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Vance T. Holliday

*Universiity of Wiconsin*, vthollid@email.arizona.edu

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# THE GEOLOGIC RECORD OF WIND EROSION, EOLIAN DEPOSITION, AND ARIDITY ON THE SOUTHERN HIGH PLAINS

Vance T. Holliday

*Department of Geography, University of Wisconsin  
Madison, WI 53706*

**Abstract.** *Evidence of wind erosion, accumulation of airborne sediments, and drought is preserved on the Southern High Plains. Eolian deposition in the Holocene concentrated between 6000 and 4500 years ago. The Blackwater Draw Formation indicates episodic wind erosion and deposition in the past 1.6 million years. The Ogallala Formation suggests a vast, sandy eolian plain accumulated episodically between 4 and 11 million years. Warmer and drier conditions predicted for the region in a globally-warmer climate will thus be superimposed upon prevailing characteristics of wind and relative aridity that have dominated recent geologic time.*

The Great Plains is one of the most persistently windy inland areas of North America, and the Southern High Plains subregion is one of the dustiest areas in North America (Johnson 1965; Orgill and Sehmel 1976; Bomar 1983, 177). Wind erosion and blowing dust are particular problems during drought, which have been frequent during the past century (Borchert 1950, 1971; Rosenberg 1980). Wind, dust, and drought are not modern developments of High Plains climate, however. A growing body of scientific evidence suggests that much of the Southern High Plains has been significantly influenced by wind erosion and episodic aridity for at least the past 11 million years. Wind, aridity, and eolian sedimentation are important characteristics of the environment throughout the Great Plains, but no other subregion contains a geologic and paleoclimatic record on a par with the Southern High Plains.

This paper summarizes a variety of data that as a body provide evidence for a long history of wind erosion, accumulation of airborne sediments, and drought on the Southern High Plains. These conclusions are significant because they indicate that drought as a natural characteristic of the High Plains climate is likely to affect the region for the foreseeable future and because some scientists predict increased frequency of drought as a result of "global warming" (e.g., Barry 1983; Hansen et al. 1988). Severe wind erosion and dust production will, therefore, almost certainly

