AEOLIAN MODIFICATION OF PLEISTOCENE TERRACES ALONG THE CIMARRON RIVER IN MAJOR COUNTY, OKLAHOMA

By

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PREFACE

The purpose of this study was to describe and interpret the interaction between fluvial and aeolian processes that are responsible for creating landforms on the terraces of the Cimarron River in Major County, Oklahoma. The landscape on the Pleistocene terraces of the Cimarron River was developed under fluctuating fluvial and aeolian processes. Aeolian processes have modified the fluvial landforms by depositing dune fields and sand sheets on the terraces. Episodes of aeolian activity have occurred throughout the Holocene. Detailed soil-stratigraphic studies and radiocarbon dating were conducted at two sites to establish the chronology of landscape formation during the Holocene on the Qt2 terrace of the Cimarron River. Radiocarbon dating of soil humates shows significant sand mobilization over the last 2,000 years. Regional geomorphic mapping and was conducted and relative dating techniques were used to assess geomorphic processes that have been active throughout the Quaternary.

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NOMENCLATURE

2-sigma	Designation of a range two standard deviations wide
AMS	Accelerator Mass Spectrometer
BP	Before Present (years)
MSL	Mean Sea Level
HCl	Hydrochloric Acid

CHAPTER I

INTRODUCTION

Landscapes on the surface of Earth are shaped by geomorphic agents, with the dominant agent of geomorphic change being water. Wind also contributes to surficial change. The action of these two agents and the landscapes formed by them are usually recognized as being distinct and separate. Landscapes are usually described as being developed by wind or water, but rarely both.

Most geomorphology textbooks treat the various geomorphic processes and landforms as isolated from each other (Ritter, et al., 1995; Thornbury, 1954). They discuss only briefly the interplay between various forces and processes. Landscapes in much of Oklahoma are the result of fluvial and aeolian processes that vary in intensity and alternate dominance as the climate varies over time. During dry periods, aeolian processes dominate; during relatively wet periods, fluvial processes dominate. Each process, therefore, operates on a landscape developed during the preceding period. The landscape is a product of the alternating forces that shape it.

Wide Pleistocene terraces flank the Cimarron River in northwest Oklahoma (Morton, 1980). In Major County, the terrace system on the north side of the river is 16 to 24 km wide and is continuous from Woods County into Payne County, about 160 km from west to east (Morton, 1980). Most of the tread surfaces of this terrace complex are nearly level; some surfaces are gently rolling with complex slopes and have the appearance of a sand sheet. Dune fields are also common, and large dunes have buried and masked the major escarpments of this terrace complex. The drainage pattern on the terrace surface is coarse and poorly developed. Only the largest streams have sufficient competence to flow through the sand dunes on the margin of the lowest terrace level (Morton, 1980).

Hypothesis

Descriptions and interpretations of the fluvial-aeolian interactions that occurred on the terraces along the Cimarron River will be the focus of this study. How sediments and processes correlate with the climatic regimes during the Late Pleistocene and Holocene will be assessed. This work will assist in understanding conditions that will mobilize sand deposits.

The primary hypothesis to be tested: during arid times, wind-blown sand moved from the southwest and blocked small consequent streams that developed on the Cimarron River terrace surface during previous wet periods. Modern wetlands on the terrace surface occupy the abandoned stream channels. This hypothesis emphasizes that climate controls the aeolian processes which build and modify sand dunes on the escarpments and on the terraces. The alternate hypothesis: no correlation exists between the sediments and climatic regime; the dunes were active because of other factors such as sand supply, and no relationship exists between the modern landscape and drainage on the old surface.

This study requires a combination of several methods to establish the processes, timing, and intensity. Stratigraphy, relative and absolute dating, soil profile development, and sediment weathering characteristics will show that this landscape developed under fluctuating geomorphic processes. This is primarily designed as a field study, with laboratory analysis as needed.

Combining several methods in the study of landscape is appropriate. Daniels and Hammer (1992) emphasize the utility, even the necessity, of integrating soil science and geomorphology. They noted that "the landscape and soils have coevolved over time. Investigation of multiple profiles in the landscape helps one to appreciate current and past dynamics of the soil system." (Daniels and Hammer, 1992, p. xvi.). They also recognized that "soils are good integrators of several factors in their past and present environments" (Daniels and Hammer, 1992, p. 1).

Geomorphologists recognize the value of an interdisciplinary approach, while admitting it is not always welcome (Butzer, in Vitek, 1989). John Hack's lifelong association with soil scientists John Cady and Constantine Nikiforoff dated from World War II (Osterkamp and Hupp, 1996; Osterkamp, 1989). Robert Ruhe worked closely with Ray Daniels to interpret the landscapes of Iowa (Olson, 1989).

The complexity of the natural world requires an interdisciplinary approach. Osterkamp and Hupp (1996) recognized complexity as a basic characteristic of geomorphology, and Vitek (1989) concluded that "The complex environment requires interdisciplinary efforts to find solutions to problems that impact human utilization of the surface."

Study Site

The study site is located in Major and Kingfisher Counties, Oklahoma, on the northeast side of the Cimarron River (Figure 1.). This location was chosen based on the complex landscape observed during preparation of wetland delineations. Specifically, the area is located in the SE/4, section 20, T. 20 N., R. 9 W., Major County (Hanor farm); and the NW/4 NW/4 section 10, T. 19 N., R. 9 W., Kingfisher County (Hajek ranch); Ames Quadrangle (Figure 2). The regional geomorphic mapping covers Major County east of Indian Creek and the Cimarron River, south of U.S. highway 412; and that part of Kingfisher County north of Oklahoma highway 51 and east of the Major County-Garfield County line (Figure 3).

Geomorphic Issues

An understanding of certain geomorphic concepts is essential to this thesis. Geomorphic thresholds, physiography and processes geomorphology, and relative dating are important concepts; they have great utility in the consideration of the landscape as a system (Ritter, et al., 1995, p. 5-8).

Geomorphic Thresholds

The dictionary definition of threshold is "a piece of wood or stone beneath a door, hence an entrance or beginning point" (Friend and Guralnik, 1957). A geomorphic threshold is a geomorphic boundary condition or limiting value in the geomorphic system (Ritter, et al., 1995, p. 18). A threshold is crossed when an event causes the system to enter into, or cross over into a new condition, and a new equilibrium must be established.

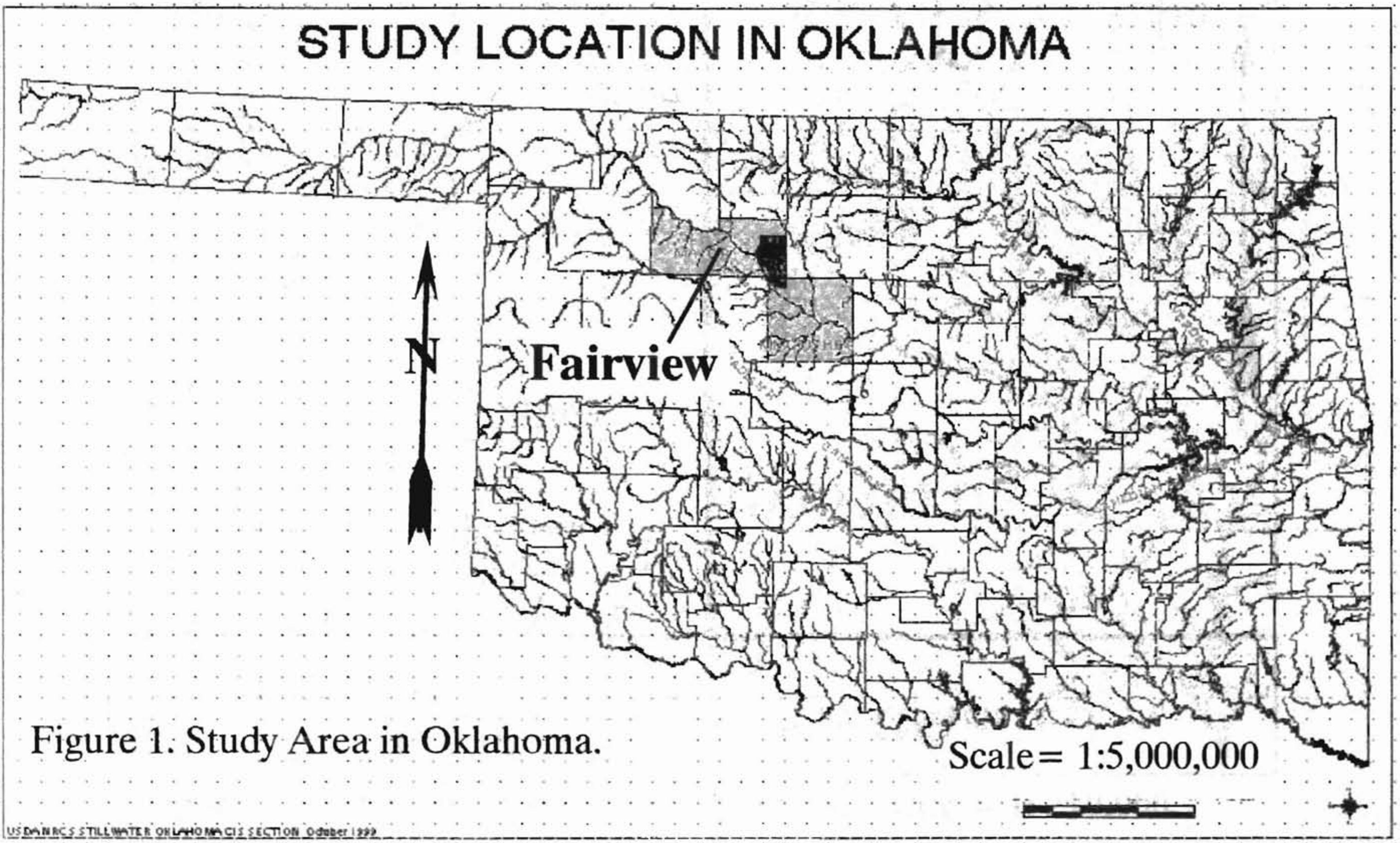


Figure 1. Study Area in Oklahoma.

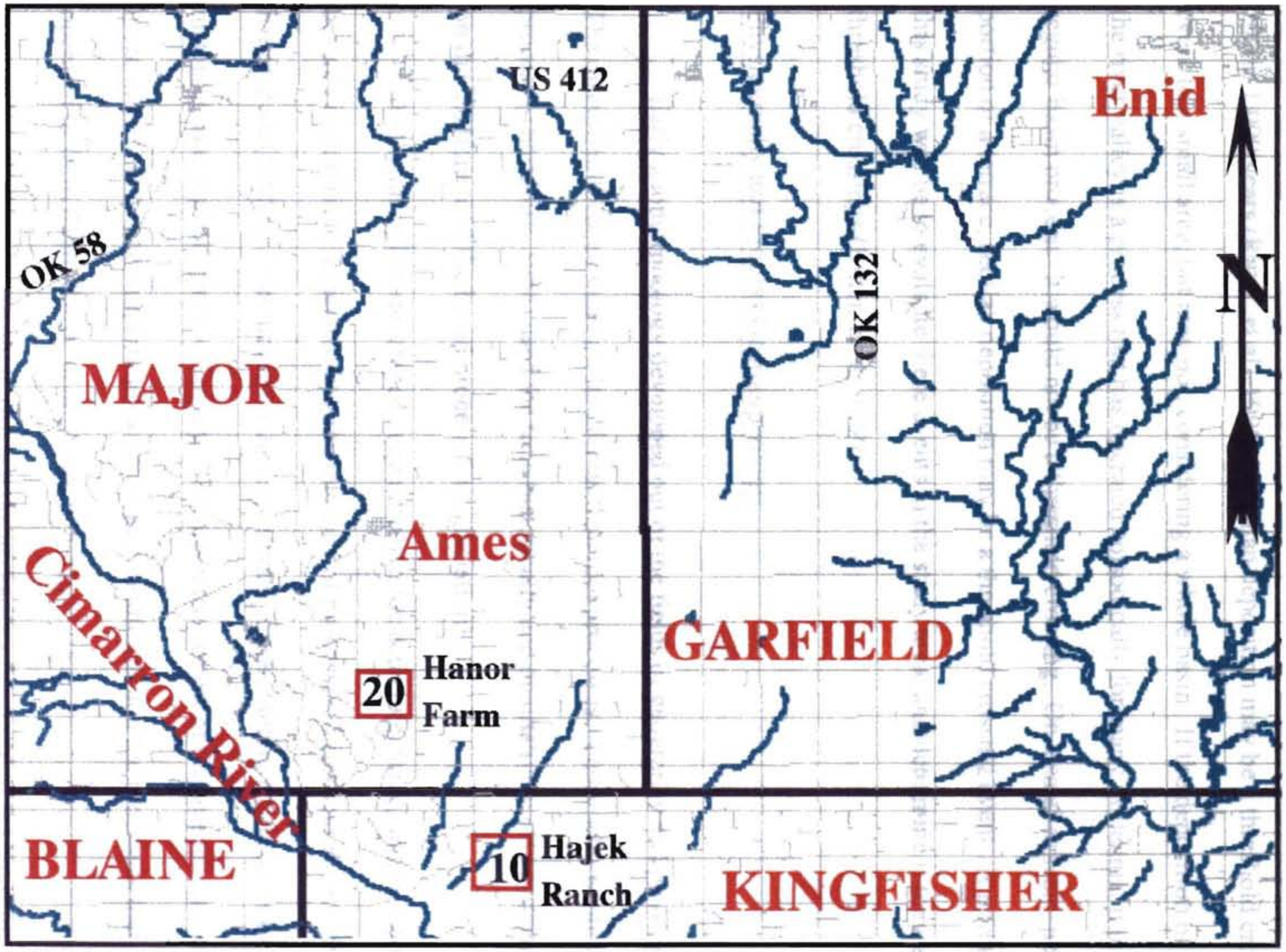


Figure 2. Detailed Location of Study Areas. Scale = 1: 210,000.

The concept of scale is important in defining a threshold crossing event. Ritter, et al. (1999) notes that these events are irreversible on a graded-time scale, a period of about 100 to 1,000 years (Ritter, et al., 1995). Aeolian deposition may be a threshold crossing event to a small area, but may not, considering a whole basin. If the deposition of sand in the river valley is a process that has operated episodically for many millennia, it is a regular basin process. It would not be a threshold crossing. On a smaller scale, perhaps a portion of a terrace, aeolian deposition may be a threshold crossing event. A portion of this study will be to evaluate these events in the study area, and determine if they are true threshold crossings (Ritter, et al., 1999).

Physiography and Process Geomorphology

Early geomorphology developed out of the fields of geography and physiography. The discipline focused more on landforms than root processes. Those who wrote of process (Thornbury, 1954) used the term historically and qualitatively. He concentrated on the landform and the broad process (i.e., glaciation).

As the discipline developed, a quantitative focus on rate, force, and threshold became important to understanding the intensity of processes (Vitek and Ritter, 1993). Ritter et al. (1995, p. 3) emphasized the importance of maintaining a balance between historical and applied geomorphology. The predictive aspect of the science has become more important as geomorphologists investigate landforms and the processes that operated to form them (Ritter, et al., 1995, p. 5-7).

This study will attempt to balance the necessity of describing the landform with quantifying the processes that develop it and correlate the processes with the driving forces. Landscape physiology must be described, but a complete study must also define the processes as driving forces. In this manner we develop a predictive model of how the landscape may change as driving forces vary.

Relative Dating

Relative dating techniques establish the relative ages of, and discriminate between, various sediments and landforms. In the study area, sediment weathering, soil development, and vegetation will correlate to delineate older dunes from younger.

Soils on dunes in the study area show distinctions in weathering based on the distance from the river. Many weathering and soil development processes operate to develop soil horizons and profiles. Translocation of calcium and bases, lowering of pH, formation and translocation of clay, destruction of the sedimentary structure, development of soil structure, and increase in soil organic matter are processes that develop aeolian sediment into soil and give a basis for differentiating the ages of specific fields of dunes. The duration and intensity of the processes create differences in soil characteristics, and help set apart the various ages of dunes. This study presumes that the source material for the dunes is sand blown from the channel of the Cimarron River, and that the characteristics of the source sand is constant. This allows comparison between ages of dunes based on weathering. If the parent material changes across the study area, these comparisons will not be as reliable.

The various plants common to the region have preferences for particular soils and sites. In general, plants are more able to compete with other species on sites that meet the plants' biological requirements. Thus, specific species discriminate between the various soils and are more abundant on the soils that give them a competitive edge. In the study area, parallel belts of different vegetative communities appear to develop on particular groups of dunes, based on site preferences. Dune age will be shown to be positively correlated with distance from the river, based on soil development, weathering, and vegetative communities.

Site Characterization

Physiography and Drainage

Physiography. The study area is located in the Osage Section of the Central Lowlands Province (Thornbury, 1965), and is in the valley of the Cimarron River. The Cimarron River basin extends from the east flank of the Rocky Mountains near Raton, New Mexico to its junction with the Arkansas River. The valley floor in the study area is almost entirely mantled with fluvial terraces, including treads and risers (escarpments). The elevation of the river channel at the study site is about 335 meters msl, the study site is about 365 meters msl, and the divide between the Cimarron River and the Salt Fork of the Arkansas River to the north is about 411 meters msl. Local relief is commonly less than 6 meters but ranges up to 30 meters.

The divides on the north and south sides of the river are capped with early Pleistocene fluvial terraces (Morton, 1980). Deep, sandy alluvium from the North Canadian River mantles the divide between the North Canadian and Cimarron Rivers (Fay, 1962). Loamy and silty alluvium (with possible loess influence) mantles the divide between the Cimarron and Salt Fork of the Arkansas Rivers. The gradient of the highest terrace on this divide is not the same as the gradient of the Cimarron River or its other terraces. They slope to the east, and are not parallel to the modern Cimarron River.

On the south side of the river, the Permian Dog Creek, Blaine, and Flowerpot Formations are exposed on the escarpment below the divide. Terrace alluvium mantles the floor of the valley below this large escarpment. Permian rocks, or soils developed from Permian rocks, are exposed at some of the minor escarpments separating terraces on the south side of the river.

On the north side of the river, the valley side is almost completely covered with alluvium. Terraces step down from the divide to the valley floor. Most of the escarpments are covered with aeolian sands, and sand sheets are present on many of the terrace treads. Permian rocks, or soils developed from Permian rocks, are exposed at a few of the escarpments. The two study sites (Hanor farm and Hajek ranch) are on the Qt2 terrace on the north side of the river.

Drainage. The Cimarron River, the primary control for drainage through the area, has a slope of about 0.87 meters per km. The river valley is over 50 km wide in the study area. Most of the tributary streams flow from the west and south. Springs flowing from gypsum in the Blaine Formation feed perennial streams that flow north from the escarpment on the south side of the river valley. Larger streams, such as Deep Creek, Cottonwood Creek, and Gypsum Creek occupy abandoned channels of the Cimarron River. Eagle Chief Creek flows as an underfit stream in the abandoned channel of the Salt Fork of the Arkansas River (Fay, 1965).

Few streams flow across the terraces on the north side of the river (Adams and Bergman, 1995). Most of the streams have low competence, and failed to maintain a channel during the episodes when the dunes were built. The streams that have sufficient competence to reach the river drain at least 8,000 hectares. The drainage area for these streams includes areas of soils that have rapid runoff.

Drainage Density. The drainage density of an area is related to the age of the terrace deposit (May, 1985). Younger areas have a very low drainage density, and older areas have medium drainage density. The texture of the sediments also influences the drainage density. Rapidly permeable sediments have less runoff and develop a less dense drainage network than less permeable sediments. The study area on the Hanor farm has no defined drainage. The Hajek ranch site has a small perennial stream draining the terrace tread and flowing through the dune field.

