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A 250,000-year record of lunette dune accumulation on the Southern High Plains, USA and implications for past climates

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ABSTRACT

A concentration of lake/playa basins occurs on the Southern High Plains (SHP) of northwest Texas and eastern New Mexico. Associated with these lake/playas are lee-side lunettes positioned on their southeast margins ranging in height from 1.5 to >10 m. An OSL dating program was applied to 30 samples from lunettes associated with large lakes and small playa basins. Samples were extracted from trenched dune sections or from deep cores. Earlier SHP lunette investigations show depositional ages primarily in the late Wisconsin and Holocene. This research extends the timing of lunette accretion to the middle Pleistocene, the earliest recorded deposition for these features. The expanded chronology permitted investigation into dune morphology on nested lunettes built on contracting lake margins. Outer lunettes formed prior to inner dunes, but simultaneous deposition occurred on downwind ridges as younger lee-side dunes were constructed. Large lake lunettes were inactive during discreet SHP pluvial episodes from early Wisconsin to LGM. Conversely, these lunettes accreted when climatic conditions promoted basin desiccation and aeolian deflation. This suggests their mode of formation contrasts with lunette models recognized for other regions. From post LGM to earliest Holocene, active lunette accretion occurred from 16 to 11 ka followed by a significant period of lunette construction during the mid-Holocene. Late Holocene-lunette deposition was interrupted by intervals of landscape stability. Lunette deposition between 1300s and 1700s corresponds with drought intervals recognized in tree-ring records from adjacent regions. Recent lunette activity on the plateau is contemporary with the 1930's 'dust bowl'. Further insight into SHP response to changing climatic conditions was given by comparing lunette depositional events with previous investigations on sedimentation intervals for draws, lake/playa basins, and sand sheets.

1. Introduction

Lunettes were first named by Hills (1940) and are important geomorphic features that have been studied in Australia (Bowler, 1983), southern Africa (Lancaster, 1978), Tunisia (Coque, 1979), and North America (Holliday, 1997a). They are aeolian landforms emplaced on the downwind margin of playa-lake basins that have been viewed as potential palaeoenvironmental archives in many arid and semi-arid regions of the world (e.g., Holliday, 1997a; Rich et al., 1999; Lawson and Thomas, 2002; Holmes and Barker, 2006; Telfer and Thomas, 2006). In North America, late Quaternary lunettes occur extensively on the Southern High Plains (SHP). One or more nested lunettes are positioned adjacent to large lakes while small playas may have a single lee-side dune. Most Quaternary research on the Southern High Plains has been focused mainly on alluvial, palustrine, and lacustrine deposits from dry river valleys (draws) and lake/playa basins (e.g., Wendorf and Hester, 1975; Reeves, 1976; Hall, 1982; Wood et al., 1992; Holliday et al., 1996), while lunettes have received relatively little attention with the exception of Stokes (1994), Holliday (1997a), and Rich et al. (1999). Exploiting suites of lunettes that flank SHP basins can offer insight into the evolution of these dunes and provide clues into the basin hydrogeological processes ultimately preserved within their stratigraphy.

Investigations into lunette development have been ongoing for decades. Hills (1940) noted that nested lunettes in Australia were built on the perimeter of successively lower lake levels uniting lunette accretion to playa-lake basin hydrology. In researching nested lunettes in the southern Kalahari, Lancaster (1978) proposed that the outer dunes, comprised of sand, are formed under relatively dry conditions by surface deflation during the initial stages of playa formation, while the inner sandy-clay dunes form when the water table declines and aeolian processes deflate the basin

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material. Between periods of lunette formation, basins are occupied by alkaline and/or saline lakes, in which lacustrine materials are deposited. Lancaster (1978) interpreted playa basin development and lunette formation as indicators of changing climatic and hydrologic environments in the Kalahari region. Conversely, others have suggested that lunette development is much more complex and that a high water level is needed. Bowler (1973, 1983) discussed how quartz-rich lunettes, associated with Australian playa-lake systems, are constructed from sediments that have accumulated on the basin margin due to wave action during high or seasonal water levels and then deflated. During times of water table fluctuation, direct basin deflation of clay pellets and subsequent deposition result in clay-rich lunettes. Holliday's (1997a) work on the origin and evolution of Southern High Plains' lunettes associated with small playa basins demonstrated that their mode of formation contrasts with lunette models recognized for other regions. Holliday (1997a) suggested that aridity promotes basin floor deflation and noted three sediment sources for SHP lunettes; low-carbonate sand from direct surface deflation, sand deposited on the playa by wind or slope wash erosion then deflated, and calcareous sandy loam derived from lacustrine carbonate materials deflated from dry lake basins. With the deposition of calcareous sediments on the lunette surface, dunes can then be welded or stabilized by dissolution and reprecipitation of the carbonate material, a necessary step to lunette construction (Holliday, 1997a).