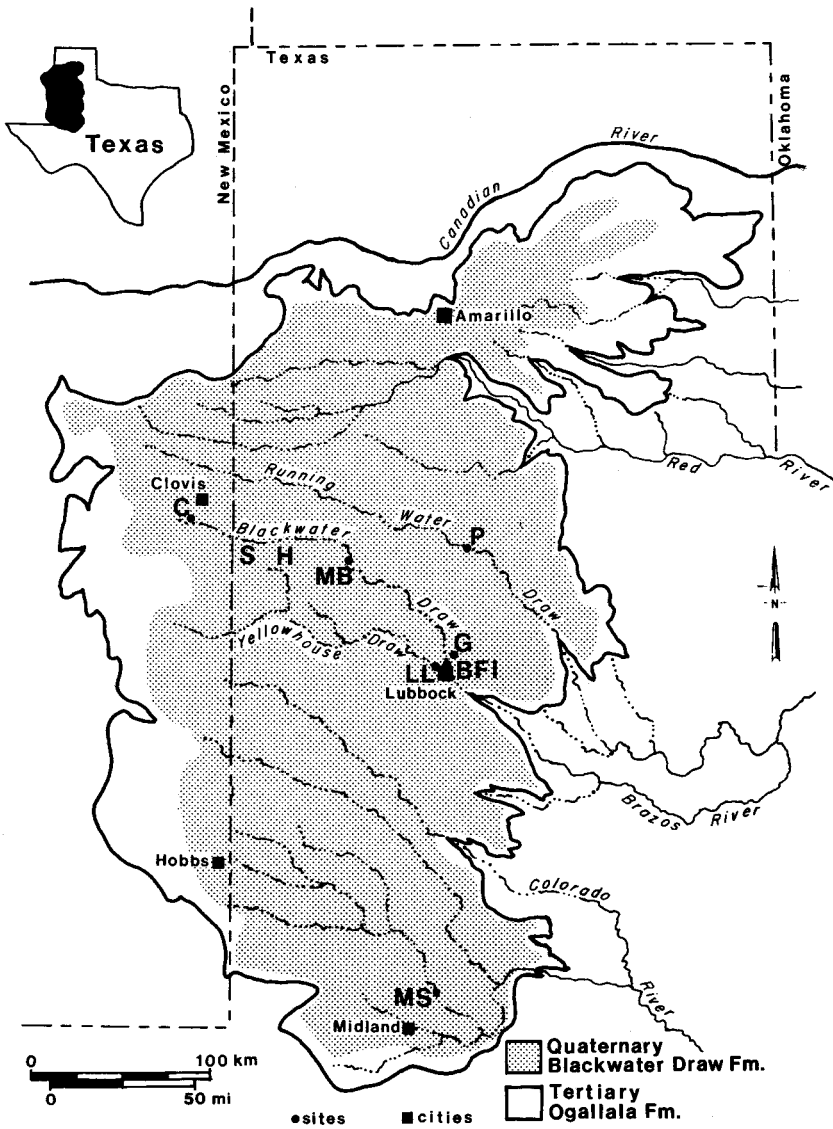


Figure 1. The Southern High Plains showing the extent of the Blackwater Draw and Ogallala Formations. Selected study localities are P = Plainview, C = Clovis, MB = Marks Beach, BFI = BFI landfill, LL = Lubbock Lake, MS = Mustang Springs, SH = Sand Hills dune field, G = B.F. Gentry playa, Sv = Silverton section.

continue to be important aspects of the Great Plains landscape and climate.

### Setting

The Southern High Plains, also known as the *Llano Estacado* (Stockaded Plain), is an extensive plateau of approximately 130,000 km<sup>2</sup> in northwestern Texas and eastern New Mexico (Fig. 1). This area is in the southern portion of the Great Plains physiographic province. The plateau is bounded on three sides by escarpments. The western escarpment separates the plateau from the Pecos River valley, and the northern escarpment separates the plateau from the Canadian River valley. Headward erosion by tributaries of the Red, Brazos, and Colorado Rivers form the eastern escarpment. The southern portion of the Southern High Plains merges with the Edwards Plateau of central Texas without a distinct topographic demarcation.

The Southern High Plains is a semiarid, short-grass prairie with an almost featureless surface, "the largest level plain of its kind in the United States" (National Oceanic and Atmospheric Administration 1982a, 3). The flat surface of the region was formed by the accumulation of thick, widespread wind-blown sediment (the Blackwater Draw Formation; Fig. 1) derived primarily from the west and southwest over the past 1.6 million years. Slight topographic relief on the High Plains surface is provided by a few sand-dune fields and thousands of small and usually dry depressions (playas) scattered across the landscape. There are also a number of northwest-to-southeast-trending dry valleys (draws) that were once-flowing tributaries of the Red, Brazos, and Colorado Rivers.

### The Climatic and Geologic Record

Evidence for the history of episodic wind erosion, eolian deposition, and aridity on the Southern High Plains is found in layers of sediment varying from a few tens of centimeters to tens of meters thick and in associated soils. Additional information on past climates and climatic change in the region is provided by the fossil remains of plants and animals preserved in the sediment. Insight into the processes that produced the geologic record and possible paleoclimatic inferences can be gained through study of the modern geologic processes and their relationship to the historic climatic record. The following discussion, therefore, begins with a summary of the processes of wind erosion and dust production and the climatology of wind and aridity on the Southern High Plains. The geologic record is then presented, starting with the youngest sediments and

moving back in time. Generally, the bodies of sediment of interest can be discussed by geologic time period. The past 12,000 years, essentially post-glacial time, includes the latest Pleistocene Epoch (12,000-10,000 years ago) and the Holocene Epoch (the past 10,000 years) and coincides with the human occupation of the region. The next oldest period, 12,000 years back to 1.6 million years, is almost all of the Pleistocene and includes most of the period of glacial expansion and contraction prior to the Holocene. The oldest period of interest, 1.6 to 11 million years, is the latter part of the Tertiary Period and largely represents preglacial times.

### Modern and Historic Climate Record

Climatic records for the Southern High Plains are incomplete for years earlier than the "Dust Bowl" period of the 1930s. Enough climatological data are available from the area and other sectors of the High Plains, however, to begin to see some trends in such characteristics as wind, drought, and blowing dust.

Persistent and occasional high velocity winds and periodic drought are significant aspects of the climate of the Southern High Plains (Table 1; Fig. 2A) (Borchert 1950, 1971; Johnson 1965), as well the entire Great Plains (Borchert 1950, 1971; Bark 1978; Barry 1983; Stockton and Meko 1983). Wind and drought often combine to produce frequent wind erosion and blowing dust (Orgill and Sehmel 1976; Wigner 1984). Blowing dust is reported for every year in which weather records are available on the

TABLE 1

AVERAGE ANNUAL AND MAXIMUM WIND VELOCITIES FOR  
SELECTED CITIES ON THE SOUTHERN HIGH PLAINS

City	Period of record	Velocity (km/hr)	
		Average annual	Maximum
Amarillo, TX	1949-1981	21.9	134.4
Lubbock, TX	1949-1981	20.0	112.0
Midland, TX	1949-1981	17.7	107.8

Source: National Oceanic and Atmospheric Administration 1982b.