Geology

Permian rocks underlie all of Major and Kingfisher Counties. The Cedar Hills sandstone, Flowerpot shale, Blaine Formation, Dog Creek shale, and Marlow Formation are exposed in the Cimarron River valley. Quaternary deposits overly the Permian rocks unconformably in most parts of the valley. The study area is underlain by the Cedar Hills member of the Hennessey Formation (Adams and Bergman, 1995).

The Cedar Hills sandstone is orange-brown sandstone and siltstone with some reddish brown shale. The Flowerpot shale is mostly reddish brown shale with thin lenses of gypsum and dolomite. West of Major County along the Cimarron River, halite is a component of the Flowerpot shale. The Blaine Formation consists of reddish-brown and red shale with several thick (up to 6 meters) gypsum members, and several thin dolomites. The Dog Creek shale is reddish-brown shale with thin gypsum, dolomite, and sandstone members. The Marlow Formation is dominantly orange-brown fine-grained sandstone and siltstone. A few thin beds of dolomite and gypsum are present (Morton, 1980). All the Permian formations dip to the southwest, toward the axis of the Anadarko Basin (Fay, 1962).

One important feature of the two study areas is that they are underlain entirely by the Cedar Hills member. This unit lacks the karst features that are occasionally associated with the gypsum and halite of the upper Permian formations. This establishes that dissolution of gypsum or halite is not involved in the development of the landscape at the study sites.

The Quaternary deposits overlying the Cedar Hills member are heterogeneous. Fluvial sediments ranging from gravel to clay are present. Aeolian deposits of sands are common, and range from Pleistocene to Recent in age. The active flood plain deposits of the Cimarron River are mostly sand, silt, and gravel, and range from 0 to 30 meters thick. The Permian Cedar Hills and Flowerpot Formations are also exposed in the river channel in several places (Adams and Bergman, 1995).

Climate

The climate of the study area - warm, temperate, and subhumid - has strong seasonal variation in temperature, precipitation, and wind direction and speed. The mean annual temperature at Fairview is 16.4° C. (Figure 1). The average temperature in January is 3.4° C., and the average temperature in July is 28.6° C. Extreme temperatures for the year may range from below -17° C. to over 38° C. (Allgood, et al., 1968).

Precipitation averages 71 cm per year, but has varied from 30 to 127 cm in the 20th century (Allgood, et al., 1968). The month of May has the highest average precipitation, 12 cm, and January the lowest, 2.2 cm. Sixty percent of the annual rainfall comes between May and September. Drought is a common occurrence and is cyclical. Cycles of drought, including the 1890s, 1930s, 1950s, and 1970s, have been observed during historical times (Muhs, et al., 1995).

Prevailing winds are from the south and southwest. Strong winds from the north and northwest occur when strong Arctic high-pressure systems move through the plains in winter. Brady (1989) examined dunes in Major and Alfalfa Counties for paleowind orientation and velocity. From his examination of slipfaces in the dunes, he concluded that the prevailing effective wind direction was south-southwest, but that northwest winds were important in the formation of some dunes. He concluded that paleowind directions and velocities for about the last 10,000 years are comparable to modern values.

Soils

Soils in the study area are developed from alluvium of Pleistocene age and aeolian sand, presumably of Recent age. Most, if not all, of the soils in the study area have a complex history. Soil profiles at the study site record several cycles of sedimentation, soil development, and erosion.

Soil Surveys. The soil surveys for Major and Kingfisher Counties have characteristics that limit their utility for this study. The two surveys contain soil maps at a scale of 1:20,000 (Allgood, et al., 1968; Fisher, et al., 1962). The smallest soil delineation is about 2 hectares, but most are considerably larger. Rangeland areas are mapped more generally, with some delineations larger than 400 hectares. The Kingfisher County Soil Survey was completed using the 1938 system of soil classification (Baldwin, et al., 1938). The Major County Soil Survey was completed just as the modern system was being adopted (Soil Survey Staff, 1975).

The two surveys were made under a system of constraints that produced a published survey in a relatively short time and with many generalizations. For example, soil scientists could establish no new series unless they proved a particular soil was more than 800 hectares in extent and materially different from all other existing series. They could not have a map unit of an existing series unless they proved the unit was over 80 hectares in extent and was materially different from other map units in the county. The system was subjective, and the correlator had much control over the definition of a materially different soil. Map units in the two counties were generalized and grouped with soils that are found up to 160 km east or west.

The classification system itself continues to undergo change, as the National Cooperative Soil Survey (NCSS) strives to incorporate changes that will make the system useful internationally (Soil Survey Staff, 1998). Generalization in soil surveys, and changes in the classification system itself result in soil surveys that are useful for the intended purpose, but lack the detail necessary for specific geomorphic studies. Soil survey maps do, however, record distinct combinations of soil, vegetation, and landscape position. The mapping gives enough information to produce a rough correlation between vegetation, soil development, relative age, and distance from the Cimarron River.

Soil Classification. In the current system, soils are classified by the presence or absence of certain diagnostic horizons, and by the degree or intensity of their expression.

The classification system does not address, per se, the genesis of the soil. Landscape position also is not a factor in the classification system. Characteristics that have a major impact on how people use the soil figure prominently in the system. Climate, parent material, fertility, weathering, and engineering response figure prominently in the system. The diagnostic horizons chosen to define the classes reflect the importance to people. In essence, the system is merely a communication tool invented to share information about soils for a specific objective (Cline, 1949).

The highest category in the system is the order. Orders are differentiated by "the presence or absence of diagnostic horizons". The differences among orders reflect the dominant soil-forming processes and the degree of soil formation. For instance, Mollisols have a surface horizon that is dark brown or black, are high in organic matter, high base saturation, a dominance of crystalline clay minerals. By interpretation, these are primarily prairie soils with high natural fertility and productivity. Currently, twelve orders are recognized by Soil Taxonomy (Soil Survey Staff, 1998).

The lower categories in the system differentiate between properties that influence soil genesis and are important to plant growth. Soil moisture and temperature regime, base status, physical and chemical properties, depth and texture are some of the properties and characteristics that are considered. Soil Taxonomy, 2nd. Edition (Soil Survey Staff, 1999) gives an overview of the levels of the system and the criteria for classification at all levels.

Soil Weathering Processes. Several weathering processes operate to form soils from aeolian and fluvial sediment. The driving forces in the environment are the seasonal fluctuations in temperature and moisture. Plants and animals participate in the weathering process physically and chemically. Several processes may operate at the same time throughout the soil profile. For example, eluviation operates on the surface horizon to remove clay, but illuviation operates to deposit clay in the argillic horizon.

Leaching is the removal of soluble material from the solum by rainwater moving down through the soil. Leaching of calcium carbonate is one of the first processes to begin. Young dunes usually have free calcium carbonate in the matrix and pH's of 7.5 to 8.2. Nobscot soils are leached of calcium carbonate and pH's of 5.5 to 6.0.

Illuviation is movement of material into a horizon. Argillic horizons are horizons where clay accumulates as it is carried down into the profile by water. Melanization is darkening of the surface horizon as organic matter from plant and animal residue accumulates. Eluviation is movement of material out of a horizon, for example, the movement of clay out of the surface horizon and into the subsoil.

Pedoturbation is a broad term denoting mixing in the soil. In sandy soils, most mixing is accomplished by plant roots and animal activity. This mixing destroys the original cross-bedding of the dune sediment.

No specific term exists for the process of development of soil structure. Structure is developed by wetting and drying cycles, pressure from plant roots, swelling and shrinking of clay minerals, and burrowing and ingestion by animals. Because development of structure is a process, individual soils reflect differences in the intensity of the process and the length of interval since development started.

Vegetation

Climate, fire, and human activities are the major influences on the vegetation in Major and Kingfisher Counties. A mosaic of tall grass prairie mixed with oak savannah was the original vegetation before the Cherokee Strip land run in 1893. Appendix A gives a list of common plants in the study area. Currently, the vegetation on individual sites is a product of cultivation, revegetation, grazing, and brush control practices. Even though people have greatly modified the plant composition, several trends are apparent.

Some plants prefer certain soils. For example, oaks prefer sandy soils with a low pH. The acidic residue and coarse, woody root mass promote lower soil pH and the accumulation of organic matter in the upper few centimeters of the soil. Grasses and forbs dominate loamy prairie sites that have medium textured soils with neutral or basic pH. Sedges, forbs, and trees that tolerate anaerobic conditions dominate wet sites.

CHAPTER II

REVIEW OF THE LITERATURE

The System Concept

Friend and Guralnik (1957) define a system as "a set or arrangement of things so related or connected as to form a unity or organic whole". Ritter et al. (1995) defines a system as "simply a collection of related components". In a geomorphic context, the system concept suggests that landforms are not isolated, geographically or temporally. A fluvial system requires us to study the whole system, if we are going to understand its complex response to a stressor (Arbogast and Johnson, 1993). This concept provides us an approach to incorporate all the processes in an area and formulate an understanding of development over time. To study a landform as an isolated entity may result in a faulty view of the processes that created it, the response of the landform to use by people, or the response of the landscape to climate change.

Chorley (1962) discussed geomorphology in the framework of general systems theory. He examined the advantages of viewing landscapes as open systems, and listed the benefits of viewing geomorphic systems as open systems. Two key elements in his study helped prepare the discipline for the concepts of threshold, process linkage, complex response, and, in general, an acceptance of complexity in the natural system. These two points are that an open system concept "directs investigation toward ... the essentially multivariate character of geomorphic phenomena" and "encourages rigorous geomorphic studies ... in those regions - and perhaps these are in the majority - where the evidence for a previous protracted erosional history is blurred, or has been removed altogether."

Any landscape system is the product of several episodes of different intensities in the driving forces. The interplay of these intensities on process makes each landscape area unique in its development. To understand the system, the effect each process has had on the landscape must be assessed. The system concept has been incorporated as an essential element into the analysis of the sites.

Most research on sand dunes has been conducted on landforms and deposits in semi-arid areas (Muhs, 1985; Wells, et al., 1990). This reflects the relative ease of study in dry areas compared to subhumid regions. Well-developed landforms, the relative simplicity of the systems, sparser vegetative cover, and less interaction with fluvial processes make the arid region studies easier, and more appealing to researchers.

This literature review is arranged by subjects pertinent to the topic: fluvial-aeolian interaction, Holocene climate and climate change, geomorphic thresholds, soil development, soil and sediment dating techniques, and aeolian landforms.

Fluvial-Aeolian Interaction

Climate is one of the forces driving processes that produce a landscape. If a particular climate persists over time (and other forces such as tectonic remain constant), eventually the landscape will be almost completely composed of landforms reflecting that climate (Ritter et al., 1995). It is improbable that a landscape exists where fluvial, aeolian, glacial, or tectonic processes operate exclusively, but it is possible to find landscapes where the landforms reflect the dominance of a single driving force. Western Oklahoma has many landscapes whose form suggests that aeolian and fluvial processes have operated to produce the present-day landscape. Landscapes with forms suggesting fluvial and aeolian influences are present throughout the Great Plains. This interaction between fluvial and aeolian processes in the landscape is an emerging topic in geomorphic research (Loope, et al., 1995).

In a system dominated by aeolian processes, wind energy works to dislodge material and deposit the sand down-wind as dunes or sand sheets. The fluvial system interacts with the aeolian system as the fluvial processes operate on aeolian sediment that may be deposited in a stream. If the intensity of the aeolian processes exceed the fluvial processes (A > F), the sand buries the channel. If the intensity of the fluvial processes exceed the aeolian processes (F > A), the channel is maintained. Thus, the landscape bears the marks of several different processes, and it follows that the driving forces must have fluctuated, or some intrinsic thresholds are present in the system.

Studies in print have focused on the effects of sand dunes that have dammed stream systems (Loope, et al., 1995; Knapp, 1985). Loope refers to these as "dune dams", and accepts them as such without further investigation. In the Nebraska Sand Hills, Loope, et al. (1995) found evidence for multiple episodes of blockage in large stream systems from dune dams. Their study of lacustrine sediments showed at least two episodes of dam building. They concluded that from a geomorphic perspective, these events have a climatic correlation. They also presented evidence for intrinsic control of the ground-water chemistry and water tables associated with the dune dams.

Knapp (1985) reported that some wetlands in Iowa were created by aeolian sand accumulating on uplands. One scenario was of existing watersheds blocked by linear dunes. Wetlands formed in the channels and valleys blocked by dunes.

Recently, Maxwell, et al. (1997) presented evidence from the Sahara that entire fluvial systems had been engulfed with sand during aeolian episodes. They used Shuttle Imaging Radar (SIR) to detect dendritic channel systems buried by sand. They hypothesize that a late Pleistocene/Holocene fluvial basin is now infilled with aeolian sediments.

Evidence is accumulating that aeolian and fluvial processes have interacted in the current century (Porter, 1997; Porter, et al., 1999). Aerial photographs from southwest Kansas show stream channels in the 1930s becoming engulfed with sand. A study of recent aerial photographs showed that in less than 50 years, some stream channels have been obliterated by aeolian sand (Olson and Porter, 1999). Current interaction includes instances where fluvial processes are also reestablishing the stream system in an aeolian landscape. In Alfalfa County, Oklahoma, (section 18, T. 23 N., R. 12 W.) fluvial processes are reestablishing a stream channel through an area of dunes probably mobilized in the 1930s and 1950s.

Soil Formation

A traditional study of soil genesis centers on the processes of soil formation (Simonson, 1959) and the five "soil forming factors" of time, parent material, topography, climate, and flora and fauna (Jenny, 1941; Buol, et al., 1973). For the most part, pedogenesis and soil forming processes are treated qualitatively. The soils and horizons are then described quantitatively by the properties of the various horizons. The factor of time is treated qualitatively, if at all. Even though soil is stated to be a dynamic system (Buol, et al., 1973, p. 13), soil science and soil classification in the United States strongly emphasizes the physical properties identified as being important to people. Most soil scientists do not have quantitative data about the time that it takes to form soil horizons. In addition, wide variations in climate affect the rate and intensity of the various processes (Simonson, 1959), making the time and rate of formation a formidable subject.

As the technologies develop to provide dates, more researchers are studying the absolute ages of soils and soil horizons. Absolute age data for specific features and horizons are more common, and cause soil scientists to re-calibrate their ideas of rates of processes and landscape stability.

Several researchers have used soil characteristics along with dating technologies to support hypotheses for sand movement during the Holocene. Arbogast (1997) showed that dunes in Michigan were of the same age by comparing soil development on the dunes. He correlated the development of the Spodosols on dunes with dated organic matter in peat underlying the dune.

Holliday (1985) studied the development of soil in mostly fine-grained aeolian sediments at the Lubbock Lake site. Of the late Holocene deposits, the youngest is <100 years old, the middle is about 450 years old, and the oldest is about 4,500 years old. The soils show a definite progression in development from younger to older. The youngest have slight additions of organic matter, little translocation of calcium carbonate, and little pedogenic development. The moderate age soils have well-developed B horizons, with strong structure and an accumulation of illuvial clay. The older soils have pachic or cumulic surfaces, weak, argillic B horizons, and significant calcium carbonate illuviation in the lower subsoil.

Gile (1981) studied sandhill soils in Bailey County, Texas. He separated 15 different 'soils' based on weathering and profile differences. The soils that developed in Holocene sediments were primarily divided on the basis of lamellae development: abundance, thickness, and depth. He also noted that "sandy C horizons between sets of genetic horizons demonstrate both the episodes of sedimentation and soil burial" (Gile, 1981). He based his relative age determinations on correlations with radiocarbon dates in the Texas panhandle.

Soil development and geomorphic position are two methods that have been used to establish relative age relationships between Quaternary deposits. Robbins (1976) used structural development, depth of calcium carbonate leaching, and geomorphic position to separate the terraces of the Cimarron River in Payne County, Oklahoma.

Muhs (1985) used soil-stratigraphic methods to derive relative age estimates. He compared soil development in the Colorado dune fields with the Nebraska Sand Hills and found similar soil development. Radiocarbon dates from the Nebraska soils had a maximum-limiting age of around 3,000 years, which led him to conclude that the Colorado sands were active from about 3,000-1,500 years BP. He also concluded that the dunes stabilized around 1,500 years BP, with pedogenesis commencing at that time.

Holocene Climate and Climate Change

An overview of research on climate change is important to this study because soil development is a function of climate, as are landforms. Widespread interest in climate change is fueled by speculation relating to global warming. There is speculation that warming on a global scale will increase temperatures in the Great Plains and have a negative effect on vegetative cover and landscape stability. Since historical records for the study area were not kept until after 1890, researchers use climatic modeling and the sedimentary record as proxies for Holocene climate and geomorphic processes.

The term 'climate change' itself is subject to misinterpretation - namely that climate is naturally stable, and any variation is 'unnatural' and hazardous. A review of climatic variability in the United States over the past 2,000 years gives evidence that the climate naturally varies, including drought of varying length, geography, and intensity (Woodhouse and Overpeck, 1998b). Emerging research from western Oklahoma indicates a 400-year cycle of mesic and xeric episodes during the last 2,000 years (Thurmond and Wyckoff, unpublished data, 1999). The concept of 'climate change' may stem from humans' limited life span and inability to perceive the natural variability of the climate.

Several researchers have concluded that significant variations in climate occurred in the Southern plains during the Late Pleistocene and Holocene (Hall, 1982, 1988, 1990; Humphrey and Ferring, 1994). Dates for large geomorphic events (i.e. paleofloods) correlate with these climatic variations in the Great Plains (Ely, 1997; McQueen, et al., 1993). It may be that periods of dune construction are associated with the system instability during these climatic shifts.

Kibler (1998) studied aeolian sediments in a rock shelter in Garza County, Texas. His analysis showed a marked increase in aeolian sediment between 900 and 700 years BP. Three separate aeolian events were recorded in the sediments in the shelter. He concluded that aeolian deposition marked a shift to a climate that was drier and more variable, and "increasingly arid in the second millennium".

Swinehart (1995) argued that the sands overlying peat in localities covering 15,000 km^2 of the Nebraska Sand Hills indicate extended drought conditions with regional mobilization of sands. Madole (1994) indicated that aeolian sand deposits in northeastern Colorado record depositional periods in the early, middle, and late Holocene. Archaeological evidence, soil development, and dune topography indicate the youngest deposits may be less than 1,000 years old.

Arbogast and Johnson (1998; Arbogast, 1994) found episodic sand mobilization throughout the last 10,000 years and significant activation in the last 2,500 years near Great Bend, Kansas. The sand sheets and dunes were mobile from about 5,700-4,800, 2,300-1,700, 1,600-800, and less than 200 years BP. Mineralogical studies of the Great Bend sand plain showed that the dunes are little weathered and are similar in composition to the source sediments from the Arkansas River (Arbogast and Muhs, 1998). They concluded that the Great Bend dunes could have formed in the last few thousand years. Swinehart (1991) studied dunes in the Nebraska Sand Hills that gave evidence of significant migration between 9,000 and 3,000 years BP, and reactivation after 2,000 years BP.

Recently published studies by Muhs, et al. (1996) gives additional evidence for deposition between 4,000-1,500 years BP and additional periods of deposition around

1,000 years BP. He concluded that northeastern Colorado is very near a climatic boundary that separates active from stable sand. This evidence from Muhs, et al. (1997) agrees with Arbogast (1993, 1994) that significant aeolian activity has taken place within the last 800 years.

The widespread deposits of aeolian sand in Colorado led Madole (1995, 1994) to conclude that the climate has been dry enough to cause regional sand mobilization in the last 1,000 years. Even though model simulations show minimal climatic variability, the stratigraphic and soils evidence supports an arid period around 1,000 years BP in eastern Colorado.

Evidence exists for severe drought on the Great Plains in the 18th century (Meko, 1992). Meko's analysis of dendrochronological data indicates that the droughts of the 1800s were more severe than the historical droughts of the 1930s and 1950s. Explorer's diaries and other written evidence (Muhs and Holliday, 1995) corroborate Meko's analysis.

