PALEOENVIRONMENTS AND DESERTIFICATION ON THE GREAT BEND SAND PRAIRIE IN KANSAS

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by

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B.A., University of Kansas, 1981
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ABSTRACT

Global circulation models (GCMs) project enhanced aridity in the central Great Plains due to increased atmospheric CO_2. Given the sensitivity of sand mantled landscapes, paleoenvironmental research has focused on the response of sand sheets and dune fields when increased drying occurs. Although appreciable work has been conducted in Nebraska, Colorado, and Texas, no detailed information has as yet emerged from Kansas.

Geomorphic research on the Great Bend Sand Prairie, a large sand sheet in south-central Kansas, indicates that two late Quaternary stratigraphic units are present. The oldest deposits are late Wisconsin, whereas the youngest are Holocene. Late Wisconsinan deposits consist of poorly sorted sand, silt, and clay (a.k.a. silty sand) that accumulated in a low energy fluvial environment. Radiocarbon ages from the lower part of the silty sand range from about 20,000 to around 9000 yrs B.P. The silty sand contains well developed soils with Btb horizons, indicating intensive post-depositional alteration. Floral (*Picea* cf. *glauca*) and faunal (e.g., *Discus cronkhitei*) remains, as well as $\delta^{13}C$ values (e.g., -25.6‰), indicate that late Wisconsinan climate was cooler with more effective moisture. Northwest winds prevailed, as evidenced by Wilson Ridge, a late Wisconsinan lunette.

Overlying the silty sand are variable thicknesses of relatively well sorted eolian sand. Radiocarbon ages from the upper 5 cm of the silty sand provide a maximum

limiting estimate for dune development. In most instances, the upper silty sand dates from 7000 to 800 yrs B.P., indicating that overlying dunes are largely Holocene deposits.

Surficial mapping of Holocene landforms recognizes six categories, ranging from level sand sheet to parabolic dunes. Values of $\delta^{13}C$ (e.g., -15.0 ‰) from dunes implies a comparably warmer climate during the Holocene and the orientation of parabolic dunes indicates prevailing, southwesterly winds. Dunes usually contain one to two weakly developed buried soils with A/AC/C horizonation, representing brief periods of landscape stability, and calibrated radiocarbon ages (2σ) imply six periods of pedogenesis during the Holocene: ca. 6300, 2300, 1500, 1000, 700, and 200 yrs B.P. Surface soils are poorly developed, suggesting that dunes can easily be mobilized if increased aridity occurs.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1
INTRODUCTION AND PROBLEM DEFINITION

Introduction

This study reconstructs the history of late Quaternary climate change and landscape evolution on the Great Bend Sand Prairie, a large sand sheet in south-central Kansas. Prior to this investigation, research of a similar nature had been conducted only in surrounding areas of the Great Plains, including northeastern Colorado, Wyoming, Nebraska, and Texas. As a result, little was known about the late Quaternary paleoenvironmental and geomorphic history, specifically the record of desertification and eolian sand mobilization, of the sand sheets in Kansas. This lack of information has precluded prediction of landscape response should Kansas experience intensive drought in the future, as is anticipated by greenhouse warming scenarios.

Origin of the Research Problem

It is widely believed that increases in atmospheric $C0_2$ and other greenhouse gases could induce significant global warming (e.g., Washington and Meehl, 1984; Hansen et al., 1988). Climatic modelling (e.g., Hansen et al., 1988; Shlesinger, 1989) has indicated that the level of warming in the next few decades may reach the maximum levels achieved during the last few interglacials, especially if current levels of volcanism and insolation remain constant (Crowley and North, 1991). Although the models suggest that warming will vary regionally, above-average levels of warming and drying are expected, beginning in the 1990s, for the already subhumid to semiarid Great Plains (Hansen et al., 1988; Wetherald and Manabe, 1988, Wendland, 1993). Landscapes of the Great Plains consisting of unconsolidated sand are particularly sensitive to climate change. Large portions of the region are mantled by sand dune fields and sand sheets (Fig. 1:1) that are presently stable (e.g.., Smith, 1940; Muhs, 1985; 1991; Madole, 1986, 1994; Holliday, 1989; Forman and Maat, 1990; Swinehart, 1990; Johnson, 1991).

Periodic desertification and mobilization of sand sheets has been demonstrated during the late Quaternary when intervals of drought reduced stabilizing vegetative cover (Madole, 1986, 1994; Holliday, 1989; Swinehart, 1990; Arbogast, 1993, 1994). Dune migration apparently occurred during both cool-arid periods such as the late Wisconsin (e.g., Wright et al., 1985; Forman and Maat, 1990) and warm-arid intervals like the middle Holocene (Ahlbrandt et al., 1983; Forman and Maat, 1990). The conditions under which these geomorphically sensitive areas would desertify again is the focus of increased speculation due to predictions of greenhouse warming and drying (e.g., Swinehart, 1990; Forman and Maat, 1990; Johnson, 1991; Muhs, 1991; Forman et al., 1992).

Although late Quaternary paleoenvironmental reconstructions have been reported for sand sheets in northeastern Colorado (Muhs, 1985, 1991; Madole, 1986, 1994; Forman and Maat, 1990; Forman et al., 1991), Wyoming (Gaylord, 1982),

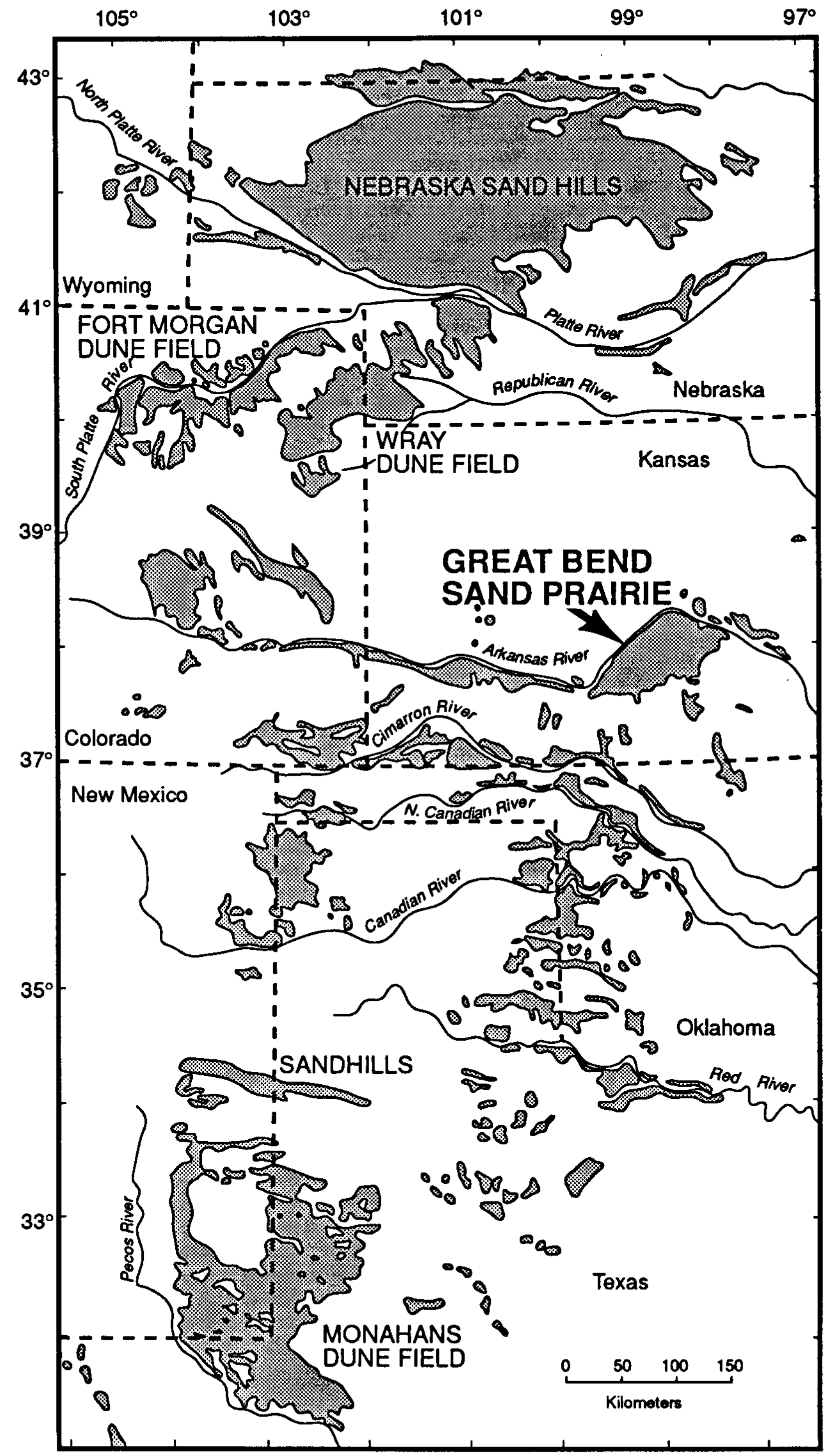


Figure 1:1. Distribution of dune fields and sand sheets in the central Great Plains.

Nebraska (Ahlbrandt and Fryberger, 1980; Ahlbrandt et al., 1983; Swinehart, 1990), and Texas (Holliday, 1985, 1989), little is known regarding the response to climate change and the chronology of geomorphic events on sand covered landscapes in Kansas. Significant portions of the south-central and south-western part of Kansas are mantled by unconsolidated sand. Most of this area is agricultural land, portions of which were destabilized and intensively eroded by wind during the "dust bowl" of the 1930s (Smith, 1940; Latta, 1950; Simonett, 1960).

Goals of the Research

The general goal of this study is to reconstruct the late Quaternary paleoenvironmental and geomorphic history of the Great Bend Sand Prairie in south-central Kansas (Fig. 1:1). The four specific objectives include: 1) constructing a detailed map of surficial geology; 2) determining the number, character, and relative ages of late Quaternary stratigraphic units; 3) reconstructing the history of paleoclimatic change by analyzing the sediments of major stratigraphic units; and 4) constructing a chronology of desertification and sand mobilization on the Great Bend Sand Prairie, and comparing it with that derived from other sand sheets in the central Great Plains.

Significance of the Research

This study contributes to understanding of the late Quaternary paleonenvironmental and geomorphic history of the Great Bend Sand Prairie, a region which is geologically unique in Kansas. Although earlier research was conducted in dune fields along the Arkansas River valley (e.g., Moore, 1920; Courtier, 1934; Smith, 1937, 1940; Simonett, 1960), it was descriptive in nature due to the lack of absolute dating techniques. From an environmental perspective, increased levels of aridity are predicted for the future in the central Great Plains, including the Great Bend Sand Prairie, if greenhouse warming is realized. Because sand sheets have been especially sensitive to increased warming in the past (e.g., 1930s), understanding the timing and magnitude of landscape response is critical if destabilization is to be curtailed. From an economic perspective, most of the Great Bend Sand Prairie is agricultural land which is either cultivated or grazed. Understanding and predicting the response of the region to increased warming could reduce the impact on the regional farm economy should less effective moisture result from increased temperatures .

CHAPTER 2
PREVIOUS RESEARCH

The evaluation of previous research is organized as two parts. In the first section, the geomorphic processes and landscapes associated with erosion, transport, and deposition of eolian sand are discussed. The second section is an examination of results derived specifically from other sand dunes and sand sheets in the Great Plains.

Geomorphic Processes and Landforms in Dune Landscapes

Eolian Erosion and Transport

Compared to fluvial processes, wind is generally a minor agent of geomorphic change (Blatt et al., 1980; Bloom, 1991), the primary reason for this being the difference in density between the two fluids. A great deal of fluvial sediment can be carried in suspension. In contrast, only very fine particles (i.e, silt and clay) can be carried in suspension by the wind. Sand grains are moved in eolian environments largely as contact load, by saltation and creep. Saltation refers to grains that bounce across the dune, whereas movement by creep occurs when grains roll or slide on a dune (Bagnold, 1941; Ritter, 1986; Bloom, 1991).

Wind erosion in dune fields occurs primarily by deflation, which results from turbulent air mobilizing loose sand. The primary variable is the wind velocity. In general, the threshold velocity for most desert sands is 16 km/hr (Ritter, 1986), but the precise value depends upon other factors such as particle shape (Williams, 1964), sorting (Woodruff and Siddoway, 1965), surface roughness, and soil moisture (Belly, 1964). Calkin and Rutford (1974), for example, reported that the threshold velocity for Antarctic dunes doubled when they were moistened by summer melting.

The principle factor governing the threshold velocity of wind is particle diameter, with .84 mm the apparent upper limit for unaided eolian transport. Sand grains with a diameter greater than .84 mm are entrained by saltating grains "splashing" on the surface. Once airborne, most sand grains are transported in short, asymmetrical trajectories within 2 m of the surface (Fig. 2:1) As grains return to earth, their impact velocity entrains certain particles on the ground, forcing them into the air. Although grains are initially mobilized by other, saltating particles, they move forward because of wind flowing above the relatively tranquil laminar boundary layer. Larger grains never enter the airstream, however, moving only along the surface as creep. Creep results when the impact of saltating grains spasmodically moves particles forward without displacing them upward (Bagnold, 1941).

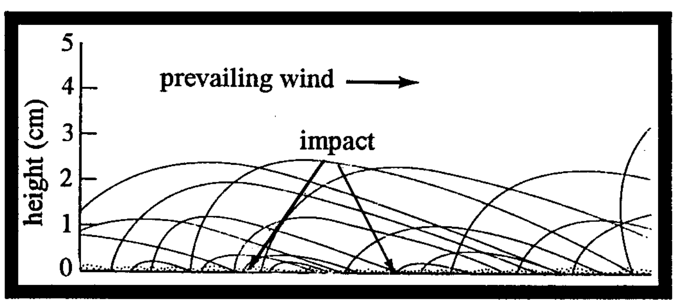


Figure 2:1. Illustration of the saltation process (modified from Ritter, 1986).

Depositional Landforms

A multitude of landforms can develop by the accumulation of wind-blown sand. The largest depositional features associated with eolian sand are sand sheets and sand seas. Sand sheets are tabular bodies of sand that exhibit little or no surface topography. In contrast, sand seas occur in vast, sandy deserts (e.g., Sahara) where enormous supplies of sand can result in a myriad of dune types and sand sheets (McKee, 1979).

Of all desert and wind phenomena, sand dunes have received the greatest scientific attention (Ritter, 1986). Although a variety of dune forms exist, geometric types are not separated by precise dimensional boundaries. Dunes typically exhibit a characteristic profile consisting of three components: the *backslope* or windward surface where erosion occurs, the *crest,* and the *slip face* or lee slope where deposition occurs. Typically, backslope declivity is between 10° and 15°. In contrast, the slip face commonly stands between 30° and 34°, near the angle of repose in most sands (Fig. 2:2).

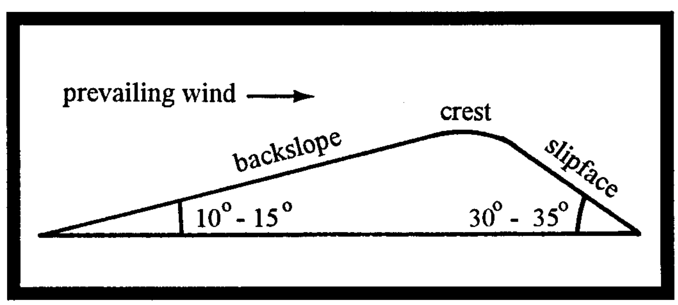


Figure 2:2. Geomorphic components of a dune (modified from Ritter, 1986).

Equilibrium in dunes represents the balance between erosion on the backslope and deposition on the lee slope, which is, in turn, influenced by particle size and wind velocity. Given these assumptions, maintenance of the equilibrium shape of a dune depends upon forward movement of the entire feature because backslope erosion must be volumetrically balanced by deposition on the lee slope (Finkel, 1959; McKee, 1966). In reality, variations in fluid dynamics and other factors (e.g., vegetation, particle size) result in very complex cross-sectional characteristics in most dunes. Despite the intricacies in dune morphology, a number of attempts have been made to categorize dunes based upon their appearance in plan view (e.g., Bagnold, 1941; Hack, 1941; McKee, 1966; 1979). Such classification schemes largely rely on a number of potentially distinguishing variables, including shape, slip-face orientation, genesis, wind type, and surface conditions. Figure 2:3 relates potential dune form with the variables of wind effectiveness, vegetative cover, and sand supply.

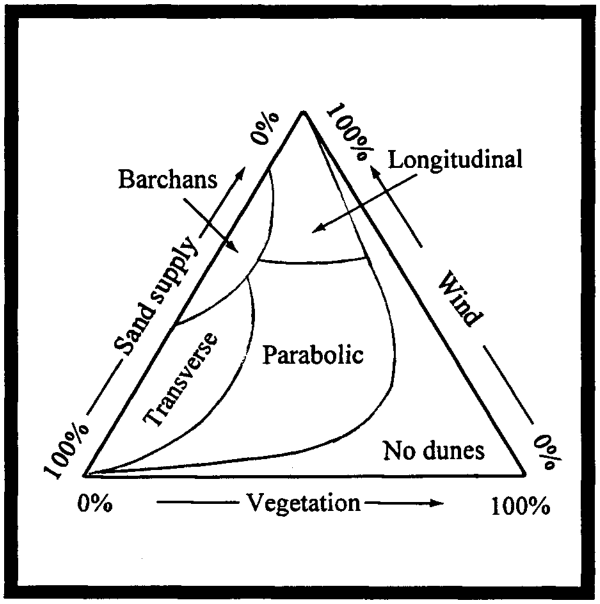


Figure 2:3. Dune form as a response to wind effectiveness, vegetation, and sand supply. Wind direction is assumed to be constant (modified from Hack, 1941).

Nine classes of dune morphology have been identified (Fig. 2:4). Each type of dune can be found in compound or complex forms. Compound dunes are dunes of the

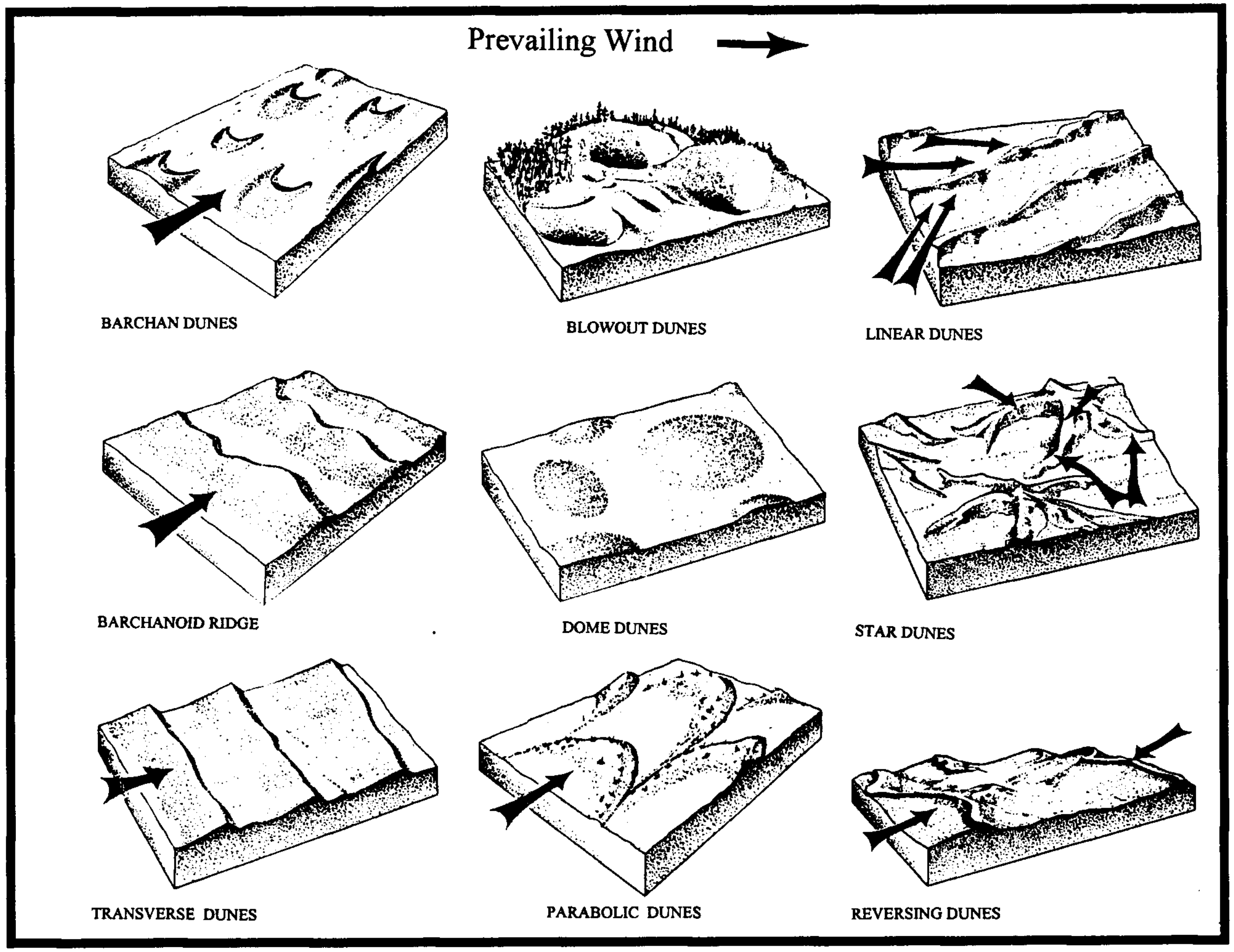


Figure 2:4. Basic dune forms (modified from McKee, 1979)

same type that are superimposed on one another. Complex dune fields are regions where more than one type of dune can be found (Breed and Grow, 1979).

Several types of dunes form without the presence of vegetation. Three dune classes, *barchan*, *barchanoid ridges*, and *transverse ridges*, are genetically similar (McKee, 1979). Barchan dunes are the classic eolian landforms in sandy landscapes. Crescentic in plan view, barchans have a gently inclined windward slope with a steep lee side around which tapering cusps of the dune project downwind. If persistently strong winds occur, or if multi-directional winds persist the crest of a barchan may be truncated and the lee slope flattened, resulting in *dome* dunes. Usually, barchans are isolated dunes that form in areas of strong wind and relatively small amounts of sand. Where winds are weak, however, barchanoid ridges may form if massive quantities of sand exist (Breed and Grow, 1979; Bloom, 1991). Barchanoid ridges have a sinous, assymetrical ridge that is transitional to a transverse ridge. Transverse ridges are primarily a consequence of unidirectional winds that result in a linear deposit of sand perpendicular to the prevailing wind direction (McKee, 1979).

Transverse ridges, at first glance, are similar to *linear dunes*, which also consist of ridge-like features that form without vegetation. Whereas transverse ridges develop perpendicular to winds, linear dunes, in contrast, basically evolve parallel to the prevailing wind, although some seasonal shifting of wind direction may occur (Livingstone, 1986; Tsoar, 1989). In areas of multidirectional winds with very little vegetation, *star dunes* may form. Star dunes can grow to be very large. In the Sahara, for example, star dunes may be several hundred meters in height and many kilometers in diameter. Rather than migrate, star dunes appear to grow in height (Breed and Grow, 1979). A transitional dune between star dunes and transverse ridges is the *reversing dune*, which forms where two winds from nearly opposite directions are balanced with respect to strength and duration. As a result, a second slipface periodically develops.

Dunes that form in the presence of vegetation and/or moisture include *parabolic* and *blowout* dunes. Both are essentially deflation features, but are depositional where margins migrate downwind. As a result, slipfaces may slope in many directions. A typical blowout is a circular bowl, whereas parabolic dunes have U- or V-shaped arms that point upwind as the nose of the dune migrates downwind (McKee, 1979).

Previous Studies of Dune Fields and Sand Sheets of the Central Great Plains

Numerous studies have been conducted about the morphology of dunes as well as history of eolian sand erosion, transport, and deposition in the central Great Plains. The following discussion reviews previous studies of late Quaternary desertification and eolian sand mobilization in the region, beginning in the Arkansas River valley of Kansas and continuing in a clockwise path in the following order: 1) the southern High Plains of Texas, 3) northeastern Colorado, 4) Wyoming, and 5) the Nebraska Sand Hills.

Arkansas River Valley in Kansas

Prior to the 1950s, geomorphic investigations of regional sand sheets was mostly qualitative in nature. In general, the research was speculative with regard to the chronology of events and associated climatic history because reliable age-determination methods (e.g., ^{14}C, thermoluminescence) were not available. According to Ahlbrandt and others (1983:379), inferences were based upon correlations with loess or terrace fill sequences and upon assumptions concerning strong katabatic winds during glacial periods. Much of the early research was conducted in Kansas, where interest focused on the dune fields along the Arkansas River valley.

In a general reconnaissance of southwestern Kansas, Hay (1893) thought the sand comprising the sand dunes along the Arkansas River was from a local bedrock source (e.g., the Ogallala Formation). In 1897, Haworth conducted a study of the physiography of western Kansas, noting that the dune sand "resembled" valley sands along the river. Neither Hay (1893) nor Haworth (1897) speculated about paleowind directions.

The direction of dune-forming paleowinds was qualitatively analyzed in studies along the Arkansas River valley in the 1920s and 1930s. In an overview of the geology of Kansas, Moore (1920) argued that the dune sand along the Arkansas River was derived from the floodplain, having blown out to the south by northwesterly winds.

In 1934, Courtier conducted the most complete study of the physiography and geology of south-central Kansas to that time. Observing that the prevailing winds during the early dust bowl years were southwesterly, he assumed similar conditions existed when the dunes originally formed. As a result, he concluded that the residual soils from the local Dakota, Ogallala, and Sanborn Formations were the sand sources and not the Arkansas River to the north. Courtier (1934:46) also theorized about paleoclimatic evidence, noting the presence of gastropods and ostracodes in a "dry, Pleistocene lake bed" in Stafford County. Referring to the Great Bend Sand Prairie region specifically, he suggested the name "Great Bend sand plains" for the portion of the area covered by sand.

Additional paleoenvironmental evidence of dune age in Kansas was supplied by Smith (1937) from a small study near Hutchinson, Kansas. He observed three soil zones exposed in a blowout, which suggested at least three periods of "alternating sand movement and stabilization" (p. 115). Also exposed in the section were the fossil remains of *Bison alieni*, which confirmed a Pleistocene age for a least one of the units. According to Smith (1937), strike and dip in a reddish-brown basal dune sand indicated northeasterly winds prevailed when the dune formed. The dune appeared to have been reworked by winds of varying directions, however, with modern blowouts resulting from southerly winds.

Smith (1939, 1940) argued that vegetation plays an important role in dune morphology on the Great Plains since pervasive dune forms (e.g., parabolic) suggest that true desert conditions have never prevailed. As a result, he concluded that sand dunes on the Great Plains evolve in two phases: *eolian* and *eluvial*. According to Smith, dunes grow during the *eolian* phase, when deflation removes sand from one part of the dune and deposits it nearby where vegetation is thick. In contrast, dune degradation occurs during the *eluvial* phase, when vegetation is sufficient to stop further erosion. As the *eluvial* phase progresses, dune contours are rounded by soil formation, creep and slope wash. Smith further argued that the cycle may be interrupted at any time and, in fact, that multiple cycles had probably occurred, giving most dunes in Kansas a "chaotic" appearance.

Smith (1940) also considered the source of sand dunes in southwestern Kansas and prevailing paleowind directions. Since the dunes are not migratory in nature, he concluded the source for sand must be local, likely a combination of fluvial and outcropping bedrock origins, Interestingly, he thought that fluvial sources contributed to the smaller dune fields in the region, but that the Arkansas River was not the origin of sand for the massive dune field along its length because dunes were not presently moving across the floodplain. He acknowledged that the dune belt along the south side of the Arkansas River valley suggested that northwesterly winds had prevailed (implying a floodplain source) when the dunes formed. According to Smith (1940), however, dominant modern winds are southerly because transverse ridges near Syracuse face north.

The last substantative work on the origin and age of sand dunes in Kansas was done by Simonett (1960) in a study of dune development and stratigraphy along the Arkansas river near Garden City and Syracuse. To determine the sand source and paleowind direction, he extracted a series of cores from a transect across the dune belt. At most localities, Simonett (1960) found Peoria loess underlying the dune sand, a relationship that indicated to him a northerly source for the sand because the loess crops out farther south. Moreover, he recognized northerly-dipping, low-angle backset beds in many dunes, further suggesting a northerly sand source. As a result, Simonett (1960:223) concluded that "Wisconsinan alluvials from the Arkansas River" were the likely source for the dune sand and that most sand movement occurred during the Wisconsin when northerly winds prevailed.

Simonett (1960) presented evidence, however, that recent dune-forming winds have been southerly in nature. He agreed with Smith's (1940) interpretation that unvegetated transverse dunes and barchanoid dunes near Syracuse with steep, north-facing, slip faces indicate southerly winds. In addition, he recognized parabolic dunes nearby with arms that open upwind to the south. Simonett (1960) also discovered that the lineation of interdune depressions near Garden City runs southwest to northeast. Based on this combined evidence, he concluded that recent southerly winds have reworked dunes initially formed by northwesterly winds.

Recently, data have begun to emerge regarding the chronology and patterns of eolian sand mobilization in the dune fields along the Cimarron River in southwestern Kansas. Porter and others (1994) reported that dunes of varying age can be identified on the basis of soil morphology, with the older dunes containing surface soils with A/Bt/2Bk horizonation, whereas the younger dunes have A/C profiles. Clay and silt mineralogy indicate the sources for older dunes were late Pleistocene braided stream channels. Apparently, many of the channels were active throughout the Holocene, causing simultaneous erosion of older dunes and deposition of fine-grained sediments.

In a review of the early descriptions of the Arkansas River valley by 19th-century explorers, Muhs and Holliday (1995) found evidence for both active and inactive sand in the area of the Great Bend Sand Prairie. At several localities, the presence of "naked sand" was noted in addition to tracts that were densely populated by sunflowers. In the western part of the region, near Pawnee County, the dunes were apparently more active, with large areas totally void of vegetation. This pattern of active and inactive dunes was described into Colorado, leading the authors to conclude that the degree of eolian sand mobilization along the Arkansas River in western Kansas varied spatially.

In the past 30 years, research on Great Plains sand sheets has shifted away from Kansas to the surrounding states of Texas, Colorado, Wyoming, and Nebraska. Moreover, geomorphic histories of dune fields have generally become more detailed and quantitative. Palynological evidence has been used increasingly to determine local paleovegetation. In addition, age-determination techniques, specifically ^{14}C, Optical Simulated Luminescence (OSL), and Thermoluminescence (TL) have been successfully used to establish chronologies of stability and instability.

Southern High Plains of Oklahoma and Texas

Research on dune fields in Oklahoma is limited. Brady (1989) appears to have produced the only chronology of eolian sand mobilization in the state derived from radiocarbon ages. In a study of Quaternary eolian sands in eastern Major and southern Alfalfa Counties, Brady determined that dunes along the Cimarron River are Holocene landforms. A basal age of 11,345±425 yrs B.P. provided a maximum-limiting age for overlying dunes. Overlying ages of 7645±280, 6385±285, and 1200±70 yrs B.P. from buried soils in dune sand indicated that eolian sand mobilization had been episodic in the region during the Holocene.

An ongoing reconnaissance of surficial materials in Oklahoma is being conducted by Olson and others (1995). The primary study area is the Cimarron basin, but data are also being collected from along the Arkansas River in Kansas and the Canadian River in Texas. Results indicate that the Cimarron generally marks the boundary for prevailing winds, with northwesterly and southwesterly winds dominant north and south of the river, respectively. Particle size distributions suggest the Cimarron is the primary source for local sand in Oklahoma. Preliminary investigations along the Canadian River imply that tributaries are the source for most eolian sand in the region.

Research south of Kansas has focused on the sand sheets and dune fields of the southern high Plains in the Texas panhandle. The earliest extensive work was conducted by Melton (1940), who classified the dune fields north of Lubbock into three series: 1) those formed in the last 5000 years; 2) those formed between 5000 and 15,000 years ago; and 3) those older than 15,000 years in age. He reported that dunes within each series could be found in simple or complex forms.

In 1965, Reeves studied the lunettes surrounding the playas on the southern High Plains to determine their age and paleowind directions. According to Reeves (1965), the dunes formed as playas deflated during dry interpluvials. He found that the number of dune ridges fringing the playas increases with playa age. The oldest features are generally on the southern side of the playas while the youngest are on the northern and eastern margins. Reeves obtained a radiocarbon age of approximately 19,000 yrs B.P. for lacustrine strata beneath a dune on the southern margin of a playa, indicating that encroachment occurred during the Wisconsin by northwesterly winds. He argued that dunes on the northern and eastern margins have formed in the last 5000 years due to strong, southerly winds.

In a study of soils in eolian sediments, Gile (1979) recognized three Holocene geomorphic surfaces and associated sediments in the Sandhills of Bailey County, Texas.

Although radiocarbon control was absent, Gile used the development of a clay band horizon and argillic horizon in Holocene sediments to serve as proxies for age. Accordingly, the oldest sediments are the Longview, which accumulated between 7000 and 4000 years ago during the Altithermal. Next oldest are the Muleshoe sediments, which range in age from 4000 to 100 yrs B.P. Deposition of Fairview sediments in the past 100 years has been related to human activities.

The most extensive research on dune fields in the southern High Plains has been conducted in the past 10 years around Lubbock Lake, Texas. In 1985, Holliday excavated the Dune Site, a lunette associated with Cone Playa. According to Holliday (1985), the dune is approximately 7 m high and is composed of gray, silty, highly calcareous material deflated from the adjacent playa. He recognized seven stratigraphic units and five buried soils in the dune, which yielded ages ranging from ca. 34,000 to 1400 yrs B.P. Based on this evidence, Holliday (1985) concluded that the Holocene geomorphic history of the region was dominated by relatively long periods of soil formation, interrupted by discrete, but intense periods of eolian activity.

A detailed study of Holocene eolian sedimentation on the southern High Plains was reported by Holliday (1989). Using stratigraphic data from a variety of sites (e.g., Blackwater Draw, Yellowhouse Draw, Lubbock Lake), he reached the following conclusions: 1) eolian sedimentation in the region first occurred locally between ca. 10,000 and 9000 yrs B.P.; 2) eolian sedimentation was episodic but widespread from

9000 to 5500 yrs B.P., with most areas affected by 6500 yrs B.P.; 3) between 5500 and 4500 yrs B.P. eolian sedimentation occurred at all localities; and 4) landscapes have been stable for the past 4500 years. Of particular importance, Holliday (1989) reported that two pulses of eolian sedimentation, separated by a brief period of soil formation, occurred during the middle Holocene: ca. 6300 to >5000 yrs B.P. and ca. 5000 to 4500 yrs B.P.

Using previous research (e.g., Wendorf and Hester, 1975; Johnson, 1986, 1987) and data on fossil gastropods collected from the Lubbock Lake site, Pierce (1987) reviewed the history of late Quaternary climate change on the southern High Plains. He argued that mean annual temperature increased from a low of 7.5° C during the late Wisconsin to an Altithermal high of 20° C. As a result, through-flowing streams disappeared by the middle Holocene. During the late Holocene, increased precipitation, along with a decrease in mean annual temperature to about 17.5° C, temporarily re-established more mesic conditions in the region. According to Pierce (1987), climate has changed slightly to the present semi-arid conditions in the past 1000 years.

The latest research from the Southern High Plains was reported by Holliday (1995). Radiocarbon ages, soils, and archaeological evidence indicate sedimentation in four phases during the past 11,000 years. In the latest Pleistocene, sand sheets accumulated in vegetated valleys and lake basins. Approximately 10,000 to 8000 yrs B.P., the first widespread dune formation occurred. Evidence for middle Holocene eolian deposition exists in valley fills, but upland dunes were probably reworked in the later Holocene. The last phase of dune construction has occurred in the past 3000 years, with multiple episodes of stability characterized by buried soils with A/C or A/Bw profiles. Holliday reports that clay bands are indicators of dune age. Older dunes, for example, contain 10 to 20 clay bands, each 5 to 10mm thick. Middle Holocene sands, in contrast, contain less than 10 clay bands. Late Holocene sands are void of clay bands.

Evidence for active dunes and wind direction in the southern High Plains during the 19th century, described by early explorers, was reported by Muhs and Holliday (1995). Apparently, the dunes along the Canadian River in Texas and New Mexico contained large areas of loose sand, which are now stabilized. In addition, the reports characterized the dunes as being on the north side of the river, suggesting a southerly prevailing wind. According to Muhs and Holliday, these observations are consistent with overall sand drift potentials derived from contemporary wind data.

Northeastern Colorado and South-central Wyoming

Abundant detailed research has been conducted on the sand sheets and dune fields of northeastern Colorado and south-central Wyoming. An early study was that of Gaylord (1982), who investigated the Ferris dune field in south-central Wyoming. Using radiocarbon ages to bracket periods of instability along Clear Creek, he concluded that two distinct intervals of dune mobility occurred during the Holocene: ca. 7660 to ca. 6460 yrs B.P. and ca. 5000 to ca. 4500 yrs B.P. Subsequently, Gaylord (1990) expanded his earlier findings to include six intervals of regional eolian sedimentation, each bracketed by radiocarbon ages: 7545 to 7035 (I), 7035 to 6460 (II), 6460 to 5940 (III), 5940 to 4540 (V), 4540 to 2155 (V), and 2155 yrs B.P. to Present (VI).

To enhance chronologic control in the Ferris dune field, Stokes and Gaylord (1993) used OSL technology to determine when periods of sand deposition occurred along Clear Creek. While similar to TL dating methodology, OSL reduces the dating signal complication by stimulating the dating signal with shining light (e.g., from a laser) (Smith et al., 1986). As a result, minimal residuals of radiation from almost instantaneous exposure to sunlight during sedimentation can be measured. At Clear Creek, radiocarbon ages reported by Gaylord (1982, 1990) served as chronostratigraphic data for correlative purposes by Stokes and Gaylord (1993). Concordance between OSL and the radiocarbon ages was good, and results indicated that two relatively short phases of Holocene sand deposition occurred in the Ferris dune field: ca. 8500 and 4000 yrs B.P.

Research in Colorado has focused on the Hudson, Wray, and Fort Morgan dune fields in the northeastern corner of the state. In a detailed study of these localities, Muhs (1985) classified dune types and determined their relative ages and source. According to Muhs, the pervasive dune type is parabolic, in compound and simple forms. Most dunes have arms that point 30° - 40° west of north, indicating prevailing northwesterly winds and the South Platte River as a sand source. Muhs estimated the approximate age of the dunes by comparing surface soil development there with localities in Nebraska studied by Ahlbrandt and Fryberger (1980) and Ahlbrandt and others (1983). He concluded that the soils, which are mostly Typic Ustipsamments with A/AC/C profiles, are similar in development. As a result, he inferred that the Wray and Fort Morgan dune fields formed at the same time (3000 - 1500 yrs B. P.) as a major period of dune development in Nebraska, one thought by Ahlbrandt and Fryberger (1980) and Ahlbrandt and others (1983) to correlate with the interstade between the Triple Lakes and Audubon glacial advances in the Front Range (Benedict, 1973).

In a brief study in the Wray dune field, Madole (1986) interpreted differences in surface roughness across the field to mean that several episodes of dune formation occurred in the late Quaternary. Recently activated dunes exhibit weakly developed surface soils with A/C or A/AC/C profiles. Older dunes, with less topographic expression, have well developed soils with A/Bt/C horizons. Madole also studied a blowout in the Wray Dune Field, one that exposed a 15-m-thick section of dune sand overlying about 7 m of pond deposits. Near the base of the lacustrine strata, a clay-silt layer containing fossil molluscs yielded a radiocarbon age of 13,120$\pm$295 yrs B.P. A thick, buried soil, with a radiocarbon age of 7870$\pm$240 yrs B.P., was present in the overlying dune sand. Madole concluded that the 13,000-yr-old pond deposits represent a period of late Wisconsinan dune stability. Sand was subsequently mobilized until soil formation ca. 8000 yrs B.P. The dune field was later modified extensively during the middle Holocene.

Additional studies in northeastern Colorado have been reported by Forman and Maat (1990), Forman and others (1992), and Madole (1994). Forman and Maat (1990) used soil morphology and age to partially reconstruct the geomorphic history of the Hudson dune field. Buried A horizons from two localities were sampled for thermoluminescence (TL) and radiocarbon age determination. One locality yielded a TL age of 8.8±1.7 ka and a radiocarbon age of 7270±110 yrs B.P., whereas another provided a TL age of 8.6±1.3 ka and radiocarbon age of 8280±150 yrs B.P. According to Forman and Maat, these results indicated that the Hudson dune field was reactivated sometime between 9000 and 7000 yrs B.P. Citing Madole's (1986) research, they concluded that the initial, "penultimate" dune-forming episode in the Hudson dune field terminated about 13,000 yrs B.P. Weakly developed surface soils in the area indicate that the Hudson dune field has stabilized only in the past 3000 years (Forman and Maat, 1990).

Forman and others (1992) used principle components analysis of Landsat Thematic Mapper (TM) images to analyze the dunes in northeastern Colorado. Results revealed that the dunes consist of single and compound parabolic dunes, 3 km long and 10 m high, as reported previously by Muhs (1985) and Madole (1986). In addition to the TM data, the stratigraphic record from a 7-m-thick section of sheet sand near

Hudson, Colorado was described in the study (Forman et al., 1992). Radiocarbon ages from four buried soils exposed in the section indicated that the sands at this locality have been reactivated at least four times during the Holocene: 9500 to 5500 yrs B.P., 5500 - 4800 yrs B.P., 4800 to 1000 yrs B.P., and < 1000 yrs B.P.

The most recent research from dune fields in northeastern Colorado was conducted by Madole (1994). Two buried soils were recognized in dunes at five, widely scattered localities along the South Platte River valley. Typically, the lower soil was better developed, with A/Bw/C horizonation, whereas the upper one was an A/C profile. Radiocarbon ages derived from the total humate fraction of the solum indicated that significant activation of eolian sand has occurred in the last 1000 years, resulting in 3 to 4 m of sand accumulation. From the lower solum, $\delta^{13}C$-corrected ages of 1380±90, 1370±90, 1150±70, and 940±110 yrs B.P. were derived. In contrast, the upper soil yielded ages of 1000±100, 910±50, 860±90, and 810±90 yrs B.P. Values of $\delta^{13}C$ ranged from -18.2‰ to -15.2‰, suggesting to Madole that plants with a C_4 pathway (warm, dry adapted) have inhabited the region in the past 1000 years.

Historical accounts of active dune sand by explorers passing through the Wray Dune Field were reported by Muhs and Holliday (1995). In their study, the authors interpreted a description by John Fremont to mean that dune crests and side slopes may have been active while interdunes were stable. Relating to the study conducted by Muhs (1985), Muhs and Holliday (1985) consider such an interpretation logical given the relative degree of soil formation documented in interdunes (A/Bt/C) and the crests and slopes (A/AC/C) of high-relief, compound parabolic dunes.

Nebraska Sand Hills

The most extensive study of sand dunes and sand sheets in the Great Plains has been conducted in the Sand Hills of Nebraska. The Sand Hills cover approximately 50,000 km^2, by far the most extensive area of eolian sand in the western hemisphere (Smith, 1965). Dunes are also much larger in the Sand Hills than elsewhere on the Great Plains. Individual barchanoid-ridge dunes, for example, may be as much as 40 km long and 150 m high. Average parabolic dune length and height is approximately 450 m and 20 m, respectively (Swinehart, 1990). The Pliocene Ogallala Formation, either as in-situ deposits or reworked alluvial sediments, is thought to be the source of the dune sand (Lugn, 1935; Swinehart, 1990).

The age of the dunes in the Sand Hills has been controversial. Some (e.g., Ahlbrandt et al., 1983; Swinehart, 1990) postulate that the dunes are entirely or mostly of Holocene age, perhaps forming during the Altithermal with extensive reworking during the late Holocene (< 5000 yrs B.P.). Others (e.g., Lugn, 1935; Smith, 1965; Wright et al., 1985) suggest that the dunes formed when strong periglacial winds prevailed during the late Wisconsinan glacial maximum (Ruddiman, 1987). Advocates of the latter hypothesis argue that the close proximity of the Sand Hills to the late

Wisconsinan loess blanket to the southeast, which fines progressively in grain size away from the Sand Hills, supports this theory.

Smith (1965) was the first to map different dune morphologies and consider their age and paleoclimatic significance. He recognized three primary categories of dunes: first, second, and third series. First-series dunes are large-scale transverse dunes representing the initial, and most extensive, period of dune formation in the Sand Hills. He believed that they formed in the early Wisconsin when strong, persistent, northwesterly winds prevailed in a periglacial desert environment. Second-series dunes are narrow, longitudinal dunes superimposed on the slopes of first-series dunes. Smith concluded that second-series dunes are reworked first-series dunes, and formed in the presence of some vegetation and prevailing northwest winds during the late Wisconsin. Dunes of the third series consist of small-scale blowouts and y-shaped forms which have formed during reworking of the Sand Hills. He thought that third-series dunes were most active during the mid-Holocene Altithermal, when strong northwesterly winds prevailed in the region.

In subsequent research, Warren (1976) sought to determine the direction of paleowinds in the region by analyzing steep-face orientations, dune volume distribution patterns, and hypsometry of the megadunes. He did not attempt to determine the age of the dunes, but assumed they formed at one time in the late Pleistocene. Warren concluded that northwesterly winds predominated, but that southwesterly winds contributed to megadune growth, resulting in long, linear megadunes.

Research by Watts and Wright (1966) and Bradbury (1980) illustrated the potential for using fossil pollen to reconstruct the environmental history of the Sand Hills. Watts and Wright (1966) analyzed a core from an alluviated lowland between two large dunes at the Rosebud site in northern Nebraska. A radiocarbon age of 12,600±160 yrs B.P. was obtained on organic sediments at the base of the core. Results indicated that a boreal spruce *(Picea* cf. *glauca*) forest existed in the region about 12,600 yrs B.P. and was soon replaced first by pine (*Pinus ponderosa*) and then by grassland. According to Bradbury (1980), the vegetation data obtained from the Rosebud site by Watts and Wright (1966) placed several constraints on the time of eolian deposition in the Sand Hills. He argued that dunes were probably present before the boreal forest, but that dunes could not have formed during forest occupation of the region. Accordingly, he concluded that the last, major period of dune movement occurred after the forests left, most likely during the middle Holocene.

Data on the geometry, primary sedimentary structures, petrography, and direction of sand movement in the Sand Hills were reported by Ahlbrandt and Fryberger (1980). In their study, Smith's (1965) classification was re-interpreted to reflect new classification systems (e.g., Tsoar, 1978; McKee, 1979) and measurements of sedimentary structures obtained from the Sand Hills by Ahlbrandt and Fryberger (1980). Based on their morphology, for example, Smith (1965), had described a large area of dunes in the central Sand Hills as being linear. After taking many cross-bed measurements from these dunes, Ahlbrandt and Fryberger (1980) concluded that they were transverse-ridge dunes migrating south. According to Ahlbrandt and Fryberger, the overall direction of sand transport in the region is northwest to southeast, with a more southerly drift in the southeast part of the Sand Hills.

Probably the most detailed and significant research in the Sand Hills was reported by Ahlbrandt and others (1983). Prior to this study, it was generally believed (e.g., Lugn, 1935; Smith, 1965; Warren, 1976; Bradbury, 1980) that the Sand Hills formed largely in the late Pleistocene with some possible reworking during the Holocene. Radiocarbon ages from organic sediments in interdune depressions had been used to support this hypothesis (e.g., Ogden and Hay, 1965; Watts and Wright, 1966; Stuiver, 1969). According to this theory, organic matter accumulated in the depressions *after* the dunes formed.

Ahlbrandt and others (1983) suggested that ages obtained from interdunes are unreliable chronostratigraphic markers because their association with dune sand has not been positively established. Instead, they argued that the only reliable ages are those from material directly *underlying* eolian sand. Ahlbrandt and others (1983) reported several radiocarbon ages, ranging from 9930±140 to 860±55 yrs B.P., on organics buried by dune sand. These ages demonstrated to them that the Sand Hills are much younger than previously thought, having formed largely in the past 7000 years.

Based on their radiocarbon ages, Ahlbrandt and others recognized two distinct and one possible period of Holocene dune formation in the Sand Hills. Radiocarbon ages of ca. 7200 and 5100 yrs B.P. bracket the Altithermal, suggesting the first episode of dune formation in the region. The best documented phase of eolian activity is the period between ca. 3000 and 1500 yrs B.P. Another, poorly documented, period of dune formation may have occurred in the latest Holocene, as indicated by a radiocarbon age of ca. 900 yrs B.P. obtained from organic-rich sand underlying 8 m of dune sand.

Debating the conclusions presented by Ahlbrandt and others (1983), Wright and others (1985) reviewed the research supporting late Pleistocene dune formation in the Sand Hills. In particular, they re-examined the studies of Ogden and Hay (1965), Watts and Wright (1966), and Stuvier (1969) where radiocarbon ages had been obtained from organic sediments in interdune localities. In those studies, radiocarbon ages of 12,630±160 (Rosebud Lake), 12,080±380 (Krause Lake), and 8950±160 yrs B.P. (Swan Lake) were obtained by Ogden and Hay (1965), Watts and Wright (1966), and Stuvier (1969), respectively.

In their review, Wright and others (1985), maintained that these radiocarbon ages suggested that the dunes formed during the late Wisconsin when organic-rich sediment accumulated in interdune swales. They argued that because dunes *surround* the depressions, a late Pleistocene age for the dune is logical. In reference to the research by Ahlbrandt and others (1983), Wright and others (1985) concluded that intensive dune reactivation has probably occurred in the Holocene.

The most extensive report regarding the Sand Hills was *An Atlas of the Sand Hills* (Bleed et al., 1990). In the *Atlas*, Swinehart (1990) included a detailed map of the region that illustrates the distribution of eight dune types, based on McKee's (1979) classification system. Swinehart (1990) also discussed the controversy surrounding the age of the Sand Hills. He maintained that radiocarbon ages used by Wright and others (1985) to indicate a late Pleistocene age for the dunes were unreliable because they were not directly overlain by dune sand. Legitimate ages, according to Swinehart (1990), included those obtained by Ahlbrandt and others (1983) that indicated most dunes in the region formed in the Holocene. Swinehart (1990) also reported a more recent radiocarbon age of 13,160±450 yrs B.P. obtained from organics buried beneath 50 m of dune sand and 3 m of alluvial sand. As a result, Swinehart (1990) concluded that the Sand Hills most likely formed during the Altithermal, between 8000 and 5000 yrs B.P. Following about 2000 years of stabilization, significant reactivation occurred between 3500 and 1500 yrs B.P. when linear and parabolic dunes developed in areas previously not covered with sand and on pre-existing dune topography.

Additional results from the Nebraska Sand Hills were reported by Ponte and others (1994). In that study, vibracores were obtained from several interdune fens in Cherry County. The base of the thickest peat sequence, which contained 70 percent spruce pollen, provided a radiocarbon age of 12,260±60 yrs B.P. Higher in the core, ages of 7670±60 and 4870±70 yrs B.P. bounded two 30 cm-thick bodies of eolian sand that were, in turn, separated by 35 cm of degraded peat. Based on unreported ages from other localities, Ponte and others (1994) hypothesized two episodes of eolian activity in the Nebraska Sand Hills during the late Holocene: 3500 to 2800 yrs B.P and after 1000 yrs B.P.

The most recent, intensive research from the Nebraska Sand Hills was reported by Loope and others (1995) and Mason and others (1995). Using subsurface data obtained from test holes, vibracores, and piston cores near the southern margin of the Sand Hills, the authors have reinterpreted the Holocene history of the area. Results indicated that prolonged arid intervals in the latest Pleistocene and middle Holocene caused eolian dune sand to block two large valley systems in western Nebraska. Consequently, water tables have risen approximately 25 m, forming the many interdune lakes. Radiocarbon ages of 4300 yrs B.P. from gyttja underlying Blue Lake and about 10,700 yrs B.P. from gyttja and peat underlying Crescent Lake provide the maximum-limiting ages for the two major periods of aridity that caused blockage of the paleovalley during the Holocene.

In a study of the geochemistry of the Nebraska Sand Hills, Muhs and others (1995) reported that dunes are mineralogically mature, depleted in K and Rb. According to the authors, this can be explained pedogenically or by the mechanical breakdown of breakdown of minerals during transport. Regardless, any theory suggests eolian sediments have been reworked many times. In addition, seventeen new radiocarbon ages, obtained by accelorator mass spectrometry (AMS), were reported and confirmed previous data that showed dune mobilization in the past 1000 years.

A recent review of historical accounts by explorers passing through the area by Muhs and Holliday (1995) indicated drifting sand existed in the Nebraska Sand Hills as early as 1796. By the middle of the 19th century, the Sand Hills were generally characterized as being about 25 percent free of vegetation. According to the authors, the nature of the descriptions imply that dune activity was confined to crests.

In summary, much research has been conducted in Great Plains sand sheets and dunes this century. The earliest work (1920s - 1960s) focused on the dune fields of Kansas, but was qualitative in nature and without absolute age control. Conclusions were based upon loess or terrace-fill sequences and oversimplified glacial chronologies. Generally, dunes along the Arkansas River valley were thought to have formed during the late Wisconsin, when strong winds theoretically blew off of the Laurentide ice sheet to the north. In fact, the primary evidence of a late Wisconsinan age for the dunes was their position on the southern side of the river which, hypothetically, would have occurred only as a result of persistant northerly winds.

Since the advent of the radiocarbon dating technique in the 1950s, detailed chronologies and associated climatic histories have been constructed for a variety of sand sheets and dune fields on the Great Plains, including those in the southern High Plains, northeast Colorado, and the Nebraska Sand Hills. Rather than a late Wisconsinan age for most dunes, results indicate that many dunes may have initially formed during the Holocene Altithermal 9000 - 6000 yrs B.P., but have been destabilized episodically since. Periods of stability have often been brief, resulting in soils with A/AC/C profiles. In addition, instability appears to have varied spatially in dune fields, with some places active whereas others were not. Prevailing winds were northwesterly in the Sand Hills and in Colorado and southwesterly on the Southern High Plains.

CHAPTER 3
STUDY AREA

The research discussed in this report was conducted on the Great Bend Sand Prairie, a large sand sheet located within the "great bend" of the Arkansas River (Fig. 1:1). Approximately 4500 km^2 in size, it includes all of Stafford County, and portions of Barton, Edwards, Kiowa, Pratt, Rice, and Reno Counties. The vast majority of investigations occurred within the jurisdiction of Groundwater Management District #5. The study area is situated mostly within the Arkansas River Lowlands physiographic province, except for the southern one-half of Pratt county, which lies in the High Plains physiographic province (Schoewe, 1949). Major tributaries to the Arkansas River in the region are the North Fork Ninnescah River, which flows generally to the southeast, and Rattlesnake Creek, a northeasterly trending stream that bisects the study area (Fig. 3:1).

Geology

The geology of the Great Bend Sand Prairie is complex. Structurally, the study area lies on the southwestern flank of the Central Kansas Uplift (Barton Arch) and the northern one-half of the Pratt Anticline (Merriam, 1963; Fig. 3:2). A generalized columnar section of the geologic units is presented in Table 3:1. Basement rocks in the region include those of Permian and early-Cretaceous age, with Cretaceous rocks present and forming the bedrock surface only in the western one-half of the study area.

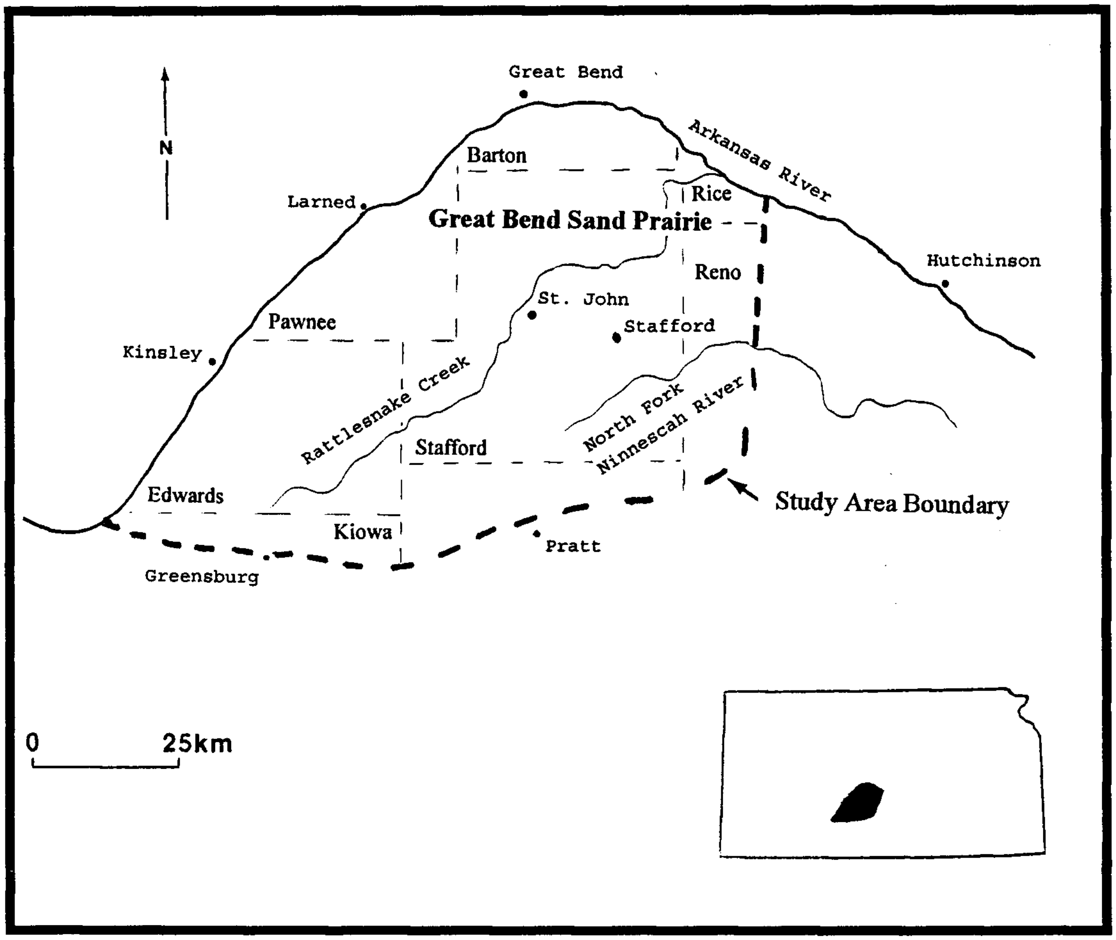


Figure 3:1. Location of major towns, county boundaries, and tributaries in the Great Bend Sand Prairie .

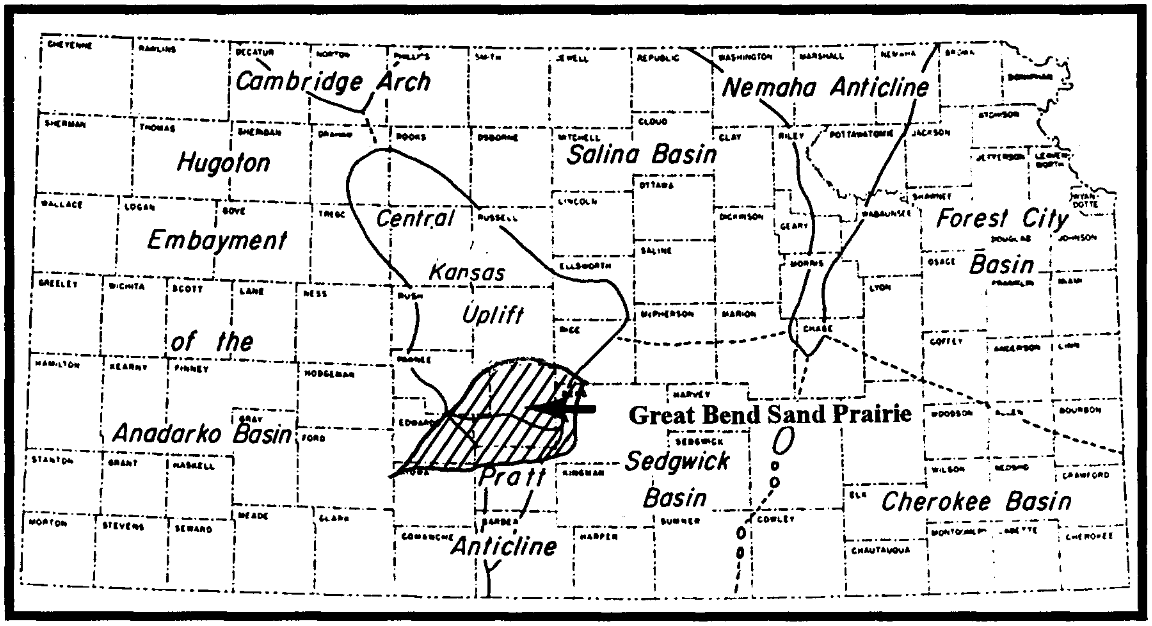


Figure 3:2. Structural elements of Kansas showing the position of the Great Bend Sand Prairie relative to the Central Kansas uplift and Pratt Anticline.

Table 3.1: Generalized columnar section of geologic units on the Great Bend Sand Prairie (modified from Fader and Stullken, 1978).

System	Geologic Unit	Max. thickness (m)	Physical Character
Quaternary	Undifferentiated Pleistocene Deposits	110	Unconsolidated deposits of sand and gravel with interbedded lenses of clay, silt, and caliche. Eolian sand occurs over most of the area.
Tertiary	Ogallala Formation (Pliocene deposits)	20	Unconsolidated deposits of silt, fine sand, and interbedded caliche.
Cretaceous	Undifferentiated Lower Cretaceous rocks	115	Upper unit (Dakota Formation) - brown fine- to medium - grained sandstone interbedded with shale. Middle unit (Kiowa Formation) - dark-gray shale interbedded with sandstone. Lower unit (Cheyenne Sandstone) - gray to brown medium-grained sandstone interbedded with shale.
Permian	Undifferentiated Permian Rocks	105	Interbedded reddish shale, siltstone, and sandstone.
	Cedar Hills Sandstone	60	Reddish shale, siltstone, and sandstone.
	Salt Plain Formation	90	Reddish-brown sandy siltstone and sandstone.
	Harper Sandstone	75	Brownish-red siltstone and silty shale.
	Stone Corral Formation	5	White and light-gray anhydrite and dolomite.
	Ninnescah Shale	120	Red and grayish-green shale, siltstone, and silty sandstone.

Permian rocks, consisting of the Ninnescah Shale, Stone Corral Formation, Harper Sandstone, Salt Plain Formation, Cedar Hills Sandstone, and Undifferentiated strata (including Whitehorse and Dog Creek Formations) are often referred to as "red beds" because they contain red to brown shale, siltstone, and sandstone with minor beds of limestone, dolomite, and anhydrite. Cretaceous rocks include the Cheyenne Sandstone, Kiowa Formation, and Dakota Formation, and generally consist of interbedded shales, sandy shales, and fine to coarse-grained sandstones.

Overlying the Permian and Cretaceous basement rocks on the Great Bend Sand Prairie are varying thicknesses of unconsolidated Tertiary and Quaternary deposits. Tertiary deposits consist of the Pliocene Ogallala Formation. In general, the Ogallala is characterized by deposits of silt and fine sand with interbedded caliche (Fader and Stullken, 1978) that were derived from the Rocky Mountains.

The surficial geology of the entire Great Bend Sand Prairie is dominated by unconsolidated Quaternary deposits of eolian and alluvial origin. Quaternary sediments of the region have a maximum thickness of about 100 m. The mineralogy (e.g., quartz, feldspar, granite) of most Quaternary deposits suggests a Rocky Mountain origin with the Arkansas River serving as the primary source. The bend of the Arkansas River is thought to have migrated laterally from the south to its present position via successive captures by its own northern tributaries, leaving a thick deposit of sand, silt, and clay behind (Fent, 1950). In general, five lithostratigraphic units have been recognized (bottom to top): 1) basal sand and gravel; 2) alternating sequences of sandy silt-clay, sand, and gravel; 3) near-surface silt-clay bed; 4) loess; and 5) sand (Rosner, 1988). The uppermost sand, which is central to this study as the primary source for dunes, varies in thickness between 1 to 15 m (Johnson, 1991).

Soils

Soils within the Great Bend Sand Prairie are classified as Mollisols, Alfisols, Entisols, or Inceptisols. Categorization is based on landscape position and parent material associations. Upland soils have formed in undulating to hilly sandy sediments, old alluvium that is dominantly sandy clay loam, silty clay loam, and clay loam in texture, and loess. Floodplain soils are those which have developed in areas with a seasonally high water table and/or in stream drainageways.

Soils that have evolved on short and medium length slopes in complex, wind-modified dune topography are those in the Pratt-Tivoli association. Both soils have formed in sediments classified as loamy fine sand. Pratt soils are less prone to eolian erosion because they occupy lower positions on the dune landscape. As a result, they are better developed (e.g., Bt horizon) and probably older than Tivoli soils which only have A/C profiles.

The Dillwyn-Tivoli soil association includes poorly developed soils with A/C profiles that have formed on short, complex slopes in a nearly level to hilly landscape that has been modified by eolian processes. Dillwyn soils are deep, somewhat poorly drained soils in areas where seasonal water tables are relatively high. Tivoli soils, in contrast, are well drained because they occupy high positions on dunes underlain by loamy fine sand.

Well drained and poorly drained upland soils that have developed on short and medium slopes in undulating to rolling sandy sediments are included within the Pratt-Carwile association. Pratt soils have developed in sediments classified as loamy fine sand on the lower and intermediate slopes of eolian dunes. As a result, permeability is high in these soils. Carwile soils, in contrast, are deep soils with a series of strongly developed Bt horizons that have formed between dunes in loamy, clayey-silt deposits (old alluvium) of low permeability

The Naron-Farnum soil association includes soils that have developed in loamy sediments on nearly level to gently sloping topography that have weakly defined drainageways. Both soils are well drained and have formed within deposits classified as loamy fine sand at the surface and sandy clay loam and clay loam in the subsurface. Farnum soils, with well developed Bt horizons, are better developed than Naron soils that have only one, moderately formed Bt horizon.

Soils that have evolved on medium and long convex ridges on upland landscapes include those in the Blanket-Farnum association. Blanket soils are deep, well drained soils with at least two Bt horizons that developed in loess parent material. Farnum soils are as well developed as Blanket soils, but have formed in loamy old alluvium rather than loess.

Soils that have evolved on low, wet terraces, floodplains, and in channeled areas of streams are included within the Natrustoll-Plevna association. Natrustolls have formed in loamy, calcareous alluvium that contains layers of sand or clay in places. They are somewhat poorly drained and often contain high concentrations of salt. Seasonal water tables are relatively high. Plevna soils typically have developed in slight depressions on floodplains and on chaotic, channeled floodplains. Parent material is usually fine sandy loam at the surface that is underlain by sandy and clayey alluvium. Plevna soils are often heavily gleyed (Dodge et al., 1978).

Climate

Several stations (e.g., Great Bend, Hutchinson, Greensburg, Hudson, Larned) near or on the Great Bend Sand Prairie have maintained temperature and precipitation records since early this century. Data indicate that the present climate of the region is semiarid to subhumid and strongly continental, characterized by extreme diurnal and annual variations in temperature. Winter usually lasts from December to February with an average low temperature of about 0° C. The summer growing season is usually from April to October, during which time the average high temperature is about 25.5° C.

Average annual precipitation in the study area reflects the position of the Great

Bend Sand Prairie on the boundary between the dry portion of western Kansas that is influenced by the rain shadow of the Rocky Mountains and the eastern regions over which moisture laden air from the Gulf of Mexico flows. Although yearly precipitation may vary widely depending upon the precise position of the boundary, mean annual precipitation on the western border (57 cm) is significantly less than average yearly rainfall on the eastern margin of the study area (80 cm) (Fader and Stullken, 1978). Most of the total annual precipitation comes from convective storms in the late spring and summer, with approximately 75 percent of the yearly amount occurring in the growing season (Dodge et al., 1978; Table 3:2)

Table 3:2 Mean Monthly Temperature and Precipitation at Hudson.

	Temperature (C°) Mean Daily Max.	Mean Daily Min.	Precipitation (mm)
J	6.0	- 7.0	1.4
F	9.0	-4.4	2.3
M	13.0	- 1.2	3.2
A	20.5	5.9	5.8
M	25.9	12.0	9.2
J	31.2	17.1	10.8
J	34.0	18.9	9.3
A	33.3	18.9	6.5
S	28.3	14.0	5.6
O	22.2	7.7	5.3
N	13.3	0.0	2.0
D	6.8	-4.5	2.2

Source: Dodge and others, 1978:56.

Vegetation

Vegetation on the Great Bend Sand Prairie can be divided into two categories: 1) natural to the area and 2) that which has been imported by European settlers (Kuchler, 1974). Land-use data for Stafford County serves as an estimate for this division between natural and cultivated vegetation on the Great Bend Sand Prairie. In 1978, approximately 375,000 acres, or about 75 percent of the total land area in Stafford County, was under cultivation. 96,000 acres, or about 19 percent of the total land area was in pasture. The remaining 6 percent of the land, such as along the Rattlesnake Creek floodplain, was regarded as unsuited for agriculture. Pasture in Stafford County is generally located on the very well drained, dune topography of high relief, while cultivated land is found nearly everywhere.

Grassland, in the form of tall and mixed-grass prairie, is the dominant natural vegetation of the study area, although wooded areas exist along streams. Common prairie grasses in high-relief dune fields include sand bluestem (*Andropogon hallii*), little bluestem (*Andropogon scoparius*), sand lovegrass (*Eragrostis trichodes*), big sandreed (*Calamovilfa gigantea*), switchgrass (*Panicum virgatum*), indiangrass (*Sorghastrum nutans*), sand dropseed (*Sporobolus cryptandrus*), and Texas bluegrass (*Poa arachnifera*). In areas of less relief where better developed, heavier soils are found, big bluestem (*Andropogon gerardi*), western wheatgrass (*Agropyron smithii*), blue grama (*Agropyron hallii*), side-oats gramma (*Bouteloua curtipendula*), tall dropseed (*Sporobolus giganteus*), and buffalograss (*Buchloe dactyloides*) are common. Riparian trees in the Great Bend Sand Prairie include eastern cottonwood (*Populus deltoides*), american elm (*Ulmus rubra*), common hackberry (*Celtis occidentalis*), sycamore (*Platanus occidentalis*), black hickory (*Carya texana*), and black walnut (*Juglans nigra*) (Dodge et al., 1978) .

Cultural History

Archaeological evidence recovered from the Great Bend Sand Prairie indicates cultural inhabitation during the past several thousand years. Eighteen prehistoric sites have been identified thus far, including Archaic, and Middle and Late Ceramic. Tool assemblages, consisting largely of projectile points and flakes, suggest the region served as a hunting ground. The Great Bend Sand Prairie was intermittently inhabited by nomadic bands of Native American Wichita, Cheyenne, Comanche, Kiowa, and Kiowa Apache during the protohistoric (Logan et al., 1993).

Large-scale, European influence in the region began during the 1820s with establishment of the Santa Fe Trail along the northern boundary of the study area. In order to protect the trail, Fort Larned was established near the site of present day Larned, in 1859. By the late 1860s, homesteaders from the eastern United States and Europe began to settle the area during the large westward migration. Migration was fueled by the establishment of the Santa Fe Railroad, which reached the town of Great Bend in

1872 (Dodge and Roth, 1978)

By 1900 the area was fully settled by European settlers. Pratt, Reno, Barton, and Edwards Counties were established in 1872, whereas Edwards and Stafford Counties were organized in 1874 and 1879, respectively (Andreas, 1883). Kiowa County was established in 1886 (Hoffman et al., 1986). According to the 1990 census, the largest cities in the region are Great Bend (pop. 15,427), Pratt (pop. 6,687), Larned (pop. 4,445), Greensburg (pop. 1,792), St John (pop. 1,274), and Stafford (pop. 1,268). Although some oil and gas speculation occurs in the area, the regional economy is largely based on farming, ranching, and related enterprises (Kansas Statistical Abstracts, 1992).

CHAPTER 4

PROJECT HYPOTHESES AND METHODOLOGY

The general goal of this study is to reconstruct the late Quaternary paleoenvironmental and geomorphic history of the Great Bend Sand Prairie. To accomplish this purpose, several hypotheses have been formulated along with the means to test them. They include:

Ho1: The Great Bend Sand Prairie exhibits eolian landforms which can be discerned, categorized, and mapped.

Research on dune fields elsewhere on the Great Plains (e.g., Smith, 1965; Ahlbrandt et al., 1983; Muhs, 1985; Madole, 1986) has shown that aerial photography can be used to categorize and map sand sheet landforms. In order to categorize and map sand sheet landforms on the Great Bend Sand Prairie, aerial photography and field survey were employed and discernable categories grouped as per McKee (1979).

Ho2: Silt layers are commonly occurring, late Wisconsinan deposits that provide a maximum age for sand dune development in the study area.

Preliminary investigations (Rosner, 1988; Johnson, 1991) suggested that silty deposits of probable late Wisconsinan age underlie most, if not all, dune fields on the Great Bend Sand Prairie. To test this hypothesis, sub-dune stratigraphy was explored throughout the region via a Giddings coring machine, backhoe, hand bucket auger, and described according to Soil Conservation Service standards. To test the age of the silty deposits and provide a maximum age for dune-field development, bulk samples ($\geq$ 4Kg) were collected from buried soils and organic-rich strata within the silty deposits for radiocarbon dating (total humate fraction). Samples were prepared at the University of Kansas where rootlets and other detrital plant material were removed by flotation, the sand fraction was separated by decantation, and carbonates eliminated by Hcl treatment. Samples were subsequently oven dried, pulverized, and sent to the University of Texas Radiocarbon Laboratory for age determination.

Ho3: Dune fields on the Great Bend Sand Prairie are generally Holocene landforms that evolved because climate shifted from cool and relatively moist in the late Wisconsin to semiarid and subhumid during the Holocene.

Numerous studies (e.g., Antevs, 1955; Gile, 1979; Ahlbrandt et al., 1983; Muhs, 1985; COHMAP, 1988; Holliday, 1989) indicate that a climate shift from cool conditions with more effective moisture to a warm/semiarid and subhumid climatic regime occurred at the Pleistocene/Holocene boundary on the Great Plains. This shift in climate is thought to have favored dune formation in northeastern Colorado (Muhs, 1985), Nebraska (Ahlbrandt et al., 1983) and in the southern High Plains (Holliday, 1985, 1989).

To test the hypothesis that a Holocene climate shift to subhumid and semiarid conditions was accompanied by dune formation on the Great Bend Sand Prairie, differences between the depositional environments of the silty deposits and overlying dune sand were analyzed in three ways:

1) Sedimentology of the silty deposits and dune sand - Preliminary, largely qualitative evidence (e.g., fining upward sequences, sorting, truncation, gleying) observed in the silty deposits suggested that the sediments accumulated in a very low energy alluvial or lacustrine environment, whereas overlying dunes developed by eolian processes. If the silty deposits were pervasive and late Wisconsin in age by radiocarbon dating, then they presumably accumulated in an environment of more effective moisture than that which promoted eolian sand deposition.

A variety of laboratory techniques were employed to characterize the silty deposits and dune sand and to test the hypothesis that they accumulated in contrasting climatic regimes. Differences in sediment texture between each unit were quantified via the pipette method (Day, 1965). In order to graphically plot textural results, Krumbein's (1934) logarithmic transformation (ϕ scale) of the Udden-Wentworth (Wentworth, 1922) grade scale was used. Subsequent graphical statistics, including the mean, median, sorting, skewness, and kurtosis (as defined by Folk and Ward, 1957) were calculated with software by Prante (1990). In general, it was thought that differences in the sedimentology, reflecting diachronous climate regimes, should be discernable between the silty deposits and dune sand.

2) Chemical composition and degree of soil formation - Recognizable differences in the chemical characteristics and the degree of soil formation between the silty deposits and dune sand could provide additional evidence for a shift towards a semiarid and subhumid climate during the Holocene.

Chemical characterization of late Quaternary sediments on the Great Bend Sand Prairie focused on calcium carbonate and organic matter analyses. Carbonate content in these quartz sand dunes was expected to be minimal, except where buried soils were present, because eolian sands are relatively porous and very well drained. In contrast, carbonate content in the silty deposits was expected to be relatively high, owing to low infiltratibility and the accumulation of illuviated calcium at an unknown depth in a cool, relatively moist climate. Accordingly, the Chittick method (Dreimanis, 1962) was used to quantify calcium carbonate concentrations. Similarly, the Walkley-Black method (Allison, 1965) was used to determine the organic matter content in sediments, to better define soil A horizons and to test for ^{14}C dating potential.

In an effort to compare the physical differences in soil development and the character of post-depositional alteration in the silty deposits and dune sand, samples for thin sections were collected at two representative sites on the Great Bend Sand Prairie. At each locality, samples were collected from buried A horizons and C horizons in dune sand and from the Btb horizons in the underlying silty deposits. Samples were sent to

Spectrum Petrographs, Inc. in Winston, Oregon, for impregnation and thin-section preparation. Analyses were conducted with the assistance of Mickey Ransom at Kansas State University.

3) Faunal and floral evidence - Differences in biota between the silty deposits and dune sand should reflect paleoenvironmental change. Faunal and floral remains were collected where possible and subsequently identified in the University of Kansas soil laboratory.

Additional paleofloral evidence was provided from $\delta^{13}C$ values obtained from ^{14}C ages on buried soils in the silty deposits and dune sand. It has been established that $\delta^{13}C$ values can be used to infer vegetation and associated paleoclimate (e.g., Krishnamurthy et al., 1982; Delaune, 1986) at the time of soil formation or deposition because many warm-climate (C_4) prairie grasses (e.g., *Andropogon gerardii*, *Panicum virgatum*) typically have mean $\delta^{13}C$ values of -12‰, whereas cool-climate (C_3) prairie grasses (e.g., *Elymus canadensis*, *Agropyron smithii*) have average $\delta^{13}C$ values of -27‰ (Deines, 1980; Krishnamurthy et al., 1982; Cerling and Quade, 1993; Nordt, et al., 1994). Buried soils in silty deposits were expected to have more negative $\delta^{13}C$ values than those obtained from buried soils in dune sand, reflecting a climate shift from cool and relatively moist to warmer and semiarid to subhumid.

Ho4: Mobilization of eolian sand on the Great Bend Sand Prairie has been episodic and patchy.

In order to test whether eolian sand mobilization in the region has been episodic, disconformities (e.g., truncation surfaces, buried soils) were analyzed in dune sections exposed in quarries, roadcuts, cutbanks, and backhoe trenches. Buried soils, in particular, were a major focus because they represent periods of stability in dune fields. To estimate when periods of dune stability occurred in the study area, radiocarbon ages were obtained on the total humate fraction of buried soils. Where more than one buried soil was recognized in a section, radiocarbon ages were obtained from sola high enough in organic carbon to provide an age. As a conservative estimate of periods of stability, all ages were calculated at 2σ, corrected for $\delta^{13}C$ fractionation (Stuiver and Polach, 1977), and calibrated to the tree-ring curve (Stuiver and Reimer, 1993). The resultant record of eolian sand stability and mobilization was subsequently compared with other dune fields on the Great Plains (e.g., Holliday, 1985; Gaylord, 1982; Muhs, 1985; Madole, 1994).

To test whether eolian sand mobilization on the Great Bend Sand Prairie differed spatially, variation in the degree of surface soil development was analyzed by consulting soil surveys and by describing backhoe trenches and hand-dug pits. Dunes with relatively less surface soil development should have been active more recently than those with better developed surface soils (e.g., Birkeland, 1984). The physical (e.g., texture, horizonation) and chemical (e.g., $CaC0_3$) properties of surface soils were determined by the methods outlined in Ho3.

CHAPTER 5
RESULTS

Introduction

This chapter summarizes the data derived from the geomorphic investigations on the Great Bend Sand Prairie. First, the reconnaisance is discussed. Second, the mapping process and outcome are analyzed. Finally, the results of detailed subsurface investigations conducted at specific sites distributed throughout the region are presented.

Reconnaisance

In preliminary studies of the late Quaternary stratigraphy and paleoenvironmental history of the Great Bend Sand Prairie, Rosner (1988) and Johnson (1991) suggested that two, primary depositional units were present: 1) an upper unit, variable in thickness, consisting of wind-blown sand and 2) an underlying, finer-grained stratum, which Rosner (1988) referred to as a "silt/clay layer" and Johnson (1991) called a "silt layer." Based on radiocarbon ages from five, widely spaced backhoe trenches, Johnson theorized that the silt layer is a ubiquitous, late Wisconsinan deposit. In an effort to test the hypothesis that the silt layer is widespread and is overlain by dune sand of variable thickness, a thorough reconnaissance was conducted at the outset of this study.

The exploratory phase of this project was essentially completed over the course of the summer 1993. During that time, 126 widely scattered localities (Fig. 5:1), were randomly selected and stratigraphically tested by bucket augering. Test depth varied considerably, ranging from about 2.5 m to around 30 cm, depending upon the depth of the silt layer, as defined by Johnson (1991). Given the inherent imprecision associated with bucket augering, stratigraphy and texture were only generally described. Basic characteristics (e.g., texture, color, structure) were noted qualitatively, with the primary goals being 1) to determine whether or not the silt layer was present at a given site and 2) to ascertain the thickness of overlying wind-blown deposits.

Of the 126 sites tested, 95 (75.4%) contained the silt layer, indicating that it is indeed widespread (Fig. 5:1). Over the course of the reconnaissance, however, it was determined that the terms "silt/clay layer" or "silt layer", which imply a single stratum, largely composed of silt, is a misnomer. In reality, it appears that the deposit, as previously defined, may include several facies, differentiated by color and texture, that intertongue in some fashion. Moreover, the unit(s) consists largely of sand at most sites, but does contain high though variable percentages of silt and clay as compared to the overlying, wind-blown sand. At all localites, well developed soils with strong structure were recognized in the deposit. Given that a generic term for the unit(s) is useful when referring to site stratigraphy, a new term, "silty sand", is proposed instead of "silt/clay layer" or "silt layer" to reflect the dominant composition of the deposit.

Results from exploratory testing qualitatively indicated that the silty sand changes considerably in depth, texture, and color in the study area. At some localites, the unit is buried by several meters of eolian sand, whereas at others, the stratum was exposed at the surface. Texture varies from silty clay loam to sandy clay loam and color ranges from black (10YR2/1; moist) to an oxidized, strong brown (7.5YR5/6; moist). As anticipated, the silty sand iss mottled or gleyed in many places due to reduction.

Mapping

Mapping of surficial deposits was conducted by analyzing aerial photography, county soil surveys, and reconnaissance. Unit boundaries were illustrated with dashed lines in order to reflect the transitional nature of dune fields. Ultimately, a map was produced that recognizes six, primary geomorphic categories in the uplands of the Great Bend Sand Prairie (Fig. 5:1) including:

1) Loess Plain (Ql) - including flat to slightly undulating topography underlain by loess in the area north and east of Stafford (Fig. 5:2).

2) Low-Relief Sand Sheet (LSS) - includes landscapes of little or no relief that are mantled by sand (Fig. 5:3).

3) High-Relief Sand Sheet (HRSS) - consisting of slightly undulating, irregular sand-mantled topography without steep faces (Fig. 5:4).

4) Compound Sub-parabolic Dunes (CSP) - including some elements of category 3, but consisting largely of dune fields displaying traces or remnants of parabolic dune limbs and steep slip faces superimposed on one another (Fig. 5:5).

5) Compound Parabolic Dunes (CP) - dune fields that consist largely of superimposed parabolic forms, but may include elements of classes 3, 4, and 6 (Fig. 5:6).

6) Parabolic Dunes (P) - dune fields composed of individual parabolic forms with steep slip faces and well defined limbs (Fig. 5:7).

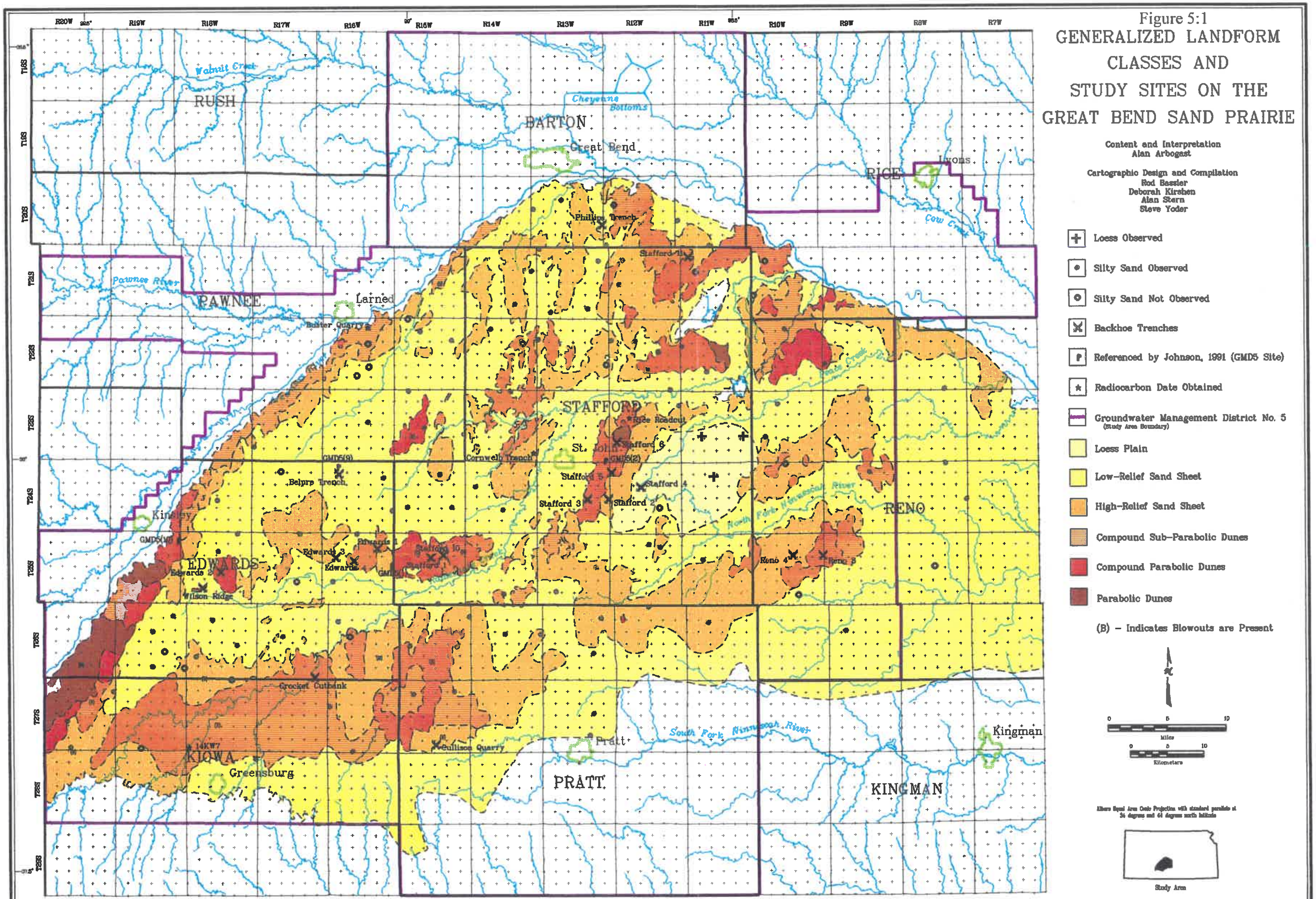


Figure 5:1
GENERALIZED LANDFORM CLASSES AND STUDY SITES ON THE GREAT BEND SAND PRAIRIE
Content and Interpretation
Alan Arbogast
Cartographic Design and Compilation
Rod Bassler
Deborah Kirshen
Alan Stern
Steve Yoder
Loess Observed
Silty Sand Observed
Silty Sand Not Observed
Backhoe Trenches
Referenced by Johnson, 1991 (GMD5 Site)
Radiocarbon Date Obtained
Groundwater Management District No. 5
(Study Area Boundary)
Loess Plain
Low-Relief Sand Sheet
High-Relief Sand Sheet
Compound Sub-Parabolic Dunes
Compound Parabolic Dunes
Parabolic Dunes
(B) – Indicates Blowouts are Present
Miles
Kilometers
Study Area
R20W
R19W
R18W
R17W
R16W
R15W
R14W
R13W
R12W
R11W
R10W
R9W
R8W
R7W
RUSH
BARTON
RICE
PAWNEE
STAFFORD
EDWARDS
RENO
KIOWA
PRATT
KINGMAN
Walnut Creek
Cheyenne Bottoms
Great Bend
Lyons
Cow Creek
Pawnee River
Larned
Kinsley
St. John
Pratt
Greensburg
Kingman
South Fork Ninnescah River
North Fork Ninnescah River
Phillips Trench
Stafford 11
Rice Roadcut
Cornwell Trench
Belpre Trench
Stafford 3
Stafford 2
Stafford 4
Stafford 5
Stafford 6
Stafford 10
Edwards 3
Edwards
Edwards 2
Wilson Ridge
Crocket Cutbank
Gullison Quarry
Reno 4
Reno 3
Butler Quarry
14KW7

Figure 5:2. Aerial photograph of the loess plain north and east of Stafford in the NE sec. 5, T.24S., R.11W. Note the general lack of surface texture, indicating level topography. For scale, distance between road intersections is approximately 1.6 km.

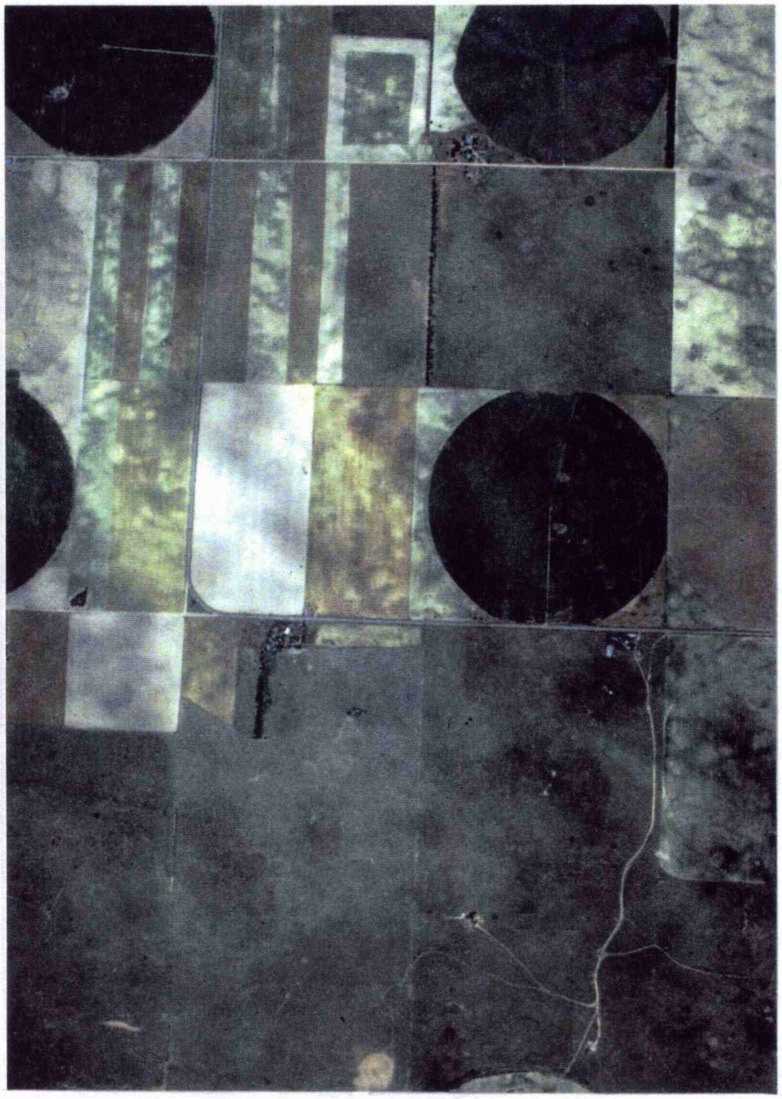


Figure 5:3. Aerial photograph of a low-relief sand sheet in secs. 13, 14, T.27S, R.20W. In comparison with Figures 5:4, 5:5, 5:6 and 5:7, note the lack of surface texture, indicating relatively level topography. Bright tones are locations where the surficial sand is thickest. For scale, circular field is approximately 0.4 km^2.