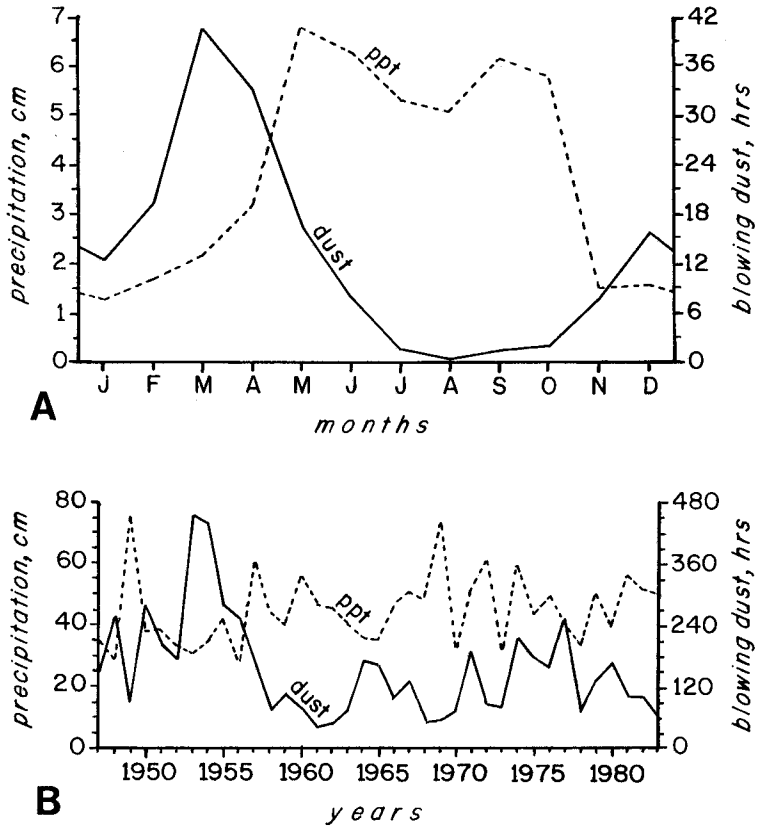


Figure 2. Variations in precipitation and persistence of blowing dust at Lubbock, Texas (A) through the period 1947 to 1982 and (B) for a typical year. Compiled from Wigner (1984) and reproduced from Holliday (1987).

Southern High Plains (Fig. 2A). Highest absolute and highest average wind velocities generally occur from December through April, which is the driest part of the year and the time soils are most susceptible to wind deflation (Johnson 1965; Orgill and Sehmel 1976; Wigner 1984). Blowing dust is, therefore, most common in late winter and early spring (Fig. 2B). Drought, with higher than average temperatures and winds, and resulting loss of soil

moisture, increases the susceptibility of surface sediment to eolian movement (Holliday 1987). Wind erosion is most severe and the production of blowing dust most common, therefore, after several years of drought (Fig. 2A; Holliday 1987).

The wind on the Southern High Plains is a significant geomorphic and sedimentologic agent. Winds can erode to a depth of one meter, as noted in a study of the February 23, 1977, dust storm near Clovis, New Mexico (McCauley et al. 1981). Fine sand derived from this erosion was deposited in sheets as much as one meter thick and two to three kilometers long downwind of the deflation blowouts. Dust storms in the Lubbock, Texas, area in 1950, a year of relatively low wind erosion and dust activity (Wigner 1984), carried an average of nearly 1600 Mg of dust per storm along an eight kilometer front (about 110 Mg/h) (Warn and Cox 1951). On a much larger scale, Lisitzin (1972) estimated that 272 million Mg of sediment, equivalent to nearly half the annual sediment load of the Mississippi River, was removed from the Great Plains by wind erosion in 1934. Despite all of the work the wind has done in eroding, transporting, and depositing sediment, there is remarkably little evidence in the geologic record of these historic events.