Ahlbrandt, et al. (1983) collected much of the research on dune fields of the northern Great Plains. They concluded that several episodes of aeolian activity occurred in the Holocene. They used evidence from several disciplines to reinforce their hypothesis, including radiocarbon dates, archaeological evidence, and palynology. Hall (1990) studied stream channels in the southern Great Plains and developed a chronology of Holocene climate based on rates of alluviation and channel trenching.

If aeolian activity affected sandy sediments during the Holocene, finer-grained materials should also have been mobilized. Willey and Johnson (1998) studied the Bignell loess in Kansas and Nebraska. They reported soil development in the loess deposits at about 7,500, 6,000, and 3,000 years BP, with deposition in the intervening intervals. The lack of soil development between 3,000 and 6,000 years BP indicates relative instability during the middle Holocene. Olson, et al. (1997), however reported middle Holocene soils developed in the loess of western Kansas. Mason and Kuzila (1998) reported a four meter thick Holocene loess sequence in central Nebraska. Three paleosols are present in the loess, dated at 9,330, 8,790, and 3,010 years BP. The paleosol dates represent stable periods, and the periods of loess deposition should correspond with arid climatic episodes.

Other measures are also a proxy for climate. The Mg/Ca ratio of ostracode shell is a proxy for salinity and aridity. Yu and Ito (1999) examined Mg/Ca ratios in ostracodes from Rice Lake, North Dakota. Their data shows a climatic periodicity of about 400, 200, 130, and 100 years. The drought history at Rice Lake correlates with principle solar oscillations of Stuiver and Braziunas (1989). They suggested that solar forcing is the dominant factor in drought frequency in North America. The 400 year cycle also correlates with data from Roger Mills County, Oklahoma (Thurmond and Wyckoff, unpublished data, 1999). Their data indicates a 400 year cycle of occupation and abandonment by native peoples, with aeolian deposition during periods of abandonment.

Sediment Dating

Radiocarbon techniques may be used to date sediments, soil organic matter, bone, charcoal, and wood. Soil humus is an important source of datable carbon on the Great Plains. Madole (1994) studied recent (<1,000 years BP) aeolian sands in Colorado.

Preliminary correlations with archaeological dates indicate the dates from total soil humate samples appear to be reliable. He argued that dates from soils in arid areas do not have the problems associated with humate samples in humid regions. Lichter (1997) used AMS 14C dates to establish the chronology of beach-ridge formation on Michigan. By careful sampling of buried plant remains, he found that the dates reliably estimated the timing of ridge development. Bartlein, et al. (1995) demonstrated the importance of calibrating radiocarbon ages. A calibration program (Stuiver and Reimer, 1993) adjusts radiocarbon dates for the fluctuating production of radiocarbon in the atmosphere.

Others are more pessimistic that the dates for soil organic carbon are reliable. Martin and Johnson (1995) split a variety of soil samples and submitted them to two laboratories for dating. They dated total, residue, and humic acid fractions, and found that dating results may vary widely between laboratories. Of 21 samples, only seven had 2-sigma (two standard deviation) ranges that overlapped. Of these seven, five were late Holocene samples. Older samples showed more variation between laboratories and methods.

Wang, et al. (1996) evaluated radiocarbon ages of soils with a mathematical model that incorporated the carbon dynamics of the system. They cautioned that dating buried horizons over-estimates the true age of burial. There are continuous additions and removal of organic matter from a soil. The age of a soil humus sample will be an average of the time since soil development began, or since a steady state was reached.

Aeolian Landforms

Brady (1989) concluded that the paleowind speed and direction that emplaced dunes in Major and Alfalfa Counties, Oklahoma were similar to the modern prevailing winds. He showed that several periods of aeolian activity occurred in the Late Pleistocene and Holocene, reporting radiocarbon dates of paleosols beneath dunes ranging from 1,200 years BP to 11,345 years BP. The correlation between dune age and the mapped soil series was low. Less developed soils sometimes occupied dunes with old radiocarbon dates.

Kocurek and Nielson (1986) and Fryberger, et al. (1979) describe factors that influence the formation of sand sheets. Wells, et al. (1990) summarized the factors that affect the formation of sand sheets. He noted that vegetation, grain size, high water tables, and surface cementation promote the formation of sand sheets. In addition, undulating topography can affect the flow of wind over the land surface and promote the formation of sand sheets. The development of sand sheets is related to relatively moister conditions than other aeolian landforms.

The most common dune form in the Chaco dune field (northwestern New Mexico) is the detached parabolic dune. Blowouts have destroyed the noses of these parabolic dunes, and they are often misidentified as parallel linear dunes (Wells, 1990). Ridge dunes also occur in the Chaco dune field on the edge of upland pediments. They are most extensive adjacent to thick fluvial deposits in paleochannels. He found a wide variety of aeolian landforms associated with late-Holocene activity. The late-Holocene landforms are the most variable of all the aeolian landforms developed during the

Quaternary. Also, the widespread sand deposits have such high infiltration rates that they restrict the development of fluvial drainage networks.

Lancaster (1997) studied dune systems in southern California from a system perspective. He showed that precipitation is the major factor in aeolian activity at a decadal to century scale. The system perspective allowed him to relate dune activity in the Coachella valley to sediment supply. The sediment supply is controlled by fluvial activity (episodic valley dissection and sediment delivery), and is related to precipitation patterns and amounts.

Fluvial Landforms

Arbogast (1994) worked to correlate events such as soil development (an indication of stability), aggradation, and channel trenching in river basins in Kansas. He found a broad correlation for Holocene climate change across the region, based on radiocarbon dates of floodplain soils and channel cuts and fills. In the Wolf Creek basin of Kansas, he found that the variation between tributaries and segments of the main channel support the ideas of complex response and process linkage in geomorphic systems.

Mandel (1998) made an extensive investigation of geomorphic processes in the Kansas and Arkansas River systems. He found that erosion, alluviation, and soil development were diachronous through a basin, but were synchronous between large basins. Small, low order tributaries reacted differently to external climatic controls than the large, high order main streams.

Ward and Carter (1999) calculated the incision rates for rivers in the middle Arkansas River basin. They used volcanic ash beds as markers and estimated incision rates since placement of the ash. As part of this study, they measured the stream gradient at locations in the study. In terms of absolute slope, the gradients varied from 0.0006 to 0.0025. Gradients vary between streams and along individual streams.

The number of terrace levels along the rivers of western Oklahoma depends on the researcher and the size of area studied. Most theses and small studies report four terraces along the Cimarron River (Nayyeri, 1975; Meyer, 1973). Carter, et al. (1990) correlated stream terraces with soil series and elevation in western Oklahoma. He identified five or six terrace levels on the south side of the Cimarron River, but made only limited investigations on the north side of the Cimarron River.

Schumm and Lichty (1963) studied the flood plain and channel of the Cimarron River in southwest Kansas. They found that channel processes on this type of river are dependent on climatic factors. Periods of low precipitation had the largest runoff producing events and largest floods. This is consistent with James' (1823, in Muhs and Holliday, 1995) observation on the Canadian River and with Bryan (1940) and Antevs (1952).

Geomorphic Issues

Intrinsic and Extrinsic Factors

Arbogast and Johnson (1998) concluded that the development of dunes and other aeolian features in Kansas were in response to climate change. Pedogenesis occurred during moist intervals, and aeolian activity, including truncation and deposition occurred during relatively dry periods.

Loope, et al. (1995) made the point that once a dune dam is in place, the hydrology of the area is controlled by intrinsic factors of the dam - hydraulic conductivity, height, and location. The initial development of the dam is controlled by the climate, an extrinsic factor.

Forman, et al. (1995) inferred that the dry middle Holocene was the result of a shift of the Bermuda high to the east of its normal position. They maintained that the aeolian activity was a response to extrinsic forcing by the climatic factors.

Lemmen (1998) studied geomorphic response to climate change on the southern Canadian prairies. He found that aeolian activity shows the "most direct and predicable response to climate change", and that widespread aeolian activity was present as recently as 150 years BP. The fluvial response is the least predictable, and that poor correlations between valleys are the result of intrinsic factors. He also concluded that dunes on the Canadian plains are close to threshold conditions for mobilization.

Complex Response

Maxson and Walby (1998) described geomorphic processes and landscape in Minnesota in the 1930s. Aeolian deposition in Lake Ann resulted from dune denudation and mobilization. At the same time, tributaries of the Mississippi River aggraded when large precipitation events eroded valleys and silty plateaus. The valleys and plateaus had low vegetative cover due to the drought.

In a study from San Diego County, California, Kochel, et al. (1997) demonstrated complex response by a landscape system to minor climatic changes. During a six year wet period (1978-1983), the landscape response varied according to the plant community. Mountain slopes experienced an increase in vegetation cover, and a low sediment yield. The desert shrub community yielded the most sediment with no increase in vegetative cover. Along the San Felipe River, aggradation and downcutting occurred simultaneously on different reaches. Aggradation began at different times on different reaches . The upper reach began to aggrade in 1983 at the end of the wet period, and continued for several years.

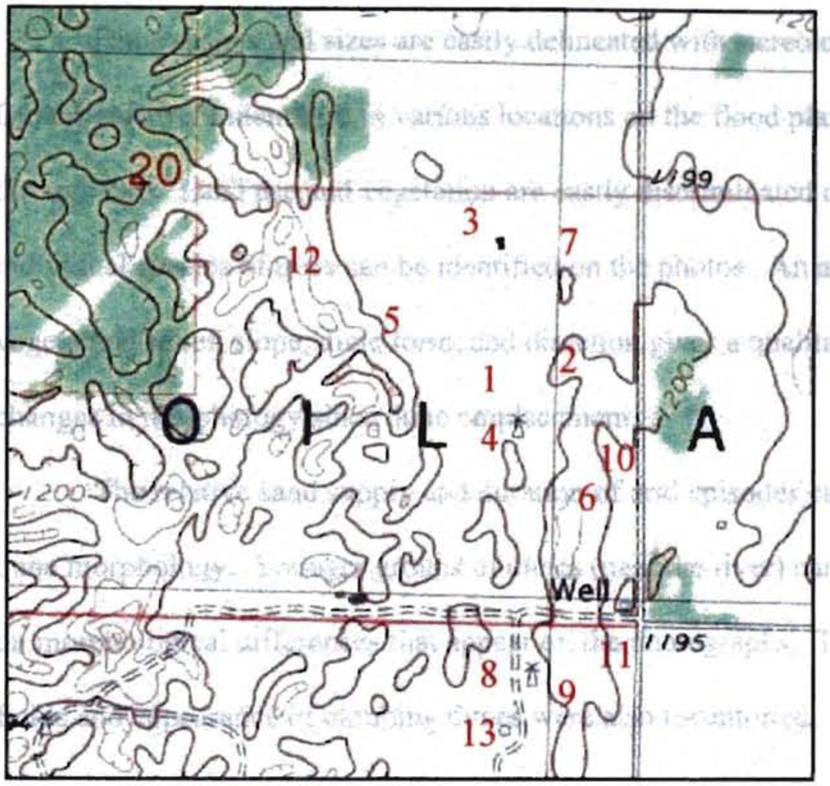
CHAPTER III

METHODS AND MATERIALS

Several methodologies were employed to investigate the geomorphic processes that have been, and are active at this site. The first action was interpretation of aerial photographs and soil maps. A regional geomorphic surface map of the region was prepared, covering about 390 km^2. Soil development and sedimentology of the site were inferred from 22 cores taken from the two sites on the Qt2 terrace (Figure 4). Selected horizons were sampled for radiocarbon dating. A total station survey of the Hanor farm site provided accurate vertical control for correlation of the profiles. Finally, gradients of the terrace levels and streams in the region were used to correlate the terrace surfaces.

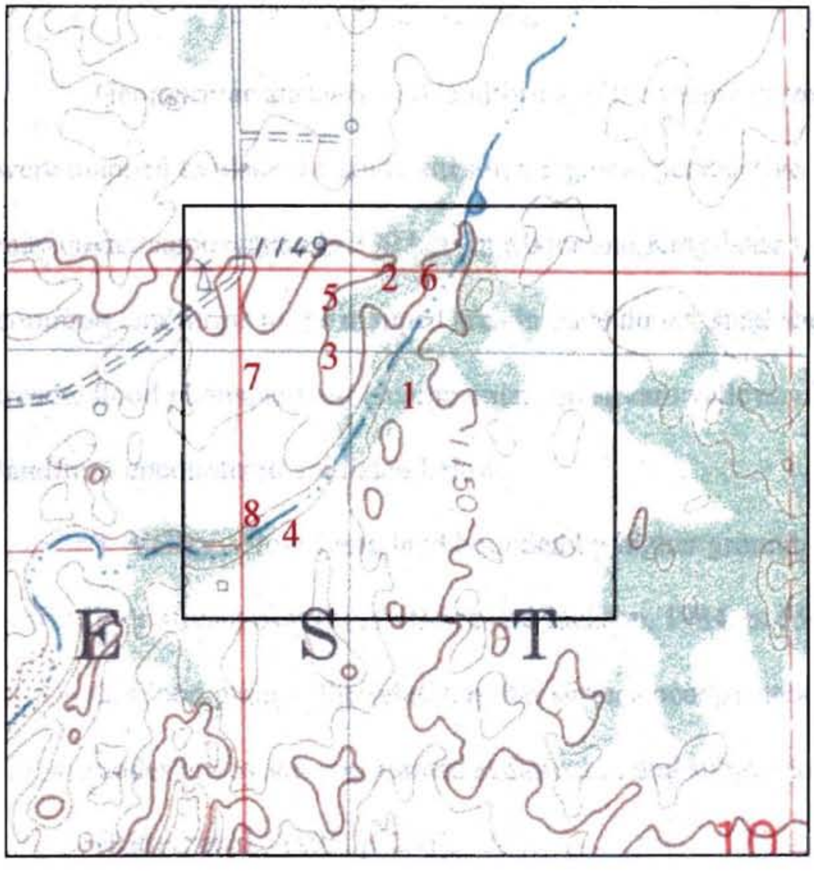
Photo Interpretation

Aerial photos of the site were obtained from the Natural Resources Conservation Service. Standard monochrome coverage at 1:7920 scale (12.6 cm per km) is usually flown during the winter (leaf-off) to obtain the best image of the ground and topography. Several different years, 1997, 1990, and 1982 were available at the office at Fairview, Oklahoma. Older aerial photos dating back to 1937 were obtained from Felder Surveying, Okeene, Oklahoma and examined.



Hanor Farm.
Scale = 1:14,000.

Figure 4. Soil Description Sites on Hanor Farm and Hajek Ranch.



Hajek Ranch.
Scale = 1:11,000.

Dune shapes and sizes are easily delineated with stereo coverage on aerial photos. Dune fields were identified in various locations on the flood plain and terrace levels Qt1 through Qt8. Land use and vegetation are easily discriminated on the photos, and many individual species of trees can be identified on the photos. An analysis of land use, vegetation, relief, slope, dune form, and direction gives a qualitative evaluation of the changes in morphology since dune emplacement.

The relative sand supply and duration of arid episodes can be inferred from the dune morphology. Younger groups of dunes (near the river) can also be separated based on morphological differences that appear on the photographs. The width of the dune fields and appearance of climbing dunes were also inventoried.

Surface Mapping

Geomorphic surfaces and landforms of the region surrounding the study sites were mapped to place the study sites in a regional perspective. The geomorphic surface map covers approximately 390 km^2 in Major and Kingfisher Counties (Figure 3). The common landforms in the mapped area include dunes, sand sheets, fluvial stream terrace treads, flood plains, terrace escarpments, and stream valleys. Definitions for each landform encountered are listed below.

1. Valley - "low-lying land bounded by higher ground, usually traversed by a stream or river..." (Bates and Jackson, 1984, p. 550).
2. Flood plain - "the relatively flat surface occupying a valley bottom, underlain by unconsolidated sediment ... and subject to periodic flooding" (Ritter, et al., 1995, p. 231).

3. Terrace - "abandoned floodplains ... formed when the river flowed at a higher level than at present"(Ritter, et al., 1995, p. 240). It is interesting to note that Ritter links landform to process with the following: "the presence of a terrace demands an episode of downcutting" (Ritter, et al., 1995, p. 241). The relatively flat upper surface of the terrace is the tread.

4. Escarpment - "the steep slope connecting the tread" of a terrace "to any surface standing lower in the valley" (Ritter, et al., 1995, p. 240).

5. Dune - "a mound, ridge, or hill of wind-blown sand..." (Bates and Jackson, 1984, p. 154).

6. Sand sheets - "tabular bodies of sand ... often marginal to dune fields" (Ritter, et al., 1995, p. 282).

The geomorphic surface map (Figure 3) was prepared using field examination, the published soil surveys, and USGS 7.5' topographic quadrangles. Observations were made along section line roads and field roads including the soils and landscape features. Features are separated based on shape, elevation, slope, vegetation, soils, and gradient direction. Most of the area is cultivated, and entire sections are usually visible. Escarpments were located visually, and confirmed on the topographic maps. Many of the terrace treads are covered with sand sheets. Relatively thin sand sheet mantles are mapped as an inclusion on the terrace surfaces. Less than about one meter of sand, slope less than 3 percent, and mostly cultivated land use were the criteria for choosing to include thin sand sheets with the terrace surface. Terrace escarpments obscured by sand dunes are not shown. Inadequate information usually did not allow accurate placement of buried escarpments.

Stream and Surface Gradients

Gradients of the streams were taken from USGS topographic maps, 7.5 minute series provided the gradients of the streams, valleys, and terraces in the region. To assess the validity of the geomorphic surface mapping, cross-sections of the topography across the terrace system were prepared. The cross-sections show the elevations from the west side of the Cimarron River to the uppermost terrace level (Figure 3). Section A-A' (Figure 5) shows elevations from the river, northeast through the Hanor farm site, to the divide west of Ames. Section B-B' (Figure 6) shows elevations from the river south of the confluence with Indian Creek, northeast to a point 1.61 km west of Meno, Oklahoma. Section C-C' (Figure 7), running east to the Garfield County line shows the surface slightly to the south of the Hanor site.

Soil Profile Coring, Description, and Sampling

A truck-mounted Giddings probe was used to procure soil cores at the study sites. The Giddings probe is a hydraulic, power take-off operated machine capable of taking undisturbed soil cores up to 12 meters deep. Actual depth achieved depended on soil texture and groundwater conditions. Augur samples can be taken with the Giddings probe up to 15 meters deep. Most cores recovered were 7.62 cm in diameter. Some of the deeper cores were 5 cm in diameter. Occasionally, soft sediments or groundwater prevented acquisition of suitable core sample. In those instances, the augur was used to obtain samples, but augur samples are well mixed, structure is destroyed, and actual depth of the sample is questionable.

