a soil morphologically like that in stratum 4 at Lubbock Lake suggests that deposition of both units ended about the same time, ca. 4500 yr B.P. Eolian sedimentation at BFI was probably more or less continuous in the middle Holocene.

The sediments at the Marks Beach site (Honea, 1980; V. T. Holliday, unpublished data) (Fig. 1) are poorly dated, but some correlations are suggested by comparing the stratigraphy and soils at the site with those at dated localities (Fig. 2). Diatomaceous, noncalcareous lacustrine deposits (zone II) are overlain by paludal marl (zone IIIA). The lower portion of zone II contained *Bison antiquus* bones which yielded a radiocarbon age of about 10,000 yr B.P. This is identical to the strata 2–3 sequence at Lubbock Lake. Above zone IIIA at Marks Beach are dune sands of the Sandhills dune field (zone IIIB) (Fig. 1). The morphology of soils in the dunes suggests a middle-Holocene age, on the basis of correlations with dune stratigraphy in Bailey County to the west (Fig. 1) (Gile, 1979).

Along upper Blackwater Draw, investigations of the late-Quaternary geology have focused on the Clovis site and neighboring localities (Figs. 1 and 2) (Haynes and Agogino, 1966; Haynes, 1975; Holliday, 1985d). Eolian sedimentation in the area first occurred from ca. 10,000 to <8500 yr B.P. (Unit E). Episodic eolian sedimentation followed, culminating in widespread, massive eolian deposition about 5000 yr B.P. (Unit F), representing a portion of the Sandhills dune field.

Most of the stratigraphic data for Running Water Draw come from the Plainview archaeological site (Figs. 1 and 2) (Holliday, 1985d, 1986). Eolian sedimentation first occurred between 10,000 and 6800 yr B.P. (Unit 3), contemporaneously with deposition of calcareous marsh sediments (both facies of Unit 3). Shortly after 6800 yr B.P., following an interval of nondeposition represented by soil formation, eolian sediments began to fill the draw (Unit 4) and up to 2 m of this material accumulated sometime before 4000 yr B.P. Stratigraphic sections identical in lithology and soils are exposed 15 km upstream and 18 km downstream from Plainview.

The one other draw locality with a described and dated middle-Holocene record is Mustang Springs, near Midland (Figs. 1 and 2) (Meltzer and Collins, 1987; Hill and Meltzer, 1987). A paludal marl, dated to about 6700 yr B.P., overlies diatomaceous lake sediments with common secondary silica (strata 3A-3H). Above the marl is a layer of silty and sandy eolian sediment (stratum 4). This deposit was originally believed to be ca. 5000 yr old, but it is now considered to be closer in age to the marl (Meltzer and Collins, 1987; Hill and Meltzer, 1987; D. J. Meltzer, personal communication, 1987).

Limited stratigraphic data and age control are available for some of the dune fields and lunettes on the Southern High Plains. The Sandhills is a linear, west–east-trending dune field that begins west of Clovis, New Mexico, and extends far into Texas (Fig.1). The dunes parallel and locally bury Blackwater Draw. Soil-stratigraphic investigations in the central Sandhills of Bailey County indicate that a significant portion of the dunes were created between about 7000 and 4000 yr B.P. (Fig. 2) (Gile, 1979), although precise age control is lacking.

A lunette located along Yellowhouse Draw adjacent to Lubbock Lake (Figs. 1 and 2) (Holliday, 1985a) has two layers of sediment (Strata V and VI) deflated from the adjacent playa between about 8800 and 7000 yr B.P. These sediments are overlain by an eolian sand (Stratum VIII) inset against the windward side of the dune. Radiocarbon ages and soil morphology indicate that Stratum VIII was deposited between about 6000 and 4500 yr B.P. The deposit is probably an upland equivalent of stratum 4 at Lubbock Lake.

The ubiquitous playa-lake basins of the region are the subject of many studies (thoroughly reviewed by Osterkamp and Wood, 1987), but sedimentological or geochronological data for these features are limited. It was proposed that many of the small basins were deflated during the Altithermal (Reeves, 1966; Reeves and Parry, 1969), but there is no direct evidence for this. Radiocarbon ages from Gentry playa (Figs. 1 and 2), in a typical small basin north of Lubbock, show that it has been filling with lacustrine sediment for the past 10,000 yr (Holliday,1987a; Osterkamp, 1987). The lake basin contains about 3 m of clayey organic-rich fill, characteristic of the lake basins in the region. However, on the southwest (upwind) side of the basin, within the clay, there is a wedge of unbedded, sandy eolian sediment thickest at the basin margin and thinning toward the center. The sandy wedge overlies lake sediment dated 5730 ± 60 yr B.P. (SMU-1375).