Much has been written about the influence of human activity on wind erosion and dust production on the Great Plains. Clearly, the destruction of the native vegetation of the region and artificial disturbance of the soil has increased the supply of sediment and affected the intensity and rate of wind erosion and development of dust storms. Human activity is not, however, responsible for eolian processes. Historical records for the High Plains of Colorado and Kansas show that severe dust storms occurred in association with droughts decades before the introduction of agriculture (Malin 1941a, 1941b, 1941c; Fryrear and Randel 1972; Idso 1976; Bark 1978; McCauley et al. 1981). Studies of native grasslands in western Kansas since 1933 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). These same processes undoubtedly occurred during droughts on the Southern High Plains before the introduction of agriculture.

### **The Last 12,000 Years**

A considerable body of paleoclimatic and paleoenvironmental data are available for the past 12,000 years on the Southern High Plains, based on the record of preserved geologic deposits and associated plant and animal remains. The most complete and intensely studied records of this time are in the draws that cross the region. Much of the data comes from research

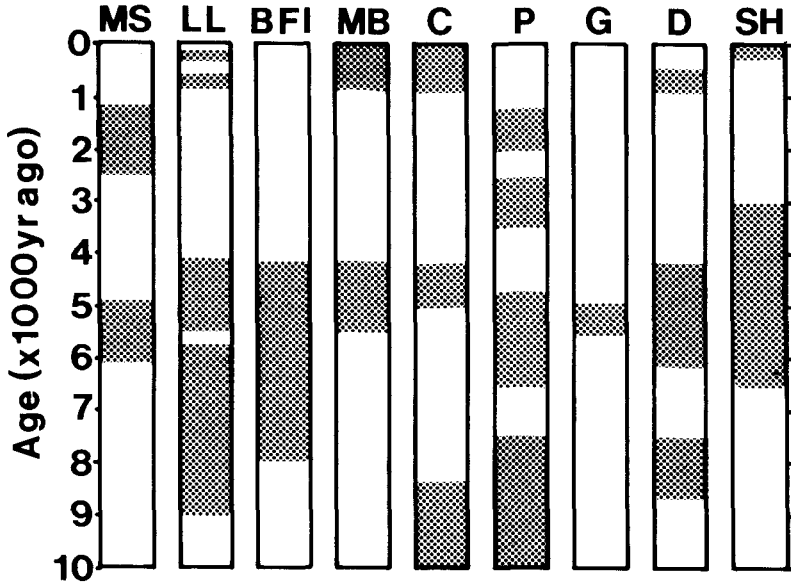


Figure 3. Age relationships of eolian sediments (shaded) accumulated at localities on the Southern High Plains over the past 10,000 years. Draw sites are P = Plainview (Sellards et al. 1947; Holliday 1985b), C = Clovis (Blackwater Draw Locality 1; Haynes and Agogino 1966; Haynes 1975), MB = Marks Beach (Honea 1980), BFI = BFI Landfill (Holliday 1985a), LL = Lubbock Lake (Holliday 1985c; Johnson 1987), MS = Mustang Springs (Meltzer and Collins 1987); playa site is G = B.F. Gentry playa (Holliday 1989a); dune sites are D = dune site at Lubbock Lake (Holliday 1985a), SH = Sand Hills dune field (Gile 1979; Holliday 1989a). See Figure 1 for locations. Modified from Holliday 1989a, Figure 2.

at six localities (five archaeological, one non-archaeological) (Fig. 3). The extraction of 176 cores and studies of artificial cuts at another seven nonarchaeological localities along the draws provide additional, generally supportive geologic and paleoclimatic data. The following summary of the geologic record of the draws is based on discussions presented by Holliday (1985a, 1989a) and Holliday and Johnson (1990). Additional paleoenvironmental data are presented by Johnson (1986, 1987).

Most of the draws have slowly filled with two to eight meters of sediment during the past 12,000 years. Throughout almost every reach of



every draw studied the basal layer of sediment is sandy clay, sand, and gravel deposited from about 12,000 to 10,000 years ago, indicating that streams flowed along the floors of the draws in the late Pleistocene. Typically overlying the stream deposits is a layer of sediment rich in calcium carbonate, indicating that hardwater marshes and ponds replaced the streams from about 10,000 to 6500 years ago. In a few locales, between the layers of stream and hardwater marsh deposits, are layers of sediment rich in plant and animal remains indicative of standing bodies of fresh water. These bodies of water were probably spring-fed ponds that existed between about 11,000 and 8000 years ago.