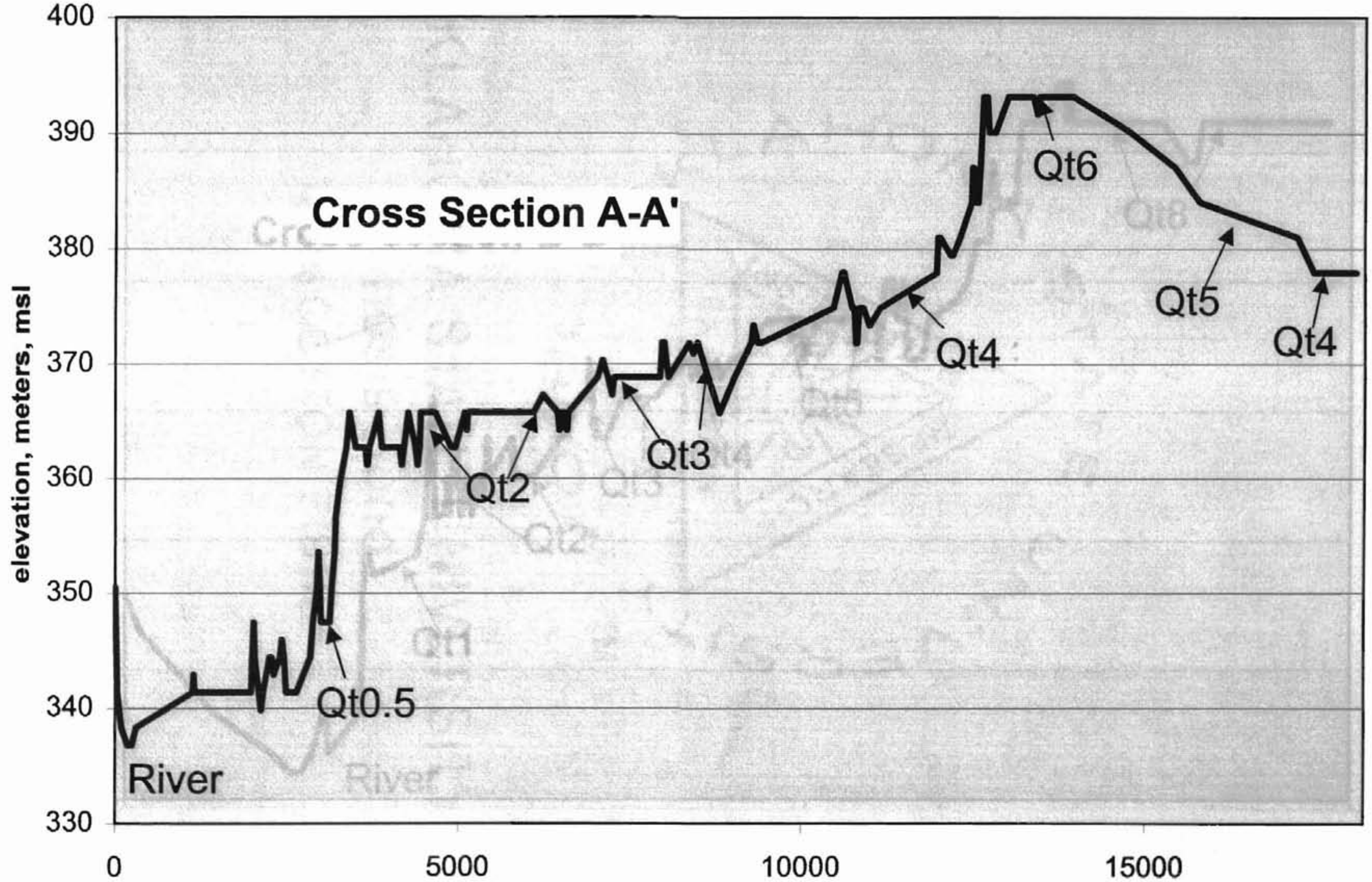


Figure 5: Cross-section A-A'

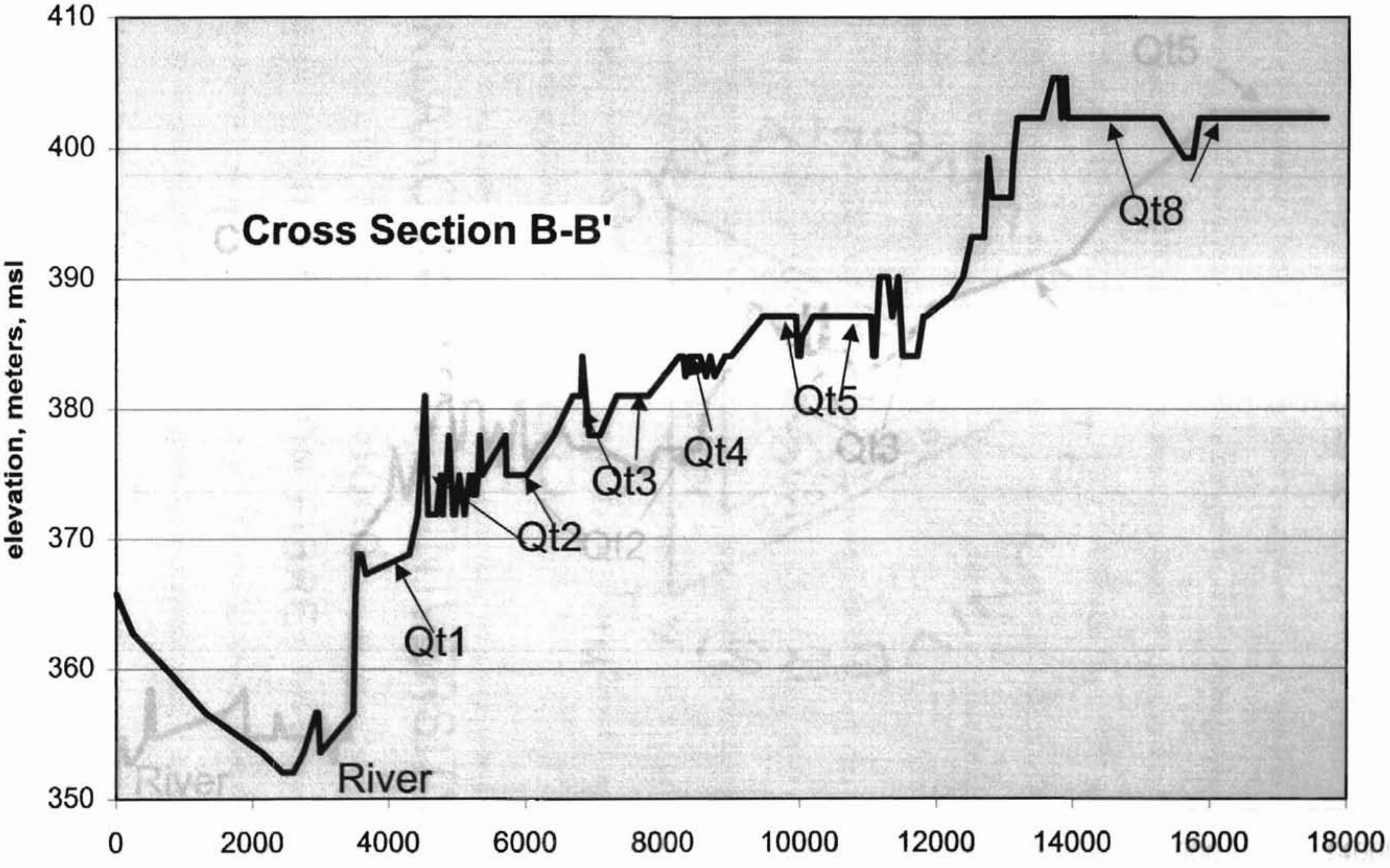


Figure 6: cross-section B-B'

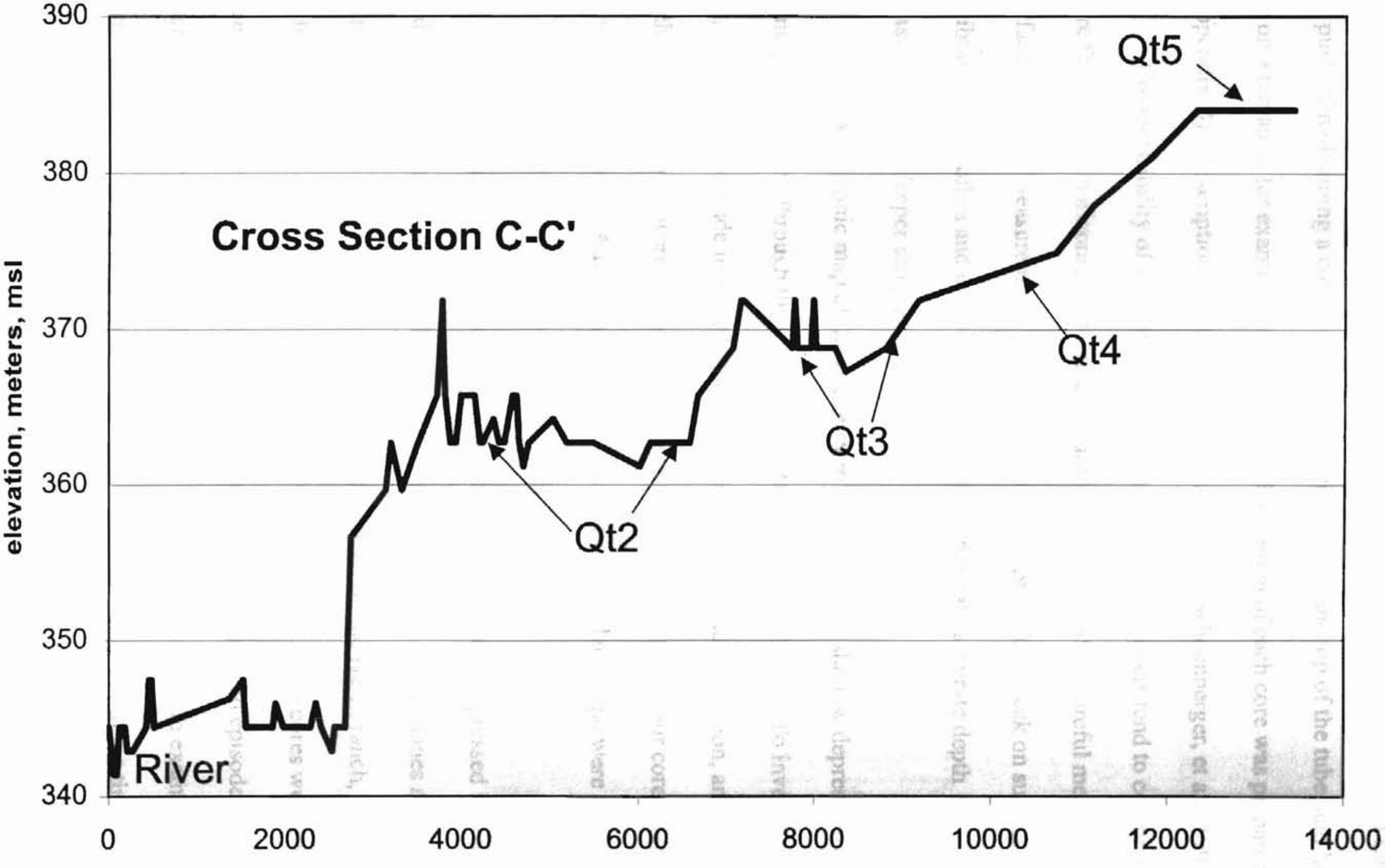


Figure 7: Cross -section C-C'

Sample tubes for the Giddings can collect up to one meter of undisturbed sample per push. On obtaining a core sample, it was removed out the top of the tube, and laid out on a tarpaulin for examination. A detailed description of each core was prepared (Appendix B). Descriptions comply with the standards of Schoenberger, et al. (1998).

Compressibility of soil samples is a concern. Surface layers tend to compress more than subsoil horizons, but vertical accuracy is maintained by careful measurement. Surface thickness measurements from satellite samples provide a check on surface layers. Calibrated probe tubes and extension bars helped to maintain accurate depth measurements of deeper samples.

The topographic map of the Hanor farm shows a wide, shallow depression running north-south through the middle of the farm (Figure 8, 9, 10). To investigate the site, a transect was made in a north-south direction through the depression, and transects on the adjacent dunes were aligned in the same directions. Three to four cores were taken in each transect. Additional cores on other parts of the landscape were taken to confirm the evidence from the primary cores (Table I).

On the Hajek ranch, the windward side of the dune field is expressed in a complex field of dunes. A small perennial stream flows southwest through the dunes at this site (Figure 4, 11, 12). Eight cores were taken and described on the Hajek ranch, and the landscape on both sides of the perennial stream was examined. Two cores were taken on dune summits to examine the highest dunes, look for the depositional episodes, and describe the underlying terrace. Four interdune locations were cored to examine the sand sheet stratigraphy and the terrace surface. Two locations were cored along the stream channel and valley to examine the sediments and processes along the stream. The cores

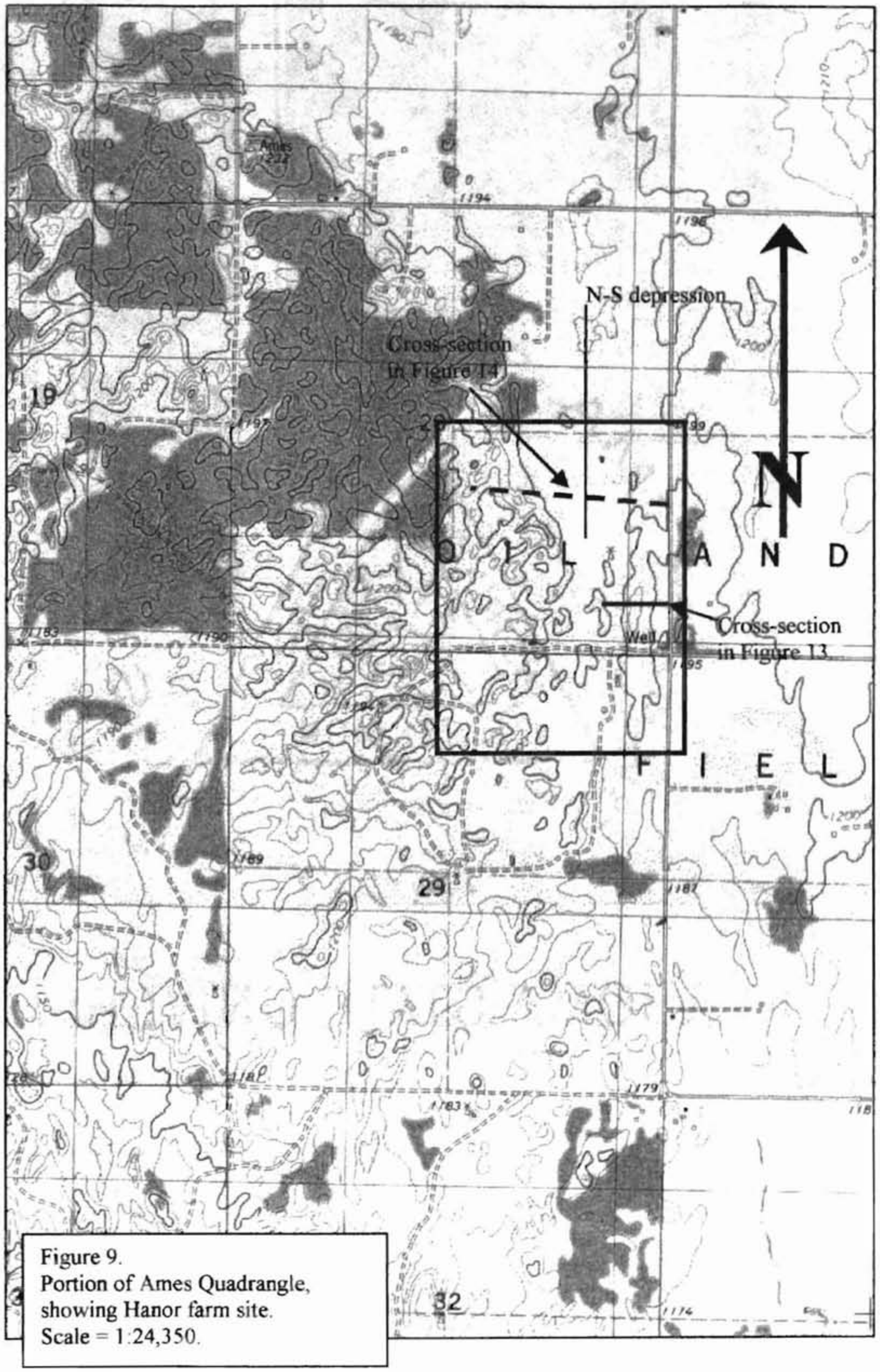


Figure 9.
Portion of Ames Quadrangle,
showing Hanor farm site.
Scale = 1:24,350.

Figure 10. Aerial Photograph of the Hanor Farm. Scale=1:10,500.

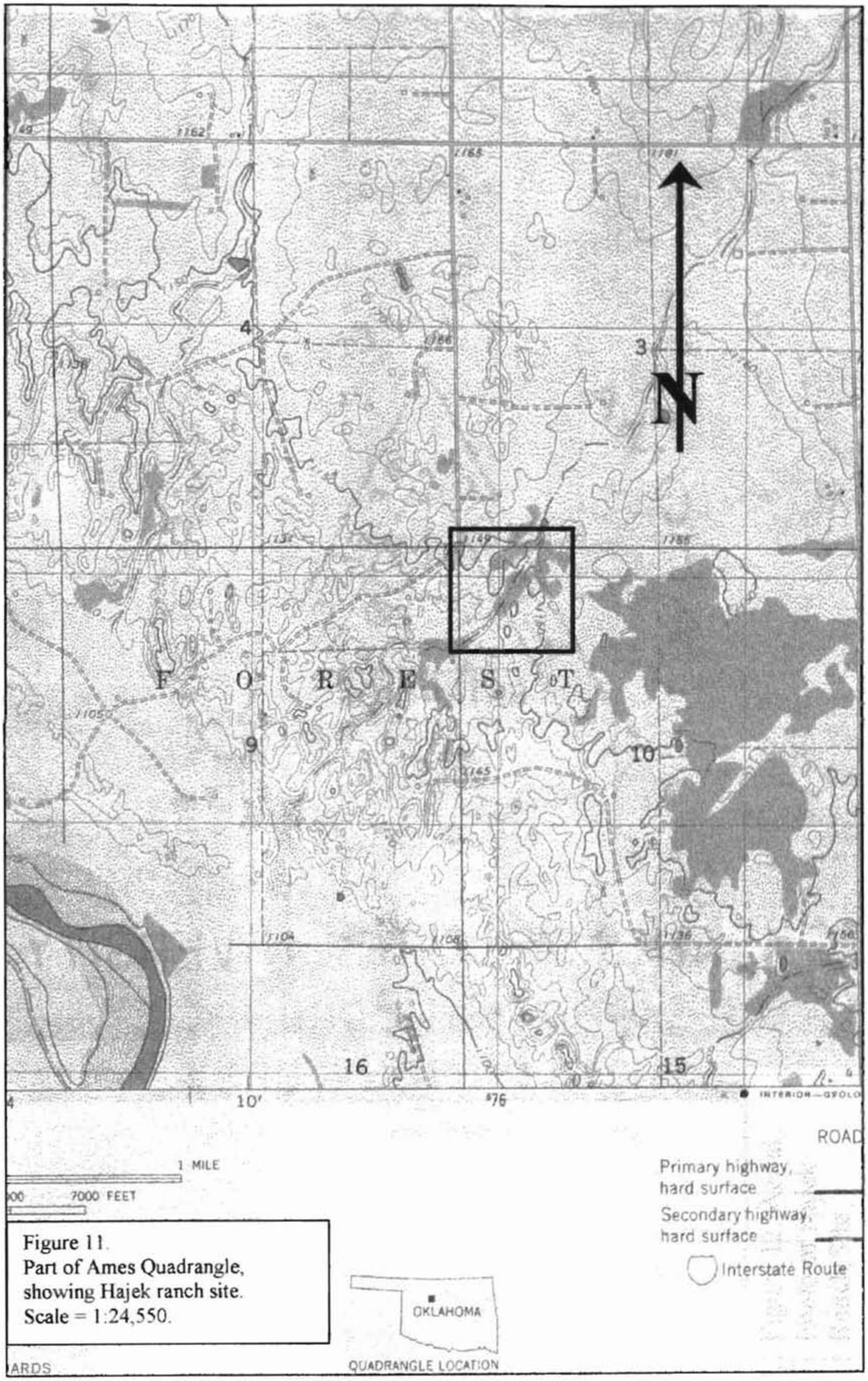


Figure 11.
Part of Ames Quadrangle,
showing Hajek ranch site.
Scale = 1:24,550.