Eolian deposition was widespread throughout the Southern High Plains during the middle Holocene (Fig. 2). These eolian sediments must have been derived from the surface of the Southern High Plains, which is composed of Pleistocene eolian deposits (Holliday, 1985a; Holliday and Gustavson, 1988), and are indicative of widespread, long-term wind erosion in the middle Holocene. This deflation probably resulted from a reduction in vegetative cover and loss of soil moisture, which allowed winds to scour the surficial sediments. The vegetation change was most likely in response to increased temperatures and lower effective precipitation relative to the preceding or following periods. Studies of native grasslands on the Great Plains clearly show that the vegetative cover is significantly reduced with the onset of drought, resulting in severe deflation and movement of considerable amounts of sediment by the wind (Weaver and Albertson, 1943; Tomanek and Hulett, 1970). Wind erosion is a common problem on the High Plains today and typically follows several years of drought (Smith *et al.*, 1970; McCauley *et al.*, 1981; Holliday, 1987b), which is usually accompanied by higher than average winds and temperatures (Holliday, 1987b). The intensity of wind erosion on the Southern High Plains today is influenced by human activity, but the process is a natural, recurring one (Holliday, 1987b).

An increase in temperature in the middle Holocene is also indicated by the presence of highly calcareous marsh sediments at many of the draw localities such as Lubbock Lake and Mustang Springs. At most sites these sediments contrast markedly with immediately underlying marsh and lake sediments containing secondarily precipitated amorphous silica. This change in mode of sedimentation denotes a significant change in the local geochemical environment, possibly due to rising temperatures. The abrupt lithological change may denote the crossing of a geochemical threshold, as the marsh waters warmed, and an environment favoring silica precipitation changed to one favoring carbonate precipitation (Holliday, 1985c).

PALEONTOLOGICAL, ARCHAEOLOGICAL, AND ISOTOPIC EVIDENCE

A variety of other forms of evidence support the interpretations from geomorphic data for a dry, hot climate on the Southern High Plains in the middle Holocene, although data are not available from as many sites. Studies of invertebrate and vertebrate faunas suggest warming and drying in the region. Gastropods from strata 3 and 4 at Lubbock Lake indicate higher temperatures and possibly reduced precipitation (Pierce, 1987), and the microvertebrate fauna from strata 3 and 4 includes arid-adapted species not present in older or younger deposits (Johnson and Holliday, 1986). Very limited data on diatoms from stratum 3 at Lubbock Lake also suggest climatic conditions drier than those of stratum 2 (Hohn and Hellerman, 1961) and studies of a few diatom samples from the marsh facies of Unit E at the Clovis site indicate increasing water salinity through the early Holocene (Patrick, 1938). Studies of mollusks from a variety of localities on the Southern High Plains suggest an aridity maximum in the middle Holocene, but stratigraphic correlations and age control at most of the sites is not clear (Drake, 1975). Finally, studies of gastropods from the Lake Theo site, immediately east of the Southern High Plains (Fig. 1), show an increase in temperature and decrease in moisture through the early Holocene and into the middle Holocene (Neck, 1987).

Considerable palynological research has been conducted on the Southern High Plains, particularly in the late 1950s and early 1960s (Hafsten, 1961; Oldfield, 1975; Oldfield and Schoenwetter, 1975; Schoenwetter, 1975; Bryant and Schoenwetter, 1987). The pollen data provide little information concerning the middle Holocene, however, because (1) little work was done on Holocene sections, (2) the few Holocene sections studied had almost no age control, and (3) because there are significant problems of interpretation of the late Quaternary pollen records of the region (Bryant and Schoenwetter, 1987; Holliday, 1987c).