Overlying the marsh and pond deposits in the draws is a layer of sediment, often sandy, always fine-grained, that is as ubiquitous as the stream sediment. This layer, usually at least one meter thick and locally up to three meters thick, is believed to be sediment deflated from the High Plains surface and deposited as wind carried the sediment over the draws. Some of these sediments were being deposited as early as 10,000 years ago, accumulating along with the hardwater marsh deposits (Fig. 3). However, the bulk of the eolian sediment accumulated between 6000 and 4500 years ago. There was little sedimentation in the draws in the late Holocene although locally there are thin layers of additional eolian deposits that accumulated within the past 2000 years (Fig. 3). The soils formed in the eolian sediment show that the draws were very stable landscapes over the past 4500 years with essentially no erosion.

Very limited geologic and paleoclimatic data for the Holocene is available from the numerous playas and dunes and dune fields on the Southern High Plains (Fig. 3), discussed by Holliday (1985a, 1989a). Lake sediment apparently accumulated in many of the playas over the past 10,000 years, but in at least some of the lake basins there is also a wedge of eolian sediment about 5000 years old (Fig. 3). This wind-derived sediment is very similar to the eolian deposits in the draws and is believed to be material deflated from the High Plains surface. Dunes are often present on the downwind side of the playas and contain a record of sediment deflated from the adjacent playa as well as from the High Plains surface. These dunes have formed for at least 30,000 years, but during the Holocene the principal period of dune building was between 6500 and 4500 years ago (Fig. 3). The sand dune fields, largely in the western half of the Southern High Plains, are almost entirely Holocene-age features, and the major phase of dune building appears to be in the middle Holocene. There is also evidence for several phases of relatively minor episodes of dune remobilization during the past 1000 years.

The geologic data presented combined with the paleoenvironmental record from fossil plant and animal remains show that the Southern High Plains underwent considerable change in climate during the past 12,000

years, although the vegetation of the region was probably a grassland throughout this time. At the beginning of the Holocene, the region was undergoing a dramatic climatic change that began 5000 to 10,000 years earlier, coincident with the decay of the massive ice sheets that covered much of northern North America. The climate was cooler and subhumid, but changing to one that was warmer and semiarid (Johnson 1986; Holliday 1989a). At 12,000 years ago there was somewhat more moisture available, relative to today, resulting from an overall cooler climate, supporting flowing streams along the floors of the draws. A few sites along the draws contained standing water in the form of large, freshwater, spring-fed ponds.

Accumulation of windborne sediment was the dominant depositional process of the Holocene and is indicative of a shift to a warmer and drier climate (Holliday 1989a). Eolian sediments began to accumulate in the draws about 9000 years ago and during the period 6000 to 4500 years ago these sediments were filling the draws and some lake basins and accumulated as dunes. These sediments are indicative of widespread, long-term wind erosion in the middle Holocene due to drought and loss of vegetative cover. As noted previously, deflation and eolian transport result from reduction of the vegetative cover in drought. Drought and significant eolian sedimentation is also reported for the middle Holocene from palynologic and geologic records throughout the midcontinent (e.g., Barnosky et al. 1987; Gaylord 1990; Keen and Shane 1990; Swinehart 1990), although the specific timing appears to vary from region to region.

The absence of significant eolian sedimentation in the late Holocene indicates that the High Plains surface became stabilized, probably the result of reestablishment of vegetation following a return to slightly more moist conditions. Within the past 2000 years, however, there were probably several climatic shifts alternating between slightly wetter and slightly drier conditions (Hall 1982; Johnson 1987).

### **12,000 to 1.6 Million Years Ago**

The level, open terrain that characterizes the modern landscape of the Southern High Plains formed by accumulation of fine grain (sandy to clayey) sediment over the past 1.6 million years. These sediments, the Blackwater Draw Formation, represent over 80,000 km<sup>2</sup> of the surface of the Southern High Plains (Fig. 1) and support the lucrative agricultural industry of the region, but have received scant geologic scrutiny considering their extent and economic significance. Recent investigations of the soils and stratigraphy of the Blackwater Draw Formation have begun to shed some light on its origins and paleoenvironmental and paleoclimatic significance. The research carried out so far (Seitlheko 1975; Holliday