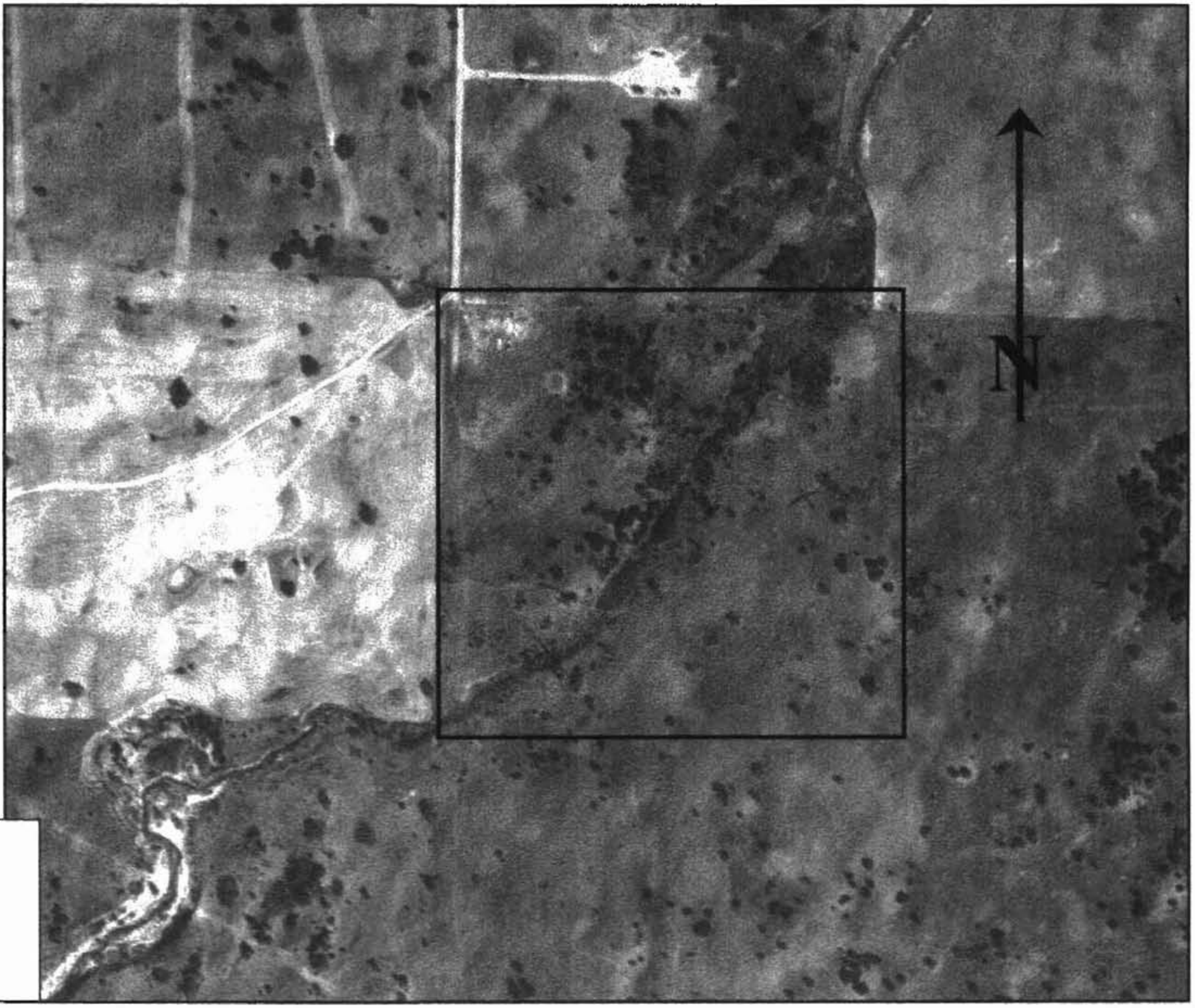


Figure 12. Aerial Photo of Hajek Ranch Site. Scale = 1:6,300.

on the Hajek ranch also were taken to locate the buried terrace surface and the buried escarpment at the proximal edge of the terrace (Table I).

Thirteen profiles on the Hanor farm and eight profiles on the Hajek ranch were cored and described, and selected profiles and horizons were sampled for radiocarbon dating. Radiocarbon samples were inspected for contamination from other horizons and any soil or dust that could contaminate the sample was removed.

TABLE I

Landscape Positions Of Described Profiles

Pedon number	Site	Position
98-OK-093-1	Hanor	depression
98-OK-093-2	Hanor	summit of longitudinal dune
98-OK-093-3	Hanor	depression
98-OK-093-4	Hanor	depression
98-OK-093-5	Hanor	summit of blowout dune
98-OK-093-6	Hanor	dune summit
98-OK-093-7	Hanor	sandsheet
98-OK-093-8	Hanor	sandsheet
98-OK-093-9	Hanor	summit of longitudinal dune
98-OK-093-10	Hanor	depression
98-OK-093-11	Hanor	depression
98-OK-093-12	Hanor	summit of ridge dune
98-OK-093-13	Hanor	depression
98-OK-073-1	Hajek	interdune
98-OK-073-2	Hajek	dune summit
98-OK-073-3	Hajek	dune summit
98-OK-073-4	Hajek	stream valley
98-OK-073-5	Hajek	interdune
98-OK-073-6	Hajek	stream floodplain
98-OK-073-7	Hajek	interdune
98-OK-073-8	Hajek	interdune

The large dune field that partially covers the Qt2 surface runs for more than 16 km along the terrace. The slip face, or lee edge, of the dune field is present on the Hanor farm. The windward proximal slope is present on the Hajek ranch.

Soil Profile Interpretation, Stratigraphic Methods

Texture, horizon development, presence or absence (truncation) of horizons, clay illuviation, buried surfaces, structure, and relationship to the surface topography provide evidence to establish the processes and stratigraphic relationships. Other soil characteristics such as color, pH, calcium carbonate content, roots, pores, and other mineral concentrations preserve relict evidence of the soil environment before burial.

Each profile was examined to establish the stratigraphy and depositional framework. The soil texture, grading, and depositional structure establish whether the sediment is aeolian or fluvial. For aeolian sands, the depth of weathering establishes the length of time since emplacement. Destruction of cross-bedding and development of soil structure is a primary measure of weathering. Buried surface horizons define the end of stable periods and the beginning of aeolian depositional events. Truncated profiles in the section are evidence of erosional events preceding subsequent deposition. Features such as illuvial clay, concretions, redoximorphic features, strong structure, and biological relicts are evidence for stable soil-forming intervals. The thickness of buried solums is evidence for the intensity and duration of soil forming intervals.

Relative Dating Methods

Relative dating methods rank a group of features, in this case, dunes from youngest to oldest. Relative dating does not provide absolute dates for deposits or processes, but establishes age relationships between features. It provides additional or corollary evidence for absolute dates and a quick way to examine large geographic areas. Relative dating methods have been used on the Cimarron River by other researchers (Robbins, 1976; Brady, 1989).

In the study area, several characteristics associated with the dunes provide information to rank the dune formations from youngest to oldest. Vegetation, depth of weathering, development of the soil profile, dune pattern, position, distance to the sand source, and dune morphology all give clues to the relative age and relationships of the major dune fields. During preparation of the geomorphic surface map, these characteristics were inventoried and used to support the correlation. The types of dunes, abundance of each type, slope, shape, and height were noted. Percentage of ground cover and percentage of the dune field cultivated, estimated from aerial photos was inventoried.

Radiocarbon Dating

Three samples were selected for radiocarbon dating and sent to Beta Analytic labs in Miami, Florida. The samples were selected to provide delimiting dates for the aeolian processes. The sample from pedon 98-OK-093-3 on the Hajek ranch is the Ab horizon, at 457 to 495 cm. This horizon was the surface of the soil that developed on a sand dune, later buried by the last aeolian episode.

The two samples from pedon 98-OK-093-6 are two buried surface soils in the high dune that is part of the eastern group of dunes on the Hanor farm. The upper sample is from the Ab horizon, at 307 to 337 cm. It is also the surface horizon of a buried dune, and stratigraphically at the same position as sample 98-OK-073-3. The lower sample is from the 4Ab horizon at 665 to 693 cm, the surface horizon of the Qt2 surface.

Sample Treatments

The amount of soil for analysis was limited to the amount from the core. About 500 grams of each sample was submitted to Beta Analytic. Pretreatments were applied to isolate the 14C that best represents the time event of interest. The pretreatment regimen depends on the material submitted and its context in the environment. Oklahoma soils are generally high in carbonates, and the pretreatment to remove them is intense (Beta Analytic, 1999). The sample was subjected to repeated acid (HCl) washes to remove carbonates. The treated sample did not have enough carbon for conventional analysis. The remaining carbon was reduced to graphite and sent to one of the collaborating facilities for accelerator-mass-spectrometer (AMS) 14C measurement. Beta Analytic prepared the calendar calibration and isotopic correction, and delivered the final results (Beta Analytic, 1999).

CHAPTER IV

RESULTS AND DISCUSSION

The sections of this chapter give the results of the different segments of this study. The sections are arranged by regional surface mapping, radiocarbon dating, soil-stratigraphic studies, and relative dating studies. The results of these analyses are used as appropriate to discuss the major points listed in the introduction and hypothesis.

Regional Surface Mapping

The surface map covers 390 km^2, and includes the Hanor farm and Hajek ranch. The boundaries of the mapped area are, on the south, Oklahoma state highway 51, on the east, the Major County line, and on the west, Indian Creek and the Cimarron River. The north boundary is the section line 1.6 km south of highway US 412.

The geomorphic surface map (Figure 3) shows eight major terraces (Qt1 thru Qt8) in the mapped area. Each terrace has a field of sand dunes associated with it. Ridge dunes are parallel with the terrace and are usually located on, or adjacent to, the escarpment. At least part of each escarpment is mantled by sand dunes. Subsequent remobilization has modified the dunes, spreading dunes and sand sheets onto terrace surfaces. A wide range of aeolian landforms is present on the terraces.

This is the first detailed mapping of the terraces on the Cimarron River in western Oklahoma. Previous work (Ward and Carter, 1999; Nayyeri, 1975; Meyer, 1973) identified 4 to 6 or more terraces. The eight terraces identified in this report define the alluvial sequence from the flood plain up to the elevation between Ringwood and Meno, Oklahoma. Additional terraces north of the mapped area are not included in this study. Two or three higher terraces are on the divide between the Cimarron River and Salt Fork of the Arkansas River, between 408 and 442 meters MSL. The highest terrace in this study has an elevation of 399 to 405 meters MSL. The elevation change between terraces is generally 3 to 6 meters.

The Qt1 terrace is an average of 17 meters above the Cimarron River. The Hanor farm and Hajek ranch sites are located on the Qt2 terrace, about 27 meters above the river. The Hanor farm is on a narrow part of the Qt2 terrace, and occupies the levee, valley flat, and backswamp positions on the terrace. The Hajek ranch site is on the proximal portion of the Qt2 terrace and occupies the levee and valley flat positions. On the Hajek ranch, dunes and the sand sheet accompanying them mask the terrace escarpment.

Several features have geomorphic significance. The terraces vary in width. Qt3, Qt5, Qt6, and Qt8 are the widest terraces. Qt1 is present at the junction of Indian Creek and the river, and a small area south along the river. Qt2 is present, but is narrower than the older terraces, and is mostly covered with dunes. Qt6 and Qt7 are associated with Turkey Creek. Qt4 is present only sporadically, but it is normal that terraces are not equally preserved. Sand is present in different abundance on each terrace. The size of an individual dune field is a relative measure of the duration and intensity of the depositional processes.

The pattern of older dunes (on the Qt4-Qt8 terraces) is more complex because of repeated mobilization. Dunes cover the terrace surfaces and join deposits of different age. Sand sheets of varying thickness mantle much of the terraces. This complex of sand hills isolates some terrace surfaces, both longitudinally and across the gradient. Surfaces are correlated based on the elevation, gradient, and relation to higher and lower terrace remnants. The cross-sections provide a test and correlation for the surface mapping.

Legend

The terrace levels are mapped from youngest (Qt1) to oldest (Qt8). One isolated area of a small terrace is designated as Qt0.5, lying below the Qt1 terrace but above the flood plain. The abundance of sand masks any other evidence of the Qt0.5 terrace. A boundary separating two terrace units indicates an escarpment.

The dune fields are mapped as Quaternary sandhills, Qsd, with the exception of the young sands mapped in the Tivoli series, Hsd. The Tivoli unit is a wide dune field occurring between the flood plain and stream terraces. It was completely deposited during the Holocene, but some of the younger Qsd dunes were possibly deposited or extensively modified during the Holocene. Multiple episodes of local and regional reactivation makes mapping divisions in the older sand deposits less meaningful at the intensity and scale of this map. The flood plain, Qal, includes all frequencies of flooding. The modern dunes on the flood plain are an inclusion in the flood plain map unit.

Cross-sections

Three cross-sections of the surface topography were prepared to test the surface mapping. Terrace treads, ridge dunes, depressions, escarpments, and sandhills are shown on cross-sections. Depressions in the landscape represent the backswamp positions. The ridge dunes appear at the escarpments, and the newest ridge dune shows up at the riverbank on section B-B' (Figure 6). The cross-sections show the relationships between the terraces and the sandhills.

Section A-A' (Figure 5) shows the topography from the river northeast through the Hanor site, to the Garfield County line. The highest terraces are absent in this transect, not extending down the interfluve between the Cimarron River and Turkey Creek. This transect shows the terraces descending towards Turkey Creek. The terraces that grade to Turkey Creek have only minor areas of sand, and the escarpments are more evident. The Qt2 and Qt3 terraces have backswamp positions that were presumably consequent streams until the aeolian sand blocked the flow. The Qt4 and Qt5 terraces are poorly represented on this transect. The sand hills have almost obscured these terraces.

Section B-B' (Figure 6) shows seven terraces from the confluence of Indian Creek and the Cimarron River to a point 1.6 km west of Meno. Ridge dunes are adjacent to the flood plain, Qt1, Qt2, and Qt6. Depressions on Qt2, Qt4, and Qt8 indicate backswamps with possible consequent streams.

Section C-C' (Figure 7) shows the surface slightly to the south of the Hanor site, running east to the Garfield County line. The ridge dunes at Qt2 and Qt3 are clearly seen. Qt4 and Qt5 are evident in this transect, but terrace Qt6 does not come this far down the interfluve. Cross-sections A-A' and C-C' clearly show the wide dune field that accompanies the Qt2 terrace. This event was clearly longer and/or more intense than some other events.

Stream and Terrace Correlation

The stream terraces appear to be related to the modern Cimarron River, although the study area includes portions of the basins of Indian Creek, Hoyle Creek, and Turkey Creek. The terrace gradient and direction are indicative of the stream that produced the terrace. Terrace Qt6 is mostly associated with Turkey Creek, but portions of Qt4 and Qt5 grade to Turkey Creek (Table II). Terraces that may be associated with Indian Creek are too small to measure gradient or direction.

TABLE II

Gradient of Streams and Terrace Surfaces

Cimarron River	absolute slope	meters/km	grading towards: direction
River	0.00089	0.89	SE
Flood plain	0.00100	1.0	SE
Qt1	0.00055	0.55	SW, to Cimarron River
Qt2	0.00114	1.14	SW, to Cimarron River
Qt3	0.00100	1.00	SW, to Cimarron River
Qt4	0.00097	0.97	SW, to Cimarron River
Qt5	0.00066	0.66	SW, to Cimarron River
Qt7	0.00063	0.63	SSW, to Cimarron River
Qt8	0.00126	1.26	ESE
Turkey Creek Terraces			
Stream	0.0006	0.6	S
Flood plain	0.0009	0.9	S
Qt4	0.0007	0.7	E, to Turkey Creek
Qt5	0.0005	0.5	E, to Turkey Creek
Qt6	0.0004	0.4	E, to Turkey Creek

Results of Radiocarbon Dating

Radiocarbon dates from three samples are reported. Two samples from profile 98-OK-093-6 on the Hanor farm and one sample from profile 98-OK-073-3 on the Hajek ranch provide absolute dates for the soil organic matter in buried surface horizons (Table III, IV).

Dating soil organic matter is considered problematic by some researchers (Wang, et al., 1996). They argue that the age of the stable organic carbon can not possibly be the same as the surface. The age of a fresh surface at 0 years will have zero organic content derived from plant/animal remains. A surface 100 years old will have an organic carbon content that has accumulated for 100 years, and will have a radiocarbon date somewhere between 0 and 100 years, younger than the true age of the surface. The radiocarbon date for organic matter in a surface horizon will be younger than the surface because of the length of time organic carbon has been accumulating. The offset between the surface age and the organic matter age is not stable; it will vary, based on rates of mineralization and formation. At some point in soil development, a steady state will result, when the rate of formation of stable organic matter balances with the rate of mineralization. Experimental evidence for the time to reach this steady state is lacking, and is considered to be climate-specific (Wang, et al., 1996). Wang et al. present a method to correlate the soil organic carbon dates, however, they admit to using assumptions because of the lack of experimental data.

The radiocarbon date of a buried soil, at the time of burial will be older than the burial date, probably about 100-300 years. As the deposit ages, the difference between the age of the surface and the radiocarbon age of the organic carbon is preserved as an offset. This offset is not easy to determine, and may require research that is specific to one climate, soil, and vegetation combination. For the samples analyzed, no method is available that can assess if the steady state in soil organic matter was reached.

The small sample size recovered from the 7.62 cm diameter core was not adequate for conventional radiometric dating, and had to be AMS dated. The depth of the samples did avoid problems commonly associated with shallow depth. Post-depositional processes often modify the organic matter in shallow samples. Modern plant roots, animal activity, soluble organic matter contamination, and carbonates all contribute to uncertainty in age determinations (Martin and Johnson, 1995). Deeper samples are less likely to be contaminated by any of these processes.

The data do not establish with certainty whether burial was rapid or slow. Deposition certainly overwhelmed the soil melanization process. No evidence was found of any modern roots or post-depositional burrowing that would affect the radiocarbon dates. No burrows or worm casts are present of younger sediment, indicating that biological activity ceased relatively quickly following the onset of deposition. The 2Ab horizon in 98-OK-093-8 (not sampled) is an example of bioturbation during slow burial. Animals brought material down into a buried horizon from fresh deposits above.

Since the reported date is a maximum limiting date, deposition did not begin before the radiocarbon age, and may have begun up to several hundred years later than the organic matter age. This would be a larger problem in younger sediments, because the error becomes more significant when we are considering a shorter time span.

Samples Beta-131206 and Beta-131207 are from stratigraphically equivalent positions. Both were taken below the dune summit and represent a stable period prior to a depositional event. The two profiles are, however, from different positions in the dune field. Profile 98-OK-073-3 is located near the proximal edge of the dune field, relative to the river, and has a conventional C14 age of 1,110 years BP. Profile 98-OK-093-6 is located near the distal edge of the dune field (away from the river), and has a conventional C14 age of 1,570 years BP. Aeolian processes last affected the ridge dune at the distal edge sometime after 1,570 years BP, but the proximal edge of the terrace sometime after 1,110 years BP. This implies more than two episodes of aeolian activity affecting different areas of this dune field.

Sample Beta-131208 is from the buried surface horizon of the soil that formed on the Qt2 terrace prior to the beginning of Holocene activity (profile 98-OK-093-6). The 2-sigma calibrated range of radiocarbon dates is 11,950 to 12,800 years BP (Figure 13). The buried surface and upper argillic horizon are and very dark grayish brown (10YR 3/2, moist) and very dark brown (10YR 2/2, moist). The dark color and the depth of dark colors indicate a pachic epipedon had developed in the soil prior to burial. The implication is that the moisture relations at the site were sufficient to grow large amounts of vegetation, leading to high levels of soil organic matter. Because not all of the buried terrace soils have this mollic epipedon, topographic relationships are indicated, similar to soil catenas seen on modern river terraces.