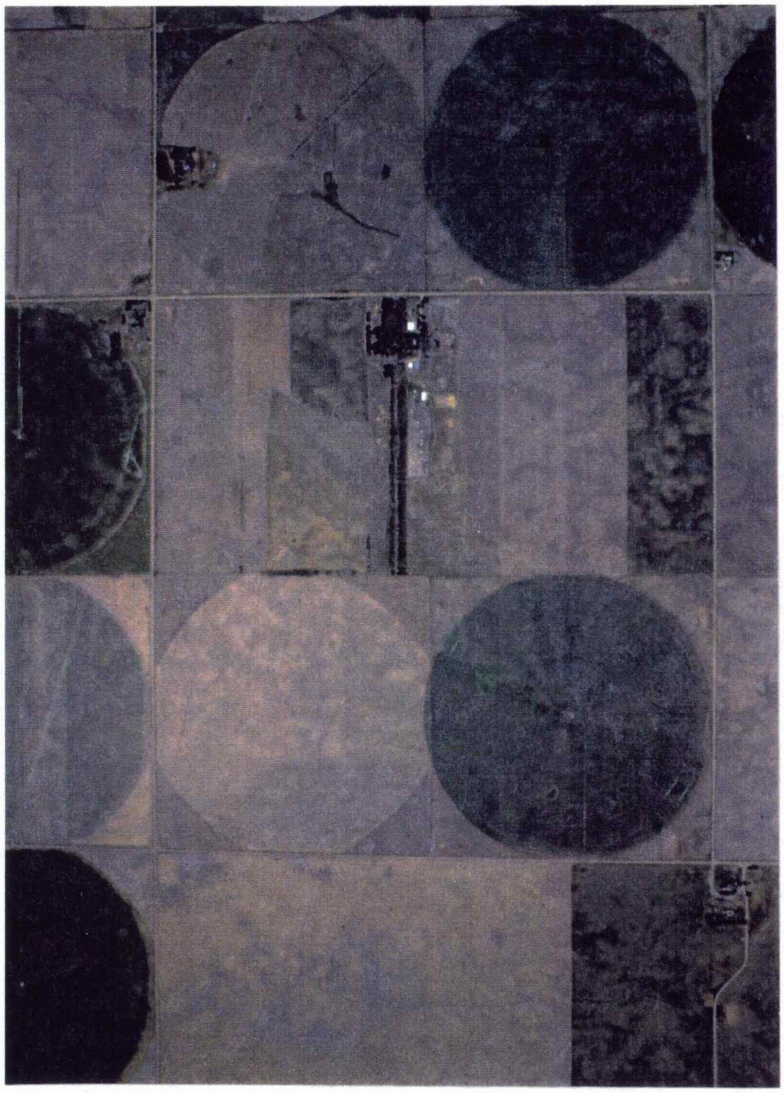


Figure 5:4. Aerial photograph of a high-relief sand sheet in sec. 24, T.24S., R17W. The high-relief sand sheet is a transitional dune category, with more surface texture than the low-relief sand sheet (Fig. 5:3), but less than better developed dune fields (Figs. 5:5, 5:6, 5:7). For scale, circular fields are approximately 0.4 km^2.

Figure 5:5. Aerial photograph of a compound sub-parabolic dune field in sec. 21, T.27, R.16. Although dunes in this field are better developed than in the high-relief sand sheet (Fig. 5:4) or the low-relief sand sheet (Fig. 5:3), they lack the clearly defined form of compound parabolic (Fig. 5:6) and parabolic (Fig. 5:7) dune fields. For scale, the circular field is approximately 0.4 km^2.

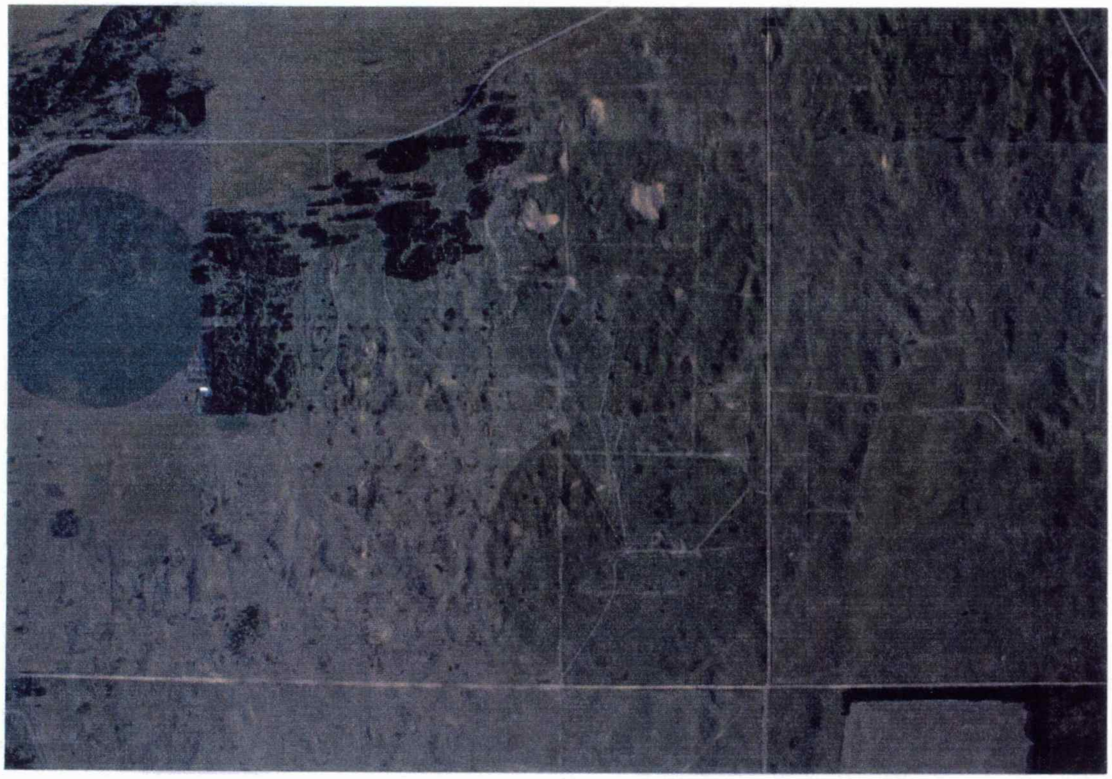


Figure 5:6. Aerial photograph of a compound parabolic dune field in sec. 19, T24, R.18W. Note the well defined, crescentic-shaped dunes in the center of the photograph. The Arkansas River is in the upper left of the photo, with the boundary between the dune field and the floodplain extending diagonally across the landscape. Dark areas near the river are trees and bright features are blowouts, where sand is locally active. For scale, circular fields are approximately 0.4 km^2.

Figure 5:7. Aerial photograph of a parabolic dune field in secs 9, 10, T.27S., R.20W. Note the well defined, crescentic-shaped dunes in the photography. Dune arms point to the southwest, indicating that prevailing winds were southwesterly. Bright spots are blowouts, where sand is locally active. Thin, bright lines are cattle trails. Distance across the photograph is approximately 3.2 km.

Detailed Stratigraphic Investigations

Eighteen sites showing the variability of late Quaternary stratigraphy on the Great Bend Sand Prairie were exposed by backhoe trenching and systematically described, sampled, and analyzed according to the methods outlined in Chapter 4. Below, presented in alphabetical order, is a discussion of the results derived from detailed stratigraphic investigations at each of the eighteen study sites. Unit designations for strata at each site are unique and do not imply any correlation among or between sites.

Belpre Trench

The Belpre Trench is a 4.11-m-deep drainage pit excavated in the NE, NW, sec. 8, T.24S., R15W (Figs. 5:1, 5:8). After the trench wall was cleaned, three pedostratigraphic units were recognized in the exposure (Figs. 5:9, 5:10, 5:11). In general, deposits are loamy, moderately to very poorly sorted,

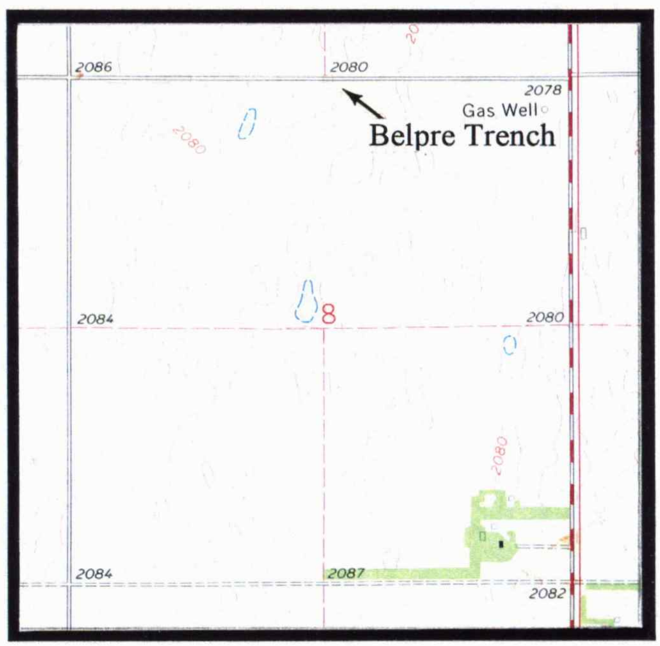


Figure 5:8. Topographic map of the area near the Belpre Trench. Scale = 1:24,000 (Belpre 7.5 min Quadrangle, 1972).

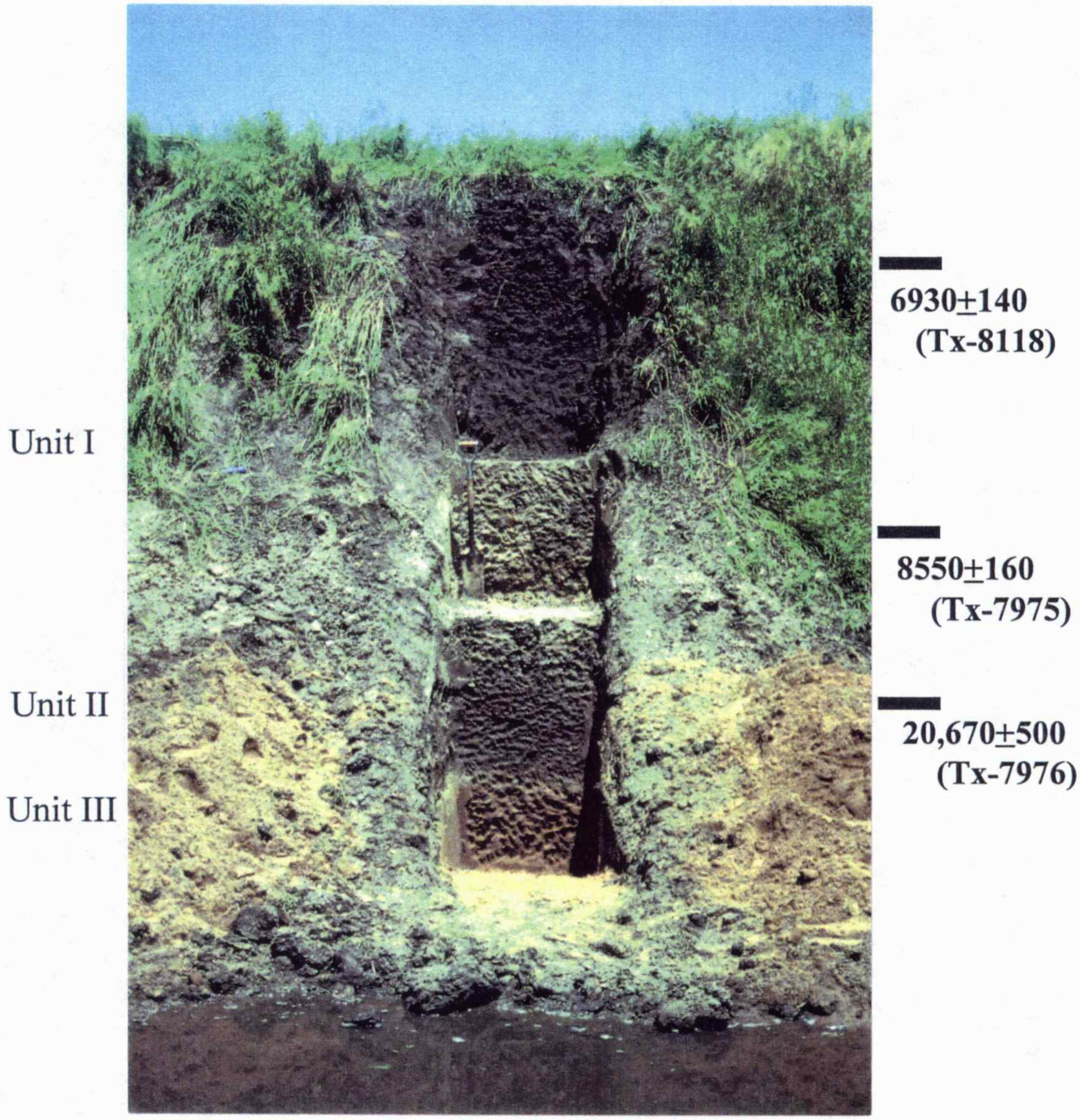


Figure 5:9. The Belpre Trench (4.11-m high) showing pedostratigrahic units and radiocarbon ages.

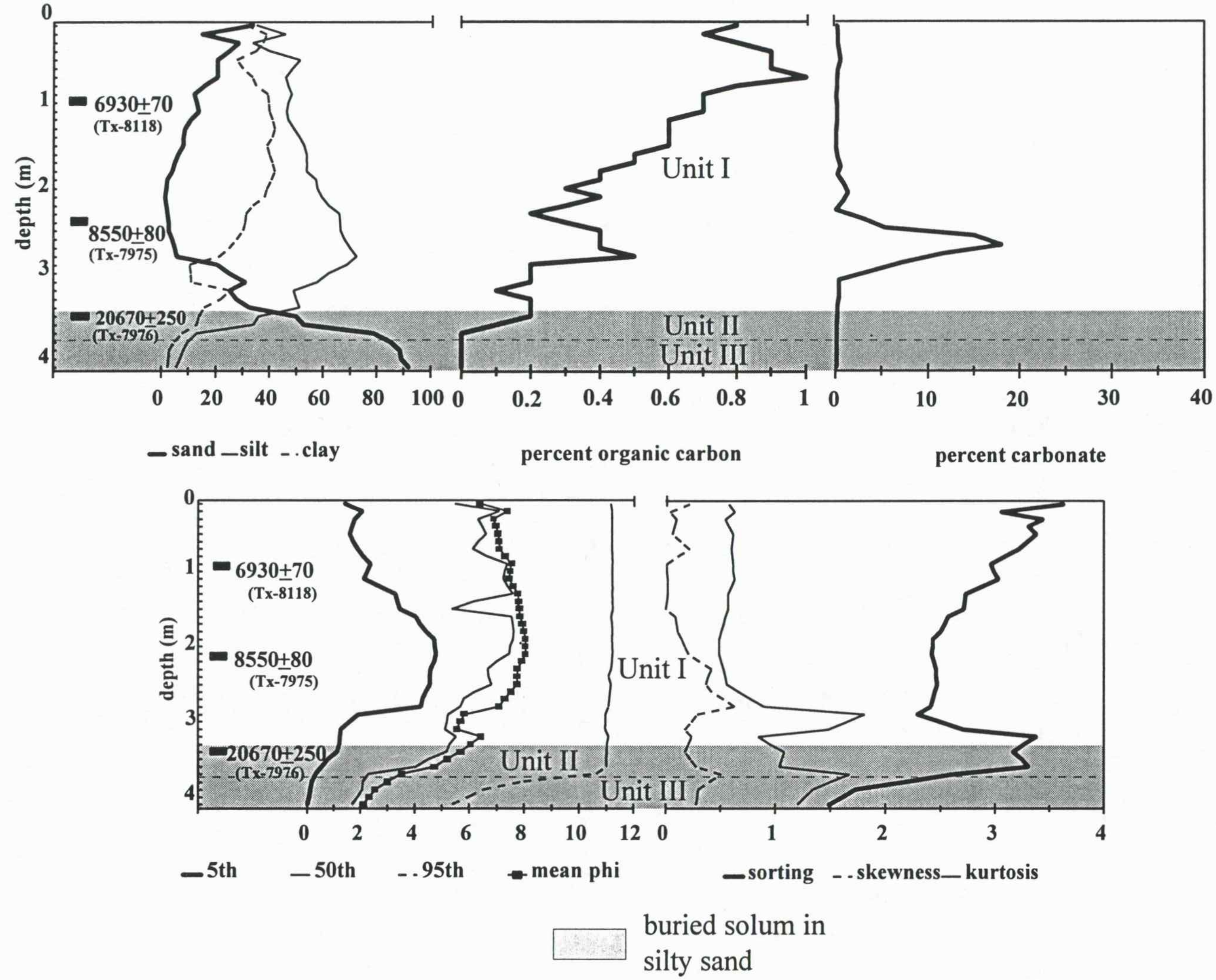


Figure 5:10. Graphical statistics and chemical composition of sediments at the Belpre Trench.

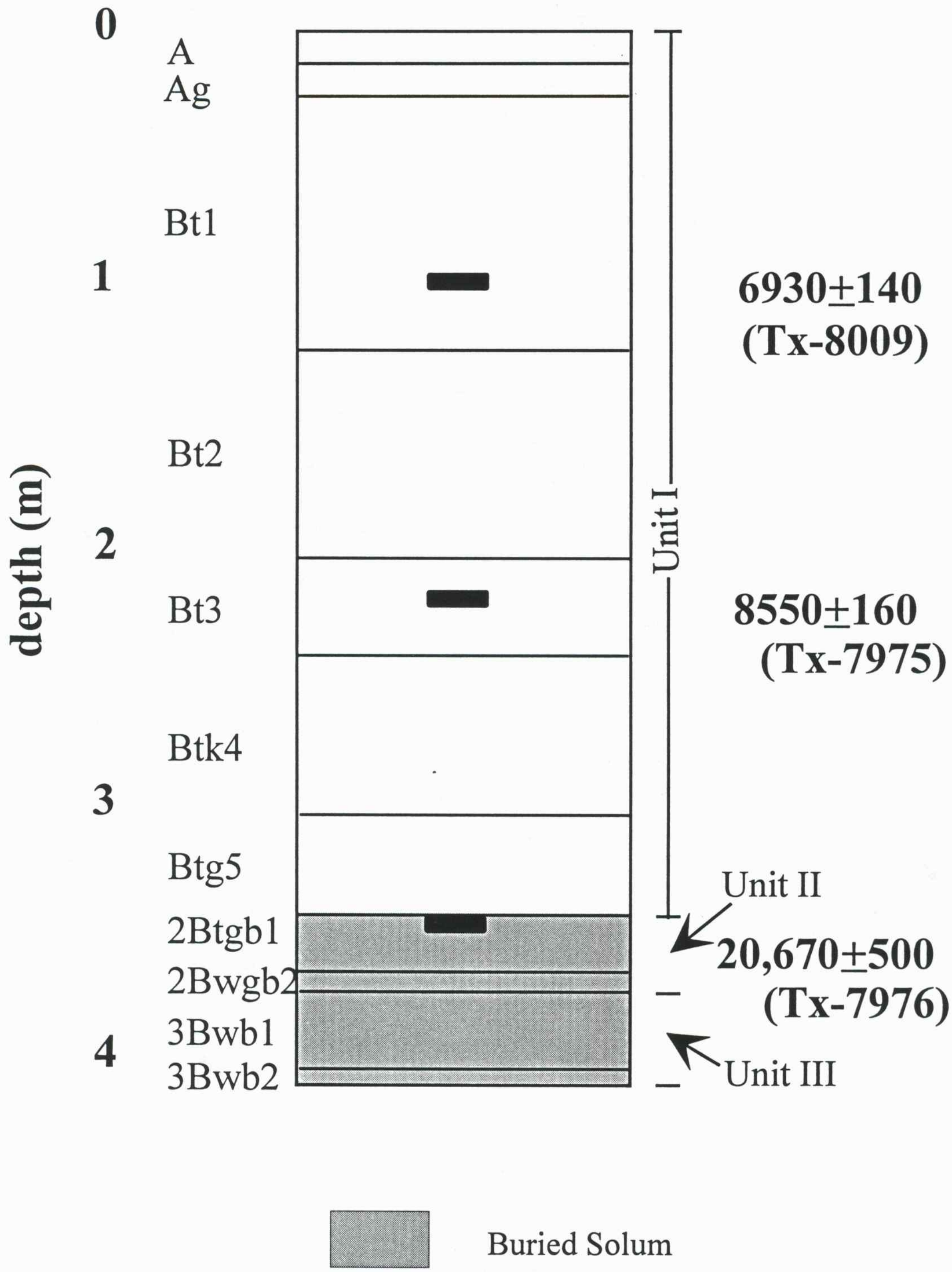


Figure 5:11. Soil stratigraphy and radiocarbon ages at the Belpre Trench.

finely to very finely skewed, and very leptokurtic to very platykurtic. Graphical statistics for sediments at the Belpre Trench are illustrated in Fig. 5:10.

Unit III is the lowermost pedostratigraphic unit, ranging from 3.74 m to the base of the profile (Figs. 5:10, 5:11). Sediments within the stratum are oxidized and very sandy, including sand and sandy loam. Mean particle size ranges from very fine sand to coarse silt. Sorting is poor because the unit includes medium sand in the 5th percentile and medium silt in the 95th. In addition, the distribution is finely skewed and leptokurtic (Fig. 5:10).

Formed within Unit III is a poorly developed soil, consisting of two 3Bwb horizons (Fig. 5:11). They are very similar in character, differing only in texture. Each is yellowish brown (10YR5/4; moist), contains less than 0.5 percent carbonate and organic carbon (Fig. 5:10), and has a weak prismatic structure that parts to weak subangular blocky. The 3Bwb2 (4.06 - 4.11m; Fig. 5:11) is sand (91.9% sand; 5.6% silt; 2.5% clay (Fig. 5:10), whereas the 3Bwb1 (3.74 - 4.06 m; Fig. 5:11) is sandy loam (68.8% sand; 28.3% silt; 2.9% clay; Fig. 5:10).

Overlying is Unit II, extending from 3.44 to 3.74 m (Figs. 5:9, 5:10, 5:11). The contact between the units is best visible in the 95th percentile and sorting parameters at 3.74 m. In general, the deposit is loamy, fining from loamy fine sand at the base to loam at the top. Accordingly, mean particle size varies from coarse to medium silt in the lower and upper parts, respectively, of the stratum. Sorting is very poor because the deposit includes medium sand in the 5th percentile and fine clay in the 95th. In addition, the distribution is finely skewed and mesokurtic to leptokurtic.

Formed within Unit II is a well developed soil, one that consists of one 2Btgb1 and 2Bwgb2 horizon, both of which are oxidized. The horizons are structurally consistent with one another, categorized as moderate prismatic parting to moderate subangular blocky, and they contain less than 0.5 percent carbonate and organic carbon (Fig. 5:10). The 2Bwgb2 horizon ranges from 3.67 to 3.74 m (Fig. 5:11), is brown (10YR5/3; moist), and loamy fine sand (79.0% sand; 13.2% silt; 7.8% clay; Fig. 5:10). Overlying is the 23-cm-thick, dark grayish brown (10YR4/2; moist) 2Btgb1 horizon (Fig. 5:11) that is sandy loam (52.9% sand; 34.1% silt; 13.0% clay; Fig. 5:10). To estimate the mean residence time of humates in the upper 5 cm (3.44 - 3.59 m) of the 2Btgb1, a sample provided a $\delta^{13}C$-corrected radiocarbon age of 20,670±500 yrs B.P. and a $\delta^{13}C$ value of -22.3 ‰ (Tx-7976).

Extending from the surface to 3.44 m is Unit I (Figs. 5:9, 5:10, 5:11). In general, sediments within the stratum contain high percentages of silt and clay, ranging from silt loam to silty clay. Accordingly, mean particle size is very fine silt. Sorting is very poor because the 5th percentile varies from very fine sand to coarse silt, whereas the 95th is consistently fine clay. In addition, the distribution is very fine to finely skewed and very leptokurtic to platykurtic (Fig. 5:10).

Formed within Unit I is an extremely well developed soil, consisting of one A and Ag horizon, three Bt horizons, and one Btk and Btg horizon. The lowermost soil horizon is the Btg5, which extends from 3.05 to 3.44 m (Fig. 5:11). Slightly oxidized and gleyed, the horizon is dark grayish brown (10YR4/2; moist) and silt loam, with percent silt increasing from 51.1 at 3.43 m to 57.9 at 3.08 m. The Btg5 is structurally moderate prismatic parting to moderate subangular blocky and contains less than 0.5 percent carbonate and organic carbon (Fig. 5:10).

Overlying is the fossiliferous and calcareous Btk4 horizon (2.43 - 2.86 m; Fig. 5:11). As is the Btg5, the Btk4 is oxidized. Color is comparably lighter, however, in the Btk4, varying from brown (10YR4/3; moist) pale brown (10YR6/3; moist). Although the horizon is silt loam with about 69 percent silt, percent clay increases from 10.4 at 2.87 m to 30.4 at 2.47 m. Percent carbonate increases sharply from 7.2 at 2.89 m to 17.6 at 2.85 m and organic carbon constitutes less than 0.5 percent (Fig. 5:10) of the horizon. Gastropods were recovered from the horizon and though the vast majority were fragmented, a few intact specimens were obtained, including *Succinea avara*, *Lymnaea parva*, *Helicodiscus singleyanus*, and an unidentified clam (Fig. 5:12).

Above is a noncalcareous and unoxidized horizon, Bt3, that extends from 2.06 to 2.43 m (Fig. 5:10). The horizon is brown (10YR5/3; moist), silt loam (ca. 2.0% sand; 63.0% silt; 35.0% clay), has a medium prismatic structure that parts to moderate subangular blocky, and contains approximately 1.0 percent carbonate and less than 0.5 percent organic carbon (Fig. 5:10). To estimate the mean residence time of humates in

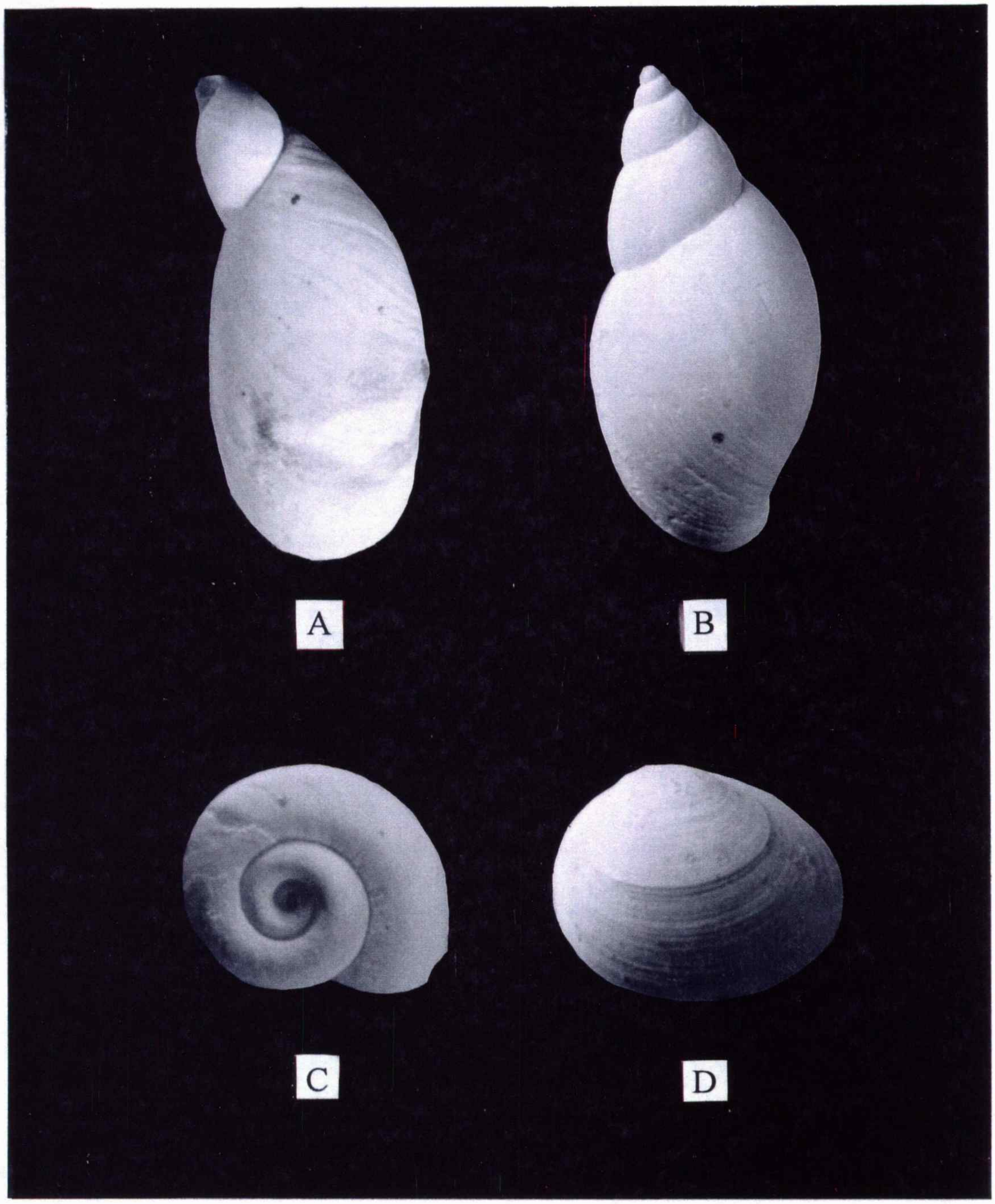


Figure 5:12. Gastropods at the Belpre Trench (magnification 10x): (A) *Succinea avara*, (B) *Lymnea parva*, (C) *Helicodiscus syngleyanus*, (D) unidentified bivalve.

the middle (2.18 - 2.23 m) of the horizon, a sample provided a $\delta^{13}C$-corrected radiocarbon age of 8550±160 yrs B.P. (Tx-7975) and a $\delta^{13}C$ value of -21‰.

Overlying is the 82-cm-thick, noncalcareous Bt2 horizon. Texture varies slightly in the horizon from silt loam (ca. 6% sand, 55% silt, 39% clay) to silt clay (4.0% sand, 54% silt, 42% clay) and structure is generally medium prismatic parting to medium subangular blocky. Percent organic carbon is approximately 1.0 percent, whereas carbonate constitutes less than 0.5 percent of the horizon (Fig. 5:10). Color gradually darkens from dark grayish brown (10YR4/2; moist) at 1.90 m to very dark brown (10YR2/2; moist) at 1.31 cm.

The Bt1 horizon extends from 39 cm to 1.24 m and is silty clay loam (ca. 15% sand, 48% silt, 37% clay) with a coarse prismatic structure that parts to coarse blocky. The horizon contains approximately 1.0 percent organic carbon and less than 0.5 percent carbonate. Due to the high concentrations of organic carbon and clay, color is consistently dark, with it being black (10YR2/1; moist) at 50 cm. To estimate the mean residence time of humates in the the Bt1, a sample collected from 95 cm to 1.0 m provided an $\delta^{13}C$-corrected radiocarbon age of 6160±160 yrs B.P. and a $\delta^{13}C$ value of -20.2‰ (Tx-8118).

The upper two soil horizons in Unit I consist of a 13-cm-thick Ag overlain by a 11-cm-thick A horizon (Fig. 5:11). At first glance they are very similar in character, since each is very dark grayish brown (10YR3/2; moist) and silty clay loam. The Ag, however, contains approximately 10 percent more silt, 9 percent more clay, and 18 percent less sand than the A horizon. Accordingly, structure is better developed in the Ag, consisting of weak subangular blocky that parts to medium platy. In contrast, the A has a weak subangular blocky structure that parts to granular. Both the A and Ag contain less than 0.5 percent carbonate and about 1.0 percent organic carbon (Fig. 5:10).

In summary, the Belpre Trench is an approximately 4-m-deep drainage trench excavated on a level sand sheet just north and west of Belpre in the west-central part of the Great Bend Sand Prairie. Three pedostratigraphic units were recognized in the exposure, with each representing a period of deposition followed by landscape stability and soil formation. Three radiocarbon ages were obtained from the site, indicating a geomorphic history that spans the past 20,000 years.

Unit III is the lowermost unit at the site, ranging from 3.74 m to at least the base of the profile. In general, the deposit consists of relatively well sorted, oxidized, and unconsolidated sand. Since sedimentary structures are not preserved in the stratum, determining a depositional facies is problematic, i.e., the unit could have accumulated in either a fluvial or eolian environment. A brief period of pedogenesis subsequently occurred, resulting in the formation of a moderately developed soil with two 3Bwb horizons.

Overlying is Unit II, which extends from 3.44 to 3.48 m. In contrast to Unit III, Unit II consists of much siltier sediments. Although sedimentary structures were not preserved, the deposit is very poorly sorted, suggesting a fluvial facies in a presumably more moist environment than at present. Following deposition, a period of pedogenesis occurred, one that promoted the formation of a well developed soil with three 2Btgb horizons. The upper part of the solum dated to approximately 20,000 yrs B.P., suggesting a Farmdalian, or perhaps Woodfordian age for both Units III and II. A $\delta^{13}C$ value of -22.3‰ implies that a mixture of plants with C_3 and C_4 pathway dominated at the site during that time. The soil is mottled, with pockets of gleying and iron oxidation present, which suggests ponding during some unkown interval of time or, alternatively, a periodically high water table.

The dominant pedostratigraphic unit at the Belpre Trench is Unit I, extending from the surface to 3.44 m. Although the deposit is largely composed of silt (e.g., 72.6 %), high percentages of clay are also present, especially in the upper part (e.g., 41.9 % at 1.30 m) of the stratum. Sedimentary structures are not preserved in the unit, so determining a depositional facies with certainty is questionable. In fact, conflicting evidence exists regarding both the method in which the unit accumulated and its age.

In general, color of the lower part (i.e., 2.06 - 3.44 m) of Unit I is consistent (e.g., pale brown; 10YR6/3; moist) with late Wisconsinan Peoria loess (Wells and Stewart, 1987; Johnson, 1993; Johnson et al., 1993), which has been recognized immediately to the north and south of the Great Bend Sand Prairie (Feng, 1991; Feng et al., 1994). Moreover, abundant late Wisconsinan gastropods, including *Succinea* *avara*, *Lymnaea parva*, and *Helicodiscus singleyanus* were recovered from the base of the deposit. On first examination, therefore, a Woodfordian age is suggested for deposition of Unit I. Approximately 20 cm above the snail zone, however, a radiocarbon age of approximately 8500 yrs B.P. was obtained, implying a very early Holocene age for the deposit. Apparently, the sample that was dated must have been contaminated in some way, possibly by Holocene organic carbon illuviated during the extensive soil development which has occurred. Given the age (ca. 20,000 yrs B.P.) derived from the top of Unit II, the presence of gastropods, and the similarity with Peoria loess, a Woodfordian age for the lower part of Unit I is more logical. In addition, an age of about 17,000 yrs B.P. was obtained by Johnson (1991) from spruce (*Picea* cf. *glauca*) charcoal in a similar stratigraphic position at GWMD#5 site 9, approximately 0.5 km to the northwest, further suggesting a Woodfordian age for Unit I. A $\delta^{13}C$ value of -21.0‰ derived from the deposit, coupled with the oxidized nature and presence of aquatic gastropods in the lower part of the unit, indicates relatively moist conditions during sedimentation.

Following deposition of Unit I, an extremely well developed soil formed throughout the entire deposit. Structure is very strong in the solum, especially in the upper 1.50 m where it is coarse prismatic parting to moderate blocky. Overall, the character of the soil suggests pedogenesis over an extended interval of time, perhaps throughout the late Holocene. In fact, the upper part of the Bt1 horizon, approximately

1.0 m below the surface, dated to approximately 6000 yrs B.P. A $\delta^{13}C$ value of -20.2‰ suggests plants with a C_3 pathway were present at that time. Apparently, water has ponded periodically at the site as the soil developed, resulting in gleying of the lower part of the A horizon.

Crocket Cutbank

The Crocket Cutbank is an 8-m-high cutbank exposure located in a compound subparabolic dune field along the outside of a meander loop of Rattlesnake Creek in the SE, SE, sec. 35, T. 26S., R. 17W (Figs. 5:1, 5:13). Through backhoe trenching, the overall height of the exposure was increased to 9.8 m. Four pedostratigraphic units were described in the profile, with two weakly developed, and narrowly separated, buried soils featured in the exposure (Figs. 5:14, 5:15, 5:16). Sediments at the site are generally sandy, have a mean particle size of fine to very fine sand, are poorly to

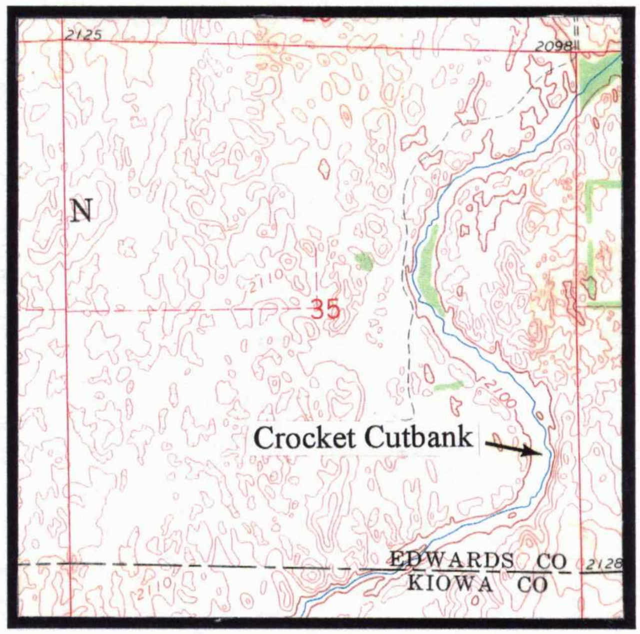


Figure 5:13. Topographic map of the area near the Crocket Cutbank. Scale = 1:24,000 (Haviland NW 7.5 min Quadrangle, 1968).

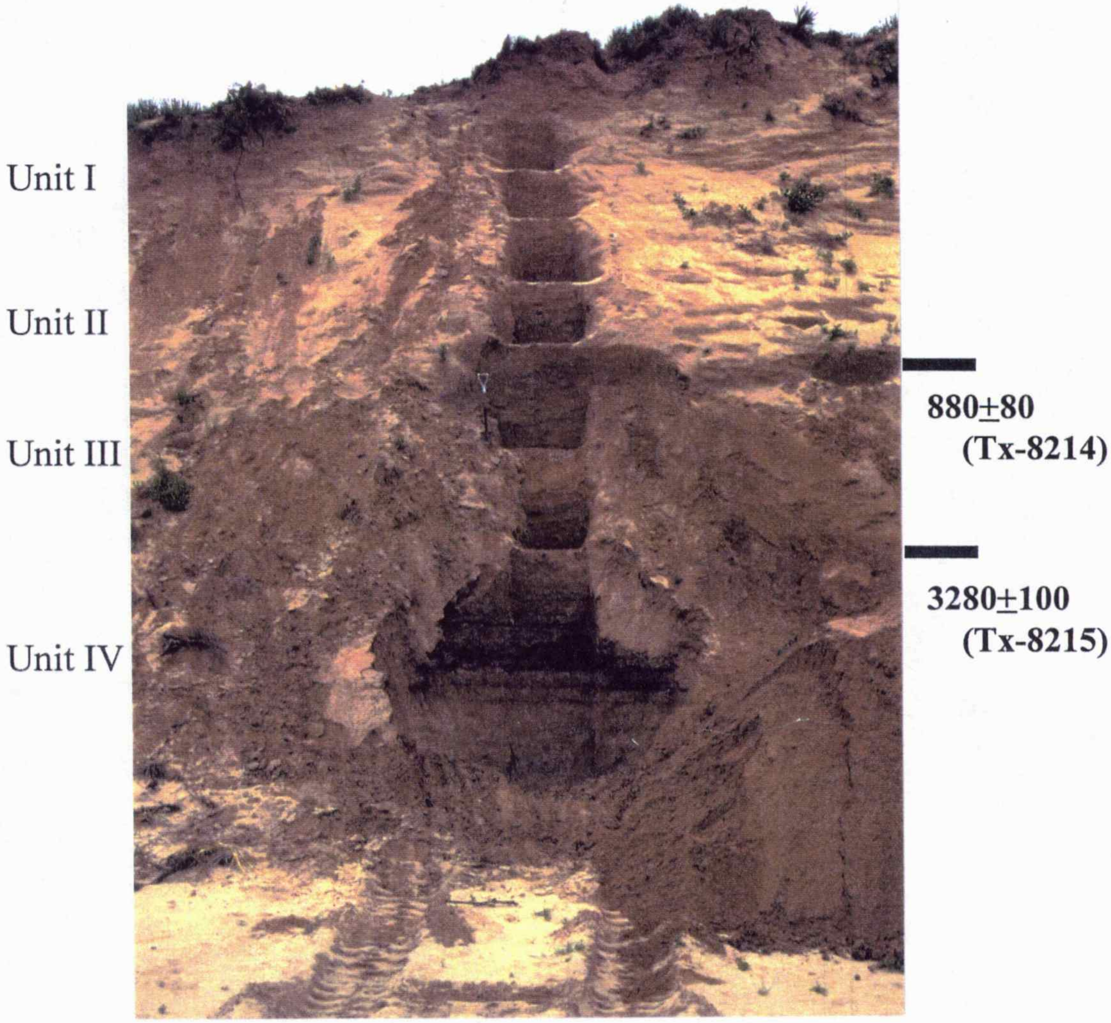


Figure 5:14. The Crocket Cutbank (9.80 m) showing pedostratigraphic units and radiocarbon ages.

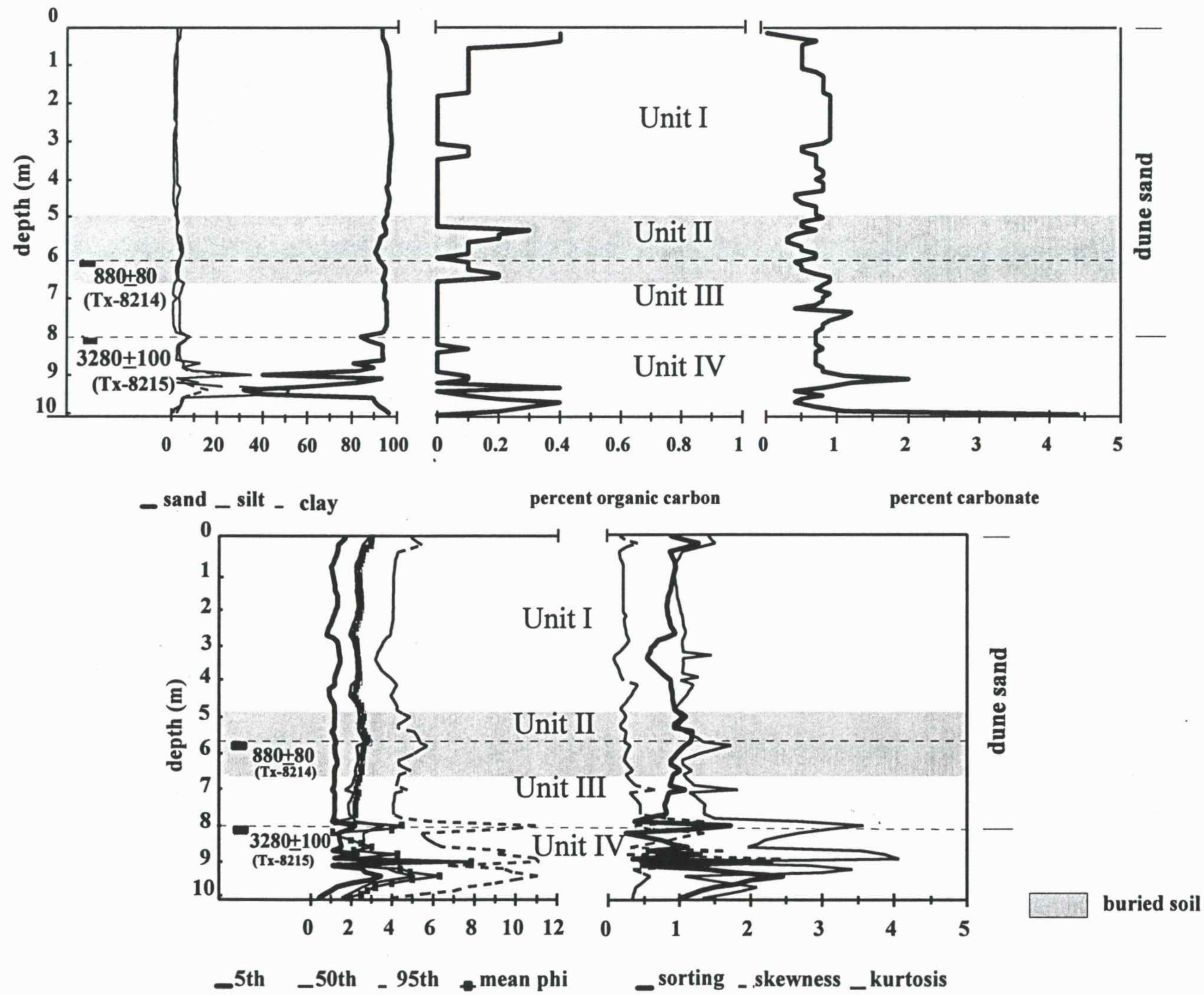


Figure 5:15. Graphical statistics and chemical composition of sediments at the Crocket Cutbank.

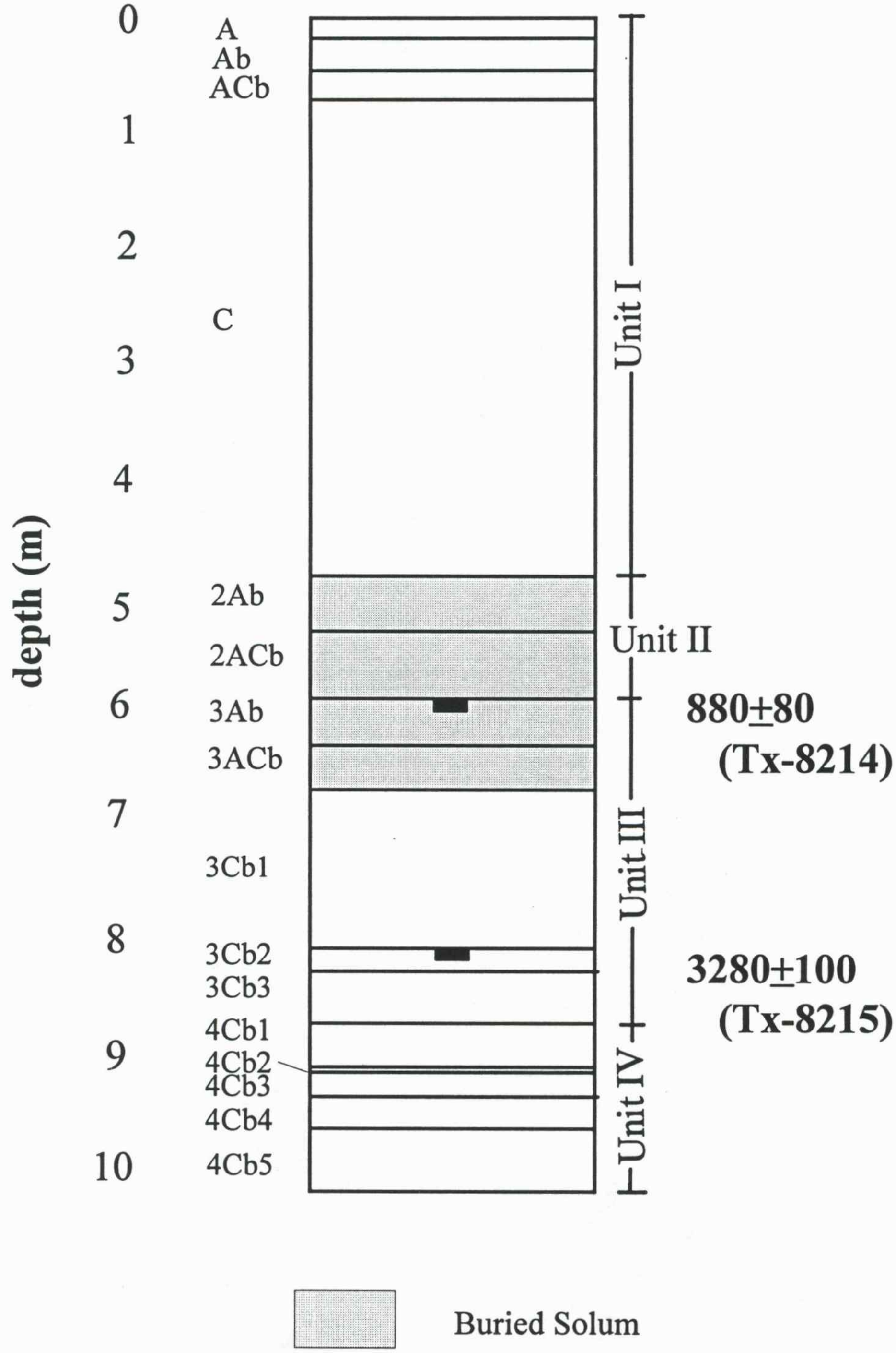


Figure 5:16. Soil stratigraphy and radiocarbon ages at the Crocket Cutbank.

moderately sorted, are finely to very finely skewed, and mesokurtic to extremely leptokurtic. Graphical statistics and the chemical composition of sediments at the Crocket Cutbank are displayed in Figure 5:15.

The lowermost stratigraphic unit (Unit IV) at the Crocket Cutbank consists of an alluvial deposit that extends from the base of the profile to a depth of 8.76 m. Unit IV is stratified, as reflected by the textural distribution, graphical statistics (Fig. 5:15), and subdivision into five 4Cb horizons (Fig. 5:16). Color generally ranges from dark yellow brown (10YR4/4; moist) to brown (10YR4/3; moist). The deposit consists largely of very fine sand with two distinct fining-upward sequences present (Fig. 5:15), that culminate in deposits of darker-colored fine sediment, probably a result of slackwater deposition at about 9.50 m (4Cb4 horizon) and 9.10 m (4Cb2 horizon). The 4Cb4 horizon, which is dark grey brown (10YR4/2; moist) and silt loam (medium to fine silt; Fig. 5:15) extends from 9.34 to 9.62 m (Fig. 5:16). In contrast, the 4Cb2 horizon is very dark grey brown (10YR3/2; moist), silty clay loam (very fine silt), and extends only from 9.10 to 9.13 m (Fig. 5:16). Sorting in Unit IV varies considerably, ranging from poor in the 4Cb4 and 4Cb2 horizons to well sorted in the intervening strata (e.g., 4Cb3 horizon). The sediment in the deposit is very finely skewed. Kurtosis ranges from extremely leptokurtic in the coarsely-textured horizons (e.g., 4Cb1) to mesokurtic in finely-textured strata (e.g., 4Cb4 horizon). Two distinct peaks are observed in both carbonate and organic carbon content. Percent carbonate is highest

(4.4 %) at 9.80 m in the 4Cb5 horizon and, following a drop to less than 0.5 percent at 9.4 m, carbonate content increases to 2.0 percent at 8.9 m. Percent organic carbon ranges from 0 in the coarsest sediments (e.g., 4Cb1) to about 0.4 percent (Fig. 5:15) in the finely-textured horizons (4Cb4, 4Cb2), undoubtedly contributing to their darker color.

Unit III is a 3.85-m-thick stratigraphic unit overlying Unit IV (Figs. 5:14; 5:15; 5:16) that is composed primarily of eolian sand. The unit contains several soil horizons, including one 45-cm-thick 3Ab horizon, a 32-cm-thick 3ACb horizon, and three 3Cb horizons (Fig. 5:16). Color ranges from light (e.g., 10YR5/4; moist) to darker (e.g., 10YR4/3) in the lower and upper parts of the unit, respectively. Sediments are generally classified as sand, with a mean particle size of very fine sand. The lower part of the deposit, from 8.76 to 8.06 m, appears to be a transitional zone, including both alluvial and eolian facies. Sedimentological parameters in the lower part of Unit III are not as variable as in Unit IV, but are much more so than in any of the overlying deposits. Sorting, for example, ranges from poor at 8.70 and 8.10 m to moderate through the remainder of the lower part of the unit (Fig. 5:15). Of particular interest is the 3Cb2 horizon, which extends from 8.06 to 8.23 m (Fig. 5:16): it is sand, but contains higher amounts of silt (8.3%) and clay (7.7 %) than any deposits within the uppermost 8.20 m at the site. Accordingly, the color of the horizon is relatively dark (10YR4/3; moist). Percent carbonate is consistently less than 1.0 throughout the lower part of Unit II (Fig.

5:15). In addition, the 3Cb2 was found to contain enough organic carbon (ca. 0.2%) for radiocarbon dating. As a result, a bulk sample provided a $\delta^{13}C$-corrected radiocarbon age of 3280±100 yrs B.P. and a $\delta^{13}C$ value of -17.7‰ (Tx-8215).

The upper part of Unit III, extending from 5.88 to 8.06 m (Figs. 5:14; 5:15; 5:16), appears to be completely of eolian origin, being classified as sand with as much as 95 percent sand (very fine sand) present. Statistically, the deposits throughout the upper part of the unit are very finely skewed and leptokurtic to mesokurtic (Fig. 5:15).

Featured in the upper part of Unit III is a weakly developed buried soil, consisting of a brown (10YR4/3; moist), 45-cm-thick 3Ab horizon overlying one dark-yellowish-brown (10YR4/4; moist), 32-cm-thick 3ACb horizon and three 3Cb horizons of variable thickness (Fig. 5:16). Each horizon contains less than 1.0 percent carbonate and organic carbon. A slight change in sedimentology exists from the 3Cb horizons to the 3ACb and 3Ab horizons (Fig. 5:15), reflecting a period of landscape stability at the site. Mean particle size fines slightly, for example, from the underlying horizons into the 3ACb and 3Ab. In addition, the degree of sorting displays a subtle shift from moderately sorted in the lower 3Cb horizons to slightly poorly sorted in the 3Ab horizon (Fig. 5:15) Both the increase in silt and clay, and the accompanying decrease in sorting, possibly reflect the influx of fines during stability, with the highest percentages (5.0 and 4.2, resp.) at the top of the soil (5.90 m). To estimate a minimum-limiting age for the host sand in the upper 3Ab, a bulk sample collected from the upper 5 cm (5.88 - 5.93) yielded a $\delta^{13}C$-corrected radiocarbon age of 880±80 yrs B.P. and a $\delta^{13}C$ value of -16.6‰ (Tx-8214).

Overlying Unit III is a thin, poorly defined, unit (Unit II) of eolian sand (Figs. 5:14, 5:15, 5:16). Unit II reflects a brief interval of increased deposition and subsequent soil formation sometime after the period of landscape stability observed at the top of Unit IV. A weakly developed buried soil (10YR4/3; moist) is expresssed throughout the unit, including a 42-cm-thick 2Ab and a 55-cm-thick 2ACb horizon (Fig. 5:16) that contain less than 1.0 percent carbonate and organic carbon (Fig. 5:15). Sediments are texturally sand, with 96 percent sand at the top of the soil (4.91m). Mean particle size is very fine sand and is finely skewed, with a leptokurtic to mesokurtic distribution. Sorting ranges from poor in the 2ACb to moderate in the 2Ab.

Overlying Unit II is a thick deposit of eolian sand (Unit I) that extends from the surface to the top of the 2Ab at 4.91 m (Figs. 5:14; 5:15; 5:16). The unit is remarkably consistent from a sedimentological perspective. Texturally, the sediment is sand (fine to very fine sand), with 97.7 percent sand at 3.0 m. Sorting is moderate throughout the unit, except for a zone of moderately well sorted sediment between 3.0 and 3.5 m and one poorly sorted at 30 cm. The deposit is generally fine- to very finely skewed and mesokurtic to leptokurtic (Fig. 5:15).

Formed in the upper part of the unit is a weakly developed surface soil, consisting of a 30-cm-thick A horizon overlying a 31-cm-thick AC horizon and one C horizon (Fig. 5:16). Each horizon generally contains less than 1.0 percent carbonate and organic carbon (Fig. 5:15) and is yellowish brown (10YR5/4; moist) to dark brown (10YR3/3; moist).

In summary, the Crocket Cutbank is an 8-m-high cutbank exposure (trenched to 9.8 m), located in a compound subparabolic dune field, on the outside of a meander loop along Rattlesnake Creek in the southwestern part of the Great Bend Sand Prairie. Four stratigraphic units were recognized in the exposure, with each consisting dominantly of fine to very fine sand. Unit IV, which extends from 8.76 m to the base of the profile, is a stratified alluvial deposit probably associated with Rattlesnake Creek. Although no radicarbon ages were obtained from the unit, the lack of cementation and floodplain position relative to Rattlesnake Creek suggest a late Holocene age.

Directly overlying is Unit III, extending from 5.88 to 8.76 m. The lower part of Unit III appears to be transitional, one that reflects a shift from alluvial to eolian sedimentation at the site. To estimate the age of this period, a radiocarbon age of approximately 3300 yrs B.P. was obtained from a silty deposit that extends from 8.06 to 8.23 m. A $\delta^{13}C$ value of -17.7‰ suggests that the site was largely populated by plants with a C_4 pathway. Given its close proximity, Rattlesnake Creek is believed to be the primary source for both floodplain and eolian facies in the unit.

The upper part of Unit III is entirely eolian, as indicated by its consistent sandy texture and moderate sorting. Formed in the upper part of the unit is a weakly developed buried soil, one that consists of a 3Ab horizon overlying a 3ACb horizon. The degree of development in this soil indicates that landscape stability and accompanying soil formation was relatively brief. A radiocarbon age of approximately 900 yrs B.P. on humates from the upper 5 cm of the soil provides a late-Holocene age for the host eolian sand. A $\delta^{13}C$ value of -16.6‰ suggests that plants with a C_4 pathway dominated at the site.

Overlying is Unit II, which consists of a nearly 1-m-thick deposit of eolian sand that contains a weakly developed buried soil with a 2Ab horizon and a 2ACb horizon. Virtually identical to the buried soil at the top of Unit III, the soil in Unit II reflects another, brief period of landscape stability that occurred sometime after approximately 900 yrs B.P. Despite their close proximity, it is unclear what the exact temporal relationship is between the two soils. Theoretically, deposition of Unit II, and subsequent soil formation, could have occurred shortly after the period of stability reflected by the 3Ab. Given this scenario, sedimentation of Unit II suggests a very brief depositional episode, one that exceeded pedogenic thresholds in the 3Ab. Conversely, deposition of Unit II and development of the 2Ab could have transpired after truncation of an older deposit that had previously buried the 3Ab. Although no radiocarbon age was obtained from the 2Ab to estimate the age of the host sand, the lack of any visible unconformities between Unit III and II suggests that Unit II sedimentation, followed by formation of the 2Ab, occurred soon after the 3Ab developed.

The uppermost stratigraphic unit at the Crocket Cutbank, Unit I, consists of a 4.91-m-thick strata of eolian sand that extends from the surface to the top of Unit II. Sedimentological data indicate that the unit is remarkably consistent in character, including deposits that are moderately sorted and as much as 97 percent sand. This evidence, coupled with the lack of any visibile unconformities, suggests that eolian sedimentation at the site has been relatively consistent in the past few hundred years. Given, the availability of fluvial sediments, Rattlesnake Creek may have been the primary source for eolian sands at the site. Recently, a poorly developed surface soil has formed, one that is consistent in its development with the buried soils recognized near the center of the exposure. A weakly developed surface soil, consisting of A/AC/C horizonation indicates that the dune had been stable for a brief period of time, perhaps less than 500 years.

Cullison Quarry

The Cullison Quarry is a 4.13-m-high quarry exposure (backhoe trenched to 5.95 m) located in a high relief sand sheet in the NE, SW, sec. 34. T.27S., R15 (Figs. 5:1, 5:17). Four pedostratigraphic units were recognized in the resultant profile, with the lower pair consisting of silty sand, and the upper two, loose sand. In general, units are loamy to sandy, very poorly to moderately sorted, very finely to finely skewed, and platykurtic to very leptokurtic. The lowermost unit is Unit IV, ranging from 5.03 to 5.95 m (Figs. 5:18, 5:19, 5:20). Sediments within the deposit are loamy and have a mean particle size of fine silt. Sorting is very poor throughout the unit because the 95th percentile is fine clay, whereas the 5th percentile is very fine sand. In addition, the distribution is finely skewed and platykurtic (Fig. 5:19).

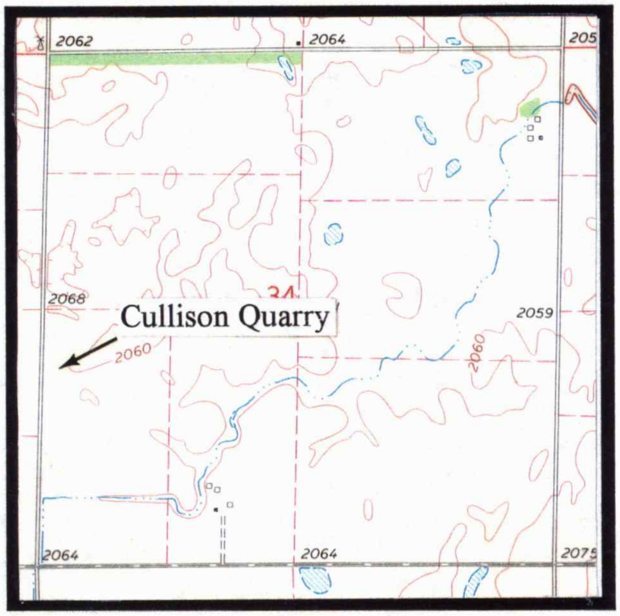


Figure 5:17. Topographic map in the vicinity of the Cullison Quarry. Scale=1:24,000 (Cullison 7.5 min. Quadrangle, 1968).

Formed within Unit IV is a well developed l, consisting of two 4Btgssb horizons. Similar in character, each is heavily gleyed, loamy in texture, has strong prismatic structure that parts to strong blocky, and well developed slickensides. Color varies slightly, with the 4Btkgss2 (5.77 - 5.95 m) dark grayish brown (10YR4/2; moist) and the 4Btgssb1 (5.03 - 5.65; Fig. 5:20) dark gray (10YR4/1; moist). The 4Btgssb2 horizon is clearly visible at 5.87 m in the carbonate curve (5.2%), which may have

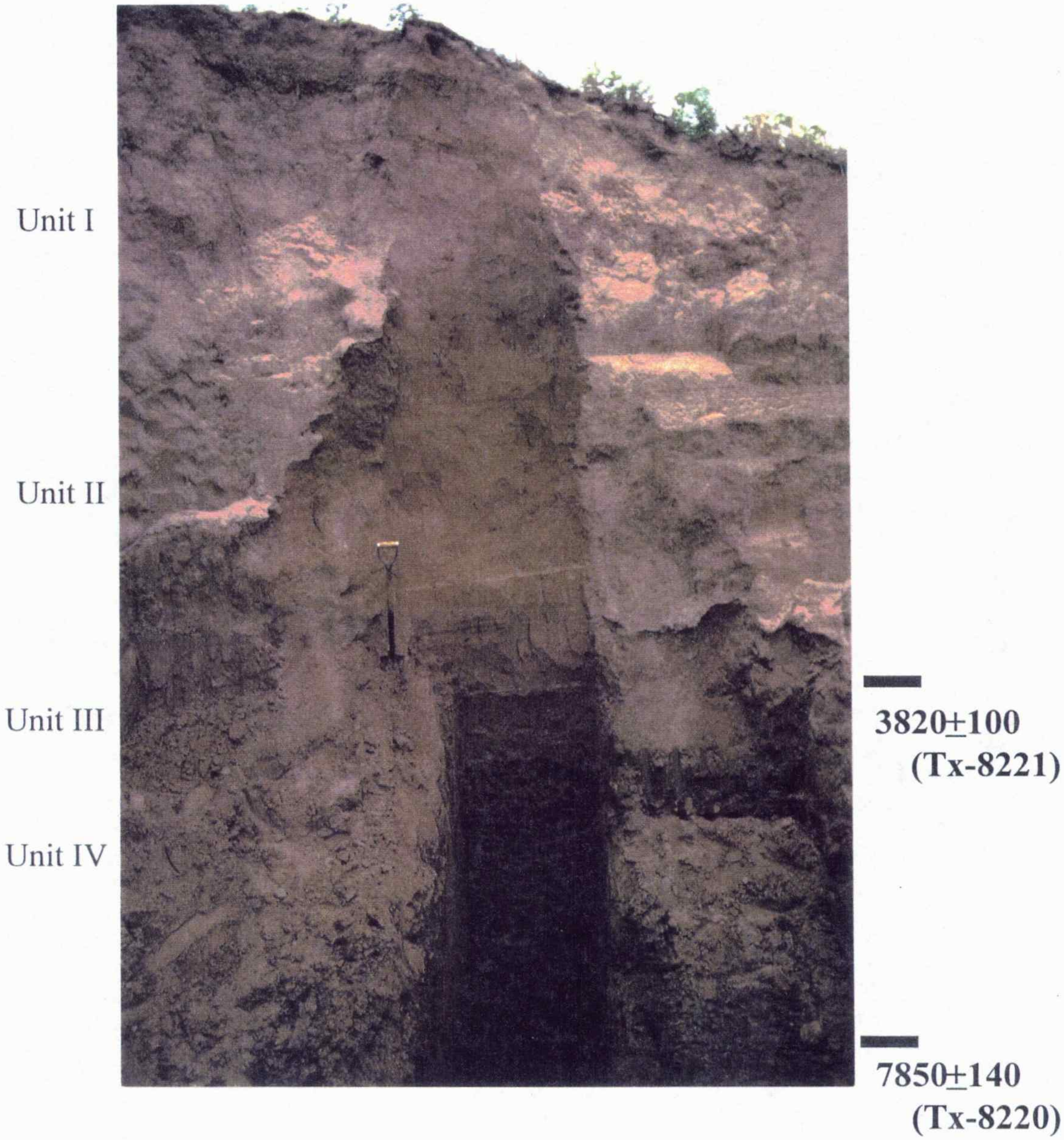


Figure 5:18 The Cullison Trench showing pedostratigraphic units and radiocarbon ages.

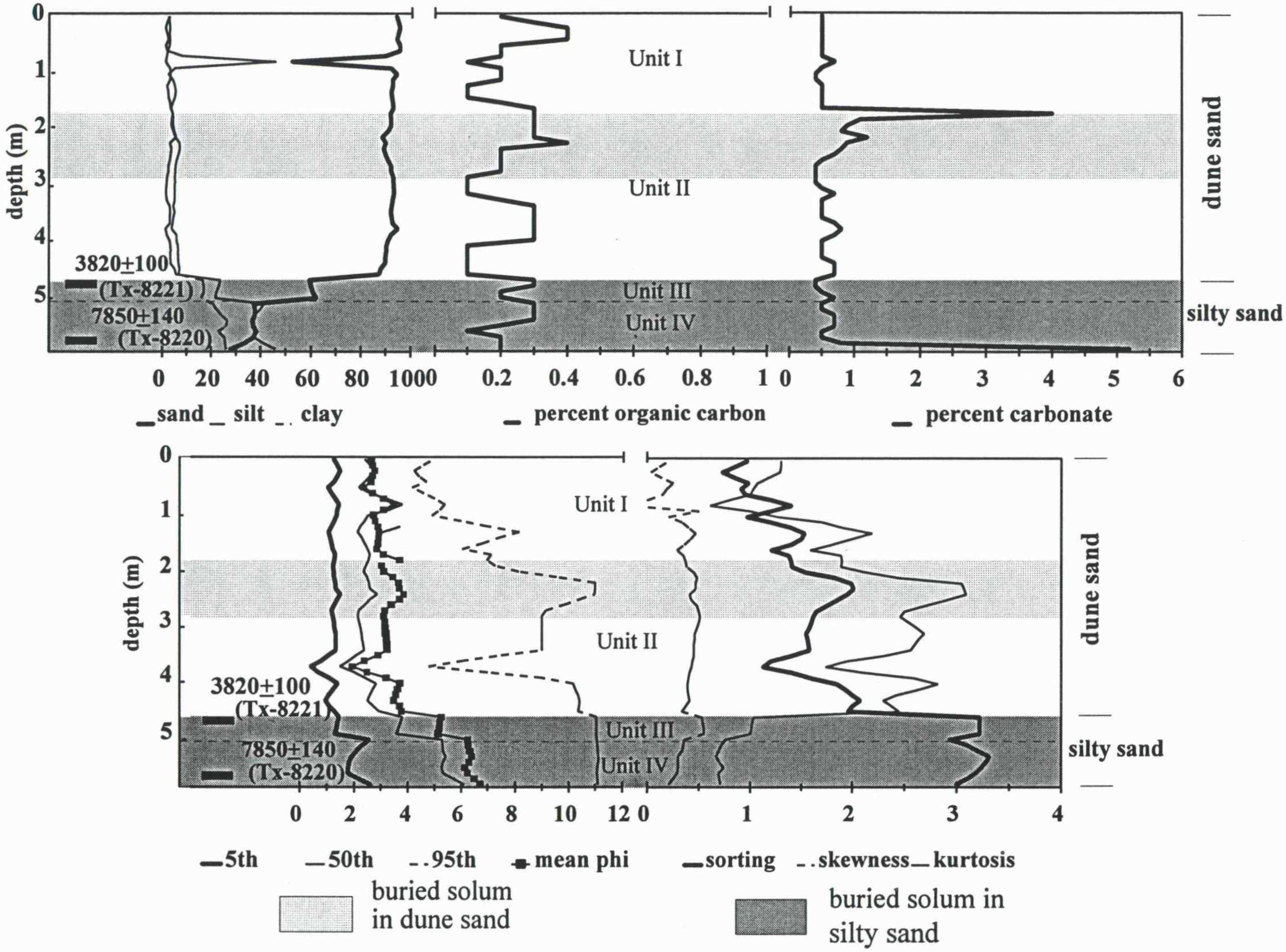


Figure 5:19. Graphical statistics and chemical composition of sediments at the Cullison Quarry.

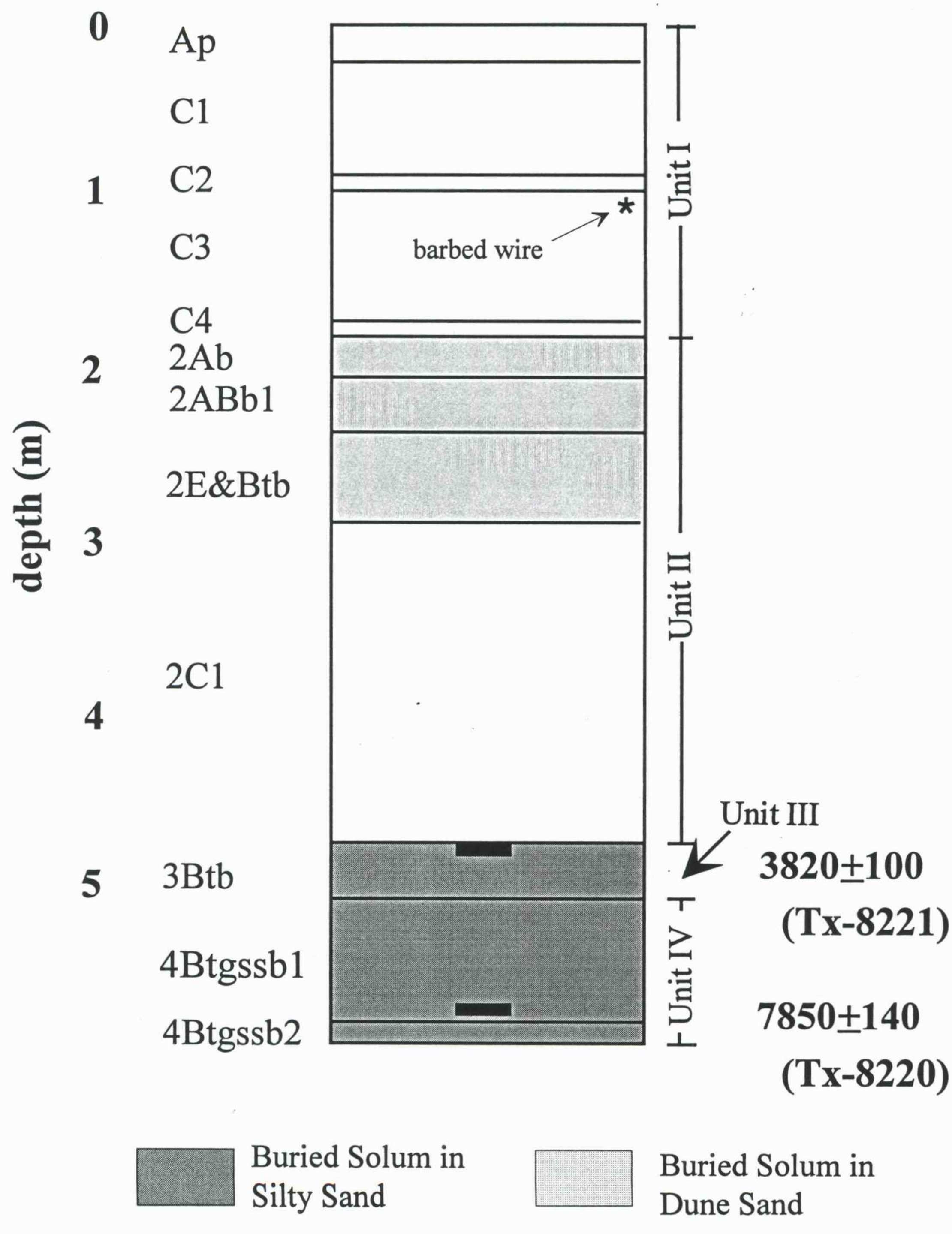


Figure 5:20. Soil stratigraphy and radiocarbon ages at the Cullison Quarry.

accumulated because of a fine texture (i.e., 28.1% sand, 46.0% silt, 25.9% clay). Texture coarsens slightly to about 37 percent sand, 38 percent silt, and 25 percent clay in the 4Btgssb1 and the horizon contains less than 1.0 percent carbonate and less than 0.5 percent organic carbon (Fig. 5:19). To estimate the mean residence time of humates from 5.65 to 5.70 m in the 4Btgssb1, a sample provided a $\delta^{13}C$-corrected radiocarbon age of 7850±140 yrs B.P. and a $\delta^{13}C$ value of -20.0‰ (Tx-8220).

Overlying, clearly visible in Figure 5:19 as the sharp increase in mean particlesize at 5.03 m, is Unit III. Ranging from 4.70 to 5.03 m (Figs. 5:18; 5:19; 5:20), Unit III contains sandier sediments that are very poorly sorted with a finely skewed and mesokurtic distribution (Fig. 5:18). Unit III consists of a 3Btb soil horizon (Fig. 5:20), one that is brown (10YR4/3; moist), sandy loam (ca. 60% sand; 22 % silt; 18% clay), has a moderate prismatic structure parting to moderate subangular blocky and contains less than 1.0 percent carbonate and organic carbon (Fig. 5:19). To estimate the mean residence time of humates in the upper 5 cm (4.70 - 4.85 m) of the 3Bt, a sample provided a $\delta^{13}C$-corrected radiocarbon age of 3820±100 yrs B.P. and a $\delta^{13}C$ value of -14.8‰ (Tx-8221).

A thin section of the 3Btb horizon is illustrated in Fig. 5:21. The matrix consists of a skeleton fabric and a fine-textured plasma and mineralogy is dominated by quartz, with occasional feldspars and rock fragments. Striations are apparent in the birefringent material that separates sand grains, indicating illuviation of clay. In addition, illuvial

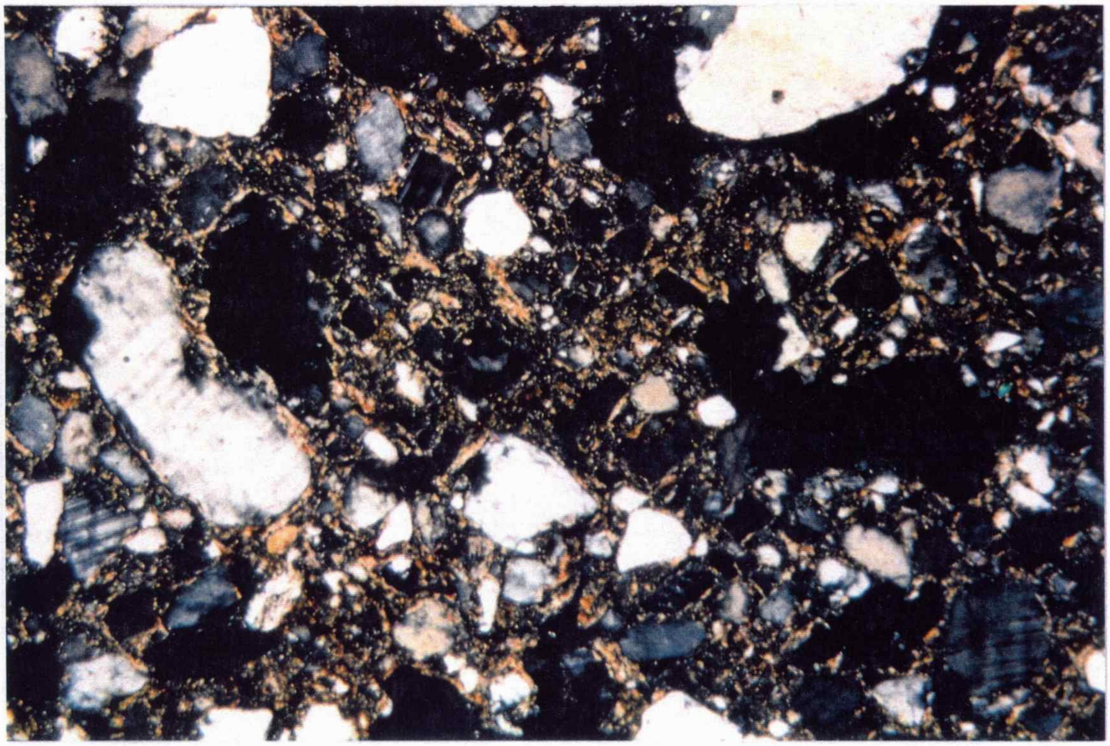


Figure 5:21. Thin section (FOV = 1.85 x 2.69 mm) collected from the upper part (4.75 m) of the 3Btb horizon.

clay lines the internal wall of voids in many places, providing further evidence of clay translocation. Many of the clays are twisted, suggesting their expansion and contraction through time (Fig. 5:21).

An abrupt stratigraphic contact at 4.70m, identifying the lower boundary of Unit II is clearly visible as a sharp increase in sand and as an improvement in sorting. Unit II (1.80 - 4.70m) consists of very sandy sediments with a mean particle size of coarse silt, but as coarse as fine sand. Sorting is generally poor because the 95th percentile ranges from medium to coarse clay, whereas the 5th percentile is fine sand. At 3.80 m, sorting is moderate, because the range of particle sizes includes medium silt and sand, and the distribution is finely skewed and very leptokurtic (Fig. 5:19).

Formed in the upper part of Unit II is a weak-to-moderately developed buried soil, consisting of a 2Ab horizon, one 2ABb horizon, one 2E&Btb horizon and one 2C horizon (Fig. 5:20), all of which are sand (Fig. 5:19). Consequently, the horizons are distinguished largely on the basis of color, and structure. The 2C horizon (2.88 - 4.74; moist; Fig. 5:20) varies slightly around dark brown (10YR3/4; moist) and has a laminated single grain structure. At 3.80 m, a particularly well defined laminae was observed, one illustrated as a sharp coarsening of sediment and improvement insorting in Figure 5:19. Carbonate content is less than 1.0 percent and organic carbon constitutes less than 0.4 percent of the deposits (Fig. 5:19).

Overlying is a 53-cm-thick 2E&Btb horizon (Fig. 5:20). Similar to the 2C1 in color, structure, and texture, the 2E&Btb was distinguished by 7 thin (< 1cm), wavy lamellae. Although the lamellae could not be individually sampled, the presence of one accounts for the relatively high amount (7.1%) of clay observed at 2.37 m. The 2E&Btb contains less than 1.0 percent carbonate and less than 0.5 percent organic carbon (Fig. 5:19).

Between 1.80 and 2.35 m, where the sediment fines and is more poorly sorted, are the 2ABb, and 2Ab horizons. The 2ABb horizon (2.03 - 2.35 m; Fig. 5:20) is dark brown, contains less than 1.0 percent carbonate and organic carbon, and is sandy (ca. 90% sand, 5% silt, 5%clay; Fig. 5:19), textured with a very weak prismatic parting to very weak subangular blocky structure. Overlying is the 2Ab horizon (1.80 - 2.03 m; Fig. 5:20), which is distinguished from the 2AB1 only by its granular structure.

Figure 5:22 illustrates the 2Ab horizon in thin section. The matrix consists largely of skeletongrains with very little plasma, and mineralogy is dominated by quartz with scattered grains of feldspar and miscellaneous rock fragments. In contrast to the thin section of the 3Btb1 horizon (Fig. 5:21), the 2Ab shows very little indication of post-depositional alteration. Occasionally, sand grains are coated with birefringent the grain as it was transported. Regardless, very little clay translocation has occurred relative to the 3Btb1 (Fig. 5:21).

Capping the section at the Cullison Quarry is Unit I, extending from the surface

Figure 5:22. Thin section (FOV = 1.85 x 2.69) collected from the upper part (2.00 m) of 2Ab horizon.

to 1.80 m (Fig. 5:18; 5:19; 5:20). In general, the deposits are sandy, except for a stratum rich in silt (46.0%) at 88 cm, and mean particle size ranges from very fine sand to coarse silt. Sorting is poor in the lower part of the unit where the 95th and 5th percentiles consist of very fine silt and fine sand, respectively, but is moderate towardsthe top because texture includes coarse silt and fine sand. In addition, the distribution of sediments is finely to very finely skewed and leptokurtic to mesokurtic (Fig. 5:19). material, probably clay, that may reflect illuviation, but may have also been present on

Formed in the upper part of Unit I is a weakly developed soil, consisting of an Ap horizon overlying four C horizons. The C4 horizon (1.70 - 1.80 m; Fig. 5:20). is sand (91.8% sand; 4.1% silt; 4.1% clay), dark brown (10YR3/4; moist), and contains about 4.0 percent carbonate and less than 0.5 percent organic carbon (Fig. 5:19). The C3 (95 cm - 1.70 m; Fig. 5:20) horizon varies slightly around dark yellowish brown (10YR4/4; moist), is sandy (ca. 93% sand; 4% silt; 3% clay), has single grain structure, and contains about 1.0 percent carbonate and less than 0.5 percent organic carbon present. Cultural material, consisting of a small piece of barbed wire, was also recovered from the top (ca. 97 cm) of the C5. Clearly visible by the peak in silt at 88 cm (Fig. 5:19) is the 11-cm-thick C2 horizon (Fig. 5:20), which is loam (52.6% sand; 46.0% silt; 1.4% clay), dark yellowish brown (10YR4/4; moist) and has a massive structure parting to single grain. Chemically, the horizon contains very little (ca. 0.5%) carbonate and organic carbon (Fig 5:19). The C1 (19 - 45 cm; Fig. 5:20) horizon is dark yellowish brown (10YR3/4; moist) to dark brown (10YR4/4; moist), contains over 94 percent sand, less than 0.5 percent carbonate and organic carbon (Fig. 5:19), and has a single grain structure. Capping the soil is the 19-cm-thick Ap horizon (Fig. 5:20) that contains less than 0.5 percent organic carbon (Fig. 5:19). The Ap is slightly lighter, dark yellowish brown (10YR3/4; moist) than the C1. Otherwise, the Ap is similar in character to the C1 and C2 horizons, differing only in its granular structure.

In summary, the Cullison Quarry is a 4.13-m-deep exposure (trenched to 5.95 m), approximately 2 miles west of Cullison in the southwestern part of the Great Bend Sand Prairie. Four pedostratigraphic units were described, with each representing a period of deposition, followed by a period of stability and soil formation. In general, they can be divided into two categories that represent diachronous depositional environments: 1) relatively cohesive deposits in the lower part rich in silt and clay (i.e., silty sand); and 2) overlying sediments consisting of loose sand.

Extending from 4.70 m to the base of the profile are Units IV and III, which contain relatively high percentages of silt and clay. Unit IV, in particular, has as much as 46.0 percent silt and 26.5 percent clay. Although sedimentary structures were not observed in either unit, sorting is very poor, suggesting a fluvial facies. Following deposition of each deposit, a period of landscape stability and soil formation occurred, resulting in well developed soils. Pedogenesis was especially intense in Unit IV, promoting development of two 4Btgssb horizons with strong, prismatic structures. A radiocarbon age of approximately 7900 yrs B.P. derived from the 4Btgssb1 horizon suggests that Unit IV accumulated between the very late Wisconsin or early Holocene. A $\delta^{13}C$ value of -20.0‰ indicates a mixture of plants with C_3 and C_4 pathways inhabited the site. Water tables must have been periodically high, for in addition to the relatively high percentage (5.2%) of carbonate in the 4Btkgssb3 horizon, all of Unit IV is heavily gleyed.

At some point, an interval of erosion apparently occurred, one that removed the 4Ab which is presumed to have existed. The sandier sediments of Unit III were subsequently deposited and a soil again formed. The entire thickness of Unit III is unknown, because only one 3Btb horizon remains. A radiocarbon age of about 3800 yrs B.P. from the upper part of Unit III suggests final exposure during the late Holocene when higher temperatures and probably less effective moisture prevailed, as indicated by a $\delta^{13}C$ value of -14.8‰. In short, the character of Units IV and III, coupled with the ages derived from them, are generally consistent with other deposits (e.g., Edwards 1, Edwards 2, Edwards 3, Stafford 3, Reno 4; for which descriptions follow) categorized as silty sand on the Great Bend Sand Prairie.

Unconformably overlying the silty sand are a pair of units, Units II and I, that are consistent in texture, structure, color, and topographic position and expression with deposits categorized as dune sand in the region. Each unit represents a period of sand accumulation, presumably during a more arid climate interval, followed by relative stability and soil formation when more effective moisture was present. A radiocarbon age of approximately 3800 yrs B.P. from the top of Unit III suggests that Units II and I are late Holocene deposits. Although the 2Ab was not dated, its position and degree of development is consistent with buried sola in the region (e.g., Crocket Cutbank, Reno 3, Reno 4) from which ages less than 1000 years have been derived. Unit I is likely less than 200 years old, as indicated by a small piece of barbed wire recovered from the center of the deposit. A weakly developed surface soil, consisting of a Ap horizon and five C horizons, coupled with the barbed wire found beneath it, strongly implies that the dune has been stable for a very brief period of time, probably around 200 years.

Edwards 1

Edwards 1 was a 3.30-m-deep backhoe trench exposure located in a compound subparabolic dune field in the SW, NE, sec. 11, T. 25S., R. 16W (Figs. 5:1,5:23). Three pedostratigraphic units, consisting of a basal silty sand, an intermediate stratum of sandier

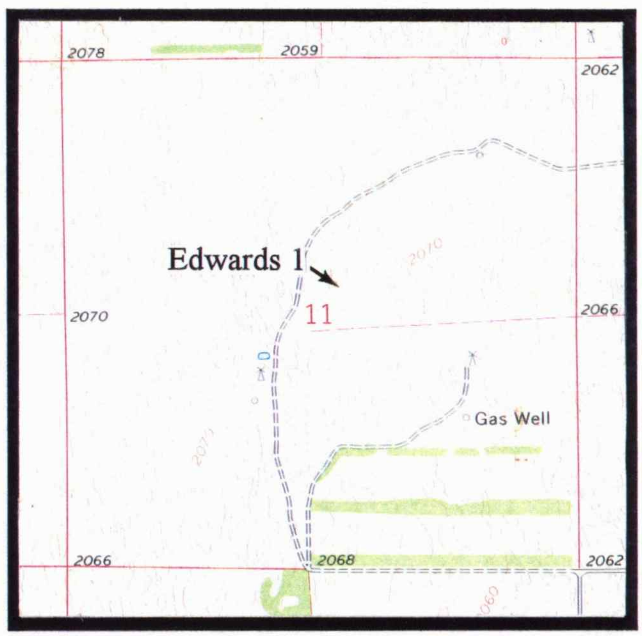


Figure 5: 23. Topographic map of the area near Edwards 1. Scale = 1:24,000 (Belpre 7.5 min. Quadrangle, 1972).

sediments, and a surficial eolian deposit were described (Figs. 5:24, 5:25, 5:26). In each of the lower two units, a well developed buried soil was recognized, whereas none were observed in the overlying eolian sand (Fig. 5:26). Sediments comprising the silty sand are loamy, very poorly sorted, very-fine to finely skewed, and mesokurtic to very leptokurtic. Overlying eolian deposits are very sandy, poorly sorted, very-fine to finely skewed, and very leptokurtic to leptokurtic. Graphical statistics and the chemical composition of sediments at Edwards 1 are illustrated in Figure 5:25.

The lowermost pedostratigraphic unit (Unit III) is a deposit of silty sand, extending from 1.65 to the base of the profile (Figs 5:24; 5:25; 5:26). Sediments throughout the unit are silt loam, with 50 to 60 percent silt consistently present and mean particle size of medium to fine silt. Sediments within Unit III are very poorly sorted, including very fine sand in the 5th percentile and fine clay in the 95th and the unit is platykurtic to mesokurtic and very finely skewed (Fig. 5:25).

Featured within Unit III is an extremely well developed buried soil, consisting of two 3Btb horizons overlying one 3Btgb horizon (Fig 5:26). The soil is brown (10YR5/3; moist), silt loam (ca. 20% sand, 56% silt, 24% clay), has a moderate prismatic structure parting to moderate subangular blocky, and contains small amounts of carbonate ($\leq$ 0.5%) and organic carbon (0.1%; Fig. 5:25). To estimate the mean residence time of humates in the top of the soil, a sample was collected from the upper 5 cm (1.65 - 1.70 m) of the soil that provided a δ^{13}C-corrected radiocarbon age of

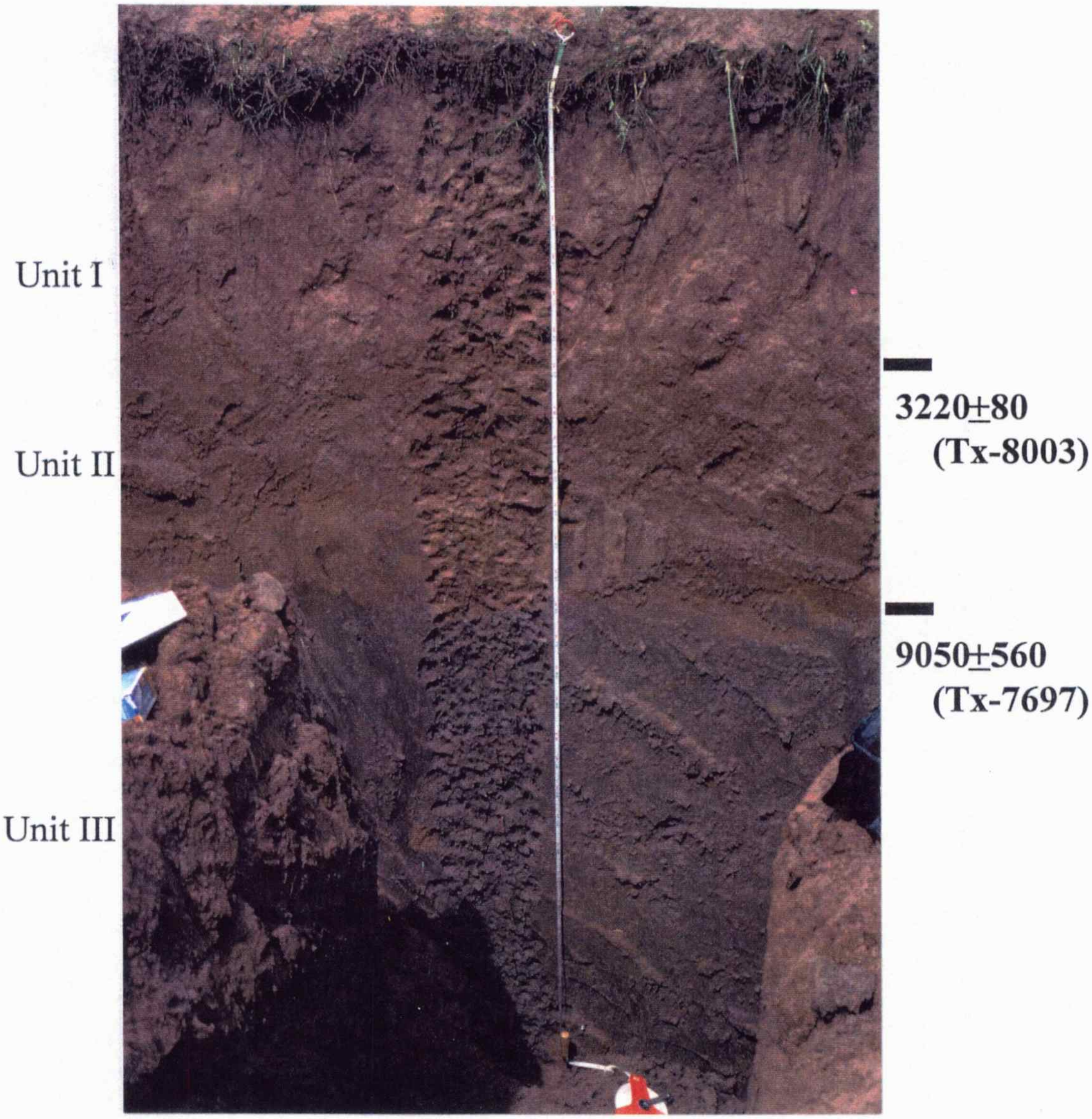


Figure 5:24. Edwards 1 (3.30 m) showing pedostratigraphic units and radiocarbon ages.