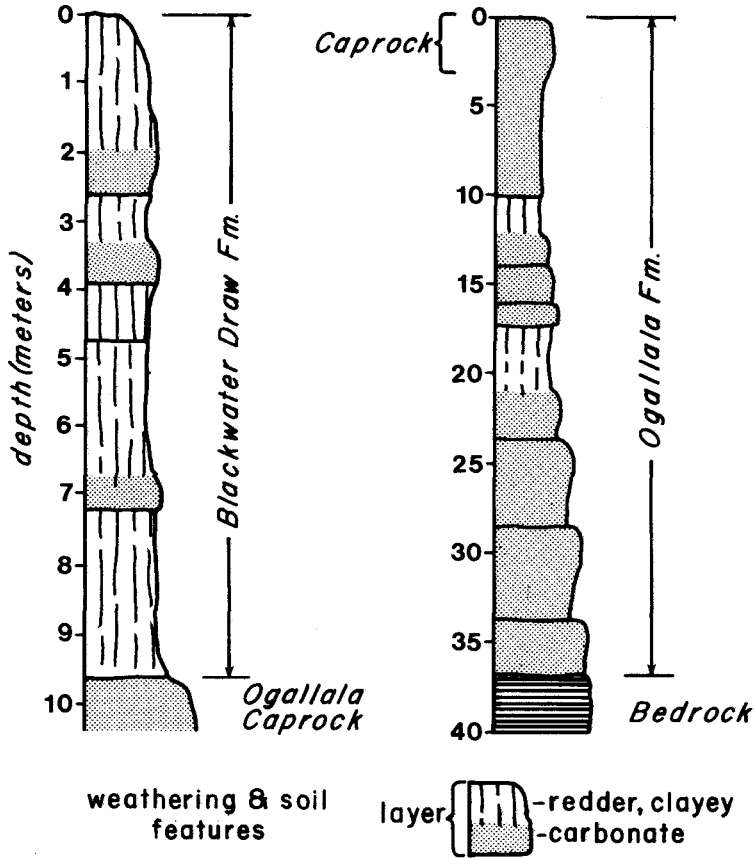


Figure 4. Vertical sections showing sediments and associated soils in the Blackwater Draw Formation (from its type site in Lubbock; from Holliday 1989b) and the Ogallala Formation (from the Silverton section; from Holliday 1990).

1988, 1989b; Nettleton et al. 1989) has focused on the surface soils of the High Plains and on geologic studies at four localities.

The Blackwater Draw Formation is a sheet-like body of sediment that covers much of the surface of the Southern High Plains (Fig. 1). The deposit is sandy in the southwestern part of the region and becomes progressively more clayey to the northeast. The deposit also varies in thickness, from a feather-edge in the southwest to as much as 30 meters in the northwest. The sediments of the Blackwater Draw Formation, based

on their extent, fine-grained texture, and position in an upland setting, are probably wind deposited. The textural variation of the sediments across the Southern High Plains, grading from coarser in the southwest to finer in the northeast, further suggests that the sediments were deposited by winds out of the southwest. These sediments were most likely derived from the Pecos River Valley. Numeric and relative dating methods such as tephrochronology, thermoluminescence, and paleomagnetism show that the Blackwater Draw Formation has accumulated for about the past 1.6 million years.

The Blackwater Draw Formation is composed of a number of individual layers, each strongly modified by weathering (Fig. 4). Deposition of each layer probably occurred under conditions of prolonged aridity. The surface layer appears to be continuous across the region, suggesting that each layer began as a continuous deposit. Erosion prior to burial of each layer is suggested by the varying number of layers present at each locality studied. Alternatively, the variation in number of layers from section to section may represent each layer being discontinuous originally. A maximum of seven layers have been identified in the Blackwater Draw Formation (Allen and Goss 1974), indicating a minimum of seven depositional events for the Blackwater Draw Formation at specific locations.

The strong weathering within each layer of the Blackwater Draw Formation indicates that there were long hiatuses between depositional episodes. The physical and chemical weathering characteristics, including reddening, accumulation of secondary clay, and downward movement and reprecipitation of calcium carbonate (caliche) are similar to or stronger than the weathering characteristics of the surface soils. These similarities suggest that the weathering in the buried layers occurred under environmental conditions generally similar to those of the surface soils. The surface soils formed between about 100,000 and 50,000 years ago, under conditions that were more moist than today (probably subhumid), changing to semiarid conditions in the Holocene (Johnson 1986; Holliday 1989a, 1989b). The evidence for stronger weathering in the buried layers indicates that these layers were exposed at the surface for perhaps several hundred thousand years between depositional events.