The 2-sigma range of 12,800 to 11,950 years BP for the bottom sample in profile 98-OK-093-6 gives a maximum limiting date for the onset of deposition. The terrace is older than the organic matter in the surface horizon, but the exact age is unknown. The well-developed argillic horizon indicates that this is a mature soil. The presence of

TABLE III

Reported Radiocarbon Dates.

Profile #	Sample #	Sample ID	Horizon	Depth cm	Measured C14 Age, years BP	C13/C12 Ratio	Conventional C14 Age, years BP
98-OK-073-3	99-OK-073-1	Beta-131206	Ab	457-495	1,110 +/- 40 BP	-16.6 o/oo	1,250 +/- 40 BP
98-OK-093-6	99-OK-093-1	Beta-131207	2Ab	307-338	1,570 +/- 40 BP	-15.6 o/oo	1,730 +/- 40 BP
98-OK-093-6	99-OK-093-2	Beta-131208	4Ab	665-693	10,207 +/- 40 BP	-16.8 o/oo	10,410 +/- 40 BP

TABLE IV

Calibration of Radiocarbon Age to Calendar Years

Profile #	Sample #	Sample ID	Horizon	Depth cm.	Conventional C14 Age, years	2 Sigma Calibrated Result, years BP
98-OK-073-3	99-OK-073-1	Beta-131206	Ab	457-495	1,250 +/- 40 BP	1,275 to 1,070 BP
98-OK-093-6	99-OK-093-1	Beta-131207	2Ab	307-338	1,730 +/- 40 BP	1,720 to 1,540 BP
98-OK-093-6	99-OK-093-2	Beta-131208	4Ab	665-693	10,410 +/- 40 BP	12,800 to 11,950 BP

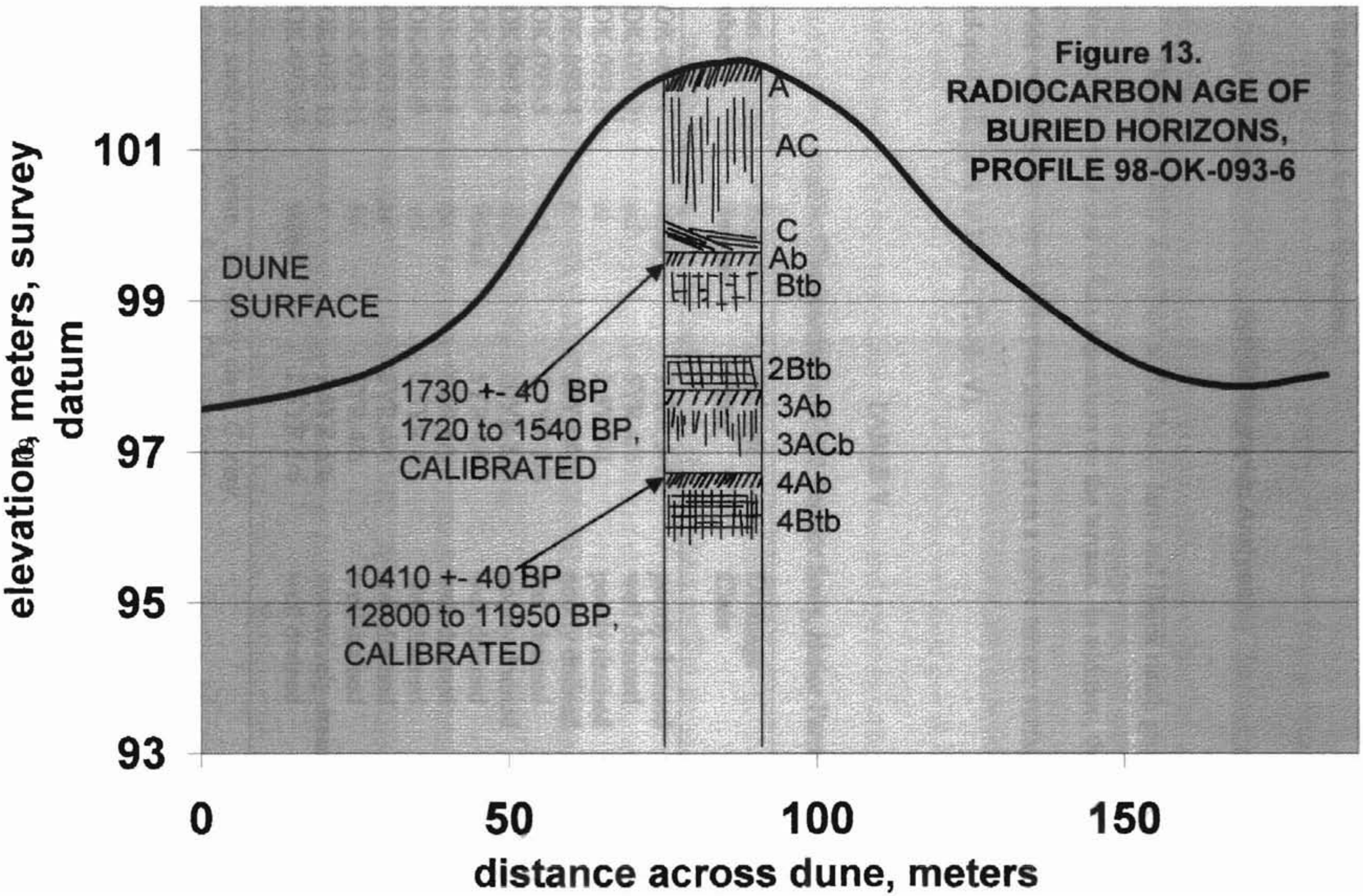


Figure 13. RADIOCARBON AGE OF BURIED HORIZONS, PROFILE 98-OK-093-6

argillic horizons in all the soils on the Qt2 surface supports the evidence that the terrace was in place prior to the Holocene.

Soil-Stratigraphic Analysis

The soil profiles described at the Hanor farm and Hajek ranch provide evidence for the fluvial terrace and eolian deposition on the terrace. In addition, the profiles provide evidence that most of the two sites were on a stable terrace surface with strongly developed soils prior to burial (Table V).

TABLE V

Argillic Characteristics of Qt2 Terrace Soils, Hanor Farm

Pedon number	Subsoil Texture	Subsoil Color	Drainage Class
98-OK-093-1	scl/sc	10YR 5/1	poorly drained
98-OK-093-2	scl	5YR 4/6	well drained
98-OK-093-3	cl	2.5Y 5/1	poorly drained
98-OK-093-4	c	10YR 4/2	poorly drained
98-OK-093-5	scl	7.5YR 5/8	well drained
98-OK-093-6	sic	10YR 5/2	poorly drained
98-OK-093-7	fsl/scl	5YR 4/4	well drained
98-OK-093-8	fsl	5YR 4/6	well drained
98-OK-093-9	scl	7.5YR 4/3	well drained
98-OK-093-10	cl	5YR 4/6	well drained
98-OK-093-11	fsl	5YR 4/6	well drained
98-OK-093-12	s	7.5YR 5/6	excessively drained
98-OK-093-13	fsl/scl	2.5YR 5/6	well drained

1. Scl: sandy clay loam, Sc: sandy clay, C: clay, Fsl: fine sandy loam; S: sand, Cl: clay loam

Evidence for the Fluvial Terrace

The Pleistocene terraces of the Cimarron River have been previously recognized and mapped (Adams and Bergman, 1995; Carter, et al., 1990). Sediments and structures identified in this study verify this is a fluvial constructional terrace. In pedon 98-OK-093-8, the 2BCb horizon has strata of stratified fine sandy loam, silt loam, and coarse sandy loam. Fine stratification in the deposit shows it is a fluvial deposit. In pedon 98-OK-073-5, the 2C2 horizon has about five percent siliceous gravel, is stratified loamy coarse sand and clay, and has fragments of locally derived shale gravel. In pedon 98-OK-073-1, the 2C horizon is stratified sand and fine sand with clay balls. An older buried profile (horizons 3A to 3BC2) underlies the 2C horizon. In pedon 98-OK-073-3, siliceous gravel is present in the 2Btb and 2Btkb horizons (Table VI). Stratified sand, clay, and silt preserved in lower horizons of the described profiles are evidence of fluvial deposition. Most of the fluvial sediments are fine sandy loam or loam, except for argillic horizons of clay loam or sandy clay loam. The alluvial gravel and fining-upward sequences are also evidence of alluvial deposition.

The profiles from the Hanor farm identify the common landforms and positions on floodplains, inherited by the terrace (Table VII). The levee is described in pedon 98-OK-093-8. The well-drained, valley flat position is the most common, and is found in profiles 98-OK-093-2, 5, 9, 10, 11, and 13. Two profiles, 98-OK-093-6 and 7, describe the somewhat poorly drained position on the surface, and profiles 98-OK-093-1, 3, and 4 are in the backswamp position, along with a consequent stream. Pedon 98-OK-093-12 is on the ridge dune burying the escarpment, and is off the Qt2 terrace. Figure 14 is a cross-section of the landforms on the Hanor farm. It shows the relationship between the modern surface and the buried Qt2 surface.

TABLE VI

Stratigraphic Characteristics of Described Profiles

Pedon number	Site	Diagnostic Characteristic
98-OK-093-6	Hanor	aeolian cross-bedding, buried truncated profile
98-OK-093-8	Hanor	fluvial stratification
98-OK-093-12	Hanor	aeolian cross-bedding
98-OK-073-1	Hajek	fluvial stratification, clay balls
98-OK-073-2	Hajek	aeolian cross-bedding
98-OK-073-3	Hajek	siliceous gravel, aeolian cross-bedding
98-OK-073-5	Hajek	fluvial stratification, siliceous gravel, aeolian cross-bedding

Soil Classification

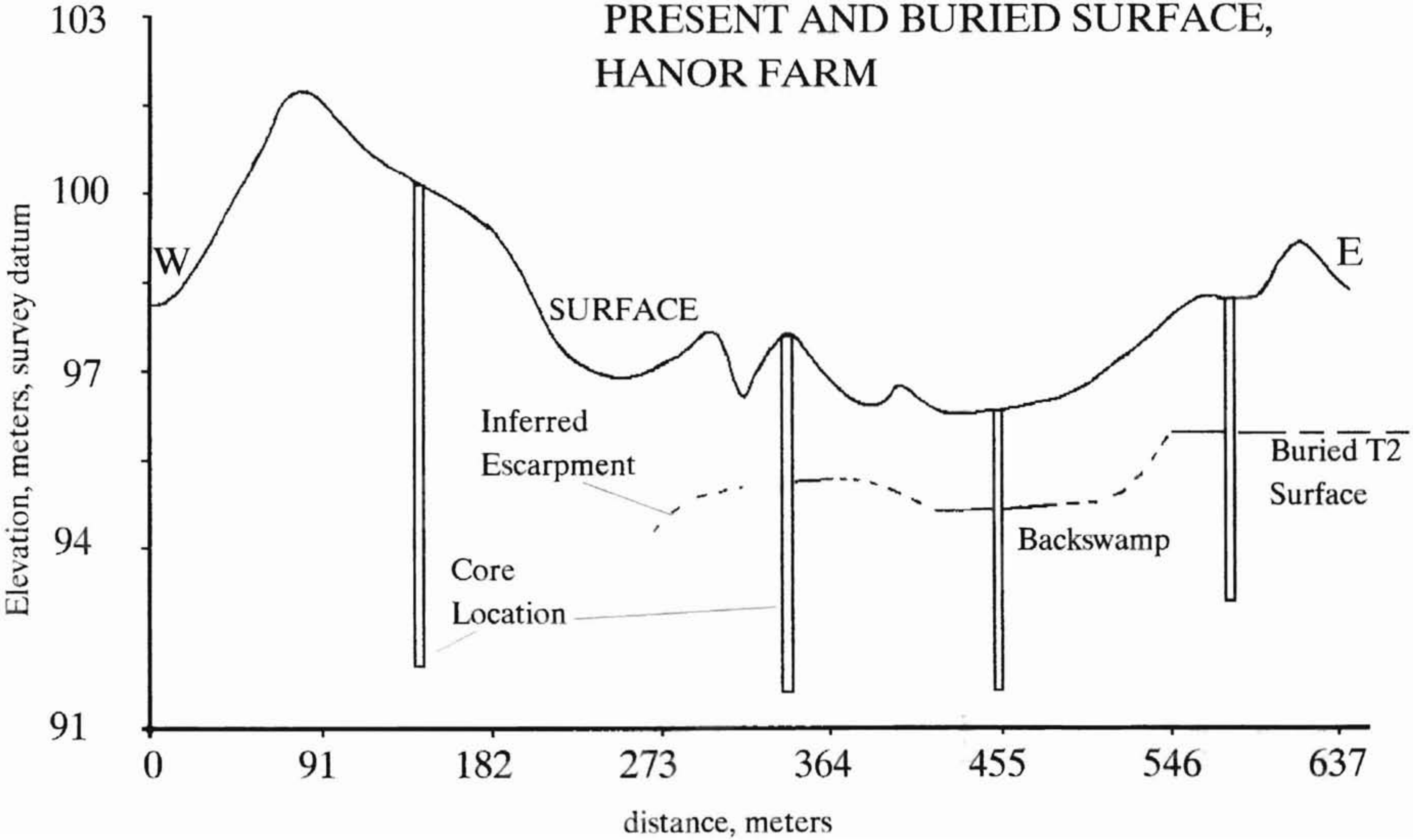
Table VIII shows the classification of the mapped soils and described profiles. Following the criteria of Soil Taxonomy, the classification is based on the uppermost deposits of each pedon. Soil Taxonomy concentrates on the latest deposit if it is at least 50 cm. thick. Thus, the classifications are remarkably similar, regardless of position or age. Because Soil Taxonomy classifies the uppermost deposits and ignores buried soils, it is not an appropriate tool for geomorphic investigation. The classification of these profiles separates only the oldest and youngest soils.

TABLE VII

Buried Qt2 Terrace Soils, Position And Drainage Class

Pedon number	Site	Qt2 Position	drainage class
98-OK-093-1	Hanor	backswamp	poorly
98-OK-093-2	Hanor	valley flat	moderately well
98-OK-093-3	Hanor	backswamp	somewhat poorly
98-OK-093-4	Hanor	backswamp	poorly
98-OK-093-5	Hanor	levee	well
98-OK-093-6	Hanor	valley flat	moderately well
98-OK-093-7	Hanor	valley flat	well
98-OK-093-8	Hanor	levee	well
98-OK-093-9	Hanor	valley flat	well
98-OK-093-10	Hanor	valley flat	well
98-OK-093-11	Hanor	valley flat	well
98-OK-093-12	Hanor	off-terrace	excessively
98-OK-093-13	Hanor	valley flat	well
98-OK-073-1	Hajek	valley flat	well
98-OK-073-2	Hajek	valley flat	well
98-OK-073-3	Hajek	valley flat	moderately well
98-OK-073-4	Hajek	valley flat	moderately well
98-OK-073-5	Hajek	valley flat	moderately well
98-OK-073-6	Hajek	valley flat	moderately well
98-OK-073-7	Hajek	valley flat	moderately well
98-OK-073-8	Hajek	valley flat	moderately well

Figure 14. RELATIONSHIP BETWEEN PRESENT AND BURIED SURFACE, HANOR FARM



Stable Terrace Surface

The buried, stable surface of the Qt2 terrace is represented in all the profiles from the Hanor farm, except for pedon 98-OK-093-12, west of the escarpment of terrace Qt2. Table IX shows the elevation of the buried terrace surface. It is undulating with a depression running north-south through the middle, and has a slight rise at the south end. Elevations shown are for the surface horizons of the terrace prior to aeolian activity.

Every profile on the Qt2 terrace has a buried solum with an argillic horizon (Table V). The texture ranges from sandy clay loam to clay loam in the well drained position, and heavy sandy clay loam, to clay in the poorly drained position. Soil structure, pores, worm casts, and root channels indicate a well-developed soil on the terrace surface.

The 4Ab horizon of pedon 98-OK-093-6 has a 2-sigma calibrated age of 12,800-11,950 years BP (Beta Analytic # 131208). Evidence for a stable surface is indicated by the soil characteristics. The significant accumulation of organic carbon from plant decomposition (denoted by the very dark brown color) indicates long-term stability. The argillic horizon below the dated layer is high in organic matter and clay. These characteristics indicate that soil had been developing for a significant length of time prior to burial.

TABLE VIII

Classification of Mapped Series and Described Profiles

Series or Profile	Classification
Nobscot	loamy, mixed, superactive, thermic Arenic Paleustolls
Meno	loamy, mixed, superactive, thermic, Aquic Arenic Haplustalfs
Shellabarger	fine-loamy, mixed, superactive, mesic Udic Argiustolls
Pratt	sandy, mixed, mesic Lamellic Haplustalfs
Lincoln	sandy, mixed, thermic Typic Ustifluvents
Eufaula	sandy, siliceous, thermic Psammentic Paleustalfs
Carwile	fine, mixed, thermic Typic Argiaquolls
Tivoli	mixed, thermic Typic Ustipsamments
98-OK-093-1 to 12	mixed, thermic Typic Ustipsamments
98-OK-073-1 to 8	mixed, thermic Typic Ustipsamments

Classifications of Named Series are the latest, based on information from the National Soil Survey Center, Lincoln, Nebraska.

TABLE IX

Fluvial Terrace Elevations, Hanor Farm

Pedon number	elevation, meters	Depth to Qt2 surface, meters	Elevation of Qt2 surface, meters
1	96	0.99	95.01
2	98.3	3.15	95.15
3	96.6	0.85	95.75
4	97.1	2.44	94.66
5	98.0	3.29	94.71
6	102.1	6.64	95.46
7	97.0	1.04	95.96
8	98.6	1.92	96.68
9	98.7	1.92	96.78
10	97.2	0.91	96.29
11	97.2	1.04	96.16
12	100.3	na	na
13	96.6	0.67	95.93

Aeolian Deposition

Every pedon described has aeolian sand ranging from one to over 6 meters thick (Table X). Surface morphology (Table I), sediment characteristics, and sedimentary structures (Table VI) are adequate evidence of aeolian deposition.

Surface morphology indicates that aeolian deposition has occurred all across both study sites. The landforms are a mixture of ridge, parabolic, blowout, and longitudinal dunes. Sand sheets occupy the surface downwind from the dunes. Drainage density of the sites is low. The only defined drainage feature is a small perennial stream that drains the Hajek ranch. The lack of drainage features indicates a combination of young surfaces and rapidly permeable, sandy soils with a low runoff potential. The sandy sediments are well sorted, and most of the sand sizes are characteristic of aeolian deposits.

At least seven profiles -- 98-OK-093-6 and 12; 99-OK-073-1; 98-OK-073-2, 3, and 5 -- have distinct cross-bedding (Table VI). Six of these profiles, except 98-OK-073-5, are on the highest dunes and have deep accumulation of sand. In each case, the modern solum is developed in a sand deposit at least three meters thick, and cross-bedding structures are preserved in the C horizon of each. Pedon 98-OK-073-5 is in an interdune position, but is well drained, and cross-bedding is preserved between 96 and 157 cm.

Truncated paleosols within some profiles indicate that erosion preceded or accompanied an event. Truncation may have removed an entire solum, or only a portion. The preserved horizons show that at least three aeolian episodes are recorded for this site since the end of the Wisconsin age.