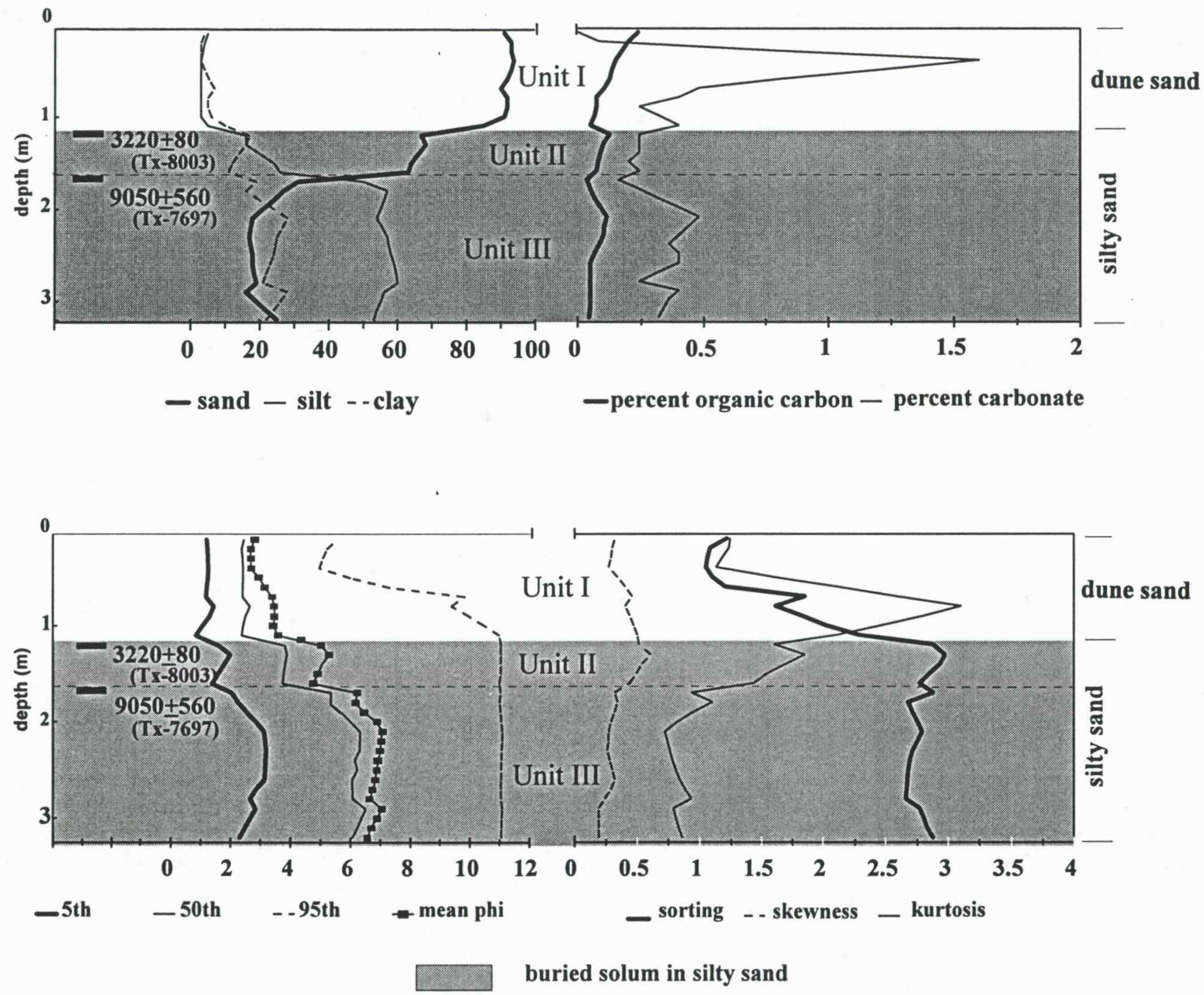


Figure 5:25. Graphical statistics and chemical composition of sediments at Edwards 1.

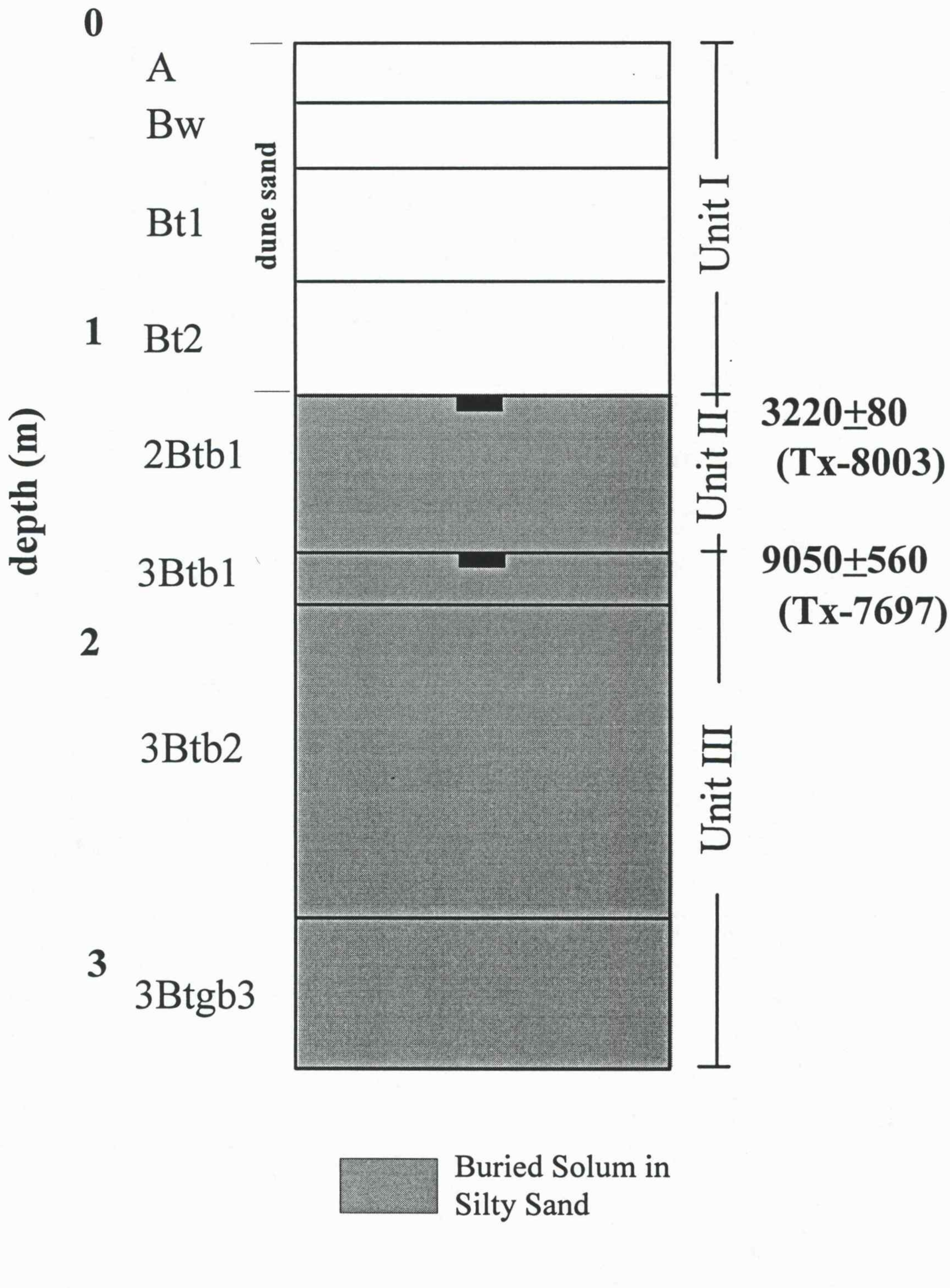


Figure 5:26. Soil stratigraphy and radiocarbon ages at Edwards 1.

9050±5600 yrs B.P and a $\delta^{13}C$ value of -22.2‰ (Tx-7697).

At a depth of 1.65 m is a sharp textural contact that represents the boundary between Units III and II (Fig 5:25). Although Unit II (1.15 - 1.65 m; Figs. 5:24; 5:25; 5:26) is much coarser (sandy loam; coarse - medium silt) than the underlying deposits, it is also very poorly sorted because the 5th percentile phi is fine to very fine sand and the 95th is fine clay. Skewness is very fine in Unit II, but kurtosis shows a sharp change at the contact, shifting from platykurtic and mesokurtic in Unit III to leptokurtic to very leptokurtic in Unit II (Fig 5:25).

Formed within Unit II is a well developed soil, consisting of a sandy loam (ca. 68% sand; 16% silt; 16% clay) 2Btb horizon (1.15 - 1.65 m; Fig. 5:26), containing less than 0.5% carbonate and organic carbon (Fig. 5:25), and with moderate prismatic structure that parts to moderate subangular blocky. The soil appears to have been oxidized, as reflected by the 7.5YR hues (7.5YR4/4; moist and (7.5YR4/6; moist) color. To estimate the mean residence time of humates in the upper 5 cm (1.15 - 1.20 m) of the soil, a sample provided a $\delta^{13}C$-corrected radiocarbon age of 3220±80 yrs B.P and $\delta^{13}C$ value of -13.2‰ (Tx-8003).

Overlying is Unit I, which consists of eolian deposits from the surface to a depth of 1.15 m (Figs. 5:24; 5:25; 5:26). The stratigraphic contact between the units is clear in each sedimentological parameter: texture, phi, and distribution. Sand content (very fine sand) increases dramatically in Unit I from the underlying units, up from about 65 in Unit II to over 90. Although sorting shows a steady improvement throughout Unit I, it reflects a wide distribution in particle size, ranging from very poor at the base (1.10 m) to poor at the top. The deposit is very finely skewed, with a slight increase towards the top of the unit. Kurtosis shows a sharp peak, very leptokurtic, at 80 cm, but decreases to leptokurtic in the upper part of the deposit (Fig. 5:25).

Formed at the surface is a moderately developed soil, consisting of a 20-cm-thick A horizon overlying a 21-cm-thick Bw horizon and two Bt horizons (Fig. 5:26) described on the basis of clay films lining root casts. Texture throughout the soil is sand (> 85% sand) and the soil contains about 1.0 percent carbonate and less than 0.5 percent organic carbon (Fig. 5:25). The Bt2 horizon, which ranges from 79 cm to 1.15 m, is slightly oxidized (7.5YR4/4; moist), has a weak prismatic structure parting to weak subangular blocky, and contains several well defined lamelli. Color in the Bt1 horizon, which extends from 41 to 79 cm (Fig. 5:26), darkens to dark yellowish brown (10YR4/4; moist). The Bw and A horizons are dark yellowish brown (10YR3/4; moist) and dark brown (10YR3/3; moist), respectively. Structure is very weak, granular parting to single grain, throughout the upper part of the soil.

In summary, Edwards 1 is a 3.30-m-deep sedimentary profile obtained from a backhoe trench in a compound subparabolic dune field in the western part of the Great Bend Sand Prairie. Three pedostratigraphic units were recognized and represent a shift from a fluvial deposition in the lower part of the exposure to eolian sedimentation at the top. Periods of episodic erosion apparently occured that truncated at least two surface soils. At the base of the profile is Unit III, which contains a consistently high percentage of silt (ca. 60%) and clay (ca. 25%) and is very poorly sorted, suggesting that it accumulated in a low energy environment, possibly fluvial or lacustrine. An extremely well developed buried soil, consisting of stacked Btb horizons, contained within the unit indicates that the surface was exposed for long periods of time. The lowermost horizon is gleyed, resulting from periodically high water tables or long-term infiltration of water from the surface. A radicarbon age of about 9000 yrs B.P. from humates in the upper 5 cm of the 3Btb1 suggests that the underlying deposits are late Wisconsin or very early Holocene in age. A $\delta^{13}C$ -22.2‰ indicates a shift to more C_3, further suggesting a relatively cool environment with probably more effective moisture.

Unit II, which is approximately 50-cm thick, is the intermediate deposit at Edwards 1. The contact between Units III and II is a major unconformity, as suggested by the truncated Ab horizon in Unit III and a late Holocene age of about 3200 yrs B.P. from the top of Unit II. Unit II is much coarser than the underlying deposit, indicating that some change in depositional environment occurred at the site. Compared to the overlying eolian sediments, however, the exact facies is uncertain. The increase in sand in Unit II, coupled with an apparent late Holocene age, favors eolian deposition. No change in sorting can be discerned from the underlying strata, however, as relatively high percentages of silt (ca. 20 %) and clay (ca. 15%) persist. Theoretically, Unit II could have accumulated when the surface occupied an interdune position on the landscape and a combination of eolian and alluvial processes might have contributed to sedimentation. The unit must have been exposed periodically, and for some time, as indicated by the strong soil that developed throughout the unit. A radiocarbon age of about 3200 yrs B.P suggests that last exposure of Unit II was during the late Holocene. Their was apparently less effective moisture and warmer temperatures at that time, as implied by a $\delta^{13}C$ value of -13.2‰ from the upper part of the stratum.

The uppermost pedostratigraphic unit at Edwards 1 is Unit I, consisting of an approximately 1.10-m-thick deposit of sand that is consitent in texture, color, and topographic position and expression with other deposits in the region identified as dune sand. Following a period of erosion that removed the Ab from the upper part of Unit II, Unit I apparently accumulated during the late Holocene. Although it is unclear when that occurred, two pieces of evidence suggest that the surface of the site has been stable for a relatively long period of time: 1) the degree of surface soil development, including a Bw and two Bt horizons with lamelli; and 2) oxidation in the Bt2 horizon. Given these variables, especially the extent of surface soil development, it is estimated that Edwards 1 has been relatively stable for at least 1000 years.

Edwards 2

Edwards 2 was a 3.15-m-deep backhoe trench, excavated in a compound parabolic dune field, located in the SE, NW, sec. 22, T.26S., R. 18W (Fig. 5:2, 5:27). Three pedostratigraphic units were described, with two consisting of silty sand and one of surficial, eolian sand (Fig. 5:28, 5:29, 5:30). In general, sediments are loamy, have a mean particle size of fine to to coarse silt, are very poorly to poorly sorted, fine to very finely skewed, and very leptokurtic to platykurtic. Graphical statistics and the chemical composition of sediments at Edwards 2 are illustrated in Figure 5:29.

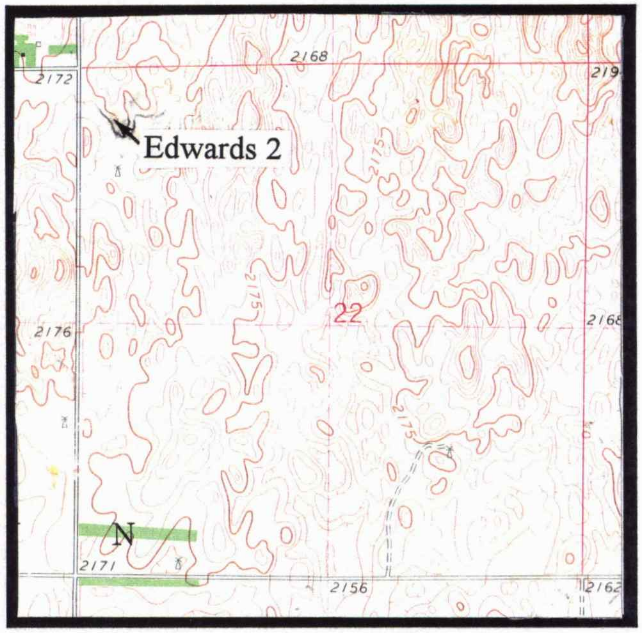


Figure 5:27. Topographic map in the vicinity of Edwards 2. Scale = 1:24,000 (Centerview 7.5 min. Quadrangle, 1972).

The lowermost unit, extending from 1.78 to base of the profile, is Unit III (Figs. 5:28, 5:29, 5:30). Texture fines upward in the unit, ranging from loamy fine sand at the base to loam at the top, and mean particle size fines from coarse e lower part to fine silt in the upper. Sorting varies from poor to very poor, the deposit is fine to very finely skewed, and very leptokurtic to leptokurtic (Fig. 5:29).

Contained with Unit III is an extremely well developed buried soil, with two 3Btgb and three 3Btb horizons (Fig. 5:30). In general, sediment texture and

Figure 5:28. Edwards 2 (3.15 m high) showing pedostratigraphic units and the radiocarbon age.

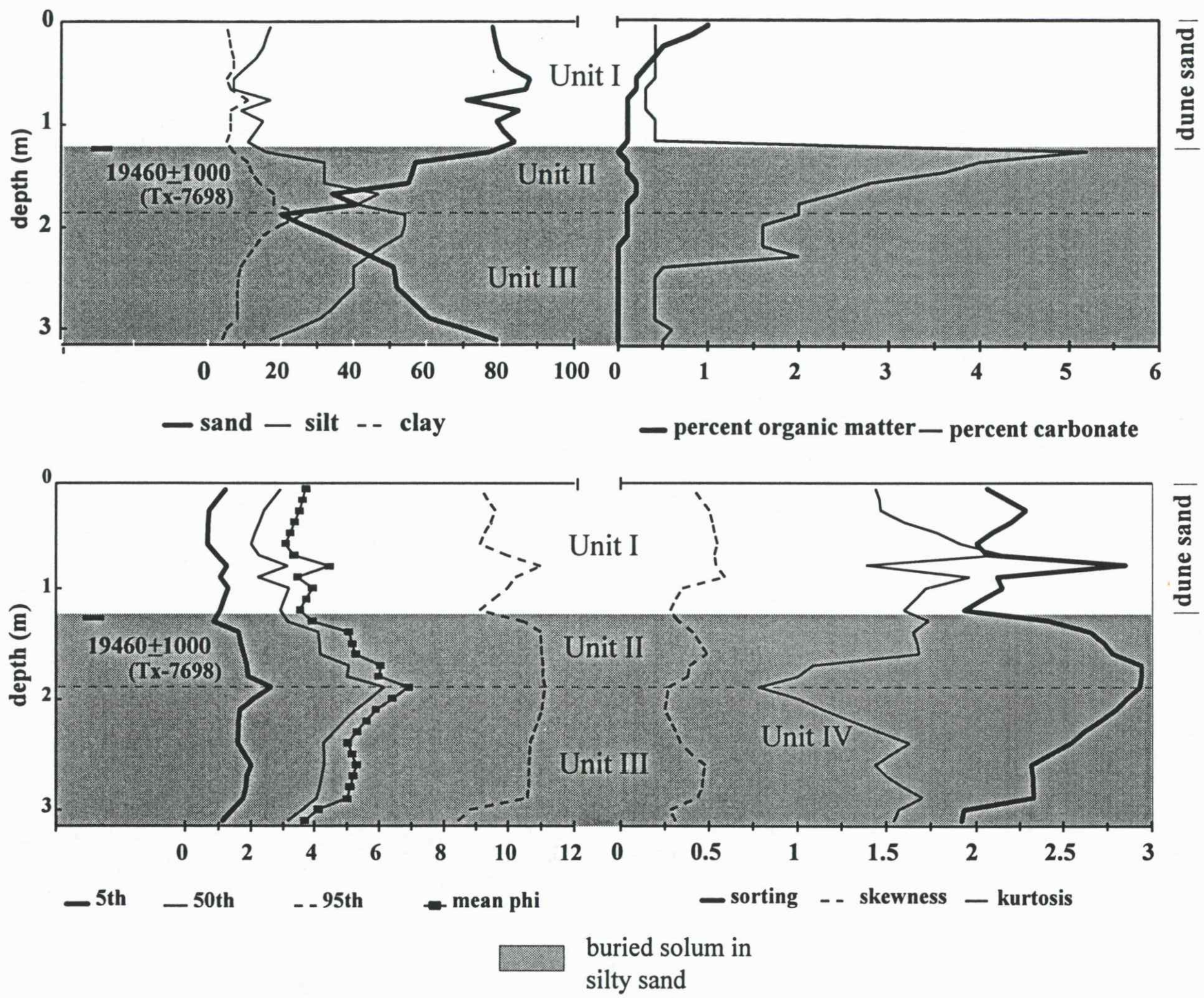


Figure 5:29. Graphical statistics and chemical composition of sediments at Edwards 2.

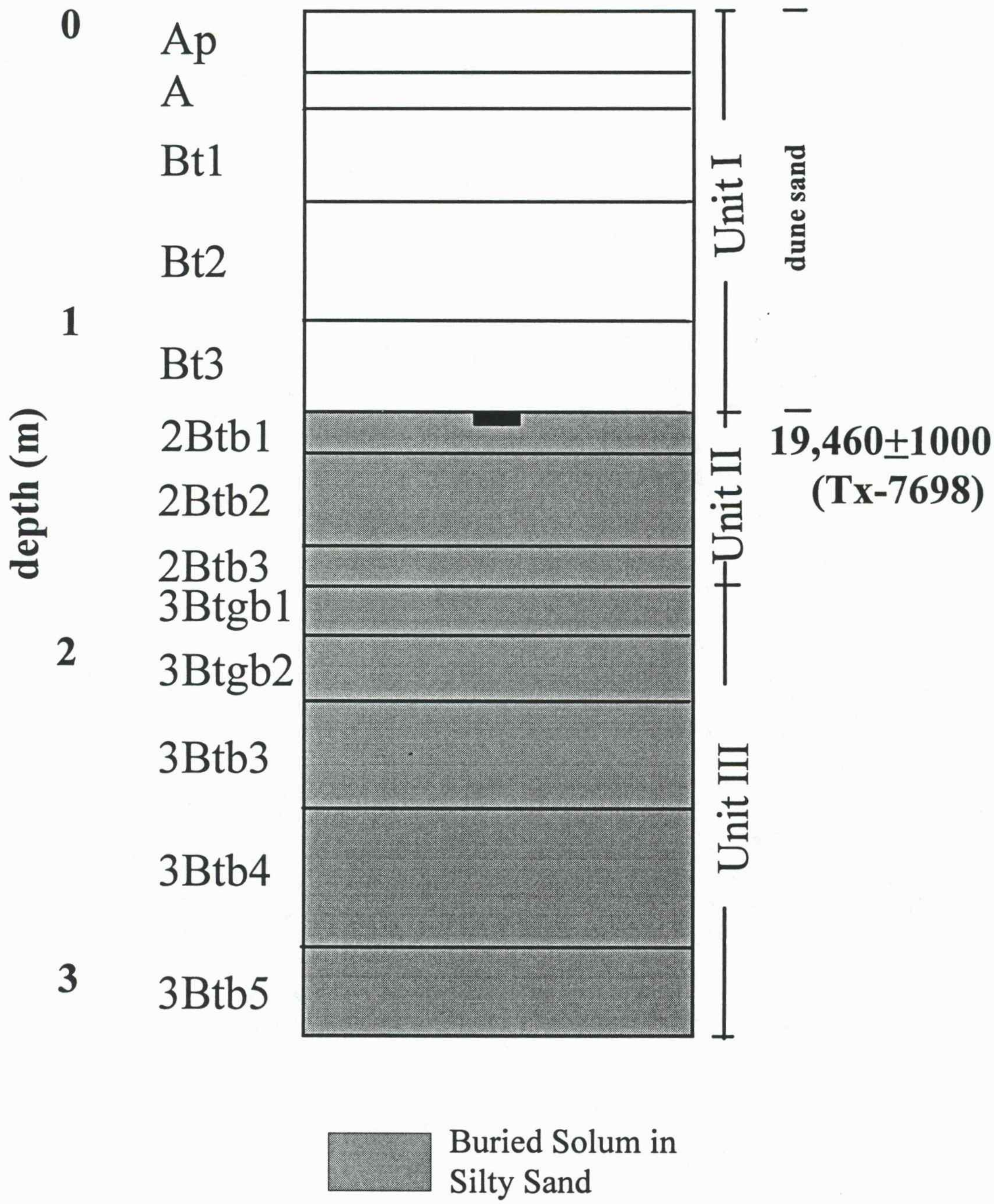


Figure 5:30. Soil stratigraphy and radiocarbon age at Edwards 2.

color were used to distinguish soil horizons because each has the same structure, moderate prismatic parting to moderate subangular blocky and contains less than 2.0 percent carbonate and less than 0.5 percent organic carbon (Fig. 5:29). The lowermost horizon, the 3Btb5, extends from 2.88 to 3.15 m (Fig 5:30) and consists of loamy fine sand (ca. 75% sand, 20% silt, 5% clay; Fig. 5:29) that is dark yellowish brown (10YR4/4; moist) and mottled. Overlying is the 43-cm-thick, sandy loam (61.3% sand, 31.2% silt, 7.5% clay; Fig. 5:29), dark yellowish brown (ca. 10YR4/3; moist) and mottled 3Btb4 horizon (Fig. 5:30). The 3Btb3 extends from 2.12 to 2.45 m (Fig. 5:30), is silt loam (32.8% sand, 52.6% silt, 14.6% clay; Fig. 5:29), and lightens to a mottled brown (10YR4/3; moist).

The uppermost two horizons in Unit III, 3Btgb2 (1.85 - 1.92 m) and 3Btgb1 (1.78 - 1.85 m; Fig. 5:30) are both gleyed. Texture in the 3Btgb2 is silt loam (19.9% sand, 54.3% silt, 25.8% clay) and color is dark grayish brown (10YR4/2; moist). In the brown (10YR5/3; moist) 3Btgb1, texture coarsens sharply to loam (41.2% sand, 41.2% silt, 17.6% clay). Both 3Btgb horizons contain approximately 2 percent carbonate and less than 0.5 percent organic matter (Fig. 5:29).

Overlying is Unit II (1.23 to 1.78 m; Figs. 5:28, 5:29, 5:30), which was distinguished because of its reddish hue (e.g. 7.5YR4/4). Sediments in Unit II coarsen from the base of the unit to the top, ranging from loam to loamy fine sand, as mean particle size varies from fine silt in the lower part to coarse silt in the upper. Sorting improves toward the top of the unit, but is generally very poor, and the stratum is fine to very finely skewed and platykurtic to very leptokurtic (Fig. 5:29).

Contained within Unit II is a well developed buried soil, consisting of three 2Btb horizons with strong prismatic structures that part to strong subangular blocky. The 2Btb3 (1.66 - 1.78 m; Fig. 5:30) is a transitional horizon from the underlying deposits: it is loam (34.0% sand, 47.5% silt, 18.5% clay), dark yellowish brown (10YR4/4; moist), and contains more carbonate (2.4%) and organic carbon (2.0%) than the upper part of Unit III (Fig. 5:29). Intermediate in Unit II is the 2Btb2 (1.23 to 1.65 m; Fig. 5:30), which is sandy loam (ca. 56.0% sand, 32% silt, 12% clay), much redder (7.5YR4/4; moist) than the underlying horizons, and contains 2.8 percent carbonate and and less than 0.5 percent organic carbon (Fig. 5:29). In the brown (7.5YR4/4; moist) 2Btb1 horizon (1.23 - 1.35 m; Fig. 5:30), texture is loamy fine sand (76.5% sand, 16.0% silt, 7.5% clay) and about 5.2 percent carbonate and less than 0.5 percent organic carbon is present (Fig. 5:29). To estimate the mean residence time of humates in the upper 5 cm (1.27 - 1.32 m) of the 2Btb1, a sample provided a δ^{13}C-corrected radiocarbon age of 19,460$\pm$1000 yrs B.P and a δ^{13}C value of -19.8 ‰ (Tx-7698).

The uppermost pedostratigraphic unit, with a clear contact in most statistical and chemical parameters, is Unit I (0 - 1.23 m; Figs. 5:28, 5:29, 5:30). Unit I consists of loamy fine sand to sand that has a mean particle size of size of coarse silt. Sorting, which is poor to very poor, does not improve markedly from the underlying deposits because sediments in the 5th percentile are fine sand and those in the 95th are medium to coarse clay. Unit I is also fine to very finely skewed and leptokurtic to very leptokurtic (Fig. 5:29).

Formed with Unit I is a well developed surface soil, consisting of an 30-cm-thick A horizon overlying three Bt horizons that contained clay films on root traces. The Bt3 horizon, which extends from 95 cm to 1.23 m (Fig. 5:30), is loamy fine sand (ca. 82% sand, 13% silt, 6% clay), dark yellowish brown (10YR4/4; moist), has weak to moderate prismatic structure parting to moderate subangular blocky, and contains less than 0.5 percent carbonate and organic carbon (Fig. 5:29). The dark yellowish brown (10YR4/4; moist) Bt2, ranging from 68 to 95 cm (Fig. 5:30), is consistently loamy fine sand, but varies in sand content from 84.0 at 1.22 m to 71.5 at 83 cm; percent carbonate is less than 0.5 throughout the horizon (Fig. 5:29). Overlying is the Bt1, extending from 30 to 68 cm (Fig. 5:30). Similar to the Bt2, the Bt1 is is sand (88% sand, 5% clay), is dark yellowish brown (10YR3/4; moist), and contains less than 0.5 percent carbonate and organic carbon (Fig. 5:29). Overlying the Bt horizons are two A horizons, extending from the surface to 30 cm (Fig. 5:30). Each A horizon consists of loamy fine sand (ca. 79% sand, 16% silt, 5% clay), containing less than 0.5 percent carbonate, with a granular structure that parts to single grain. The distinguishing characteristics are percent organic carbon, increasing from 0.5 in the A2 to 1.0 in the Ap (Fig. 5:29) and color, which darkens from dark brown (10YR3/3; moist) in A2 to very dark grayish brown (10YR3/2; moist) in the Ap.

In summary, Edwards 2 consists of a 3.15-m-deep backhoe trench excavated in a compound parabolic dune field in the western portion of the Great Bend Sand Prairie. Three pedostratigraphic units were recognized, consisting of two in silty sand and a surficial deposit of eolian sand. In general, the sedimentological differences between the units reflect contrasting depositional environments, probably ranging from low energy fluvial or lacustrine to eolian.

The lowermost unit is Unit III, extending from 1.78 m to the base of the profile. Texture fines sharply from loamy fine sand at the base to loam at the top. Deposits in the lower part are consistent in texture and distribution with surficial wind-blown sands, suggesting an eolian facies. The nature (e.g., heavy texture, very poor sorting) of the upper portion of Unit II, however, indicates a shift in depositional environment to some form of low energy fluvial process. Mottling and gleying in the unit indicate periodically high water tables, or long-term ponding.

Overlying is Unit II, which is characterized by color and a coarsening in texture toward the top of the unit. At the base of Unit II, the sediment is loam, but percent sand increases sharply to 77 percent, however, at the top of the unit. Sorting is very poor from bottom to top. Of particular interest is the color (7.5YR4/4; moist) of the unit, suggesting oxidation. A radiocarbon age of about 19,000 yrs B.P., and a $\delta^{13}C$ value of -19.8‰, from the upper part of the unit indicates that underlying deposits, including all of Units III and II, accumulated by the early late Wisconsin at a time when C_3 plants were present in high at the site.

Although sedimentological evidence in Units III and II generally point to alluvial sedimentation, the degree of soil formation observed in each unit indicates that stable surfaces existed for some time at the site. During intervals of soil formation, intense illuviation occurred that leached carbonate from the lower part of the deposit, and may have contributed to mottling and gleying of Unit III. The lack of buried A horizons suggests that, following stability, erosion occurred, truncating the upper part of the soil. In many places, clay skins can be traced from the top of Unit II to the base of Unit III, indicating that the soils are now welded.

A sharp contact at 1.23 m separates the underlying deposits of Units III and II from the surficial, sandy sediments of Unit I. As much as 88 percent sand, Unit I is consistent in character (e.g., texture, structure, color, topographic position and expression) with other eolian units observed on the Great Bend Sand Prairie that accumulated in a warm, relatively dry environment. Uncharacteristically, the deposit is very poor to poorly sorted, owing to the relatively large percentage of silt (17%) and clay (11%). Theoretically, Unit I may represent both fluvial and eolian facies. The sharp decrease in sorting at 82 cm, for example, may reflect alluvial deposition in an interdunal environment, with subsequent burial by eolian sand. Alternatively, the local source for Unit I contained abundant silt and clay, as well as sand.

Evidence indicates that the surface soil has been stable for a relatively long period of time, at least for a deposit of eolian sand on the Great Bend Sand Prairie. Three Bt horizons were described on the basis of clay films that lined root traces, indicating an extended period of soil formation for a dune in the study area. Most importantly, a radiocarbon age of approximately 19,000 yrs B. P. obtained from the top of Unit II, provides a maximum-limiting, late Wisconsinan age for the base of Unit I. Although truncation of a part of Unit I may have occurred during the Holocene, it is apparent that the basal, eolian deposits in the unit are of late Wisconsin age. Overall, the evidence suggests that the dune at Edwards 3 has been stable for a relatively long period of time.

Edwards 3

Edwards 3 was a 3.3-m-deep backhoe trench, excavated on the level sand sheet, in the NW, NW, sec. 17, T. 25S., R16W (Figs. 5:1, 5:31). Four pedostratigraphic units were described, with three consisting of silty sand and one of surficial, eolian sand. In general,

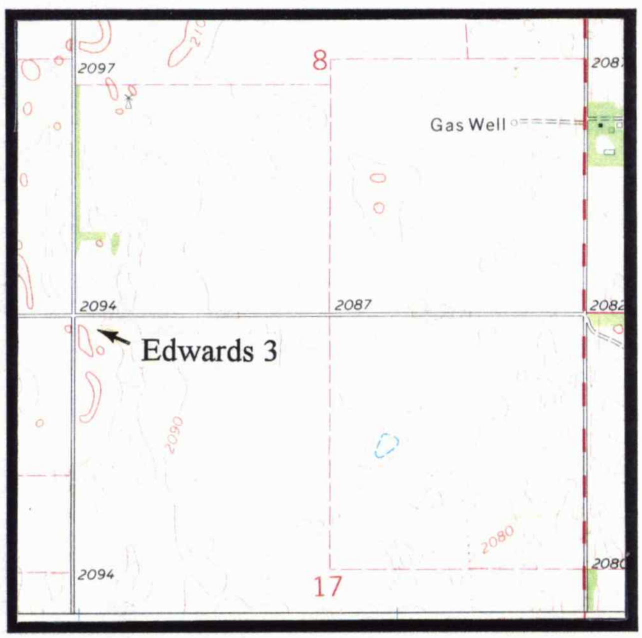


Figure 5:31. Topographic map in the vicinity of Edwards 3. Scale = 1:24,000 (Belpre 7.5 min. Quadrangle, 1972).

deposits are loamy, have with a mean particle size of very fine to coarse silt, are very poorly sorted, fine to very finely skewed, and platykurtic to very leptokurtic.

The lowermost stratigraphic unit (Unit IV) extends from 2.72 m to the base of the profile (Figs. 5:32, 5:33, 5:34). Sediments fine upward from the base of the unit to the top and are classified as loam and clay loam, respectively, with a mean particle size of fine silt. The deposit is very poorly sorted because the 5th percentile is very fine sand whereas the 95th percentile is fine clay, and is very fine to finely skewed and platykurtic (Fig. 5:33).

Contained within Unit IV is a well developed buried soil, consisting of two 4Btb horizons with weak prismatic structures parting to medium subangular blocky that contain little carbonate ($\leq$ 1.0%) and organic carbon (< 0.5%). The 4Btb2 horizon, which extends from 3.21 m to the base of the profile (Fig. 5:34), is distinguished by its texture, loam (35.5% sand; 38.8% silt, 25.7% clay; Fig. 5:33), and reddish (7.5YR5/6; moist) color. Overlying is the 4Btb1 horizon (2.72 - 3.21 m; Fig. 5:34), which is yellowish brown (10YR5/4; moist) and clay loam (ca. 24% sand; 44% silt, 32% clay). The rise in clay is accompanied by a decrease in sand from 35 percent in the 4Btb2 to 25 percent at the top of the 4Btb1 (Fig. 5:33). To estimate the radicarbon age of the humates in the upper 5 cm (2.72 - 2.77 m) of the 4Btkb1 horizon, a sample provided a $\delta^{13}C$-corrected radiocarbon age of 13,290$\pm$780 yrs B.P. and $\delta^{13}C$ value of -24.7‰ (Tx-8115).

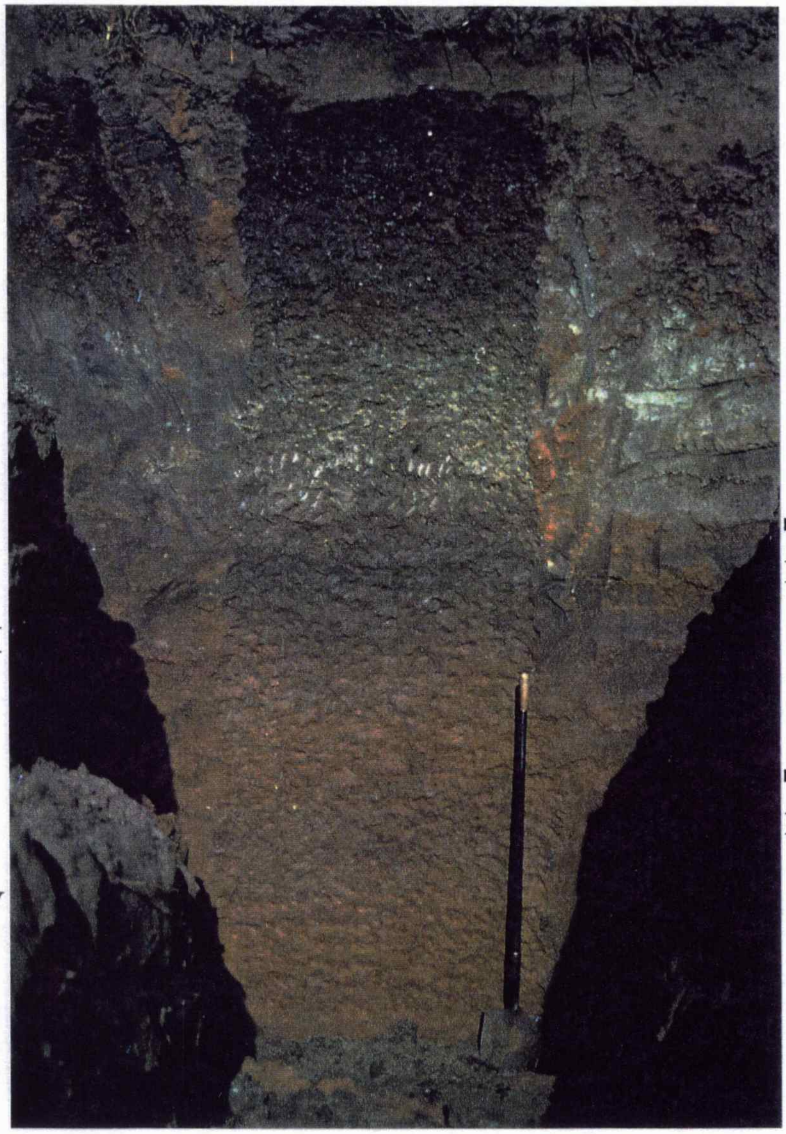


Figure 5:32. Edwards 3 (3.30-m high) showing pedostratigraphic units and radiocarbon ages.

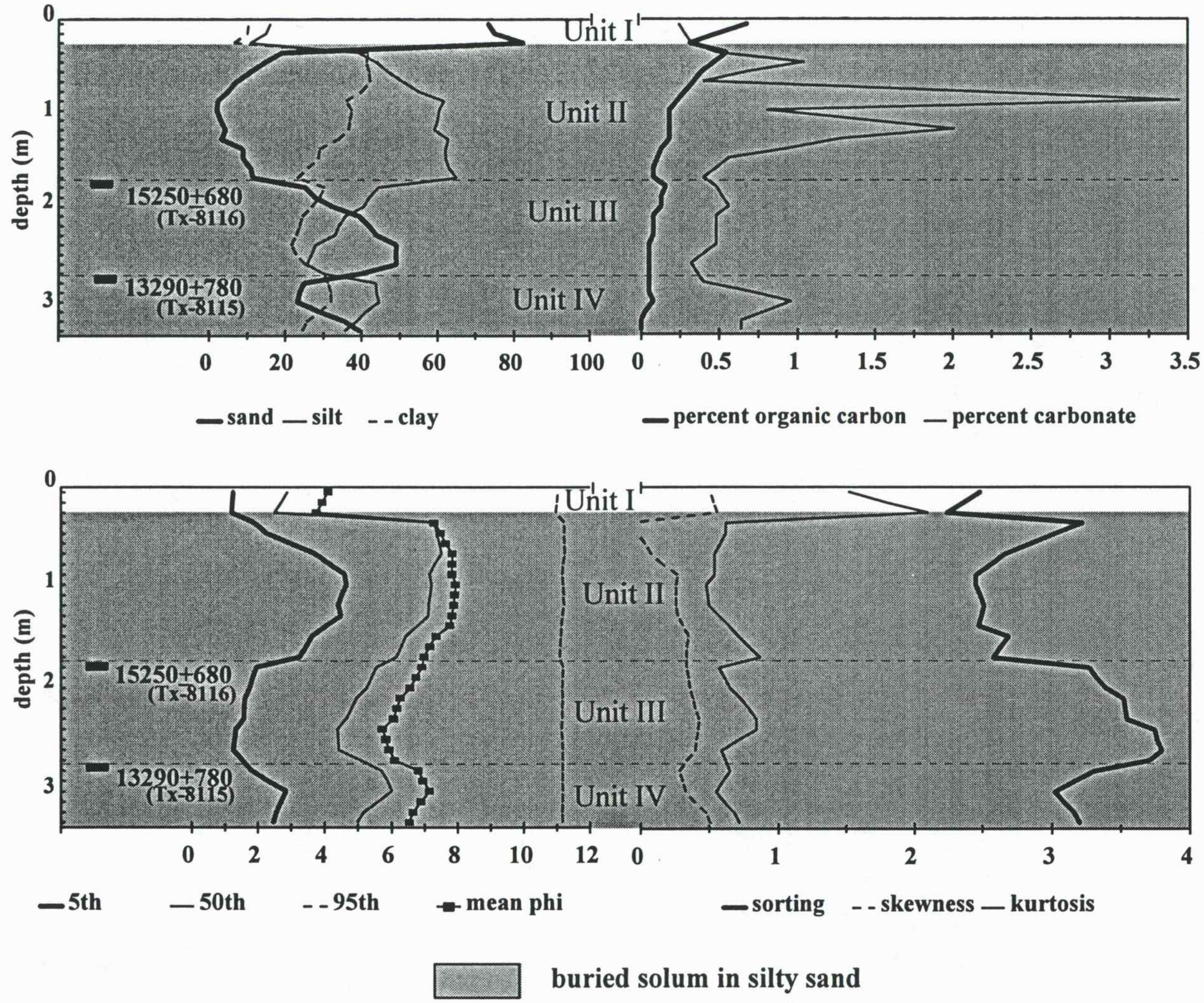


Figure 5:33. Graphical statistics and chemical composition of sediments at Edwards 3.

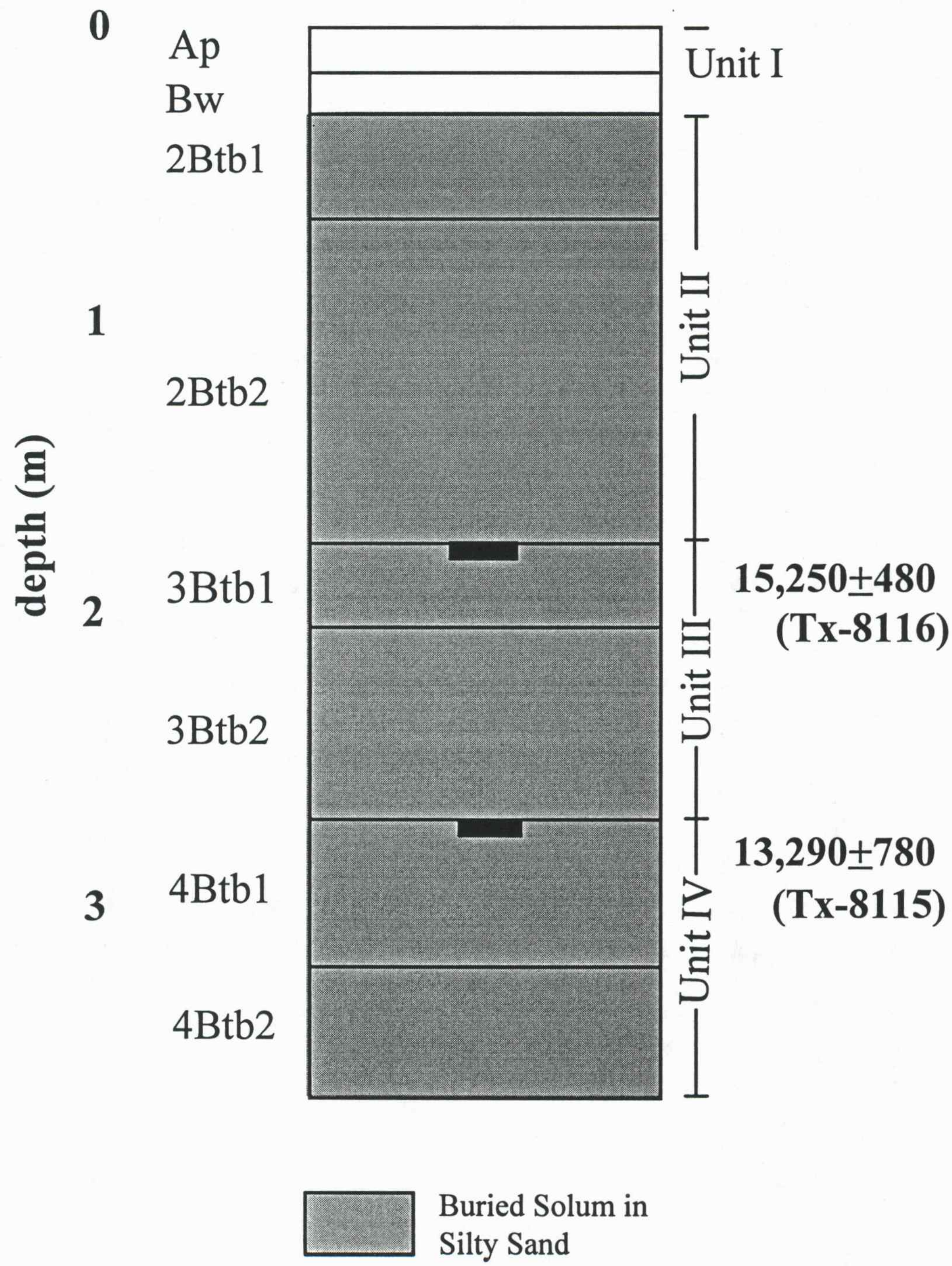


Figure 5:34. Soil stratigraphy and radiocarbon ages at Edwards 3.

Overlying is Unit III, which extends from 1.78 to 2.72 m (Figs. 5:32; 5:33; 5:34). The stratigraphic contact separating Units III and IV is clear in the textural curve, with a sharp increase in sand from 25.0 at 2.78 m to 49.1 percent at 2.60 m. Sediments in Unit IV are loamy, fine upward from sandy clay loam at the base to clay loam at the top, and have a mean particle size that fines upward from fine to very fine silt. Sorting is very poor, as reflected by a wide range of texture, including fine sand in the 5th percentile and fine clay in the 95th, and the deposit is also finely skewed and platykurtic (Fig. 5:33).

Contained within Unit III is an extremely well developed buried soil with two 3Btb horizons distinguished largely by their texture: the 3Btb2 (2.08 - 2.72 m; Fig. 5:34) is sandy clay loam (ca. 49% sand, 27% silt, 24% clay) to loam (ca. 41% sand, 35% silt, 24% clay; Fig. 5:33), whereas the 3Btb1 (1.72 - 2.08 m; Fig. 5:34) is clay loam (ca. 29% sand, 42% silt, 29% clay). Structure is moderate prismatic parting to moderate subangular blocky throughout the soil. Color is largely yellowsh brown (10YR5/4; moist), but darkens slightly to dark yellowish brown (10YR4/4; moist) in the middle of the 3Btb2 (2.35 m) and dark grayish brown (10YR4/2; moist) in the upper part of the 3Btb1 (1.80 m). Percent carbonate is less than 1.0 percent and organic carbon is less than 0.5 percent (Fig. 5:33) throughout the soil. To estimate the mean residence time of humates in the upper 5 cm (1.72 - 1.77 m) of the 3Btb1, a sample provided a $\delta^{13}C$-corrected radiocarbon age of 15,250$\pm$460 yrs B.P. and a $\delta^{13}C$ value of -25.6 ‰ (Tx-

8116).

Overlying is Unit II, which extends from 30 cm to 1.72 m (Figs 5:32; 5:33; 5:34). The stratigraphic contact separating the two units is clear in the textural, phi, and distribution parameters. Sediments in the unit are loamy, fining upward from silt loam (fine silt) at the base to clay loam (very fine silt) towards the top. Sorting is clearly better in Unit II than in the underlying deposits, reflecting the decrease in the 5th percentile from very fine sand to coarse silt, but remains very poor. Skewness and kurtosis vary from very fine and platykurtic, respectively, in the lower part of the unit to near-symmetrical and very platykurtic, respectively, in the upper (Fig. 5:33).

Contained with Unit II is an extremely well developed buried soil, consisting of two 2Btb horizons with moderate prismatic structures that part to moderate subangular blocky. Soil horizonation was determined on the combined variables of texture, color, and chemical composition. The brown (10YR5/3; moist) 2Btb2 horizon (81cm - 1.78 m; Fig. 5:34) is silty clay loam, but texture fines from 11.7% sand, 65.0 percent silt, and 23.3 percent clay at 1.70 m to 4.2 % sand, 59.2 percent silt, and 36.6 percent clay at 1.18 m. Percent carbonate increases from less than 0.5 percent at the base (1.70 m) of the 2Btb4 to about 2.0 towards the top (1.18 m), whereas organic carbon content is consistently less than 0.5 percent (Fig. 5:33). The 2Btb1 horizon, which extends from 30 to 81 cm (Fig. 5:34), is distinguished primarily by its silty clay (14.7% sand; 44.0% silt, 41.3% clay) texture, and slight increase (1.0%) in carbonate (Fig. 5:33); it ranges from dark (10YR4/2; moist) to very dark grayish brown (10YR3/2; moist).

The uppermost stratigraphic unit at Edwards 3 is Unit I, extending from the surface to 30 cm (Figs. 5:32; 5:33; 5:34). In the parameters of texture, chemical composition, phi, and distribution, the contact between Units I and II is clear. Texturally, the deposits comprising Unit I consist of loamy fine sand, with an increase in sand from 19 percent in the upper part of Unit II to 82 percent in the lower portion of Unit I. Correspondingly, mean particle size increases from fine silt at the top of Unit II to coarse silt in Unit I. Although sorting improves in Unit I from Unit II, it remains very poor, largely because fine clay continues to comprise the 95th percentile of the deposit. Skewness shifts from near-symmetrical in the upper part of Unit II to fine in Unit I. Kurtosis shows a sharp peak to very leptokurtic in Unit I, one that changed from platykurtic in Unit II (Fig. 5:33).

Formed throughout Unit I is a moderately developed surface soil, one that consists of a 17-cm-thick A horizon overlying 13-cm-thick Bw horizon (Fig. 5:34). Because soil texture is consistent (i.e., loamy fine sand; ca. 78% sand, 13% silt, 9% clay) between the horizons, color, structure, and percent organic matter were used as distinguishing variables. In the Bw horizon, structure is weak subangular blocky that parts to single grain, color is dark brown (10YR3/3; moist), and organic matter content is less than 0.5 percent. In contrast, the A horizon has a granular structure that parts to single grain and a very dark grayish brown (10YR3/2; moist) color that reflects an increase in organic matter to about 0.7 percent (5:33).

In summary, Edwards 3 was a 3.3-m-deep backhoe trench excavated on a level sand sheet in the western part of the Great Bend Sand Prairie. Four pedostratigraphic units were recognized, consisting of three in silty sand and a thin, surficial deposit of sand. In general, the sedimentological difference between the silty sand and the overlying sand probably represent a change in depositional environment from low energy fluvial or lacustrine to eolian.

From 30 cm to the base of the profile, the deposits consist of silty sand. Two, distinguishable fining upward sequences were observed, with each comprising a single stratigraphic unit. At the base of the exposure, Unit IV fined from loam at the base to clay loam at the top of the unit. In the lower part of Unit III, texture coarsened to sandy clay loam, with a subsequent fining to clay loam towards the top of Unit III. In Unit II, the sediment fined dramatically, culminating in 42 percent clay and 7 percent sand in the upper part of the unit. The fining-upward sequences, coupled with the very high percentage of clay and very poor sorting, strongly suggest deposition in a fluvial environment where energy fluctuated from relatively high to very low. Although radiocarbon ages from the middle and base of the deposit are inverted, they generally suggest that deposits accumulated during the late Wisconsin. Values of $\delta^{13}C$ from the silty sands range from -25.6‰ and -24.7‰, indicating that proportionately a high number of C_3 plants inhabited the site.

Although the sedimentological evidence favors fluvial deposition, the formation of three, well developed buried soils in the silty sand indicate that stable surfaces existed for long periods of time. Each soil consists of stacked Btb horizons, with no Ab, suggesting that stability was followed by an erosional episode that truncated the upper part of the solum. In many instances, clay skins can be traced from the top of Unit II to the bottom of the profile, indicating that the soils are now welded.

A sharp contact at 30 cm separates the underlying silty sands from the surficial sediments of Unit I. Composed largely of sand, Unit I is consistent in character (i.e., texture, structure, color) with dune sand, deposits that accumulated in a relatively warm, arid environment. Uncharacteristically, the sediment in Unit I is very poorly sorted, owing to the high percentages of silt (ca. 10%) and clay (ca. 10%). Although a precise determination can not be made based on the conflicting evidence regarding facies, it may have resulted from eolian input of different intensities. Theoretically, the sandcould have accumulated initially, followed by a subsequent and infiltrating input of silt and clay. Alternatively, the local source for Unit I contained a high percentage of silt and clay that was reworked. Regardless, the moderate development of the surface soil suggests that deposition of Unit I occurred during the late Holocene, probably in the past 1000 years.

Edwards 4

Edwards 4 was a 3.31-m-deep backhoe trench excavated in a compound subparabolic dune field in the SW NE sec. 16, T.25S., R16 (Figs. 5:1; 5:35). Three pedostratigraphic units, consisting of one in silty sand, and two in surficial eolian sand,were described in the profile (Figs. 5:36, 5:37, 5:38). In general, sediments at the site are loamy, have a mean particle size of medium to coarse silt, are very poorly to poorly sorted, very finely skewed, and leptokurtic to very leptokurtic in their distribution. Graphical statistics, and the chemical composition of the sediment are illustrated in Figure 5:37.

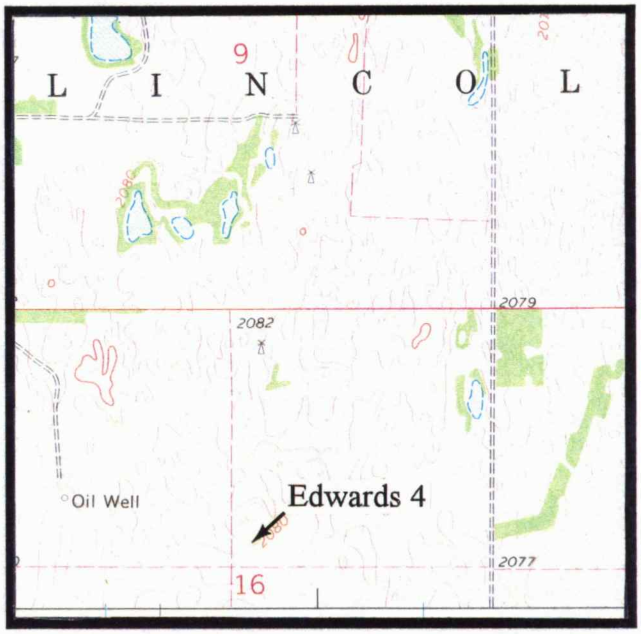


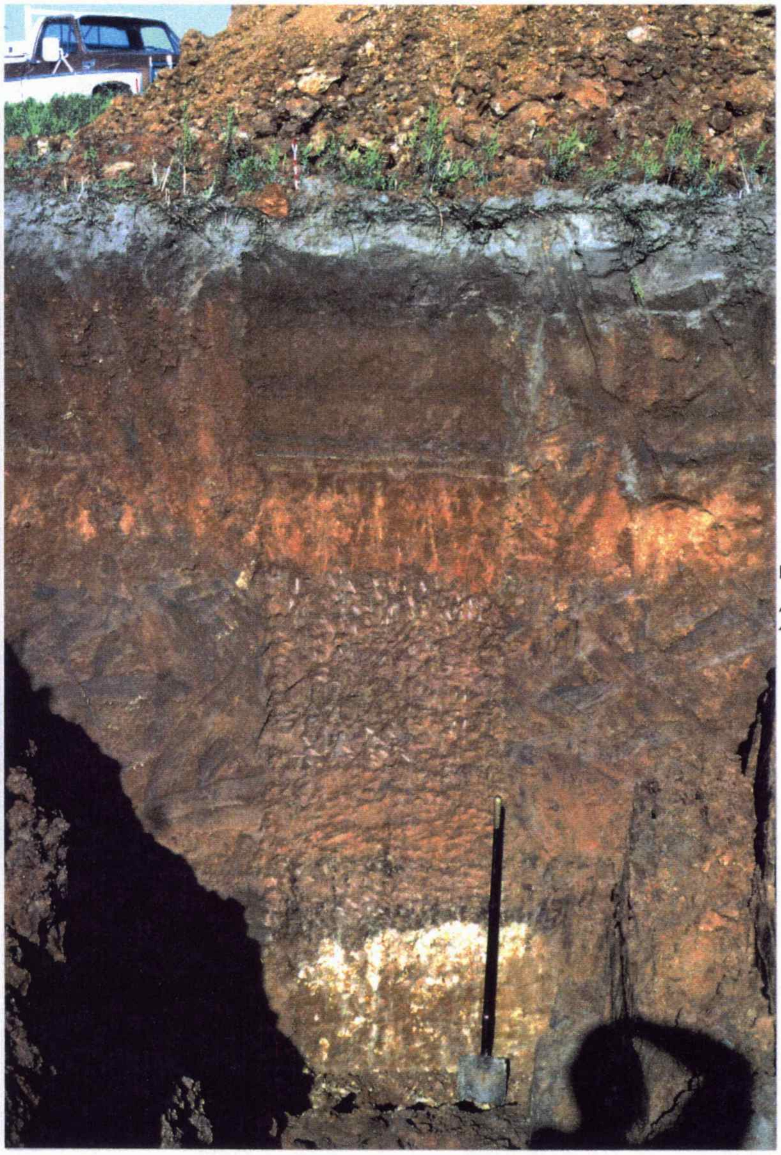
Fig. 5:35. Topographic map in the vicinity of Edwards 4. Scale = 1,24,000 (Belpre 7.5 min. Quadrangle, 1972).

The lowermost pedostratigraphic unit at Edwards 4, ranging from 1.58 to the base of the profile, is Unit III (Figs. 5:36, 5:37, 5:38). In general, Unit III is a sequence of oxidized sediments that fine upward from fine sandy loam at the base of the deposit to loam at the top; mean particle size is medium silt. Sorting is very poor, owing to the presence of fine sand in the 5th percentile and fine clay in the 95th. The distribution of

Unit I

Unit II

Unit III



2730±180 (Tx-8314)

Figure 5:36. Edwards 4 (3.31-m high) showing pedostratigraphic units and radiocarbon age.

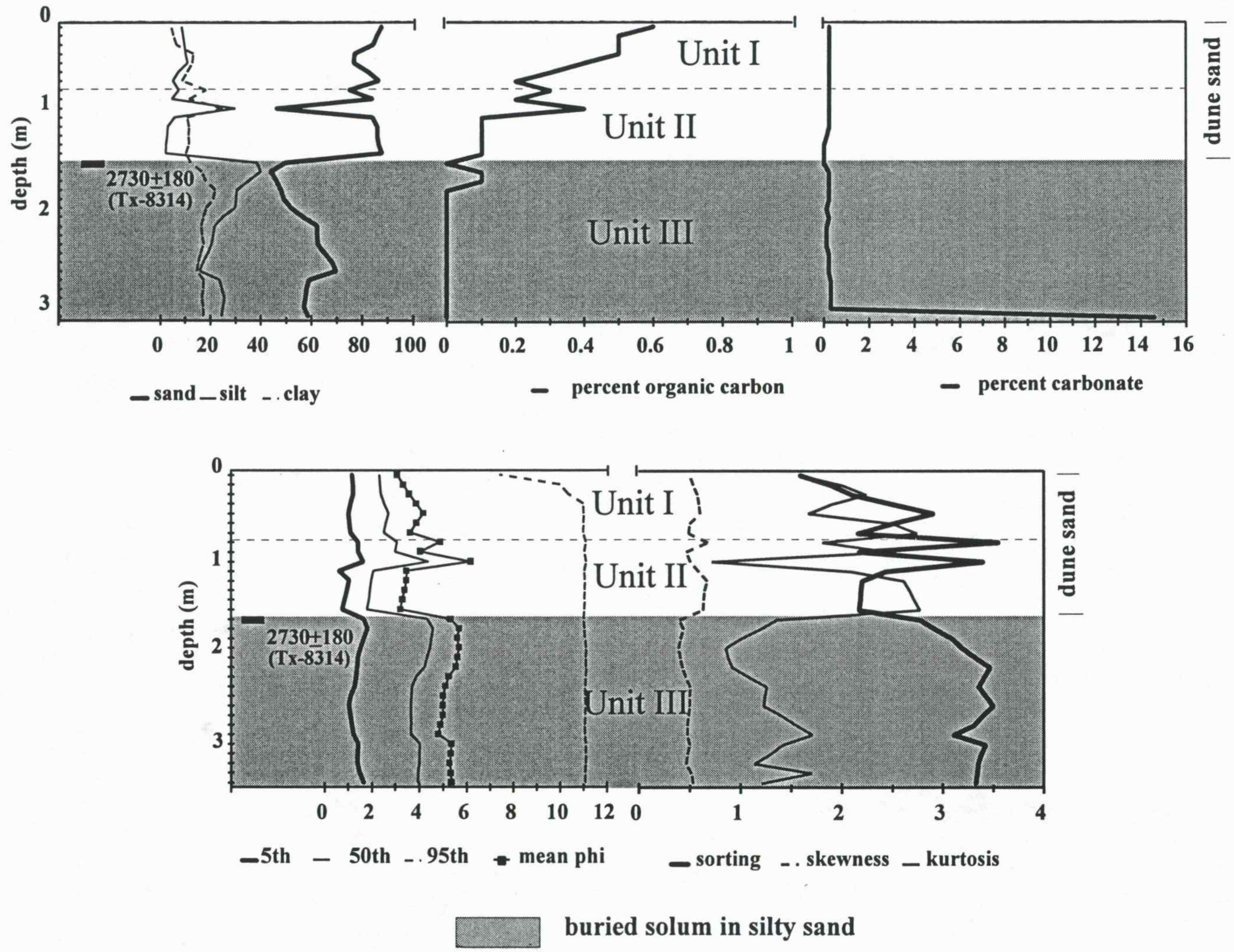


Figure 5:37. Graphical statistics and chemical composition of sediments at Edwards 4.

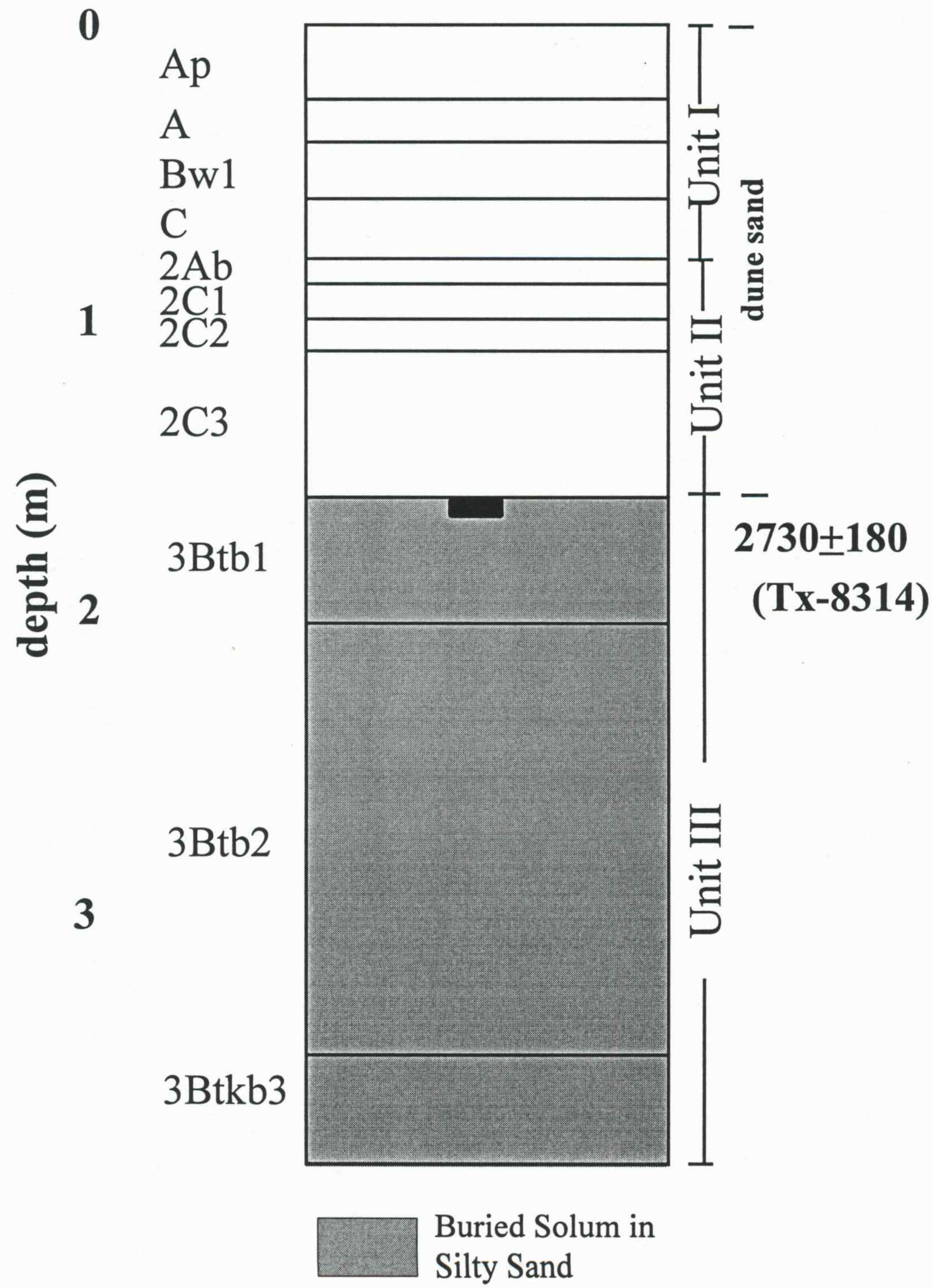


Figure 5:38. Soil stratigraphy and the radiocarbon age at Edwards 4.

texture is very finely skewed, and varies in kurtosis from very leptokurtic in the lower part to mesokurtic in the upper part of the unit (Fig. 5:37).

Contained within Unit III is a well developed soil, consisting of two 3Btb horizons and one 3Btkb horizon that were distinguished on the basis of subtle differences in texture, coupled with changes in color or chemical composition. The lowermost horizon, the brown (7.5YR5/4; moist) 3Btkb3 (3.23 - 3.48m; Fig. 5:38), consists of oxidized fine-sandy-loam (58.6% sand, 24.3% silt, 17.1% clay) sediments that have a moderate prismatic structure that parts to weak subangular blocky. Although the 3Btkb3 contains no organic carbon, it does hold 14.6 percent carbonate (Fig. 5:37).

The remaining horizons in Unit III, 3Btb1 and 3Btb2, are very similar in character, consisting of noncalcareous, oxidized sediments, with little organic carbon, that have a moderate prismatic structure that parts to moderate subangular blocky. Carbonate drops to less than 0.5 percent in the 3Btb2 (Fig. 5:37), which ranges from 2.01 to 3.23 m (Fig. 5:38) and consists of strong brown (7.5YR4/6; moist), loamy fine sand (57.7% sand, 25.7% silt, 16.6% clay; Fig. 5:37). Formed within the upper part of Unit III is the 3Btb1 horizon (Fig. 5:38), which is loam (ca. 47% sand; 37% silt, 16% clay; Fig. 5:37) and varies in color from strong brown (7.5YR4/6; moist) at the base of the horizon to dark brown (7.5YR4/4; moist) at the top. To estimate the mean residence time of humates in the upper 5 cm (1.58 - 1.63 m) of the 3Btb1, a sample provided a $\delta^{13}C$-corrected radiocarbon age of 2730$\pm$180 yrs B.P. and a $\delta 13C$ value of -17.3‰

(Tx-8314).

Overlying is Unit II, extending from 79 cm to 1.58 m (Figs. 5:36, 5:37, 5:38). The contact between the two units is clear in most parameters, but it is very uneven, suggesting truncation of Unit III. In general, sediments within Unit II are loamy, ranging from loamy fine sand in the lower part to sandy loam in the upper. Moreover, they are very poorly sorted due to the presence of fine sand in the 5th percentile and fine clay in the 95th; they are also very finely skewed, and very leptokurtic to mesokurtic (Fig. 5:37).

Contained within Unit II is a poorly developed buried soil, consisting of a 2Ab horizon overlying three 2C horizons that were distinguished on the basis of texture and color. Each horizon contains less than 1.0 percent carbonate and organic carbon and all of the 2C horizons have single grained structure. Sharp changes in texture, coupled with variable degrees of sorting between and 1.18 m and 98 cm (Fig. 5:37) identify the stratified 2C3 (1.09 - 1.58 m) and 2C2 (98 cm - 1.09 m) (Fig. 5:38) horizons, respectively. The 2C3 is loamy fine sand (ca. 86% sand, 3% silt, 11% clay; Fig. 5:37), dark brown (7.5YR3/4; moist). A sharp decrease in sand to 46.1 percent, accompanied by an increase in silt and clay to 29.5 and 24.4 percent (Fig. 5:37), respectively, occurs in the loam and dark brown (7.5YR3/3; moist) 2C2 horizon.

At the base of the dark brown (7.5YR3/4; moist) 2C1 (88 cm - 98 cm; Fig. 5:38) a sharp increase in sand occurs, one accompanied by a corresponding decrease in silt

(4.5%) and clay (11.5%; Fig. 5:37). Overlying is a weakly developed, 11-cm-thick 2Ab horizon (Fig. 5:38) that is fine sandy loam (74.8% sand; 7.2% silt, 18.0% clay; Fig. 5:37), dark yellowish brown (10YR3/4; moist), and has a granular structure.

The uppermost stratigraphic unit is Unit I (Figs 5:36, 5:37, 5:38). Extending from the surface to 79 cm, the unit consists of fine sandy loam and sandy sediments that have a mean particle size ranging from coarse silt to very fine sand. Sorting is poor at the base of the unit because the distribution includes very fine sand in the 5th percentile and fine clay in the 95th. Towards the top, sorting improves to poor due to a shift in the 95th percentile to very fine silt. Skewness in Unit I is very fine, and the deposit is very leptokurtic (Fig. 5:37).

Formed at the surface is a weak to moderately developed soil, consisting of an Ap horizon overlying an A, Bw, and C horizon (Fig. 5:38), with each containing less than 0.5 percent carbonate and organic carbon. The C horizon, extending from 59 to 79 cm, consists of dark yellowish brown (10YR3/4; moist) sand (86.5% sand, 4.9% silt, 8.6% clay; Fig. 5:37) with a single grain structure. Overlying is a 19-cm-thick, dark brown (10YR3/3; moist) Bw horizon (Fig. 5:38) that is fine sandy loam (74.8% sand; 7.2% silt, 18.0% clay; Fig. 5:37) and has a weak prismatic structure that parts to weak subangular blocky structure due to its higher percentage of clay. Capping the surface soil is a 15-cm-thick A horizon and 25-cm-thick Ap horizon (Fig. 5:38). Although structure varies slightly from granular in the A to single grain in the Ap, texture is sand (ca. 85% sand, 5% silt, 5% clay; Fig. 5:37) in both. The A horizon is dark brown (10YR3/3; moist), whereas the Ap is dark yellowish brown (10YR3/4; moist).

In summary, Edwards 4 consists of a 3.31-m-deep backhoe trench, excavated in a compound subparabolic dune field in the western part of the Great Bend Sand Prairie. Three pedostratigraphic units were recognized, consisting of one in silty sand, capped by two in surficial sand. In general, the sedimentological difference between the silty sand and the overlying sand may reflect a shift from a low energy fluvial or lacustrine environment to one where eolian processes dominated in a time of increased aridity.

The lowermost stratigraphic unit, Unit III, ranges from 1.58 m to the base of the profile. Texture within the unit generally fines from loamy fine sand at the base of the exposure to loam towards the top. In addition, sorting is very poor due to high percentages of silt and clay, suggesting a mixed sediment load and accumulation in a very low energy environment. Although Unit III appears to be an alluvial deposit, a stable, exposed surface must have existed periodically, for a buried soil is present that is very well developed (i.e., two 3Btb horizons and one 3Btkb3 horizon). Long-term stability is further indicated by the oxidized color (e.g., 7.5YR4/4; moist), prismatic structure, and intense illuviation of carbonate to the lower part of the unit. Overall, the deposit is consistent with silty sand elsewhere (e.g., Edwards 1, 2, Stafford 1, Stafford 2) in the region, suggesting accumulation during the Woodfordian. The surface of the deposit appears to have been severly truncated, probably by fluvial processes. An age of about 2300 yrs B.P. from the uppermost 5 cm of the unit implies last exposure during the late Holocene. A δ13C value of -17.3‰ suggests the site was inhabited by relatively relatively high percentages of C_4 plants.

Overlying is Unit II, extending from 79 cm to 1.58 m. Classified as loamy fine sand, loam, and fine sandy loam, the deposits in Unit III are consistent in texture, structure, color, and topgraphic position and expression with other units of eolian sand, those that accumulated in a relatively warm probably more arid environment, on the Great Bend Sand Prairie. The sediments are very poorly to very poorly sorted, however, suggesting variable wind intensity and/or a nearby, poorly sorted source. Potentially, sediments in Unit II originated from exposures of the silty sand that were deflated during periods of aridity and high wind. Formed within Unit II is a poorly developed buried soil, consisting of an 11-cm-thick 2Ab horizon overlying three 2C horizons. The overall lack of structure (e.g., single grain, granular), as compared to that in the underlying silty sand (e.g., prismatic), in the soil further reflects eolian origins. Evidence suggests that Unit II accumulated during the late Holocene. Although a radiocarbon age was not obtained from the 2Ab, the age of from the upper 3Btb1 provides a maximum-limiting age for the deposit. In addition, the slightly oxidized color (e.g., 7.5YR3/4; moist) of the 2C horizons suggests a minimum-limiting age of greater than 1000 years. Apparently, the period of stability was less than 1000 years, as indicated by the overall lack of development.

Overlying is Unit I, extending from the surface to 79 cm. Fine sandy loam and sand, as well as single grain to granular structurally, Unit I is consistent with other eolian-sand deposits observed in the region. Sorting ranges from very poor to poor in the unit, suggesting winds of variable intensity and/or a nearby, poorly sorted source (e.g. silty sand). Contained within Unit I is a moderately to weakly developed surface soil consisting of two A horizons, a Bw, and C horizon. The character of the soil, coupled with its unoxidized color (e.g., 10YR3/4; moist) suggests that the site has been stable for between 500 and 1000 years.

Phillips Trench

The Phillips Trench is a 2.7-m-deep drainage trench located in a level sand sheet in the NE, NE, sec. 25, T13S., R20W (Fig. 5:1, 5:39), that was discovered during the reconnaissance phase of the project. Three pedostratigraphic units were described, with the

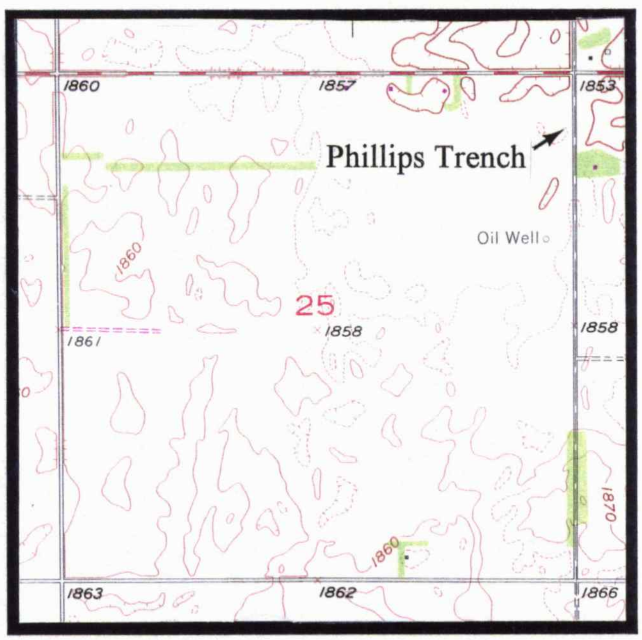


Figure 5:39. Topographic map in the vicinity of the Phillips Trench. Scale = 1:24,000 (Ellinwood SW 7.5 min. Quadrangle, 1957).

lower pair in silty sand and the upper in sand. In general, deposits are loamy, very poorly sorted, finely to very finely skewed, and very platykurtic to leptokurtic.

The lowermost unit is Unit III, ranging from 2.35 m to the base of the trench at 2.72 m (Figs. 5:40, 5:41, 5:42). Sediments are loam and have a mean particle size consisting of medium to fine silt. Sorting is very poor because the 95th percentile is fine clay and the 5th percentile is very fine sand, and the distribution is finely skewed and leptokurtic to mesokurtic (Fig. 5:41).

Formed throughout Unit III is a well developed soil, consisting of two, slightly oxidized 3Btb horizons that contain less than 0.5 percent carbonate and organic carbon. The 3Btb2 (2.61 - 2.80 m; Fig. 5:42) is sandy loam (62.5% sand; 25.0% silt; 12.5%clay; Fig. 5:41), brown (10YR5/3; moist), and has a moderate prismatic structure that parts to weak to moderate subangular blocky. Overlying is the 3Btb1 horizon (2.35 - 2.61m; Fig. 5:42). Although texture is loam throughout the 3Btb1, percent silt increases from 38.8 at 2.60 m to 49.9 at 2.48 m. The 3Btb1 is dark brown (10YR4/3; moist) and has a moderate prismatic structure that parts to moderate subangular blocky. Although a radiocarbon age was not obtained on the 3Btb1, it is very similar in color, texture, and stratigraphic position with a soil dated to about 21,000 yrs B.P. at the Belpre Trench.

Overlying is Unit II, ranging from 33 cm to 2.35 m (Figs. 5:40; 5:41; 5:42) and clearly illustrated by the high percentages of silt and clay in the middle part of the profile. Texture ranges from silt loam to silty clay loam and mean particle size varies

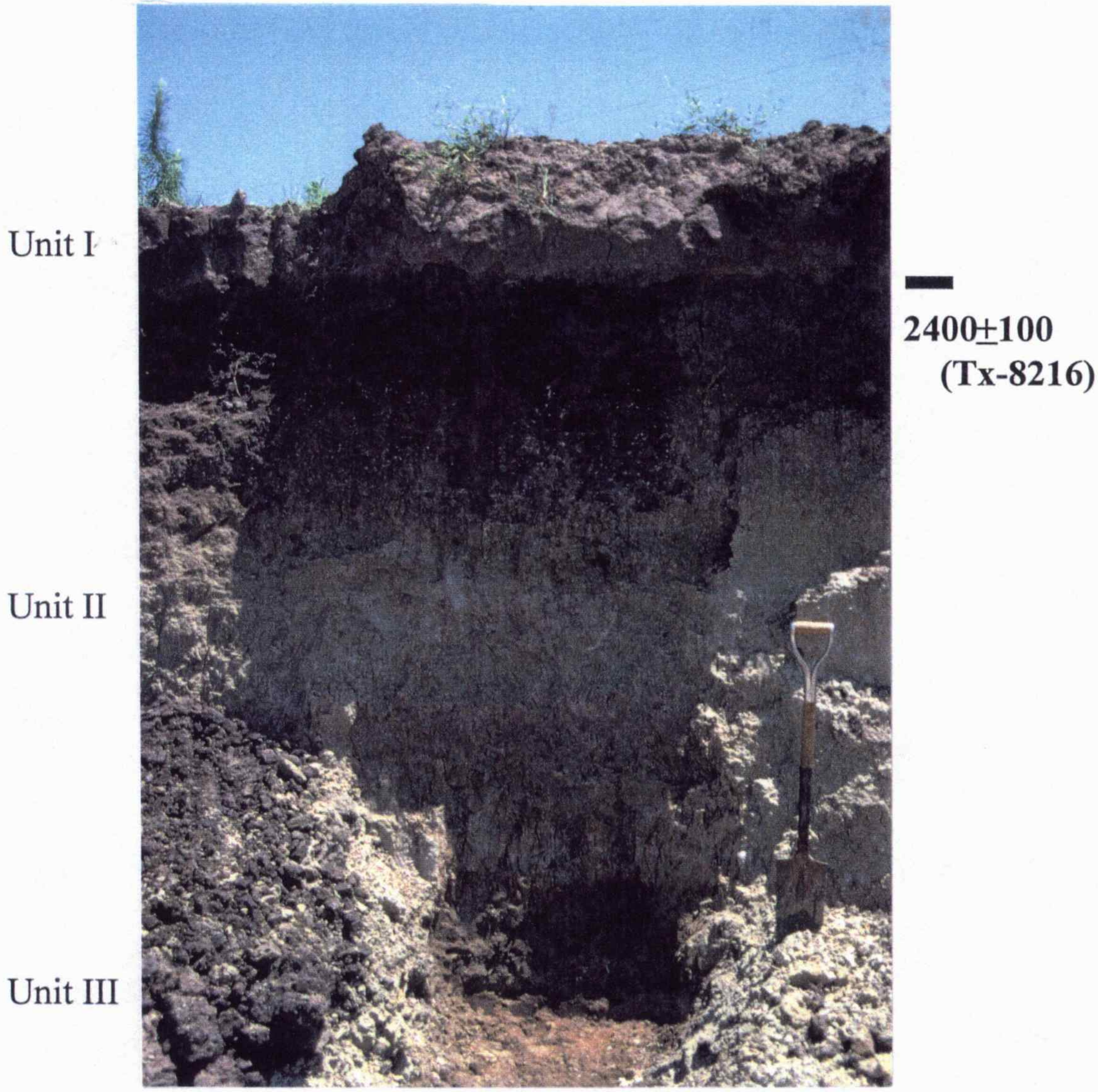


Figure 5:40. Phillips Trench (2.70-m high) showing pedostratigraphic units and radiocarbon age.

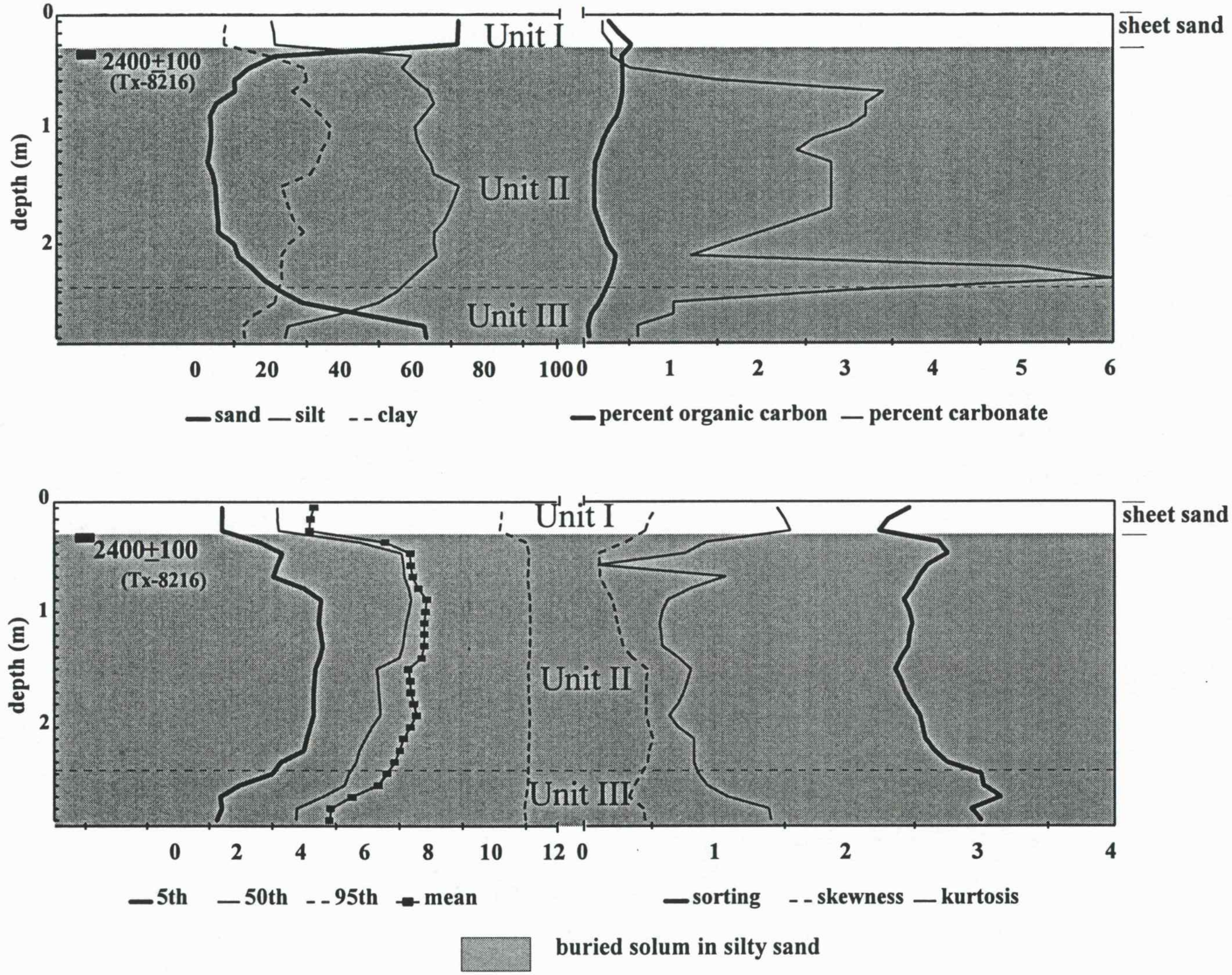


Figure 5:41. Graphical statistics and chemical composition of sediments at the Phillips Trench.

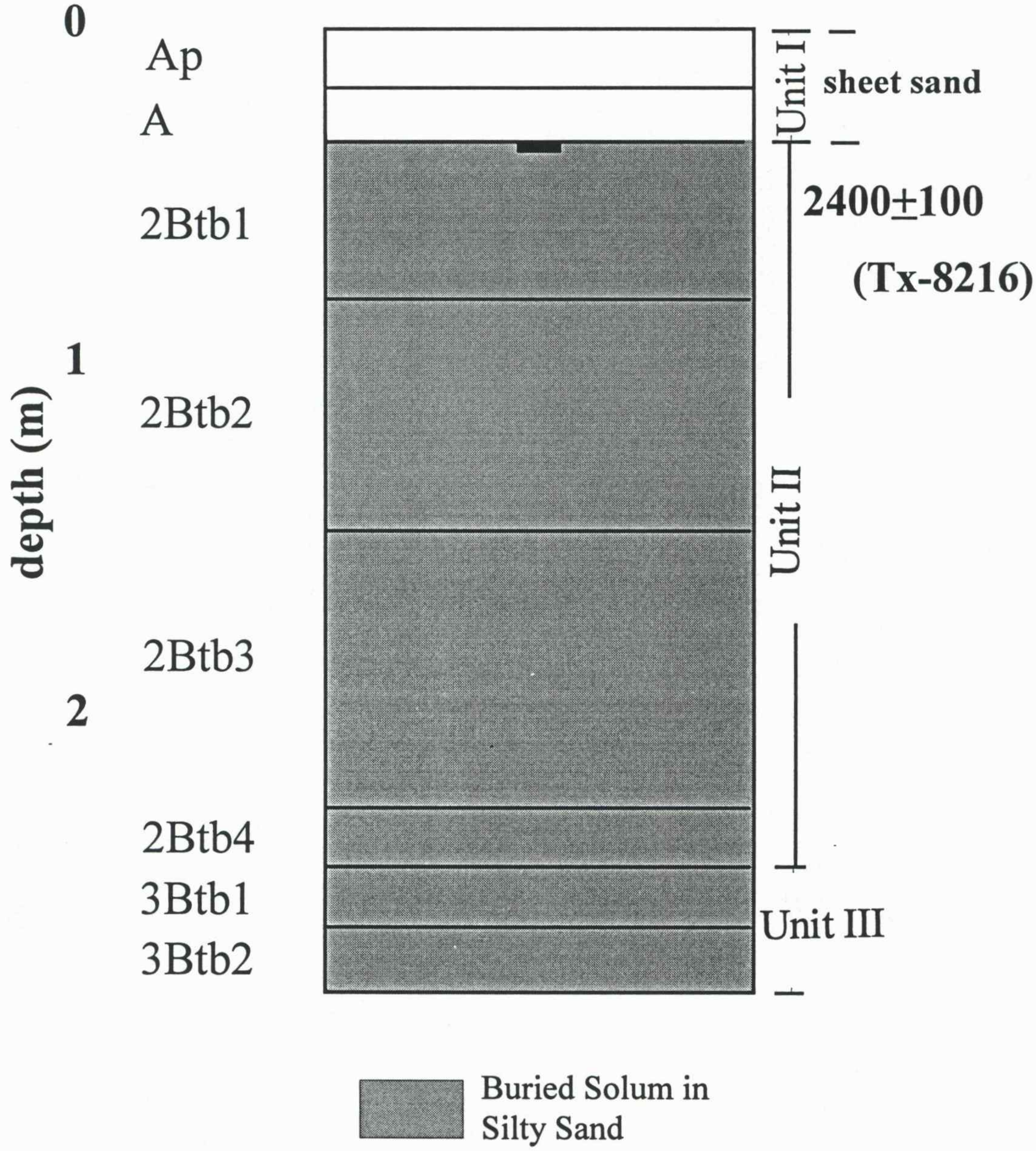


Figure 5:42 Soil stratigraphy at the Phillips Trench.

from fine to very fine silt. Although sorting is noticeably better in Unit II than Unit III, it remains very poor because the 95th percentile is fine clay, whereas the 5th is coarse silt. In addition, the distribution is fine to very finely skewed and mesokurtic to very platykurtic (Fig. 5:41).

Formed throughout Unit II is a well developed soil, one consisting of four 2Btb horizons. The 2Btb4 horizon (2.18 - 2.35 m; Fig. 5:42) is silt loam (ca. 15% sand, 61% silt, and 24% clay), pale brown (10YR6/3; moist), has a moderate prismatic structure that parts to moderate subangular blocky, and contains between 6.0 (2.28 m) and 1.6 percent (1.6 m) carbonate and less than percent organic carbon (Fig. 5:41). Of particular interest, the 2Btb4 contains abundant gastropods, the vast majority of which are fragmented. A few intact specimens were recovered, however, including the terrestrial species *Discus cronkhitei*, *Helicodiscus singleyanus*, *Succinea avara*, and *Vertigo tridentata*. In addition, a single clam was recovered, which may be *Spaerium solidulum* (Fig. 5:43).