Available data suggest that the deposition and weathering of the Blackwater Draw Formation was cyclic. Each cycle began as the wind blew sediment from the Pecos Valley onto the High Plains surface at a rate faster than erosion or weathering, resulting in deposition of a more or less continuous sheet of eolian sediment across the area. Sedimentation then slowed, and if erosion was minimal a soil formed in the eolian sheet. Enough time elapsed to allow formation of a well-developed soil similar to the surface soils of the area. Wind erosion of the High Plains surface occurred immediately before or perhaps coeval with the early stages of

subsequent deposition. Deflation in one region of the Southern High Plains could have resulted in deposition in a downwind area. This process began about 1.6 million years ago and appears to be continuing. Presently the Southern High Plains is in the phase of the cycle dominated by landscape stability and soil formation, although some deflation and sedimentation by the wind is also occurring. At least six complete cycles of deposition-weathering-erosion are recorded in the Blackwater Draw Formation.

The general uniformity of depositional styles and weathering processes inferred from the Blackwater Draw Formation further suggest that the environment of the Southern High Plains has oscillated during the past 1.6 million years. Generally stable landscapes occurred under subhumid to semiarid conditions, similar to the conditions of the past several tens of thousands of years. Long-term, regional wind deflation and eolian deposition occurred during periods of prolonged drought. Paleontological evidence suggests that vegetation on the Southern High Plains throughout much of the Quaternary was probably a grassland to savanna grassland, possibly shifting between a tall-grass prairie (subhumid environment) and short-grass prairie (semiarid environment), with some scrub vegetation present in some areas during the driest periods (Johnson 1986, 1987; Schultz 1986).

The long record of eolian sedimentation preserved in the Blackwater Draw Formation appears to be unique in the North American mid-continent. Thick deposits of loess, some as old as 600,000 years, are reported for some areas (e.g., Fredlund et al. 1985; Norton et al. 1988; Clark et al. 1989), but none are known to span the Quaternary. The genesis of the loess deposits is also distinctly different, being directly linked to glacial activity (Norton et al. 1988)

### **1.6 to 11 Million Years Ago**

Underlying the Blackwater Draw Formation is a deposit of mostly sand and gravel typically 50 to 100 meters thick known as the Ogallala Formation. Determining the age of the Ogallala Formation has proven difficult, but available data indicate that it accumulated largely between about 11 and 4 million years ago (Gustavson et al. 1990). The deposit contains the Ogallala Aquifer, which is the principal groundwater resource of the region. The Ogallala was classically described as composed of sandy and gravelly stream sediments, interpreted to represent a series of coalesced alluvial fans (Sellards et al. 1932; Bretz and Horberg 1949a; Frye and Leonard 1964; Seni 1980; Reeves 1984). Eolian sediments were noted locally in the formation (Evans 1949; Reeves 1972; Hawley 1984), but until recently such deposits were not fully described and their significance was

seldom considered. A substantial revision of the classical interpretation of the Ogallala was recently proposed based on sedimentological and paleontological investigations (Gustavson and Holliday 1985; Winkler 1987; Gustavson and Winkler 1988). The sandy and gravelly stream deposits are confined largely to paleovalleys cut into much older bedrock. Sandy and sandy silt eolian deposits cap most of the stream deposits and the divides between the paleovalleys. The upper Ogallala appears to have accumulated largely as a vast, sandy eolian plain.

A recent, detailed investigation of an exposure of the Ogallala near Silverton, Texas, on the northeastern edge of the Southern High Plains, provides additional information on its eolian history (Fig. 4; Holliday 1990). At this locality the Ogallala Formation is over 40 meters thick, including several layers of sandy, eolian sediment that total 38 meters in thickness. These layers accumulated episodically and were modified by weathering and soil formation prior to burial by the overlying layer. The evidence for weathering is the presence of zones one or two meters thick containing reprecipitated calcium carbonate. Two of the layers have soil zones that are also deeply reddened and have significant accumulation of secondary clay. The physical and chemical characteristics of weathering and soil formation in the eolian sediments comprising the Ogallala Formation are very similar to those of the soils buried within and at the surface of the Blackwater Draw Formation. The layers of sediment and associated soils exposed at the Silverton section can be traced along the High Plains escarpment for tens of kilometers to the south, showing that the Silverton section is representative of the Ogallala throughout the region.

The similarities in sedimentary and weathering characteristics of the Ogallala and Blackwater Draw Formations, combined with limited paleontological and paleobotanical data (Frye and Leonard 1957; Thomasson 1979; Winkler 1987), suggest comparable genetic histories. The eolian deposits of the Ogallala probably accumulated as sandy or sandy silt sheets under arid to semiarid conditions. Sedimentation slowed and weathering occurred under a semiarid to subhumid environment. The dominant vegetation type throughout development of the Ogallala was probably a grassland or savanna.