This paper reports new observations on Pleistocene and Holocene SHP lunette activity in order to produce an improved understanding of the long-term evolution of the basin-lunette systems. An OSL dating program has been applied to quartz grains from stratigraphic sequences of lunette material in order to provide detailed chronologic control of accretionary periods. The lunette chronology will also be compared with timing of other depositional events taken from alluvial, palustrine, and lacustrine deposits of the dry river valleys (draws) or lake/playa basins and sand sheets (e.g., Reeves, 1965, 1976; Reeves and Parry, 1969; Wendorf and Hester, 1975; Hall, 1982, 1990b; Holliday et al., 1983, 1996; Wood and Osterkamp, 1987; Wood and Sanford, 1990, 1995; Wood et al., 1992; Holliday, 1995; Rich and Stokes, 2001, 2011). This approach will provide a greater understanding of the evolving SHP environment over time. The paper will also compare and contrast SHP lunette dynamics to the various models of lunette development that have been suggested by others (e.g., Bowler, 1973; Lancaster, 1978).

2. Southern High Plains' study area

2.1. Physical setting

The number and size of individual lunettes on the SHP varies depending on whether the dune is adjacent to a large lake basin or small playa. Concentric lunette dunes (two or more) with relief up to 30 m (Sabin and Holliday, 1995) are primarily associated with the 40–50 large lake basins (>15 m^2 and 20–30 m deep) (Wood et al., 1992; Wood, 2002). In comparison, there are ~25,000 small playa basins that vary in size (~2.5 km–0.1 km diameter) with only ~4% having lunettes flanking their leeward side (Sabin and Holliday, 1995; Holliday et al., 2008).

Lunettes and other aeolian features provide limited topography on the relatively flat SHP. This vast (~80,000 km^2) plateau of northwestern Texas and eastern New Mexico is a southerly extension of the American Great Plains (Fig. 1a). It is well defined from the surrounding region by a 50–200 m escarpment on its eastern, northern, and western sides (Fig. 1b). Its southern border merges subtly with the Edwards Plateau (Reeves, 1976; Gustavson, 1990) (Fig. 1a and b). The landscape configuration isolates the region hydrographically, with groundwater recharge restricted to direct precipitation on the plateau (Wood et al., 2002).

The SHP main Cenozoic deposits are the Ogallala and overlying Blackwater Draw Formations. The Ogallala (Miocene-Pliocene) is the principal aquifer for the region and formed from fluvial sand/gravel deposits supplied from the ancestral Rocky Mountains. It developed a thick (>1 m) pedogenic caliche caprock during the final development phase that controls the present plateau topography (Gustavson, 1987; Wood, 2002). The Blackwater Draw Formation (Pleistocene) is aeolian in origin and forms most of the SHP surface (Reeves, 1976; Holliday, 1990; Muhs and Holliday, 2001). Later Pleistocene, Holocene, and historic geomorphic features (e.g., sand sheets and dune fields) rest unconformably on the Blackwater Draw (Hawley et al., 1976; Holliday, 1995; Rich et al., 1999; Holliday, 2001; Rich and Stokes, 2011), while small playa basins are eroded into the formation's surface (Holliday, 1997a). Large lake basins lie within both the Blackwater Draw and Ogallala Formations (Wood et al., 1992; Wood, 2002).

2.2. Present climate

The Southern High Plains' climate is continental semi-arid, with long hot summers and cold winters (Larkin and Bomar, 1983). Average monthly temperatures for Lubbock, Texas (33° 39′ N; 101° 49′ W, elevation 993.6 m) located near the center of the SHP, range from 3.8 °C (January) to 26.7 °C (July) (NOAA, 2002).

The precipitation gradient is aligned generally north–south with annual means of 36 cm along the Pecos River valley escarpment, increasing to 56 cm along the northeastern edge of the plateau. Annual potential evaporation averages nearly 193 cm, increasing towards the south (NOAA, 2002) (Fig. 2). Annual distribution of precipitation reflects changes in atmospheric circulation, air masses, and storm types.

Winds on the SHP are variable with a strong prevailing south to southwesterly component as recorded by weather stations at Amarillo, Lubbock, and Midland, Texas (Larkin and Bomar, 1983). Fryberger and Dean (1979) developed a method to estimate wind potential for sand movement that was used by Muhs and Holliday (2001) to determine annual resultant drift potentials (RDP) and resultant drift directions (RDD) for northern Texas and New Mexico. They determined that the RDD for the Southern High Plains is generally southwest to northeast, with RDP values ranging from 47 to 318 (mean = 155) (Muhs and Holliday, 2001), which according to the Fryberger and Dean (1979) method defines the Southern High Plains as a low energy environment (Fig. 2). Under the present SHP climate regime the lunette dunes are stable and support native vegetation, which includes grama (*Bouteloua* sp.) and buffalo grass (*Buchloe dactyloides*).

3. Previous research

3.1. Southern High Plains' large lake basins

While this research focuses mainly on SHP lunettes, the associated large lake basins will also be addressed. Previous research on Southern High Plains' large lake basins has been ongoing for over a century. G.K. Gilbert (1895) in his paper "Lake basins created by wind erosion" postulated an aeolian origin for these features. During the early 20th century, challengers questioned Gilbert's hypothesis. Baker (1915) and Meigs et al. (1922) proposed an alternative explanation for lake basin creation resulting from evaporite dissolution at depth, with subsequent collapse of the overlying materials. Decades later, detailed stratigraphic analysis put into question this hypothesis when studies showed no evidence of sediment collapse or sufficient subsurface evaporite removal to