The 2Btb3 and 2Btb2 are unoxidized, very silty, and slightly calcareous horizons that vary primarily in texture and color. The pale brown (10YR6/3; moist) 2Btb3 (1.44 - 2.18 m; Fig. 5:42) horizon is silt loam (ca. 5% sand; 70% silt; 25% clay), has a moderate prismatic structure that parts to moderate subangular blocky, and contains about 3.0 percent carbonate and less than 0.5 percent organic carbon (Fig. 5:41). Overlying is the 66-cm-thick, dark grayish brown (10YR4/2; moist) to very dark grayish

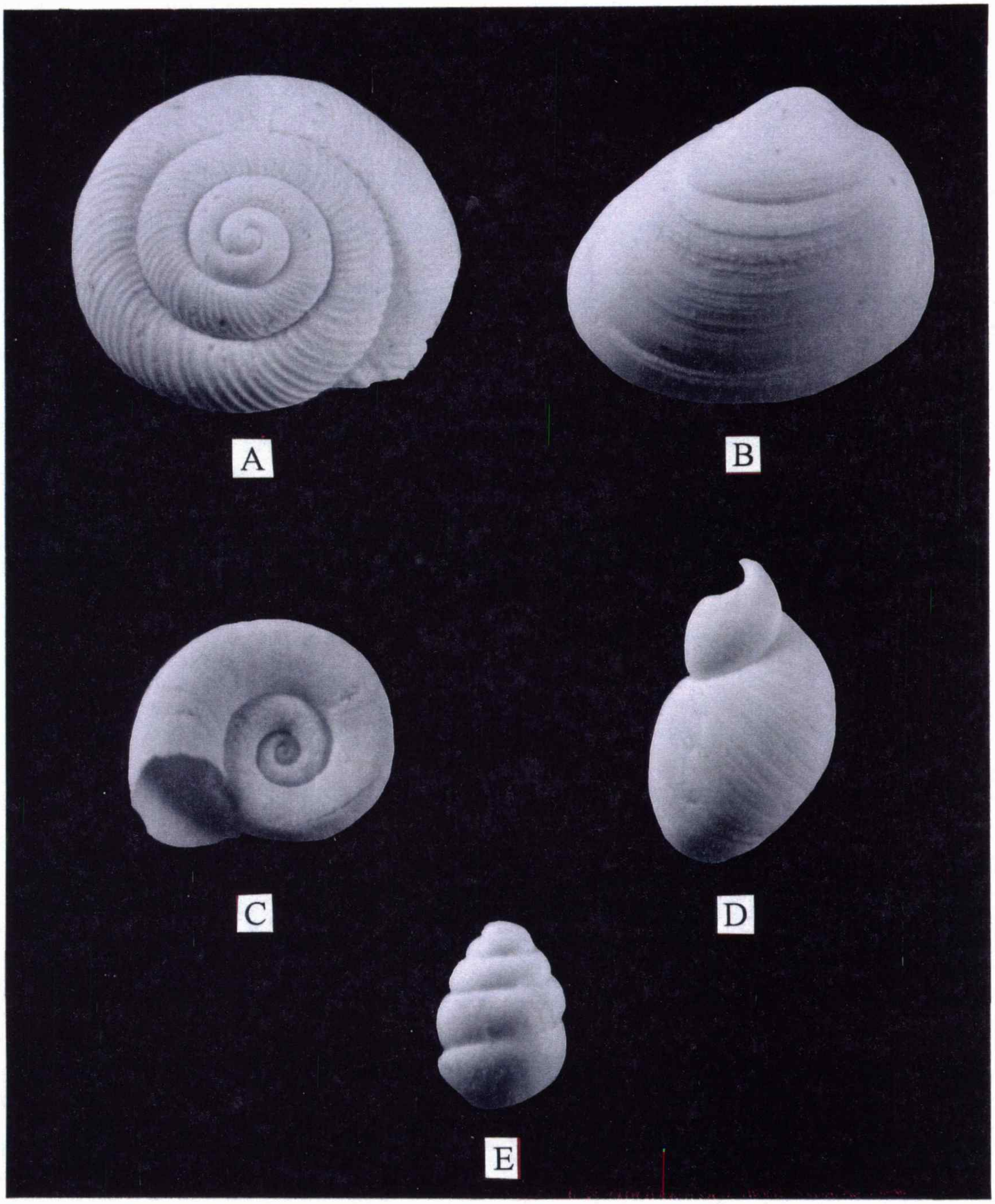


Figure 5:43 Gastropods at the Phillips Trench (magnification 10x): (A) *Discus cronkhitei*, (B) unidentified bivalve, (C) *Helicodiscus syngleyanus*, (D) *Succinea avara*, (E) *Vertigo tridentata*.

brown (10YR3/2; moist) 2Btb2 horizon (Fig. 5:42). Silty clay loam (2.7% sand; 64.1% silt; 33.2% clay) in texture, the 2Btb2 has a moderate prismatic structure that parts to moderate subangular blocky (Fig. 5:41). The 2Btb1 horizon (33 - 78 cm; Fig. 5:42) is very dark grayish brown (10YR3/2; moist) to black (10YR2/1; moist), silt loam (10.3% sand; 63.7% silt; 26.0% clay), contains about 3.5 percent carbonate and less than 0.5 percent organic carbon (Fig. 5:41), and has a strong prismatic structure that parts to strong subangular blocky. To estimate the mean residence time of humates in the upper 5 cm (33 - 38 cm) of the 2Btb1 horizon, a sample provided a $\delta^{13}C$-corrected radiocarbon age of 2400$\pm$100 yrs B.P. and a $\delta^{13}C$ value of -15.8‰ (Tx-8216).

Overlying, with sharp stratigraphic contact at 33 cm (Fig. 5:41), is Unit I (Figs. 5:40, 5:41, 5:42). In contrast to Unit II, Unit I is much coarser, consisting of about 72 percent sand with coarse silt as a mean particle size. Although sorting is clearly better in Unit I than the underlying deposits, it remains very poor because the distribution ranges from medium clay in the 95th percentile to very fine sand in the 5th. In addition, the distribution is finely skewed and very leptokurtic (Fig. 5:41).

Essentially, Unit I consists of a weak to moderately developed surface soil, consisting of an 18-cm-thick Ap and 15-cm-thick A horizon (Fig. 5:42). Both the Ap and A are loamy fine sand (ca. 72 % sand; 21% silt; 7% clay), very dark grayish brown (10YR3/2; moist), and contain less than 1.0 percent carbonate and organic carbon (Fig. 5:41). The primary difference between the Ap and A horizon is structural, with the A weak subangular blocky parting to single grain while the Ap has a single grain structure.

In summary, the Phillips Trench is a 2.72-m-deep, drainage-pit exposure in the low relief sand sheet southwest of Great Bend. Three pedostratigraphic units were recognized, indicating at least three intervals of rapid sedimentation, interrupted by landscape stability and soil formation, occurred at the site during the late Quaternary.

Unit III is the basal deposit, ranging from about 2.35 to 2.7 m and consisting of very poorly sorted, sandy sediments that are rich in silt. The deposit is slightly oxidized, indicating that some wetting and drying occurred following sedimentation. A well developed soil subsequently formed, consisting of at least two 3Btb horizons. Although a radiocarbon age was not obtained from the soil, the solum is very similar in color, texture, and stratigraphic position with a buried soil recognized at the Belpre Trench that was dated to about 21,000 yrs B.P. As a result, Unit III is assigned a late Wisconsin age.

Overlying is a 1.98-cm-thick deposit, dominately composed of calcareous silt and clay, that comprises Unit II. The lower 58 cm of Unit II is slightly oxidized, suggesting periodically moist conditions. Abundant gastropods, the majority of which were fragmented, were also observed at the base of the deposit. A few intact specimens were recovered, however, and their speciation (i.e., *Discus cronkhitei, Helicodiscus singleyanus, Succinea avara, Vertigo tridentata*) provide additional evidence for a cooler environment with probably more effective moisture, possibly during the early

Woodfordian. Subsequently, a 1.12-m-thick deposit of silt and clay accumulated that is slightly calcareous. In general, the stratum is similar in character (e.g., color, texture) with Peoria loess (Wells and Stewart, 1987; Johnson, 1993; Johnson et al., 1993) which has been recognized to the north and south the Great Bend Sand Prairie (Feng, 1991; Feng et al., 1994). Given the late Farmdalian age assigned to the top of Unit III, a Woodfordian age is logical for Unit II. Although no sedimentary structures were observed, the very poorly sorted nature of Unit II, coupled with its loess-like nature, implies deposition by eolian processes. A long period of landscape stability must have subsequently occurred, promoting formation of a very well developed soil. A radiocarbon age of about 2400 yrs B.P. was obtained from the upper 5 cm of Unit II, suggesting exposure during the late Holocene.

Overlying, with an extremely sharp stratigraphic contact, is Unit I. Whereas Unit II consists largely of silt and clay, Unit I is dominantly sand. Unit I is very poorly sorted, suggesting a nearby source (e.g., silty sand) that had a wide range of textures available for transport. A maximum-limiting age of approximately 2400 yrs B.P., derived from the top of Unit II, indicates that Unit I is a late Holocene deposit. Moreover, a $\delta^{13}C$ value of -15.8‰ implies that the climate was relatively warm and probably dry, as compared to when gastropods inhabited the site during the Woodfordian. The surface has been stable for a relatively brief period of time, as indicated by the weakly developed surface soil which has formed.

Reno 3

Reno 3 was a 3.24-m-deep backhoe trench exposure, excavated in a compound parabolic dune field, in the SE SE sec. 12, T.25S., R10 W (Figs. 5:1; 5:44). Four pedostratigraphic units were recognized, consisting of one in silty sand and two in sediments dominantly composed of sand (Figs. 5:45, 5:46, 5:47). In general, sediments at Reno 3 are loamy, have a mean particle size of medium silt to very fine sand, are very poorly to moderately sorted, very fine to finely skewed, and platykurtic to very leptokurtic. Graphical statistics, as well as the chemical composition of sediments are illustrated in Figure (Fig. 5:46). The lowermost unit, extending from 2.70 to the base of the profile, is Unit IV (Figs. 5:45; 5:46; 5:47). Generally, the sediments in Unit IV are heavily gleyed and fine textured, consisting of sandy clay loam at the base and silt loam at the top; meanparticle size is medium silt. Sorting is very poor because the 5thpercentile is fine sand and the 95th is fine clay, and the deposit is very finely skewed

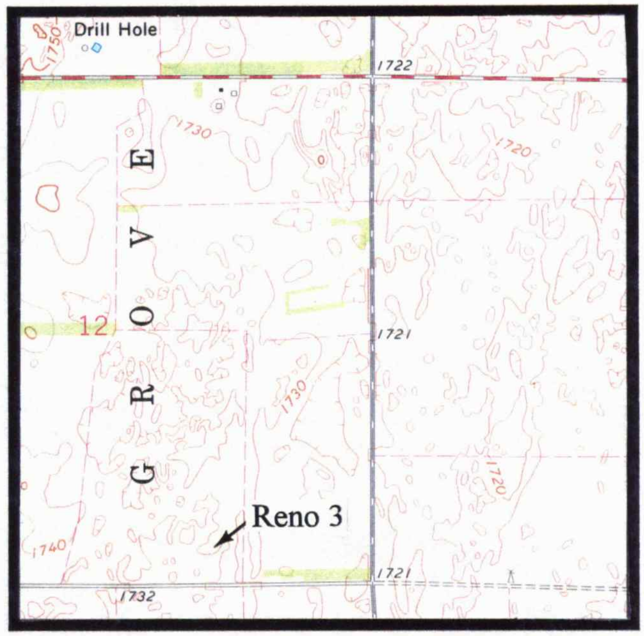


Figure 5:44. Topographic map in the vicinity of Reno 3. Scale = 1:24,000 (Plevna 7.5 min. Quadrangle, 1971).

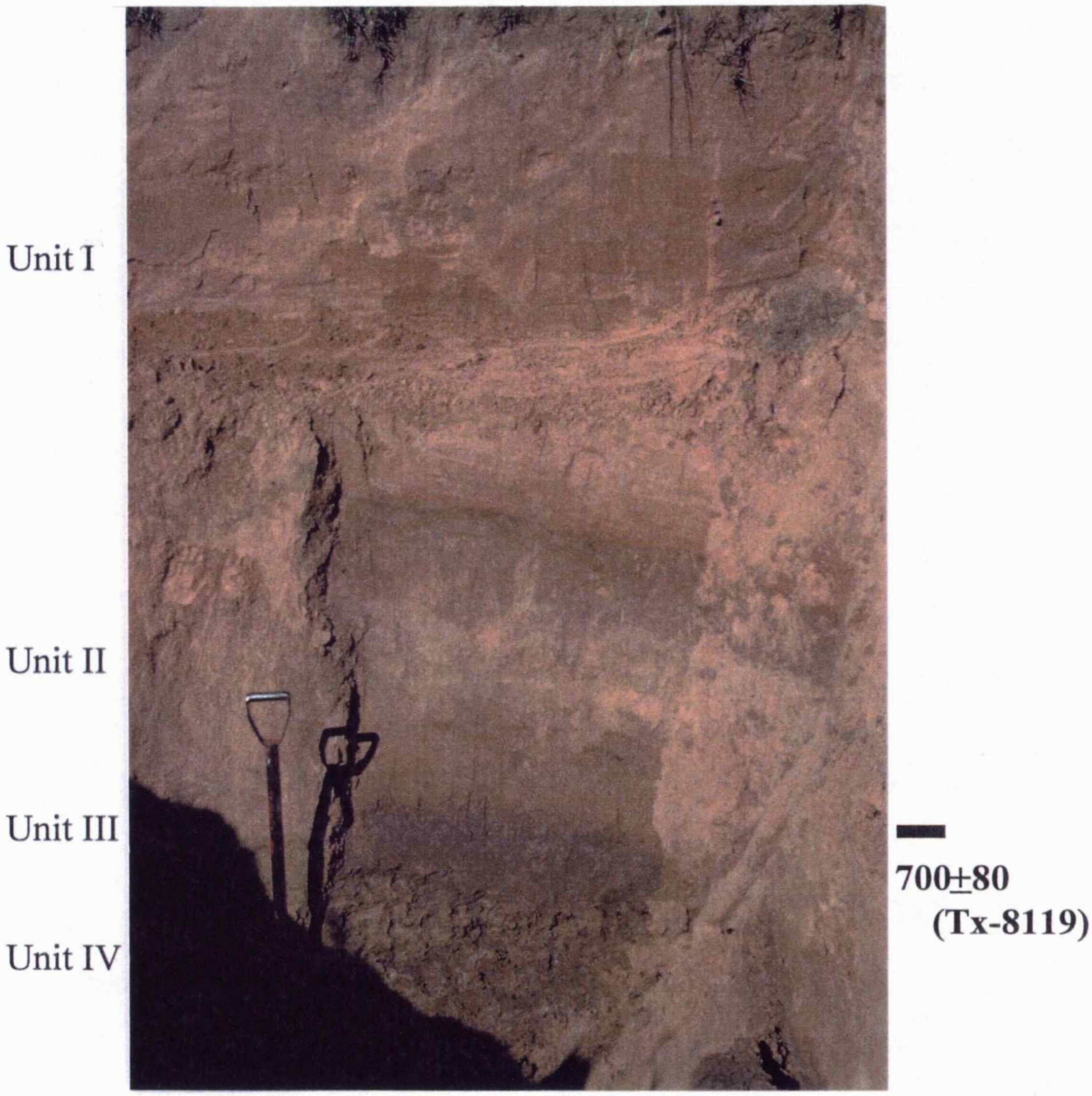


Figure 5:45. Reno 3 (3.24-m high) showing pedostratigraphic units and radiocarbon age.

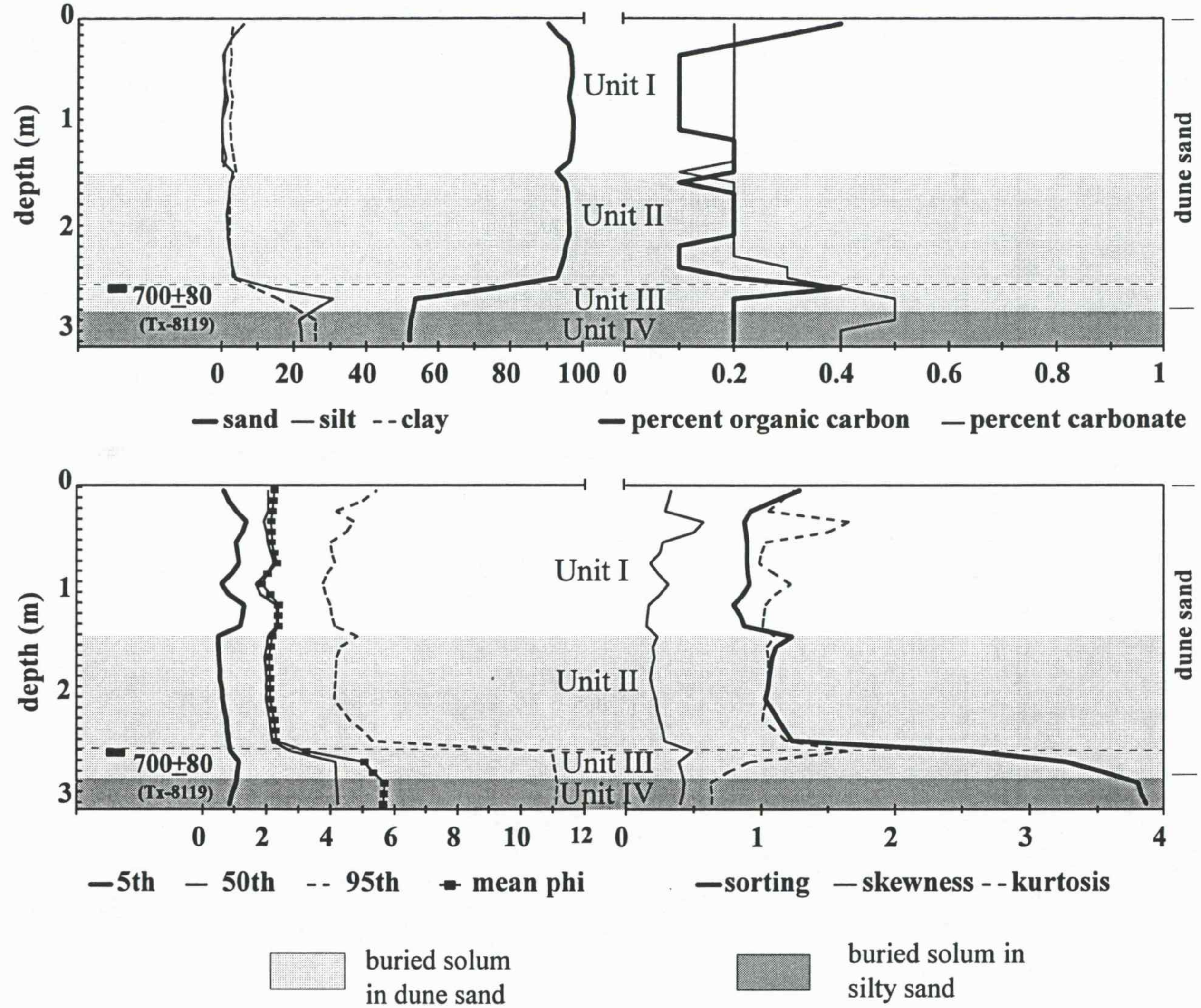


Figure 5:46. Graphical statistics and chemical composition of sediments at Reno 3.

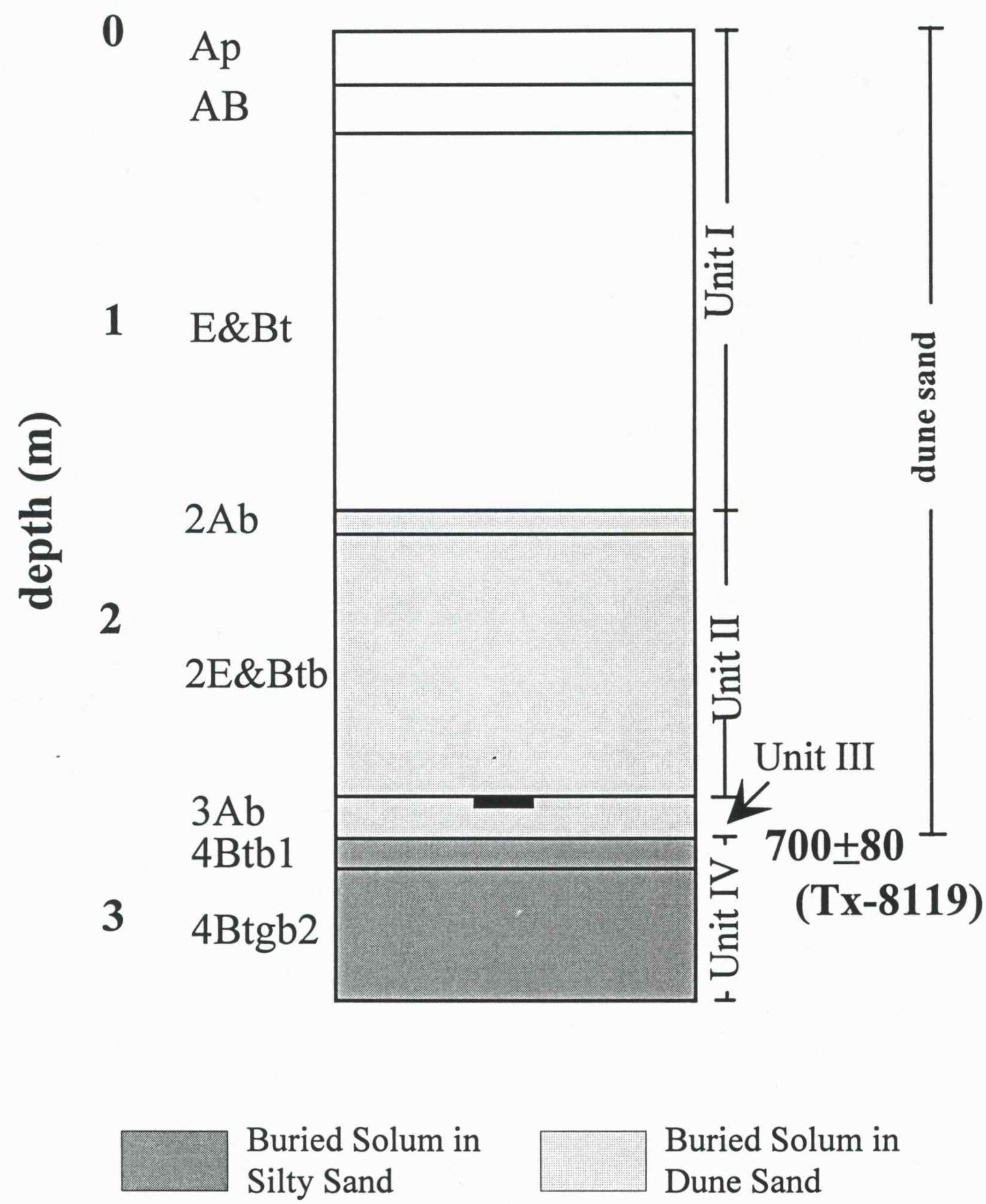


Figure 5:47. Soil stratigraphy and the radiocarbon age at Reno 3.

and platykurtic (Fig. 5:46). Contained within Unit IV is a well developed buried soil, consisting of one 4Btb and one 4Btgb that were very similar in character, i.e., mottled brown (10YR5/3; moist), sandy clay loam (ca. 51.8% sand, 22.1% silt, 26.1% clay), containing less than 1.0 percent carbonate and organic carbon (Fig. 5:46), and having a moderate prismatic structure that parts to moderate subangular blocky. The 4Btgb2 horizon extends from 2.81 to the base of the profile, whereas the 4Btb1 ranges from 2.70 to 2.81 m, (Fig. 5:47).

A sharp stratigraphic contact at 2.70 m, observed in nearly all parameters, identifies the boundary between Unit IV and Unit III. Mean particle size, for example, shifts to very fine sand, and is accompanied by a further improvement in sorting (Fig. 5:46). Essentially, Unit III consists of a 13-cm-thick 3Ab horizon (Fig. 5:47), one that is loamy fine sand (76.6 % sand; 14.0 % silt; 9.4% clay), has prismatic to granular and single grained structure, and contains less than 0.5 percent carbonate and organic carbon (Fig. 5:46). Compared to the deposits above and below, the color of the 3Ab is darker, dark brown (10YR3/3; moist). To estimate the mean residence time of humates in the upper 5 cm (2.57 - 2.62 m) of the 3Ab, a sample provided a $\delta^{13}C$-corrected radiocarbon age of 700±80 yrs B.P. and $\delta^{13}C$ value of -14.4‰ (Tx-8119)

Overlying is Unit II, ranging from 1.50 to 2.57 m (Figs. 5:45; 5:46; 5:47). The contact between Units III and II is very sharp, as evidenced by the dramatic shift in many parameters. The amount of sand, for example, increases from approximately 76 percent at 2.59 m in Unit III to 93 percent at 2.55 m in Unit II. Sediments throughout Unit II are sand, with a mean particle size of very fine sand. Sorting improves from the underlying deposits, becoming slightly poor to moderate because the 95th percentile shifts to medium silt, and the distribution is very finely skewed and mesokurtic (Fig. 5:46).

Contained within Unit II is a weak to moderately developed buried soil, consisting of a 7-cm-thick 2Ab horizon overlying a 1.0-m-thick 2E&Btb horizon (Fig. 5:47) that was distinguished by the presence of four, thin (< 1 cm), weakly developed and convoluted lamellae. The sediment in both horizons is sand (ca. 95% sand; 2.5% silt; 2.5% clay), with the highest percentage of sand (e.g., 96.3%) in the 2E&Btb at a depth of 2.07 m. In the 2Ab, the amount of sand decreases slightly to 92.7 percent as silt and clay increase to 3.1 and 4.2 percent, respectively. Structure improves somewhat from single grain in the 2E&Btb to weak, fine subangular blocky, parting to single grain, in the 2Ab. Color is dark brown (10YR4/3; moist) at 2.53 m in the 2E&Btb and in the upper 19 cm of the soil. In between, color is dark yellowish brown (10YR4/4; moist). In general, both horizons contain less than 0.5 percent carbonate and organic carbon (Fig. 5:46).

The uppermost deposit, Unit I, extends from the surface to 1.50 m (Figs. 5:45; 5:46: 5:47). In general, the deposit is consistent with Unit II, i.e., sediments are sandy in texture, contain less than 0.5 percent carbonate and organic carbon, are moderately sorted, finely skewed, and mesokurtic (Fig. 5:46). Contained within Unit I is the surface soil, consisting of an 18-cm-thick A horizon, a 15-cm-thick AB horizon, and 1.17-m-thick E&Bt horizon (Fig. 5:47) that was distinguised by 7 to 10 thin (< 1 cm), weakly developed and convoluted lamellae. Similar to the 2E&Btb, the E&Bt is sand (ca. ca. 96% sand; 2% silt; 2% clay; Fig. 5:46), with the highest percentage of sand (97.4%) occurring at 1.0 m, dark yellowish brown (10YR4/4; moist), and has a structure of single grain. Transitional to the A horizon is the very dark grayish brown (10YR3/2; moist) AB horizon (18 - 33 cm; Fig. 5:47), which is sand (96.0% sand; 1.6% silt; 2.4% clay; Fig. 5:46), and has a very weak subangular blocky structure that parts to single grain. Overlying is the very dark grayish brown (10YR3/2; moist) Ap horizon, ranging from the surface to 18 cm (Fig. 5:47). Although the Ap is texturally similar (i.e., sand) to the underlying horizons, percent sand decreases to 90.4 percent whereas silt and clay increase to 6.3 and 3.3 percent, respectively (Fig. 5:46). Structure within the Ap is granular parting to single grain.

In summary, Reno 3 is a 3.24-m-deep stratigraphic profile obtained from a backhoe exposure in a compound parabolic dune field in the eastern part of the Great Bend Sand Prairie. Four pedostratigraphic units were recognized, one in silty sand and three largely composed of sand. In general, the sedimentological differences between the silty sand and the overlying sand appear to reflect a shift in depositional environment from low energy alluvial or lacustrine to one where eolian processes dominated in a relatively warm, possibly more arid climate.

The lowermost deposit is Unit IV, extending from 2.70 m to the base of the profile. Unit IV includes very poorly sorted sediments, sandy clay loam in texture, that are consistent with other deposits in the region generically categorized as silty sand. Evidence (e.g., very poor sorting, fining upward sequences) obtained elsewhere (e.g., Edwards 2 - 4) suggests that these deposits accumulated during the late Wisconsin or very early Holocene in a relatively moist, low energy environment where fluvial or lacustrine processes probably dominated. Periodically, Unit IV must have been exposed and stable, as evidenced by a well developed buried soil, consisting of three Btb horizons with prismatic structure, that formed in the deposit. Gleying in the lower two horizons suggests long term ponding of surface water or high groundwater tables from time to time.

Overlying is Unit III, ranging from 2.57 - 2.70 m. In general, Unit III is consistent in texture, structure, and color with sediments categorized as eolian sand in the region, deposits that accumulated in a relatively warm, arid environment. Texture, for example, shows an abrupt increase in sand from the underlying, presumably alluvial unit, Unit IV. Although sorting is improved in Unit III, it is still very poor, suggesting a nearby, very poorly sorted source area such as the underlying silty sand. Alternatively, mobilizing winds could have varied in intensity, resulting in accumulation of various textures. Essentially, Unit III consists of a 3Ab soil horizon with weak subangular blocky structure, parting to single grain, that is also characteristic of a soil buried in eolian sand. A radiocarbon age of about 700 yrs B.P. suggests accumulation during the very late Holocene when the climate was apparently warm with less effective moisture, one that promoted inhabitation by C_4 plants, as implied by a $\delta^{13}C$ value of -14.4‰.

The surficial deposits at Reno 3 consist of two stratigraphic units, Units II and I. Similar in character, the sediments clearly represent a period of eolian sand deposition, one that was punctuated by a brief period of soil formation at the end of Unit II sedimentation. The deposits in both units are classified as sand, with as much as 97.4 percent sand present (e.g., 1.0 m). Compared to the underlying deposits, sorting improves sharply to moderate, suggesting that eolian processes were dominant and the source was relatively well sorted. Each unit contains a weakly developed soil virtually identical in character, consisting of thin A horizons overlying thick E&Bt horizons. Although the development of Bt horizons suggest long term stability, they are distinguished only by the presence of thin, weakly developed silt and clay lamellae that could have formed in a relatively brief period of time. In addition, the structure of the E&Bt horizons is single grain, further indicating short-term pedogensis. Overall, both Units II and I appear to have accumulated in approximately the last 1000 years, as suggested by a maximum-limiting age of about 700 yrs B.P from the underlying 3Ab.

The last milenium at Reno 3, therefore, can be characterized as a period of episodic, eolian sand deposition. The lack of a well developed surface soil suggests that the site has been stable for only a brief period of time.

Reno 4

Reno 4 was a 4-m deep backhoe-trench exposure located in a compound sub-parabolic dune field in the SE, SW, sec. 10, T.25S., R.10W (Figs. 5:1, 5:48). Three pedostratigraphic units, consisting of a deposit of silty sand overlain by eolian sand were described (Figs. 5:49, 5:50, 5:51). Sediments are generally loamy, poorly to very poorly sorted, finely skewed, mesokurtic to very leptokurtic, and have a mean particle size ranging from fine silt to fine sand (Fig. 5:50).

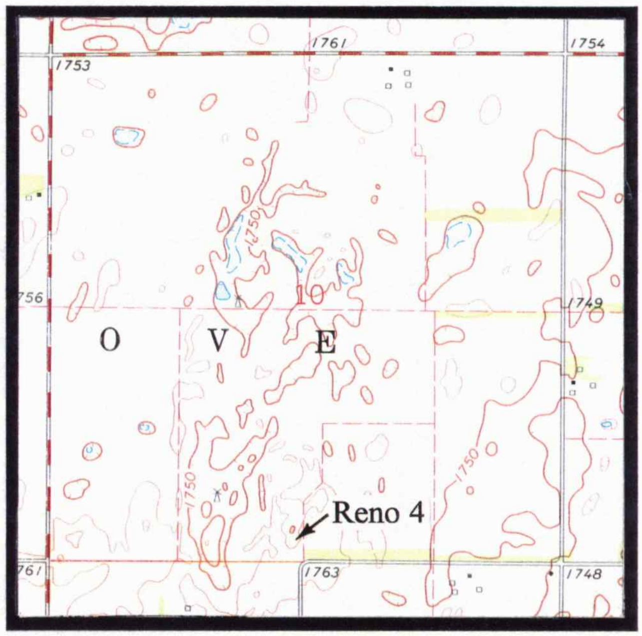


Figure 5:48. Topographic map in the vicinity of Reno 4. Scale = 1:24,000 (Sylvia 7.5 min. Quadrangle, 1971).

The lowermost pedostratigraphic unit at Reno 4 is Unit III, ranging in depth from about 2.27 m to the base of the profile (Figs. 5:49, 5:50, 5:51). Sediments fine upward

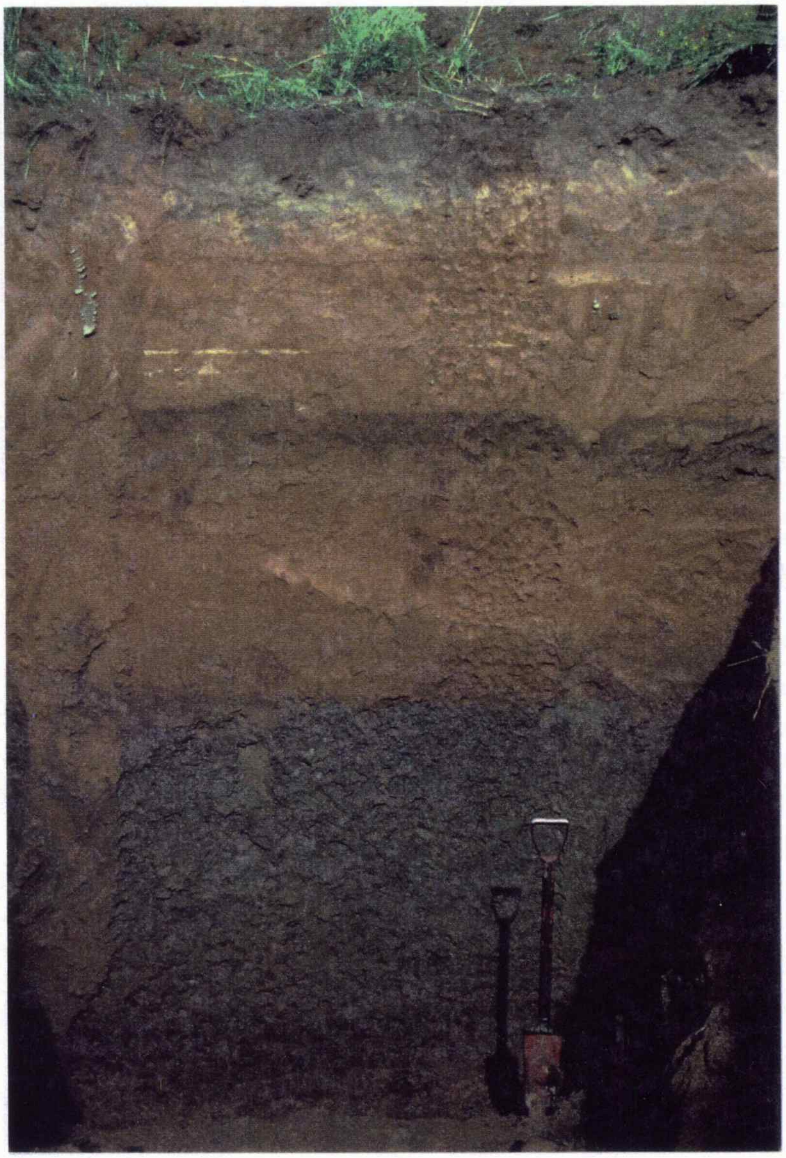


Figure 5:49. Reno 4 (4.0-m high) showing pedostratigraphic units and radiocarbon ages.

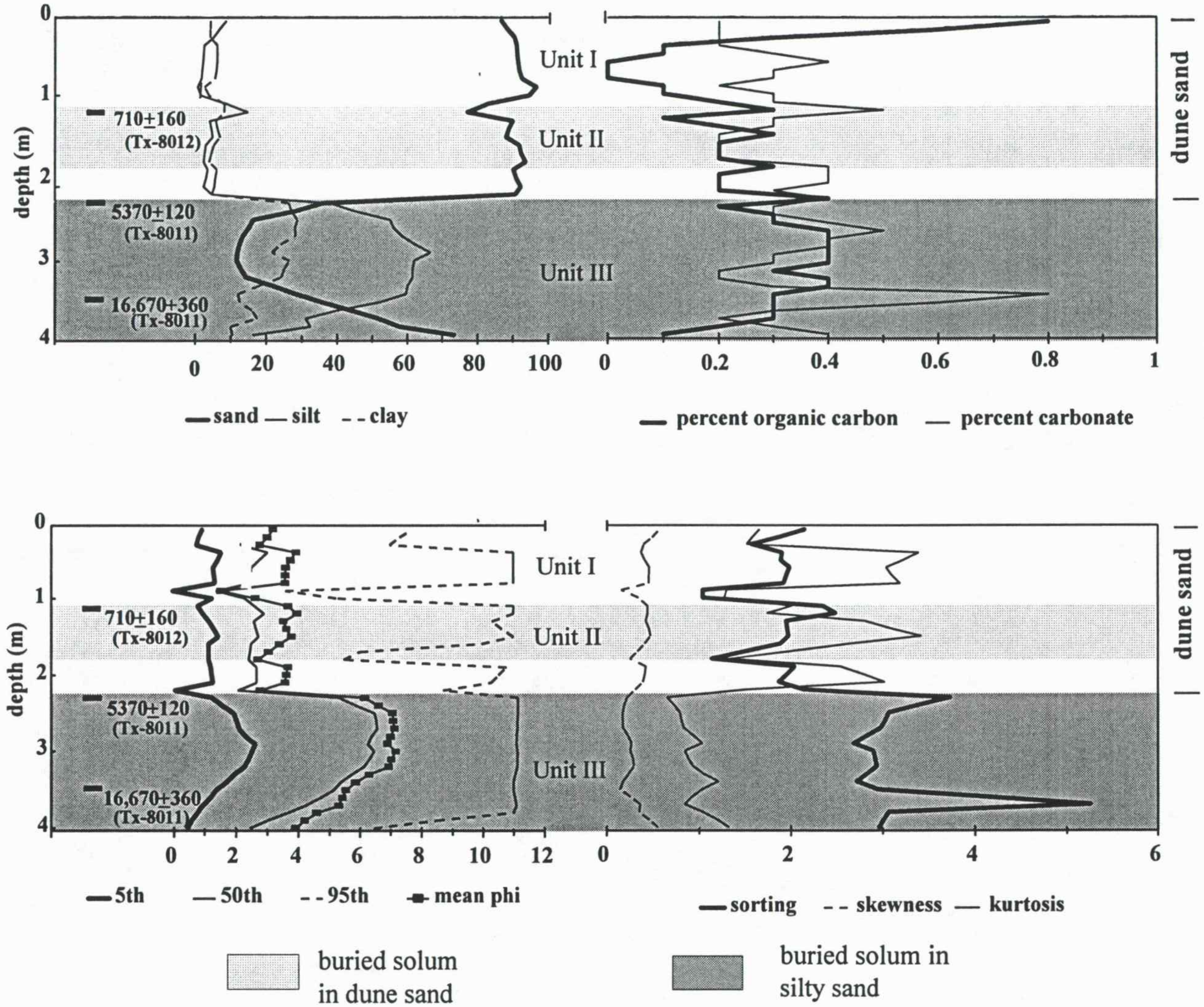


Figure 5:50. Graphical statistics and chemical composition of sediments at Reno 4.

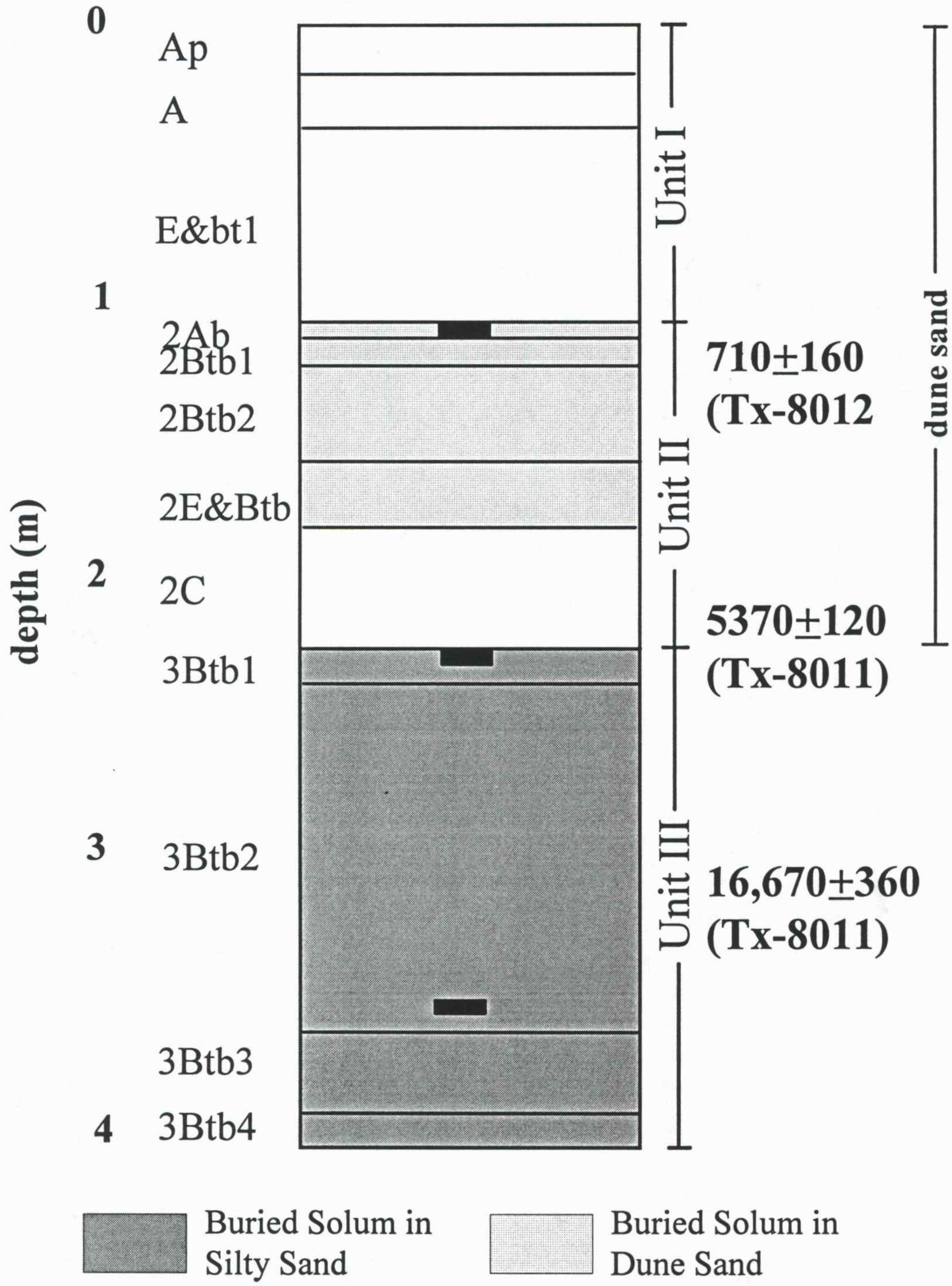


Figure 5:51. Soil stratigraphy and radiocarbon ages at Reno 4.

from silt loam, loam, sandy loam, and fine sandy loam to the top of the unit. Sorting is very poor, and is extremely poor from about 3.5 to 3.6 m because particle size ranges from fine sand in the 5th percentile to fine clay in the 95th. In addition, the stratum is very fine skewed and slightly leptokurtic to mesokurtic (Fig. 5:50).

Formed throughout Unit III is a well developed buried soil, consisting of four 3Btb horizons (Fig. 5:51) that are distinguished by texture and color because they are structurally (i.e., weak prismatic parting to moderate subangular blocky) and chemically (i.e., <1% carbonate; ca. 0.5% organic carbon; Fig. 5:50) consistent. The 3Btb4 horizon (3.95 - 4.07 m; Fig. 5:51) is loamy fine sand (73.3% sand, 16.1% silt, 10.6% clay) and dark brown (10YR4/3; moist). Overlying is the dark brown (10YR4/3; moist), sandy loam (ca. 54% sand, 32% silt, 14% clay; Fig. 5:50) 3Btb3 horizon, which extends from 3.66 to 3.95 m (Fig 5:51).

The 3Btb2 (2.40 - 3.66 m; Fig. 5:51) is silt loam (ca. 15% sand, 60% silt, 25% clay; Fig. 5:50), dark brown (10YR4/3; moist) to dark grayish brown (10YR4/2; moist), and has moderate prismatic parting to moderate subangular blocky structure. To approximate the mean residence time of humates in the lower part (3.50 - 3.55 m) of the 3Btgb3, a sample provided a $\delta^{13}C$-corrected radiocarbon age 16,670$\pm$360 yrs B.P. and a $\delta^{13}C$ value of -19.9‰ (Tx-8010).

Percent sand increases sharply in the 13-cm-thick 3Btb1 horizon (Fig. 5:51), which is classified as loam (35.8% sand, 38% silt, 26.2% clay; Fig. 5:50), and dark grayish brown (10YR4/2; moist). To determine the mean residence time of humates in the upper 5 cm (2.27 - 2..32 m) of the 3Btb1, a sample produced a $\delta^{13}C$-corrected radiocarbon age of 5370±120 yrs B.P. and a δ^{13} value of -17.7‰ (Tx-8011). Overlying, with a very sharp contact at 2.27 m (Figs. 5:49, 5:50, 5:51), is Unit II. Extending from 1.10 to 2.27 m, Unit II is very sandy, very poorly to poorly sorted, finely skewed, and leptokurtic to very leptokurtic (Fig. 5:50).

Formed in Unit II is a moderately developed soil, comprised of a 2Ab horizon that overlies two 2Btb horizons, one 2E&Btb horizon, and one 2C horizon. The 2C horizon (1.84 - 2.27 m; Fig. 5:51) is sandy (ca. 91% sand, 4% silt, 5% clay), dark yellowish brown (10YR4/4; moist), has single grain structure, and contains less than 0.5 percent carbonate and organic carbon (Fig. 5:50).

Overlying is a 24-cm-thick 2E&Btb horizon (Fig. 5:51). Sand (93.7% sand, 2.4% silt, 3.9% clay), with a very weak subangular blocky structure and dark yellowish brown (10YR4/4; moist) color, the 2E&Btb was distinguished on the basis of seven, convoluted lamellae less than 1 cm thick; the 2E&Btb contains less than 0.5 percent carbonate and organic carbon (Fig. 5:50).

Two 2Btb horizons, which were described on the basis of illuviated clay films in root casts, lie above the 2E&Btb horizon. Very similar to one another, the 2Btb2 (1.26 - 1.60 m) and 2Btb1 (1.15 - 1.26 m; Fig. 5:51) differ slightly in color and texture. The 2Btb2 is brown (10YR4/3; moist) sand (ca. 90% sand, 5% silt, 6% clay). In contrast, the 2Btb1 is dark brown (10YR3/3; moist) and loamy fine sand (77.1% sand, 14.9% silt, 8.0% clay). Otherwise, each horizon has the same structure (i.e., weak subangular blocky), and contains less than 0.5 percent carbonate and organic carbon (Fig. 5:50).

Developed at the top of the soil in Unit II is a 5-cm-thick, very dark grayish brown (10YR3/2; moist) 2Ab horizon (Fig. 5:51) that has a very weak subangular blocky structure that parts to single grain, a fine sandy loam (83.0% sand, 8.6% silt, 8.4% clay) texture, and contains less than 0.5 percent carbonate and organic carbon (Fig. 5:50). To estimate the mean residence time of humates from the upper 5 cm (1.10 - 1.15 m) of the 2Ab, a sample provided a $\delta^{13}C$-corrected age of 710$\pm$80 yrs B.P. and a $\delta^{13}C$ value of -12.4 (Tx- 8012).

Capping the stratigraphy at Reno 4 is Unit I, extending from the surface to 1.10 m (Figs. 5:49, 5:50, 5:51). In general, sediments in the unit are very sandy, very poorly to poorly sorted, finely skewed, and leptokurtic to very leptokurtic (Fig. 5:50).

Formed within Unit I is a weak-to-moderately developed surface soil, consisting of two A horizons and one E&Btb horizon. The dark yellowish brown (10YR4/4; moist) to dark brown (10YR3/3; moist) E&Btb horizon (40 cm - 1.10 m; Fig. 5:51) is sand, with percent sand highest (96.8%) at 92 cm. Structurally, the horizon is weak subangular blocky structure that parts to single grain, and it contains less than 0.5 percent carbonate and organic carbon (Fig. 5:50).

Overlying are two A horizons. The A ranges from 20 to 40 cm, whereas the Ap extends from the surface to 20 cm (Fig. 5:51). Both horizons are very dark grayish brown (10YR3/2; moist) and contain less than 0.5 percent carbonate, but percent organic carbon increases sharply from less than 0.5 percent in the A to about 1.0 percent in the Ap. The horizons differ slightly with the A sand (90.6% sand, 5.1% silt, 4.3% clay) and the Ap loamy fine sand (86.8% sand, 8.8% silt, 4.4% clay; Fig. 5:50). The horizons also differ subtly from a structural perspective: the A is weak subangular blocky parting to single grain; the Ap is granular parting to single grain.

In summary, Reno 4 is an approximately 4-m-deep stratigraphic profile described from a backhoe exposure in the compound subparabolic dune field in the eastern part of the Great Bend Sand Prairie. Three pedostratigraphic units were recognized, with the basal one (Unit III) in silty sand overlain by two (Units II, I) in nearly pure sand. In general, the sedimentological and pedogenic differences between Units III and Units II and I appear to reflect diachronous depositional environments at the site in the past 20,000 years.

The lower unit (Unit III), ranging from 2.27 m to the base of the profile, consists largely of gleyed silt, with significant amounts of sand and clay. Essentially, Unit III is very poorly sorted, but is extremely poorly sorted in some places. A radiocarbon age of about 17,000 yrs B.P. was derived from the lower part of the stratum, suggesting sedimentation during the Woodfordian. Unfortunately, diagnostic sedimentary structures are not preserved, making a precise facies determination problematic. The very poorly sorted nature of the deposit, coupled with a distinct fining upward sequence, however, suggests a low energy fluvial or lacustrine environment. Cool conditions, with possibly more effective moisture apparently existed during sedimentation, as implied by a δ^{13} value of -19.9‰ near the base of the unit. Overall, the character of Unit III is entirely consistent with other deposits (Edwards 1 - 4, Reno 3) generally categorized as silty sand on the Great Bend Sand Prairie.

Subsequent to the deposition of Unit III, an extremely well developed soil formed. Whether the soil formed in one interval or several is impossible to determine. The solum is slightly gleyed and contains very little carbonate, suggesting intensive illuviation and/or high groundwater tables. A radiocarbon age of about 5400 yrs B.P. was obtained from the top of the soil, implying exposure during the late Holocene.

Overlying are Units II and I. Although Units II and I represent different pedostratigraphic intervals, they can be grouped together because they are so similar in nature. In stark contrast to the underlying silty sand, Units II and I consist of very sandy deposits that are much better sorted. Essentially, Units II and I are virtually identical in character (e.g., texture, color, structure, stratigraphic position, topographic expression) with deposits recognized throughout the Great Bend Sand Praire as wind-blown, dune sand. Implied in an eolian source, is a relatively warm environment with less effective moisture in comparison to the silty sand.

A maximum-limiting age of approximately 5300 yrs B.P. from the top of Unit III suggests that dune sand has accumulated during the late Holocene at Reno 4. Sedimentation of eolian sand has been episodic, as indicated by the buried soil recognized at the top of Unit II. A radiocarbon age of about 700 yrs B.P. from the upper part of the soil suggests stability occurred between 1000 and 500 years ago. Soil formation evidently lasted for some time, as indicated by the Btb horizons and E&Btb horizon observed in the solum. Apparently, the soil was rapidly buried by an influx of relatively coarse, better sorted eolian sand. Approximately 1.10 m of sand has accumulated at Reno 4 in the past few hundred years. The degree of surface soil development (i.e. two A horizons, E&Bt horizon) indicates that the dune has been stable for perhaps several hundred years.

Stafford 1

Stafford 1 was a 2.50-m-deep backhoe trench exposure excavated in a compound parabolic dune field in the NW, NW, sec. 15, T.25S., R.15W (Figs. 5:1, 5:52). Two pedostratigraphic units were described in the profile, one in silty sand and another, in sand. In general, the deposits at Stafford 1 are loamy, have a mean particle size ranging from medium to coarse silt, are very poorly to poorly sorted, and are very finely skewed and leptokurtic to very leptokurtic.

The lowermost stratigraphic unit is Unit II, ranging from 98 cm to the base of the profile (Figs. 5:53; 5:54; 5:55). Generally classified as sandy loam, the deposit has a mean particle size of medium silt. Figure 5:54 illustrates that the sediment in Unit II is coarsest, however, in the middle of the deposit and fines slightly toward the top and bottom. Sorting is very poor because there is very fine sand in the 5th percentile and fine clay in the 95th. In addition, the distribution is very finely skewed and leptokurtic (Fig. 5:54).

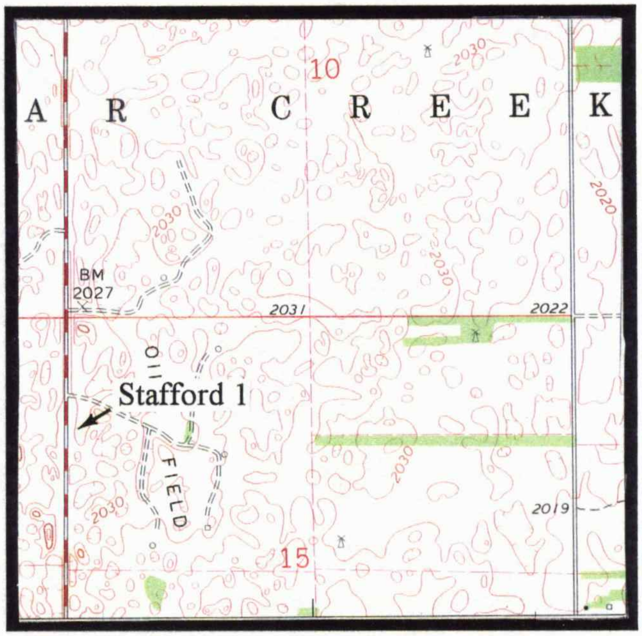


Figure 5:52. Topographic map in the vicinity of Stafford 1. Scale = 1:24,000 (Macksville 7.5 min. Quadrangle, 1972).

Formed in Unit II is a well developed buried soil, consisting of one 2Btkb, one 2Btgb, and two 2Btb horizons that are distinguished by texture, color and chemical composition. The 2Btb5 horizon (2.29 - 2.50 m; Fig. 5:55) is gleyed, sandy loam (ca. 47% sand; 40% silt; 13% clay), brown (10YR5/3; moist), has a moderate prismatic structure that parts to moderate subangular blocky and contains about 1.6 percent carbonate and no organic carbon (Fig. 5:54). Overlying is the 29-cm-thick 2Btkb4 horizon. (Fig. 5:55), which is sandy loam (58.0% sand; 27.4% silt; 14.6% clay) mottled,

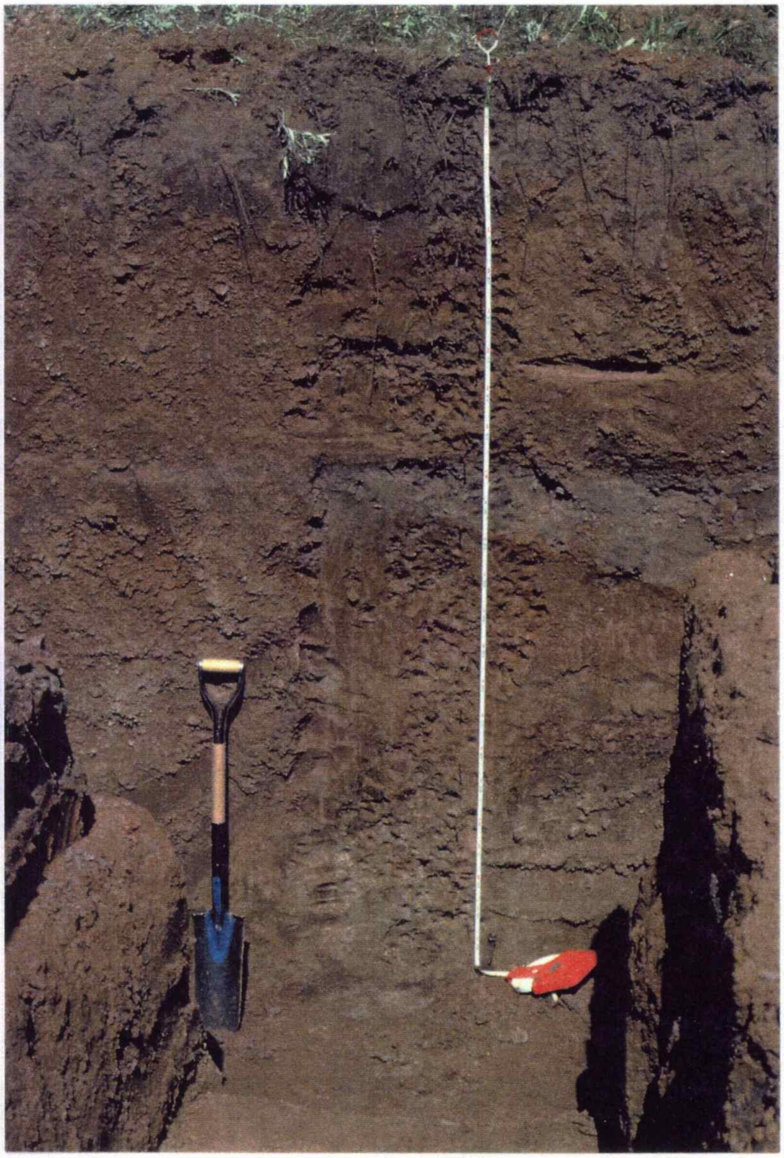


Figure 5:53. Stafford 1 (2.50-m high) showing pedostratigraphic units and radiocarbon age.

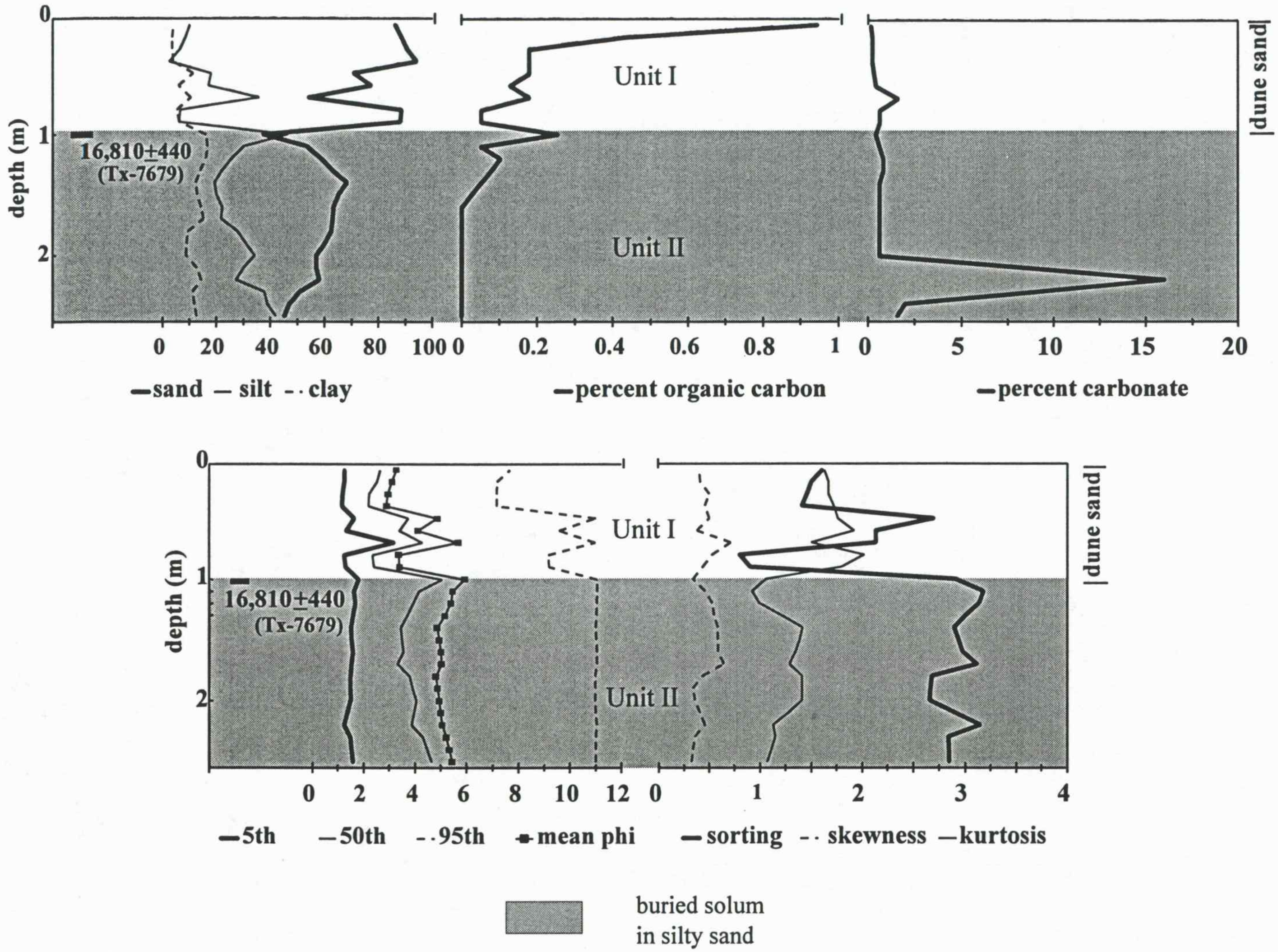


Figure 5:54. Graphical statistics and chemical composition of sediments at Stafford 1.

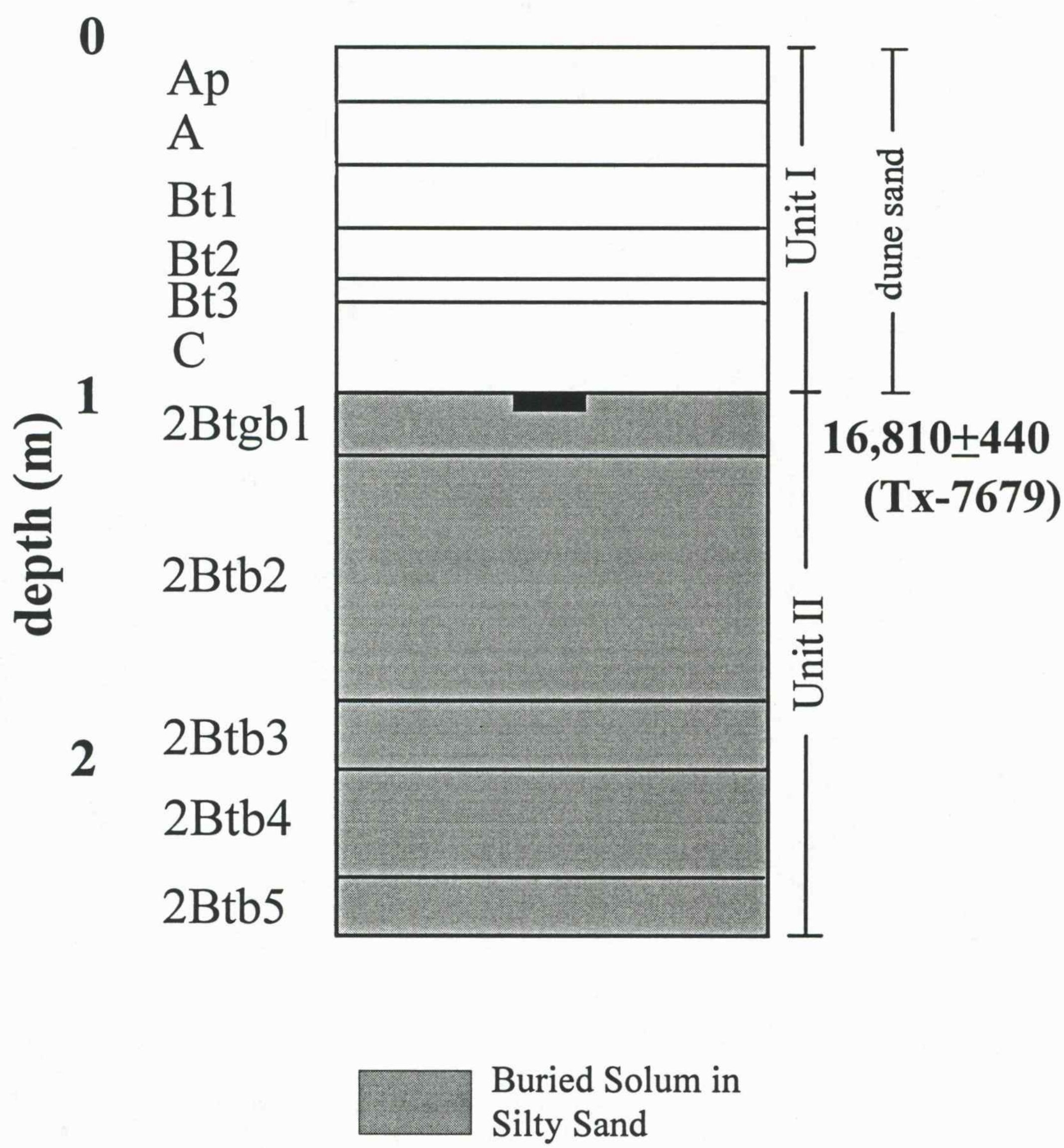


Figure 5:55. Soil stratigraphy and the radiocarbon age at Stafford 1.

yellowish brown (10YR5/4; moist), and has a moderate prismatic structure that parts to moderate subangular blocky. Although no organic carbon is present, carbonate content rises sharply from about 1.6 percent in the 2Btb5 to around 16.0 percent at 2.18 m in the 2Btkb4. Carbonate drops abruptly to less than 1.0 percent in the 2Btb2 horizon (Fig. 5:54), which extends from 1.83 to 2.02 m (Fig. 5:55). The 2Btb3 is sandy loam (58.0% sand; 27.4% silt; 14.6% clay), yellowish brown (10YR5/4; moist), has a moderate prismatic structure that parts to subangular blocky, and contains no organic carbon (Fig. 5:54).

Color is increasingly red, strong brown (7.5YR4/6; moist), in the 2Btb2 (1.15 - 1.83 m; Fig 5:55) horizon. The horizon is sandy loam (62.6% sand; 27.9% silt; 9.5% clay), has a moderate prismatic parting to moderate subangular blocky structure, and contains less than 1.0 percent carbonate and no organic carbon (Fig 5:54). Capping the soil in Unit II is the 2Btgb horizon (98 cm - 1.15 m; Fig. 5:55), which is brown (10YR4/3; moist), has a moderate prismatic structure that parts to moderate subangular blocky, and contains less than 1 percent carbonate. Particle size fines slightly from sandy loam (53.4% sand, 30.0% silt, 16.6% clay) at 1.12 m to loam (37.3% sand; 46.4% silt, 16.3% clay) at 98 cm and organic carbon constitutes less than 0.5 percent of the horizon (Fig. 5:54). To estimate the mean residence time of humates in the upper 5 cm (98 cm - 1.03 m) of the 2Btgb1, a sample yielded a $\delta^{13}C$-corrected radiocarbon age of 16,810±440 yrs B.P. and a $\delta^{13}C$ value of -21.9‰ (Tx-7679).

Overlying Unit II, with a visible contact at 98 cm (Fig. 5:54), is Unit I (0 to 98 cm; Figs. 5:53; 5:54; 5:55). Unit I is generally much sandier, consisting largely of loamy fine sand, than Unit II, and mean particle size is medium to coarse silt. Although better than in the underlying deposits, sorting in Unit I is generally poor due to the presence of fine sand in the 5th percentile and fine clay to coarse silt in the 95th; it is especially poor in the middle part of the unit. In addition, Unit I is also very finely skewed and leptokurtic to very leptokurtic (Fig. 5:54).

Contained within Unit I is a moderate to well developed surface soil, consisting of one Ap and A horizon, three Bt horizons, and a C horizon. The C horizon (72 - 98 cm) overlies the 2Btgb1 in Unit II (Fig 5:55), and is identified by the sharp increase in sand at 90 cm. Loamy fine sand (88.4% sand; 6.5% silt; 5.1% clay), the C horizon is dark yellowish brown (10YR4/6; moist), has single grain structure and contains less than 0.5 percent carbonate and organic carbon (Fig. 5:54).

Overlying are three Btb horizons (Fig. 5:55), described on the basis of traceable clay films lining root casts and illustrated clearly in a series of peaks in the textural, phi, and sorting parameters from 35 to 72 cm (Fig. 5:54). The Bt3 horizon lies between 65 and 72 cm (Fig. 5:55), and is recognized by a major decrease in sand to 54.1 percent, a corresponding increase in silt and clay to 35.6 and 10.3 percent, respectively, and a sharp decrease in sorting. In addition, color darkens to dark yellowish brown (10YR4/4; moist), structure is weak prismatic parting to weak subangular blocky, and the horizon contains about 1.5 percent carbonate and less than 0.5 percent organic carbon (Fig. 5:54). Above is the Bt2 horizon (52 - 65 cm; Fig. 5:55), a dark yellowish brown (10YR4/4; moist) horizon that has a weak, prismatic structure that parts to weak subangular blocky and contains less than 0.5 percent carbonate and organic carbon. Texture coarsens somewhat, at the expense of sorting, to loamy fine sand (77.2% sand; 17.0% silt; 5.8% clay) in the Bt2. The Bt1 horizon (35 - 51 cm; Fig 5:55) contains less than 0.5 percent carbonate and organic carbon, is dark yellowish brown (10YR3/4; moist), and has single grain structure. Texture coarsens sharply upward from loamy fine sand (70.7% sand; 18.0% silt; 11.3% clay) at 50 cm to sand (93.9% sand; 2.3% silt; 3.8% clay; Fig. 5:54) at the top (37 cm) of the horizon.

Overlying are two A horizons, extending from the surface to 35 cm (Fig. 5:55) that contain less than 0.5 percent carbonate. Both are loamy fine sand (ca. 87% sand; 9% silt; 4% clay; Fig. 5:54) and have single grain structure. The A horizon, which is 17-cm-thick (Fig. 5:55) and dark brown (10YR3/3; moist), contains about 0.5 percent organic carbon. In the Ap, organic carbon sharply increases to about 1.0 percent (Fig. 5:54), with a resultant darkening to very dark brown (10YR2/2; moist).

In summary, Stafford 1 is a 2.50-m-stratigraphic profile exposed by backhoe trenching in a compound parabolic dune field in the western part of the Great Bend Sand Prairie. Two pedostratigraphic units, Units II and I, were recognized. Sediments within each unit are loamy, with the deposits in Unit II containing substantially higher percentages of silt and clay than Unit I. In addition, sorting is very poor throughout all of Unit II, whereas it is moderate to very poor in Unit I. In general, the sedimentological difference between the two units appears to reflect contrasting depositional environments, consisting of low energy fluvial or lacustrine in Unit II and dominantly eolian in Unit I.

Unit II is the thickest deposit, extending from 98 cm to the base of the profile. Deposits are generally sandy loam, containing as much as 46.4 percent silt and 16.6 percent clay. In addition to its very poor sorting, the distribution is very finely skewed and leptokurtic. Overall, Unit II is consistent with other deposits, generically categorized as silty sand, recognized in the region. The degree of sorting, coupled with a subtle, but steady fining-upward sequence, suggests accumulation during a time of increased effective moisture, one that resulted in low energy alluvial or lacustrine sedimentation. Periods of exposure and relatively long-term stability must have occurred, however, as indicated by the thick, well developed soil with prismatic structure that formed within the unit. Alternating periods of wetting and drying are suggested by soil characteristics. Towards the base, the solum is gleyed, mottled, and relatively rich in calcium carbonate, suggesting ponded water and/or high ground water tables. In the middle of the solum, however, the sediment is slightly oxidized, indicating weathering in a more arid environment. In the upper part of the soil, the sediment is once again gleyed, implying a return to moist conditions. Ultimately, the soil must have again been exposed, and for some time, resulting in complete truncation of the A horizon. A radiocarbon age of about 17,000 yrs B.P from the upper part of the soil indicates that Unit II is probably a late Wisconsin deposit. In addition, a $\delta^{13}C$ value of -21.9‰ suggests proportionately high percentages of C_3 plants inhabited the site, further implying a relatively cool climate with possibly more effective moisture.

The surficial deposit is Unit I, consisting largely of single-grained sand between the surface and 98 cm. At the base of the unit, the deposit contains approximately 90 percent sand, but texture fines sharply in the middle of the stratum, with about 36 percent silt and 10 percent clay present. Towards the top of the unit, sand content increases sharply again to around 90 percent.

Overall, the nature (e.g., texture, structure, color, topographic position and expression) of Unit I is consistent with other deposits generally classified as eolian sand in the region. A sharp improvement in sorting, as compared to the underlying deposits, in the lowermost stratum of Unit I is indicative of eolian sedimentation. Apparently, this change in facies occurred sometime during the late Wisconsin, as suggested by an approximate age of 17,000 yrs B.P. from the uppermost part of Unit II. Varied textures in the middle of Unit I, coupled with a sharp decrease in sorting, imply mixed alluvial and eolian deposition, possibly when the site occupied an interdunal position. Near the surface, a sharp improvement in sorting, coupled with percentages of sand of about 90 percent, suggest a return to eolian sedimentation.

It is difficult to estimate the age of Unit I. Several variables insinuate that the unit is relatively old, possibly early Holocene. As documented above, the lowermost part of Unit I appears to be a late Wisconsinan deposit as indicated by an underlying, maximum-limiting radiocarbon age. Assuming no truncation, the entire deposit would then be of a similar age. In contrast, the development of the surface soil, although excellent for one in eolian sand, does not imply great antiquity. Accordingly, it appears that an unconformity exists between the upper and lower parts of Unit I and that two periods of eolian sedimentation are represented. The development of the surface soil, with illuviated clays lining root casts, strongly suggests that Stafford 1 has been stable for a relatively long period of time for an eolian deposit on the Great Bend Sand Prairie, possibly since the early Holocene.

Stafford 2

Stafford 2 was a 3.65-m-deep backhoe trench exposure excavated in a high relief sand sheet in the NE, NE, sec. 24, T.24S, R. 13W (Figs. 5:1, 5:56). Four pedostratigrphic units were recognized in the profile. In general, the deposits are loamy and fine sand and mean particle size is fine to coarse silt. The distribution of sediments is very poor to poor in regards to its sorting, is consistently very finely skewed, and is very leptokuric to mesokurtic.

The lowermost pedostratigraphic unit at Stafford 2 is Unit IV, extending from

.3.08 m to the base of the profile (Figs. 5:57; 5:58; 5:59). Sediments contained within the unit fine upward slightly, ranging from sandy loam at the base to loam towards the top and mean particle size fluctuates from medium to fine silt. Sorting is very poor, owing to the presence of fine sand in the 5th percentile and fine clay in the 95th. In addition, the deposit is very finely skewed and leptokurtic to very leptokurtic in its distribution (Fig. 5:58).

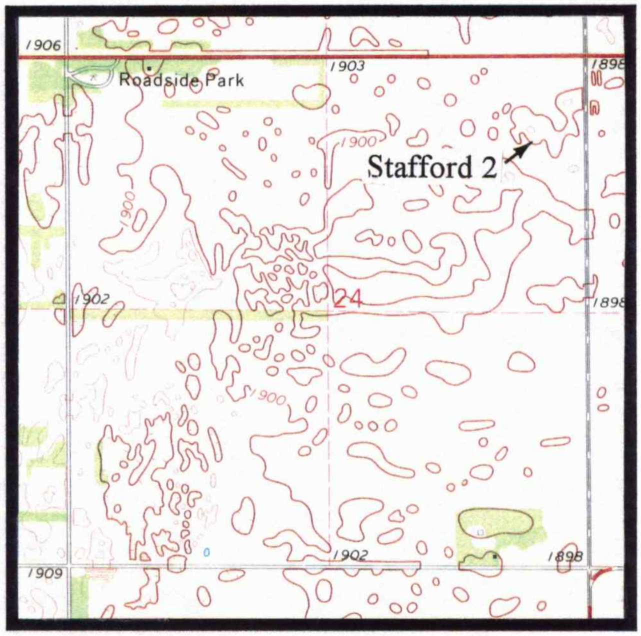


Figure 5:56. Topographic map in the vicinity of Stafford 2. Scale = 1:24,000 (Stafford NW 7.5 min. Quadrangle, 1972).

Formed throughout Unit IV is a strongly developed buried soil, consisting of two 4Btb horizons that are distinguished primarily by texture because each is reddish, strong brown (7.5YR4/6; moist) and contain less than 0.5 percent carbonate and organic carbon. The 4Btb2 extends from 3.26 to 3.65 m, whereas the 4Btb1 ranges from 3.08 to 3.26 m, respectively (Fig 5:59). Texture in the 4Btb2 is sandy loam (ca. 65% sand; 20% silt; 15% clay) and structure is weak prismatic parting to weak subangular blocky. The 4Btb1 can be identified by the peak in texture at 3.10 m, reflecting a drop in

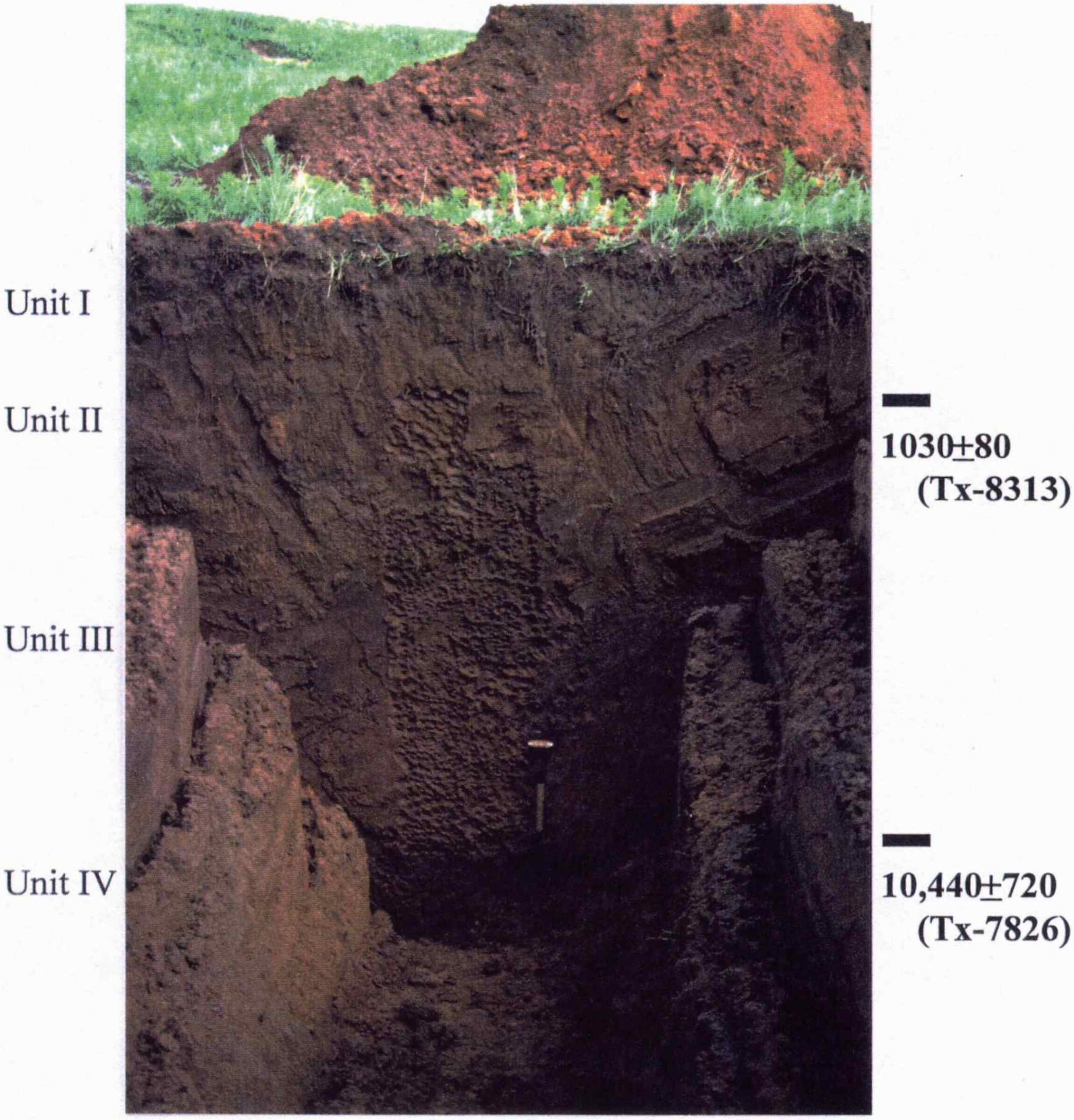


Figure 5:57. Stafford 2 (3.65-m high) showing pedostratigraphic units and radiocarbon ages.

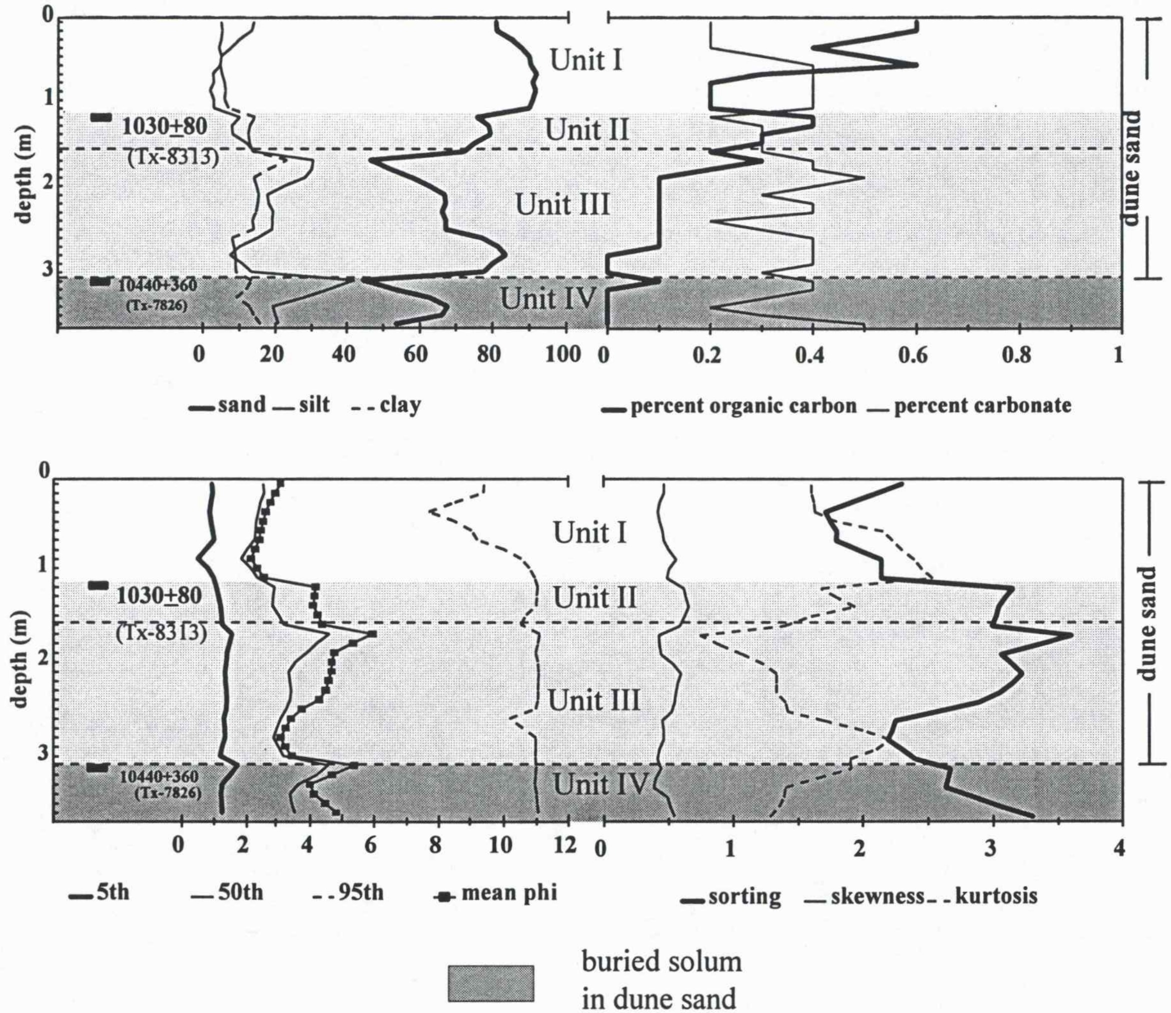


Figure 5:58. Graphical statistics and chemical composition of sediments at Stafford 2.

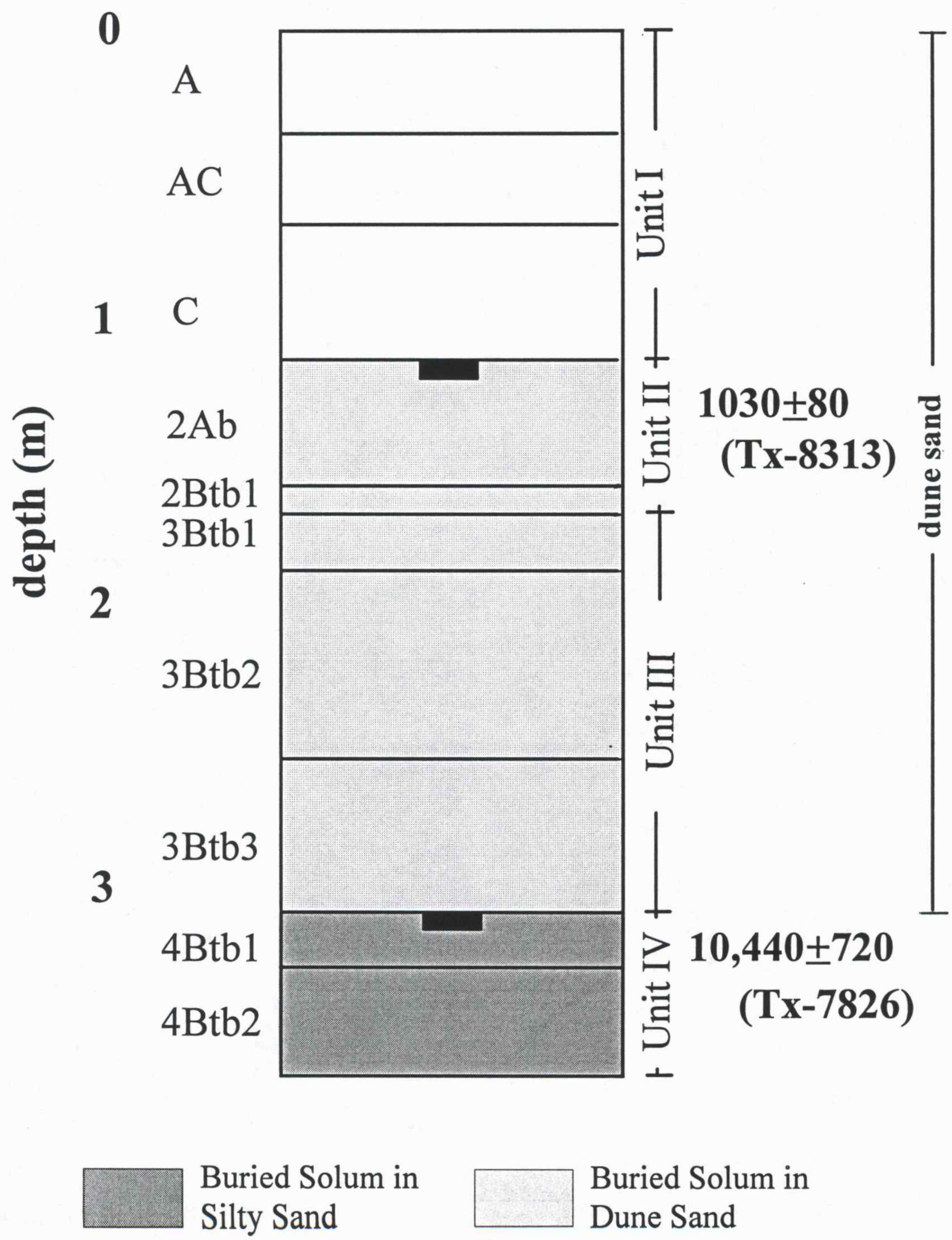


Figure 5:59. Soil stratigraphy and radiocarbon ages at Stafford 2.

sand to 44.5 percent and increased silt to 42.0 percent and clay to 13.5 percent. Structure in the 4Btb1 is moderate prismatic parting to moderate subangular blocky (Fig. 5:58). To estimate the mean residence time of humates in the upper 5 cm (3.08 - 3.13 m) of the 4Btb1, a sample provided a $\delta^{13}C$-corrected radiocarbon age of 10,440±720 yrs B.P and a $\delta^{13}C$ value of -23.6‰ (Tx-7826).

Overlying is a 1.40-m-thick pedostratigraphic unit, Unit III (Figs. 5:57, 5:58, 5:59). The contact between Units IV and III is clear at 3.08 m in texture and phi. Texture coarsens sharply at the base of Unit III, reflecting a 30 percent increase in sand, but fines towards the top because percent silt and clay increases. Similarly, mean particle size fines from coarse to fine silt from the lower to the upper part of the unit, respectively. Sorting is generally very poor, because fine sand is in the 5th percentile and fine clay in the 95th, but improves toward the top of the unit. In addition, Unit III is very finely skewed and kurtosis varies from very leptokurtic in the lower sediments of the unit to mesokurtic in the upper (Fig. 5:58).

Formed throughout Unit III is a well developed buried soil, consisting of three 3Btb horizons. The 3Btb3 horizon, which extends from 2.54 to 3.08 m (Fig. 5:60), is reddish, strong brown (7.5YR4/6; moist), loamy fine sand (ca. 80% sand; 11% silt; 9% clay), has structure that is weak prismatic parting to weak subangular blocky, and contains less than 0.5 percent carbonate and percent organic carbon.

A sharp decrease in sand at approximately 2.50 m (Fig. 5:58) identifies the lower boundary of the 66-cm-thick 3Btb2 horizon (Fig. 5:59). Sandy loam (67.2% sand; 19.1% silt; 13.7% clay), the horizon is dark brown (7.5YR4/4; moist), has a weak to moderate prismatic structure that parts to moderate subangular blocky, and contains less than 0.5 percent carbonate and organic carbon (Fig. 5:58).

Formed in uppermost part of Unit III, clearly visible by the sharp increase in silty and clay at 1.68 m, is the 3Btb1 (1.68 - 1.88 m; Fig. 5:59). The 3Btb1 is reddish, dark brown (7.5YR4/4; moist), loam (46.5% sand; 30.3% silt; 23% clay), has a moderate prismatic structure parting to moderate subangular blocky, and contains less than 0.5 percent carbonate and organic carbon (Fig. 5:58).

Overlying is Unit II, a pedostratigraphic unit extending from 1.14 to 1.68 m (Figs. 5:57, 5:58, 5:59). The lower boundary of Unit II is a sharp contact with the underlying deposits, one that reflects an abrupt increase in sand and a mean particle size of coarse silt. Sorting is very poor, resulting from fine sand in the 5th percentile and fine clay in the 95th, and the distribution is very finely skewed and very leptokurtic (Fig. 5:58).

Recognized in Unit II is a well developed buried soil, consisting of a 45-cm-thick 2Ab horizon overlying an 11-cm-thick 2Bt1 horizon (Fig. 5:59). Both the 2Ab and the 2Bt1 are loamy fine sand (ca. 75% sand; 11% silt; 14% clay) and contain less than 0.5 percent carbonate and organic carbon (Fig. 5:58). Structure is slightly stronger in the 2Btb1, consisting of weak prismatic that parts to weak subangular blocky, whereas the 2Ab is granular to weak prismatic. The primary difference in the horizons is color, with the 2Btb1 dark yellowish brown (10YR3/4; moist) and the 2Ab dark brown (10YR3/3; moist). To estimate the mean residence time of humates in the upper 5cm (1.14 - 1.19 m) of the 2Ab, a sample provided a $\delta^{13}C$-corrected radiocarbon age of 1030±80 yrs B.P. and a $\delta^{13}C$ value of -13.3‰ (Tx-8313).