TABLE X

Aeolian Features of Described Profiles

Pedon number	Site	Depth of Aeolian sediment, cm.	Number of Aeolian events
98-OK-093-1	Hanor	99	1
98-OK-093-2	Hanor	315	3
98-OK-093-3	Hanor	86	1
98-OK-093-4	Hanor	240	2
98-OK-093-5	Hanor	330	1
98-OK-093-6	Hanor	665	3
98-OK-093-7	Hanor	231	2
98-OK-093-8	Hanor	191	1
98-OK-093-9	Hanor	190	1
98-OK-093-10	Hanor	91	2
98-OK-093-11	Hanor	104	1
98-OK-093-12	Hanor	na	3+
98-OK-093-13	Hanor	66	1
98-OK-073-1	Hajek	335	2
98-OK-073-2	Hajek	335	2
98-OK-073-3	Hajek	614	2
98-OK-073-4	Hajek	254	2
98-OK-073-5	Hajek	157	1
98-OK-073-6	Hajek	69	1
98-OK-073-7	Hajek	160	2
98-OK-073-8	Hajek	254	2

Number and Timing of Aeolian Events

The number of aeolian events in the region is established by the number of aeolian units preserved, and the timing is established by radiocarbon dating. Several profiles have more than one solum developed in aeolian sediments. Profiles 98-OK-093-6 and 98-OK-073-3 are examples of dunes that record more than one aeolian depositional event. At 98-OK-093-6, a total of five profiles are preserved. The upper three are clearly aeolian, the fourth is mixed fluvial/aeolian, and the lowest solum is developed on the Qt2 terrace surface (Figure 13).

Some depositional events are local; others are regional. The mixture of regional and local sand deposits in the Great Plains create a complex landscape (Arbogast, 1996). Because paleosols may be destroyed by erosion, the described profiles do not necessarily preserve evidence of every event. An event preserved at one location may not be preserved at another, or an event may have been local in extent. Some of the described profiles have truncated buried soils from erosion at the beginning of an aeolian event.

Field examination reveals that variations exist in the depth to cross-bedding. The youngest dunes have cross-bedding immediately below the surface, whereas slightly older dunes have cross-bedding at about 1.2 meters, and the cross-bedding in the next older dunes begins at about 2.4 meters.

Evidence is mounting that arid episodes are a regular occurrence in the Great Plains. Thurmond and Wyckoff (unpublished data, 1999) have documented a 2,000 year record of aeolian deposition, soil development, and human occupation in Roger Mills County, Oklahoma. The Dempsey Divide Site records paired mesic/xeric episodes averaging 392 years in length, with an average xeric episode of 197 years and an average mesic episode of 195 years. Arbogast (1996) identified five soil forming intervals bracketing aeolian episodes in the Great Bend Sand Prairie of Kansas. He identified stable periods at approximately 2,300, 1,400, 1,100 to 900, 700 to 500, and 300 calibrated years BP. Earlier work by Arbogast (1994) identified episodes of aeolian activity at 2,300-1,700 and 1,600-800 years BP.

The radiocarbon dates from this study indicates that sand on the Hanor farm and Hajek ranch was most recently mobilized after 1,620 years BP and again after 1,180 years BP. These dates are maximum limiting ages for the sand deposited above the dated layer. These dates also represent the times of stability when soils formed. As such, these dates intercept the mesic episodes identified by Thurmond and Wyckoff (unpublished data, 1999). The younger date (Hajek ranch) intercepts with Arbogast's data from the Great Bend Sand Plain. The older date identifies a period of stability not identified in the Great Bend Sand Plain. The dates in this study do, however, correlate with earlier work by Arbogast and Johnson (1993; Arbogast, 1994).

An assumption that periods of stability and aeolian activity should correlate perfectly across the Great Plains is probably invalid. The drought database prepared by the National Geographic Data Center/National Climatic Data Center (NGDC/NCDC) shows that the spatial extent and severity of drought varies greatly from year to year (Woodhouse and Overpeck, 1998a). Aeolian activity may be dominant in one area, but it may be absent in another at the same time.

Relative Dating

A correlation exists between dune age, the present soil, and the plant community. The combination of soil, vegetation, and surface morphology on a dune is related to the age of the dune and distance the river. In general, the more well-developed soils (considered older) occur on dunes farther from the river. Various plant species dominate particular sites and correlate with the soil and weathering regime of the dune.

Soils

Soil profile development is associated with weathering. Leaching of calcium carbonate, melanization of the surface horizon; and creation, eluviation, and illuviation of clays in the profile are processes that proceed with time, and the degree of expression of each establishes relative age relationships. Destruction of cross-bedding and development of soil structure are concurrent processes that differentiate soils based on relative age. The results of these processes, operating for various time spans, can be seen in the area.

Depth of weathering separates the younger dune fields. During pedogenesis, cross-bedding of aeolian sands is replaced by prismatic soil structure. Wetting/drying cycles, root growth, and animal activity destroy the cross-bedding and replace it with soil structure. The youngest dunes have cross-bedding just below the surface horizon. Progressively older dunes have cross-bedding at progressively deeper depths. The youngest dunes also show the least chemical and biological weathering. They have free calcium carbonate near the surface. The surface horizon is poorly developed, and has a low content of organic matter.

The medium-aged dunes are in a belt parallel to, but farther from the river. They are leached of calcium carbonate, and prismatic soil structure is developed to a depth of one to 1.5 meters. Cross-bedding has been destroyed by plant and animal activity, and pH is neutral. Slightly older dunes have soil structure developed to depths of two to 2.5 meters, and cross-bedding is present below 2.5 meters. The dunes on the Hanor farm are part of this group.

The oldest dunes have argillic horizons developed at depths of 0.5 to 1.5 meters. Iron and clay have been translocated from the surface to the argillic horizon. The pH of the surface horizon may be as low as 5.5. In addition, the organic acid residue from the deciduous woody vegetation has bleached the subsurface horizon. Table XI gives an overview and comparison of characteristics of different ages of dune fields.

Vegetation

Plants common to the region have preferences for particular soils and sites. Generally, plants are better able to compete with other species on sites that meet the biological requirements of the plants. Thus, specific species discriminate between the various soils and are more abundant on the soils that give them a competitive edge. In the study area, different vegetative communities develop on particular groups of dunes, based on site preferences. Because plants tend to colonize preferred sites where they have a competitive edge, succession is a process that leads to unique plant communities on soils and surfaces of different ages. Based on vegetative communities, the age of dunes is positively correlated with distance from the river.

On the youngest dunes - represented by the Tivoli and Jester soil series - pioneering plants are more prevalent. Little bluestem prefers soils that have free calcium carbonate and will colonize new deposits that are not leached of lime. Plum, elm, hackberry, and skunkbush sumac are the dominant woody species on the youngest dunes.

Sand sagebrush is found on medium age dunes (mapped as the Eda soil series) that are leached of calcium carbonate but have a neutral pH. Tall grasses such as sand bluestem and Indiangrass are abundant. Woody species such as eastern redcedar, red sumac, and elm also will colonize the medium aged sites.

Blackjack oak and post oak are present on the oldest dunes. These species prefer soils that are sandy and have low pH. The oaks are attracted to acid soils and in turn drive these soils to a more acid condition, which accelerates weathering of clays. In virgin condition, the Nobscot and Eufaula soils support a savannah of widely spaced large oaks with tall grass in between. Thus, woody vegetation correlates with the relative age of the dunes.

This broad correlation is subject to anomalies. Plants do not have an absolute preference for particular soil. Moreover, human activity has radically affected the plant communities since settlement. The natural variability of plant communities prevents a perfect correlation of a specific plant with a specific age of dune. Little bluestem colonizes dunes with abundant calcium carbonate, but persists in lesser amounts in all the plant communities. Blackjack oak, an indicator species for the Nobscot soil, begins to colonize dunes as the pH begins to fall. It is an important species on all the dunes from terrace level Qt2 to Qt8. Trees increase on sites deprived of fire, but are subject to periodic removal by humans, and re-colonize sites at different rates. Recruitment of some species is dependent on infrequent weather conditions.

Surface Morphology

Surface morphology of the dunes changes regularly with distance from the river. Differences noted while preparing the surface map were confirmed by examining aerial photographs. Selected dune fields on the margins of terraces were examined for slope, relief, vegetation, land use, and type of dune. Table XI shows the differences between dune fields. Changes are apparent from photo interpretation of dune forms. Weathering and aging features result from alteration of the landform after deposition. Dunes are also subject to pedogenesis and additions of dust.

Eight general trends are apparent from examination of the photos

1. Younger dunes have steeper slopes than older dunes.
2. Younger dunes have more recognizable dune forms (ie. parabolic, ridge, barchanoid, star, and climbing) than older dunes.
3. Younger dunes have narrower summits than older dunes.
4. Younger dunes have greater local relief than older dunes.
5. Younger dunes have lower percentage of natural vegetative cover than old dunes.
6. Older dunes have a higher percentage of the area cultivated than younger dunes.
7. Lee faces are more recognizable on younger dunes than older dunes.
8. Individual dunes in older deposits have a larger footprint, that is, cover more area, than individual dunes in younger dune fields.

Surface Morphology, Young Dunes

Examination of photographs close to the Cimarron River indicates several very recent aeolian episodes. Soil development and surface morphology indicate that two of these deposits are younger than the modern soils in the dated profiles on the Hanor farm and Hajek ranch. Dune morphology in these more recent deposits is distinctive, compared with older dunes. Figure 15 is a photograph of section 5, T. 19. N., R. 9 W. This section joins the flood plain, and illustrates the young dunes resulting from recent

TABLE XI
Comparison of Dune Morphology and Features

Position	Relief (meters)	Slope	Vegetation Type	Dune Type	Soil Series
T0 (flood plain)	3	5-10%	ridge dunes (3)	Jester	
T0/QT1	15	10-30%	sagebrush woody veg. tall grass	young ridge dune climbing on compound parabolic dunes with blow out features. the compound parabolic dunes are climbing on the QT1 sandsheet which is blown out compound parabolic dunes	Jester, Tivoli
QT1/Qt2	23	20-40%	oak savannah tall grass sagebrush	ridge dune with superimposed blowout dunes	Eda Eufaula
Qt4/Qt5	<8	3-5%	oak savannah cultivated	chaotic blow-out, 100%	Nobscot
Qt5/Qt6	<5	3-5%	oak savannah 60% cultivated	low relief blow-out dunes	Nobscot
Qt5/Qt6	<5	<5%	oak savannah 60% cultivated	low relief blow-out dunes	Nobscot
Qt7	1.5-5	3-8%	cultivated tame pasture	sand sheet, blow out dunes	Nobscot

activity. Stereo photography reveals that two recent events have emplaced two deposits of climbing dunes upon the sand sheet that covers the Q0/Qt1 escarpment.

Variations in dune type, vegetation, percent of ground cover, slope, and height are evidence for the delineation of the two younger dune fields. The slip face of each climbing dune is clearly revealed using stereo pairs. The youngest climbing dune rests on the second field of dunes. The slip faces of the forward parabolic dunes rest on the undulating surface of the sandsheet. The youngest dune has an estimated 60 percent cover, most of which is shrubs. The second field is composed of compound parabolic dunes, with blowouts forming on some of the noses and arms. Vegetative cover is higher, with more trees on the north sides of dunes. The oldest field of dunes in this photo is composed of low-relief blowout dunes with a few modified parabolic dunes.

Difficulties

Three difficulties are associated with relative dating techniques: rejuvenation of the landscape during arid periods, human modification of vegetation and landscape, and natural variability in the plant communities and succession. Rejuvenation occurs when periodic aridity facilitates aeolian processes on an aeolian landscape. Rejuvenation may destroy or truncate soil profiles. The resulting deposit has all the marks of a new dune deposit. The source (ie. a blowout) may have a truncated argillic horizon or fresh, un-weathered, parent material at the surface. The resulting landscape is extremely complex, and presents a challenge to an investigator (Gile, 1980). Brady (1989) noted inconsistencies in soil profile development in Major and Alfalfa Counties, Oklahoma.

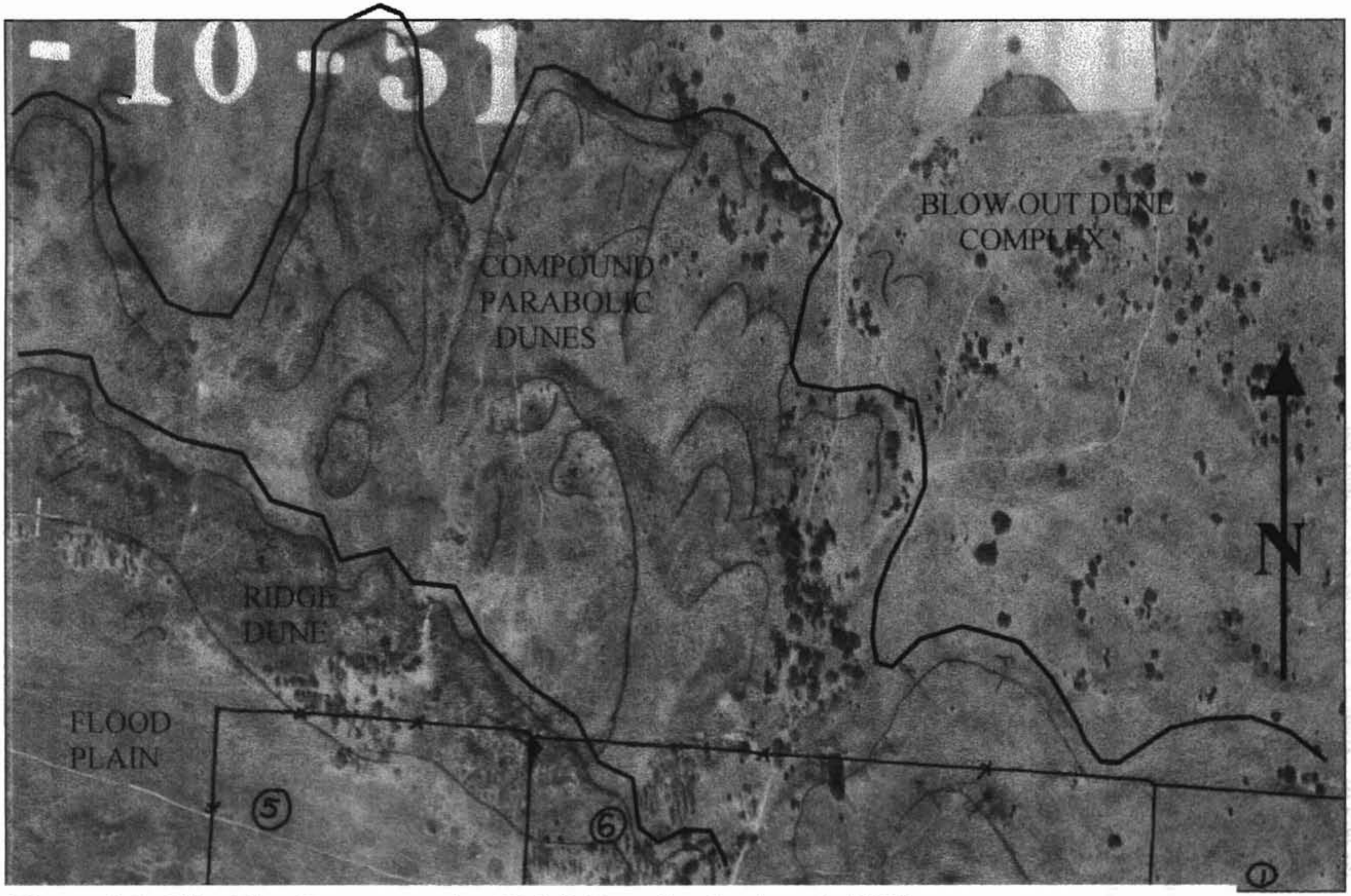


Figure 15: Climbing Dunes on the Hajek Ranch. Scale = 1:7920.

The effect of human activity on the native vegetation is variable. In places, people have removed the native vegetation and planted crops or introduced grasses. Periodic brush control and overgrazing have changed the composition of native rangeland. In addition, plant succession follows any disturbance, and sites in various stages of succession are present. Other human activity - fire prevention - has had a major effect on plant community structure. The species composition of rangeland changes where fire is prevented. Rangeland areas have more woody species than before statehood. People also modify the landscape by diverting streams, building dams, fencing, building drainage ditches, and smoothing dunes with large earth moving equipment. All these activities are present in the study area, and affect the landscape.

Several lines of evidence support the relative dating scheme presented above. The combination of features less likely to be affected by humans -- dune morphology and spatial arrangement -- provides a reliable correlation of the dunes. In the mapped area, the older dunes have been deposited as ridge dunes, then modified and weathered without being transported long distances.

Geomorphic Issues

Climatic Control of Aeolian Processes

The evidence shows that the landforms in this study had to form under a different climate than is currently present, because a different set of soil-geomorphic processes are currently operating. The evidence supports a rapid deposition of aeolian sand, which is not occurring in the present climate. In the absence of other evidence, many other studies have concluded that climate is the main control of aeolian processes. Climate operates as an extrinsic control and is currently contributing stability. The landscape is passive; unless acted upon, sediment will remain in place.

Evidence From Active Sand Bodies. Five areas of active sand dunes (three along the Cimarron River in Woods Co., Ok., and two along the North Canadian River in Beaver Co., Ok.) are present in northwestern Oklahoma. Aerial photographs of these five areas were examined to look for trends in size. Photos from 1952 and 1997 were available from the USDA-Natural Resources Conservation Service. The comparison of old and new photographs shows that the active dune areas are smaller now than 50 years ago. Each area is smaller now than in 1952. The loss of bare areas is evidence that the forces responsible for the instability are weaker than the stabilizing forces. Recreation and overgrazing are anthropogenic inputs that contribute to instability and are active on the areas, but not enough to maintain the active dunes.

If dune mobilization is an intrinsic process, it should exist randomly throughout the region. Instances of events in early, middle, and late stages of occurrence should be detected. The only active areas are growing smaller and support the hypothesis that the present climate favors stability. The present activity appears to be the last vestige of the previous mobilization.

The current lack of activity does not prove climatic forcing of aeolian processes. It does establish that the current climate favors stability in the sand dunes. Relatively little sediment is moving at this time, even in locations that are cultivated. The development of modern A horizons in the described profiles indicates stability, and compare with the buried A horizons in the dunes. The presence of aeolian sand deposits is evidence for periodic instability. When periods of aeolian activity correspond with periods of aridity, it is easy to ascribe the activity to climatic forcing.

Correlation With Other Studies. Several researchers have made a correlation between climate and aeolian activity (Muhs, 1985; Muhs, et al., 1996; Arbogast, 1996; Arbogast and Johnson, 1998; Forman, et al., 1995). Most of these have concluded that climate is the major factor in aeolian activity in the Great Plains.

Data from this study does establish a correlation between aeolian activity and climate in western Oklahoma. The delta 13C values from the buried Ab horizons are consistent with aridity, but the delta 13C value from the terrace surface is not consistent with the cooler and wetter conditions that characterized the late Wisconsin age.

The dates for late Holocene soil development in Major County are consistent with data from the Great Bend Sand Plain in Kansas (Arbogast, 1996) and north-eastern Colorado (Madole, 1995). Their studies agree that arid episodes demonstrate climatic forcing.

Limited data supports a high-resolution picture of the climate for the past 2,000 years. Thurmond and Wyckoff's unpublished data (1999) from Roger Mills County, Oklahoma supports a high-resolution picture of climate over the last 2,000 years. Their studies generally show a 400 year cycle, roughly split between 200 year mesic periods and 200 year xeric periods. Radiocarbon dates for the buried soils in this study (Table III, IV) correspond with the mesic, or stable, periods in Roger Mills, County.

This study brackets the timing of change in the landscape, the geomorphic response. It does not establish, at high resolution, the exact dates of the response, if it was rapid and step-like, or gradual (depending on the time scale), how rapidly the environment changes, or how rapidly the geomorphic processes respond. The climate changed, and geomorphic processes responded, but this study does not establish quantitatively the rate and date of the response. Qualitative measurements, such as rate of deposition exceeding rate of melanization, are possible with this study.

Twidale (1999) cautions that the interpretation of recent landforms is complex. Climate may be only one of several factors involved in landscape change. Arbogast (1996) recognizes this when he discusses the need for additional research into the influence of migratory bison herds. The role of fire in landscape change is also a factor that needs research in the Great Plains.