The archaeological record from the Southern High Plains provides very telling evidence of decreased effective precipitation in the middle Holocene. Three localities yielded evidence for the excavation of wells by prehistoric occupants in the middle Holocene. At the Clovis site at least 19 wells are known (Evans, 1951; Green, 1962), most dug from the top of Unit E and buried by Unit F. At Mustang Springs six wells were discovered, excavated from the eroded surface of stratum 3 and buried by stratum 4 (Meltzer and Collins, 1987). Excavations at Marks Beach yielded evidence for a well dug from the base of Zone IIIB down to Zone II (Honea, 1980). All investigators of these features have taken them to indicate a decline in the water table, such that the local inhabitants had to dig holes in the floors of the draw to reach drinking water. The lowered water table is attributed to a decrease in effective precipitation through the early Holocene and drought in the middle Holocene.

Finally, isotopic data from bone is also used as an indicator of climate on the Southern High Plains. Meltzer and Collins (1987) propose that Altithermal-age bison bone should yield lower $\delta^{13}C$ values relative to earlier and later Holocene bone. This is because bison prefer warm-season (C_4) grasses and such grasses are sensitive to summer drought. If the Altithermal was characterized by a deficiency in summer effective precipitation, then bison probably had to incorporate more cool-season (C_3) grasses in their diet. This would be reflected in fluctuations in $\delta^{13}C$ values. Meltzer and Collins, using data from Stafford (1984), present tentative support for a drop in $\delta^{13}C$ values in middle-Holocene bone from Lubbock Lake, although few samples of bone from this period were analyzed and Stafford (1984) urges considerable caution in using the bone isotopes for paleoecological reconstructions.

DISCUSSION AND CONCLUSIONS

Geomorphological, paleontological, and archaeological data show that in the middle Holocene the Southern High Plains was subjected to warmer climate with reduced effective precipitation relative to that of the early or late Holocene, as first proposed by Antevs (1955). These data are from a relatively small number of widely scattered localities, but a comparison of the stratigraphic and geochronologic data (Fig. 2) nevertheless suggests a regional chronology for middle-Holocene events, with several local perturbations. Eolian sedimentation began at least locally between 10,000 and 9000 yr B.P. It was episodic but widespread from 9000 until 5500 yr B.P., with most areas affected by 6500 yr B.P. Between 5500 and 4500 yr B.P. eolian sedimentation occurred at all localities. The climatic record appears to be more complex than the two-drought Altithermal proposed for Lubbock Lake (Holliday, 1985b; Johnson and Holliday, 1986). Furthermore, geological, palynological, paleontological, and archaeological data from a number of localities throughout the Great Plains (Benedict and Olson, 1978; Benedict, 1979; Gaylord, 1982; Dean *et al.*, 1984; Winkler *et al.*, 1986; Barnosky *et al.*, 1987; Graham *et al.*, 1987) show that similar climatic conditions affected the entire region.

Models of middle-Holocene climate for continental interiors in the northern middle-latitudes indicate that seasonality was more pronounced than at present. Summer temperatures were probably warmer than today, resulting in a net annual moisture deficit (Kutzbach and Guetter, 1986). This is hinted at by the isotopic data of Stafford (1984), as interpreted by Meltzer and Collins (1987), from bone from the Southern High Plains, although considerably more evidence is needed.

The Altithermal was a significant climatic event during the late Quaternary on the Southern High Plains. More geomorphic change occurred in the Altithermal than any other equivalent period of time for which data are available; valleys aggraded, the High Plains surface was deflated, and dune fields were built up. There was also a significant impact on the flora, fauna, and human populations of the region. The reduced vegetative cover probably resulted in a decrease of the bison population (Meltzer and Collins, 1987), though not a complete disappearance of bison as proposed by Dillehay (1974) (Johnson and Holliday, 1986). Locally humans were apparently forced to excavate wells for water and very limited archaeological data suggests a population movement out of the Southern High Plains (Johnson and Holliday, 1986), an event also suggested for the Northern High Plains (Benedict and Olson, 1978; Benedict, 1979).

ACKNOWLEDGMENTS

I thank Vaughn M. Bryant (Texas A&M University), James C. Knox (University of Wisconsin-Madison), John E. Kutzbach (University of Wisconsin-Madison), David J. Meltzer (Southern Methodist University), and several anonymous reviewers for their very helpful comments on this manuscript. This research was supported by E. Johnson (Director, Lubbock Lake Landmark, The Museum, Texas Tech University) with funds from the National Science Foundation (SOC75-14857, BNS76-12006, BNS76-12006-A01, BNS78-11155), Moody Foundation (Galveston), West Texas Museum Association, and Institute of Museum Research, and The Museum, Texas Tech University. Support was also provided to the author by the Graduate School of the University of Wisconsin-Madison.

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