The uppermost pedostratigraphic unit is Unit I, extending from the surface to 1.14 m (Figs 5:57, 5:58, 5:59). A sharp contact at 1.14 m identifies the lower boundary, reflecting an increase in sand from Unit II to about 90 percent and a shift in mean particle size to very fine sand. In addition, sorting improves abruptly from very poor Unit II to poor in Unit I because the 95th percentile phi shifts to medium clay and subsequently, to coarse clay. The distribution of Unit I is also very finely skewed and very leptokurtic (Fig.5:58).

Contained within Unit I is the poorly developed surface soil, consisting of a 35-cm-thick A horizon overlying a 29-cm-thick AC horizon and a 50-cm-thick C horizon (Fig. 5:59). Each horizon contains less than 0.5 percent carbonate and about 0.5 percent organic carbon. The C horizon is dark brown (10YR3/3; moist), sand (ca. 91% sand; 4% silt; 5% clay; Fig. 5:58), with single-grain structure. Transitional is the very dark grayish brown (10YR3/2; moist) AC horizon, which classified as sand with a weak, granular structure that parts to single grain. The uppermost horizon is the A (0 - 35 cm; Fig. 5:59), which is loamy fine sand (ca. 81% sand; 14% silt; 5% clay; Fig. 5:58), very dark brown (10YR2/2; moist), and has granular structure parting to single grain.

In summary, Stafford 2 is a 3.65-m-deep section exposed during backhoe excavations in a high relief sand sheet in the central part of the Great Bend Sand Prairie. Four pedostratigraphic units were recognized, reflecting episodic sedimentation and stability. Sediments are loamy, dominated by sand, with a mean particle size of medium silt to very fine sand. Sorting is very poor to poor and the deposit is very finely skewed and very leptokurtic to mesokurtic.

In general, the deposits at Stafford 2 can be considered as two units: 1) a surficial deposit of loose, unoxidized sand (Unit I); and 2) an underlying sequence of oxidized, siltier sediments containing Units II - IV. The origin of the upper unit can be determined with certainty. Conflicting evidence exists, however, as to the depositional environment in which Units II through IV accumulated. Three variables suggest that Units II - IV are consistent with silty sand. Initially, the deposit is very poorly sorted, suggesting a mixed sediment load that may occur in a low energy fluvial or lacustrine environment. As evidence of a cool climate with possibly more effective moisture, a $\delta^{13}C$ value of -23.6‰ was derived from the top of the deposit, suggesting that C_3 plants were present in high numbers at the site. In addition, the deposit contains two, well defined fining upward sequences, further indicative of alluvial sedimentation.

There is also evidence, however, that favors an eolian source for Units II - IV.. Sand is a proportionately much larger component, for example, in the stratum at Stafford

2 than in other silty sands, achieving percentages as high as 85.1 percent. Most importantly is the radiocarbon age, approximately 10,400 yrs B.P., obtained from the base of the deposit. At other localities (e.g., Edwards 2, 3, Reno 4) where the lower part of the silty sand was dated, late Wisconsinan ages greater than 13,000 yrs B.P. were derived. The age provided from the base of Stafford 2, however, strongly suggests that the remainder of the section accumulated during the Holocene, a time of demonstrably warmer, more arid conditions. Overall, the conclusion is that Units II through IV are dominantly eolian in nature, especially in the lower part, but probably include some deposits of a very low energy, (e.g, interdune) fluvial origin. Regardless, the presence of three, well developed buried soils indicate that sedimentation was episodic, and was punctuated by periods of long term stability.

Although the origin of the underlying deposits is problematic, the surficial deposit clearly consists of eolian sand, for it is similar in stratigraphic position, topographic expression, age, color, texture, and structure to other deposits in the region identified as wind-blown sand. Moreover, the sorting of the upper unit, although poor, is much better than the deposits it overlies. The overall lack of sorting in the sand, in fact, suggests that Unit II, or a nearby outcrop of very poorly sorted sediments (e.g., silty sand) was the sediment source. A radiocarbon age of about 1000 yrs B.P. from the upper part of the underlying 2Ab provides a maximum limiting, late Holocene age for Unit I. In addition, a δ^{13}C value of -13.3‰ clearly implies that the associated climate was relatively warm with probably less effective moisture. The degree of surface soil development (i.e., A/AC/C horizonation) suggests that, in general, the dune field immediately surrounding Stafford 2 has been stable for a relatively short period of time, probably less than 500 years.

Stafford 3

Stafford 3 was a 4.58-m-deep backhoe trench, excavated in a compound parabolic dune field, in the NW, NW, sec. 23, T.24S., R.13W (Figs. 5:1, 5:60). Three pedostratgraphic units were recognized, consisting of one in silty sand (Unit III) and two in eolian sand (Units II, I) (Figs. 5:61, 5:62, 5:63). In general, the sediments are loamy in Unit III, with high percentages of silt and clay. Contrastingly, texture in the overlying deposit is sand. Sorting is very poor in the silty sand and very poor to poor in the surficial sand. Skewness varies little betweenthe

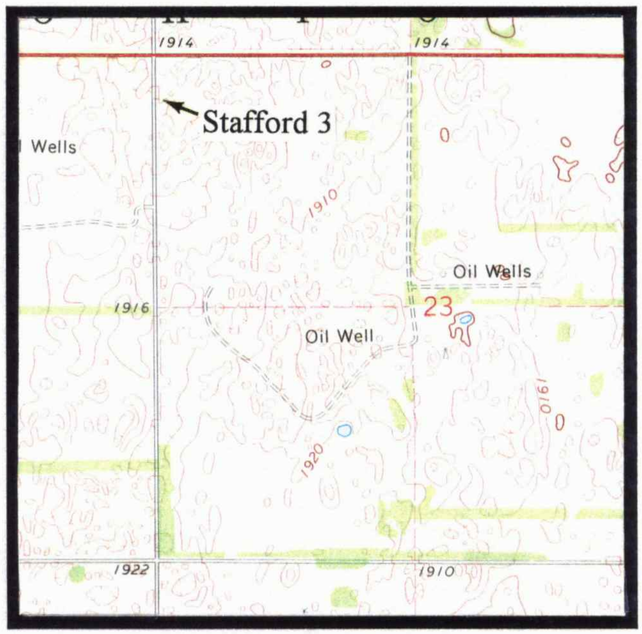


Figure 5:60. Topographic map in the vicinity of Stafford 3. Scale = 1:24,000 (Stafford NW 7.5 min. Quadrangle, 1972).

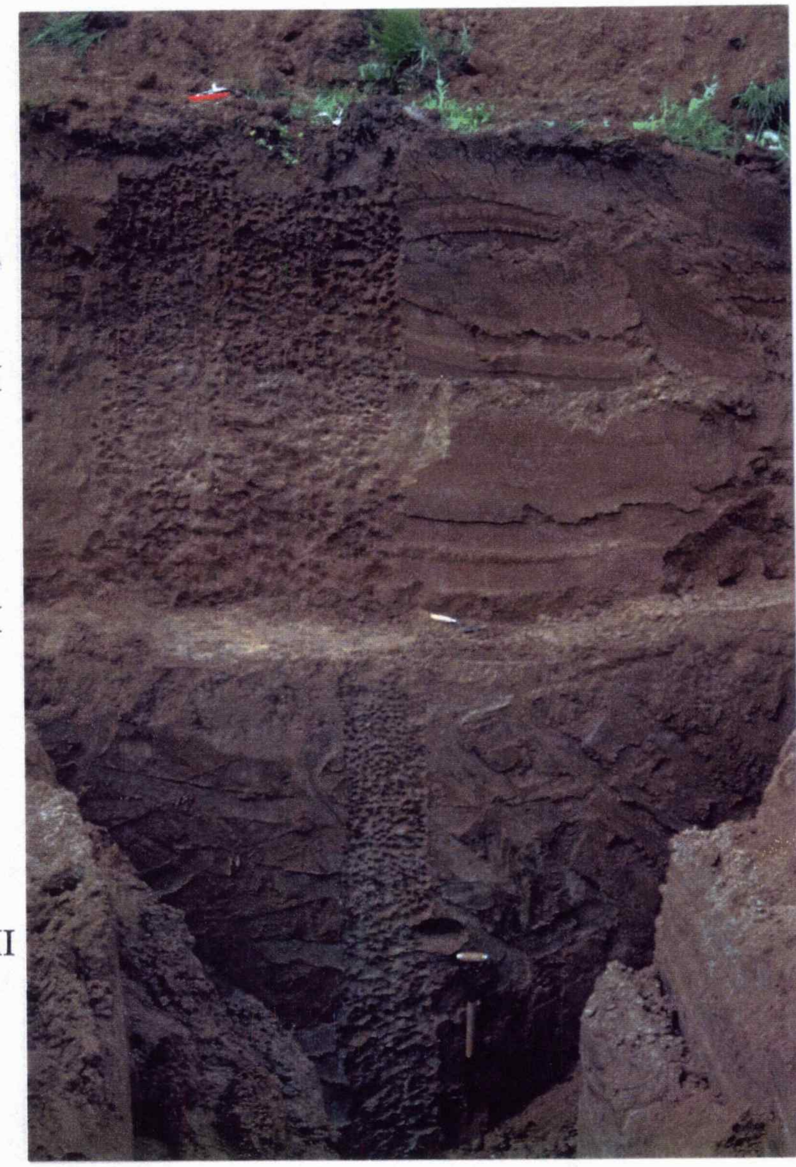


Figure 5:61. Stafford 3 (4.58-m high) showing pedostratigraphic units and radiocarbon age.

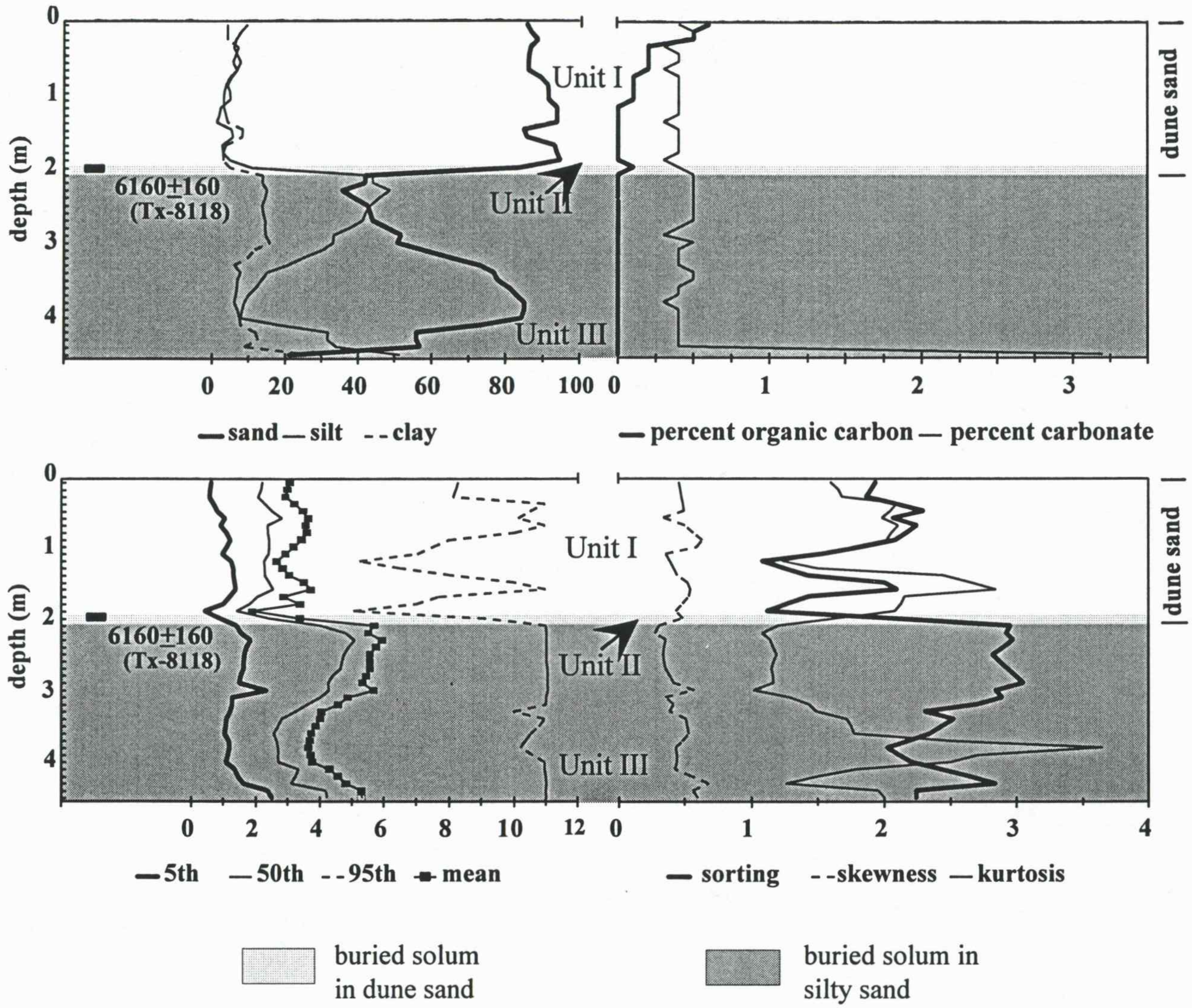


Figure 5:62. Graphical statistics and chemical composition of sediments at Stafford 3.

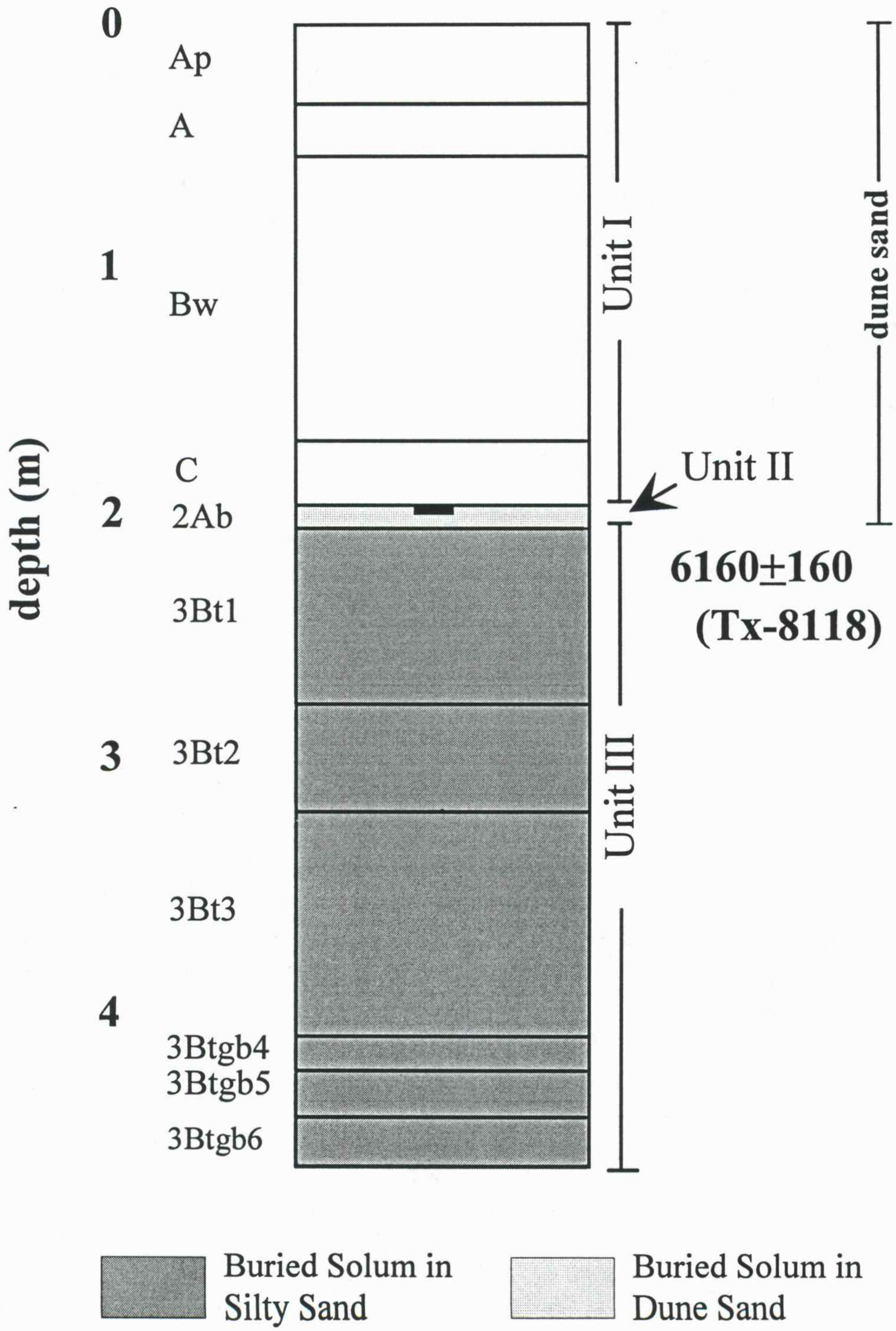


Figure 5:63. Soil stratigraphy and the radiocarbon age at Stafford 3.

strata, being finely skewed and kurtosis ranges from very leptokurtic to leptokurtic in both units. Graphical statistics and the chemical composition of sediments at Stafford 3 are illustrated in Figure 5:62.

Unit III consists of mottled and gleyed sediments, loamy in character, that range from 2.07 m to the base of the profile (Figs. 5:61, 5:62, 5:63). Most obvious in the particle size distribution is the gradual, but large variations in percent silt and sand that result in texture ranging from clay loam to loamy fine sand. Accordingly, mean particle size varies from medium silt at the base of the unit, to coarse silt in the middle, and back to medium silt at the top of the unit. Sorting is very poor because the 5th percentile generally consists of fine sand, whereas the 95th percentile is fine clay. In addition, the deposit is finely skewed leptokurtic to very leptokurtic (Fig. 5:62).

Formed in Unit III is a strongly developed buried soil, consisting of three 3Btb horizons, and three 3Btgb horizons.. The lowermost horizon, 3Btg6 (4.48 - 4.58 m; Fig. 5:63) is clay loam (21% sand; 51.4% silt; 27.6% clay), light gray (10YR7/2; moist), has a moderate to strong prismatic structure that parts to moderate to strong subangular blocky and contains no organic carbon. Color, in large part, is a function of the degree of gleying in the horizon and the relatively high percentage (ca. 3.0%) of carbonate present (Fig. 5:62).

Overlying are two more gleyed horizons, the 3Btgb5 (4.28 - 4.48 m) and the 3Btgb4 (4.11 - 4.28 m; Fig. 5:63). Both the 3Btgb5 and 3Btgb4 are pale brown

(10YR6/3; moist), have moderate prismatic structure parting to moderate subangular blocky, and contain less than 0.5 percent carbonate and no organic carbon. The primary difference between the horizons is textural, with the 3Btgb5 sandy loam (ca. 57% sand, 33% silt; 11% clay) and the 3Btgb4 loamy fine sand (73.6% sand; 18.6% silt; 7.6% clay; Fig. 5:62).

The remaining soil horizons in Unit III, ranging from the 3Btb1 to the 3Btb3 are very similar in appearance. Each horizon is mottled light yellowish brown (10YR6/4; moist) to yellowish brown (10YR5/6; moist), has a moderate prismatic structure parting to moderate subangular blocky, and contains no organic carbon and less than 0.5 percent carbonate. The principal contrast is texture, reflecting the coarsening in the middle, and fining in the upper part of the unit, respectively (Fig. 5:62). The 3Btb3 (3.21 m - 4.11 m; Fig. 5:63) is loamy fine sand (84.3% sand; 8.1% silt; 7.6% clay; Fig. 5:62). In the 43-cm-thick 3Btb3 horizon (Fig. 5:63), texture changes to sandy loam, with a continued fining upward from 65.2 percent sand, 25.1 percent silt, and 9.7 percent clay at 3.20 m, to 51.8 percent sand, 33.5 percent silt, and 14.7 percent clay at 2.39 m (Fig. 5:62). The uppermost horizon is the 3Btb1 (2.07 - 2.78 m; Fig. 5:63), which coarsens from loam (ca. 43% sand; 43% silt; 14% clay) at 2.31 m to loam (45.6% sand, 43.8% silt, and 10.6% clay; Fig. 5:62) at 2.08 m.

Overlying, with a sharp stratigraphic contact at 2.07 m in Figure 5:62, is Unit II, which consists of a 11-cm-thick, weakly developed 2Ab horizon (Fig. 5:63) that formed in a deposit of single grained sand. Loamy fine sand (83.7% sand; 11.1% silt; 5.2% clay), the 2Ab is dark yellowish brown (10YR4/4; moist) and contains less than 0.5 percent carbonate and organic carbon (Fig. 5:63). To estimate the mean residence time of humates in the upper 5 cm (1.96 - 2.01 m) of the 2Ab, a sample provided a $\delta^{13}C$-corrected radiocarbon age of 6160±160 yrs B.P. and a $\delta^{13}C$ value of -17.9‰ (Tx-8118).

The uppermost pedostratigraphic unit at Stafford 3, clearly visible in Figure 5:62 as an abrupt contact with Unit II, is Unit I (0 - 1.96 m; Figs. 5:61, 5:62, 5:63). Unit I is very sandy and mean particle size is generally coarse silt to very fine sand. Sorting differs greatly, ranging from nearly moderate to very poor. Where sorting is relatively good, it is because the 5th percentile of sediment is medium sand and the 95th is medium silt. In contrast, the influx of fine clay as the 95th percentile at some depths results in very poor sorting. Unit I is very finely skewed, and is leptokurtic to very leptokurtic (Fig. 5:62).

Formed throughout most of Unit I is a moderately developed surface soil, consisting of an Ap, A, Bw, and C horizon that contains less than 0.5 percent carbonate. The C horizon, which extends from 1.70 to 1.96 m (Fig. 5:63), is dark yellowish brown (10YR4/6; moist), contains sediments classified as sand (ca. 94% sand; 2.5% silt; 3.5% clay) that are single grained in structure and holds no organic carbon (Fig. 5:62). Overlying is the dark yellowish brown (10YR3/6; moist) Bw1 horizon (53 cm - 1.70 m; Fig. 5:63), which consists of sand with a very weak subangular blocky structure.

Percent sand is greatest (94.1%) at 1.43 m and is least (86.2%) at the top of the horizon and organic carbon comprises less than 0.5 percent of the horizon (Fig. 5:62). Capping the surface soil are two A horizons, the A (32 - 53 cm) and the Ap (0 - 32 cm; Fig. 5:63). Both are sand (ca. 87% sand; 7% silt; 6% clay), with granular structure that parts to single grain. The A is lighter, dark yellowish brown (10YR3/6; moist) than the Ap, which is dark brown (10YR3/3; moist). Color is likely a function of organic carbon content, increasing from 0.2 percent in the A to 0.6 percent (Fig. 5:62) at the top of the Ap.

In summary, Stafford 3 is a 4.58-m-thick sequence of sediments exposed by backhoe trenching in a compound parabolic dune field in the central part of the Great Bend Sand Prairie. Three pedostratigraphic units were described, with each reflecting a period of rapid sedimentation, followed by stability and soil formation. The lowermost unit, Unit III, consists of very poorly sorted sediments rich in silt and clay. Units II and I, in contrast, are much sandier and better sorted. In general, the sedimentological differences between Unit III, and Units II and I, appear to reflect diachronous depositional environments. Theoretically, Unit III represents a dominantly low energy fluvial or lacustrine facies that accumulated in a wetter climate, whereas Units II and I, in contrast, are a result of eolian sedimentation in a relatively arid environment.

Characteristically, Unit III is consistent with other silty sands recognized elsewhere on the Great Bend Sand Prairie. The stratigraphic position of the deposit (i.e., underlying eolian sand), coupled with the degree of sorting, and high percentages of silt and clay favor this assignment. Unfortunately, deposits such as Unit III contain no sedimentary features, rendering the assignment of facies difficult. Sedimentologically, Unit III is very poorly sorted, indicative of a low energy fluvial or lacustrine environment where a mixed sediment load existed. In addition, the deposit contains two, very distinct, fining upward sequences, which futher imply fluvial sedimentation. Potentially, the deposit is a result of both fluvial and eolian sedimentation. The lack of organic carbon precluded an effort to estimate the age through radiocarbon dating of the deposit. Ages obtained from similar units elsewhere (e.g., Edwards 2, Edwards 3, Stafford 1, Reno 4) suggest deposition occurred sometime between 20,000 and 13,000 yrs B.P. As a result, Unit III at Stafford 3 is assigned a late Wisconsin age.

Regardless of when and how Unit III accumulated, it is clear that following sedimentation, a stable surface existed for some time, one that promoted formation of a very strongly developed soil. Each horizon is strongly mottled, with the lower three heavily gleyed, suggesting that ponded water at the surface and/or high water tables promoted chemical illuviation. At some point, a period of surficial erosion must have transpired, one that truncated the A horizon from the top of the soil.

Although the origin and age of Unit III is problematic, the derivation of Units II and I can be ascertained with relative certainty. Both are consistent in stratigraphic position, texture, cohesiveness, color, and sorting with eolian sand. Unit II, which is 11-cm-thick, sits unconformably on Unit III. Essentially, Unit II consists of a 2Ab horizon that formed following deposition of wind-blown sand. A radiocarbon age of about 6200 yrs B.P. from the upper part of the 2Ab suggests last exposure, during the middle Holocene when climate was relatively warm, as indicated by a $\delta^{13}C$ value of -17.9‰. Moreover, the age provides a maximum-limiting age for the overlying, 1.96-m-thick dune deposits of Unit I. Formed in Unit I is a moderately developed surface soil, containing two Bw horizons. Although the 6200 yrs B.P. age obtained from Unit II implies a middle Holocene age for Unit I, the relative lack of soil formation at the surface is contradictory. Apparently, an unconformity exists somewhere in Unit I, one that represents a period of erosion in the later Holocene that removed the upper part of a pre-existing dune, but did not scour Unit II. Subsequently, the remainder of Unit I was deposited and the surface soil developed. Overall, the degree of soil formation suggests that the dune has been stable for less than 1000 years.

Stafford 4

Stafford 4 is a 3.75-m-sedimentary sequence exposed by backhoe trenching in the NW, NE, sec. 16, T.24S, R.12W. Although the trench was excavated to 3.75 m, instability precluded sampling below 2.85 m. Located in the loess plain near the town of Stafford (Figs. 5:1, 5:64), the site contains two pedostratigraphic units (Figs 5:65, 5:66, 5:67). In general, deposits at the site are loamy, have a mean particle size ranging from coarse to fine silt, are very poorly sorted, and are very fine to finely skewed and very leptokurtic to mesokurtic.

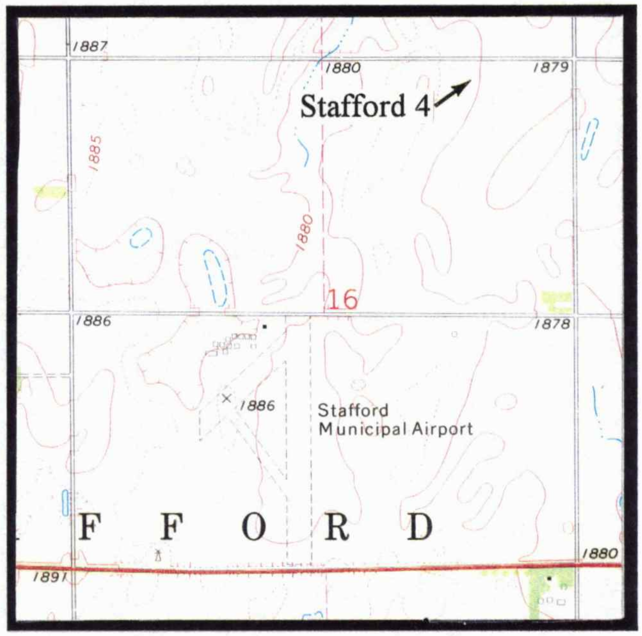
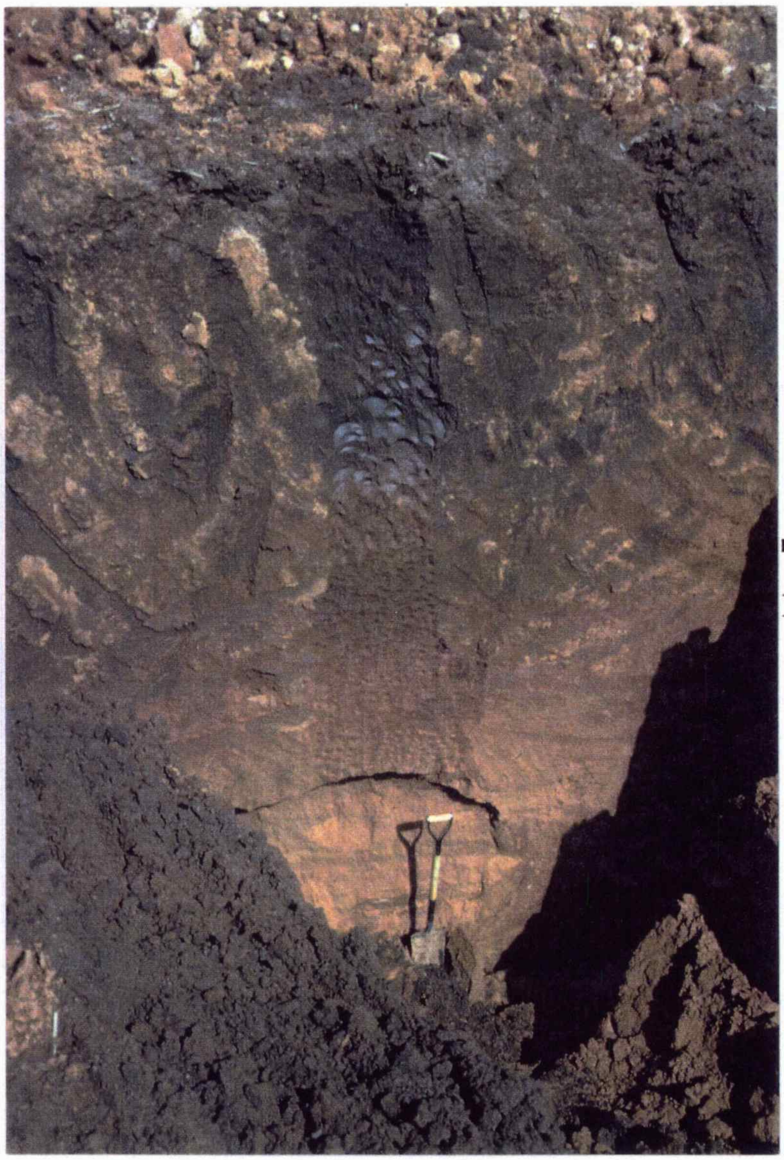


Figure 5:64. Topographic map in the vicinity of Stafford 4. Scale = 1:24,000 (Stafford NW 7.5 min. Quadrangle, 1972).

Unit II is lowermost at the site, ranging from 1.66 m to the base of the profile (Figs. 5:65, 5:66, 5:67). Due to slumping in the lower part of the exposure (Fig. 5:65), sampling was conducted only to 2.85 m. In this part of the unit, deposits range from sandy loam to loam. Based on observation, it appears that texture coarsens to sand in the lower 90 cm of the stratum, accounting for the instability of the unit. Mean particle size in the sampled section ranges from coarse to fine silt. Sorting is generally very poor due to the presence of fine clay in the 95th percentile and fine sand in the 5th percentile. In addition, the sediments in Unit II are very fine to finely skewed and very leptokurtic to leptokurtic (Fig. 5:66). Formed within Unit II is a moderately well developed buried soil, consisting in the sampled part of the section of one 2Ab and one 2ABb horizon and two 2Btb horizons. Between 2.85m and the base of the profile, Unit I



Unit II

12,820±340
(Tx-7999)

Figure 5:65. Stafford 4 (3.75-m high) showing pedostratigraphic units and radiocarbon age.

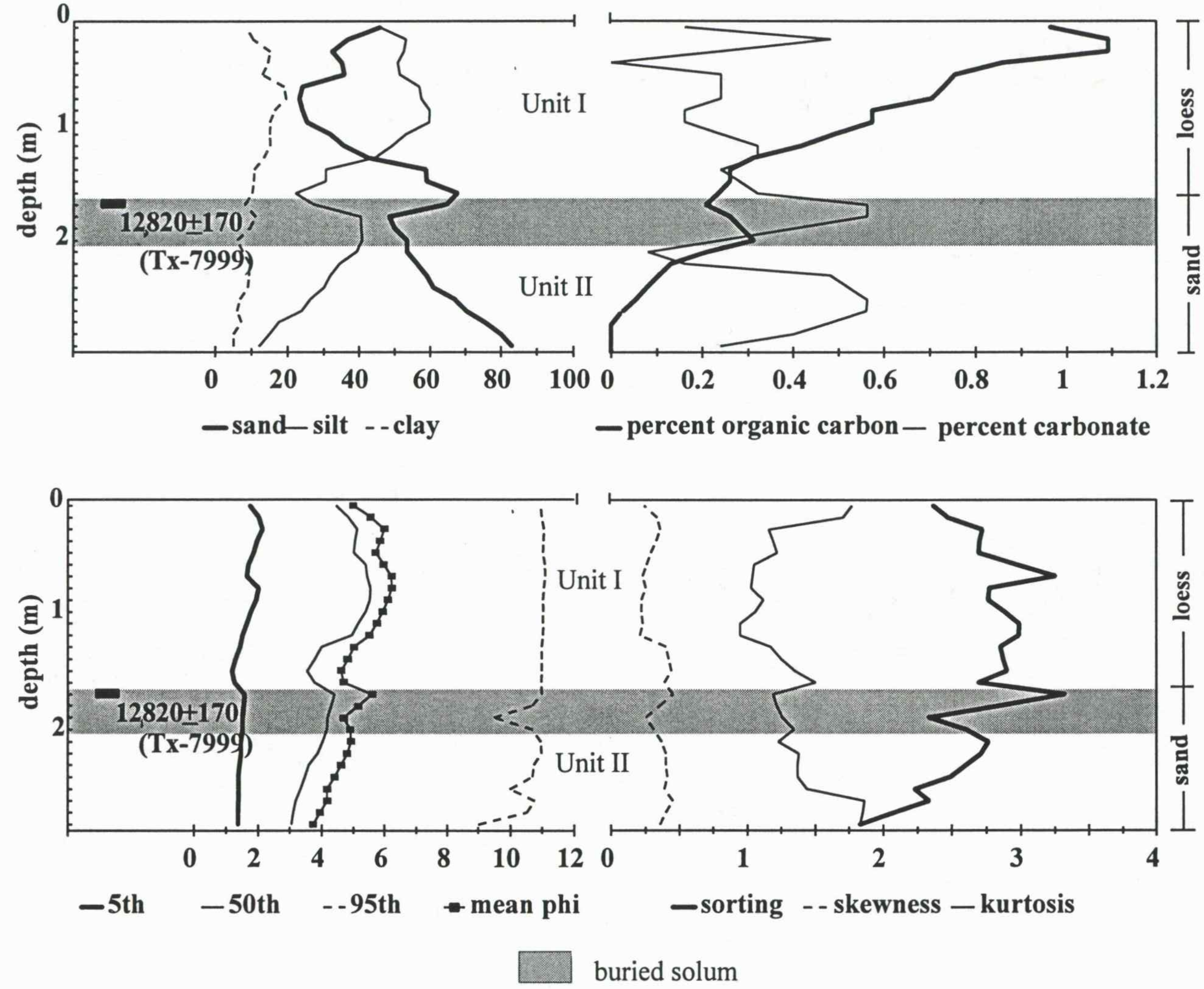


Figure 5:66. Graphical statistics and chemical composition of sediments at Stafford 4.

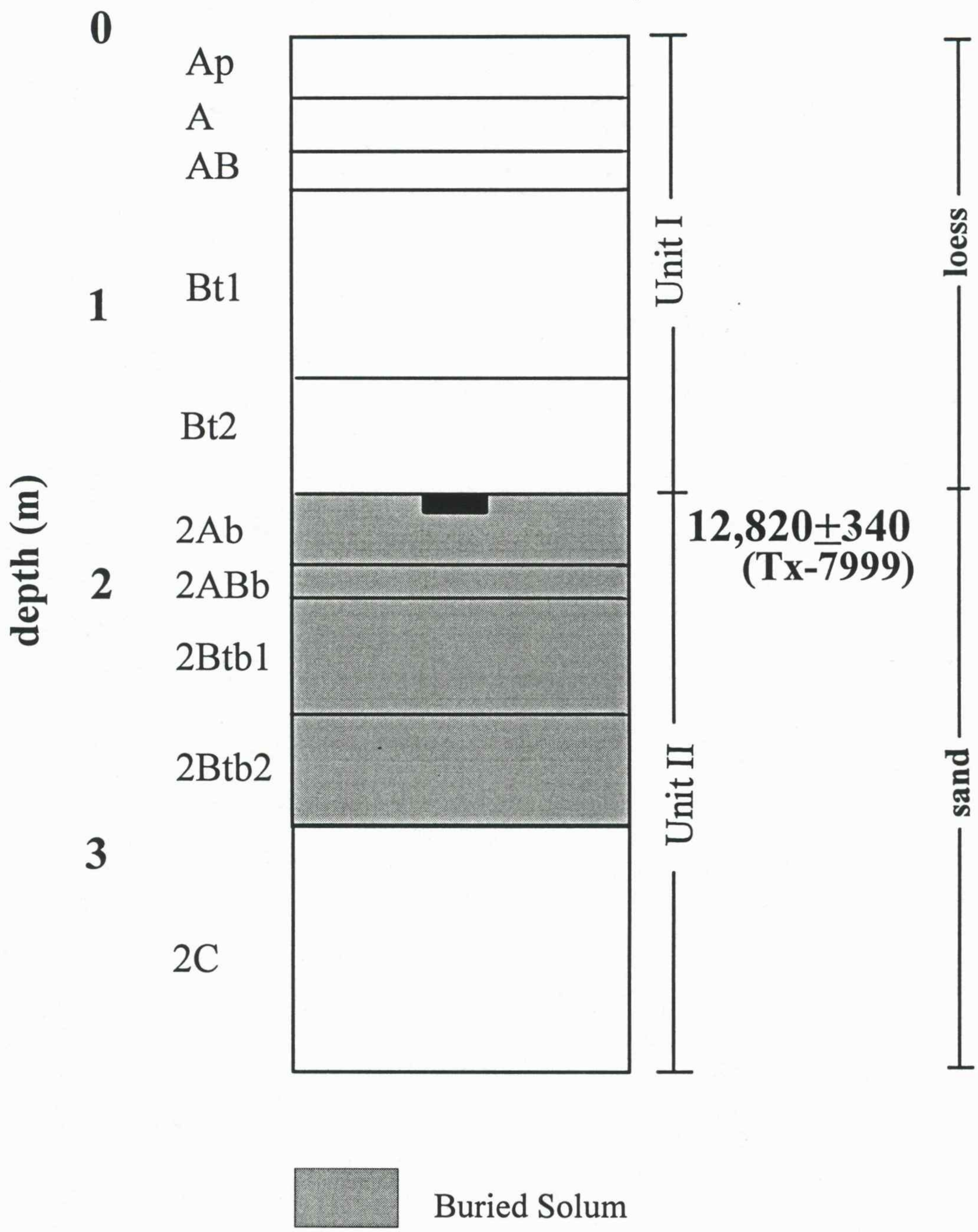


Figure 5:67. Soil stratigraphy and the radiocarbon age at Stafford 4.

the soil appears to contain several, slightly laminated, 2C horizons. Texture in the 2C horizons is very sandy, tentatively classified as sand, and structure is assumed to be single grained. Emperically, color in the 2Cs is consistent with the 2Btb2, i.e., reddish yellow (7.5YR6/6; moist).

Overlying between 1.66 and 2.85 m is the sampled part of the soil, containing less than 0.5 percent carbonate and organic carbon (Fig. 5:66). At the base is the 2Btb2 horizon (2.71 - 2.85 m; Fig. 5:67), which is loamy fine sand (83.1% sand; 11.9% silt; 5.0% clay; Fig. 5:66), reddish brown (7.5YR6/6; moist) and has a very weak prismatic structure that parts to very weak subangular blocky. Above is the 2Btb1 horizon (2.06 - 2.71 m; Fig. 5:67), which is largely loamy fine sand (ca. 73% sand, 20% silt, 7% clay; Fig. 5:66), has a weak prismatic structure parting to weak subangular blocky, and ranges from strong brown (7.5YR4/6; moist) to dark brown (7.5YR4/4; moist).

The uppermost part of Unit II includes two A horizons that contain less than 0.5 percent carbonate and percent organic carbon. Transitional is the dark brown (7.5YR3/4; moist) 2ABb horizon (1.92 - 2.06 m; Fig. 5:67), which is sandy loam (53.3 % sand; 39.2% silt; 7.5% clay; Fig. 5:66) and has a weak prismatic structure that parts to weak subangular blocky. Capping the soil is the dark brown (7.5YR3/3; moist), loam textured (48.6% sand; 40.4% silt; 11.0% clay) 2Ab horizon, extending from 1.79 to 1.92 m (Fig. 5:67). Poorly developed clay skins in the horizon suggest that the 2Ab has been modified by surficial soil processes at the site. As a result, structure in the 2Ab is relatively strong for an A horizon, consisting of weak prismatic parting to weak subangular blocky. To estimate the mean residence time of humates in the upper 5 cm (1.66 - 1.71 m) of the 2Ab1, a sample provided a $\delta^{13}C$-corrected age of 12,820±340 yrs B.P. and a $\delta^{13}C$ value of -14.2‰ (Tx-7999).

Overlying is Unit I (0 - 1.66 m; Figs. 5:65, 5:66, 5:67), with the contact clear as the peak in sand at about 1.64 m. In general, Unit I is loamy, with a shift from sandy loam at the base of the unit to silt loam and loam towards the top. Mean particle size fluctuates from coarse silt in the lower part of the unit to fine silt in the upper. Sorting is very poor because the 95th percentile consists of fine clay whereas the 5th percentile is fine sand. In addition, the unit is very fine to finely skewed and mesokurtic to very leptokurtic (Fig. 5:66).

Formed in Unit I is a well developed surface soil, consisting of one Ap, A, an AB horizon and two Bt horizons (Fig. 5:67) that contain less than 1.0 percent carbonate and organic carbon. Essentially, the Bt horizons reflect a gradual fining of the sediment from the base of the unit to about 57 cm (Fig. 5:66), coupled with a slow darkening in color that accompanies a consistent increase in organic carbon. The Bt2 horizon (1.25 - 1.66 m; Fig. 5:67) is sandy loam (ca. 64% sand; 27% silt; 9% clay; Fig. 5:66), dark yellowish brown (10YR3/4; moist), and has a weak prismatic structure parting to weak subangular blocky. Overlying is the 68-cm-thick Bt1 horizon (Fig. 5:67), which is dark brown (10YR3/3; moist) to very dark grayish brown (10YR3/2; moist), silt loam (ca.

25% sand, 60% silt, 15% clay) to loam (ca. 40% sand; 45% silt; 15% clay; Fig. 5:66), and has a moderate prismatic structure that parts to moderate subangular blocky.

Capping the soil are three A horizons, distinguished by a gradual increase in sand from 57 cm to the surface, coupled with a decrease in structure. Each contain less than 0.5 percent carbonate and about 1.0 percent organic carbon (Fig. 5:66). Transitional is the AB horizon, ranging from 41to 57 cm (Fig. 5:67). Although texture in the AB is consistent with the Bt1 (i.e., sandy loam), sand increases to 35.8 percent in the AB with a corresponding decrease in silt and clay to 51.3 and 12.9 percent, respectively (Fig. 5:66). Structure in the AB, weak prismatic parting to weak subangular blocky, is noticeably less than the Bt1. Overlying is the 19-cm-thick A horizon (Fig. 5:67), which is very dark grayish brown (10YR3/2; moist), silt loam (ca. 34% sand; 51% silt; 14% clay; Fig. 5:66), and has granular structure. Capping the soil is the Ap horizon (0 - 19 cm; Fig. 5:67), which is loam (45.9% sand; 45.7% silt; 8.4% clay; Fig. 5:66), dark brown (10YR3/3; moist), and has granular structure.

In summary, Stafford 4 consists of a 3.75-m-high stratigraphic profile exposed by backhoe trenching in the loess plain northwest of Stafford in the central part of the Great Bend Sand Prairie. Due to instability in the lower 90 cm of the exposure, detailed description and sampling was confined to the upper 2.85 m. Two pedostratigraphic units were recognized: from bottom to top, Units II and I. Each represents a period of deposition followed by landscape stability and soil formation.

In general, the lowermost part Unit II consists of very sandy sediments (> 83% sand), slightly laminated, that lack structure. The nature (e.g., texture, structure, sorting) of these deposits is consistent with dune sand. In the upper part of Unit II, the sediment is much siltier (e.g., 40%) in the presence of a moderately well developed buried soil, one that consists of one 2Ab horizon, one 2ABb horizon, and two 2Btb horizons. A radiocarbon age of approximately 12,800 yrs B.P. from the upper part of the soil indicates that Unit II is likely a late Wisconsinan deposit. In addition, the unit is slightly oxidized (e.g., 7.5YR4/6; moist), further suggesting relative antiquity. At most localities (e.g., Edwards 1; Edwards 2; Edwards 3; Stafford 1; Reno 4) where late Wisconsinan ages have been obtained, the associated deposits imply a fluvial or lacustrine facies of mixed energy. The age obtained from the 2Ab at Stafford 4 suggests that dune formation apparently occurred in some parts of the study area between 20,000 and 10,000 yrs B.P. A $\delta^{13}C$ value of -14.2‰ suggests that plants specialized for sandy, well-drained landscapes dominated the site.

Conformably overlying is Unit I, extending from the surface to 1.66 m. Fundamentally, Unit I is silty, very poorly sorted, and lacks defineable sedimentary structures. At first glance, the unit is similar to other strata in the study area categorized as silty sand, but in this case it is not buried. However, the radiocarbon age of approximately 12,800 yrs B.P. from the underlying 2Ab provides a maximum-limiting, late Wisconsinan age for the unit, a chronology recognized at several localilties (e.g., Edwards 3; Stafford 11) where the silty sand has been recognized. On closer examination, however, several variables suggest that Unit I reflects a different environment from that in which the silty sand accumulated. First, the unit lies conformably over Unit II, a relationship unrecognized elsewhere in the region. Second, the deposits associated with Unit I have not been reduced or oxidized as has the silty sand at other localities. Third and most importantly, the soil horizons associated with Unit I have relatively poor structure, largely weak prismatic parting to weak subangular blocky, when compared to the moderate to strong prismatic structure observed elsewhere in the silty sand. The nature of Unit I implies an eolian facies, one which consisted predominantly of silt at Stafford 4 rather than sand. As a result, Unit I is interpreted to be Holocene wind-blown deposit. Apparently, the site has been stable for at least 1000 years, as suggested by a well developed surface soil that includes four Bt horizons.

Stafford 5

Stafford 5 is a 3.46-m-high stratigraphic profile exposed by backhoe trenching in a compound parabolic dune field in the SW, SW, sec. 6, T.24S.., R.13W. (Figs 5:1, 5:68). Three pedostratigraphic units were described consisting of one in very poorly sorted deposits of sand, silt, and clay, and two in overlying loose, relatively well sorted sand. In general, the deposits at Stafford 5 are loamy, have a mean particle size of medium silt to very fine sand, are very poorly to moderately sorted, very finely to finely skewed, and mesokurtic to very leptokurtic.

The lowermost pedostratigraphic unit at Stafford 5 is Unit III, ranging from 2.03 m to the base of the profile (Figs. 5:69, 5:70, 5:71). Deposits within Unit III are heavily gleyed, loamy, including sandy loam to loam. Mean particle size is coarse to medium silt, with three fining upward sequences distinguishable. Sorting is very poor because the 5th percentile consists of fine sand, whereas the 95th is fine clay. In addition, Unit III is very finely skewed and mesokurtic to very leptokurtic (Fig. 5:70). Formed within Unit III is a well developed buried soil, consisting of one 3Btgb horizon (Fig. 5:71) that contains about 1.0 percent carbonate and no organic carbon, is largely sandy loam (ca. 60% sand, 20% silt, 20% clay; Fig. 5:70), generally has moderate prismatic parting to moderate subangular blocky structure, and ranges in color from light brownish gray (10YR6/2; moist) to grayish brown (10YR5/2; moist).

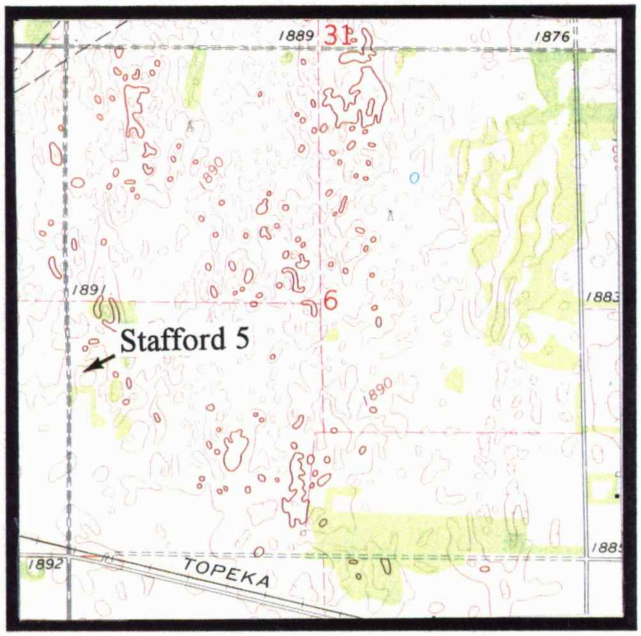


Figure 5:68. Topographic map in the vicinity of Stafford 5. Scale = 1:24,000 Stafford NW 7.5 min. Quadrangle, 1972).

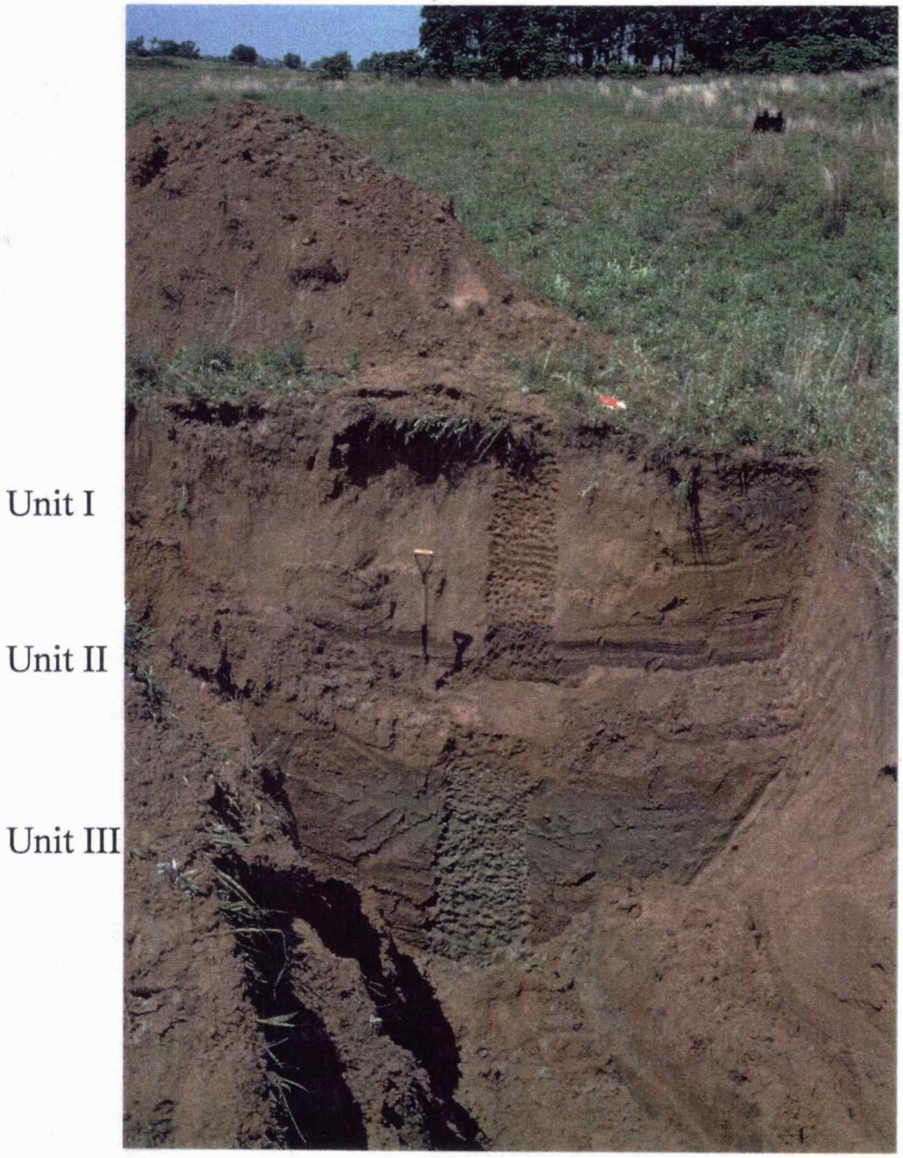


Figure 5:69. Stafford 5 (3.46-m high) showing pedostratigraphic units.

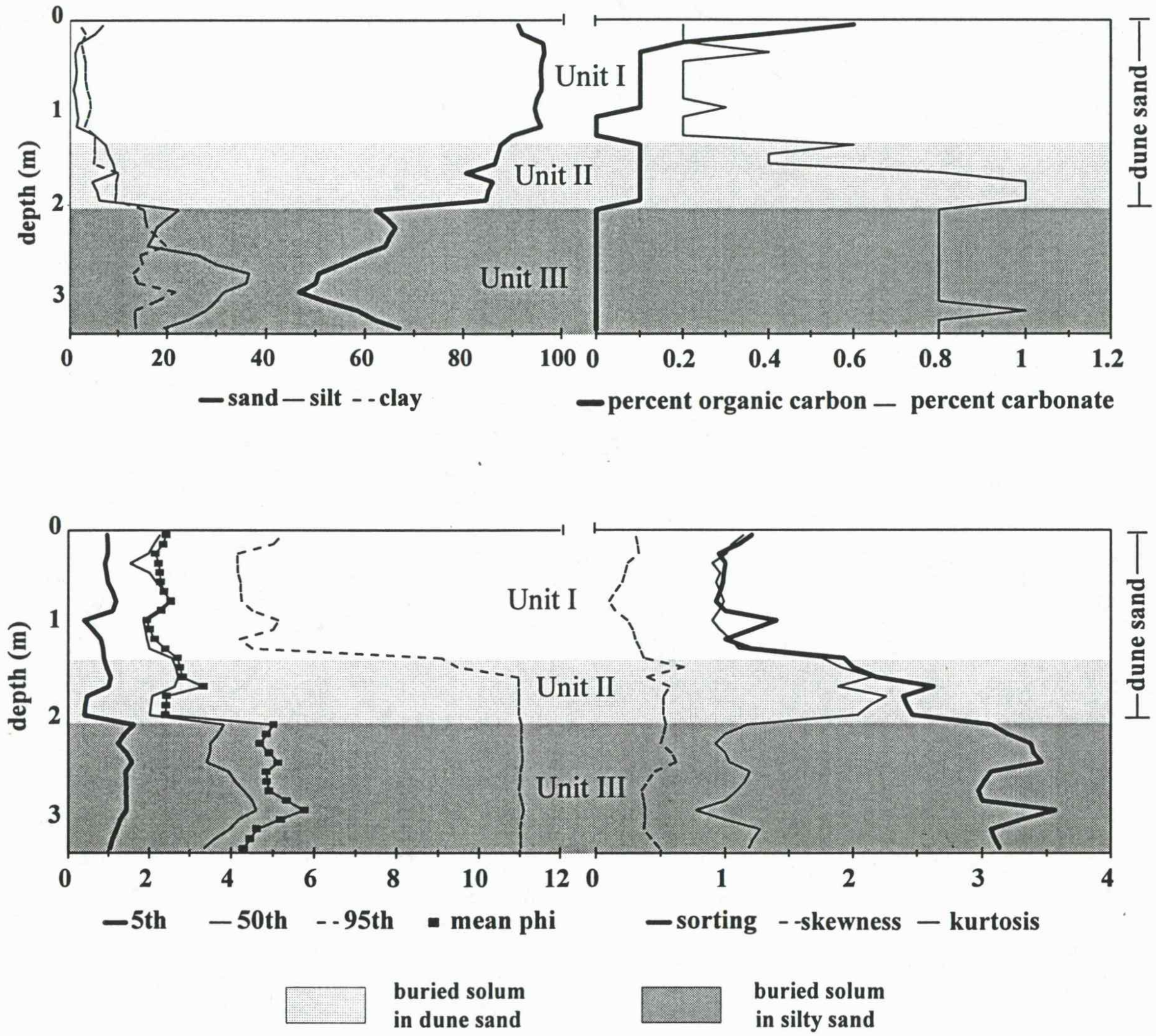


Figure 5:70. Graphical statistics and chemical composition of sediments at Stafford 5.

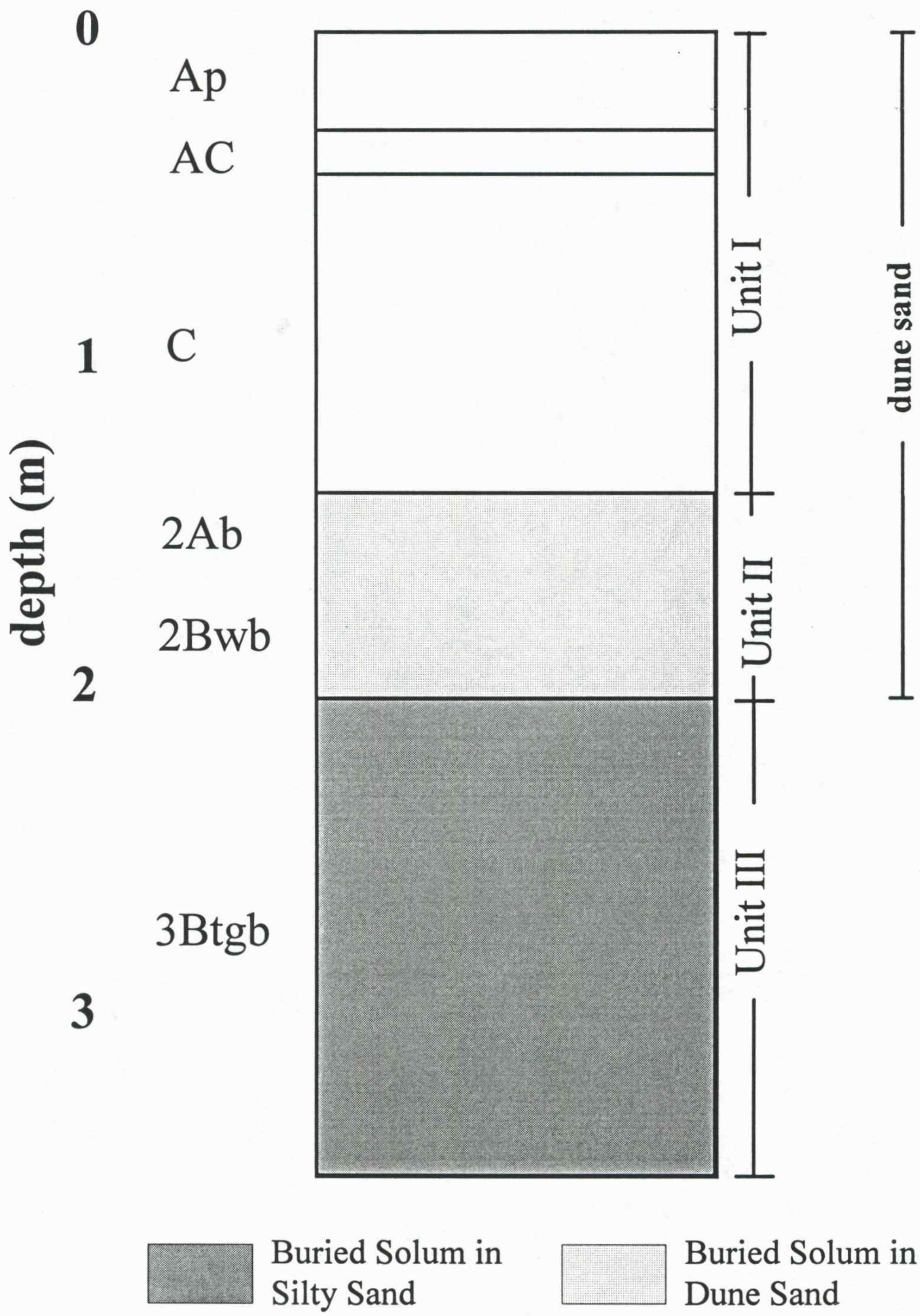


Figure 5:71. Soil stratigraphy at Stafford 5.

Overlying Unit III, identified as a sharp contact at 2.03 m (Fig. 5:70), is Unit II. Ranging from 1.40 to 2.03 m (Figs. 5:69, 5:70, 5:71), Unit II is sandier than the underlying deposits, with a mean particle size that shifts from medium silt to very fine sand. Although sorting improves from Unit III, it is generally very poor in Unit II due to the presence of medium sand in the 5th percentile and fine clay in the 95th. The sediment in Unit II is very finely skewed and very leptokurtic (Fig. 5:70).

Formed within Unit II is a weak to moderately developed buried soil, consisting of a 2Ab and 2Bwb hoirzon that contains less than 1.0 percent organic carbon and carbonate (Fig. 5:70). The 2Bwb, which extends from 1.63 to 2.03 m (Fig. 5:71), is loamy fine sand (84% sand; 7% silt; 9% clay), dark yellowish brown (10YR4/4; moist), and has a very weak prismatic structure that parts to very weak subangular blocky. Overlying, the 2Ab (1.40 - 1.63 m; Fig. 5:71) which is sand (ca. 87% sand, 9% silt, 4% clay), dark grayish brown (10YR4/2; moist) and has a granular structure that parts to single grain.

Unit I extends from the surface to 1.40 m (Figs 5:69, 5:70, 5:71) and is distinguished by the abrupt shift in all parameters in Figure 5:71. Although mean particle size remains very fine sand, the overall amount of sand increases to about 95 percent. Of particular interest is the clear improvement in sorting, increasing from very poor in Unit II to moderate in Unit I because the 95th percentile abruptly changes from coarse clay to medium silt, respectively. Kurtosis also changes noticeably, from very leptokurtic in Unit II to mesokurtic in Unit I. In addition, Unit I is finely skewed (Fig 5:70).

Formed in the upper part of Unit I is a weakly developed soil, consisting of a 25-cm-thick Ap horizon, overlying a 14-cm-thick AC horizon and 1.01-m-thick C horizon (Fig. 5:71) that contains less than 1.0 percent carbonate and organic carbon. The C horizon is dark yellowish brown (10YR4/4; moist), sand (ca. 96.5 sand; 3% silt; 2% clay; Fig. 5:70) and has single grain structure. Transitional is the 14-cm-thick AC horizon (Fig. 5:71). Similar in texture, structure, and chemical composition as the underlying C, the AC differs primarily by color, which darkens slightly to dark brown (10YR3/3; moist). Overlying is the A horizon, consisting of sand (92.1% sand; 6.8% silt; 2.0 % clay; Fig. 5:70) with a granular structure that parts to single grain. The primary difference between the A and the underlying horizons in Unit I is color, which darkens to very dark grayish brown (10YR3/2; moist) in the A.

In summary, Stafford 5 is a 3.46-m-deep stratigraphic profile, exposed by backhoe trenching, in a compound parabolic dune field in the central part of the Great Bend Sand Prairie. Three pedostratigraphic units were recognized, with the basal one (Unit III) containing deposits relatively rich in silt and clay and the upper two (Units II and I) dominantly composed of sand. In general, the contrasting sedimentology between Unit III and the overlying deposits appears to reflect diachronous depositional environments at the site in the past 20,000 years. Two buried soils were described, indicating that sedimentation was punctuated by periods of stability and pedogenesis.

Unit III ranges from 2.03 m to the base of the profile. Although abundant in sand (e.g., 66.2 percent), it also contains relatively high amounts of silt (e.g., 36.5 percent) and clay (21.8 percent) and, as a result, is very poorly sorted. The overall lack of sorting, coupled with the presence of three fining-upward sequences in the stratum, suggest accumulation in a very low energy fluvial or lacustrine environment. A fluvial association is tentative, however, because sedimentary structures are not preserved. Deposition must have been episodic, because the stratum contains a well developed soil, one that consists of a heavily gleyed Btb horizon. Implicit in the presumed sedimentary environment is a climate of more effective moisture that that present today. In addition, the gleyed nature of the soil suggests ponded water at the surface and/or higher groundwater tables. Although no radiocarbon ages were obtained from Unit III, the character of the unit is consistent with other silty sands recognized elsewhere (e.g., Stafford 1, Edwards 2, Reno 4), demonstrated to be late Wisconsinan in age. As a result, Unit III at Stafford 5 is assigned a Woodfordian age..

Although the origin of the facies associated with Unit III is uncertain, the origins of Units II and I can be made with confidence. In general, the sediments in Units II and I consist of loose, single grain sand that is much better sorted than the underlying deposits. The character of the deposits, coupled with their topographic position and expression, correlates very well with dune sand. Inherent in dune development is a relatively warm, arid environment, one promoting destabilization and eolian mobilization of sand. Soil development throughout Unit II, and at the surface of Unit I, indicate episodic sedimentation. Following deposition of Unit II, a brief period of pedogenesis occurred that resulted in the development of a soil with A/Bw horizonation. Although no radiocarbon ages were obtained from the 2Ab, its character (e.g., color, structure, position) suggests a middle to late Holocene age. Subsequent to development of the 2Ab, at least 1.40 m of eolian sand accumulated. Given that the surface soil is weakly developed, with A/AC/C horizonation, it is concluded that Stafford 5 has been stabilized for a brief period of time.

Stafford 6

Stafford 6 is a 2.30-m-thick sequence of sediments exposed by backhoe trenching in a parabolic dune field located in the SW. NE sec. 29, T.23S, R12W (Figs. 5:1, 5:72). Four pedostratigraphic units are recognized in the profile (Figs. 5:73, 5:74, 5:75), with one in deposits rich in silt and three in

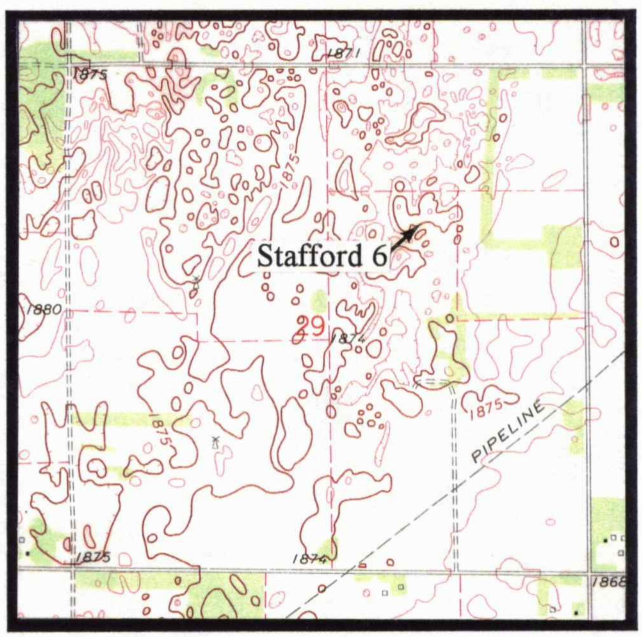


Figure 5:72. Topographic map in the vicinity of Stafford 6. Scale = 1:24,000 (Hudson 7.5 min. Quadrangle, 1971).

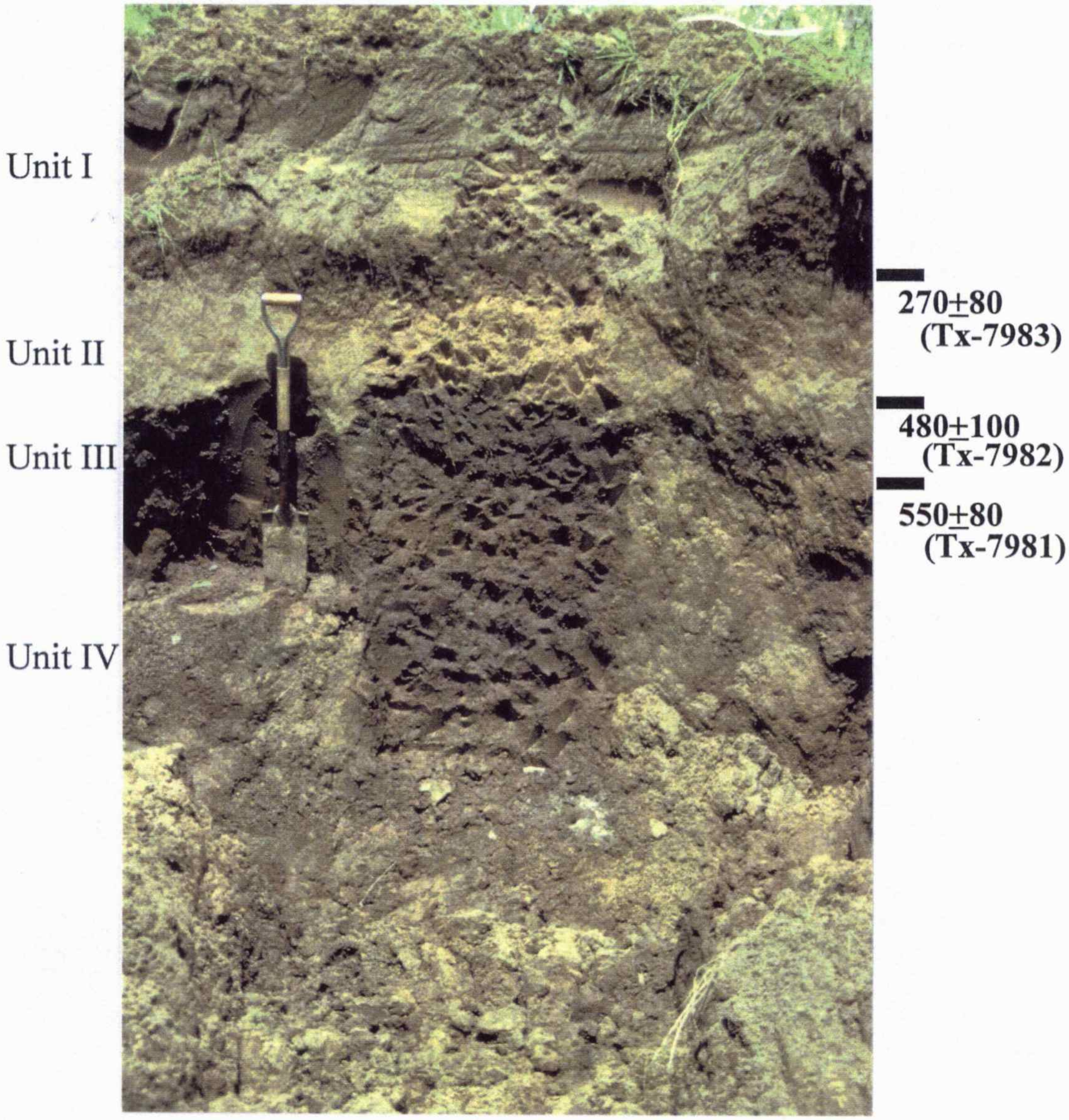


Figure 5:73. Stafford 6 (2.30-m high) showing pedostratigraphic units and radiocarbon ages.

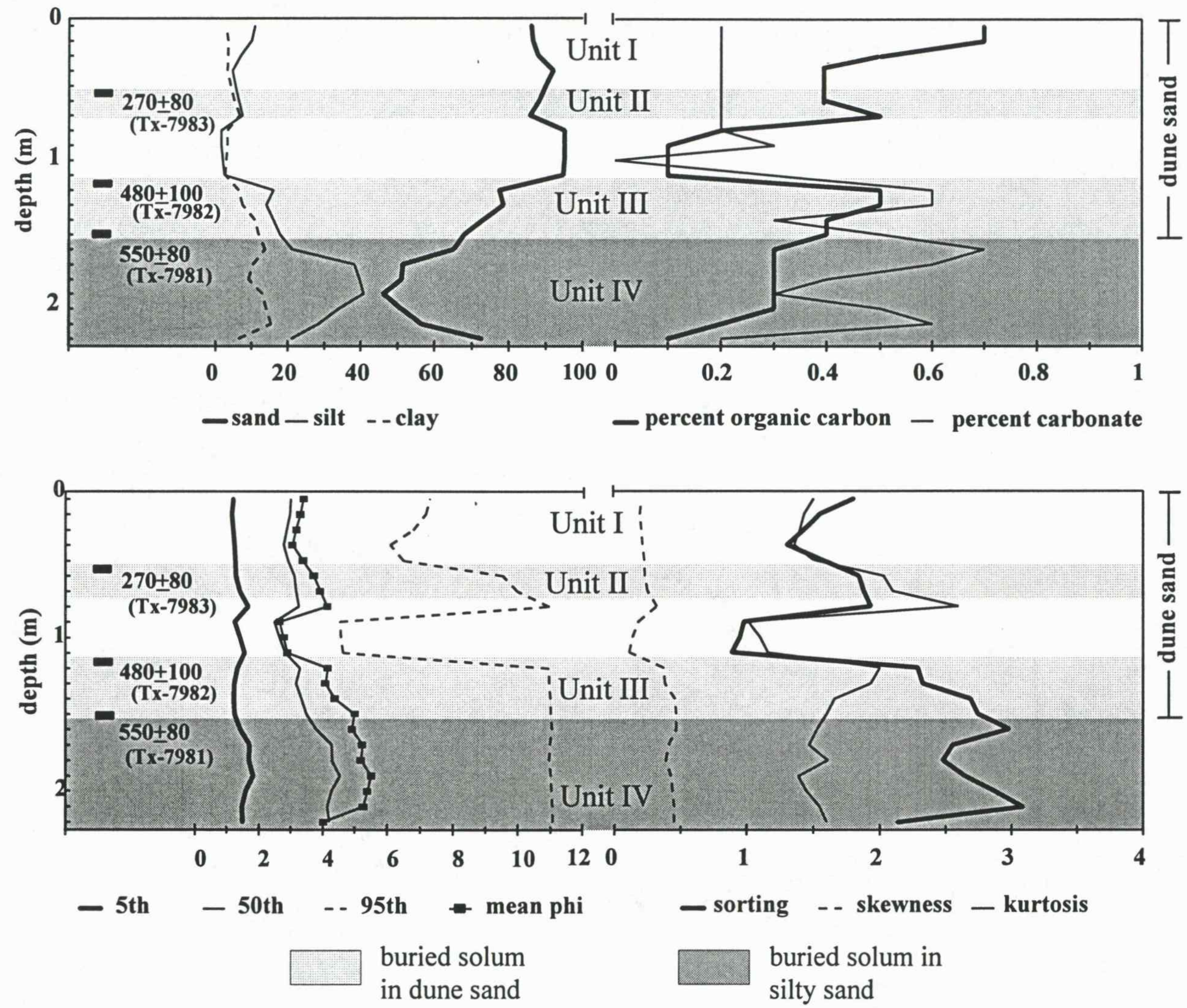


Figure 5:74. Graphical statistics and chemical composition of sediments at Stafford 6.

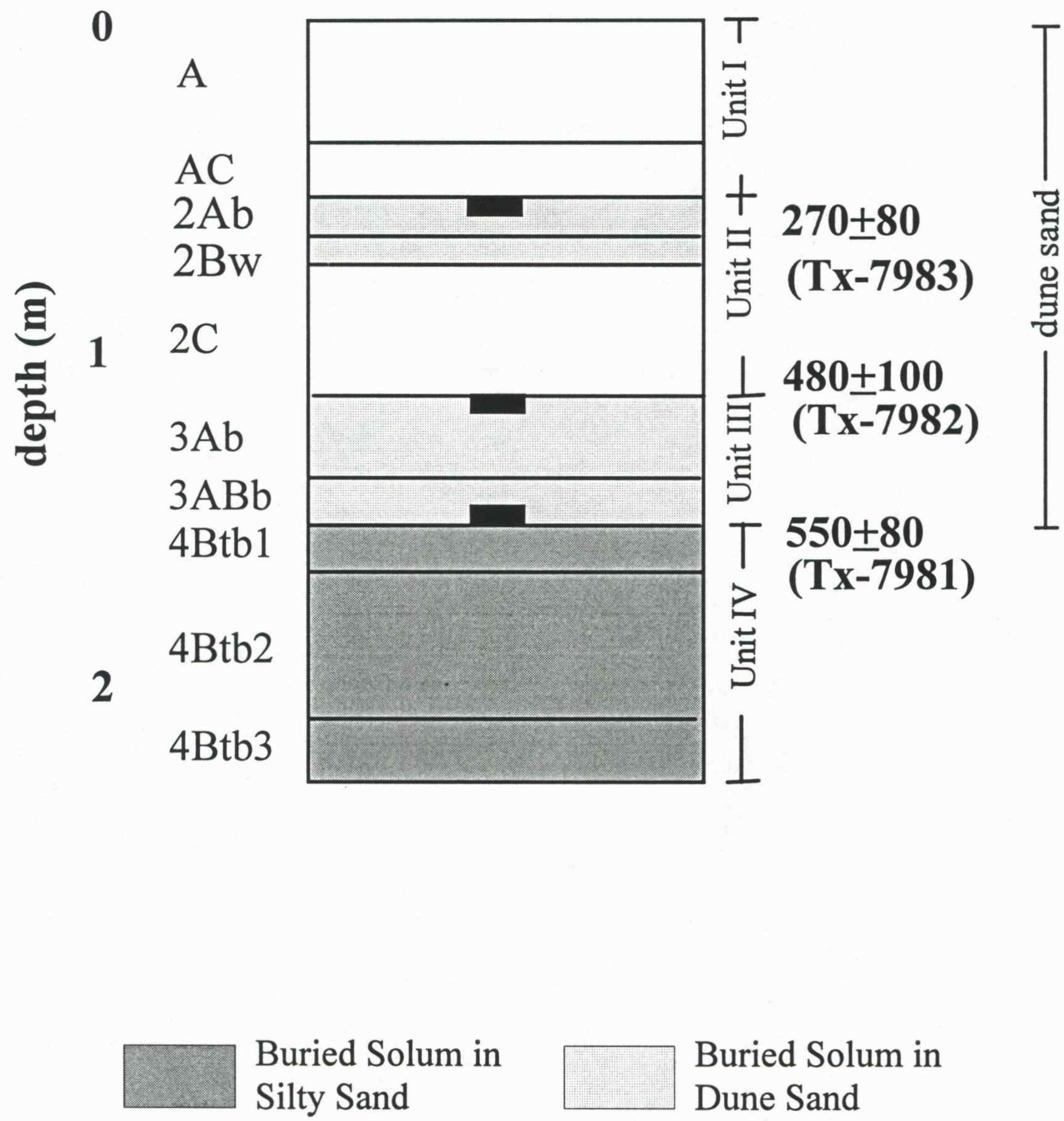


Figure 5:75. Soil stratigraphy and radiocarbon ages at Stafford 6.

surficial, loose sand. In general, the sediments at Stafford 6 are loamy, have a mean particle size ranging from coarse silt to very fine sand, are very poorly sorted to moderately sorted, and very fine to finely skewed and leptokurtic to very leptokurtic. Graphical statistics and the chemical composition of sediments at Stafford 6 are illustrated in Fig. 5:74.

The lowermost pedostratigraphic unit is Unit IV, extending from 1.52 m to the base of the profile (Figs. 5:72, 5:73, 5:74). Texture in Unit IV is loamy, ranging from loamy fine sand to loam and mean particle size varies from coarse silt at the base to medium silt in the upper part of the deposit. Sorting is very poor because fine sand comprises the 5th percentile and fine clay the 95th and the stratum is very finely skewed and leptokurtic to very leptokurtic (Fig. 5:74).

Formed within Unit IV is a well developed buried soil, consisting of three 4Btb horizons that contain less than 1.0 percent carbonate and organic carbon. The lowermost horizon is the 4Btb3 (2.11 - 2.30 m; Fig. 5:75), which is light yellowish brown (10YR4/4; moist), loamy fine sand (72.6% sand; 20.9% silt; 6.5% clay), has a weak prismatic structure that parts to weak subangular blocky, and contains 0.1 percent organic carbon (Fig. 5:74). Overlying, is the 45-cm-thick 4Btb2 horizon (Fig. 5:75), which is dark grayish brown (10YR4/2; moist), largely sandy loam (ca. 56.% sand; 283% silt; 15.% clay; Fig. 5:74), and has a weak to moderate prismatic parting to weak to moderate subangular blocky structure. Capping the soil is the dark yellowish brown

(10YR3/4; moist) 4Btb1 horizon, extending from 1.52 to 1.66 m (Fig. 5:75). Although sandy loam, the 4Btb1 contains approximately 14 percent more sand (i.e., 65%), with a corresponding decrease in silt (i.e., to 21.2%) and clay (i.e., to 13.8%; Fig. 5:74) than either the 4Btb2 or 4Btb3. The 4Btb1 has a weak to moderate prismatic structure, one that parts to moderate subangular blocky.

Unit III extends from 1.13 to 1.52 m (Figs. 5:73, 5:74, 5:75) and is loamy, with a mean particle size of medium silt. Sorting in the deposit is generally very poor because the 5th percentile is fine sand and the 95th, fine clay. Sorting improves to poor, however, in the uppermost part due to a shift in the 95th percentile to very fine silt. In addition, the stratum is very finely skewed and very leptokurtic (Fig. 5:74).

Unit III consists of a poorly developed soil, formed within a thin deposit of sand, that contains less than 1.0 percent carbonate and organic carbon. The soil is comprised of two horizons, a 27-cm-thick 3Ab overlying a 12-cm-thick 3ABb (Fig. 5:75). Although both horizons are loamy fine sand (>73% sand), the 3ABb appears to be a transitional illuvial horizon, as suggested by the increased clay (11.0%) and structure (weak prismatic parting to weak subangular blocky) than that embodied in the 3Ab (i.e., 7% clay; Fig. 5:74; granular structure parting to single grain). Color darkens from brown (10YR4/3; moist) in the 3ABb to very dark brown (10YR2/2; moist) in the 3Ab. To estimate the maximum-limiting age of the host sand in the lower 5 cm (1.47 - 1.52 m) of the solum, a sample was collected that provided a $\delta^{13}C$-corrected radiocarbon age of 550±80 yrs B.P. and a $\delta^{13}C$ value of -13.4‰ (Tx-7981). Similarly, a $\delta^{13}C$-corrected radiocarbon age of 480±100 yrs B.P. (Tx-7982) was obtained from the upper 5 cm (1.13 - 1.18 m) of the 3Ab. In the upper part of the 3Ab a $\delta^{13}C$ value of -15.0‰ was derived.

A sharp contact in all parameters at 1.13 m identifies the base of Unit II (Figs. 5:73, 5:74, 5:75). Extending from 53 cm to 1.13 m, Unit II is very sandy, with a mean particle size that varies from very fine sand in the lower part of the unit to coarse silt in the upper part. Sorting improves sharply from very poor in the underlying deposits to moderate at the base of Unit II because the 95th percentile coarsens to medium silt. Towards the top of the stratum, sorting decreases to poor, largely due to an influx of fine clay in the 95th percentile. Unit II is very finely skewed, and kurtosis varies from leptokurtic at the base to very leptokurtic towards the top (Fig. 5:74).

Contained within Unit II is a weakly developed buried soil, consisting of a 2Ab, 2Bw, and one C horizon (Fig 5:75). The C horizon lightens slightly from dark yellowish brown (10YR3/6; moist) in the lower part to dark yellowish brown (10YR3/4; moist) in the upper. Otherwise, the horizon is sandy (ca. 95% sand; 2% silt; 3% clay), has single grain structure, and contains less than 0.5 percent carbonate and organic carbon.

At a depth of 75 cm, a relatively sharp decrease in sand occurs to 85.8 percent (Fig. 5:74), marking the lower boundary of the 11-cm-thick 2Bw horizon (Fig 5:75).

Although texture remains sand, silt and clay increase to 7.6 and 6.6 percent, respectively (Fig. 5:74). The 2Bw has a very weak subangular blocky structure and is dark brown (10YR3/3; moist). Capping the solum is an 11-cm-thick 2Ab horizon (Fig. 5:75) which is dark brown (10YR3/3; moist), has a granular structure that parts to single grain, and contains less than 0.5 percent carbonate and organic carbon. Percent sand increases slightly to 88.2 percent with a corresponding drop of silt to 6.5 percent and clay to 5.3 percent (Fig. 5:74). To estimate the mean residence time of humates in the upper 5 cm (53 - 64 cm), a sample provided a $\delta^{13}C$-corrected radiocarbon age of 270$\pm$80 yrs B.P. and a $\delta^{13}C$ value of -15.2‰ (Tx-7983) .

The surficial deposit is Unit I (0 - 53 cm), consisting of sandy sediments (Figs. 5:73, 5:74, 5:75) that have a mean particle size of coarse silt. Sorting is best in the lower part of the deposit, resulting from an increase in the 95th percentile to medium silt. The deposit is very finely to finely skewed and leptokurtic to very leptokurtic (Fig. 5:74).

Formed within Unit I is a poorly developed surface soil, including a 38-cm-thick A horizon overlying a 15-cm-thick AC horizon (Fig. 5:75) that contain less than 2.0 percent carbonate and about 1.0 percent organic carbon. The very dark grayish brown (10YR3/2; moist) AC horizon reflects an increase in sand of approximately 4.0 percent from the underlying 2Ab, whereas silt and clay decrease to 4.7 and 3.3 percent, respectively (Fig. 5:74). Overlying is the very dark brown (10YR2/2; moist) A horizon

(Fig. 5:76). The A is also sand, but shows a decrease in sand to about 87 percent, while silt increases to approximately 10 percent (Fig. 5:74).

In summary, Stafford 6 is a 2.30-m-thick stratigraphic sequence exposed by backhoe trenching in a parabolic dune field in the north central part of the Great Bend Sand Prairie. Four pedostratigraphic units were recognized, with each representing a period of relatively rapid sedimentation and subsequent stability and soil formation. In general, the units can be grouped into two categories: 1) a basal stratum of very poorly sorted, silt-rich sediments (Unit IV); and 2) overlying deposits of loose, relatively well sorted sandy deposits (Units III - I).

Unit IV extends from 1.52 m to the base of the profile. The deposits are loamy and very poorly sorted because of high percentages of sand, silt, and clay. As a result, the sediments are extremely cohesive. In its character (e.g., texture, structure, color, stratigraphic position), Unit IV is similar to other silty sands elsewhere (e.g., Edwards 1 - 4, Stafford 1, Stafford 2) in the region. Unfortunately, unlike other localities, sedimentary structures are not preserved which would attest to the facies. The overall lack of sorting, coupled with a clear fining-upward sequence in the middle of the deposit, suggest a low energy fluvial or lacustrine facies. Implicit is a diachronous climate from the present, one that was apparently more moist. Although an estimated age for Unit I was not obtained through radiocarbon dating, the deposit is consistent with others (e.g., Edwards 1, Edwards2, Reno 4, Stafford 1) assigned a late Wisconsinan age. As a result, Unit IV at Stafford 6 is considered to be a late Wisconsinan stratigraphic unit. Regardless of when and how the stratum accumulated, the formation of a strongly developed soil indicates that the unit was exposed for some period of time. A rather intense period of erosion must have subsequently occurred, one that truncated the 4Ab that is presumed to have existed.

A sequence of relatively uncohesive, sandy sediments, extending from the surface to 1.52 m, are included within Units I to III. Their overall character, including very sandy texture, poor structure, relatively good sorting, color, and topographic position and expression, qualify them as wind-blown, dune sand. Given no significant truncation, the sequence represents at least three cycles of rapid eolian sedimentation during a relatively warm, arid climate, followed by brief periods of soil formation during periods of more effective moisture. Following deposition of Unit III, a poorly developed soil formed. Radiocarbon ages of about 550 yrs B.P. from the base of the 3ABb, and 480 yrs B.P. from the top of the 3Ab, suggest two things: 1) sedimentation occurred in the past 1000 years, and 2) pedogenesis lasted for at most, a few hundred years. Soon after this soil formed, at least 70 cm of sediment accumulated that buried the 3Ab. Another brief period of soil formation subsequently occurred, one that altered the upper part of Unit II. A radiocarbon age of about 270 yrs B.P. from the upper part of the 2Ab verifies a very late Holocene age for the overall deposit. Values of $\delta^{13}C$ are about 15.0‰ in both buried soils, suggesting C_4 plants dominated the site in the past

1000 years. Subsequent to the development of the 2Ab, at least 53 cm of eolian sand accumulated. The overall lack of surface soil development, which includes an A and AC horizon, coupled with the radiocarbon ages obtained from the underlying soils, suggests that the Stafford 6 has been stable for a brief period of time.

Stafford 10

Stafford 10 is a 3.0-m-deep stratigraphic section exposed by backhoe trenching in a compound subparabolic dune field in the SW, SW, sec. 11, T25S., R15W (Figs. 5:1, 5:76). Four pedostratigraphic units were described in the profile, with two in silty sand and two in sand (Figs. 5:77, 5:78, 5:79). In general, the silty sand is loamy, ranging from sandy loam to loam.

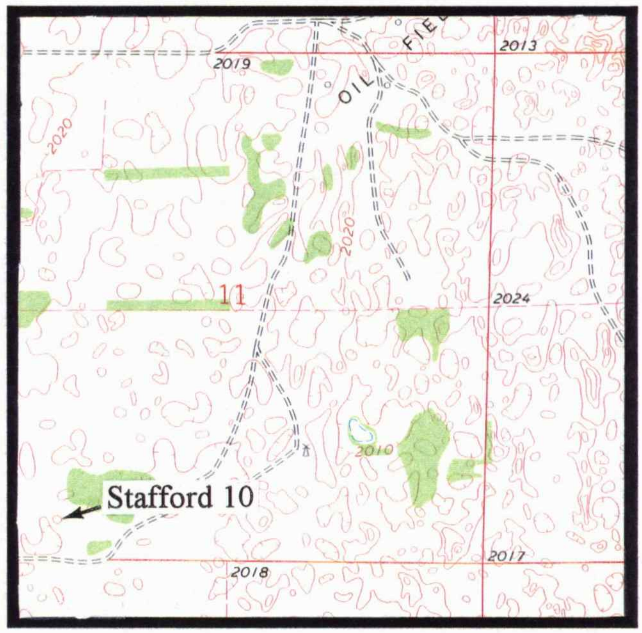


Figure 5:76. Topographic map in the vicinity of Stafford 10. Scale = 1:24,000 (Macksville 7.5 min. Quadrangle, 1972).