At the top of the Silverton exposure is a zone of very strongly cemented calcium carbonate (a calcrete) about three meters thick, and known as the Ogallala "Caprock Caliche". The Ogallala Caprock is a prominent ledge-forming zone along the escarpments and walls of deeper drainages of the Southern High Plains. The Caprock has long been recognized as representing a considerable period of nondeposition and stability under semiarid conditions following deposition of the Ogallala (Bretz and Horberg 1949a, 1949b; Brown 1956; Swineford et al. 1958). The duration of this period of stability is not known, but based on rates of

carbonate accumulation determined in other areas it was at minimum several hundred thousand years and more likely several million years (Holliday 1990).

Elsewhere on the Great Plains there are no records of late Tertiary eolian deposition comparable to the Ogallala of the Southern High Plains. Upper Tertiary deposits north of the Canadian River, including the Ogallala, are primarily alluvial (e.g., Diffendal 1982; Zakrzewski 1988).

### Conclusions

The erosion, transportation, and accumulation of sediment by wind on the Southern High Plains are significant aspects of the evolution of the landscape and appear to be directly related to climate change. Moreover, these processes are apparent at all scales of time and space. Wind erosion and dust production are annual events in the region, but are most severe and extensive during prolonged (multiyear) drought. Drought is a recurrent feature of the modern and historic climatic record. Strong winds often accompany drought, resulting in the production of dust as the vegetative cover is reduced. Historically, the introduction of agriculture in the region affected the intensity of wind erosion and dust production, but is not responsible for the processes themselves. There is no evidence on the landscape of these modern or historic events at the regional or local scale.

On the scale of the human occupation of the region (the past 12,000 years), there was considerable deposition of eolian sediment beginning about 10,000 years ago, but concentrated between about 6000 and 4500 years ago. Prolonged drought reduced the vegetation and allowed considerable wind erosion, providing a source for the eolian sediments. The results of these events are apparent on the landscape at the local scale. The draws were filled with several meters of sediment and extensive sand dune fields were constructed.

On the scale of hundreds of thousands to millions of years the effects of eolian sedimentation are seen throughout the Southern High Plains. Tens of meters of wind-derived eolian deposits accumulated episodically over the past 11 million years, slowly elevating and smoothing the landscape. The region first became an eolian plain about 11 million years ago as sandy, windborne sediments began to accumulate in extensive sheets. Sediment accumulated on the landscape until about four million years ago. This accumulation was interrupted several times by periods without deposition during which the sediments weathered. Between roughly four and two million years ago there was apparently little deposition and the Caprock Caliche formed, inhibiting subsequent erosion along the margins of the Southern High Plains. Regional, episodic eolian sedimentation resumed about 1.6 million years ago and continued to add

to the High Plains surface until about 50 to 100 thousand years ago. The open, flat terrain that characterizes the modern landscape was then in place.

The climate throughout the 11-million-year evolution of the High Plains was probably always relatively dry. Eolian sedimentation most likely occurred under arid to semiarid conditions, when vegetation was more sparse than today. Under more moist conditions (semiarid to subhumid), when vegetation cover was more continuous, sedimentation slowed and weathering of the sediments occurred. The dominant vegetation on the Southern High Plains during all of this time was probably a grassland or savanna.

The upper Cenozoic sediments of the Southern High Plains contrast markedly with those of the rest of the Great Plains and midcontinent. Depositional processes outside of the Southern High Plains are controlled by or linked to alluvial or glacial activity, with the exception of the Holocene record of eolian sedimentation, which is ubiquitous on the Great Plains and generally linked to aridity.

The geologic record indicates that wind and relative aridity have been two of the more persistent and conspicuous climatic features of the Southern High Plains throughout the past 11 million years. Drought has also been a significant, though more episodic, climatic phenomena and wind deflation and eolian sedimentation are significant geologic processes accompanying drought.

Given the long geologic and paleoclimatic record of eolian processes and drought, there is a strong likelihood that these characteristics of the regional climate will persist and, therefore, will continue to play an important role in the short- and long-term future of human occupation. Moreover, some predictions for global warming of the environment include scenarios for longer and more intense drought conditions in the near future throughout the Great Plains (Barry 1983; Hansen et al. 1988), events that could have a severe impact on the agriculture and hydrology of the region.

#### **Acknowledgments**

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