Dune sand, in contrast, is classified as sand. Mean particle size in the silty sand ranges from coarse to fine silt, with two, distinct fining-upward sequences, and the deposit is very poorly sorted, fine to very finely skewed, and mesokurtic to very leptokurtic. In

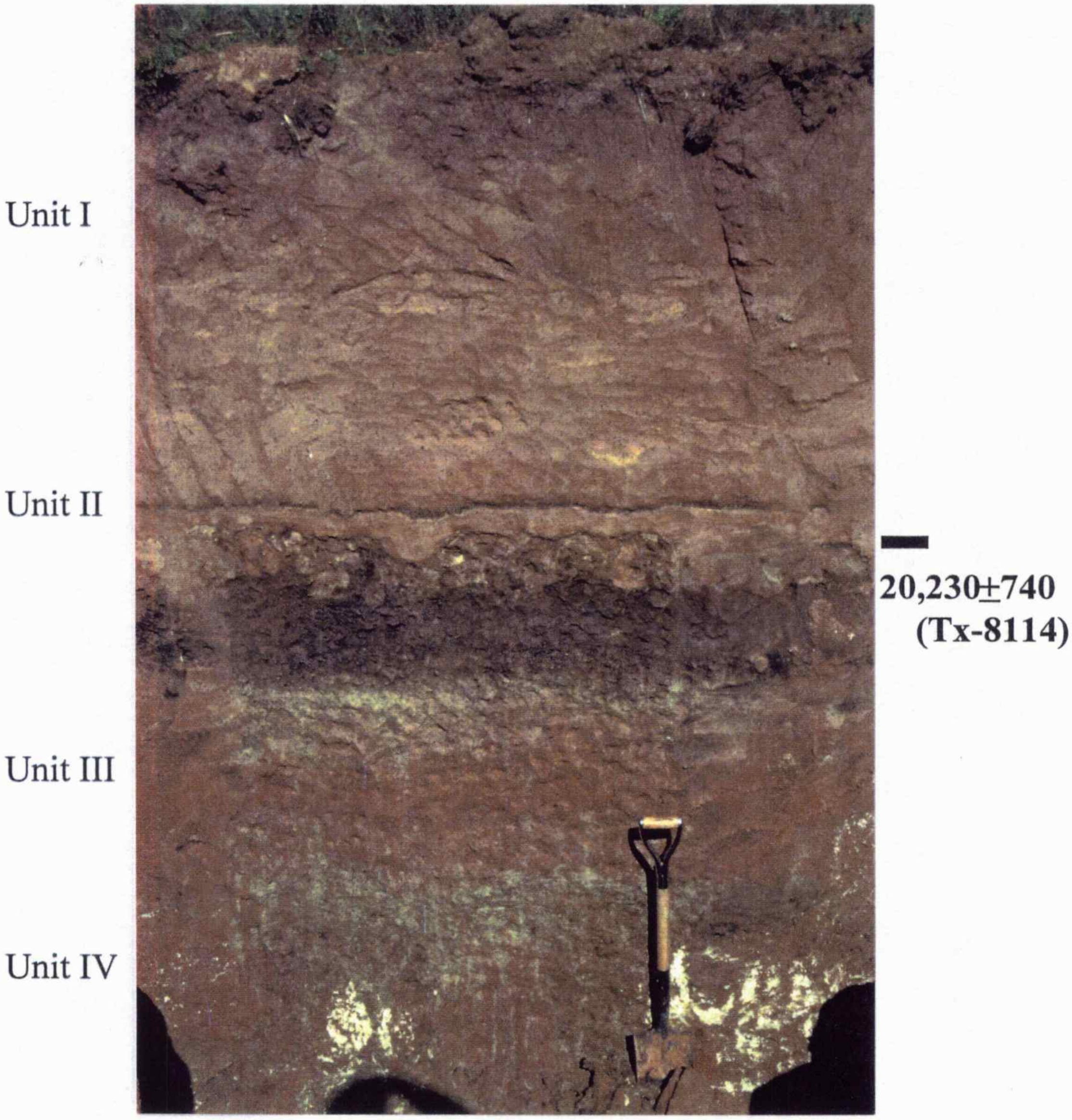


Figure 5:77. Stafford 10 (3.0-m high) showing pedostratigraphic units and radiocarbon age.

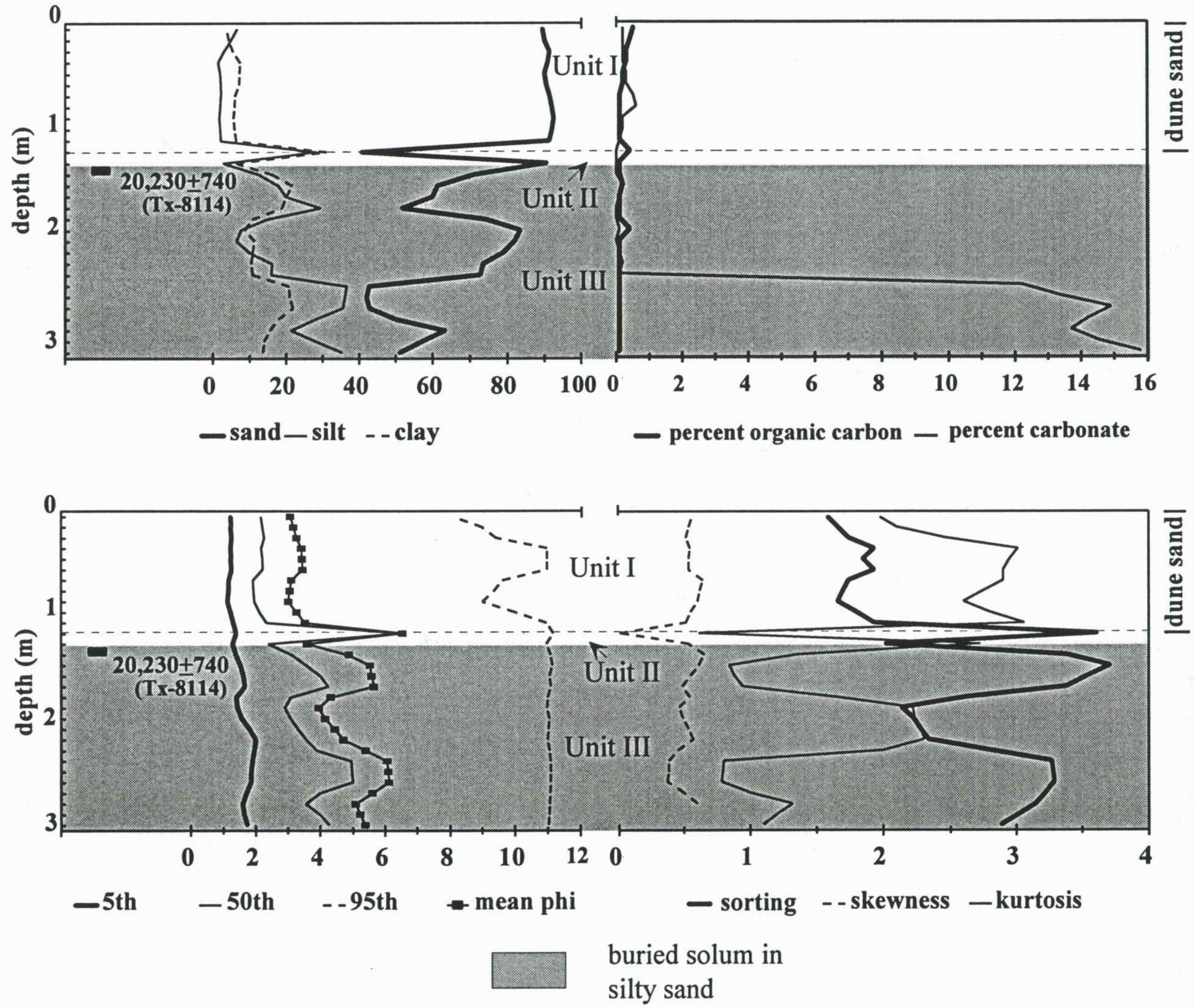


Figure 5:78. Graphical statistics and chemical composition of sediments at Stafford 10.

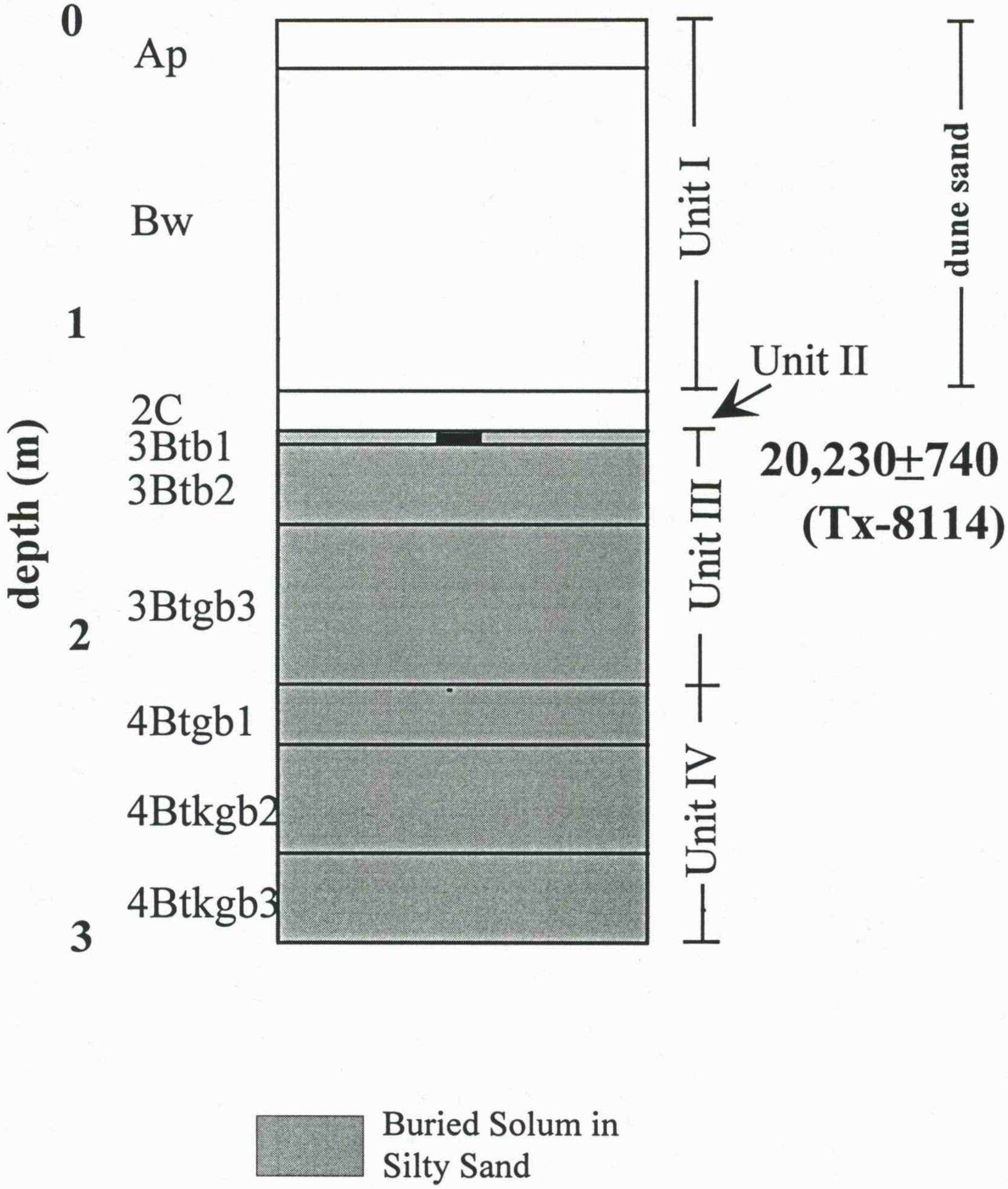


Figure 5:79. Soil stratigraphy and the radiocarbon ageat Stafford 10.

the dune sand, mean particle size is coarse silt to very fine sand, sorting is poor, and the deposit is very fine to finely skewed and platykurtic to very leptokurtic. Graphical statistics and the chemical composition of sediments are illustrated in Figure 5:78.

The lowermost pedostratigraphic unit, ranging from 2.17 m to the base of the profile, is Unit IV (Figs. 5:77, 5:78, 5:79). Unit IV consists, sedimentologically, of one fining-upward sequence. Deposits within the unit range from sandy loam to loam and mean particle size varies between fine to medium silt. Sorting is very poor, owing to the presence of fine clay in the 95th percentile and very fine sand in the 5th. In addition, Unit IV is very finely skewed and leptokurtic to mesokurtic (Fig. 5:78).

Formed within Unit IV is a well developed buried soil, consisting of two 4Btkgb horizons and one 4Btgb horizon. The 4Btkgb3 (2.72 - 3.00 m) and 4Btkgb2 (2..38 - 2.72 m; Fig. 5:79) horizons are similar, differing largely in texture. Both are brown (7.5YR5/4; moist), contain about 14% carbonate and less than 0.5 percent organic carbon, and have medium prismatic parting to medium subangular blocky structure. Texture in the 4Btgb3 is sandy loam, with an increase in sand from 51.0 percent at 2.98 m to 63.1 percent at 2.79 m. Correspondingly, silt and clay fluctuate from 35.4 percent and 13.6 percent, respectively at 2.98 m, to 15.6 percent and 15.3 percent, respectively, at 2.79 m. The 4Btgb2 is loam (ca. 43.0% sand; 36% silt; 21% clay), with the base of the horizon represented by the sharp decrease in sand at 2.60 m (Fig. 5:77). Overlying is the 21-cm-thick 4Btgb1 horizon (Fig. 5:79), which is loamy fine sand (73.5% sand, 16.1% silt, 10.4% clay; Fig. 5:78), contains less than 0.5 percent carbonate and organic carbon, is strong-brown (7.5YR4/6; moist) and has moderate prismatic structure that parts to moderate subangular blocky.

Unit III ranges from 1.32 to 2.17 m (Figs 5:77, 5:78, 5:79). Deposits include sandy loam to loamy fine sand, with one fining-upward sequence present in the stratum. Accordingly, mean particle size varies from coarse silt at the base of the deposit to fine silt towards the top. Although sorting is noticeably better in the lower part of the unit, it is very poor throughout the strata because the 95th percentile contains fine clay whereas the 5th percentile is very fine sand. In addition, Unit III is finely skewed and mesokurtic to very leptokurtic (Fig. 5:78).

Formed within Unit III is a well developed buried soil, consisting of two 3Btb and one 3Btgb horizons. The sandy loam (ca. 65% sand, 20% silt, 15% clay; Fig. 5:78) 3Btgb horizon extends from 1.65 to 2.17 m (Fig. 5:79), is dark brown (10YR4/4; moist) to very dark grayish brown (10YR4/2; moist), contains less than 0.5 percent carbonate and organic carbon (Fig. 5:78), and has moderate prismatic structure that parts to moderate subangular blocky.

Overlying are two 3Btb horizons with moderate prismatic structure that parts to moderate subangular blocky and that contain less than 0.5 percent carbonate and organic carbon. The 3Btb2 horizon (1.39 - 1.65 m; Fig. 5:79) is very dark grayish brown

(10YR3/2; moist), and has loamy fine sand texture that coarsens from 61.2 percent sand, 17.2 percent silt, 21.6 percent clay at 1.72 m to 61.2 percent sand, 17.2 percent silt, and 16.2 percent clay at 1.43 m (Fig. 5:78). The 3Btb1 horizon (1.32 - 1.39 m; Fig. 5:79) differs from the 3Btb2 because it is lighter (dark yellowish brown; 10YR3/6; moist) and sand (90.8% sand; 2.9% silt; 6.3% clay; Fig. 5:78). To estimate the mean residence time of humates in the upper 5 cm (1.32- 1.37 m) of the 3Btbl, a sample provided a $\delta^{13}C$-corrected radiocarbon date of 20,230±740 yrs B.P. and a $\delta^{13}C$ value of -20.1 (Tx-8114).

Overlying, with a very uneven contact (Fig. 5:81) at 1.32 m, is a 12-cm-thick deposit (Unit II) that consists of stratified sand, silt, and clay (Figs 5:77, 5:78, 5:79). No evidence of pedogenesis exists in the unit, hence, it's classification as a 2C horizon. The best defineable layer within the strata is a 2-cm-thick, dark brown (10YR3/3; moist), organic rich (0.4%), loamy (40.6% sand; 28.3% silt; 31.1% clay) deposit, illustrated clearly at 1.25 m (Fig. 5:78).

The uppermost pedostratigraphic unit is Unit 1, extending from the surface to 1.20 m (Figs. 5:77, 5:78, 5:79). Fundamentally, the unit is sand with a mean particle size of coarse silt. Sorting is poor with fine sand present in the 5th percentile and coarse to fine clay in the 95th and the distribution is finely skewed and very leptokurtic (Fig. 5:78).

Formed within Unit I is a moderately developed surface soil, consisting of an A

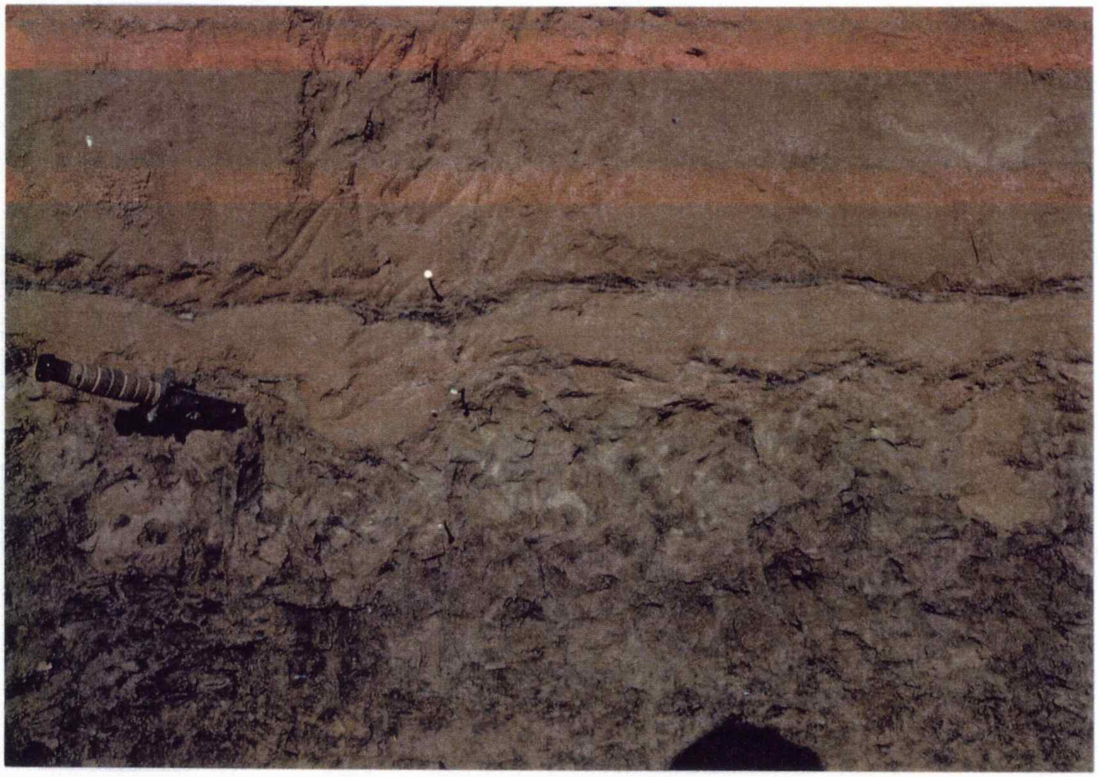


Figure 5:80. Photograph of truncated surface at the top of Unit III at Stafford 10.

horizon and a Bw horizon (Fig. 5:79). Given the similarity in texture (e.g., sand; 91% sand; 2.5% silt; 6.5% clay), and chemical composition (< 1% carbonate and organic carbon; Fig. 5:78), the horizons are distinguished by color and structure. The Bw horizon (18 cm - 1.20 m) ranges from dark yellowish brown; 10YR3/6; moist) to darkbrown (10YR4/4; moist) and has weak to moderate prismatic structure that parts to weak to moderate subangular blocky. Capping the soil is the A horizon (0 - 18 cm; Fig. 5:79), which is dark brown (10YR3/3; moist) and has granular structure.

In summary, Stafford 10 is a 3.0-m sedimentary sequence exposed by backhoe trenching in a compound subparabolic dune field in the western part of the Great Bend Sand Prairie. Three pedostratigraphic units (Units IV, III, and I) were described, with each representing at least one period of deposition followed by an interval of landscape stability and soil formation. In addition, another, very thin, stratigraphic unit (Unit II) was recognized that contained no evidence of pedogenic alteration. In general, the sedimentological differences between Units IV and III, and Unit I, appear to reflect diachronous depositional environments, which, in turn, apparently resulted from a shift in climate at the site in the past 20,000 years.

In general, Units IV and III can be grouped together. Although each represents a unique period of deposition, they are sedimentologically consistent because they are loamy, have relatively strong structure, and are very poorly sorted. The primary difference is color, with Unit IV being slightly oxidized. Both units are also gleyed to some degree, reflecting a period of sediment saturation. Although sedimentary features are not preserved, the deposits appear to have accumulated in a fluvial or lacustrine environment of mixed energy because two, distinct fining-upward sequences are present. After each unit was deposited, intervals of long-term landscape stability occurred, resulting in extremely well developed buried soils with stacked Bt horizons. Subsequently, there must have been a period of erosion since soil A horizons are truncated. Overall, Units IV and III are consistent with silty sand described elsewhere (e.g., Edwards 1, Edwards 2, Edwards 3, Edwards 4, Reno 4) in the region. A radiocarbon age of approximately 20,300 yrs B.P. obtained from the top of Unit III suggests that the underlying silty sand is probably a late Wisconsin deposit. In addition, a $\delta^{13}C$ value of -20.1‰ suggests relatively high proportions of C_3 plants inhabited the site, providing evidence of a relatively cool climate with possibly more effective moisture.

Unconformably overlying is Unit II, a 12-cm-thick deposit of stratified sand, silt, and clay. Overall, the relationship of Units III and II suggests a mixed environment, one that promoted both erosion and deposition. The contact between Units III and II is very uneven, with small channels visible in cross section that indicate flowing water of unkown energy. Following truncation of Unit III, Unit II apparently resulted from fluvial processes that culminated in deposition of a 2-cm-thick silty-clay drape toward the top of the unit. Given the late Wisconsinan age of the top of Unit III, it is theorized that truncation of Unit III, and subsequent deposition of Unit II, occurred sometime between approximately 20,000 and 15,000 yrs B.P.

Overlying Units II to IV, ranging from the surface to 1.20 m, is Unit I, Fundamentally, Unit I is over 90 percent sand and the topographic position and expression, color, structure, and texture of the stratum is consistent with other deposits in the region categorized as dune sand. In contrast to the underlying silty sand, Unit I likely reflects a period of increased aridity, one that promoted accumulation of wind-blown sand. Assigning a time of deposition is difficult, because conflicting evidence exists. At first glance, it appears that Unit I is a late Wisconsinan deposit, based on a maximum-limiting age of approximately 20,300 yrs B.P. from the upper part of the silty sand 12 cm below the base of the dune. Unit I may be a Holocene deposit, however. In this scenario, Unit II could have been much thicker at some unknown point in time than at present. Theoretically, a period of erosion could have occurred during the early or middle Holocene, one that removed the majority of Unit II, but did not reach the top of Unit III because the silty-clay drape in Unit II resisted further truncation. Subsequently, eolian processes promoted deposition of Unit I on the remnants of Unit II. Surface soil development may provide a clue. Although the soil is relatively well developed, consisting of A/Bw horizonation, it does not appear to reflect 20,000 years of landscape stability. In fact, equilibrium throughout the Holocene is difficult to imagine. More likely, Unit I is a middle to early late Holocene deposit that has been stable only during the late Holocene.

Stafford 11

Stafford 11 is a 2.90-m-deep stratigraphic section exposed by backhoe trenching, in the SW, SE, sec. 6, T.21S, R.11W (Figs. 5:1, 5:81). Located in a compound subparabolic dune field (Fig. 5:1), the site contains three pedostratigraphic units: a lower one in silty sand overlain by two in loose sand (Figs. 5:82, 5:83, 5:84). In general, deposits in the lower part of the profile are loamy, very poorly sorted, finely skewed and very leptokurtic to leptokurtic. In contrast, overlying sandy deposits are classified as sand, are poorly to moderately sorted, finely to very finely skewed, and very leptokurtic to leptokurtic. Graphical statistics and the chemical composition of sediments are illustrated in Figure 5:83.

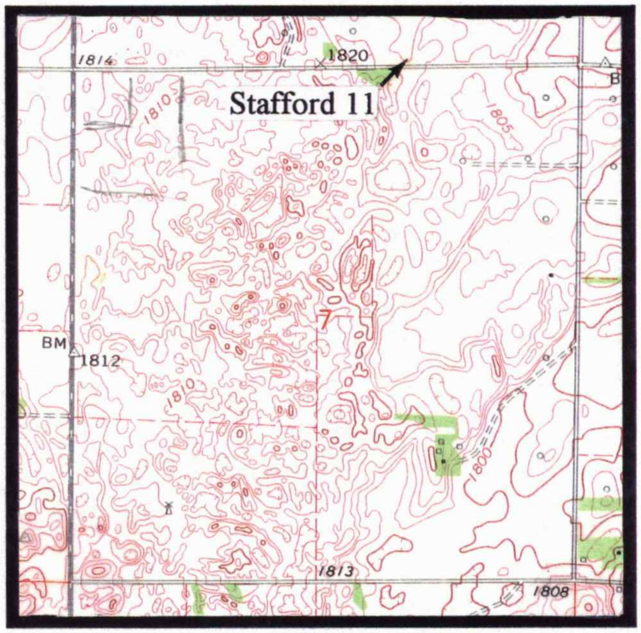


Figure 5:81 Topographic map in the vicinity of Stafford 11. Scale = 1:24,000 (Big Salt Marsh 7.5 min. Quadrangle, 1971).

Unit III consists of sediments in the lower part of the profile, ranging from 1.07

Figure 5:82. Stafford 11 (2.90-m high) showing pedostratigraphic units and radiocarbon ages.

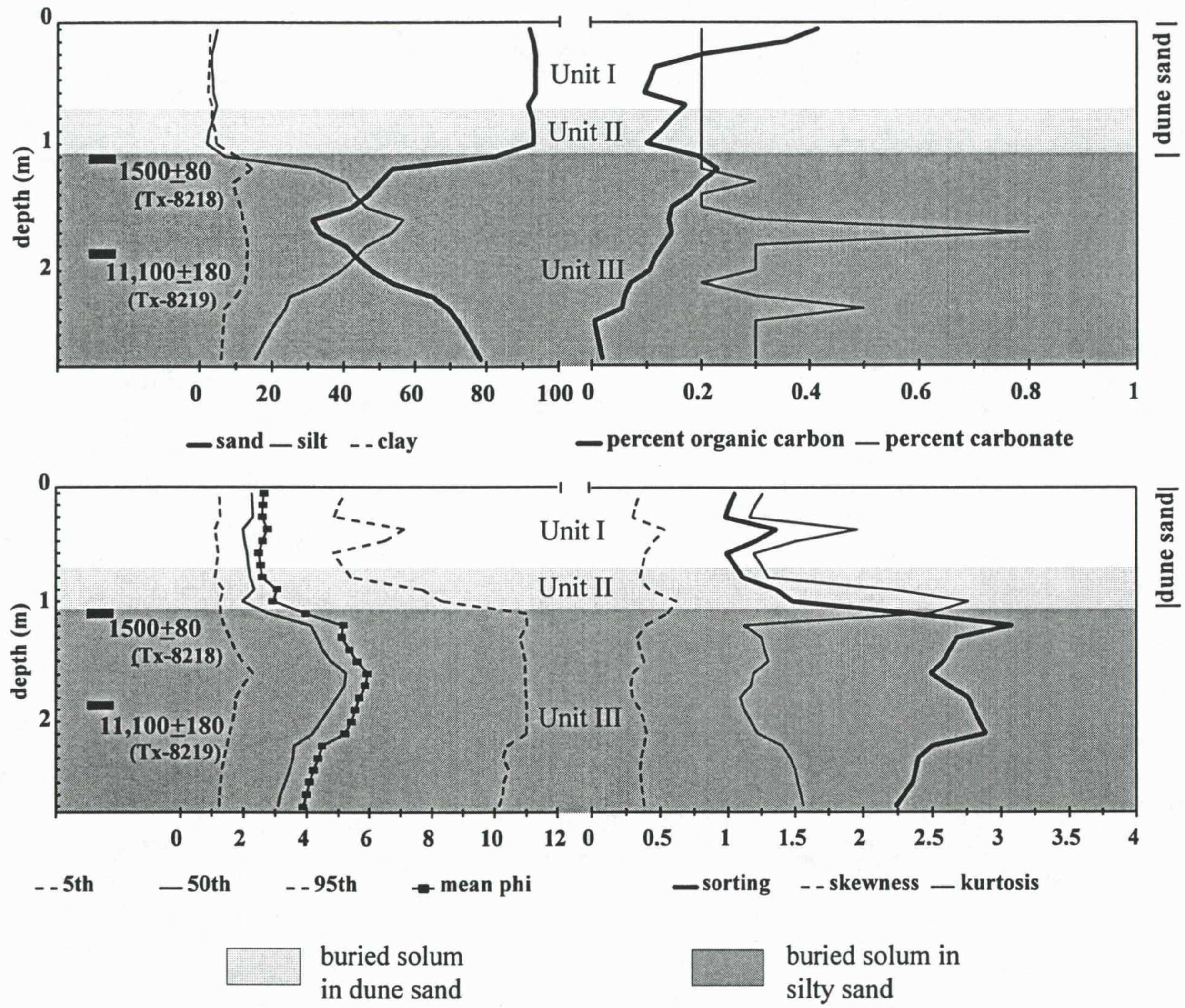


Figure 5:83. Graphical statistics and chemical composition of sediments at Stafford 11.

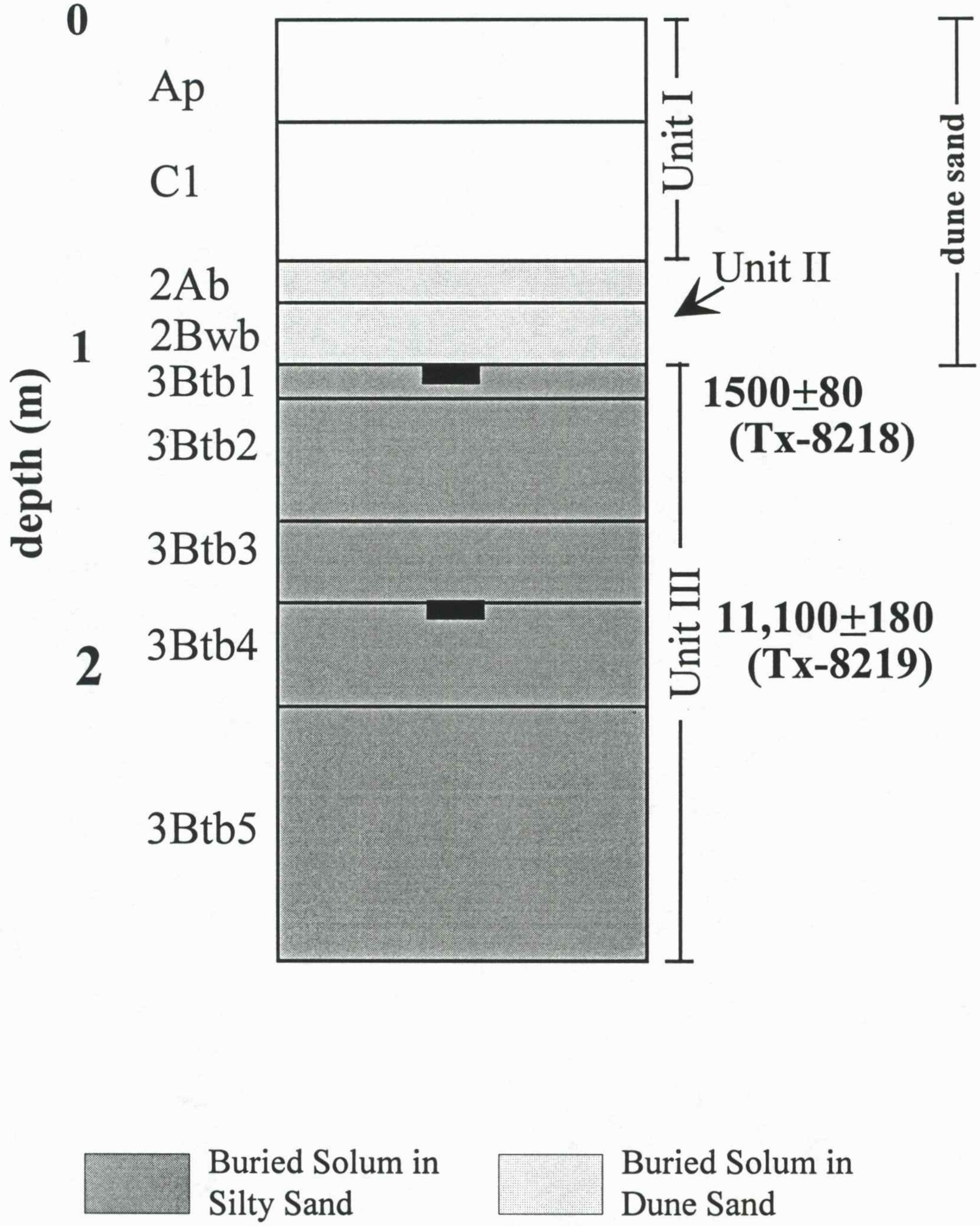


Figure 5:84. Soil stratigraphy and radiocarbon ages at Stafford 11.

to 2.90 m (Figs. 5:82, 5:83, 5:84). Texture ranges from loamy fine sand to loam, with a clear fining in the upper third of the unit. Accordingly, mean particle size varies from coarse silt in the lower part of the unit to fine silt towards the top. Sorting is very poor because the 95th percentile consists of medium to fine clay, whereas the 5th percentile is fine to very fine sand. In addition, the distribution is very finely skewed and very leptokurtic to leptokurtic (Fig. 5:83).

Formed within Unit III is a well developed buried soil, consisting of five 3Btb horizons that contain less than 0.5 percent carbonate and organic carbon. The lowermost horizon, 3Btb5 (2.12 - 2.90 m; Fig. 5:84), is dark yellowish brown (10YR4/4; moist), slightly mottled, loamy fine sand (ca. 75% sand; 18% silt; 7% clay) to sandy loam (ca. 71% sand; 22% silt; 7% clay; Fig. 5:83), and has weak prismatic structure that parts to weak subangular blocky. Sediment fines throughout the loamy, 42-cm-thick 3Btb4 horizon (Fig. 5:84), with percent sand variable between 47.9 percent (39.1% silt; 13.0% clay) at 2.02 m and 40.7 percent (46.1% silt; 13.2% clay; Fig. 5:83) at 1.80 m. Due to the increase of silt and clay, structure in the 3Btb4 is strong prismatic parting to strong subangular blocky. To estimate the mean residence time of humates in upper 5 cm (1.82 - 1.87 m) of the 3Btb4, a sample was collected that provided a $\delta^{13}C$-corrected radiocarbon age of 11,100±180 yrs B.P. and a $\delta^{13}C$ value of -16.5‰ (Tx-8219).

Overlying is the 3Btb3 (1.55 - 1.80 m; Fig. 5:84), which is silt loam (ca. 32%

sand; 55% silt; 13% clay; Fig. 5:83), and has a strong prismatic structure that parts to strong subangular blocky. Figure 5:85 illustrates the 3Btb3 horizon, representative for Btb horizons in the silty sand throughout the region, in thin section. The matrix consists of skeleton grains of sand and silt surrounded by a clayey plasma. Minerology is dominated by quartz, but isolated grains of feldspar and rock fragments (e.g., biatite) are scattered throughout the section. The plasma is composed largely of striated clays, which indicate intensive illuviation of fine-grained material during pedogenesis. Clay skins are located primarily on the edge of sand grains, but also line the inside of voids. Many of the sand grains are highly stained with iron, indicating oxidation. In addition, several sand grains are pitted, suggesting transport.

Overlying is the dark yellowish brown (10YR3/6; moist) 3Btb2 horizon, extending from 1.17 to 1.55 m (Fig. 5:84). The 3Btb2 is loam, with an increase in sand from 41.9 percent (46.5% silt; 11.6% clay) at 1.54 m to 50.1 percent sand (40.6% silt; 9.4% clay; Fig. 5:83) at 1.27 m. Structure in the 3Btb2 is moderate prismatic parting to moderate subangular blocky. Above the 3Btb2 is the 10-cm-thick 3Btb1 horizon (Fig. 5:84), which has loamy fine sand (82.3% sand; 71% silt; 10.6% clay; Fig. 5:83) texture, and weak prismatic structure that parts to weak subangular blocky. To estimate the mean residence time of humates in the upper 5 cm (1.07 - 1.12 m) of the 3Btb1, a sample provided a $\delta^{13}C$-corrected radiocarbon date of 1500±80 yrs B.P. and a $\delta^{13}C$ value of -15.7‰ (Tx-8218).

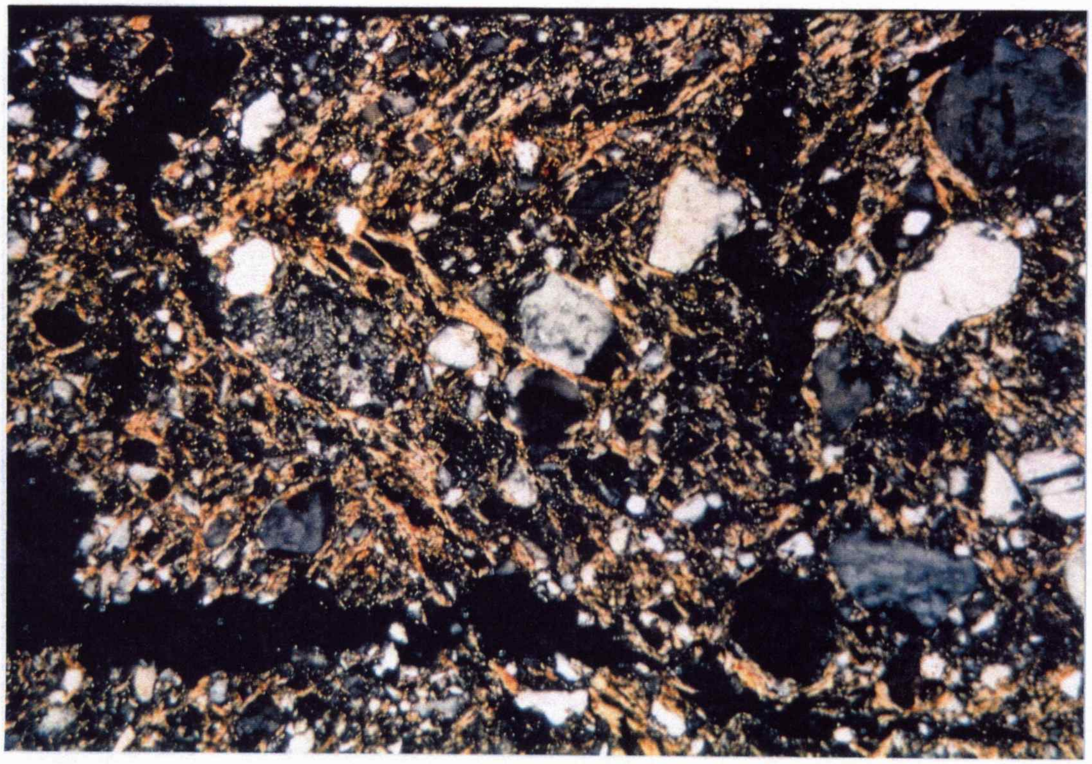


Figure 5:85. Thin section (FOV = 1.85 x 2.69 mm) collected from the upper part of the 3Btb3 horizon at a depth of 1.80 m.

Intermediate at Stafford 11 is Unit II, extending from 73 cm to 1.07 m (Figs. 5:82, 5:83, 5:84). Clearly visibile at 1.07 m as the peak in the texture, the sharp improvement in sorting, and coarsening of mean particle size, Unit II contains more than 91 percent sand and has a mean particle size of very fine sand. Although sorting is technically poor, it is nearly moderate due to the presence of very fine silt in the 95th percentile and fine sand in the 5th. In addition, the distribution is very finely skewed and very leptokurtic to leptokurtic.

Formed within Unit II is a moderately developed buried soil, consisting of a 2Ab and 2Bwb horizon that contain less than 0.5 percent carbonate and organic carbon (Fig. 5:83), and are dark yellowish brown (10YR4/4; moist). The 2Bwb, which has a very weak prismatic structure that parts to very weak subangular blocky, extends from 87 cm to 1.07 m. In contrast, the 2Ab (73 - 87 cm; Fig. 5:83) has a granular structure. Figure 5:86 illustrates the 2Ab, representative for buried A horizons in dunes throughout the region, in thin section. The matrix consists primarily of skeleton grains of sand and, to a lesser extent, silt. Birefringent material surrounding sand grains is probably clay. Although the presence of clay on sand grains implies illuviation, the clay could be present from previous weathering episodes and was transported with the sand. Occasionally, sand grains are pitted and are lined with iron oxide. According to Ransom (pers. comm.), this evidence is inconsistent with the environment in which the grains

Figure 5:86. Thin section (FOV = 1.85 x 2.69 mm)collected from the upper part of the 2Ab horizon at 87 cm.

are now found, further indicating transport. In addition, many of the grains are frosted, which is consistent with eolian deposition.

Capping the sequence at Stafford 11 is Unit I, ranging from the surface to 73 cm (Figs. 5:82, 5:83, 5:84). Over 91 percent sand, sediments in Unit I have a mean particle size of very fine sand. Although sorting is poor over most of the deposit, it is moderate in some places (e.g., 30 cm, 60 cm), and nearly moderate elsewhere because the 95th percentile consists of fine to medium silt, whereas fine sand constitutes the 5th percentile. In addition, the distribution in the stratum is very finely skewed and leptokurtic to very leptokurtic (Fig. 5:83).

Formed in the upper part of Unit I is a poorly developed surface soil, containing one Ap horizon and one C horizon. The C horizon (31 - 73 cm; Fig. 5:84) ranges from dark yellowish brown (10YR4/4; moist) to brown (10YR4/3; moist), is sand (ca. 93.7% sand; 3.5% silt; 2.8%) has single grain structure, and contains less than 0.5 percent carbonate and organic carbon (Fig. 5:83). Figure 5:87 illustrates the C horizon, representative for unaltered parent material in dunes throughout the region, in thin section. In general, the thin section is very similar to that derived from the 2Ab (Fig. 5:86). The matrix consists primarily of skeleton grains of sand, and to a lesser extent, silt. Mineralogy is dominated by quartz, although scattered grains of feldspar and rock fragments are present (Fig. 5:87). As in the 2Ab (Fig. 5:86), several of the grains are lined with clay. Given the single grain structure of the horizon, this clearly suggests

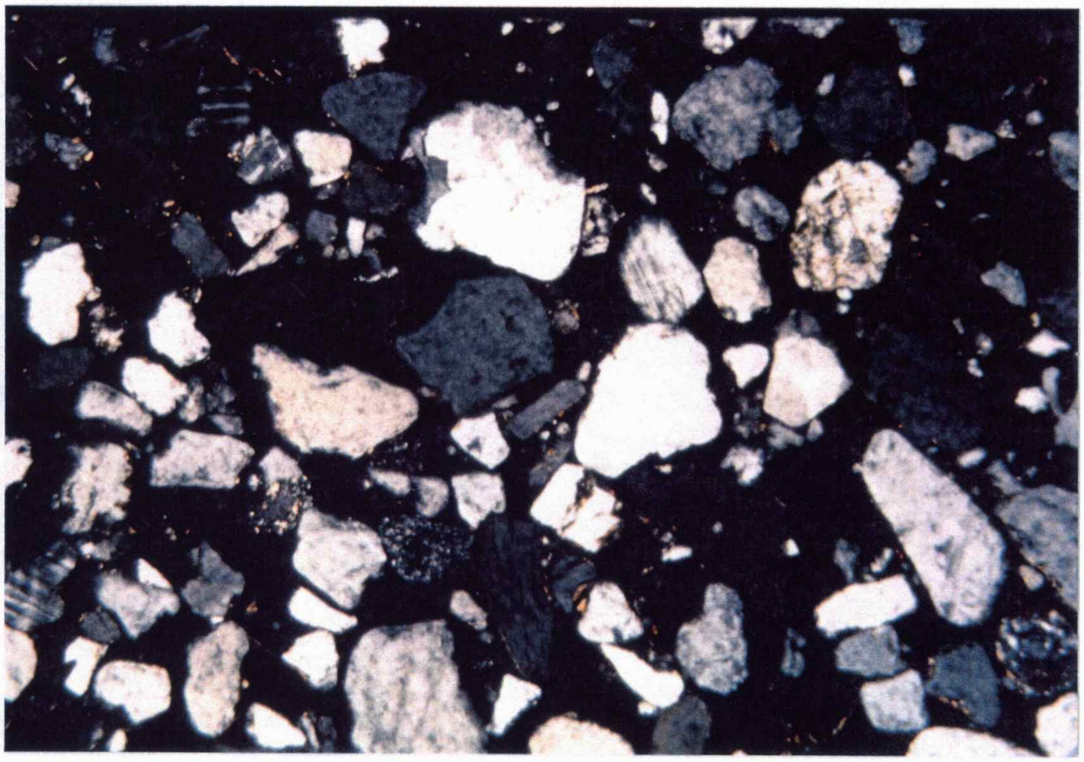


Figure 5:87 Thin section (FOV = 1.85 x 2.69 mm) collected from the C2 horizon at 65 cm.

transport rather than illuviation of clay. Further evidence of transport lies in the many pitted grains, covered with iron oxide observed, and the frosting observed on many particles in the section (Fig. 5:87).

Overlying is the Ap horizon, which ranges from the surface to 31 cm (Fig. 5:84). The horizon is brown (10YR4/3; moist), sand (92.0% sand; 5.0% silt; 3.0% clay), has a granular structure that parts to single grain, and contains less than 0.5 percent carbonate and organic carbon (Fig. 5:83).

In summary, Stafford 11 consists of a 2.90-m-thick sequence of sediments exposed by backhoe trenching in the north central part of the Great Bend Sand Prairie. Three pedostratigraphic units were recognized, with each representing an interval of deposition followed by relative landscape stability and soil formation. In general, the sedimentological diffferences existing between Units III and Units II and I appear to reflect diachronous depositional facies resulting from moist conditions during the late Wisconsin that shifted to more arid in the Holocene.

Unit III extends from 1.07 m to the base of the profile and is consistent in character with silty sand elsewhere (e.g., Edwards 1, Edwards 2, Edwards 4, Reno 4) in the study area. Two radiocarbon ages were derived from the deposit: one of approximately 11,000 yrs B.P. from the center of the unit suggests deposition during the late Wisconsin; an age of about 1500 yrs B.P. from the top of the stratum implies exposure during the late Holocene. Values of $\delta^{13}C$ of about -16.0‰ were obtained from the ages, suggesting C_4 plants have dominated the site for the past 11,000 years. Unit III is also loamy, containing high percentages of silt (ca. 57) and clay (ca. 14.5). Very poorly sorted, the stratum contains a well defined fining upward sequence, one similar to those described at other localities (e.g., Edwards 4, Reno 4, Stafford 3) in the region. Although no sedimentary structures were discerned, the nature of the unit suggests deposition in a fluvial environment of mixed energy. Following sedimentation, Unit III was evidently exposed, and essentially stable, for a very long period of time, one that promoted formation of a strongly developed buried soil consisting of five 3Btb horizons with moderate to strong prismatic structure. An erosional episode subsequently occurred, resulting in complete truncation of the 3Ab horizon. Water tables must have been periodically high, because the 3Btb6 and 3Btb7 horizons are slightly mottled.

Units II and I overlie Unit III with an apparent unconformity and sharp contact at 1.17 m. Since they are similar in character, Units II and I can be grouped for purposes of discussion. Both, for example, contain over 90 percent sand that is poorly to moderately sorted. In addition, each contains a weakly developed soil with dominantly single grain structure. Overall, they are consistent in texture, sorting, structure, and topographic position and expression with dune sand In short, Units II and I reflect episodic sedimentation of eolian sand during a more arid climate than that which promoted Unit III. A radiocarbon age of about 1500 yrs B.P. from the top of Unit III provides a maximum-limiting, late Holocene age for wind-blown sand deposition. Following accumulation of Unit II, a brief period of landscape stability and soil formation occurred that resulted in development of a 2Ab and 2Bwb horizon. Although no radiocarbon age was obtained from this soil, it is similar in development and position with solums dated to less than 1000 yrs B.P. in the region (e.g., Crocket Cutbank, Reno 3, Reno 4, Stafford 2, Stafford 6, Rice Roadcut). Another period of deposition subsequently occured, resulting in Unit I. A very weakly developed surface soil, consisting of an Ap and C horizon suggests that the site has been stable for a relatively brief period of time.

CHAPTER 6

EVALUATION OF HYPOTHESES

Introduction

This chapter discusses the results of hypotheses testing according to the methodology outlined in Chapter 4. As noted above, the following hypotheses were tested: 1) The Great Bend Sand Prairie exhibits eolian landforms which can be discerned, categorized, and mapped; 2) Silt layers are commonly occuring, late Wisconsinan deposits that provide a maximum age for sand dune development; 3) Dune fields are generally Holocene landforms that evolved because climate shifted from cool/moist in the late Wisconsin to semiarid and subhumid during the Holocene; and 4) Eolian sand mobilization and stability on the Great Bend Sand Priaire has been episodic and patchy. Given the interrelationship of hypotheses, methodology, and results, verification is presented in the following manner: 1) Mapping and silty sand distribution; 2) Sedimentological analyses of silty sand and dune sand; 3) Radiocarbon dating of late Quaternary deposits; and 4) Evidence for late Quaternary climate change.

Mapping and Silty Sand Distribution

As noted in Chapter 5, aerial photography was used to determined whether landforms on uplands of the Great Bend Sand Prairie could be categorized. Analysis indicated that six geomorphic categories exist on the uplands, ranging from loess to parabolic dune fields (Fig. 5:1).

During mapping and reconnaisance, a primary goal was to test whether or not the silty sand is commonly occurring on the Great Bend Sand Prairie. One-hundred-twenty-six sites were examined by bucket augering for the presence or absence of the silty sand. Including the eighteen sites that were backhoe trenched, one hundred eleven, or 77 percent, contained the silty layer(s) within the depth reached, indicating that it is indeed widespread.

Sedimentological Analyses of Silty Sand and Dune Sand

To ascertain the depositional environment in which the silty sand and dune sand accumulated, scatterplot analyses of textural variables (e.g., Folk and Ward, 1957; Friedman, 1972) have been conducted. A total of 140 samples were analyzed from the twelve sites (e.g., Stafford 1, Edwards 3, Reno 4) where both the silty sand and dune sand were well expressed. Variables examined include mean phi, sorting, skewness, and kurtosis.

Figure 6:1 is a scatterplot of skewness plotted against kurtosis for the silty sand and dune sand, illustrating that both deposits have about the same skewness, generally fine to very fine. A slight difference exists in kurtosis, with the silty sand primarily very platykurtic to leptokurtic. Dune sands, in contrast, have a broader range in kurtosis, extending from extremely leptokurtic to platykurtic (Fig. 6:1).

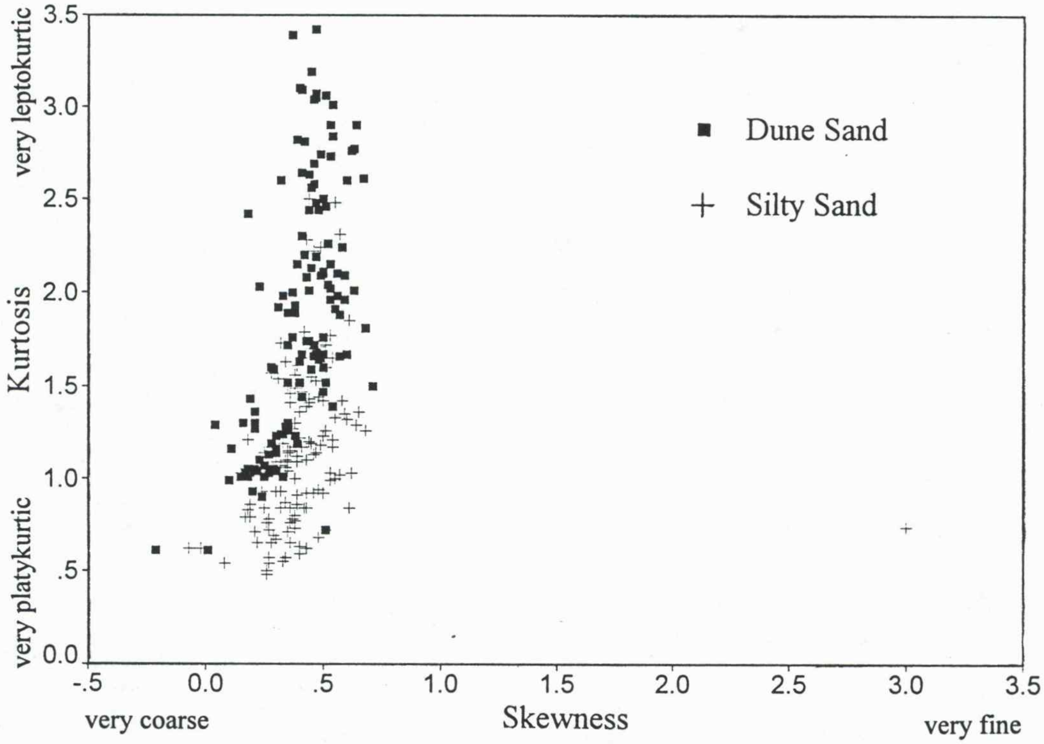


Figure 6:1. Scatterplot of skewness versus kurtosis for silty sand and dune sand.

When sorting is plotted against skewness (Fig. 6:2), a relationship inverse to Figure 6:1 is observed. As in the previous plot, the silty sand and dune sand are similarly skewed. A clear distinction can be made in sorting, however, with very little overlap; sorting in the dune sand ranges primarily moderate to poor. In contrast, sorting in the silty sand is largely very poor (Fig. 6:2). The scatter appears very similar to sorting when skewness and mean phi are plotted. Again, both deposits are equally skewed, but mean particle size of the dune sand is much coarser than in the silty sand (Fig. 6:3).

The distributions become more clear when kurtosis and mean phi (Fig. 6:4), sorting and kurtosis (Fig. 6:5), and sorting against mean phi (Fig. 6:6) are plotted. The variables that best segregate the silty sand and dune sand are mean particle size and sorting. As illustrated in Figure 6:6, dune sand has a coarser average texture compared to the silty sand, ranging between very fine sand and coarse silt. As noted above, dune sand is moderately to poorly sorted, with a near linear relationship to mean texture. In contrast, mean phi in the silty sand includes coarse to fine silt. Apparently, sorting has a much poorer relationship to texture in the silty sand, as the scatter for the two variables is much more dispersed.

In summary, when scatterplots of the textural variables mean phi, sorting, skewness, and kurtosis are plotted, visible differences in the sedimentology between the silty sand and dune sand become apparent. Although skewness varies little between the

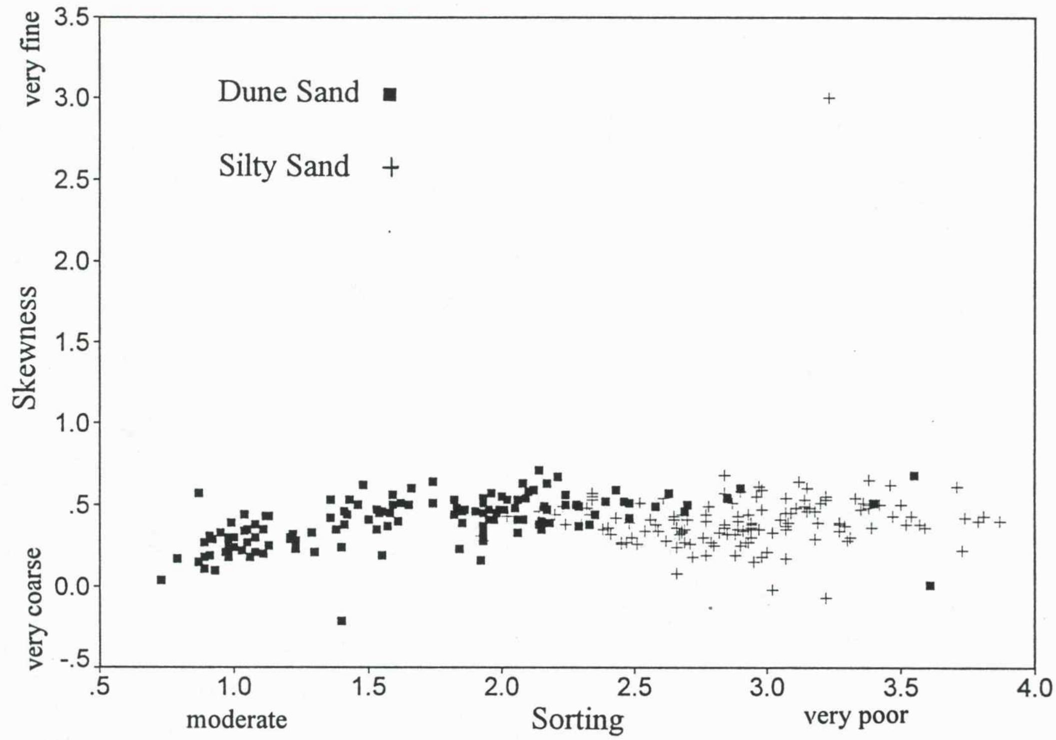


Figure 6:2. Scatterplot of sorting versus skewness in the silty sand and dune sand

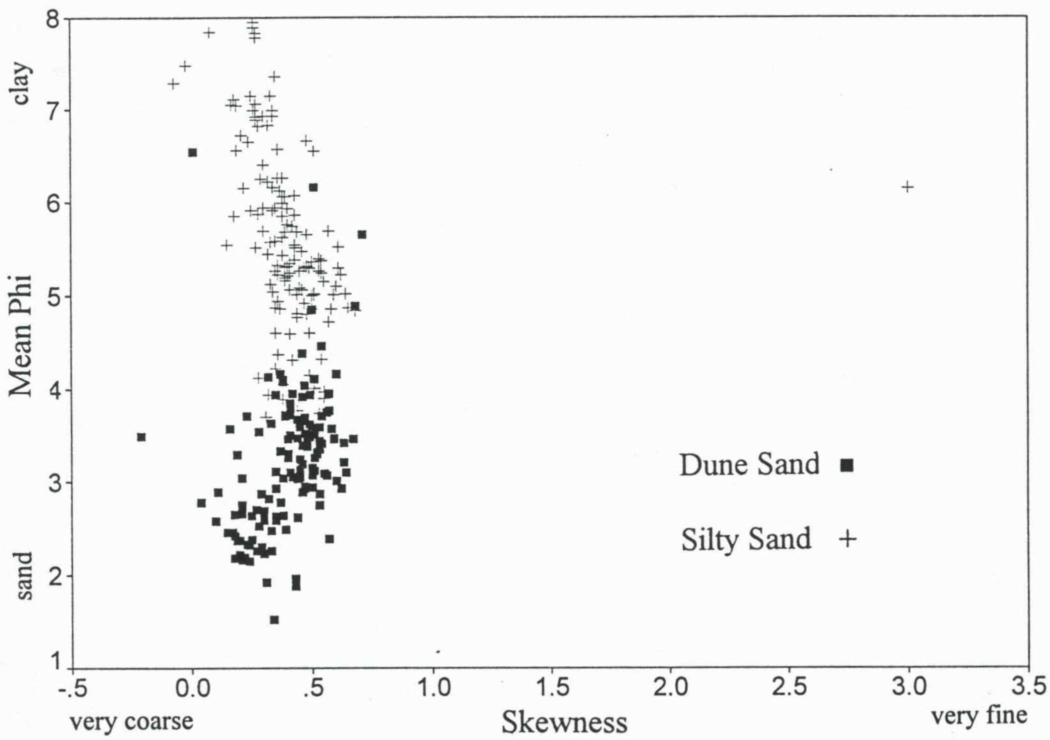


Figure 6:3. Scatterplot of skewness versus mean phi in the silty sand and dune sand.

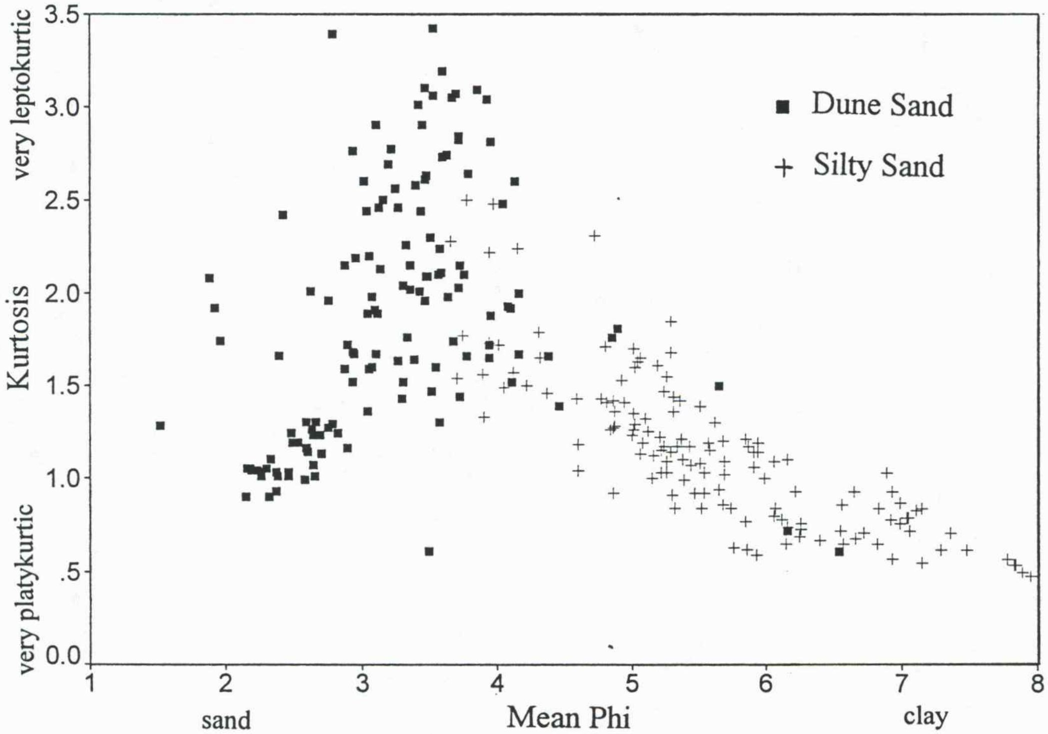


Figure 6:4. Scatterplot of kurtosis against mean phi in the silty sand and dune sand.

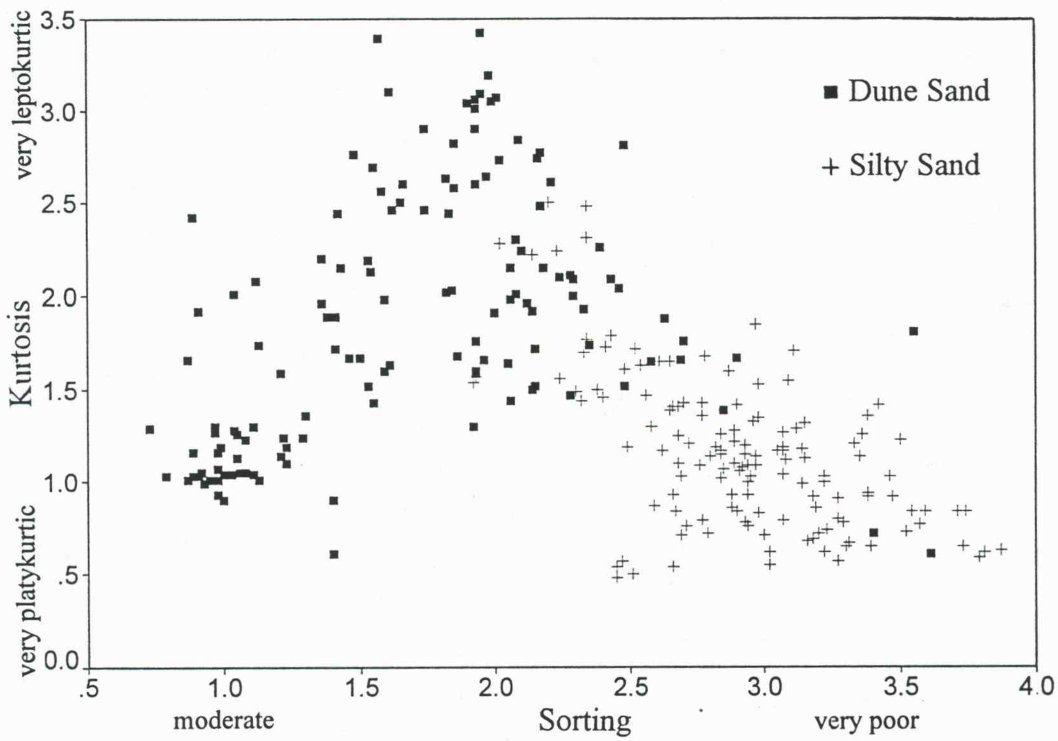


Figure 6:5. Scatterplot of kurtosis and sorting in the silty sand and dune sand.

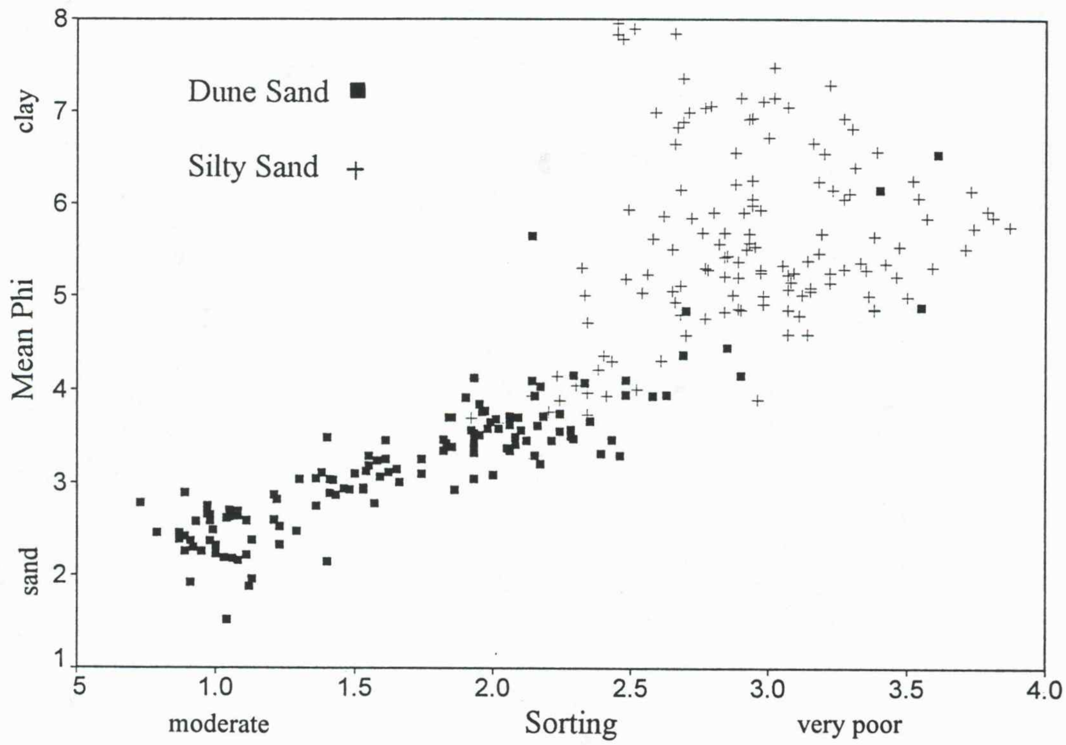


Figure 6:6. Scatterplot of mean phi and sorting in the silty sand and dune sand.

units, kurtosis appears to differ slightly, with dune sand slightly more leptokurtic than the silty sand. Unfortunately, variability in kurtosis has not been correlated with specific depositional environments (Enos, pers. comm.).

The variables that best distinguish the silty sand from dune sand are mean particle size and sorting. Mean phi in silty sand is coarse to fine silt, reflecting the high percentages of silt in the deposit. In contrast, average texture in dune sand ranges from coarse silt to very fine sand. Mean texture does not appear to be a good indicator of paleodepositional environment, however, because eolian deposits have been recognized in the central Great Plains that consist predominantly both of sand (e.g., Simonett, 1960; Ahlbrandt et al., 1983; Muhs, 1985; Swinehart, 1990) and loess (e.g., Schultz and Stout, 1945; Martin, 1990; Feng, 1991; Johnson and May, 1992).

Ultimately, the variable that appears to distinguish the depositional processes associated with silty sand and dune sand is sorting. According to Friedman (1967), fluvial deposits include sediments transported by a combination of processes: saltation, rolling or sliding, and suspension. As a result, they tend to be poorly sorted because fines, carried in suspension, are trapped between sand grains or are deposited with them when discharge diminishes. In contrast, eolian sands are better sorted because grains are transported largely by saltation. Although poorly sorted eolian deposits (e.g., "loamy coversand," "sandloess") have been recognized in Alaska (Lea and Waythomas, 1990) and Europe (Koster, 1988; Schwan, 1988), they are well stratified with horizontal bedding and lack the clay which composes as much as 40 percent of the deposits at Great Bend. Moreover, at two sites (e.g., Edwards 3, Stafford 10), the upper part of the silty sand was very unevenly and sharply truncated (Fig. 5:80), suggesting flowing water was present. Given these combined variables, it appears that the silty sand on the Great Bend Sand Prairie accumulated in a fluvial environment. Dune sand, in comparison, resulted primarily from eolian proccesses.

Radiocarbon Dating of Late Quaternary Deposits

A total of forty-nine $\delta^{13}C$-corrected radiocarbon ages, obtained from backhoe trenches, roadcut exposures, and quarries, establish a generalized chronology of deposition and landscape stability for late Quaternary deposits on the Great Bend Sand Prairie. Ages were derived from three distinct, stratigraphic positions: 1) lower silty sand (i.e., deep within the silty sand); 2) upper silty sand (i..e, upper 5 cm of the deposit); and 3) buried soils in the dune sand. Of the forty-nine ages, thirteen are from the lower silty sand, seventeen from the upper silty sand, and fifteen from buried soils in dune sand. Ages from the lower silty sand theoretically provide a relative estimate for when pedogenesis occurred following deposition of the unit, at least that exposed in backhoe trenches. Ages obtained on the upper silty sand, in contrast, generally appraise the mean residence time of humates associated with pedogenesis at the top of the deposit. Finally, ages secured from buried soils in dune sand provide maximum ages for overlying sand and minimum ages for underlying sand. Ages on which the chronology is based are listed in Table 5:2. Potential sources of error in the ages are presented in Table 5:3.

Figures 6:7 and 6:8 illustrate that a generalized age/stratigraphic relationship exists between the three positions where samples were collected. In Figure 6:7, a summary stratigraphic diagram of the eighteen sites discussed in Chapter 5 is presented, whereas the distribution of all radiocarbon ages derived from dune fields is shown in Figure 6:8.

The lower part of the silty sand dates to the late Wisconsin or early Holocene, ranging from approximately 20,000 to 8000 yrs B.P. Of the thirteen ages derived from the deposit, nine are within the late Wisconsin (Fig. 6:8). Ages are considered to be reliable because consistent estimates were obtained on both humates and charcoal (*Picea* cf. *glauca*) from similar stratigraphic settings. Overall, the distribution of ages derived from lower silty sand strongly suggest that the stratum accumulated between 20,000 and 10,000 yrs B.P. As a result, the unit is generally assigned a late Wisconsin age.

Radiocarbon ages obtained from the upper part of the silty sand hypothetically estimate the mean residence time of pedogenically-derived soil humates. Theoretically, soil formation in the upper part of the silty sand continued, resulting in consistent input of fresh humates, until the deposit was rapidly buried by dune sand. When burial occurred, the silty sand was isolated from the surface and the $^{14}C/^{12}C$ ratio began to

Table 6:1. Radiocarbon ages[1] used to estimate the age of the silty sand and dune sand.

Location	Stratigraphic Position[2]	Horizon (depth)	Lab No. (Tx-)	Uncorrected ^{14}C Age	δ^{13}C-corrected ^{14}C Age[3]	δ^{13}C (‰)	Calibrated Age[4]
Buster Dune	ds	2Ab (0.82-0.87)	7980	modern	modern	-17.9	modern
Harvey/Reno	ds	2Ab (1.47-1.52)	7828	40±100	210±100	-14.2	320(160)60
Stafford 6	ds	2Ab (0.53-0.58)	7983	110±80	270±80	-15.2	464(299)146
Rice Roadcut	ds	2Ab (1.28-1.33)	7978	230±80	380±80	-16.0	504(467)315
Stafford 6	ds	3Ab (1.13-1.18)	7982	320±100	480±100	-15.0	560(510)320
Rice Roadcut	ds	2Ab 1.69-1.74)	7977	340±80	490±80	-15.9	559(517)454
Stafford 6	ds	3Ab (1.47-1.52)	7981	360±80	550±80	-13.4	644(542)507
Reno 3	ds	3Ab (2.57-2.62)	8119	520±80	700±80	-14.4	701(657)554
Reno 4	ds	2Ab (1.10-1.15)	8012	510±80	710±80	-12.4	717(660)556
GWMD5 #2[5]	uss	2Ab (1.63-1.68)	9743	660±60	810±120	-15.5	910(700)650
Crocket Cutbank	ds	3Ab (5.88-5.93)	8214	750±80	880±80	-16.6	913(774)695
Stafford 2	ds	2Ab (1.14-1.19)	9313	840±80	1030±80	-13.3	1056(936)792
14KW7	ds	2Ab (5.12-5.17)	7777	920±60	1090±120	-14.5	1170(970)910
Stafford 11	uss	3Btb1(1.07-1.12)	8218	1350±80	1500±80	-15.7	1502(1354)1301
Buster Quarry	ds	3Ab (4.55-4.60)	7979	1350±100	1500±100	-15.8	1510(1350)1300
GWMD5 #7[5]	uss	2Ab (1.02-1.07)	6744	1440±160	1620±160	-14.7	1700(1520)1340
GWMD5 #10[5]	uss	2Ab (1.43-1.48)	7700	2130±140	2250±140	-17.3	2360(2230)2020
Cornwell Trench	ds	2Ab (1.48-1.53)	7998	2140±100	2310±100	-14.3	2380(2340)2150
Phillips Trench	uss	2Btb1 (0.33-0.38)	8216	2250±100	2400±130	-15.8	2710(2360)2330
Edwards 4	uss	3Btb1 (1.60-1.65)	8314	2610±90	2730±180	-17.3	3080(2790)2710
GSMD5 #10[5]	uss	2Ab (1.43-1.48)	6745	2810±160	2940±160	-17.0	3450(3070)2750
Edwards 1	uss	2Btb1 (1.15-1.20	8003	1690±80	3220±80	-13.2	3555(3425)3349
Crocket Cutbank	ds	3C5 (8.06-8.11)	8215	3160±50	3280±100	-17.7	3630(3470)3380
Cullison Quarry	uss	3Btb1 (4.70-4.75)	8221	3660±100	3820±100	-14.8	3822(3677)3478
GWMD5 #7[5]	uss	2Ab(2.02-2.07)	6877	4530±160	4620±160	-16.6	4400(4180)4000

GWMD5 #9[5]	uss	2Ab (1.30-1.35)	6477	4680±200	4840±200	-15.2	6290(6180)5990
Reno 4	uss	3Btb1 (2.27-2.32)	8011	5260±120	5370±120	-17.7	7020(6720)6390
GWMD5 #9[5]	uss	2Ab (1.40-1.45)	6478	5740±300	5870±300	-17.6	7210(7020)6860
Stafford 3	ds	2Ab (1.96-2.01)	8118	6050±160	6160±160	-17.9	7900(7690)7580
Belpre Trench	uss	Bt3 (0.95-1.00)	8009	6850±140	6930±140	-20.2	8440(8340)8130
Cullison Quarry	lss	4Btgb1 (565-5.70)	8220	7770±140	7850±140	-20.0	8950(8560)8780
Belpre Trench	lss	Btk8 (2.20-2.25)	7975	8490±160	8550±160	-21.0	9840(9490)9370
Edwards 1	lss	3Btb1 (1.65-1.70)	7697	8990±560	9050±560	-22.2	10,883(10,000)9453
Reno 5	lss	4C1 (3.10-3.15)	8013	8910±260	9160±260	-9.5	10,387(10,040)9905
Stafford 2	lss	4Btb (3.08-3.13)	8117	10,440±720	10,460±720	-23.6	13,096(12,370)10,964
Stafford 11	lss	3Btb4 (1.82-1.87)	8219	10,970±180	11,100±180	-16.5	13,230(13,010)12,810
Stafford 4	lss	2Ab (1.66-1.71)	7999	12,640±340	12,820±340	-14.2	15,710(15,150)14,560
Edwards 3	lss	4Btkb(2.72-2.77)	8115	13,280±780	13,290±780	-24.7	16,840(15,870)14,690
GWMD5 #1[5]	uss	2Ab (2.49-2.54)	6742	13,620±560	13,670±1340	-20.9	17,939(16,380)14,389
Edwards 3	lss	3Btkb (1.79-1.84)	8116	15,260±680	15,250±680	-25.6	18,836(18,170)17,429
Reno 4	lss	3Btb3 (3.50-3.55)	8010	16,590±360	16,670±360	-19.9	20,260(19,450)18,960
Stafford 1	uss	2Btb1 (0.98-1.03)	7679	16,760±440	16,810±440	-21.9	20,593(19,830)19,213
GWMD5 #9[5]	lss	2Bk2 (2.02)	6479*	17,950±660	17,970±660	-23.7	22,300(21,450)20,510
Edwards 2	uss	2btb1 (1.23-1.28)	7698	19,370±1000	19,460±1000	-19.8	na
Stafford 10	lss	3Btb (1.45-1.50)	8114	20,150±740	20,230±740	-20.1	na
Belpre Trench	lss	Btkg13 (344-3.49)	7976	20,620±500	20,670±500	-22.3	na

1: All ages from soils were obtained on the base soluble fraction of total soil humates, except for Tx-6479*, which was derived from charcoal.

2: ds = dune sand; uss = upper silty sand; lss = lower silty sand

3: For a discussion of the δ^{13}C-correction procedure, see Stuiver and Polach (1977) and Taylor (1987).

4: Calibrated from conventional δ^{13}C-corrected radiocarbon age to calendar years using a tree-ring curve. All calibrations reported here were based upon the 20-year atmospheric curve (e.g., Linick et al., 1985; Stuiver et al., 1986. Program used is discussed in Stuiver and Reimer (1993).

5: Reported in Johnson (1991).

Table 6:2 Potential Sources of Error Associated with Radiocarbon Dating.

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1) *Problems of sample selection.* Misinterpretation of radiocarbon ages may result from inconsistencies in sample collection. Not all researchers, for example, systematically collect from the top, middle, or bottom of a buried soil. According to Johnson and Martin (1987: 118) a discrepancy of up to 1000 years may exist between the top and bottom of an A horizon.

2) *Problems of contamination.* It is difficult to remove all rootlets and other modern carbon from a sample (Valastro, pers. comm.). Moreover, carbonate-bearing materials such as gastropods and bone are particularly prone to intrusion by modern carbon because they easily interact with ground and/or meteoric water.

3) *Fractionation effects.* Some plants preferentially incorporate ^{14}C over ^{12}C. As a result, systematically young ages are produced (Bradley, 1985; Taylor, 1987). As noted above, all radiocarbon ages in this study have been corrected for isotopic fractionation, which was accomplished by measuring the ^{13}C content in the sample.

4) *Reservoir effects.* Due to changing concentrations of radiocarbon in the atmosphere over time, there are predictable differences between radiocarbon and calendar ages. As the amount of radiocarbon in the atmosphere increases, the ratio of of $^{14}CO_2$ to $^{12}CO_2$ also increases, providing an age which is too young. As noted above, all ages less than 18,000 yrs B.P. were corrected for reservoir effects through the tree-ring calibration curve developed by Stuiver and Reimer (1993).

5) *Laboratory variability.* Variation exists in the manner which laboratories pretreat and process samples (Bradley, 1985; Taylor, 1987; Martin and Johnson, 1995). As noted above, all samples in this study were processed at the Radiocarbon Laboratory at the University of Texas at Austin.

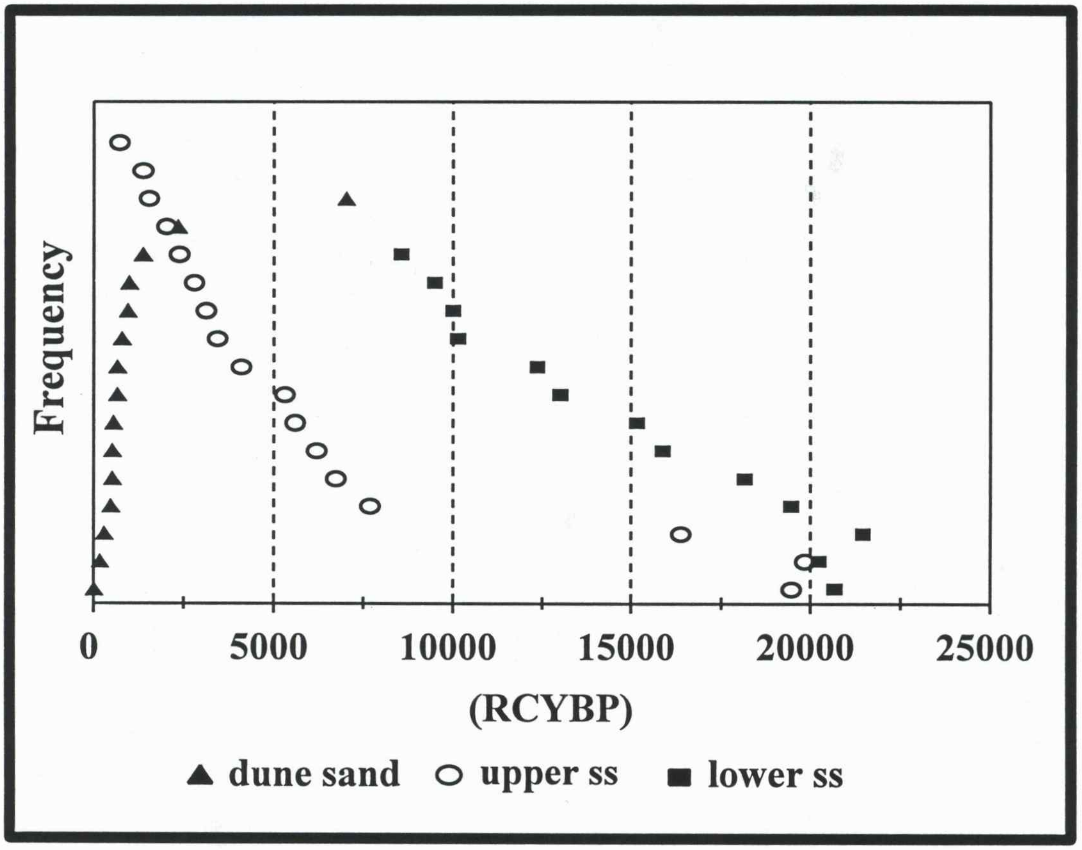

Figure 6:8. Radiocarbon age and stratigraphic position on the Great Bend Sand Prairie.

decrease (Scharpenseel and Schiffmann, 1977). At localities where the silty sand was buried and has never been exhumed, the $^{14}C/^{12}C$ ratio has decreased at a uniform rate (Libby, 1955) because no mixing of younger humates (Scharpenseel and Schiffman, 1977) has occurred. Evidence exists, however, that there there has been an episodic input of fresh soil humates in the upper silty sand in most places throughout the late Quaternary.

Figure 6:9 illustrates a site where the silty sand is exposed, but is overlain by variable thicknesses of dune sand elsewhere in the vicinity. Assuming the mobile nature of dune sand, it is possible that silty sand at any given locality has been buried and exposed one or more times during dune evolution. Where the silty sand crops out in Figure 6:9, pedogenesis has hypothetically been rejuvenated because the once buried solum has been exhumed (Ruhe and Daniels, 1958). As a result, fresh humus is being added to pre-existing humus. In all likelihood, there has been episodic renewal of pedogenesis in the silty sand at random intervals and localities throughout the history of late Quaternary dune mobilization in the study area. Given the theoretical principles (i.e., half-life of ^{14}C) of the radiocarbon dating method (Libby, 1955), one would expect older estimates of the mean residence time of humates where dune sand has overlain the silty sand much longer. Conversely, younger radiocarbon ages should result where the silty sand has been exhumed more recently (e.g., Fig. 5:96) and young humates have mixed with older humus.

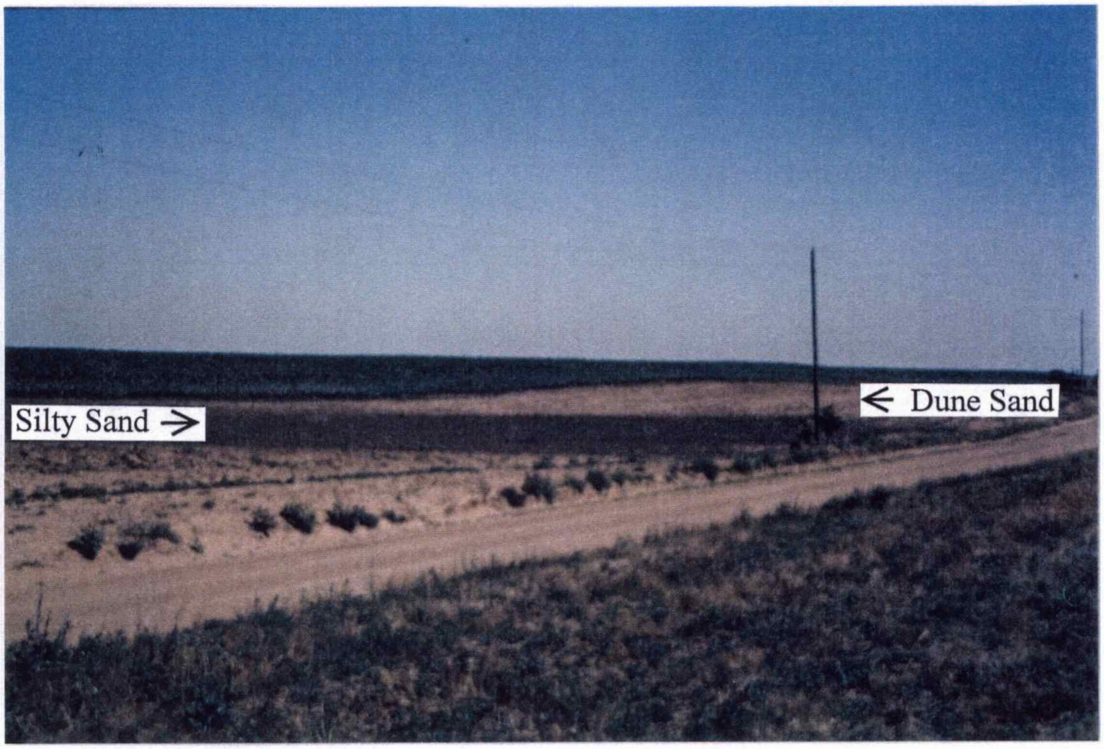

Figure 6:9. Site in the NW, NW, sec. 24, T26S., R15W. At this locality, the silty sand has been exhumed by mobilizing dune sand.

As noted above, seventeen radiocarbon ages were derived from the upper silty sand in this study. At three sites (Edwards 3, Stafford 10; Fig. 6:7; GWMD5 #1) the top of the silty sand dated to the late Wisconsin, with ages of approximately 20,000, 17,000 and 14,000 yrs B.P., suggesting that eolian sand deposits accumulated at some localites during the late Wisconsin because Holocene humates apparently were not incorporated (i.e., the silty sand was not exposed during the Holocene) into the deposit. In large part, however, the upper silty sand dates to the middle and late Holocene, with fourteen of the seventeen ages spanning the interval between approximately 7000 and 800 yrs B.P. (Fig. 6:8).

Assuming that ages from the upper silty sand reflect the mean residence time of humates incorporated during many cycles of burial and exposure by mobilizing sand, the ages provide, at best, a maximum-limiting estimate for the overlying dune sand. Since the vast majority of ages fall within the middle and late Holocene, the logical conclusion is that the upper silty sand may have been exposed intermittently throughout the middle and late Holocene and that the overlying dunes are generally late Holocene deposits.

Although radiocarbon ages from the upper silty sand generally provide a maximum-limiting boundary for dune evolution, an effort was made to estimate when landscape stability and soil formation occurred in dunes by dating humates in buried solums of the surficial, wind-blown deposits. As noted above, fifteen ages were derived from buried sola within dunes (e.g., Crocket Cutbank, Reno 3, Reno 4, Stafford 2, Stafford 3; Fig. 6:7) ranging from approximately 6000 yrs B.P. to modern. The 6000-yr age from Stafford 3 is an obvious outlier because fourteen of the ages are less than about 2500 yr B.P. and ten fall within the past 1000 years (Fig. 6:8). At first glance, the ages verify the Holocene age of most of the dunes, indicating a much younger depositional interval as compared to the underlying silty sand. If the 6000-yr age from Stafford 3 is excluded, in fact, a hiatus of approximately 5000 years exists between the youngest age derived from the lower silty sand and the next oldest age of about 2300 yrs B.P., obtained from the Cornwell Trench (Fig. 6:10). Although middle Holocene dune deposits may be sporadically preserved at localities such as Stafford 3, it is clear that the majority of eolian deposits on the Great Bend Sand Prairie are Holocene, and apparently very late Holocene landforms.

Radiocarbon evidence, in conjunction with stratigraphic information, indicates that dune fields on the Great Bend Sand Prairie have episodically mobilized during the late Holocene. Figure 6:11 illustrates the distribution of calibrated radiocarbon ages, at two standard deviations, from buried sola in late Holocene dune sand. Conservatively, four distinct age groupings can be discerned where little, if any, statistical overlap exists: around 2300, 1400, 1000, and 700 to 200 years (Fig. 6:11). As a result, the data suggest at least four periods of prehistoric landscape stability, and, therefore, five intervals of prehistoric dune mobilization in approximately the past 2500 years. When stratigraphic

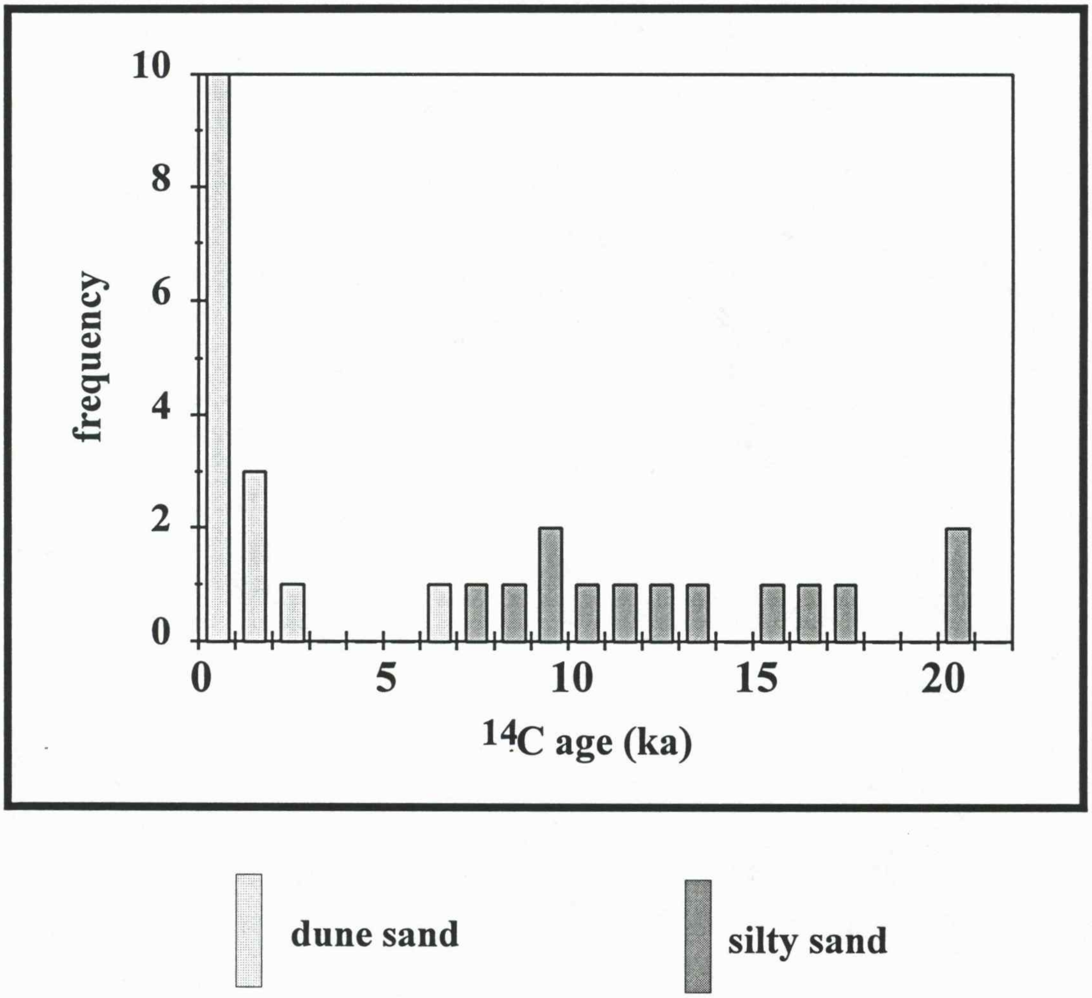

Figure 6:10. Frequency distribution of ^{14}C ages in lower silty sand and dune sand.

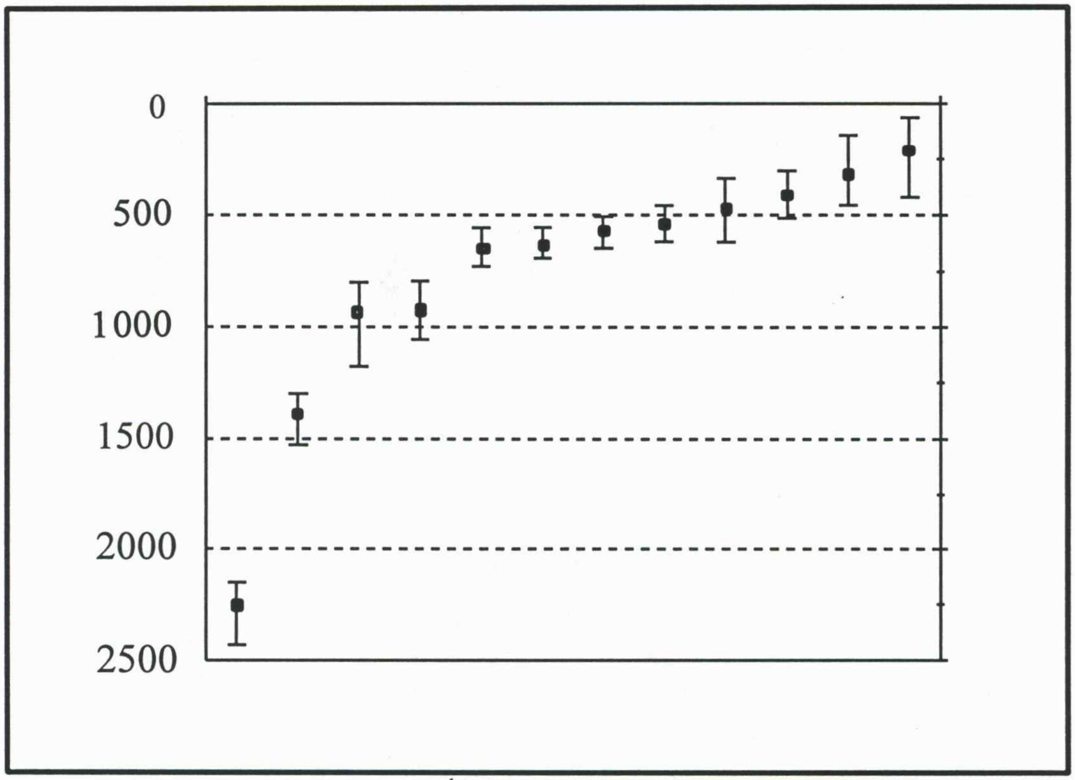

Figure 6:11. Distribution of calibrated radiocarbon ages derived from late Holocene dune sand at two standard deviations.

information derived from dunes is considered, the episodic nature of stability and mobilization is even more apparent. Specifically, two buried soils recognized in the dune at Stafford 6 yielded calibrated ages, from bottom to top, of about 540 and 300 yrs B.P. (Fig. 6:7). As a result, it is concluded that at least five periods of prehistoric soil formation, generally bracketing intervals of eolian sand mobilization, have occurred in dunes of the Great Bend Sand Prairie in the past 2500 years at approximately 2300, 1400, 1000, 700 to 500 and 300 yrs B.P.

In addition to the episodic nature of late Holocene eolian sand stability, the spatiality of soil equilibrium has been patchy in the region. Indirect evidence of the spatial variabilty in dune stability is the relative degree of soil formation at specific sites examined in this study. At several localities (e.g., Edwards 1, Edwards 2, Stafford 1, Stafford 10) surface soils in dune sand were comparably well developed, consisting of A horizons overlying stacked Bt horizons. At other sites (e.g., Crocket Cutbank, Cullison Trench, Stafford 11), surface soils were very poorly developed, including A horizons and several C horizons. According to Birkeland (1984), relative degree of soil development is an indicator of age because eolian influx, weathering, clay formation and translocation are time dependent properties. Assuming that stronger developed surface soils in dunes indicate a longer period of stability than dunes with poorly developed surface soils, it is logical to conclude that dune stability on the Great Bend Sand Prairie has been patchy. Direct evidence appears on aerial photography in the form of blowouts in modern dune fields (Fig. 5:7). It is reasonable that blowouts have existed in dune fields of the Great Bend Sand Prairie throughout their evolution, further indicating that dune stability has varied spatially.

Evidence For Late Quaternary Climate Change

Introduction

A variety of methods, outlined in Chapter 4, were employed to test whether climate change has occurred on the Great Bend Sand Prairie in the past 20,000 years. In this discussion, sedimentological, floral and faunal, and isotopic data are presented as evidence for climate change.

Sedimentology

Sedimentological data, in conjunction with radiocarbon ages, obtained from the silty sand and dune sand provide evidence for late Quaternary climate change. As noted above, the silty sand dates primarily to the late Wisconsin, whereas dune sands were deposited in the Holocene. Scatterplots of statistical parameters (i.e., mean phi, sorting, skewness, kurtosis) reveal obvious differences in sedimentology between the silty sand and dune sand. Specifically, when sorting and mean phi are plotted against one another (Fig. 6:6), two distinct populations result with sorting the primary, distinguishing variable. Given the disparity in sorting between the silty sand and dune sand on the

Great Bend Sand Prairie, it is concluded that fluvial processes dominated in the Woodfordian, whereas sand was transported by wind during the Holocene. It is logical to conclude, therefore, that the climate was one of more effective moisture between about 20,000 and 10,000 yrs B.P. than in the past 10,000 years.

Floral and Faunal Remains

Floral and faunal remains obtained from the Great Bend Sand Prairie provide direct and indirect evidence for climate change in the region during the past 20,000 years. The lone floral sample recovered from late Quaternary deposits was a fragment of *Picea* (cf. *glauca*) charcoal, dated to about 17,000 yrs B.P., recovered from silty sand (ca. 2.0 m) approximately .5 km northwest of the Belpre Trench at GWMD5 (9) by Johnson (1991). The presence of white spruce during the Woodfordian is consistent with other localities in the Arkansas River valley (Jaumann, 1991), Cheyenne Bottoms (Fredlund, 1995) immediately to the north of the Great Bend Sand Prairie, Muscotah Marsh in northeastern Kansas (Gruger, 1973), and Harlan County Lake in Nebraska (Wells and Stewart, 1987). At present, white spruce is associated with the Neoarctic taiga, growing from Alaska to Newfoundland and along the eastern flank of the Rocky Mountains to Montana. Outliers of white spruce in the United States are found in the Black Hills of South Dakota, which is approximately 600 km northwest and about 1000-m higher in elevation than the Great Bend Sand Prairie.

Faunal assemblages recovered from the Great Bend Sand Praire consist of gastropods collected from two sites: Belpre Trench and Phillips Trench. At both localities, fossiliferous deposits are consistent in character to the Woodfordian Peoria loess (Wells and Stewart, 1987), which is noted for containing numerous landsnails (Leonard, 1952; Wells and Stewart, 1987), and directly overlie buried sola similar in development. At the Belpre Trench, the buried solum underlying the loess dated to approximately 21,000 yrs B.P., an age that is correlative to terminal dates derived from the pre-Peoria, Gilman Canyon Formation (Johnson, 1990; Johnson et al., 1990).

Landsnails at the Belpre and Phillips Trenches include the species *Discus cronkhitei*, *Helocodiscus singleyanus*, *Lymnea parva*, *Succinea avara*, and *Vertigo tridentata,* and an unidentified aquatic bivalve (Figs 5:12, 5:43), all of which are extinct in the central Great Plains. Landsnails are most abundant in forested environments where they feed on decomposing plant litter, suggesting that thick stands of trees were present in some places in the region during the Woodfordian on the Great Bend Sand Prairie (Frye and Leonard, 1954). The present distribution of *Discus cronkhitei* is illustrated in Figure 6:12, generally occurring in areas of North America cooler than the present climate of the Great Bend Sand Prairie. According to Leonard (1952), the limiting ecological variable for Woodfodian gastropods may be the occurrence of high temperatures coupled with aridity, which presumably happened more often during the Holocene and resulted in the extinction of late Wisconsinan landsnails on the Great

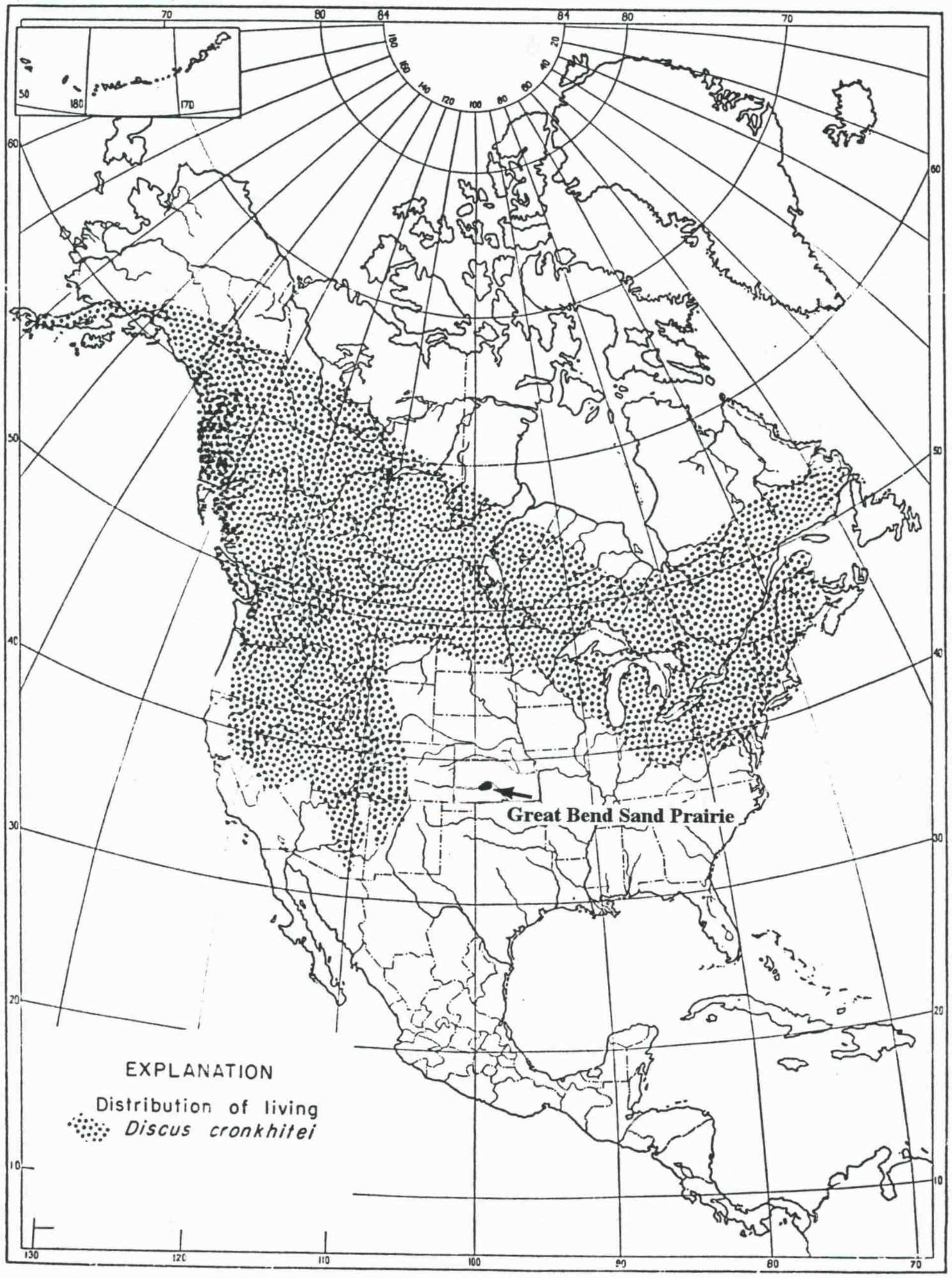

Figure 6:12. Present distribution of *Discus Cronkhitei* in North America (modified from Leonard, 1952).

Bend Sand Prairie.

Stable Isotopes

As noted in the Chapter 4, it has been established that $\delta^{13}C$ values can be used to infer vegetation at the time of soil formation or deposition (Krishnamurthy et al., 1982; Delaune, 1986). Many tropocal and warm-climate grasses (e.g., *Andropogon gerardii*, *Panicum virgatum*), with a C_4 pathway, typically have $\delta^{13}C$ values that range from -10‰ to -17‰. In contrast, cool-season grasses (e.g., *Elymus canadensis*, *Agropyron smithyii*) with a C_3 pathway usually have $\delta^{13}C$ values ranging from about -21‰ to -35‰ (Dienes, 1980; Hoefs, 1980; Krishnamurthy et al., 1982; Cerling and Quade,1993).

Figure 6:13 illustrates the graphical distribution of $\delta^{13}C$ values, plotted against radiocarbon age, derived from the silty sand and dune sand at backhoe trenches (e.g., Edwards 1 - 4, Reno 4, Stafford 1), roadcut exposures (e.g., Rice Roadcut) and quarries (e.g., Buster Dune, Cornwell Trench) on the Great Bend Sand Prairie. In general, results indicate that more negative $\delta^{13}C$ values correlate with Woodfordian radiocarbon ages, whereas less negative $\delta^{13}C$ values correspond with Holocene ages. A potential bias exists, however, with $\delta^{13}C$ values derived from the upper silty sand, which, as noted above, potentially contains an unkown mixture of very young and old $\delta^{13}C$ at any given site. If $\delta^{13}C$ values from the upper silty sand, as well as three outliers from the lower

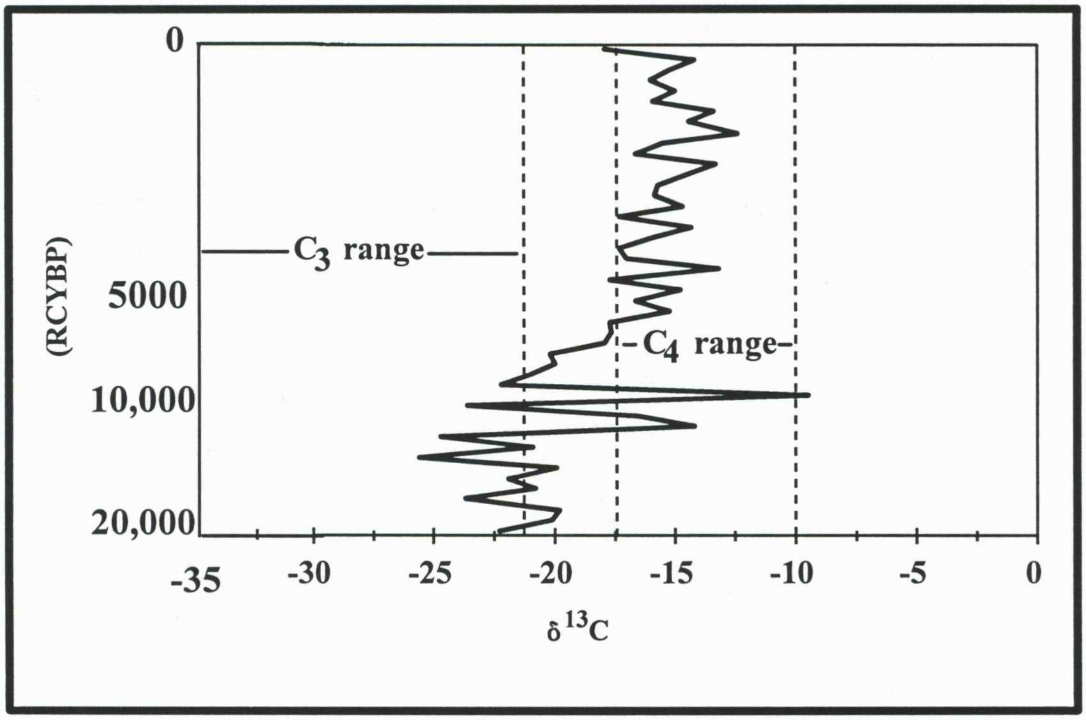

Figure 6:13. Distribution of $\delta^{13}C$ values and radiocarbon age on the Great Bend Sand Prairie.

silty sand, are removed from the plot, then an excellent correlation exists between radiocarbon age and $\delta^{13}C$ (Fig. 6:14). In summary, Figure 6:14 shows that $\delta^{13}C$ values derived from the lower silty sand indicate the presence of C_3 plants during the Woodfordian. Values of $\delta^{13}C$ obtained from late Holocene dunes, in contrast,demonstrate that plants with a C_4 pathway grew on the landscape in the past 5000 years. These results correspond nicely with a $\delta^{13}C$-derived paleoclimatic reconstruction constructed by Johnson and Valastro (1993), further illlustrating that climate in the central Great Plains, including the Great Bend Sand Prairie, changed from cool and relatively moist during the late Wisconsin to comparably warm and dry during the Holocene.

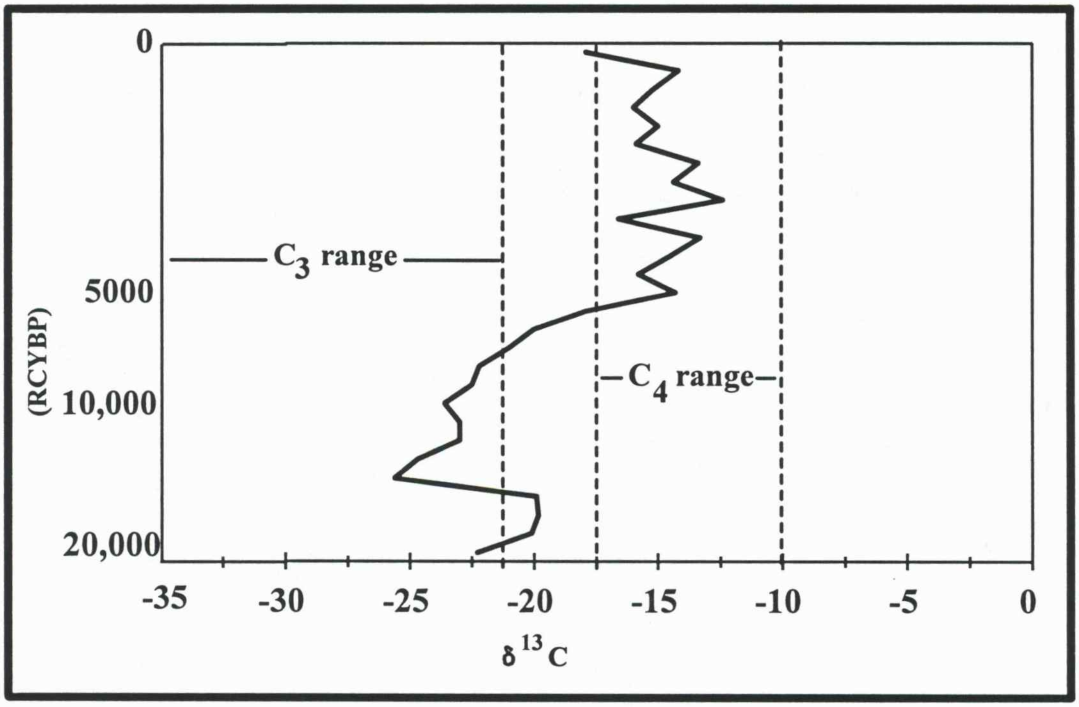

Figure 6:14. Distribution of $\delta^{13}C$ values and radiocarbon age from the lower silty sand and dune sand on the Great Bend Sand Prairie.

CHAPTER 7

WILSON RIDGE

Introduction

During the mapping phase of the project, a large anamolous dune was recognized in the west central part of the Great Bend Sand Prairie. The dune was unusual because of it's size, relationship to other landforms, and orientation as compared to other dunes in the study area. Given the potential for significant paleoenvironmental data that could supplement the entire study, detailed investigations were conducted and are presented below.

The site is located in the S1/2, secs. 28, 29, T.25S., R18W (Figs. 5:2, 7:1, 7:2) and was named Wilson Ridge after the landowner, Chad Wilson of Lewis, Ks. Whereas, the majority of dunes in the study area are ≤ 100 m in length (e.g., Fig. 5:7) Wilson Ridge is approximately 1.5-km long. In addition, the dune is concave in a northwesterly

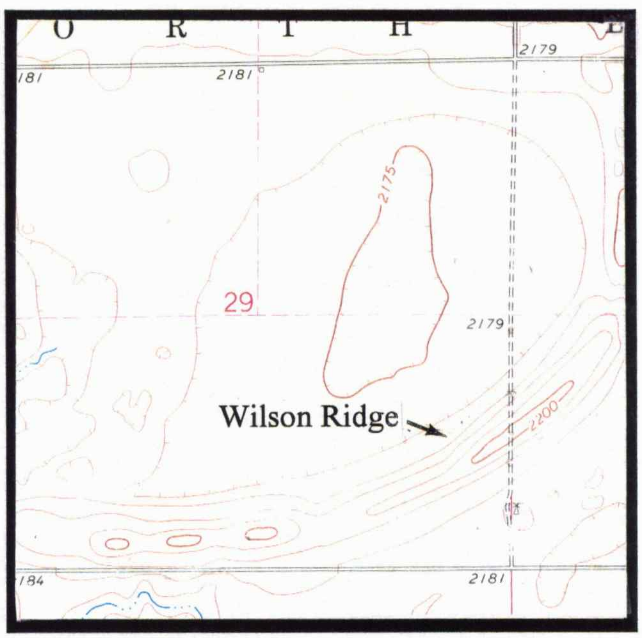

Figure 7:1. Topographic map in the vicinity of Wilson Ridge. Scale = 1:24,000 (Centerview 7.5 min. Quadrangle, 1972).

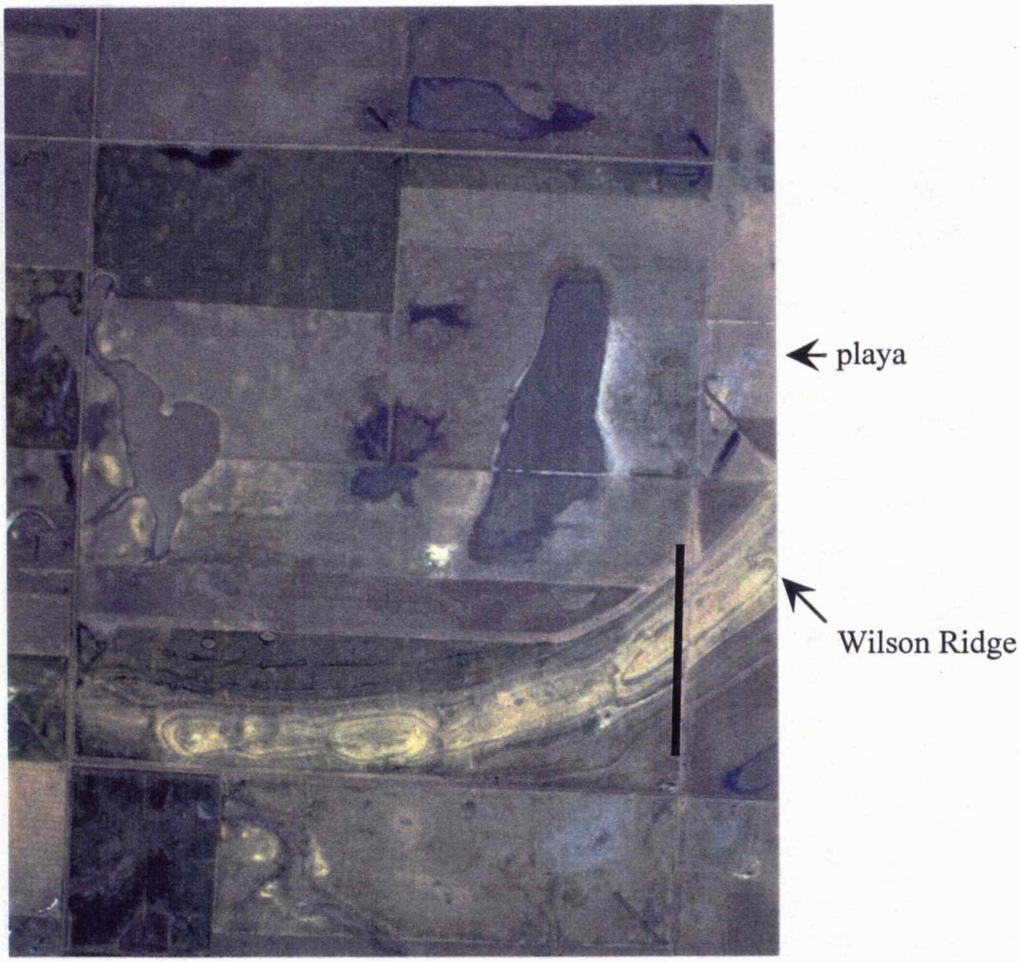

Figure 7:2. Aerial photograph of Wilson Ridge showing the position of the lunette relative to the playa and study transect (black line). For scale, the distance between section corners is approximately 1.6 km.

direction (Fig. 7:2), rather than southwesterly as are other parabolic dunes in the region (e.g., Fig. 5:7). When first discovered, the dune appeared to be related to a playa-lake basin immediately to the north. Preliminary investigations revealed a complex stratigraphy in the dune and a clear association with the playa. As a result, a hypothesis was formulated that the dune was a lunette, one that formed as sediment was deflated from the nearby lake bed during dry periods. This conclusion alone was of interest because lunettes had not been formally recognized in the central Great Plains of Kansas and Nebraska. In fact, lunettes in the Great Plains had been previously identified only in the southern High Plains (Reeves, 1965, 1966; Holliday, 1985, 1989, 1995). Of further significance, however, were the chronologic and paleoenvironmental ramifications of Wilson Ridge to the study as a whole. If indeed the feature was a lunette, then the dune must have formed when northerly or northwesterly winds prevailed in order to scour the adjacent playa and construct the dune. Theoretically, northwest winds are thought to have last dominated during the late Wisconsin (COHMAP, 1988). As a result, a final hypothesis was constructed, stating that Wilson Ridge was a lunette that formed during the Woodfordian when northwesterly winds prevailed.

Methodology

To test the theory that Wilson Ridge is a late Wisconsinan lunette, stratigraphic information was obtained from six backhoe trenches excavated along a south to north transect across the dune axis. In order to correlate stratigraphy among trenches, twelve cores were extracted with a Giddings coring machine (Fig 7:3). Stratigraphic units, radiocarbon ages, and chemical and textural parameters were derived in the manner described in Chapter 4.

Stratigraphy of Wilson Ridge

Ten late Quaternary stratigraphic units were identified through backhoe trenching and coring. The chronology of these ten was established with twelve radiocarbon ages (Table 7:1). Several well developed buried soils were recognized that formed in sediments ranging from clay loam to sandy loam (Fig. 7:4; appendix). A cross section illustrating the location of backhoe trenches and cores and correlation of stratigraphic units is presented in Figure 7:5.

The basal unit (Unit I), which was recognized in trench 6 (Figs. 7:4, 7:6) and cores 2 to 4, 6 to 9, and 11, underlies the lunette (Fig. 7:5). The unit consists of gleyed silt and clay containing fragmented gastropods. As illustrated in figure 7:5, it is about 3 m higher beneath the lunette than in the playa. In an effort to estimate the mean residence time of humates in the upper 5 cm (3.58 - 3.63 m) of Unit I in trench 6, a sample was collected that provided a δ^{13}C-corrected radiocarbon age of 17,540$\pm$520 yrs B.P. and a δ^{13}C value of -20.8‰ (Tx-7995).

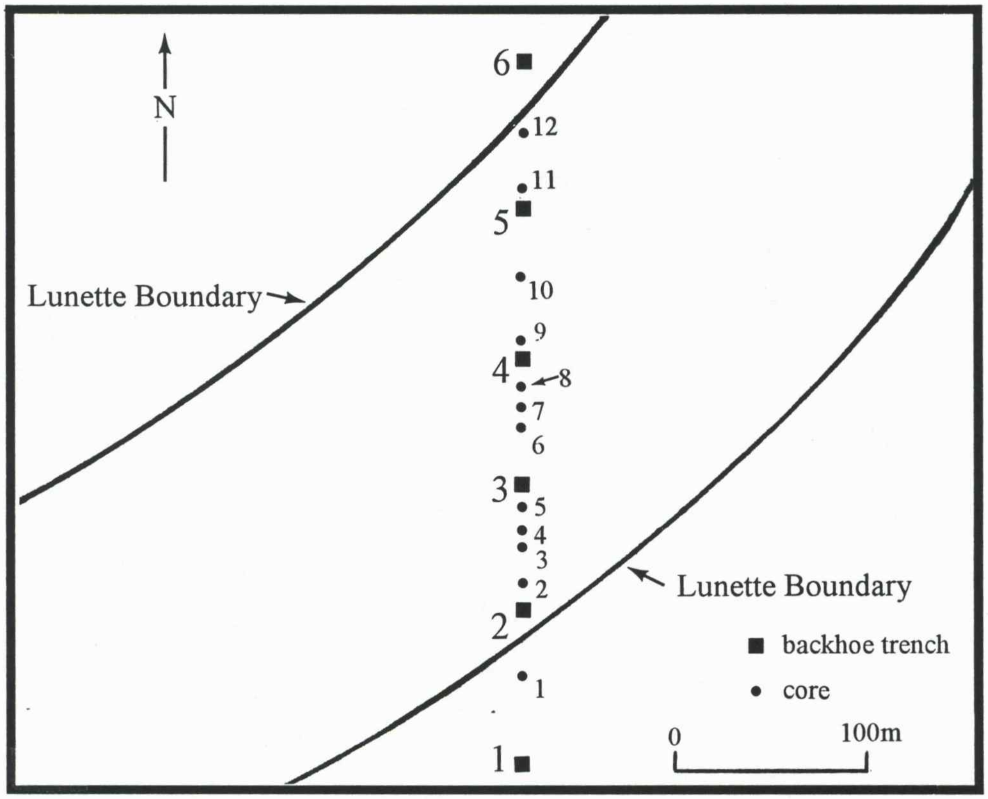

Figure 7:3 Position of backhoe trenches and cores extracted from Wilson Ridge.

Table7:1. Radiocarbon ages[1] from Wilson Ridge.

Backhoe Trench	Depth (m)	Laboratory Number	Uncorrected ^{14}C age (yrs B.P.)	$\delta^{13}C$ (‰)	Corrected ^{14}C age (yrs B.P.)	Calibrated age[2] (yrs B.P.)
Trench 1	2.45-2.50	Tx-8005	10,220±200	-18.3	10,330±200	12,520(12,200)11,550
Trench 2	1.18 - 1.23	Tx-7827	5490±140	-13.6	5670±140	6640(6450)6310
Trench 3	1.59 - 1.64	Tx-7996	8680±180	-14.2	8860±180	9990(9890)9570
Trench 3	2.65 - 2.70	Tx-7826	10,180±200	-14.2	10,360±200	12,550(12240)11,670
Trench 3	2.91 - 2.96	Tx-8004	12,000±220	-18.1	12,110±240	14,550(14,130)13,760
Trench 4	2.60 - 2.65	Tx-7825	16,330±380	-11.9	16,520±400	20,070(19,450)18,960
Trench 5	.95 - 1.00	Tx-8014	9460±180	-13.0	9840±180	11,660(11,000)10,870
Trench 5	2.25 - 2.30	Tx-7824	16,950±460	-11.9	17,180±480	21,137(20,370)19,611
Trench 6	.73 - .78	Tx-8002	2600±100	-12.4	2800±100	3020(2870)2770
Trench 6	1.13 - 1.18	Tx-7695	3220±80	-13.2	3410±80	3822(3677)3478
Trench 6	1.94 - 1.99	Tx-7997	7410±160	-15.6	7560±160	8440(8340)8130
Trench 6	3.58 - 3.63	Tx-7995	17,480±520	-20.8	17,540±260	21,620(20,880)20,070

1: All ages were obtained on the base soluble fraction of total soil humates.

2: Calibration from a conventional $\delta^{13}C$pcorrected radiocarbon age to calibrated calendar uyears using a tree-ring curve. All calibrations reported here were based upon the 20-year atmospheric curve (see Linick et al., 1985, 1986; Kromer et al., 1986; Mook, 1986; and Stuiver et al., 1986. Program used for calibration is discussed in Stuiver and Reimer (1993).

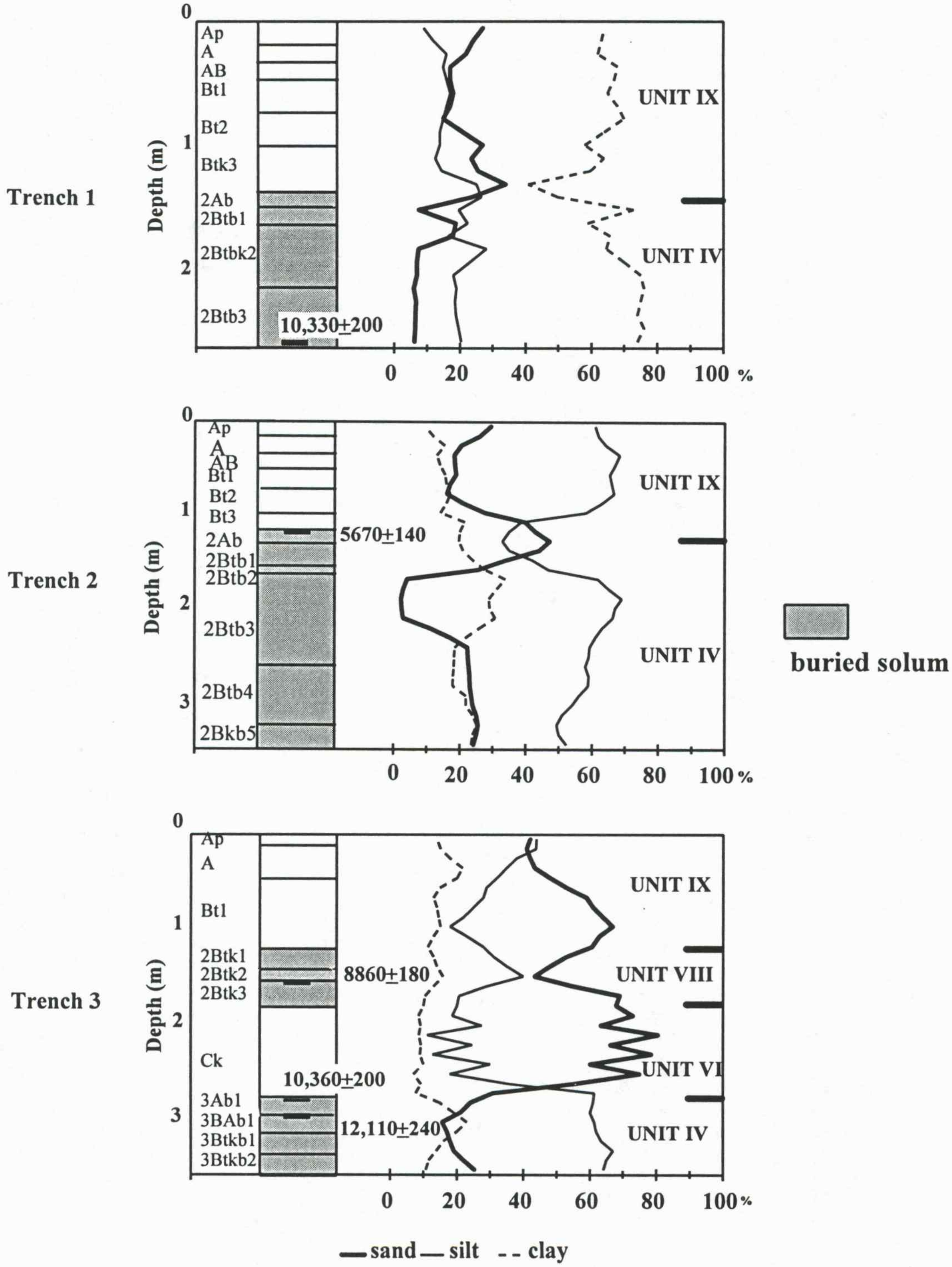

Figure 7:4. Trench and soil stratigraphy, including radiocarbon ages, at Wilson Ridge.

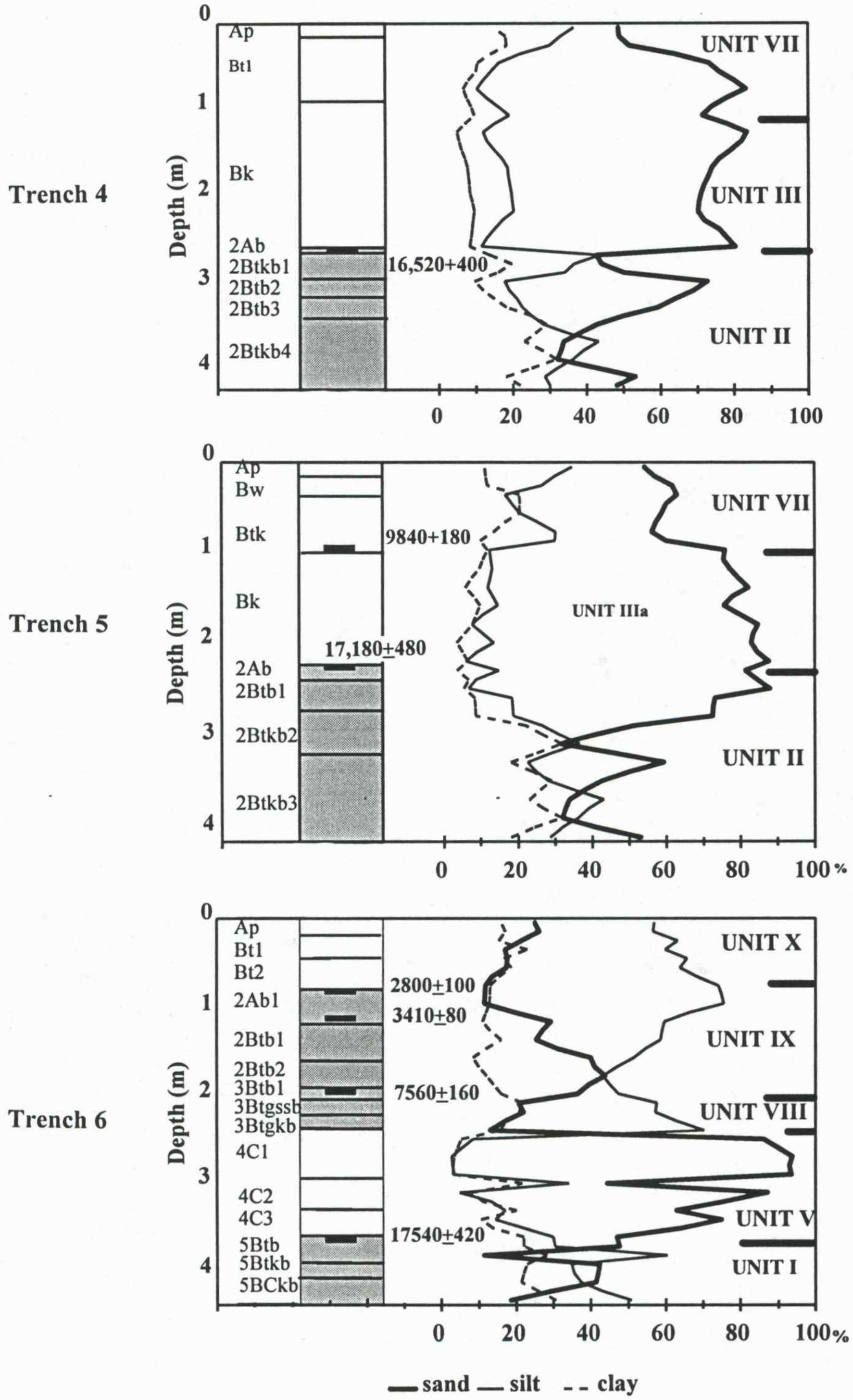

Figure 7:4 (cont).

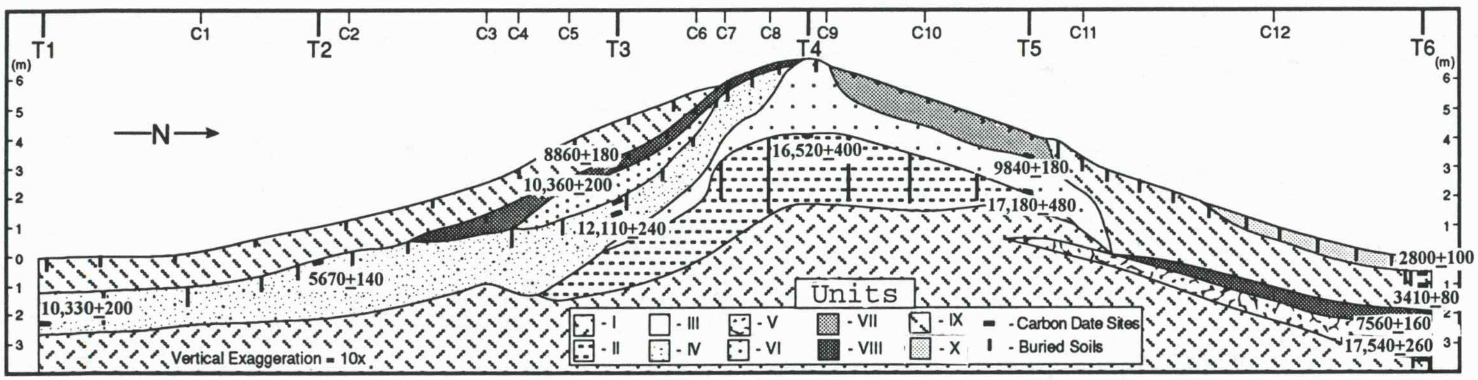

Figure 7:5 Cross-section showing the position of stratigraphic units, trenches, and cores at Wilson Ridge.

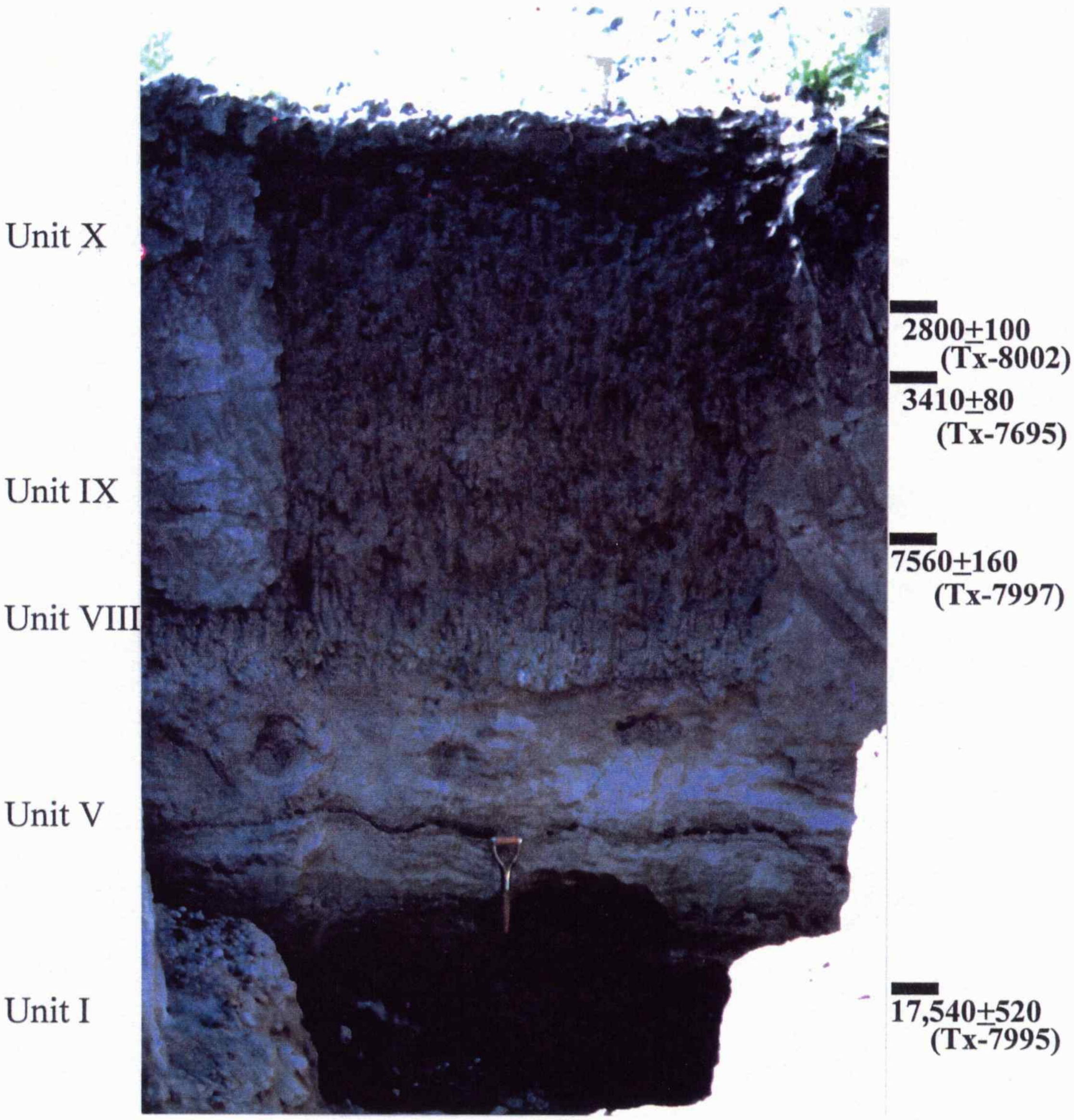

Figure 7:6. Trench 6 (4.20-m high) at Wilson Ridge showing stratigraphic units and radiocarbon ages.

Unit II (Fig. 7:5) is loamy (Fig. 7:4) and recognized in trenches 4 (Figs. 7:5, 7:7) and 5 (Figs. 7:5, 7:8), as well as in cores 7 to 10 (Fig. 7:5). The unit contains numerous gastropod fragments and is highly calcareous (appendix). It is thickest (ca. 2 m) in the center of the dune, but pinches out or is truncated both to the north and south. Formed throughout the deposit is a well developed buried soil, consisting of several Btb horizons. To estimate the mean residence time of humates in the upper 5 cm of Unit II in trench 4 (2.60 - 2.65 m), a sample was collected that provided a $\delta^{13}C$-corrected radiocarbon age of 16,520±400 yrs B.P. and a $\delta^{13}C$ value of -11.9‰ (Tx-7825). Similarly, the upper 5 cm of Unit II in trench 5 (2.25 - 2.30 m) dated to 17,180±480 yrs B.P., also with a $\delta^{13}C$ value of -11.9‰ (Tx-7824).

Unit III consists of calcareous, sandy sediments (Fig. 7:5; appendix), containing fragmented gastropods, overlying Unit II in the center and north slope of the dune. The deposit, which has a maximum thickness of about 2.6 m, was recognized in trenches 4 (Fig. 7:7) and 5 (Fig. 7:8) as well as in cores 6 to 11. It appears to have been truncated on both the north and south slopes (Fig. 7:5). Although no radiocarbon ages were obtained directly from Unit III, ages of approximately 17,000 and 9800 yrs B.P. obtained from trench 4 effectively bracket the deposit.

Capping Units I, II, and III, recognized in trenches 1 (Fig. 7:9), 2, (Fig. 7:10), 3 (Fig. 7:11), and in cores 1 through 8, is Unit IV. Composed of pale-brown (10YR6/3; moist) silt, the deposit has a maximum thickness of about 1.4 m (Figs., 7:5, 7:9, 7:10).

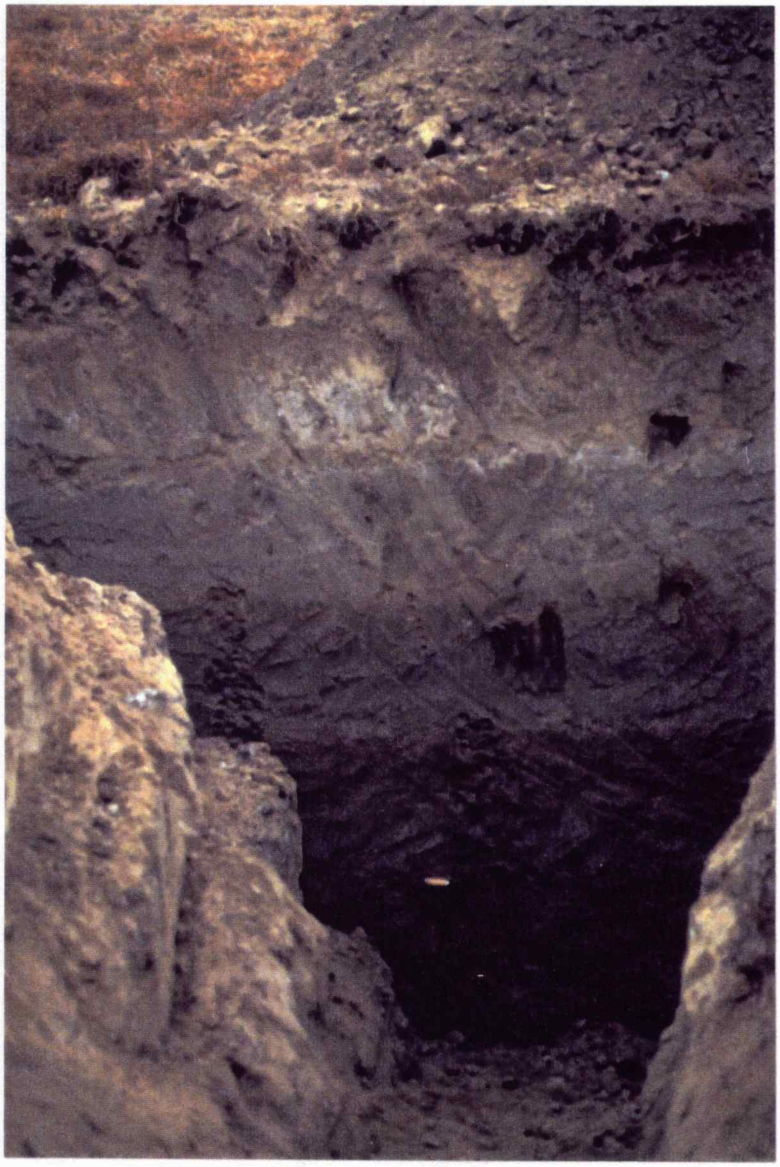

Figure 7:7. Trench 4 (4.22-m high) at Wilson Ridge showing stratigraphic units and radiocarbon age.

Figure 7:8. Trench 5 (4.18-m high) at Wilson Ridge showing stratigraphic units and radiocarbon ages.

Figure 7:9. Trench 1 (3.31-m high) at Wilson Ridge showing stratigraphic units and radiocarbon age.

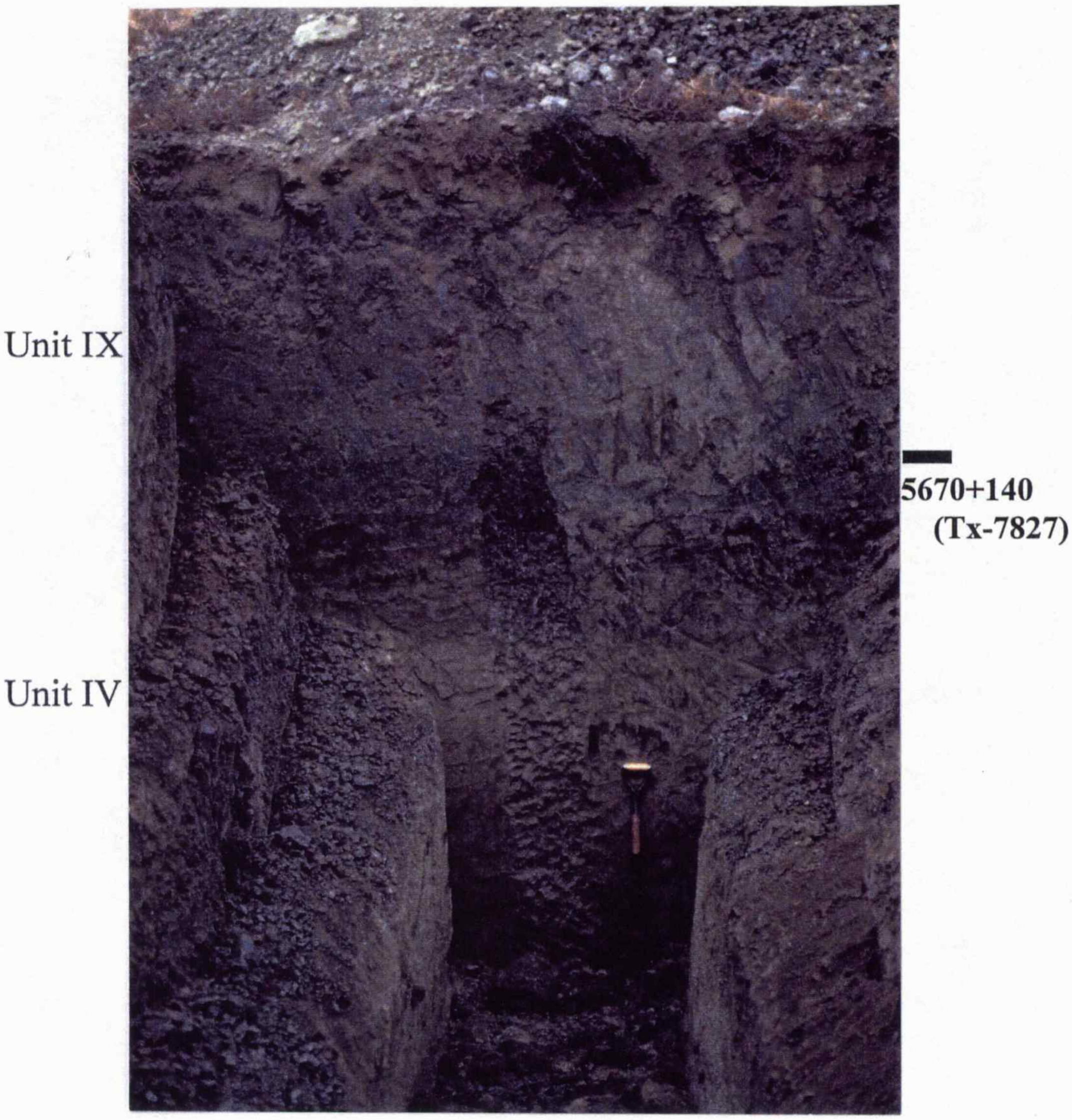

Figure 7:10. Trench 2 (3.22-m high) at Wilson Ridge showing stratigraphic units and radiocarbon age.

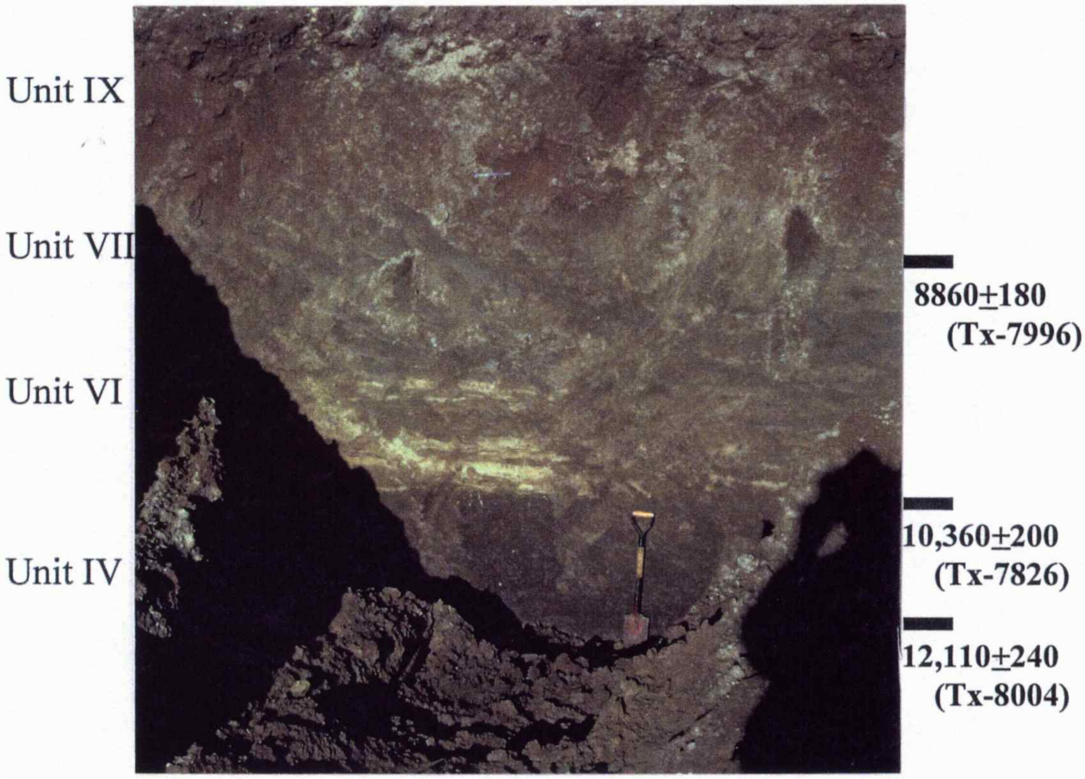

Figure 7:11. Trench 3 (3.24-m high) at Wilson Ridge showing stratigraphic units and radiocarbon ages.

Inset against Unit III in the center of the dune, Unit IV overlies Unit I on the south slope (Fig. 7:5). The stratum contains a well developed soil recognized in most of the dune's south slope that merges with the surface soil at the dune crest (Fig. 7:5). To estimate the mean residence time of humates in the lower 5 cm (2.91 - 2.96 m) of the 3Ab in trench 3, a sample was collected which provided a $\delta^{13}C$-corrected radiocarbon age of 12,110±240 yrs B.P. and a $\delta^{13}C$ value of -18.1‰ (Tx-8004).

Unit V includes laminated deposits of sand and silt (Fig. 7:4) recognized in the playa in trench 6 (Fig. 7:6) and in cores 11 and 12 on the dune's north slope. The maximum thickness of the unit is about 1.5 m (Fig. 7:5). Although no radicarbon age was derived from the stratum, ages of about 17,000 and 7,500 yr B.P. in trench 6 bracket the deposit.

Unit VI is a lens of laminated sand and silt identified on the south flank of Wilson Ridge in trench 3 (Fig, 7:11) and in cores 4 to 6 . Approximately 1.4 m thick in trench 3, the deposit pinches both up and downslope (Fig. 7:5). Sedimentary features (e.g., small cross-beds, convolutions; Fig 7:12) in the stratum suggest accumulation in a saturated environment, possibly as a slump. Many of the laminae are similar in texture and color to the underlying soil, suggesting it may have been an upslope source for sediment. A $\delta^{13}C$-corrected radiocarbon age of 10,360±200 ($\delta^{13}C$ value: -14.2‰; Tx-7826) from the upper 5 cm (2.65 - 2.70 m) of the 3Ab in trench 3 provides a maximum-limiting age for Unit VI. Conversely, a $\delta^{13}C$-corrected radiocarbon age of 8860±180

Figure 7:12. Sedimentary structures, including laminations and load structures, in Unit VI in Trench 3 at Wilson Ridge.

($\delta^{13}C$ value: -14.2‰; Tx-7996) derived from the overlying Btk6 (1.59 - 1.64 m) estimates the minimum-limiting age of Unit VI (Figs 7:5, 7:11). These ages, coupled with the nature of the deposit, further suggest relatively rapid accumulation. As a result, Unit VI separates two buried soils in trench 3 that are otherwise welded and cumulic at the surface upslope in cores 7 and 8 and farther downslope in trenches 1 and 2 and core 1 (Fig. 7:5).

Overlying Unit III on the upper north slope of the dune is Unit VII (Fig. 7:5), which is a lens of sandy silt and sand (Fig. 7:4). Observed in trench 5 (Figs. 7:5, 7:8) and cores 9 and 10 (Fig. 7:5), it is similar in character to the underlying Unit III, but may represent a different depositional interval since it does not contain gastropods. To estimate the mean residence time of humates in the lower5 cm (95 cm - 1.00 m) of the Bk horizon of Unit VII in trench 5, a sample was collected that provided a $\delta^{13}C$-corrected radiocarbon age of 9840±180 yrs B.P. and a $\delta^{13}C$ value of -13.0‰ (Tx-8014).

Unit VIII is a thin veneer of silty (Fig. 7:4) sediment recognized in trench 6 (Fig. 7:6) and core 12 (Fig. 7:5), and on the south slope of the dune in trench 3 (Fig. 7:11) and cores 3 to 7 (Fig. 7:5). In the playa, the deposit is about 42-cm-thick where it overlies Unit V. In order to estimate the minimum-limiting age of Unit VIII in trench 6, a sample was collected from the upper 5 cm (1.94 - 1.99 m) of the 2Btb5 horizon that provided a $\delta^{13}C$-corrected radiocarbon age of 7560±160 yrs B.P. and a $\delta^{13}C$ value of -15.6‰ (Tx-7997). Better age control exists for Unit VIII on the south slope of the dune, where it is about 1.5 m thick, is capped by a truncated buried soil, and overlies the stratified deposits of Unit VI. Radiocarbon ages ($\delta^{13}C$ corrected) of 8860±180 yrs B.P. ($\delta^{13}C$ value: -14.2‰; Tx-7996) at the base of the deposit in trench 3 (Figs. 7:5, 7:11), and 5670±140 yrs B.P. ($\delta^{13}C$ value: -13.6‰; Tx-7287) from the upper 5 cm (1.18 - 1.23 m) of the 2Ab in trench 2 (Fig. 7:5, 7:10) provide maximum and limiting ages, respectively, for Unit VIII on the south slope of the dune.

Unit IX consists of silty sediment on both the north and south side of the dune (Figs 7:4, 7:5). On the north side, it was recognized in trench 6 (Figs. 7:4, 7:6) and cores 11 and 12 (Fig. 7:5). The deposit is thickest (1.21 m) in trench 6 where it is bracketed by radiocarbon ages of about 7500 and 3400 yrs B.P. On the south side of the dune, the stratum was recognized in trenches 1 to 3 and cores 1 to 6 where it has an average thickness of about 1.2 m (Figs. 7:4, 7:5). A radiocarbon age of approximately 5700 yrs B.P., derived from the 2Ab in trench 2 (Figs. 7:4, 7:10), provides a maximum-limiting age for Unit IX on the south side of the dune.

Unit X is a thin veneer of sediment, positively identified in the playa within trench 6 (Figs. 7:4, 7:6). The unit is a 73-cm-thick deposit of silt (Fig. 7:4) that buried a well developed soil soon after 2800 yr B.P (Fig. 2). Unit X may thinly mantle most of the dune, however, as suggested by the silty texture and relative similarity in surface soil development (i.e., thermic, pachic Argiustoll) that occurs over most of the dune, except for the north slope.

Discussion

Stratigraphic and chronologic data indicate a complex late-Quaternary history at Wilson Ridge. Ten stratigraphic units, including six buried soils, are recognized at the site and represent a variety of depositional events and facies. Based on the discriminating characteristics (e.g., sedimentology, radiocarbon ages) of each unit, the geomorphic history can be reconstructed. In addition, paleoclimatic conditions can be inferred for the site from radiocarbon-derived $\delta^{13}C$ values (Krishnamurthy et al., 1982) and faunal remains.

It is unknown precisely when Wilson Ridge began to form. As with other lunettes (e.g., Reeves, 1965; Holliday, 1985, 1989), the dune has a close association with an adjacent playa (Fig. 7:1). Unit I, a unit of gleyed silt and clay underlying the entire dune (Fig. 4), is consistent with other late Wisconsinan deposits on the Great Bend Sand Prairie (e.g., Edwards 1 - 4, Reno 4). A radiocarbon age of about 17,000 yrs B.P. from a buried soil in Unit I estimates a minimum age for the unit. Research on the southern High Plains indicates some lunette formation prior to 30,000 yrs B.P. (Holliday, 1985), and Reeves (1965) obtained a radiocarbon age of approximately 19,000 yrs B.P. from directly beneath a lunette in Texas. Given that Wilson Ridge overlies a demonstrably late Wisconsinan lacustrine unit similar to that described by Reeves (1965), dune formation is estimated to have begun about 20,000 yrs B.P. Eolian deposition apparently began because Unit II, which was deflated from the playa, accumulated on the lee side of a slight topographic high (strandline?) in Unit I. This age estimate coincides with the onset of Peoria loess sedimentation in the central Great Plains (Wells and Stewart, 1987; Johnson et al., 1993; Maat and Johnson, 1994).

Stratigraphic evidence from Wilson Ridge indicates that deposition of Unit II continued on the lee side of the playa until roughly 17,000 yrs B.P. Calcareous sediment, including numerous gastropods crushed during transportation, was apparently deflated from the playa by prevailing northwesterly winds. Temporally, Unit II correlates to an interval of Peoria loess accumulation in the central Great Plains recognized during the last glacial maximum from 18,000 to 17,000 yrs B.P. (Johnson, 1993). Subsequently, the playa stabilized, resulting in the formation of a well developed soil in both the lake bottom and on the dune. Values of $\delta^{13}C$ from this time suggest vegetation predictably varied between the two edaphic environments: -20.9‰ from the playa indicates a higher proportion of C_3 plants, while -11.9‰ demonstrates that the well-drained dune was xeric.

Following stability about 17,000 yrs B.P., deposition of eolian sediment continued at Wilson Ridge in two stages until around 12,000 yrs B.P., a time that correlates to the major late Wisconsinan deglaciation (Ruddiman, 1987). Initially, Unit III was deposited on the north slope and crest of the dune in the form of calcareous sandy sediment deflated from the adjacent playa by prevailing northwesterly winds (COHMAP, 1988). Shortly therafter, Unit IV accumulated on the south slope of the dune (Fig. 7:3). As much as 70 percent silt, Unit IV is similar in color and texture to Peoria loess (Wells and Stewart, 1987; Johnson, 1993, Johnson et al., 1993) that has been recognized immediately to the north and south of the Great Bend Sand Prairie (Feng, 1991; Feng et al., 1994).

Following deposition of Units III and IV, a well developed soil formed that caps Unit IV on the upper, south slope of the dune (Figs 7:2, 7:3). Radiocarbon ages from the lower and upper boundaries of the soil demonstrate that landscape stability occurred for two-thousand years. This period of pedogenesis correlates reasonably well with the Brady soil, a major period of landscape stability recognized in the central Great Plains (Schultz and Stout, 1948; Frye and Leonard, 1951; Caspall, 1970, 1972; Feng et al., 1994a, b) at the Pleistocene-Holocene climatic boundary (Johnson and May, 1992). Generally, the interval of Brady pedogenesis is thought to range from approximately 10,500 to 8500 yrs B.P., but most observations are from northern Kansas (e.g., Johnson, 1993) and Nebraska (e.g., Johnson and May, 1992; Johnson et al., 1993), suggesting that the Brady may be time-transgressive.

Given that the Brady soil is so well developed at Wilson Ridge, it is interesting that it occurs only on the dune's south slope. Two theories may explain this pattern: 1) a soil developed only on the south slope of the dune because persistant northwesterly flow continually destabilized the north slope; or 2) soil formation occurred over the entire dune between about 12,000 and 10,000 yrs B.P., with subsequent, early Holocene truncation on the north slope. Four characteristics of the soil favor the second theory: 1) the degree of development on the south slope coupled with the pervasiveness of the Brady soil in the region indicate a major period of landscape stability; 2) the Brady has a steeper dip than the modern surface, and merges with the surface soil on the crest, suggesting that at one time that the dune was higher with the soil continuing to the north slope; 3) values of $\delta^{13}C$ change from -18.1‰ to -14.2‰ on the lower and upper boundaries, respectively, of the paleosol on the south slope of the dune - this decrease in $\delta^{13}C$ suggests a shift to higher temperatures and a potentially unstable environment with increased aridity towards the end of pedogenesis; and 4) the soil was partially truncated on the lower part of the dune's south slope.

The nature of early Holocene deposits at Wilson Ridge suggest that a significant period of landscape instability occurred soon after about 10,000 yrs B.P., resulting in complete truncation of the Brady soil on the north slope and partialy truncation of it on the south slope. Specifically, the position and sedimentology of Unit VI on the south slope (Fig. 3) implies a major erosional event(s) in the early Holocene. As mentioned previously, Unit V consists of well laminated deposits of sand and silt, containing convolutions and load structures, that overlie the Brady soil. A radiocarbon age of approximately 8900 yrs B.P. from directly above Unit VI, coupled with the sedimentology of the deposit, indicate rapid accumulation in a saturated environment. Stringers of organic-rich laminae in the unit, apparently derived from the Brady, suggest that mass wasting of upslope sediment during this interval contributed to truncation of the soil near the crest of the dune. The net result has been a probable decrease in the height of the dune and a shifting of the crest from north to south.

The Holocene geomorphic history at Wilson Ridge is one of episodic deposition in a periodically more arid, destabilizing environment. Apparently, the playa was the sediment source for most of the early Holocene, potentially creating the major unconformity between units V and VIII, when it was deflated by strong, northwest winds. As a result, the north slope and crest were the most unstable surfaces on the dune, whereas the southern slope was relatively tranquil. Accumulation of relatively sandy sediment (Unit VII) began approximately 9000 yrs B.P. on the north slope of the dune. The onset of this period of sedimentation correlates with regionally recognized Bignell loess deposition (Frye et al., 1968; Feng, 1991; Johnson, 1993) and localized eolian erosion and sedimentation in the southern High Plains (Holliday, 1989). A $\delta^{13}C$ value of -13.0‰ associated with Unit VII suggests increasingly arid conditions at the site during the early Holocene. Moreover, the lack of gastropods in Unit VII, which are numerous in underlying deposits, further indicates increased overall aridity. Early-Holocene deposition on the north slope was probably episodic because a well developed interval of soil formation occurred in the playa at about 7500 yrs B.P. This period of stability correlates reasonably well with soil formation in a playa located in Haskell County (Mandel and Olson, 1995).

Although the north slope of Wilson Ridge was generally unstable throughout the early Holocene, it appears that the south slope was largely in equilibrium. Other than deposition of Unit VI and erosion of the Brady soil on the extreme upper and lower parts of the south slope, extended pedogenesis prevailed. On the upper south slope, a period of soil formation began soon after deposition of Unit VI that lasted until about 5800 yrs B.P. Immediately south of the dune, long-term pedogenesis from roughly 10,300 to 5800 yrs B.P. resulted in a thick, cumulic buried soil.

It is suprising that the south slope of Wilson Ridge remained essentially undisturbed throughout the early Holocene while the north slope was severly truncated, especially since evidence suggests an increasingly destabilizing environment. Documented early Holocene climate change (Webb, 1985; Crowley and North, 1991) reflects a gradual temperature increase which culminated in the middle Holocene as an extended warm, dry period (Wright, 1970; Benedict and Olson, 1978; Barry, 1983; Holliday, 1989) identified as the Altithermal (Antevs, 1955). Values of $\delta^{13}C$ from Wilson Ridge change from -18.3‰ at about 10,300 yrs B.P. to -13.6‰ around 5800 yrs B.P. in the soil buried on the south side of the dune, further suggesting early Holocene warming. Geomorphic evidence from the southern High Plains indicates increasingly drier conditions during the early Holocene (Holliday, 1989). Given the evidence for instability on both a regional and local scale, the south slope of Wilson Ridge theoretically should have been active. A possible explanation for its inactivity is that early Holocene winds sufficient to mobilize sand may have occurred only from the northwest, resulting in a "windshadow" that protected the south slope.

During the late Holocene, Wilson Ridge has largely been a stable landform with relatively little erosion and deposition. Local climate has generally remained warm and dry, as indicated by low (e.g., -12.4‰) $\delta^{13}C$ values. Sedimentation in the playa (Unit IX) has been episodic with soil formation occurring between about 3500 and 2800 yrs B.P., which correlates to a period of relative stability recognized in a playa in Haskell County that began about 4000 yrs B.P. (Mandel and Olson, 1995). On the south slope of the dune, an approximately 1-m-thick deposit of sandy silt (Unit IX) has accumulated in the past 5000 to 6000 years, a period of eolian sand mobilization recognized elsewhere on the Great Bend Sand Prairie (e.g., Reno 3, Reno 4, Stafford 6) and in the region (Ahlbrandt et al., 1983; Muhs, 1985; Madole, 1986; Forman and Maat, 1990). For example, radiocarbon ages and soil morphology from a lunette adjacent to Yellowhouse Draw in the Sandhills of Texas indicate eolian sedimentation between about 6000 and 4500 yrs B.P. (Holliday, 1989). In contrast to earlier deposits which were mobilized by northwest winds, Unit IX on the south slope of Wilson Ridge apparently resulted from documented southerly winds on the Great Bend Sand Prairie in the late Holocene (Arbogast, 1993a, b). Additional deposits of sand and silt also accumulated on the crest and north flank of the dune and in the playa. At most localities across the dune and playa, the surface soil is well developed, indicating relatively long-term (ca. 1000 yrs) stability at the site. The lone exception is on the upper north slope where the surface soil is less well developed, suggesting that this area of the dune has recently been active and that northwest winds continue to provide sediment.

CHAPTER 8

DISCUSSION AND CONCLUSIONS

Chronology of Late Quaternary Landform Evolution and Paleoenvironmental Change

Integration of data collected from reconnaissance, mapping, backhoe-trench investigations, roadcut exposures, quarries, and previous research has provided a chronology of late Quaternary landform evolution and paleoenvironmental change on the Great Bend Sand Prairie in south-central Kansas. Earlier studies in Kansas were largely qualitative in nature and based upon outdated glacial chronologies due to the paucity of reliable dating techniques. Because of extensive use of the radiocarbon method for age control, previously accepted theories regarding landscape evolution in the region have been significantly revised.

The history of late Quaternary sedimentation, landscape stability, geomorphic process, and climate change on uplands throughout the Great Bend Sand Prairie document the pattern of landscape evolution and paleoenvironmental change. The chronology is organized in three parts: late Wisconsin (ca. 21 - 10 ka), early to middle Holocene (ca. 10,000 - 4000 yrs B.P.), and late Holocene (4000 yrs B.P. - Present) (Table 8:1).

Late Wisconsin (ca. 21 - 10 ka)

From a regional perspective, conflicting evidence exists regarding the precise environmental conditions in the central Great Plains during the late Wisconsin. Certainly, the climate was cooler, and probably less seasonal than at present. Climatic modelling (e.g., CLIMAP members, 1981; Kutzbach, 1987; COHMAP members, 1988) of glacial maximum atmospheric circulation patterns

Table 8:1. Generalized Geologic and Environmental Chronology for the Great Bend Sand Prairie: 21,000 yrs B.P. to Present.

Time (RCYBP)	**Event**	**Dominant Process**	**Environment**
Historical	Erosion and Deposition	Eolian	Episodic Drought (C_4 plants)
200 - 6100	Episodic and Spatially Variable Instability	Eolian	Episodic Drought (C_4 plants)
6100 -10,000	Widespread Erosion and Sedimentation	Transition from Fluvial to Eolian	Transition from C_3 to C_4
10,000 - 20,000	Sedimentation, Erosion, and Stability	Fluvial	Relatively Cool and Moist (C_3 plants)

shows a westerly jet stream that was split into northern and southern branches over North America. Delcourt (1979) and Delcourt and Delcourt (1983) argued that the mean position of the polar front, which today is located in southern Canada, was at approximately 34° N about 18,000 yrs B.P. As a result, mean annual surface temperatures in the central Great Plains were probably 2° to 4° cooler than today (Kutzbach, 1987). Prevailing winds were northwesterly (Fig. 8:1), as indicated by the orientation of late glacial eolian features (Wells, 1983), and were perhaps 20 to 50 percent stronger than at present (Crowley and North, 1991). Faunal investigations in the Pleistocene biota of the central Great Plains indicate more complex and diverse biological communities, reflecting cooler summers and warmer winters than those of the Holocene (Martin, 1984; Martin and Hoffman, 1987; Martin and Martin, 1987).

Although surface temperatures for the Woodfordian are relatively well understood, conflicting evidence exists regarding moisture conditions. A large body of data implies that the climate was relatively moist compared to the Holocene. The floral record, in particular, suggests more effective moisture. Wells and Stewart (1987) found needle leaves of *Pinus flexilis* (limber pine) and *Picea* (cf. *glauca*) in charcoal that dated about 14500 yrs B.P. in south-central Nebraska. Data from Sander's well in north-eastern Kansas and from North Cove on Harlan County Lake in south-central Nebraska, imply that a *Populus* (aspen) parkland existed on uplands between 24,000 and 12,800 yrs B.P. (Fredlund and Jaumann, 1987; Fredlund, 1989). In addition, analysis of grass phytoliths in Peoria loess exposed at the Eustis ash pit in south-central Nebraska indicates deposition on a well vegetated surface, one consistent with high effective moisture (Fredlund et al., 1985).

Although ample evidence for more effective moisture during the Woodfordian

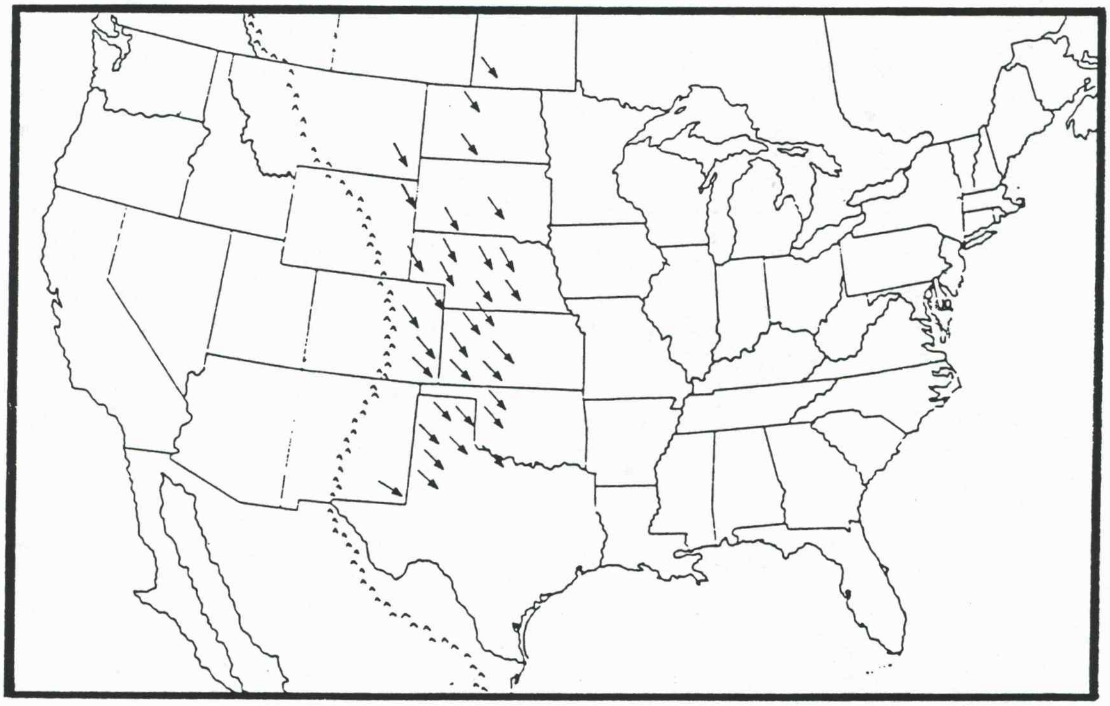

Figure 8:1. Inferred surface winds in the Great Plains approximately 18 ka as derived from the orientation of late glacial geomorphic features (modified from Wells, 1983).

exists, other data point to increased aridity. Holliday (1987) challenged the cool and moist climatic model for the late Wisconsin, arguing that pollen data which suggest a spruce parkland are misleading because spruce pollen is resistant to weathering as compared to other pollen varieties. Moreover, Holliday concluded that buried soils in Woodfordian deposits would exhibit evidence of podzolization if conifers truly dominated in a more moist environment. According to Feng (1991), no evidence for podzolization (e.g., E horizon) exists in the Peoria loess.

Changes in the rate of deposition between the Farmdalian and Woodfordian further imply a shift to increased aridity at the glacial maximum. During the Farmdalian, upland landscapes were very stable, with extended soil development in the Gilman Canyon Formation (Fredlund et al., 1985; Johnson et al., 1993). Regionally, the termination of Farmdalian stability and Peoria loess deposition occurred sometime between 24,000 and 22,000 yrs B.P. The onset of loess deposition is thought (e.g., Johnson, 1993; Johnson et al., 1993) to represent a period of increased aridity, a hypothesis that agrees with climatic modelling experiments (e.g., Kutzbach and Wright, 1985, COHMAP 1988; Crowley and North, 1991).

Evidence exists for increased late Wisconsinan aridity near Great Bend. Fredlund (1995) noted a major unconformity at Cheyenne Bottoms, one that spans the entire Woodfordian. He hypothesized that Cheyenne Bottoms was primarily a barren playa basin throughout the early Woodfordian, with both eolian deposition and erosion occurring. According to Fredlund, early Woodfordian aridity is not necessarily incompatible with the pollen record, which suggests the expansion of trees because limited taxa may have persisted. In fact, Fredlund argues that the Woodfordian may be subdivided on the basis of climate into an early Woodfordian, which was more xeric, and a more mesic late Woodfordian. The regional data are inconclusive. Wells and Stewart (1987) assign an early Woodfordian age to landsnail assemblages in Peoria loess. Leonard (1951, 1952) in contrast, correlates the same fauna with the late Woodfordian. Unfortunately, the record from Cheyenne Bottoms does not resolve the issue because the unconformity persists until the early Holocene (Fredlund, 1995).

Although the regional record regarding late Wisconsinan climates is unsettled, data from the Great Bend Sand Prairie indicate a more mesic environment than at any time during the Holocene, with cooler temperatures and more effective moisture. A fragment of *Picea* (cf. *glauca*) dated to about 17,000 yrs B.P. was recovered from GWMD5 (10) by Johnson (1991), indicating that white spruce was growing in the region around the glacial maximum. This finding is consistent with those elsewhere in the Arkansas River valley (Jaumann, 1991), Cheyenne Bottoms (Fredlund, 1995), Muscotah Marsh (Gruger, 1973) in northeastern Kansas, and Harlan County Lake in Nebraska (Wells and Stewart, 1987). Based upon the pollen assemblage in Cheyenne Bottoms, Fredlund (1995) characterized the region as a spruce parkland toward the end of the Farmdalian. The presence of land snails (e.g., *Discus cronkhitei*, *Succinea avara*) and an aquatic bivalve at the Belpre and Phillips Trenches on the Great Bend Sand Prairie further indicates a more mesic environment because observed species are presently extant only in the subalpine taiga of the Rocky Mountains (Leonard, 1952, Bequaert and Miller, 1973) and the more humid southeastern and northeastern parts of North America (Leonard, 1952). Finally, values of $\delta^{13}C$ derived from Woodfordian deposits generally range from -25‰ to -17‰, suggesting that C_3 plants were more prevalent. This finding corresponds well with a $\delta^{13}C$-derived paleoenvironmental reconstruction of the central Great Plains completed by Johnson and others (1993).

The cool, relatively moist Woodfordian environment on the Great Bend Sand Prairie promoted accumulation of a very poorly sorted, generally noncalcareous, deposit of sand, silt, and clay (a.k.a. silty sand). The extremely widespread silty sand underlies most of the study area, but varies considerably in texture from a spatial perspective. At some localities (e.g., Edwards 4), the silty sand is consistently 60 percent sand, whereas at others (e.g., Reno 4, Belpre Trench) the deposits contain as much as 80 percent silt or 40 percent clay. The majority of study sites exhibit at least one, but typically two to three, fining-upward sequences. Overall, the spatial variability in the silty sand suggests lateral differences in facies. Fining-upward sequences within the silty sand at specific sites imply that subtle changes in depositional regime also occurred on a temporal basis.

It is difficult to determine with certainty the process which resulted in accumulation of the silty sand. At Cheyenne Bottoms, Fredlund (1995) reported a major unconformity between Farmdalian and Holocene deposits, which he argued occurred because climate was more arid and surface winds were stronger in the Woodfordian than in the Holocene. In general, results from this study contradict Fredlund's (1995) conclusions because the silty sand is so pervasive and demonstrably Woodfordian in age. Unfortunately, no diagnostic sedimentary structures were discerned in the silty sand in any of the sites studied.

There is indirect evidence that the silty sand may be an eolian deposit. Specifically, the high percentages of silt in much of the silty sand suggest an eolian source, at least in part, because substantial deposits of Peoria loess accumulated in the central Great Plains during the Woodfordian (Frye and Leonard, 1952; Wells and Stewart, 1987; Johnson, 1993; Johnson et al., 1993), including sites immediately north Barton County Landfill) and south (Pratt County Landfill) of the study area (Feng, 1991; Feng et al., 1994). Given the documented presence of Peoria loess surrounding the study area, it is logical that deposition of eolian silt also occurred on the Great Bend Sand Prairie. In fact, Peoria loess may exist in scattered localities in the region, as suggested by deposits of buff-colored, relatively calcareous silt recognized at the Belpre Trench, Phillips Trench, and the south flank of Wilson Ridge. At the Belpre and Phillips Trenches, the silt overlies a buried soil considered to be equivalent to the Gilman Canyon Formation (Reed and Dreeszen, 1965), based upon a radiocarbon age of about 21,000 yrs B.P. from the Belpre Trench. In addition, landsnails comparable to those described elsewhere in the Peoria loess (e.g., Leonard, 1952; Wells and Stewart, 1987) were recovered from the deposits at both localities.

The silty sand may also be an eolian deposit similar to "coversands" in Alaska (Lea and Waythomas, 1990) and Europe (e.g., Koster, 1988; Schwan, 1988) which accumulated downwind of glacial outwash streams. Given the position of the Arkansas River generally to the north of the Great Bend Sand Prairie and the prevailing northwesterly winds of the Woodfordian, the floodplain certainly could have been a source for eolian sediment.

Although eolian processes probably contributed to the silty sand, the evidence suggests that fluvial processes were also present and potentially dominant. The silty sand differs from coversand because the silty sand lacks stratification and contains very high percentages of clay at some sites. Additionally, the surface of the unit is sharply and very unevenly truncated at two sites (e.g., Edwards 3, Stafford 10), suggesting that flowing water was responsible for erosion. These characteristics coupled with the many fining upward sequences and very poor sorting, imply sedimentation in a low-energy fluvial system. Given the textural variability in the silty sand throughout the study area, it appears that facies included main channel, secondary channel, and backswamp. Radiocarbon ages from trench 6 at Wilson Ridge indicate the presence of at least one playa in the region during the late Wisconsin. Although it is impossible to determine with the data now available, perhaps the study area was covered by a series of interconnected lakes with a very low gradient. Such a scenario is logical, and may account for the near ubiquity of the silty sand, while allowing for the tremendous spatial diversity in the deposit.

The discrepancy between Fredlund's (1995) conclusions and the results of this study are especially interesting and may shed further light on depositional process associated with the silty sand on the Great Bend Sand Prairie. It is possible that Fredlund's data is biased because it was obtained from only one core. If a major Woodfordian unconformity does exist at Cheyenne Bottoms, however, one would expect to find it on the Great Bend Sand Prairie. In fact, both areas are similar in character, consisting of poorly drained, lowland topography. The primary difference between the two regions is drainage area. Cheyenne Bottoms is located within a structurally controlled, closed basin fed by Blood and Deception Creeks (Latta, 1950; Bayne, 1977). The Great Bend Sand Prairie, in contrast, is part of the much larger Arkansas River basin, which originates in the Rocky Mountains. The Arkansas River was probably a meltwater stream (Schumm and Brackenridge, 1987) during the late Wisconsin. As a result, discharge would have varied tremendously as mountain glaciers fluctuated. Johnson (1988) has found paleomeanders on Pleistocene terraces in western Kansas that suggest the Arkansas was a much narrower, deeper stream, one that carried fine-textured sediment at much higher discharge, during the late Wisconsin. Given that the gradient of the Arkansas declines sharply in the vicinity of the Great Bend Sand Prairie (Fent, 1950), the Arkansas might have regularly flooded the study area during the late Wisconsin, which may have contributed to deposition of the silty sand in a marshy environment.

Although the silty sand is likely a product of regional processes, evidence from Wilson Ridge indicates that eolian sedimentation occurred on a local scale. Situated on the southern margin of a playa, Wilson Ridge contains at least two buried soils that date to the Woodfordian. Eolian deposition apparently began approximately 20,000 yrs B.P., a period of lunette formation recognized by Reeves (1965) in the southern High Plains, when northwest winds deflated sediment from the nearby lake bed. Sedimentation continued until around the glacial maximum when a well developed soil formed in the dune. Eolian sedimentation was subsequently renewed until approximately 12,000 yrs B.P., when another soil formed, one generally equivalent in age to the Brady soil (Schultz and Stout, 1948; Frye and Leonard, 1951; Caspall, 1970; Johnson and May, 1992).

All of the described Woodfordian deposits on the Great Bend Sand Prairie have been tremendously altered by post-depositional processes. Specifically, soil formation in the silty sand has been very strong, potentially obliterating any diagnostic sedimentary structures. In each instance where the silty sand was described, buried soils consisted of stacked Btb horizons that spanned the entire thickness of the exposed section. Well defined clay films, traceable in sola over several meters, were commonly observed in exposures and thin section, indicating that soil formation was intense and of long duration. Slickensides were also noted on occasion (e.g., Cullison Quarry) suggesting that sola in the silty sand have expanded and contracted over time due to wetting and drying.

Late Wisconsinan deposits have also been altered by oxidation and reduction, probably in conjunction with soil formation. According to Birkeland (1984), oxidation and reduction are biproducts of deep chemical weathering, with reduction occurring in a semi-saturated environment where oxygen is low. Apparently, there has been substantial spatial and temporal variability in the depth to water table or other saturating conditions (e.g., ponding) in the study area, resulting in tremendous variability in the color of the silty sand. At localities where there has been a great deal of oxidation (e.g., Edwards 3, 4, Stafford 2), the silty sand is orange (e.g., 7.5YR4/6). In contrast, there are a number of sites (e.g., Cornwell Quarry, Reno 4, Stafford 3) where the entire deposit of silty sand is heavily gleyed and mottled, suggesting consistently high water tables for a long period of time. In another comparison, the degree of oxidation and reduction varied sharply with depth at Edwards 1 and 2, implying that the degree of saturation differed over time. At two sites (e.g., Belpre Trench, Phillips Trench), there seems to have been very little chemical weathering, because late Pleistocene deposits range in color from brown (10YR3/2; moist) to black (10YR2/1; moist).

Early to Middle Holocene (10,000 - 4000 yrs B.P.)

Very little direct evidence for early to middle Holocene events exists on the Great Bend Sand Prairie. From an environmental perspective, the transition from the late Wisconsin to the Holocene was a period of major climatic and vegetational change across the central Great Plains. Immediately to the north of the Great Bend Sand Prairie, Fredlund (1995) reports a dramatic increase in Cheno-Am populations soon after 11,000 yrs B.P. at Cheyenne Bottoms that reflect sharp fluctuations in water levels within the basin as the climate became more unstable. At Muscotah Marsh in northeastern Kansas, a sharp decline in *Picea* began about 12,000 yrs B.P., concurrent with an increase in *Quercus*, *Ulmus*, *Fraxinus*, and *Salix*. By approximately 10,500 yrs B.P., *Picea* had completely been replaced by deciduous forest (Gruger, 1973). The driving mechanism behind the region's environmental change was disintegration of the Laurentide ice sheet (Andrews, 1987), which promoted generally drier, zonal atmospheric flow (Knox, 1983). Perhelion was in July, and this, in conjunction with a decrease in the earth's tilt (obliquity 24.23°), increased summer solar radiation at the top of the atmosphere to about 8 percent greater than at present (Kutzbach, 1981, 1985, 1987). At Muscotah Marsh, these combined effects resulted in the complete displacement of forest by grassland by 9000 yrs B.P. (Gruger, 1973)

As the Laurentide ice sheet wasted during the early Holocene, the steep north-south temperature gradient which had been present during the late Wisconsin continued to weaken, promoting further zonal flow (Knox, 1983). As a result, seasonal temperature extremes began to increase (COHMAP, 1988). In combination with one another, these factors triggered the generally warm and dry conditions of the Altithermal (Antevs, 1955) that prevailed in central North America from about 8000 to 5000 ka (Knox, 1983; Kutzbach, 1985, 1987, COHMAP members, 1988; Crowley and North, 1991). By approximately 6000 ka, mean summer temperatures on the Great Bend Sand Prairie could have been 2° to 4° higher than at present (COHMAP members, 1988; Crowley and North, 1991). In addition, annual precipitation was potentially as much as 25 percent less than today (Bartlein et al., 1984; Kutzbach, 1987). In Cheyenne Bottoms, the Altithermal promoted stable, but probably lower water levels that depressed Cheno-Am populations that otherwise thrive in basins where water levels fluctuate (Fredlund, 1995).

Stratigraphic information derived from the Great Bend Sand Prairie suggests that the environment during the early and middle Holocene became increasingly arid and unstable. The primary evidence for greater aridity is termination of silty-sand deposition, a widespread and probable fluvial facies in the late Wisconsin and extinction of landsnails Secondarily, $\delta^{13}C$ values suggest the growing dominance of C_4 grasses.

As the climate became more xeric during the early Holocene, eolian processes, rather than fluvial, became the most important means of sediment transport on uplands of the Great Bend Sand Prairie. Direct evidence for sediment transport by wind during the early and middle Holocene was recognized at Wilson Ridge, Stafford 2, Stafford 4, and Stafford 6. On the north slope of Wilson Ridge, an eolian unit accumulated sometime after about 10,000 yrs B.P. At Stafford 2, a maximum-limiting radiocarbon age of approximately 10,000 yrs B.P. from the upper silty sand suggests that a poorly sorted unit of eolian sand accumulated during the early Holocene. At Stafford 6, humates in a weakly developed buried soil in dune sand date to around 6000 yrs B.P.

The best evidence for large-scale, early Holocene transport of wind-blown sediment is at Stafford 4, where grayish, unweathered loess overlies a buried soil dated to about 12,000 yrs B.P. In fact, loess was recognized in reconnaissance over a relatively large (ca. 97 km^2) area north of Stafford. Given the underlying radiocarbon age at Stafford 4, the loess could be Pleistocene loess or Bignell loess (Frye et al., 1968), an early Holocene loess which has been recognized to the north and south of the study area at the Barton and Pratt County landfills, respectively (Feng, 1991). In general, Bignell loess is thought to be reworked sediment from the Brady soil, which accounts for its grayish color (Frye et al., 1968; Johnson and May, 1992; Johnson, 1993). Bignell loess is typically thin and discontinuous, filling slight depressions on upland topography (Frye et al., 1968). If the loess north of Stafford is Bignell loess, it represents one of the largest uninterrupted expanses of the unit in the central Great Plains.

In addition to the direct evidence for increasingly arid conditions during the early and middle Holocene, there is indirect confirmation of sediment transport by wind.

Although middle Holocene radiocarbon ages were derived from the upper part of the silty sand, they are considered unreliable estimates of exposure because of the wide range of humate ages that exist. A better indicator for early and middle Holocene exposure is the truncation of the upper part of the silty sand, which suggests that extensive eolian erosion occurred sometime after soil formation. The silty sand, of demonstrated late Wisconsinan age, contains an extremely well developed buried soil at every site described in this study. Although Bt horizons are well preserved in the unit, overlying A horizons are rarely observed, suggesting that they were stripped during erosional episodes in the Altithermal. Regionally, widespread eolian sand mobilization has been recognized during the middle Holocene in the southern High Plains (Holliday, 1989, 1995). Given the demonstrably drier climate of the early and middle Holocene, it is logical that the surface of the silty sand was exposed to deflating winds.

Late Holocene (4000 yrs B.P. - Present)

The climate of the central Great Plains was apparently more moist in the early part of the late Holocene than during the Altithermal. Evidence for this shift can be seen at Muscotah Marsh in northeastern Kansas, when deciduous forest (e.g., *Quercus, Carya*) repopulated portions of the landscape after 5000 yrs B.P. (Gruger, 1973). Since that time, however, the climate has apparently fluctuated between relatively moist and dry. According to Fredlund (1995), for example, high percentages of Cheno-Am pollen indicate that water levels have varied, resulting in basin-wide drying, throughout the late Holocene in Cheyenne Bottoms. Values of $\delta^{13}C$ derived from Great Bend suggest that C_4 grasses have inhabited the area throughout the late Holocene.

Stratigraphic evidence derived from the Great Bend Sand Prairie indicates that environmental conditions have often fluctuated between relatively moist and dry in the past several thousand years. In general, landscapes were unstable during arid intervals, resulting in eolian mobilization of dune sand. As moisture levels increased, in contrast, dunes stabilized and surface soils formed. No discernable early late Holocene deposits were identified in this study, suggesting that eolian sedimentation occurred soon after the post-5000 yrs B.P. mesic interval defined by Gruger (1973) at Muscotah Marsh.

Contemporary dunes on the Great Bend Sand Prairie are generally late Holocene deposits and are found in several forms according to their degree of development: high-relief sand sheet, compound sub-parabolic, compound parabolic, and parabolic. With the exception of the Cornwell Trench, where a buried soil dated to about 2300 yrs B.P. underlies a high relief sand sheet, no clear relationship exists between dune form and age.

In most parabolic dune fields the orientation of dune limbs is southwesterly, although some dunes are oriented northwesterly. Wind data from Hutchinson, immediately to the east of the Great Bend Sand Prairie, illustrate the probable cause for dune orientation. During the winter months prevailing winds are northwesterly (Fig.

8:2A), whereas in the summer they are southerly to southwesterly (8:2B). When annual data are summarized, the region can be characterized as a high energy environment (DP = 1090) with multidirectional winds. Summer winds are strongest, resulting in an overall northeasterly resultant drift direction (RDD; Fig. 8:2C; Muhs, unpub. data). Given the orientation of most parabolic dunes, summer winds are considered to be largely responsible for dune migration. Northwesterly oriented dunes indicate that mobilization of sand has also occurred during the winter.

Potentially, three source areas exist for late Holocene dunes: 1) Holocene floodplains, 2) exposures of silty sand, and 3) older dune sand. Although each has probably contributed to some extent, the lack of Altithermal dune sand suggests that late Holocene dunes are reworked middle Holocene eolian sand deposits.

Evidence for regional landscape instability about 1000 yrs B.P., potentially resulting from increased dryness (Hall, 1982), is well documented throughout the central Great Plains. Following a period of stability approximately 1200 yrs B.P., for example, streams throughout the region entrenched dramatically (e.g., Johnson and Logan, 1990; Arbogast and Johnson, 1994). Significant mobilization and deposition of eolian sand since 1000 yrs B.P. is documented at five widely scattered sites on the Great Bend Sand Prairie. At the Crocket Cutbank, a maximum-limiting age of around 900 yrs B.P. was derived from a buried soil underlying approximately 6 m of dune sand. Similarly, buried soils in dune sand at Reno 3 and Reno 4 dated to about 700 yrs B.P. At the Rice

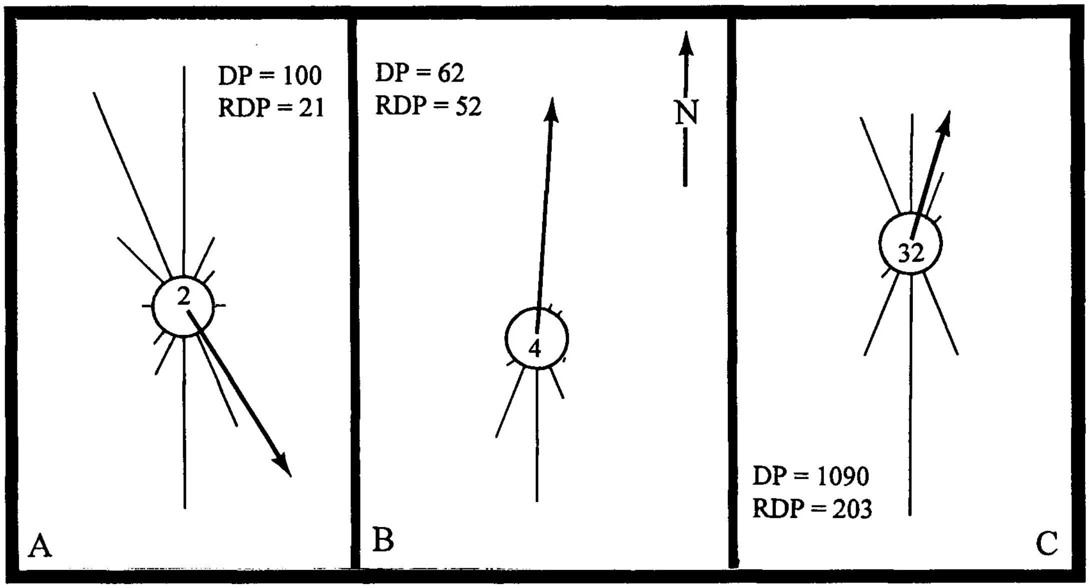

Figure 8:2. (A) February sand rose diagram (complex) from Hutchinson. Winds are multidirectional, with the prevailing wind from the northwest and a southeasterly resultant drift direction (RDD; modified from Muhs, unpub. data). Drift potential (DP; measured in vector units) is a measure of relative sand moving capability of wind, whereas the RDP is the resultant drift potential. The reduction factor, which is the number by which the vector-unit total of each sand rose arm was divided so the longest arm would plot at < 50 mm (Fryberger and Dean, 1979) is 2. (B) July sand rose diagram (wide unimodal) for Hutchinson. Winds are dominantly southerly with a north to northeasterly RDD. (C) Annual summary of sand rose diagrams (complex) for Hutchinson (modified from Muhs, unpub. data).

Roadcut, ages of around 500 and 400 yrs B.P. were obtained from the bottom and top, respectively, of a buried soil in dune sand. The episodic nature of dune stability in the past 1000 years is best illustrated at Stafford 6, where two periods of soil formation apparently occurred in the past 600 years. Two ages were obtained from the lowermost soil buried at the site: approximately 600 and 500 yrs B.P. from the bottom and top, respectively. Following deposition of about 60 cm of eolian sand, a brief period of soil formation occurred around 300 yrs B.P.

Eolian sand mobilization on the Great Bend Sand Prairie since 1000 yrs B.P. compares favorably with other findings from the Great Plains in the past 10 years. Late Holocene dune formation has been reported in Nebraska (Ahlbrandt et al., 1983; Swinehart and Diffendal, 1990; Ponte et al., 1994; Muhs et al., 1995) and northeastern Colorado (Muhs, 1985; Madole, 1985, 1994; Forman and Maat, 1990). Widespread dune formation since 1000 yrs B.P. in the Great Bend Sand Prairie correlates especially well with events recently documented in northeastern Colorado by Madole (1994). Madole (1994) also recognized multiple buried soils at five localities in northeastern Colorado, a finding consistent with the stratigraphic record in this study. Muhs and Holliday (1995), citing dendroclimatic data, reported several droughts in the 19th century that correlate with sightings of active sand in the Great Plains by explorers passing through the region.

Although dunes have mobilized in the late Holocene on the Great Bend Sand

Prairie, instability has differed spatially. Surface soil development varies in many dune fields, including solums with A/Bt/C or A/AC/C horizonation, providing an indirect measure of the spatial deviation in dune stability. Calibrated radiocarbon ages from the top and bottom of buried soils at the Rice Roadcut and Stafford 6 suggest that soils with A/AC/C profiles formed within 300 years. As a result, many dunes (e.g., Crocket Cutbank, Cullison Trench) have been stable for a relatively brief period of time. In contrast, dunes with A/Bt/C horizonation in their surface soils must have been stable for a longer period of time (e.g., Birkeland, 1984). These findings are consistent with accounts of early 19th-century explorers, reported by Muhs and Holliday (1995), who noted both active and inactive dunes along the Arkansas River valley.

There is also direct evidence that instability in dunes varies spatially in the study area. At the Buster Quarry, for example, a "modern" age was derived from a soil buried by 80 cm of stabilized dune sand. Barbed wire was found overlying a buried soil in a dune at the Cullison Quarry. Blowouts are commonly occurring features in many dune fields, contributing to the "chaotic" appearance defined by Smith (1940) and indicating that many dune fields are presently near the threshold for instability (e.g., Muhs and Maat, 1993).

Contributions of This Study

This study has added to the chronology of late Quaternary landform evolution and climate change in the central Great Plains. Among the important results are:

1) Preliminary research (Johnson, 1991; Feng, 1991) characterized the silty sand as Peoria loess. Although Peoria loess may be incorporated in the deposit, this study illustrates that the unit is dominantly fluvial in nature, with several facies that may have accumulated in a marshy environment of interconnected lakes.

2) The Brady soil, previously identified only in loess and alluvium, occurs in dunes (e.g., Wilson Ridge) as well.

3) Prior to this study, lunettes (e.g., Wilson Ridge) were not recognized north of the southern High Plains. In addition, the orientation of Wilson Ridge indicates that northwest winds prevailed as far south as Kansas during the late Wisconsin.

4) Bignell loess, previously thought to exist only in small, discontinuous areas, may be present in a relatively broad expanse in the loess plain north of Stafford on the Great Bend Sand Prairie.

5) Early researchers (e.g., Smith, 1940; Simonett, 1960) of eolian sand mobilization along the Arkansas River assumed, without absolute age control, that dunes were late Wisconsinan landforms because they were on the southern side of the river (i.e., northwest winds produce the dunes). Although late Wisconsinan eolian sand deposits do occur (e.g., Wilson Ridge) results from this study demonstrate that most dunes in the Great Bend region are very young landforms with significant activation in the last 1000 yrs due to prevailing southwest winds.

6) Surface soils in dunes, consisting of A/AC/C profiles, form in 200 to 300 years.

The record of late Holocene eolian sand stability and mobilization on the Great Bend Sand Prairie is especially significant in the context of greenhouse warming scenarios. Intuitively, it would appear that a dramatic shift toward a more arid climate must occur for dunes in the region to become mobilized in a widespread fashion. Although droughts have occurred periodically (e.g., 1890s, 1930s, 1950s) since climate data have been compiled for the area, they have not been severe enough to promote extensive eolian sand mobilization. On the contrary, these and other results (e.g., Madole, 1994) recently derived from the central Great Plains document intensive dune formation in the past 1000 yrs B.P., even though atmospheric circulation models indicate little variation in average surface temperature and annual precipitation during the last millenium (Kutzbach, 1987). Muhs and Maat (1993) predicted that dunes in the Great Plains could increase one activity class (e.g., inactive to active crests), using Lancaster's (1988) dune mobility index, assuming a 4° C increase in temperature as per many GCMs (Hansen et al., 1988; Wetherald and Manabe, 1988, Wendland, 1992). This study verifies the climatic sensitivity of dunes and sand sheets of the central Great Plains, indicating that the threshold for soil stability can be crossed much more easily than once thought (e.g., Smith, 1940; Simonett, 1960). These results are especially significant for land use planning in the region if the levels of projected greenhouse warming and drying actually occur.

Future Research

Much remains to be done in the Great Bend Sand Prairie before a comprehensive model of late Quaternary landscape evolution can emerge. Specifically, future study in the region should focus on 1) origin and post-depositional alteration of the silty sand, and 2) construction of a detailed chronology of late Holocene eolian sand mobilization.

Although intensive sampling and textural analyses of the silty sand were conducted in this study, the precise mode of sedimentation remains unclear. Sedimentological evidence (e.g., sorting, fining-upward sequences, spatial variability in texture) suggests deposition in a very low energy fluvial environment of some kind during the late Wisconsin. Paleomeanders along the Arkansas River west of Great Bend indicate that discharge was much higher during the late Wisconsin (Johnson, 1988) and may have maintained a network of playas (e.g., Wilson Ridge) and/or shallow lakes on the Great Bend Sand Prairie that were interconnected by distributary streams. Given widespread deposition of Peoria loess in the area surrounding Great Bend at the same time, however, eolian silt sedimentation must have occurred in the silty sand as well. Future research should attempt to quantify the relative input of fluvial and eolian processes in this widespread, late Wisconsinan unit. In addition, an attempt should be made to clarify the history of stability, soil formation, and weathering in the unit. In particular, it would be useful, regarding dune chronologies, to determine whether the well developed soils in the silty sand formed in one extended event, or through the episodic burial and exhumation that has apparently occurred because of surficial, mobilizing sand.

Another avenue of potential research is refining the chronology of late Holocene eolian sand mobilization and stability of dunes in the study area. Based on the results of this study, all radiocarbon ages on buried soils generally estimate when periods of stability occurred, as opposed to dating the interval when deposition of dune sand transpired. In the future, an effort should be made to establish when periods of eolian sand mobilized through optical simulated luminescence (OSL) dating. In Wyoming, Stokes and Gaylord (1993) successfully used OSL to refine the chronology of dune instability in the Ferris dune field. At Great Bend, there is an excellent opportunity to enhance the history of eolian sand mobilization through OSL dating at sites such as the Crocket Cutbank, Rice Roadcut, and Stafford 6, where good radiocarbon control on buried solums has been established in this study.

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APPENDIX A: TEXTURAL AND CHEMICAL DATA OBTAINED FROM INTENSIVELY-SAMPLED SITES ON THE THE GREAT BEND SAND PRAIRIE.

This appendix contains textural and chemical data and soil horizonation from the sites where detailed descriptions and samples at close intervals were obtained in this project. All measurements are given as depths (in meters) below the top of the section.

Belpre Trench

Soil Horizon	Depth (m)	Color (moist)	Sand (%)	Silt (%)	Clay (%)	$CaC0_3$ (%)	OM (%)
A	0.09-0.11	10YR3/2	33.7	35.2	31.1	0.2	0.8
Ag	0.20-0.22	10YR3/2	15.2	45.9	38.9	0.3	0.7
Bt1	0.29-0.31	10YR3/2	28.8	33.6	37.6	0.3	0.7
Bt2	0.50-0.52	10YR2/1	20.9	51.2	27.9	0.5	0.9
	0.69-0.71	10YR2/2	20.4	46.1	33.5	0.2	1.0
	0.89-0.91	10YR2/2	12.3	48.4	39.3	0.1	0.7
	1.08-1.10	10YR2/1	13.8	46.3	39.9	0.2	0.7
	1.29-1.31	10YR2/2	8.8	49.3	41.9	0.2	0.6
	1.50-1.52	10YR2/2	8.3	53.8	39.9	0.1	0.6
	1.60-1.62	10YR3/2	6.3	53.8	39.9	0.1	0.5
	1.81-1.83	10YR3/2	4.0	53.7	42.3	0.6	0.4
	1.90-1.92	10YR4/2	2.2	57.3	40.5	0.3	0.4
Bt3	2.10-2.12	10YR5/3	1.6	59.6	38.8	1.4	0.4
	2.28-2.30	10YR5/3	2.3	66.1	31.6	0.1	0.2
Btk4	2.47-2.49	10YR6/3	3.0	66.6	30.4	5.4	0.4
	2.84-2.86	10YR6/3	6.0	72.6	21.4	17.6	0.4
	2.87-2.89	10YR4/3	20.7	68.9	10.4	7.2	0.2
Btg5	3.08-3.10	10YR4/2	30.9	57.9	11.2	0.4	0.2
	3.19-3.20	10YR4/2	25.4	49.1	25.5	0.4	0.1
	3.41-3.43	10YR4/2	32.8	51.1	16.1	0.3	0.2
2Btgb1	3.44-3.45	10YR4/2	49.9	37.0	13.1	0.3	0.2
	3.60-3.62	10YR4/2	52.9	34.1	13.0	0.2	0.1
2Bwgb2	3.70-3.72	10YR5/3	79.0	13.2	7.8	0.2	0.0
3Bwb1	3.88-3.90	10YR5/4	68.8	8.3	2.9	0.2	0.0
3Bwb2	4.09-4.11	10YR5/4	91.9	5.6	2.5	0.2	0.0

Crocket Cutbank

Soil Horizon	Depth (m)	Color (moist)	Sand (%)	Silt (%)	Clay (%)	$CaCO_3$ (%)	OM (%)
C	0.10-0.12	10YR4/3	93.7	3.8	2.5	0.0	0.4
Ab	0.28-0.30	10YR3/3	93.6	3.8	2.6	0.7	0.4
ACb	0.43-0.45	10YR4/3	95.5	1.9	2.6	0.5	0.1
Cb	0.91-0.93	10YR4/4	96.3	1.1	2.6	0.5	0.1
	1.18-1.20	10YR4/4	96.9	1.1	2.0	0.8	0.1
	2.00-2.02	10YR5/4	96.7	1.2	2.1	0.9	0.0
	2.79-2.81	10YR5/4	97.2	1.0	1.8	0.9	0.0
	2.98-3.00	10YR5/4	97.7	0.8	1.5	0.5	0.1
	3.49-3.51	10YR5/4	96.9	0.9	2.2	0.7	0.0
	4.09-4.11	10YR5/4	96.4	1.1	2.5	0.8	0.0
	4.19-4.21	10YR5/4	95.5	1.0	3.5	0.4	0.0
	4.49-4.51	10YR5/4	96.9	0.4	2.7	0.7	0.0
	4.79-4.81	10YR5/4	95.6	1.7	2.7	0.8	0.0
2Ab	4.91-4.93	10YR4/3	96.0	1.4	2.6	0.5	0.1
	5.11-5.13	10YR4/3	94.2	3.1	2.7	0.7	0.3
	5.31-5.33	10YR4/3	95.3	2.4	2.3	0.3	0.2
2ACb	5.33-5.35	10YR4/3	95.3	2.4	2.3	0.3	0.1
	5.48-5.50	10YR4/3	93.0	4.2	2.8	0.5	0.1
	5.86-5.88	10YR4/3	91.4	5.1	3.5	0.4	0.0
3Ab	5.88-5.90	10YR4/3	90.8	5.0	4.2	0.4	0.1
	6.31-6.33	10YR4/3	95.1	1.9	3.0	0.9	0.2
3ACb	6.37-6.39	10YR4/3	95.2	1.8	3.0	0.9	0.0
	6.62-6.64	10YR4/3	94.1	2.8	3.1	0.7	0.0
3Cb1	6.68-6.70	10YR5/4	95.1	1.4	3.5	0.9	0.0
	7.00-7.02	10YR5/4	95.5	0.6	3.8	0.7	0.0
	7.09-7.11	10YR4/3	94.5	2.2	3.3	0.4	0.0
	7.19-7.21	10YR5/4	95.7	0.7	3.6	1.2	0.0
	7.49-7.51	10YR5/4	95.7	0.7	3.6	0.8	0.0
	7.79-7.81	10YR5/4	95.7	1.0	3.3	0.7	0.0
	7.99-8.01	10YR4/4	94.0	1.9	4.1	0.7	0.0
3Cb2	8.08-8.10	10YR4/3	84.1	8.3	7.6	0.8	0.1
3Cb3	8.23-8.25	10YR4/4	93.7	3.0	3.3	0.7	0.0
	8.74-8.76	10YR4/4	94.0	2.0	4.0	0.8	0.0
4Cb1	8.79-8.81	10YR4/3	80.9	13.5	5.6	1.1	0.1
	8.88-8.90	10YR4/3	90.0	4.9	5.1	2.0	0.1
	9.00-9.02	10YR4/4	83.4	9.6	7.0	1.2	0.0
4Cb2	9.10-9.12	10YR3/2	0.0	71.5	28.5	0.8	0.4
4Cb3	9.18-9.20	10YR5/4	93.5	2.3	4.3	0.4	0.0
	9.28-9.30	10YR4/3	82.6	12.1	5.3	0.8	0.1
4Cb4	9.49-9.51	10YR4/2	31.6	52.1	16.3	0.4	0.4
4Cb5	9.79-9.81	10YR4/4	90.6	5.0	4.4	4.4	0.0

Cullison Quarry

Soil Horizon	Depth (m)	Color (moist)	Sand (%)	Silt (%)	Clay (%)	$CaC0_3$ (%)	OM (%)
Ap	0.09-0.10	10YR3/4	94.3	3.1	2.6	0.5	0.2
C1	0.28-0.30	10YR4/4	95.7	1.3	3.0	0.5	0.4
	0.40-0.42	10YR4/4	94.7	2.4	2.9	0.5	0.4
	0.58-0.60	10YR3/4	95.9	1.4	2.7	0.5	0.2
C2	0.88-0.90	10YR4/4	52.6	46.0	1.4	0.5	0.1
C3	1.08-1.10	10YR4/4	94.4	2.4	3.2	0.4	0.2
	1.38-1.40	10YR4/4	92.2	5.5	2.2	0.5	0.1
	1.68-1.70	10YR3/4	93.1	3.6	3.3	0.5	0.2
C4	1.78-1.80	10YR3/4	91.8	4.1	4.1	4.0	0.2
2Ab	1.99-2.01	10YR3/3	91.9	4.4	3.7	0.9	0.3
2ABb1	2.07-2.09	10YR3/3	91.0	4.6	4.4	0.8	0.3
	2.20-2.22	10YR3/4	88.9	5.8	5.3	1.2	0.3
	2.30-2.32	10YR3/4	90.1	3.0	6.9	0.9	0.4
2E&Btb	2.37-2.39	10YR3/4	89.2	3.7	7.1	0.8	0.2
	2.47-2.49	10YR3/4	90.1	3.4	6.5	0.7	0.2
	2.77-2.79	10YR3/4	92.4	2.5	5.1	0.4	0.2
2C	2.89-2.91	10YR3/4	93.1	2.0	4.9	0.4	0.1
	3.19-3.21	10YR3/4	93.5	1.6	4.9	0.7	0.1
	3.49-3.51	10YR3/4	92.0	3.1	4.9	0.5	0.3
	3.79-3.81	10YR3/4	94.9	1.3	3.8	0.8	0.3
	4.09-4.11	10YR3/4	90.5	3.3	6.2	0.5	0.1
	4.39-4.41	10YR4/3	89.8	3.5	6.7	0.7	0.1
	4.59-4.61	10YR4/3	87.4	5.8	6.8	0.7	0.1
3Btb	4.70-4.72	10YR4/3	59.6	23.6	16.8	0.4	0.3
	5.01-5.03	10YR4/3	62.3	21.8	15.9	0.7	0.2
4Btgssb1	5.09-5.11	10YR4/1	37.6	41.6	20.8	0.5	0.3
	5.39-5.41	10YR4/1	36.9	36.6	26.5	0.7	0.3
	5.62-5.65	10YR4/1	38.2	38.8	23.0	0.5	0.2
	5.67-5.69	10YR4/2	37.2	37.5	25.3	0.5	0.2
4Btkgssb2	5.87-5.89	10YR4/2	28.1	46.0	25.9	5.2	0.2

Edwards 1

Soil Horizon	Depth (m)	Color (moist)	Sand (%)	Silt (%)	Clay (%)	$CaCO_3$ (%)	OM (%)
A	0.10-0.12	10YR3/3	90.7	5.6	3.7	0.0	0.2
Bw	0.21-0.22	10YR3/4	93.2	3.6	3.2	0.8	0.2
	0.39-0.41	10YR3/4	93.7	3.4	2.9	1.6	0.2
Bt1	0.69-0.71	10YR4/4	90.4	2.6	7.0	0.5	0.1
Bt2	0.79-0.81	7.5YR4/4	92.1	2.5	5.4	0.4	0.1
	0.89-0.91	7.5YR4/4	91.1	2.8	6.1	0.2	0.1
	1.09-1.11	7.5YR4/4	84.7	5.7	9.6	0.4	0.1
2Btb1	1.17-1.19	7.5YR4/6	67.1	16.2	16.7	0.2	0.1
	1.29-1.31	7.5YR4/4	68.4	15.8	15.8	0.2	0.1
	1.59-1.61	7.5YR4/4	63.2	26.1	10.7	0.2	0.1
3Btb1	1.68-1.70	10YR5/3	31.3	49.8	18.9	0.2	0.0
	1.80-1.82	10YR5/3	26.5	57.1	16.4	0.2	0.1
3Btb2	2.07-2.09	10YR5/3	17.8	53.9	28.3	0.5	0.1
	2.30-2.32	10YR5/3	17.6	56.7	25.7	0.4	0.1
	2.58-2.60	10YR5/3	18.2	59.1	22.6	0.4	0.1
	2.78-2.80	10YR5/3	19.4	59.5	21.1	0.2	0.1
3Btgb3	2.90-2.92	10YR5/3	16.5	55.5	28.0	0.4	0.1
	3.20-3.22	10YR5/3	25.0	52.9	22.1	0.3	0.0

Edwards 2

Soil Horizon	Depth (m)	Color (moist)	Sand (%)	Silt (%)	Clay (%)	$CaCO_3$ (%)	OM (%)
Ap	0.09-0.11	10YR3/2	78.2	16.6	5.2	0.4	1.0
A	0.28-0.30	10YR3/3	79.1	15.0	5.9	0.4	0.5
Bt1	0.41-0.43	10YR3/4	87.8	7.1	5.1	0.4	0.2
	0.61-0.63	10YR3/4	87.1	7.1	5.8	0.3	0.2
Bt2	0.81-0.83	10YR4/4	71.5	17.4	11.1	0.3	0.1
	0.91-0.93	10YR4/4	84.9	8.8	6.3	0.3	0.1
Bt3	0.96-0.98	10YR4/4	79.0	14.8	6.2	0.4	0.1
	1.20-1.22	10YR4/4	84.0	10.9	5.1	0.4	0.1
2Btb1	1.27-1.29	7.5YR4/4	76.5	16.0	7.5	5.2	0.1
2Btb2	1.37-1.39	7.5YR4/4	57.0	32.5	10.5	4.0	0.1
	1.61-1.63	7.5YR4/4	55.0	31.5	13.5	2.8	0.2
2Btb3	1.69-1.71	10YR4/4	34.0	47.5	18.5	2.4	0.2
3Btgb1	1.79-1.81	10YR5/3	41.2	41.2	17.6	2.0	0.1
3Btgb2	1.89-1.91	10YR5/3	19.9	54.3	25.8	2.0	0.1
	2.09-2.11	10YR4/2	32.8	52.6	14.6	1.6	0.1
3Btb3	2.29-2.31	10YR4/3	51.3	40.0	8.7	2.0	0.0
3Btb4	2.59-2.61	10YR4/2	51.7	39.9	8.4	0.4	0.0
	2.79-2.81	10YR4/3	61.3	31.2	7.5	0.4	0.0
3Btb5	2.99-3.01	10YR4/4	71.4	23.8	4.8	0.6	0.0
	3.09-3.11	10YR4/4	78.9	16.7	4.4	0.5	0.0

Edwards 3

Soil Horizon	Depth (m)	Color (moist)	Sand (%)	Silt (%)	Clay (%)	$CaC0_3$ (%)	OM (%)
Ap	0.09-0.11	10YR3/3	73.4	16.2	10.4	0.2	0.7
Bw	0.28-0.30	10YR3/3	82.6	10.8	6.6	0.3	0.3
2Btb1	0.39.0.41	10YR3/2	19.3	39.2	41.5	0.5	0.5
	0.49-0.51	10YR4/2	14.7	44.0	41.3	1.0	0.5
	0.69-0.71	10YR4/2	7.1	50.7	42.2	0.4	0.3
2Btb2	0.89-0.91	10YR5/2	2.3	61.7	36.0	3.5	0.2
	1.10-1.12	10YR5/2	2.1	60.3	37.6	1.4	0.2
	1.18-1.20	10YR5/3	4.2	59.2	36.6	2.0	0.2
	1.29-1.31	10YR5/3	3.3	62.8	33.9	1.3	0.2
	1.49-1.51	10YR5/3	9.1	62.2	28.7	0.6	0.1
	1.69-1.71	10YR5/3	11.7	65.0	23.3	0.4	0.1
3Btb1	1.78-1.80	10YR4/2	25.4	44.4	30.3	0.5	0.2
	1.99-2.01	10YR4/2	32.5	40.5	27.0	0.6	0.1
3Btb2	2.10-2.12	10YR4/3	39.5	35.9	24.6	0.5	0.1
	2.28-2.30	10YR5/4	44.0	33.0	23.0	0.5	0.1
	2.39-2.41	10YR5/4	49.2	29.0	21.8	0.5	0.1
	2.59-2.60	10YR5/4	49.1	25.7	25.2	0.3	0.1
4Btb1	2.78-2.80	10YR5/4	25.0	43.7	31.3	0.4	0.1
	2.99-3.01	10YR5/4	23.3	44.6	32.1	1.0	0.1
4Btb2	3.19-3.21	7.5YR5/6	35.5	38.8	25.7	0.8	0.0

Edwards 4

Soil Horizon	Depth (m)	Color (moist)	Sand (%)	Silt (%)	Clay (%)	$CaC0_3$ (%)	OM (%)
Ap	0.09-0.11	10YR3/4	87.6	8.4	4.0	0.2	0.6
A	0.28-0.30	10YR3/3	84.2	9.5	6.3	0.2	0.5
Bw	0.49-0.51	10YR3/3	76.7	10.6	12.7	0.2	0.4
C	0.69-0.71	10YR3/4	86.5	4.9	8.6	0.2	0.2
2Ab	0.79-0.81	10YR3/4	74.8	7.2	18.0	0.2	0.3
2C1	0.88-0.90	7.5YR3/4	84.0	4.5	11.5	0.2	0.2
2C2	0.99-1.01	7.5YR3/3	46.1	29.5	24.4	0.2	0.4
2C3	1.09-1.11	7.5YR3/4	83.9	5.5	5.5	0.2	0.1
	1.18-1.20	7.5YR3/4	85.8	2.8	11.4	0.1	0.1
	1.52-1.54	7.5YR3/4	87.8	2.0	10.2	0.0	0.1
3Btb1	1.58-1.60	7.5YR4/4	49.6	38.5	11.9	0.0	0.1
	1.69-1.71	7.5YR4/4	44.0	39.7	16.3	0.2	0.1
	1.94-1.96	7.5YR4/4	47.8	30.5	21.7	0.2	0.1
3Btb2	2.08-2.10	7.5YR4/6	51.8	29.9	18.3	0.1	0.0
	2.28-2.30	7.5YR4/4	62.2	21.5	16.3	0.1	0.0
	2.45-2.47	7.5YR4/4	62.5	20.4	17.1	0.1	0.0
	2.83-2.85	7.5YR4/4	69.6	15.8	14.6	0.2	0.0
	2.86-2.88	7.5YR4/4	59.1	23.6	17.3	0.3	0.0
	3.08-3.10	7.5YR4/6	57.7	25.7	16.6	0.3	0.0
3Btkb3	3.29-3.31	7.5YR5/4	58.6	24.3	17.1	14.6	0.0

Phillips Trench

Soil Horizon	Depth (m)	Color (moist)	Sand (%)	Silt (%)	Clay (%)	$CaC0_3$ (%)	OM (%)
Ap	0.09-0.11	10YR3/2	72.0	20.3	7.7	0.2	0.3
A	0.27-0.29	10YR3/2	71.7	21.2	7.1	0.3	0.5
2Btb1	0.37-0.39	10YR2/1	21.2	58.9	19.9	0.3	0.4
	0.47-0.49	10YR3/1	14.2	56.4	29.4	0.5	0.4
	0.69-0.71	10YR3/2	10.3	63.7	26.0	3.4	0.4
2Btb2	0.89-0.91	10YR3/2	3.4	62.4	34.2	3.2	0.4
	1.09-1.11	10YR4/2	3.5	60.5	36.0	2.6	0.2
	1.29-1.31	10YR6/2	2.7	64.1	33.2	2.8	0.1
2Btb3	1.48-1.50	10YR6/3	4.7	72.1	23.2	2.8	0.1
	1.68-1.70	10YR6/3	5.2	69.6	25.2	2.8	0.1
	1.89-1.91	10YR6/3	5.6	65.2	29.2	2.0	0.2
2Btb4	2.11-2.13	10YR6/3	11.1	65.8	23.1	1.6	0.3
	2.28-2.30	10YR6/3	18.3	58.5	23.2	6.0	0.3
3Btb1	2.48-2.50	10YR4/3	29.0	49.9	21.1	1.0	0.2
	2.58-2.60	10YR4/3	45.5	38.8	15.7	1.0	0.1
3Btb2	2.69-2.71	10YR5/3	62.5	25.0	12.5	0.6	0.0

Reno 3

Soil Horizon	Depth (m)	Color (moist)	Sand (%)	Silt (%)	Clay (%)	$CaC0_3$ (%)	OM (%)
A	0.09-0.11	10YR3/2	90.4	6.3	3.3	0.2	0.4
AB	0.29-0.31	10YR3/2	96.0	1.6	2.4	0.2	0.2
E&Btb	0.37-0.39	10YR4/4	96.9	0.4	2.7	0.2	0.1
	0.59-0.61	10YR4/4	97.1	0.9	2.0	0.2	0.1
	0.79-0.80	10YR4/4	96.2	0.8	3.0	0.2	0.1
	0.99-1.01	10YR4/4	97.4	0.2	2.4	0.2	0.1
	1.19-1.21	10YR4/4	97.2	0.3	2.5	0.2	0.2
	1.31-1.41	10YR4/4	96.3	0.2	3.5	0.2	0.2
2Ab	1.50-1.52	10YR4/3	92.7	3.1	4.2	0.1	0.2
2E&Btb	1.57-1.59	10YR4/4	95.2	2.4	2.4	0.2	0.1
	1.67-1.69	10YR4/4	95.8	2.1	2.1	0.2	0.2
	1.87-1.89	10YR4/4	96.2	1.5	2.3	0.2	0.2
	2.07-2.09	10YR4/4	96.3	1.6	2.1	0.2	0.2
	2.27-2.29	10YR4/4	94.9	2.6	2.5	0.2	0.1
	2.51-2.53	10YR4/4	93.0	3.8	3.2	0.3	0.2
3Ab	2.57-2.59	10YR3/3	76.6	14.0	9.4	0.4	0.4
4Btb1	2.70-2.72	10YR4/3	53.5	30.8	15.7	0.5	0.2
4Btgb2	2.88-2.90	10YR5/3	52.3	21.6	26.1	0.5	0.2
	3.09-3.11	10YR5/3	51.8	22.1	26.1	0.4	0.2

Reno 4

Soil Horizon	Depth (m)	Color (moist)	Sand (%)	Silt (%)	Clay (%)	$CaCO_3$ (%)	OM (%)
Ap	0.09-0.11	10YR3/2	86.8	8.8	4.4	0.2	0.8
A	0.29-0.31	10YR3/2	90.6	5.1	4.3	0.2	0.3
E&Bt	0.40-0.42	10YR3/3	91.2	2.5	6.3	0.2	0.1
	0.60-0.62	10YR3/3	91.7	2.1	6.2	0.4	0.0
	0.80-0.82	10YR3/3	92.7	1.7	5.6	0.3	0.0
	0.90-0.92	10YR4/4	96.8	0.6	2.6	0.2	0.1
	1.08-1.10	10YR4/4	94.7	1.5	3.8	0.3	0.1
2Ab	1.11-1.13	10YR3/2	83.0	8.6	8.4	0.3	0.2
2Btb1	1.19-1.21	10YR3/3	77.1	14.9	8.0	0.5	0.3
2Btb2	1.26-1.28	10YR4/3	90.0	4.1	5.9	0.3	0.1
	1.48-1.50	10YR4/3	88.3	4.8	6.9	0.2	0.3
	1.58-1.60	10YR4/3	91.9	2.9	5.2	0.2	0.2
2E&Btb	1.78-1.80	10YR4/4	93.7	2.4	3.9	0.2	0.2
2C	1.88-1.90	10YR4/4	90.6	3.4	6.0	0.4	0.3
	2.08-2.10	10YR4/4	92.3	2.4	5.3	0.4	0.2
	2.18-2.20	10YR4/4	90.7	4.6	4.7	0.3	0.2
3Btb1	2.27-2.29	10YR4/2	35.8	38.0	26.2	0.4	0.4
3Btb2	2.47-2.49	10YR4/2	16.3	55.0	28.7	0.4	0.3
	2.67-2.69	10YR4/2	13.4	58.4	28.2	0.5	0.4
	2.91-2.93	10YR4/2	11.9	66.5	21.6	0.4	0.4
	2.97-2.99	10YR4/3	11.7	61.9	26.4	0.3	0.4
	3.17-3.19	10YR4/3	14.3	61.5	24.2	0.2	0.3
	3.41-3.43	10YR4/3	28.4	59.5	12.1	0.3	0.4
	3.49-3.51	10YR4/3	35.5	52.2	12.3	0.8	0.3
3Btb3	3.67-3.69	10YR4/3	51.6	31.0	17.4	0.3	0.3
	3.77-3.79	10YR4/3	57.7	32.4	9.9	0.2	0.3
3Btb4	3.97-3.99	10YR4/3	73.3	16.1	10.6	0.4	0.1

Stafford 1

Soil Horizon	Depth (m)	Color (moist)	Sand (%)	Silt (%)	Clay (%)	OM (%)	$CaC0_3$ (%)
Ap	0.09-0.11	10YR2/2	86.2	10.0	3.8	0.9	0.1
A	0.18-0.20	10YR3/2	88.4	8.3	3.3	0.4	0.2
	0.28-0.30	10YR3/2	90.4	3.3	3.3	0.2	0.2
Bt1	0.37-0.39	10YR3/3	93.9	2.3	3.8	0.2	0.2
	0.50-0.52	10YR3/3	70.7	18.0	11.3	0.2	0.3
Bt2	0.59-0.61	10YR4/4	77.2	17.0	5.8	0.1	0.4
Bt3	0.69-0.71	10YR4/4	54.1	35.6	10.3	0.2	1.6
C	0.79-0.81	10YR4/6	88.4	6.5	5.1	0.1	0.6
2Btgb1	0.98-1.00	10YR4/3	37.3	46.4	16.3	0.3	0.4
	1.11-1.13	10YR4/3	53.4	30.0	16.6	0.1	0.6
2Btb2	1.17-1.19	7.5YR4/6	58.3	25.6	16.1	0.1	0.8
	1.37-1.39	7.5YR4/6	68.3	19.3	12.4	0.1	0.6
	1.62-1.64	7.5YR4/6	63.4	22.2	14.4	0.0	0.6
	1.67-1.69	7.5YR4/6	63.0	21.8	15.2	0.0	0.6
	1.81-1.83	7.5YR4/6	62.6	27.9	9.5	0.0	0.6
2Btb3	1.99-2.01	10YR5/4	57.0	34.3	8.7	0.0	0.6
2Btkb4	2.18-2.20	10YR5/4	58.0	27.4	14.6	0.0	16.0
2Btb5	2.31-2.33	10YR5/4	50.7	38.0	11.3	0.0	8.8
	2.47-2.49	10YR5/4	45.4	41.9	12.7	0.0	1.6

Stafford 2

Soil Horizon	Depth (m)	Color (moist)	Sand (%)	Silt (%)	Clay (%)	$CaCO_3$ (%)	OM (%)
A	0.09-0.11	10YR2/2	80.5	14.5	5.0	0.2	0.6
	0.19-0.21	10YR2/2	81.3	13.4	5.3	0.2	0.6
AC	0.39-0.41	10YR3/2	87.9	7.7	4.4	0.2	0.4
	0.59-0.61	10YR3/2	90.4	4.8	4.8	0.4	0.6
C	0.68-0.70	10YR3/3	91.9	2.9	5.2	0.4	0.3
	0.89-0.91	10YR3/3	91.7	2.1	6.2	0.4	0.2
	1.11-1.13	10YR3/4	90.0	3.0	7.0	0.4	0.2
2Ab	1.17-1.19	10YR3/3	75.7	10.0	14.3	0.2	0.4
	1.39-1.41	10YR3/3	79.4	8.2	12.4	0.3	0.3
2Btb1	1.59-1.61	10YR3/4	72.2	14.1	13.7	0.3	0.2
3Btb1	1.68-1.70	7.5YR4/4	46.5	30.3	23.2	0.4	0.3
3Btb2	1.88-1.90	7.5YR4/4	57.8	28.3	13.9	0.5	0.1
	2.01-2.03	7.5YR4/4	62.7	22.5	14.8	0.4	0.1
	2.07-2.09	7.5YR4/4	66.9	17.7	15.4	0.3	0.1
	2.27-2.29	7.5YR4/4	66.1	19.3	14.6	0.4	0.1
	2.38-2.40	7.5YR4/4	67.2	19.1	13.7	0.2	0.1
3Btb3	2.59-2.61	7.5YR4/6	77.0	15.0	8.0	0.4	0.1
	2.79-2.81	7.5YR4/6	83.5	7.4	9.1	0.4	0.0
	2.99-3.01	7.5YR4/6	77.6	13.4	9.0	0.3	0.0
4Btb1	3.08-3.10	7.5YR4/6	44.5	42.0	13.5	0.4	0.1
4Btb2	3.28-3.30	7.5YR4/6	62.9	27.8	9.3	0.3	0.1
	3.38-3.40	7.5YR4/6	67.7	19.4	12.9	0.2	0.0
	3.58-3.60	7.5YR4/6	63.5	20.8	15.7	0.5	0.0

Stafford 3

Soil Horizon	Depth (m)	Color (moist)	Sand (%)	Silt (%)	Clay (%)	$CaC0_3$ (%)	OM (%)
Ap	0.09-0.11	10YR3/3	85.9	9.6	4.5	0.4	0.6
	0.30-0.32	10YR3/3	88.8	6.7	4.5	0.5	0.5
A	0.38-0.40	10YR3/6	86.8	5.8	7.4	0.3	0.2
Bw1	0.59-0.61	10YR4/6	86.2	8.1	5.7	0.4	0.2
	0.69-0.71	10YR3/6	86.2	7.0	6.8	0.3	0.1
	0.89-0.91	10YR3/6	91.6	4.4	4.0	0.4	0.1
	1.09-1.11	10YR3/6	91.6	5.1	3.3	0.4	0.1
	1.19-1.21	10YR3/6	94.1	2.5	3.4	0.4	0.0
	1.41-1.43	10YR3/6	94.1	1.5	4.4	0.3	0.0
	1.59-1.61	10YR3/6	85.9	5.7	8.4	0.4	0.0
C	1.70-1.72	10YR4/6	93.3	2.8	3.9	0.4	0.0
	1.91-1.93	10YR4/6	94.8	2.0	3.2	0.3	0.0
2Ab	2.03-2.05	10YR4/4	83.7	11.1	5.2	0.4	0.1
3Btb1	2.07-2.09	10YR5/4	45.6	43.8	10.6	0.5	0.0
	2.17-2.19	10YR5/4	42.0	44.1	13.9	0.5	0.0
	2.29-2.31	10YR5/4	36.1	48.9	15.0	0.5	0.0
	2.39-2.41	10YR6/3	42.7	43.5	13.8	0.5	0.0
	2.69-2.71	10YR5/6	44.0	41.3	14.7	0.5	0.0
3Btb2	2.89-2.91	10YR5/4	51.8	33.5	14.7	0.3	0.0
	3.00-3.02	10YR6/3	51.0	33.2	15.8	0.5	0.0
	3.10-3.12	10YR5/6	57.5	30.5	12.0	0.4	0.0
	3.19-3.21	10YR6/4	65.2	25.1	9.7	0.4	0.0
3Btb3	3.29-3.31	10YR6/4	73.2	20.7	6.1	0.4	0.0
	3.39-3.41	10YR6/3	76.9	15.1	8.0	0.5	0.0
	3.59-3.61	10YR6/3	81.1	12.1	6.8	0.4	0.0
	3.81-3.83	10YR6/3	85.1	8.8	6.1	0.3	0.0
	3.99-4.01	10YR6/4	84.3	8.1	7.6	0.4	0.0
3Btgb4	4.21-4.23	10YR6/3	73.6	18.6	7.6	0.4	0.0
	4.33-4.35	10YR6/3	56.1	31.5	12.4	0.4	0.0
3Btgb5	4.37-4.39	10YR6/3	56.9	34.1	9.0	0.4	0.0
3Btgb6	4.48-4.50	10YR7/2	21.0	51.4	27.6	3.2	0.0

Stafford 4

Soil Horizon	Depth (m)	Color (moist)	Sand (%)	Silt (%)	Clay (%)	$CaCO_3$ (%)	OM (%)
Ap	0.09-0.11	10YR3/3	45.9	45.7	8.4	0.2	1.0
A	0.20-0.22	10YR3/2	36.8	53.0	10.2	0.5	1.1
	0.27-0.29	10YR3/2	32.4	52.4	15.2	0.2	1.1
	0.39-0.41	10YR3/2	35.0	50.7	14.3	0.0	0.9
AB	0.49-0.51	10YR3/2	35.8	51.3	12.9	0.2	0.8
Bt1	0.57-0.59	10YR3/2	25.1	56.5	19.4	0.2	0.7
	0.70-0.72	10YR3/2	23.2	57.4	19.4	0.2	0.7
	0.77-0.79	10YR3/2	24.0	59.6	16.4	0.2	0.6
	0.87-0.89	10YR3/2	25.3	59.6	15.1	0.2	0.6
	1.11-1.13	10YR3/3	35.7	49.2	15.1	0.3	0.4
	1.19-1.21	10YR3/3	42.4	44.3	13.3	0.3	0.3
Bt2	1.29-1.31	10YR3/4	58.7	30.5	10.8	0.2	0.3
	1.49-1.51	10YR3/4	67.8	22.2	10.0	0.3	0.2
	1.62-1.64	10YR3/4	64.6	27.2	8.2	0.6	0.2
2Ab	1.67-1.69	7.5YR3/3	48.6	40.4	11.0	0.6	0.3
	1.90-1.92	7.5YR3/4	53.4	40.8	5.8	0.2	0.3
2ABb	1.97-1.99	7.5YR3/4	53.3	39.2	7.5	0.1	0.2
2Btb1	2.07-2.09	7.5YR4/4	56.3	34.4	9.3	0.2	0.1
	2.17-2.19	7.5YR4/4	58.9	31.9	9.2	0.5	0.1
	2.41-2.43	7.5YR4/4	66.8	26.4	6.8	0.6	0.1
2Btb2	2.47-2.49	7.5YR4/6	70.3	23.9	5.8	0.6	0.0
	2.57-2.59	7.5YR4/6	75.5	17.5	7.0	0.5	0.0
	2.83-2.85	7.5YR6/6	83.1	11.9	5.0	0.2	0.0

Stafford 5

Soil Horizon	Depth (m)	Color (moist)	Sand (%)	Silt (%)	Clay (%)	$CaC0_3$ (%)	OM (%)
Ap	0.09-0.11	10YR3/2	91.2	6.8	2.0	0.2	0.6
AC	0.27-0.29	10YR3/3	96.2	1.6	2.2	0.2	0.1
C	0.39-0.41	10YR4/4	96.5	0.9	2.6	0.4	0.1
	0.59-0.61	10YR4/4	95.8	1.2	3.0	0.2	0.1
	0.79-0.81	10YR4/4	96.0	0.6	3.4	0.2	0.1
	0.99-1.01	10YR4/4	94.6	1.3	4.1	0.3	0.1
	1.19-1.21	10YR4/4	95.9	1.3	2.8	0.2	0.0
	1.37-1.39	10YR4/4	87.5	7.4	5.1	0.6	0.0
2Ab	1.41-1.43	10YR4/2	86.7	8.9	4.4	0.4	0.1
	1.61-1.63	10YR4/2	86.3	8.9	4.8	0.4	0.1
2Bwb	1.66-1.68	10YR4/4	80.5	9.4	10.1	0.8	0.1
	1.77-1.78	10YR4/4	85.9	4.5	9.6	1.0	0.1
	2.01-2.03	10YR4/4	84.6	6.0	9.4	1.0	0.1
3Btgb1	2.07-2.09	10YR5/2	62.2	22.4	15.4	0.8	0.0
	2.26-2.28	10YR6/2	64.0	20.0	16.0	0.8	0.0
	2.28-2.30	10YR6/2	66.2	17.9	17.9	0.8	0.0
	2.49-2.51	10YR6/2	64.1	16.1	19.8	0.8	0.0
	2.58-2.60	10YR6/3	59.0	26.5	14.4	0.8	0.0
	2.78-2.80	10YR6/3	50.6	36.5	12.9	0.8	0.0
	2.97-2.99	10YR6/3	46.7	31.5	21.8	0.8	0.0
	3.19-3.21	10YR6/3	58.4	28.1	13.5	1.0	0.0
	3.37-3.39	10YR6/3	67.1	19.3	13.6	0.8	0.0

Stafford 6

Soil Horizon	Depth (m)	Color (moist)	Sand (%)	Silt (%)	Clay (%)	$CaC0_3$ (%)	OM (%)
A	0.09-0.11	10YR2/2	88.4	9.5	3.1	0.1	0.7
	0.19-0.21	10YR2/2	86.5	10.0	3.5	0.2	0.7
AC	0.38-0.40	10YR3/2	92.0	4.7	3.3	0.2	0.4
2Ab	0.59-0.61	10YR3/3	88.2	6.5	5.3	0.2	0.4
2Bw	0.69-0.71	10YR3/3	85.8	7.6	6.6	0.2	0.5
2C	0.77-0.79	10YR3/4	95.0	1.7	3.3	0.2	0.1
	0.87-0.89	10YR3/4	95.0	1.7	3.3	0.3	0.1
	1.11-1.13	10YR3/6	94.7	2.5	2.8	0.3	0.1
3Ab	1.17-1.19	10YR2/2	77.5	16.0	6.5	0.6	0.5
	1.31-1.33	10YR2/2	78.5	14.0	7.5	0.6	0.5
3ABb	1.40-1.42	10YR4/3	73.0	16.0	11.0	0.3	0.4
4Btb1	1.60-1.62	10YR3/4	65.0	21.2	13.8	0.7	0.3
4Btb2	1.67-1.69	10YR3/3	51.4	38.3	10.3	0.6	0.3
	1.83-1.85	10YR3/3	51.1	39.8	9.1	0.4	0.3
	1.88-1.90	10YR3/3	46.2	40.8	13.0	0.3	0.3
	2.08-2.10	10YR4/2	56.4	28.3	15.3	0.6	0.2
4Btb3	2.19-2.21	10YR4/4	72.6	20.9	6.5	0.2	0.1

Stafford 10

Soil Horizon	Depth (m)	Color (moist)	Sand (%)	Silt (%)	Clay (%)	$CaC0_3$ (%)	OM (%)
A	0.09-0.11	10YR3/3	90.0	6.6	3.4	0.2	0.5
Bw	0.29-0.31	10YR3/4	91.4	3.0	5.6	0.1	0.4
	0.41-0.43	10YR3/4	91.0	1.6	7.4	0.2	0.3
	0.58-0.60	10YR3/4	90.6	2.2	7.2	0.3	0.2
	0.69-0.71	10YR4/4	91.6	2.3	6.1	0.5	0.1
	0.89-0.91	10YR4/4	92.5	1.8	5.7	0.2	0.1
	1.09-1.11	10YR3/6	91.3	2.4	6.3	0.1	0.1
2C	1.24-1.26	10YR3/3	40.6	28.3	31.1	0.0	0.4
3Btb1	1.32-1.34	10YR3/6	90.8	2.9	6.3	0.0	0.1
3Btb2	1.41-143	10YR3/2	71.2	12.6	16.2	0.0	0.1
	1.47-1.49	10YR3/2	61.2	17.2	21.6	0.2	0.2
3Btgb3	1.70-1.72	10YR4/2	51.7	29.5	18.8	0.0	0.1
	1.80-1.82	10YR5/3	74.3	14.9	10.8	0.0	0.1
	1.91-1.93	10YR5/3	83.6	7.7	8.7	0.1	0.4
	1.97-1.99	10YR4/4	82.1	6.6	11.3	0.0	0.1
4Btgb1	2.17-2.19	7.5YR4/6	73.5	16.1	10.4	0.2	0.1
4Btkgb2	2.39-2.41	7.5YR5/4	43.0	36.4	20.6	12.2	0.1
	2.59-2.61	7.5YR5/4	42.7	35.5	21.8	14.9	0.1
4Btkgb3	2.79-2.81	7.5YR5/4	63.1	15.6	15.3	13.7	0.1
	2.98-3.00	7.5YR5/4	51.0	35.4	13.6	15.8	0.1

Stafford 11

Soil Horizon	Depth (m)	Color (moist)	Sand (%)	Silt (%)	Clay (%)	$CaCO_3$ (%)	OM (%)
Ap	0.09-0.11	10YR4/3	92.0	5.0	3.0	0.2	0.4
C	0.31-0.33	10YR4/3	93.7	3.5	2.8	0.2	0.2
	0.41-0.43	10YR4/3	93.7	3.5	2.8	0.2	0.1
	0.60-0.62	10YR4/4	93.8	3.9	2.3	0.2	0.1
	0.67-0.69	10YR4/4	91.7	4.8	3.5	0.2	0.2
2Ab	0.79-0.81	10YR4/4	92.8	3.9	3.3	0.2	0.2
2Bwb	0.87-0.90	10YR4/4	93.1	2.6	4.3	0.2	0.1
	0.99-1.01	10YR4/4	93.2	2.1	4.7	0.2	0.1
3Btb1	1.07-1.09	10YR3/3	82.3	7.1	10.6	0.2	0.2
3Btb2	1.22-1.24	10YR3/6	53.6	31.9	14.5	0.2	0.2
	1.27-1.29	10YR4/4	50.1	40.6	9.4	0.3	0.2
	1.52-1.54	10YR4/4	41.9	46.5	11.6	0.2	0.2
3Btb3	1.57-1.59	10YR4/4	31.3	56.7	12.0	0.3	0.1
	1.67-1.69	10YR4/4	33.7	53.5	12.8	0.8	0.2
3Btb4	1.80-1.82	10YR4/4	40.7	46.1	13.2	0.3	0.2
	2.00-2.02	10YR4/4	47.9	39.1	13.0	0.3	0.1
3Btb5	2.10-2.12	10YR4/4	54.1	33.4	12.5	0.2	0.1
	2.28-2.30	10YR4/4	69.6	23.5	6.9	0.5	0.1
	2.38-2.40	10YR4/4	72.2	21.1	6.7	0.5	0.0
	2.68-2.70	10YR4/4	78.6	15.3	6.1	0.3	0.0

APPENDIX B: STATISTICAL RESULTS DERIVED FROM TEXTURAL ANALYSES AT BACKHOE TRENCHES EXCAVATED ON THE GREAT BEND SAND PRAIRIE

This appendix contains the statistical results derived from textural analyses of sediments in backhoe trenches on the Great Bend Sand Prairie. All measurements are given as depths (in meters) below the banktop at the sampled section

Belpre Trench

Soil Horizon	Depth (m)	Mean Phi	Sorting	Skewness	Kurtosis
A	0.09-0.11	7.40	3.06	0.04	0.63
Ag	0.20-0.22	7.40	3.10	0.10	0.70
Bt1	0.29-0.31	6.88	3.44	0.10	0.55
Bt2	0.50-0.52	7.06	3.38	0.06	0.62
	0.69-0.71	7.09	3.22	0.22	0.60
	0.89-0.91	7.54	2.96	0.01	0.62
	1.08-1.10	7.46	3.03	0.02	0.63
	1.29-1.31	7.77	2.73	0.02	0.57
	1.50-1.52	7.83	2.71	0.00	0.57
	1.60-1.62	7.86	2.57	0.09	0.55
	1.81-1.83	8.00	2.50	0.11	0.51
	1.90-1.92	8.05	2.43	0.15	0.49
Bt3	2.10-2.12	8.05	2.42	0.21	0.49
	2.28-2.30	7.76	2.46	0.42	0.53
Btk4	2.47-2.49	7.75	2.47	0.37	0.56
	2.84-2.86	7.08	2.41	0.63	0.90
	2.87-2.89	5.82	2.29	0.29	1.81
Btg5	3.08-3.10	5.55	2.71	0.18	1.48
	3.19-3.20	6.41	3.38	0.24	0.85
	3.41-3.43	5.69	3.17	0.18	1.08
2Btgb1	3.44-3.45	5.15	3.25	0.24	1.06
	3.60-3.62	4.73	3.31	0.28	1.04
2Bwgb2	3.70-3.72	3.53	2.60	0.51	1.67
3Bwb1	3.88-3.90	2.54	1.73	0.30	1.34
3Bwb2	4.09-4.11	2.11	1.49	0.28	1.20

Crocket Cutbank

Soil Horizon	Depth (m)	Mean Phi	Sorting	Skewness	Kurtosis
C	0.10-0.12	3.00	0.88	0.15	1.40
Ab	0.28-0.30	2.95	0.40	0.40	1.50
Cb	0.43-0.45	2.59	0.86	0.14	1.05
	0.91-0.93	2.37	0.94	0.20	0.94
	1.18-1.20	2.40	0.91	0.20	0.92
	2.00-2.02	2.49	0.81	0.20	0.99
	2.79-2.81	2.10	0.94	0.25	1.08
	2.98-3.00	2.27	0.69	0.29	1.03
	3.49-3.51	2.35	0.54	0.07	1.05
	4.09-4.11	2.40	0.87	0.20	1.02
	4.19-4.21	2.30	0.87	0.40	1.19
	4.49-4.51	2.14	0.90	0.32	1.10
2Ab	4.79-4.81	2.49	0.92	0.19	0.96
	4.91-4.93	2.50	0.92	0.17	0.96
	5.11-5.13	2.64	1.05	0.24	1.11
2ACb	5.31-5.33	2.51	0.92	0.17	1.00
	5.33-5.35	2.51	0.92	0.17	1.00
	5.48-5.50	2.66	1.18	0.25	1.06
3Ab	5.86-5.88	2.89	1.15	0.22	1.33
	5.88-5.90	2.64	1.08	0.30	1.72
3ACb	6.31-6.33	2.54	0.88	0.21	1.03
	6.37-6.39	2.50	0.87	0.26	1.04
	6.62-6.64	2.53	1.01	0.34	1.16
3Cb1	6.68-6.70	2.43	0.91	0.25	1.06
	7.00-7.02	2.30	0.86	0.38	1.20
	7.09-7.11	2.26	1.08	0.64	1.81
	7.19-7.21	2.36	0.85	0.30	1.14
	7.49-7.51	2.21	0.79	0.44	1.36
	7.79-7.81	2.21	0.81	0.44	1.34
	7.99-8.01	2.69	1.25	0.37	1.35
3Cb2	8.08-8.10	4.47	1.72	0.37	3.57
3Cb3	8.23-8.25	2.88	1.09	0.25	1.35
	8.74-8.76	3.03	1.12	0.31	1.97
4Cb1	8.79-8.81	3.55	2.13	0.55	1.60
	8.88-8.90	4.27	1.30	0.26	3.87
	9.00-9.02	4.06	2.12	0.34	2.42
4Cb2	9.10-9.12	7.82	2.29	0.42	0.62
4Cb3	9.18-9.20	2.83	1.42	0.47	1.45
	9.28-9.30	4.42	1.39	0.35	3.41
4Cb4	9.49-9.51	6.31	2.45	0.57	1.07
4Cb5	9.79-9.81	3.18	1.49	0.38	2.08

Cullison Quarry

Soil Horizon	Depth (m)	Mean Phi	Sorting	Skewness	Kurtosis
Ap	0.09-0.10	2.66	0.97	0.21	1.30
C1	0.28-0.30	2.78	0.73	0.04	1.29
	0.40-0.42	2.64	0.98	0.25	1.07
	0.58-0.60	2.37	0.91	0.19	1.03
C2	0.88-0.90	3.49	1.40	-0.21	0.61
C3	1.08-1.10	2.75	0.97	0.21	1.27
	1.38-1.40	2.95	1.53	0.47	2.19
	1.68-1.70	2.87	1.21	0.29	1.59
C4	1.78-1.80	3.11	1.38	0.35	1.89
2Ab	1.99-2.01	3.04	1.41	0.38	1.89
2ABb1	2.07-2.09	3.13	1.54	0.45	2.13
	2.20-2.22	3.43	1.83	0.48	2.44
	2.30-2.32	3.66	1.99	0.47	3.05
2E&Btb	2.37-2.39	3.69	2.01	0.47	3.07
	2.47-2.49	3.85	1.95	0.41	3.09
	2.77-2.79	3.15	1.65	0.50	2.50
2C	2.89-2.91	3.12	1.62	0.51	2.46
	3.19-3.21	3.19	1.55	0.46	2.69
	3.49-3.51	3.24	1.58	0.45	2.56
	3.79-3.81	1.96	1.13	0.43	1.74
	4.09-4.11	3.71	1.85	0.39	2.82
	4.39-4.41	3.50	2.08	0.41	2.30
	4.59-4.61	3.77	1.96	0.34	2.45
3Btb	4.70-4.72	5.26	3.22	0.53	1.03
	5.01-5.03	5.15	3.22	0.55	1.00
4Btgssb1	5.09-5.11	6.26	2.94	0.36	0.76
	5.39-5.41	6.40	3.31	0.30	0.67
	5.62-5.65	6.16	3.23	0.30	0.74
	5.67-5.69	6.25	3.18	0.29	0.69
4Btkgssb2	5.87-5.89	6.72	3.00	0.21	0.71

Edwards 1

Soil Horizon	Depth (m)	Mean Phi	Sorting	Skewness	Kurtosis
A	0.10-0.12	2.82	1.22	0.32	1.24
Bw	0.21-0.22	2.69	1.08	0.30	1.23
	0.39-0.41	2.70	1.05	0.27	1.13
Bt1	0.69-0.71	3.39	1.85	0.46	2.58
Bt2	0.79-0.81	3.46	1.61	0.40	3.10
	0.89-0.91	3.47	1.82	0.44	2.81
	1.09-1.11	3.58	2.28	0.50	2.11
2Btb1	1.17-1.19	5.02	2.87	0.51	1.60
	1.29-1.31	5.29	2.97	0.61	1.85
	1.59-1.61	4.77	2.77	0.44	1.43
3Btb1	1.68-1.70	6.22	2.88	0.32	0.93
	1.80-1.82	6.16	2.68	0.34	1.10
3Btb2	2.07-2.09	7.06	2.79	0.27	0.72
	2.30-2.32	6.99	2.71	0.26	0.76
	2.58-2.60	6.83	2.67	0.32	0.84
	2.78-2.80	6.65	2.66	0.24	0.93
3Btgb3	2.90-2.92	7.04	2.77	0.19	0.79
	3.20-3.22	6.56	2.88	0.19	0.86

Edwards 2

Soil Horizon	Depth (m)	Mean Phi	Sorting	Skewness	Kurtosis
Ap	0.09-0.11	3.72	2.06	0.41	1.44
A	0.28-0.30	3.51	2.28	0.50	1.47
Bt1	0.41-0.43	3.09	2.00	0.55	1.91
	0.61-0.63	3.35	2.06	0.53	2.15
Bt2	0.81-0.83	4.46	2.85	0.54	1.39
	0.91-0.93	3.46	2.12	0.59	1.96
Bt3	0.96-0.98	3.94	2.15	0.35	1.71
	1.20-1.22	3.54	1.93.	0.28	1.60
2Btb1	1.27-1.29	3.94	2.41	0.32	1.73
2Btb2	1.37-1.39	5.06	2.65	0.41	1.65
	1.61-1.63	5.29	2.78	0.49	1.68
2Btb3	1.69-1.71	6.06	2.94	0.39	1.09
3Btgb1	1.79-1.81	5.99	2.94	0.38	1.00
3Btgb2	1.89-1.91	6.92	2.93	0.27	0.78
	2.09-2.11	5.91	2.80	0.25	1.14
3Btb3	2.29-2.31	5.04	2.54	0.34	1.63
3Btb4	2.59-2.61	5.31	2.32	0.48	1.44
	2.79-2.81	5.01	2.33	0.44	1.70
3Btb5	2.99-3.01	4.12	1.93	0.28	1.57
	3.09-3.11	3.70	1.92	0.31	1.54

Edwards 3

Soil Horizon	Depth (m)	Mean Phi	Sorting	Skewness	Kurtosis
Ap	0.09-0.11	4.11	2.48	0.51	1.52
Bw	0.28-0.30	3.75	2.24	0.56	2.10
2Btb1	0.39.0.41	7.29	3.22	-0.07	0.62
	0.49-0.51	7.48	3.02	-0.02	0.62
	0.69-0.71	7.84	2.66	0.08	0.54
2Btb2	0.89-0.91	7.83	2.45	0.27	0.54
	1.10-1.12	7.95	2.45	0.26	0.48
	1.18-1.20	7.89	2.51	0.26	0.50
	1.29-1.31	7.78	2.47	0.27	0.57
	1.49-1.51	7.36	2.69	0.35	0.71
	1.69-1.71	6.99	2.58	0.34	0.87
3Btb1	1.78-1.80	6.93	3.27	0.34	0.57
	1.99-2.01	6.57	3.39	0.36	0.65
3Btb2	2.10-2.12	6.26	3.52	0.38	0.73
	2.28-2.30	6.07	3.54	0.43	0.84
	2.39-2.41	5.74	3.74	0.42	0.84
	2.59-2.60	5.93	3.79	0.40	0.59
4Btb1	2.78-2.80	6.82	3.30	0.28	0.65
	2.99-3.01	7.15	3.02	0.33	0.55
4Btb2	3.19-3.21	6.66	3.16	0.48	0.68

Edwards 4

Soil Horizon	Depth (m)	Mean Phi	Sorting	Skewness	Kurtosis
Ap	0.09-0.11	3.07	1.59	0.50	1.60
A	0.28-0.30	3.57	2.10	0.58	2.24
Bw	0.49-0.51	4.16	2.90	0.60	1.67
C	0.69-0.71	3.62	2.16	0.49	2.74
2Ab	0.79-0.81	4.89	3.55	0.68	1.81
2C1	0.88-0.90	4.04	2.17	0.47	2.48
2C2	0.99-1.01	6.16	3.40	0.51	0.72
2C3	1.09-1.11	3.47	2.43	0.59	2.09
	1.18-1.20	3.46	2.21	0.67	2.61
	1.52-1.54	3.21	2.17	0.63	2.77
3Btb1	1.58-1.60	5.31	2.77	0.40	1.36
	1.69-1.71	5.68	2.93	0.44	1.20
	1.94-1.96	5.68	3.19	0.39	0.86
3Btb2	2.08-2.10	5.54	3.47	0.43	0.92
	2.28-2.30	5.01	3.36	0.51	1.26
	2.45-2.47	5.00	3.50	0.50	1.23
	2.83-2.85	4.80	3.11	0.48	1.71
	2.86-2.88	5.36	3.42	0.50	1.42
	3.08-3.10	5.29	3.35	0.47	1.14
3Btkb3	3.29-3.31	5.37	3.33	0.54	1.21

Phillips Trench

Soil Horizon	Depth (m)	Mean Phi	Sorting	Skewness	Kurtosis
Ap	0.09-0.11	4.31	2.46	0.53	1.45
A	0.27-0.29	4.17	2.23	0.45	1.55
2Btb1	0.37-0.39	6.55	2.68	0.31	0.91
	0.47-0.49	7.34	2.75	0.10	0.75
	0.69-0.71	7.42	2.53	0.11	1.06
2Btb2	0.89-0.91	7.86	2.42	0.20	0.62
	1.09-1.11	7.79	2.48	0.24	0.56
	1.29-1.31	7.78	2.45	0.28	0.58
2Btb3	1.48-1.50	7.28	2.35	0.47	0.80
	1.68-1.70	7.37	2.43	0.46	0.74
	1.89-1.91	7.53	2.54	0.46	0.63
2Btb4	2.11-2.13	7.13	2.58	0.51	0.82
	2.28-2.30	6.85	2.74	0.47	0.82
3Btb1	2.48-2.50	6.33	3.02	0.37	0.92
	2.58-2.60	5.51	3.15	0.33	1.07
3Btb2	2.69-2.71	4.84	2.93	0.44	1.38

Reno 3

Soil Horizon	Depth (m)	Mean Phi	Sorting	Skewness	Kurtosis
A	0.09-0.11	2.48	1.29	0.33	1.24
AB	0.29-0.31	2.30	0.92	0.29	1.05
E&Btb	0.37-0.39	2.39	0.87	0.57	1.66
	0.59-0.61	2.26	0.89	0.27	1.03
	0.79-0.80	2.42	0.89	0.18	0.98
	0.99-1.01	1.92	0.91	0.31	1.22
	1.19-1.21	2.46	0.79	0.17	1.03
	1.31-1.41	2.46	0.87	0.15	1.01
2Ab	1.50-1.52	2.33	1.23	0.23	1.10
2E&Btb	1.57-1.59	2.22	1.11	0.20	1.04
	1.67-1.69	2.16	1.08	0.21	1.05
	1.87-1.89	2.18	1.06	0.18	1.05
	2.07-2.09	2.19	1.03	0.22	1.04
	2.27-2.29	2.38	1.13	0.25	1.01
	2.51-2.53	2.53	1.23	0.28	1.19
3Ab	2.57-2.59	3.94	2.58	0.49	1.65
4Btb1	2.70-2.72	5.30	3.27	0.39	0.91
4Btgb2	2.88-2.90	5.86	3.81	0.43	0.62
	3.09-3.11	5.79	3.87	0.40	0.63

Reno 4

Soil Horizon	Depth (m)	Mean Phi	Sorting	Skewness	Kurtosis
Ap	0.09-0.11	3.30	2.15	0.57	1.66
A	0.29-0.31	2.78	1.57	0.40	1.52
E&Bt	0.40-0.42	3.92	1.90	0.37	3.39
	0.60-0.62	3.59	1.98	0.46	3.04
	0.80-0.82	3.57	1.92	0.45	3.19
	0.90-0.92	1.52	1.04	0.16	1.30
	1.08-1.10	2.62	1.04	0.34	1.28
2Ab	1.11-1.13	3.67	2.35	0.44	2.01
2Btb1	1.19-1.21	3.95	2.48	0.44	1.74
2Btb2	1.26-1.28	3.52	1.95	0.42	2.81
	1.48-1.50	3.78	1.97	0.47	3.42
	1.58-1.60	3.41	1.88	0.41	2.64
2E&Btb	1.78-1.80	2.70	1.14	0.25	1.34
2C	1.88-1.90	3.66	2.04	0.42	2.54
	2.08-2.10	3.57	1.87	0.39	3.02
	2.18-2.20	2.78	2.14	0.31	1.53
3Btb1	2.27-2.29	6.15	3.73	0.22	0.65
3Btb2	2.47-2.49	7.05	3.07	0.17	0.79
	2.67-2.69	7.11	2.98	0.18	0.83
	2.91-2.93	6.89	2.69	0.27	1.03
	2.97-2.99	7.15	2.90	0.25	0.84
	3.17-3.19	6.93	2.94	0.30	0.93
	3.41-3.43	5.85	2.72	0.18	1.21
	3.49-3.51	5.54	2.95	0.15	1.03
3Btb3	3.67-3.69	5.32	3.59	0.36	0.84
	3.77-3.79	4.60	3.07	0.35	1.04
3Btb4	3.97-3.99	3.90	2.96	0.55	1.33

Stafford 1

Soil Horizon	Depth (m)	Mean Phi	Sorting	Skewness	Kurtosis
Ap	0.09-0.11	3.26	1.61	0.40	1.63
A	0.18-0.20	3.10	1.50	0.41	1.67
	0.28-0.30	2.94	1.46	0.50	1.67
Bt1	0.37-0.39	2.89	1.41	0.46	1.72
	0.50-0.52	4.85	2.70	0.50	1.76
Bt2	0.59-0.61	4.10	2.14	0.38	1.92
Bt3	0.69-0.71	5.65	2.14	0.71	1.50
C	0.79-0.81	3.35	1.82	0.53	2.02
2Btgb1	0.98-1.00	5.91	2.91	0.34	1.06
	1.11-1.13	5.47	3.18	0.46	0.92
2Btb2	1.17-1.19	5.39	3.14	0.53	0.99
	1.37-1.39	4.86	2.90	0.58	1.42
	1.62-1.64	5.01	2.98	0.59	1.35
	1.67-1.69	5.02	3.12	0.64	1.29
	1.81-1.83	4.81	2.68	0.44	1.41
2Btb3	1.99-2.01	4.94	2.66	0.36	1.41
2Btkb4	2.18-2.20	5.06	3.15	0.46	1.13
2Btb5	2.31-2.33	5.22	2.84	0.36	1.15
	2.47-2.49	5.44	2.85	0.32	1.07

Stafford 2

Soil Horizon	Depth (m)	Mean Phi	Sorting	Skewness	Kurtosis
A	0.09-0.11	3.89	2.24	0.53	1.62
	0.19-0.21	3.51	2.11	0.46	1.60
AC	0.39-0.41	3.04	1.71	0.41	1.63
	0.59-0.61	3.15	1.80	0.45	2.15
C	0.68-0.70	3.15	1.79	0.46	2.22
	0.89-0.91	3.09	2.14	0.55	2.39
	1.11-1.13	3.49	2.14	0.48	2.53
2Ab	1.17-1.19	4.39	3.15	0.61	1.68
	1.39-1.41	4.35	3.04	0.65	1.94
2Btb1	1.59-1.61	4.59	2.99	0.58	1.39
3Btb1	1.68-1.70	5.99	3.60	0.42	0.74
3Btb2	1.88-1.90	5.06	3.06	0.44	1.07
	2.01-2.03	4.91	3.14	0.53	1.23
	2.07-2.09	4.84	3.22	0.59	1.33
	2.27-2.29	4.78	3.05	0.55	1.33
	2.38-2.40	4.67	2.89	0.54	1.40
3Btb3	2.59-2.61	4.00	2.25	0.45	1.70
	2.79-2.81	3.91	2.19	0.46	2.21
	2.99-3.01	4.11	2.40	0.41	1.90
4Btb1	3.08-3.10	5.47	2.67	0.44	1.91
4Btb2	3.28-3.30	4.53	2.63	0.38	1.40
	3.38-3.40	4.56	2.85	0.49	1.39
	3.58-3.60	4.93	3.30	0.54	1.28

Stafford 3

Soil Horizon	Depth (m)	Mean Phi	Sorting	Skewness	Kurtosis
Ap	0.09-0.11	3.05	1.93	0.45	1.59
	0.30-0.32	2.93	1.86	0.47	1.68
A	0.38-0.40	3.48	2.29	0.49	2.09
Bw	0.59-0.61	3.63	2.06	0.33	1.98
	0.69-0.71	3.56	2.24	0.50	2.10
	0.89-0.91	3.42	2.08	0.63	2.01
	1.09-1.11	2.93	1.53	0.35	1.52
	1.19-1.21	2.64	1.08	0.38	1.23
	1.41-1.43	3.03	1.42	0.44	2.44
	1.59-1.61	3.71	2.09	0.54	2.84
C	1.70-1.72	2.87	1.43	0.53	2.15
	1.91-1.93	1.88	1.12	0.43	2.08
2Ab	2.03-2.05	3.38	2.05	0.48	1.64
3Btb1	2.07-2.09	5.35	2.76	0.31	1.15
	2.17-2.19	5.51	2.92	0.27	1.08
	2.29-2.31	5.94	2.97	0.35	1.14
	2.39-2.41	5.57	2.82	0.33	1.19
	2.69-2.71	5.58	2.93	0.35	1.15
3Btb2	2.89-2.91	5.34	3.05	0.41	1.17
	3.00-3.02	5.69	2.84	0.57	1.02
	3.10-3.12	4.87	2.89	0.35	1.28
	3.19-3.21	4.59	2.70	0.41	1.43
3Btb3	3.29-3.31	4.05	2.30	0.38	1.49
	3.39-3.41	4.01	2.52	0.51	1.72
	3.59-3.61	3.74	2.34	0.53	1.77
	3.81-3.83	3.65	2.02	0.43	2.28
	3.99-4.01	3.77	2.20	0.44	2.50
3Btgb4	4.21-4.23	4.31	2.43	0.42	1.79
	4.33-4.35	4.84	2.84	0.68	1.26
3Btgb5	4.37-4.39	5.30	2.24	0.56	1.95
3Btgb6	4.48-4.50	5.15	2.40	0.60	1.84

Stafford 4

Soil Horizon	Depth (m)	Mean Phi	Sorting	Skewness	Kurtosis
Ap	0.09-0.11	5.01	2.36	0.24	1.77
A	0.20-0.22	5.55	2.47	0.34	1.70
	0.27-0.29	5.99	2.72	0.36	1.16
	0.39-0.41	5.86	2.70	0.33	1.19
AB	0.49-0.51	5.72	2.69	0.29	1.22
Bt1	0.57-0.59	6.01	3.01	0.26	1.10
	0.70-0.72	6.22	3.25	0.23	1.04
	0.77-0.79	6.23	2.77	0.25	1.03
	0.87-0.89	6.11	2.76	0.22	1.12
	1.11-1.13	5.76	2.99	0.23	0.95
	1.19-1.21	5.52	2.98	0.21	0.95
Bt2	1.29-1.31	5.04	2.85	0.40	1.17
	1.49-1.51	4.63	2.90	0.44	1.35
	1.62-1.64	4.72	2.69	0.39	1.50
2Ab	1.67-1.69	5.62	3.32	0.45	1.19
	1.90-1.92	4.72	2.33	0.25	1.26
2ABb	1.97-1.99	4.92	2.60	0.31	1.34
2Btb1	2.07-2.09	4.94	2.76	0.37	1.23
	2.17-2.19	4.82	2.71	0.40	1.38
	2.41-2.43	4.42	2.49	0.41	1.37
2Btb2	2.47-2.49	4.19	2.23	0.39	1.44
	2.57-2.59	4.19	2.33	0.45	1.86
	2.83-2.85	3.73	1.83	0.36	1.83

Stafford 5

Soil Horizon	Depth (m)	Mean Phi	Sorting	Skewness	Kurtosis
Ap	0.09-0.11	2.60	1.21	0.30	1.14
AC	0.27-0.29	2.26	0.95	0.33	1.01
C	0.39-0.41	2.32	1.00	0.24	0.90
	0.59-0.61	2.37	0.98	0.20	0.93
	0.79-0.81	2.58	0.93	0.10	0.99
	0.99-1.01	2.15	1.40	0.24	0.90
	1.19-1.21	2.23	1.00	0.30	1.04
	1.37-1.39	3.33	1.93	0.37	1.76
2Ab	1.41-1.43	3.51	2.03	0.38	1.92
	1.61-1.63	3.72	2.18	0.39	2.15
2Bwb	1.66-1.68	3.95	2.63	0.57	1.88
	1.77-1.78	3.32	2.39	0.52	2.26
	2.01-2.03	3.30	2.46	0.52	2.04
3Btgb1	2.07-2.09	5.24	3.07	0.54	1.17
	2.26-2.28	5.10	3.25	0.52	1.03
	2.28-2.30	4.86	3.38	0.50	0.92
	2.49-2.51	5.22	3.46	0.62	1.03
	2.58-2.60	5.08	3.07	0.45	1.19
	2.78-2.80	5.26	2.97	0.35	1.09
	2.97-2.99	5.85	3.57	0.38	0.77
	3.19-3.21	4.86	3.07	0.37	1.27
	3.37-3.39	4.60	3.14	0.49	1.18

Stafford 6

Soil Horizon	Depth (m)	Mean Phi	Sorting	Skewness	Kurtosis
A	0.09-0.11	3.15	1.50	0.20	1.40
	0.19-0.21	3.29	1.55	0.19	1.43
AC	0.38-0.40	3.04	1.30	0.21	1.36
2Ab	0.59-0.61	3.71	1.84	0.23	2.03
2Bw	0.69-0.71	3.80	1.89	0.26	2.10
2C	0.77-0.79	4.13	1.93	0.32	2.60
	0.87-0.89	2.65	0.98	0.18	1.01
	1.11-1.13	2.89	0.89	0.11	1.16
3Ab	1.17-1.19	4.16	2.29	0.37	2.00
	1.31-1.33	4.08	2.33	0.38	1.93
3ABb	1.40-1.42	4.38	2.69	0.46	1.66
4Btb1	1.60-1.62	4.92	2.98	0.47	1.53
4Btb2	1.67-1.69	5.24	2.56	0.41	1.47
	1.83-1.85	5.19	2.48	0.39	1.61
	1.88-1.90	5.51	2.65	0.43	1.39
	2.08-2.10	5.26	3.09	0.45	1.55
4Btb3	2.19-2.21	5.35	3.15	0.44	1.59

Stafford 10

Soil Horizon	Depth (m)	Mean Phi	Sorting	Skewness	Kurtosis
A	0.09-0.11	3.07	1.59	0.56	1.98
Bw	0.29-0.31	3.26	1.74	0.51	2.46
	0.41-0.43	3.41	1.93	0.54	3.01
	0.58-0.60	3.44	1.93	0.53	2.90
	0.69-0.71	3.10	1.74	0.64	2.90
	0.89-0.91	3.01	1.66	0.60	2.60
	1.09-1.11	3.52	1.93	0.51	3.06
2C	1.24-1.26	6.54	3.61	0.01	0.61
3Btb1	1.32-1.34	2.60	2.02	0.53	2.73
3Btb2	1.41-1.43	4.80	3.38	0.65	1.36
	1.47-1.49	5.50	3.71	0.61	0.84
3Btgb3	1.70-1.72	5.55	3.38	0.48	0.94
	1.80-1.82	3.76	2.61	0.54	1.65
	1.91-1.93	3.09	2.14	0.46	2.22
	1.97-1.99	3.39	2.23	0.49	2.24
4Btgb1	2.17-2.19	4.18	2.34	0.57	2.31
4Btkgb2	2.39-2.41	6.04	3.27	0.38	0.80
	2.59-2.61	6.08	3.29	0.37	0.78
4Btkgb3	2.79-2.81	4.95	3.15	0.60	1.32
	2.98-3.00	5.09	2.89	0.43	1.10

Stafford 11

Soil Horizon	Depth (m)	Mean Phi	Sorting	Skewness	Kurtosis
Ap	0.09-0.11	2.63	1.05	0.35	1.26
C	0.31-0.33	2.59	0.98	0.30	1.16
	0.41-0.43	2.75	1.36	0.53	1.96
	0.60-0.62	2.49	0.99	0.39	1.19
	0.67-0.69	2.75	1.18	0.34	1.37
2Ab	0.79-0.81	2.59	1.11	0.35	1.30
2Bwb	0.87-0.90	3.05	1.36	0.42	2.20
	0.99-1.01	2.93	1.48	0.62	2.76
3Btb1	1.07-1.09	3.97	2.34	0.55	2.48
3Btb2	1.22-1.24	5.16	3.08	0.39	1.12
	1.27-1.29	5.12	2.68	0.33	1.25
	1.52-1.54	5.62	2.58	0.38	1.30
3Btb3	1.57-1.59	5.94	2.49	0.30	1.19
	1.67-1.69	5.87	2.62	0.28	1.17
3Btb4	1.80-1.82	5.69	2.77	0.30	1.09
	2.00-2.02	5.43	2.84	0.38	1.17
3Btb5	2.10-2.12	5.21	2.89	0.40	1.22
	2.28-2.30	4.37	2.40	0.36	1.46
	2.38-2.40	4.22	2.38	0.35	1.50
	2.68-2.70	3.89	2.24	0.38	1.56

APPENDIX C: TEXTURAL AND CHEMICAL DATA OBTAINED FROM BACKHOE TRENCHES AT WILSON RIDGE.

This appendix contains the textural and chemical data and soil horizonation from the backhoe trenches excavated at Wilson Ridge.

Trench 1

Soil horizon	Depth (m)	Color (moist)	Sand (%)	Silt (%)	Clay (%)	$CaC0_3$ (%)	OM (%)
Ap	0.00-0.21	10YR3/2	30.2	62.3	7.5	2.4	1.1
A	0.21-0.36	10YR2/2	22.4	64.3	13.3	2.2	1.2
AB	0.36-0.52	10YR3/1	19.6	67.6	12.8	2.4	1.1
Bt1	0.52-0.80	10YR3/2	19.9	63.7	16.4	1.6	0.9
Bt2	0.80-1.15	10YR3/3	23.6	63.8	12.6	0.8	0.5
Btk3	1.15-1.38	10YR3/3	25.7	59.8	14.5	14.8	0.5
2Ab	1.38-1.50	10YR3/1	23.6	49.8	26.6	13.1	0.5
2Btb1	1.50-1.63	10YR4/2	18.9	58.8	22.3	34.1	0.4
2Btkb2	1.63-1.76	10YR4/2	17.8	65.6	16.6	18.0	0.5
	1.76-2.35	10YR5/3	6.8	74.6	18.6	4.0	0.3
2Btb3	2.35-2.50	10YR5/3	6:2	73.4	20.4	1.2	0.2

Trench 2

Soil horizon	Depth (m)	Color (moist)	Sand (%)	Silt (%)	Clay (%)	$CaCO_3$ (%)	OM (%)
Ap	0.00-0.21	10YR3/2	29.4	61.0	9.6	2.4	1.1
A	0.21-0.36	10YR2/2	20.4	64.2	15.4	2.2	1.2
AB	0.36-0.50	10YR3/1	18.4	65.5	13.1	2.4	1.1
Bt1	0.50-0.74	10YR3/2	18.8	65.5	15.7	1.6	0.9
	0.74-1.00	10YR3/2	16.1	66.7	17.2	0.4	1.1
	1.00-1.18	10YR3/3	27.6	58.2	14.2	0.4	0.6
2Ab	1.18-1.30	10YR3/2	39.9	38.6	21.5	0.8	0.6
2Btb1	1.30-1.54	10YR3/2	47.2	33.0	19.8	1.6	0.4
2Btb2	1.54-1.66	10YR3/2	25.5	47.0	27.5	1.6	0.4
2Btb3	1.66-1.87	10YR4/2	4.2	62.0	33.8	2.0	0.3
	1.87-2.08	10YR4/2	2.2	68.9	28.9	3.2	0.3
	2.08-2.36	10YR5/3	2.9	66.3	30.8	3.6	0.2
2Btb4	2.36-2.55	10YR5/3	22.3	59.2	18.5	2.8	0.1
	2.55-3.22	10YR5/3	23.1	58.9	18.0	2.4	0.1
2Bkb5	3.22-3.35	10YR5/3	25.5	49.4	25.1	12.0	0.1
	3.35-3.70	10YR5/3	24.3	52.3	23.4	11.2	0.0

Trench 3

Soil horizon	Depth (m)	Color (moist)	Sand (%)	Silt (%)	Clay (%)	$CaCO_3$ (%)	OM (%)
Ap	0.00-0.19	10YR3/2	41.0	43.8	15.2	0.3	0.9
A	0.19-0.50	10YR3/3	46.2	44.4	9.4	0.3	0.6
Bt1	0.50-0.82	10YR4/3	59.0	28.0	13.0	0.4	0.5
	0.82-1.04	10YR4/2	66.9	18.0	15.1	0.4	0.9
	1.04-1.23	10YR4/2	60.6	28.1	11.3	0.4	0.3
2Bt1	1.23-1.42	10YR4/2	62.2	23.5	14.3	2.0	0.3
2Bt2	1.42-1.59	10YR4/2	44.4	39.8	15.8	5.2	0.3
2Bt3	1.59-1.83	10YR4/2	69.0	20.5	10.5	4.3	0.1
Ck	1.83-2.65	10YR5/3	72.9	18.6	8.5	3.1	0.0
3Ab1	2.65-2.91	10YR3/2	30.9	61.3	7.8	1.3	0.6
3BAb1	2.91-3.12	10YR3/2	15.6	61.4	23.0	0.8	0.8
3Btkb1	3.12-3.37	10YR3/1	19.2	67.0	13.8	0.3	0.9
	3.37-3.60	10YR5/3	25.2	64.1	10.7	0.4	0.3

Trench 4

Soil horizon	Depth (m)	Color (moist)	Sand (%)	Silt (%)	Clay (%)	$CaC0_3$ (%)	OM (%)
Ap	0.00-0.19	10YR3/3	48.6	36.6	14.8	0.1	0.7
Bt1	0.19-0.33	10YR3/3	51.7	29.9	18.4	0.1	0.6
	0.33-0.59	10YR3/4	73.2	16.3	10.5	0.1	0.3
	0.59-0.93	10YR5/3	83.1	10.2	6.7	3.2	0.3
Bk	0.93-1.20	10YR5/3	71.4	19.1	9.5	10.0	0.3
	1.20-1.37	10YR5/3	83.3	11.9	4.8	15.0	0.2
	1.37-2.01	10YR5/3	74.0	18.4	7.6	11.2	0.4
	2.01-2.38	10YR5/3	70.2	20.2	9.6	9.2	0.1
	2.38-2.60	10YR5/3	80.3	11.4	8.3	5.6	0.1
2Ab	2.60-2.68	10YR5/3	42.6	43.6	13.8	4.0	0.3
2Btkb1	2.68-2.93	10YR5/3	44.0	36.5	19.5	8.0	0.3
2Btkb2	2.93-3.09	10YR4/3	72.6	17.7	9.7	11.6	0.2
2Btkb3	3.09-3.45	10YR4/3	59.4	43.1	23.1	7.6	0.1
2Btkb4	3.45-4.20	10YR4/3	32.0	36.2	31.8	10.8	0.2

Trench 5

Soil horizon	Depth (m)	Color (moist)	Sand (%)	Silt (%)	Clay (%)	$CaCO_3$ (%)	OM (%)
Ap	0.00-0.19	10YR3/3	54.1	34.7	11.2	2.4	0.7
Bwk	0.19-0.42	10YR4/2	61.7	26.5	11.8	13.0	0.6
Btk	0.42-1.00	10YR5/2	56.2	30.3	13.5	19.1	0.3
Bk	1.00-2.25	10YR5/3	84.7	7.6	7.7	9.6	0.1
2Ab	2.25-2.41	10YR4/2	81.4	14.9	3.7	6.5	0.1
2Btb1	2.41-2.72	10YR4/3	87.8	6.8	5.4	4.2	0.0
2Btkb2	2.72-3.25	10YR5/2	51.4	26.6	22.0	10.1	0.2
2Btkb3	3.25-4.20	10YR4/2	33.8	43.1	23.1	10.0	0.2