Wetlands on Terrace Surfaces

Wetlands are common on the terrace surfaces in the study area. Regional water tables are rising, and wetlands occupy most of the concave landscape positions on the Cimarron River terraces. Examination of wetlands on aerial photos and in the field reveals that the pattern of wetlands is not random. They form linear groups, and these linear groups of wetlands are parallel to each other.

Topographic and Soil Evidence. The wetland areas usually occur in the Carwile soil series. This soil has redoximorphic features in the surface and subsoil that indicate periodic ponding or saturation by water. Delineations of Carwile soil are separated by Meno or Shellabarger soils that developed on low dunes or sand sheets. Sand sheets or dunes isolate individual wetlands.

The cross-sections of the surface topography (Figure 5, 6, and 7) show concave depressions mostly on the distal side of each terrace, next to the escarpment.

Backswamps occupy the lowest elevations of a terrace, and usually have the most clayey soils on the terrace. Wetlands are present in these backswamps.

Photo interpretation of the area reveals many linear wetlands crossing the terraces from north to south. These wetlands appear to occupy old stream channels that were blocked by dunes advancing from the proximal margin (toward the stream) of the terrace tread. An examination of the streams in the area reveals that only streams having a drainage area greater than 8,000 hectares presently maintain a flow through the dunes. Most of the small streams fail to maintain a channel and are blocked entirely by sand dunes on the terraces. Others show evidence of past blockage and breech episodes.

The Hanor farm includes an area of wetland that occupies the backswamp position of the terrace. It is at the southern end of a linear group of wetlands following the backswamp position of the terrace. The terminus of this wetland is the dune front.

Soil profile descriptions support the interpretation of a backswamp. Profiles 98-OK-093-1, 3, and 4 are located along the north/south axis of the depression (Figure 4, 8). Aeolian sand buries the soil that developed in the backswamp. Typically, the buried soil has a strongly developed argillic horizon with texture ranging from heavy sandy clay loam, clay loam, or clay. The argillic horizon has moderate to strong prismatic and subangular blocky structure. The colors are 10YR 4/1 to 5/2 and are strongly gleyed, indicating poorly drained conditions. Still, the presence of the argillic horizon indicates that the soil dried occasionally.

Consequent Stream

The surface morphology of the region suggests that the linear groupings of wetlands were intermittent streams draining the backswamps before the aeolian deposition. Profile descriptions of the soils and sediments in the backswamp positions were examined for evidence of a stream.

Textural Evidence. The particle size dominant in the soil is the primary evidence for the depositional environment. In addition, the particle size reflects the parent material available for transport. The profiles in the depression contain the most clay of any on the terrace. The texture is consistent with deposition in a backswamp, where clays and silt settle out of slowly moving water. Channel or bed load deposits, such as coarse sand and gravel, were not found, as would be expected in a typical stream. Coarse sand and gravel are rare in the current Cimarron River channel. A very small amount of coarse material occurs in the terrace, and overbank flooding would not deliver coarse sediments to this position on the surface. The lack of coarse channel deposits, then, does not rule out the existence of a consequent stream in this position, and the texture supports deposition by slowly moving water. The buried backswamp soil and topography correlates with modern flood plains in the region.

Surface Gradient Evidence. The gradient of the buried surface provides additional information about the previous landscape. Figure 16 shows the gradient of the buried soil surface along the axis of the backswamp. Sites 3, 1, and 4 are described profiles. South of the Hanor farm, the terrace surface is exposed. The last two points are elevations along the surface to the south. The slope is 0.6 meters per km in the measured section, and about 1.1 meters per km in the north section.

This data supports the existence of a backswamp, most likely with an intermittent, low-velocity stream. The sediments are consistent with low velocity fluvial deposits. This is not conclusive proof because the entire terrace is composed of fluvial deposits. The exposed backswamp to the south has a comparable soil and gradient. This drainage becomes an intermittent stream with a defined channel about 1 km south in section 33, T. 20 N., R. 9 W.

The modern day landscape does provide some other information to the operation of these streams. Two small backswamp streams do currently exit the terrace system to the south. The gradient of these streams, shown on Figure 11 is 3.4 (west) and 4.0 (east) meters per km, respectively. These streams currently exit through the sand dunes and reach the river. They have a greater slope than the buried channel, but the aerial photographs show that these streams are also affected by aeolian action. In addition, these streams get steeper as they near the edge of the terrace and breach the escarpment.

Coincidence of Buried and Modern Topography. A possible objection to the concept of a buried backswamp stream is as follows. The gleyed layers and heavy argillic horizons could develop merely from the position in a current topographic depression. The excess water from overland flow and interflow could produce the features in the buried soils.

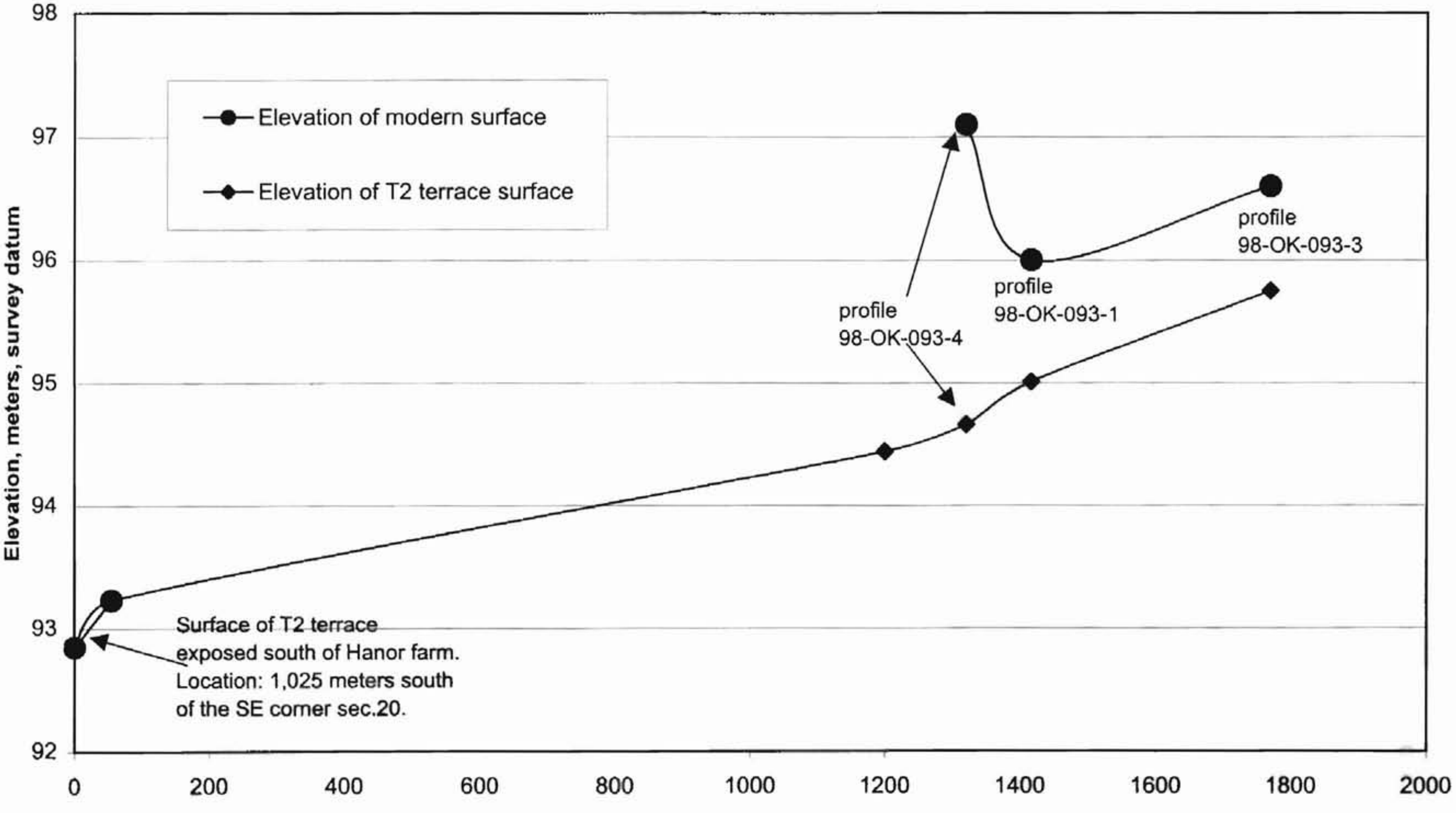


Figure 16. Gradient of Backswamp, T2 Surface.

To test this possibility, two other profiles were cored in topographic lows. Pedon 98-OK-093-10 is in a small circular depression at the east edge of the Hanor farm. This depression holds water enough of the time to be bare of vegetation. The soil has redoximorphic depletions at 17 to 40 cm, but overlies the well-drained terrace soil. The modern depression did not cause the strongly gleyed features in the backswamp. Pedon 98-OK-093-13 is in a large depression south of the buried backswamp area. The soil at the surface is well drained. The buried argillic horizon of sandy clay loam is moderately well drained, and has a moist color of 2.5YR 4/6. A few redoximorphic depletions in this horizon indicate current periodic wetness. The presence of a modern depression alone is not the cause of the strong gleying and high clay content in the backswamp. These two locations show that the location of the buried backswamp in a topographic low is coincidence.

Stream Competence

The implication from the buried backswamp is that the intermittent streams in the backswamp position of these terraces have low competence. The intermittent nature of the stream, low gradient, and small drainage area together affect the competence. The result is that the stream could not maintain a channel during the periods of aeolian deposition. When the aeolian processes exceed the fluvial processes (A > F), the stream fails because it can not remove the aeolian material.

Soil Profile Evidence. In Pedon 98-OK-093-6, depositional layers at the contact with the terrace surface provide evidence of changing environmental conditions. This pedon, prior to burial, was on a somewhat poorly drained position, less than 1 meter above the low backswamp.

The buried terrace surface horizon (4Ab) is easily recognized. It is very dark grayish brown silt loam (10YR 3/2 moist) with granular structure, pores, old root channels and worm casts. The 3C2 horizon above is stratified light yellowish brown (10YR 6/4 moist) loamy fine sand and very dark grayish brown (10YR 3/2 moist) loam. Individual strata are 0.5 to 1.25 cm thick. The 3C2 horizon rests abruptly on the 4Ab horizon. The 3C1 horizon is yellowish red (5YR 5/6 moist) loamy fine sand. The interpretation is that a blockage by sand deposits to the south first caused overflow and deposition on the 4Ab horizon. Continued aeolian activity deposited the 3C1 horizon as a layer of sand that may have been reworked. A total of 137 cm of mixed fluvial and aeolian material was deposited before the site was buried, eventually, by another 528 cm of aeolian sand.

The surface topography shows that channel blocks occur north of the large dune dam, pedon 98-OK-093-6. The surface has many small, isolated depressions. Low dunes separate these depressions, creating many wetlands of varying size in sections 21 and 17. The U.S.G.S. topographic map, Ames Quadrangle (Figure 9), shows the depressions, but without much detail. The stream is blocked, and aeolian sand deposits fragment the drainage basin.

The effect is a complete blockage of the stream system on the backswamp. On the Hanor farm, the large dune is the landform designated a "dune dam" by Loope, et al. (1995). Aerial photos of the Hajek ranch site show this process of blockage has been active in more recent times. Photos from the 1930s to the 1990s reveal that a dune dammed the stream, but the dam was breached during the 1950s. The site on the Hanor farm never was never breached and is currently blocked.

Overview and Summary of Landscape Formation

Ridge Dune Formation. A ridge dune is the sand deposit that forms at the edge of a braided river channel. During times of low flow, wide areas of bare sand are subject to detachment by wind. The resulting dune is linear, parallel to the river channel, and usually covers the escarpment and portions of the adjacent flood plain. This initial sand deposit may be modified by subsequent aeolian episodes.

The author has observed this process of ridge dune development in the late 1970s. Other historical accounts collected by Muhs and Holliday (1995) also indicate this process was observed on the Great Plains by explorers and travelers during the 1820s and 1850s. The historical accounts indicate that during major droughts enough sand is moved to create the dune fields present today.

The initial ridge dune is present on aerial photographs of the Cimarron River. Figure 17 shows one ridge dune along the bank, and several others on the flood plain, isolated from the bank by channel migration. These are shown as white streaks running parallel to the channel. If the river downcuts, the flood plain and ridge dune will become a terrace. Migration and down cutting by the Cimarron River has isolated previous ridge dunes and flood plains. The resulting terraces often have remnant ridge dunes. The cross-sections of the landscape derived from the surface mapping (Figures 5, 6, 7) identify ridge dunes that remain on the terraces, although they are modified by geomorphic processes after formation.

Processes Creating Terrace/Dune Pairs. The landscape evidence supports the following sequence of landscape evolution. When the river downcut to a new elevation, the flood plain with ridge dunes became a stream terrace with ridge dunes on the levee position and on the terrace surface. The ridge dunes and terrace were then isolated and preserved. Aeolian episodes modified the original dunes, and subsequent downcutting episodes created a series of terrace/sandhill pairs. These are generally parallel to the river. Sandsheets are often deposited in the lee of the dunes, modifying the terrace surfaces.

One objection to this process is that the sediment source for the sand hills is the stable river channel. The sandhill/terrace landscape is built as the sediments move away from the source. The surface mapping, cross-sections, surface morphology, and relative dating relationships, support the process described above.

Soil development on the higher and more distal dunes provides substantial evidence that these deposits are older than dunes near the river. The Nobscot series that dominates the older dunes is well developed. A Nobscot soil has a well-developed argillic horizon. The texture is commonly fine sandy loam. Because the parent material had very few weatherable minerals, the texture is significant. The base saturation of this soil is low, calcium carbonate is not present in the soil, and the native pH is usually 5.5 or less. Post-depositional morphological changes in the shape, type, and slope of the dunes also evidence a long period of weathering in place.

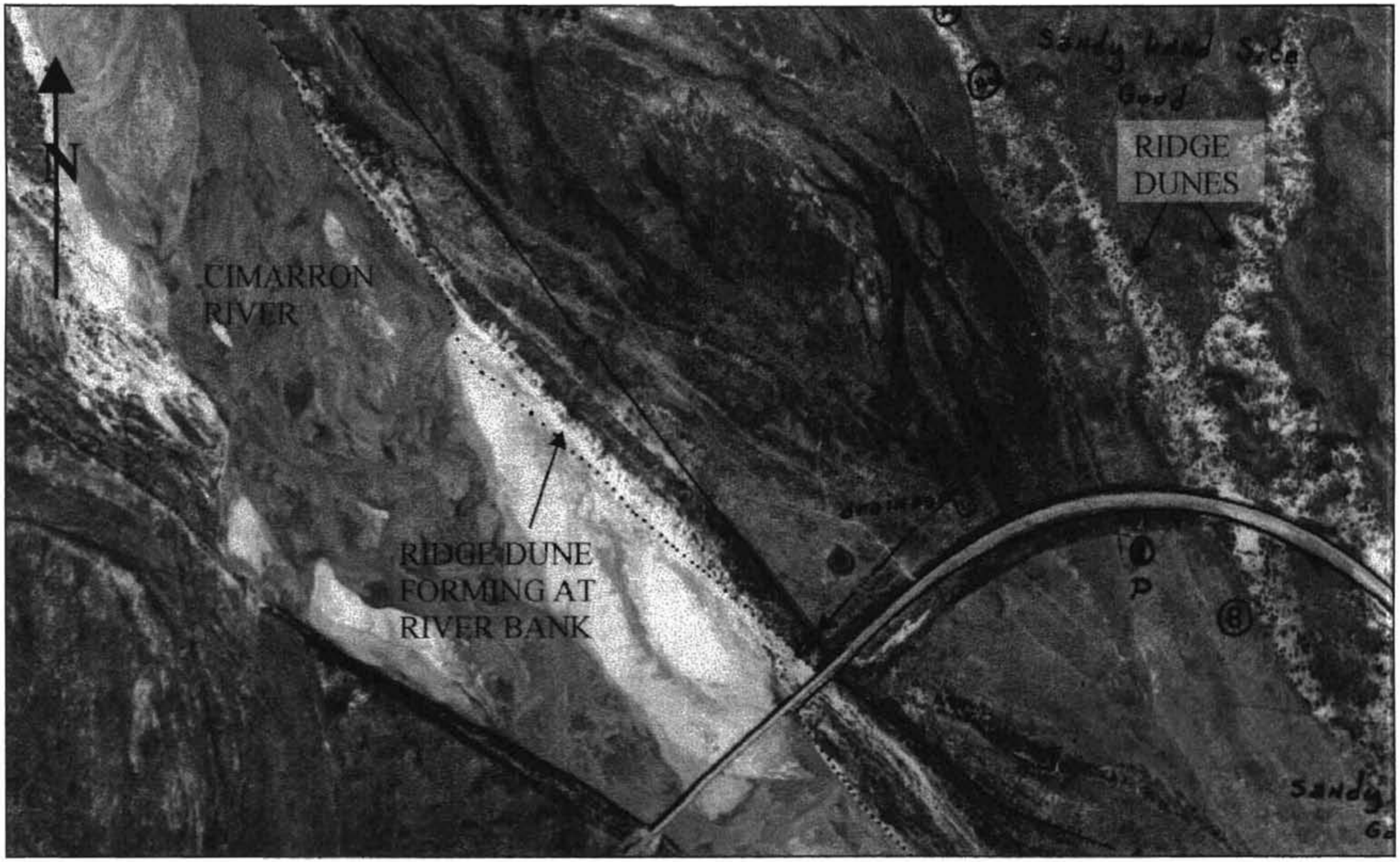


Figure 17: Cimarron River with Ridge Dunes on Flood Plain and at Edge of Channel. Scale = 1:7920.

Landscape Response to Climate Change

At first glance, the concept -- landscape response to climate change -- might infer that landscapes only respond to change, and are little affected by the antecedent climate condition and forces. This would be quite false, akin to an illustration that only acceleration by an automobile is important, whereas the initial speed or direction is not. The antecedent climate is driving particular processes at some given rate, leading to landforms in balance with the geology, vegetation, and intrinsic thresholds. A major or minor change of climate drives processes in a different direction and rate, acting on the pre-developed landscape. New landforms are imposed on the old, and a variety of complex landforms are produced. A geographical region subject to frequent climate change will have a wide variety of landforms. In very few instances will the previous landscape be obliterated before the climate shifts again.

Local Site Response. Driving forces always act on the product of a previous episode. Currently, driving forces that act on sandy sediments are facilitating soil development and enriching ground water rather than producing fluvial sediment. Evidence of fluvial activity is minimal. Aerial photos indicate that additional ground water aids spring activity and ground water sapping at sites below the Qt2 terrace. At the Hanor farm, in response to arid episodes, sand is detached, moved, and deposited by wind in dunes or sand sheets. The response of older dunes is to change shape and relief as wind modifies the dune.

The response will be buffered by other factors. The duration and intensity of the arid episode will determine the extent of activity. Conditions in the river (braided condition, sediment load, and width) will affect the sand supply. Vegetation, animals, and fire will have a screening effect (Ritter, et al., 1995, p.44) on the processes.

Late-Wisconsin and Holocene activity at the site began sometime after 12,800 years BP. Assuming an average age of 200 years for the soil organic matter at the time of burial, deposition on the Qt2 surface (at 98-OK-093-6) began between 12,600 and 11,700 years BP. The first deposits above the dated Qt2 surface are fluvial grading to fluvial/aeolian and imply fluctuating processes. The altithermal interval appears to be poorly represented at the site. It could be represented by the third and fourth solum buried in profile 98-OK-093-6. These profiles record fluvial/aeolian deposition, soil development, truncation, and another aeolian deposition. Because these layers were not radiocarbon dated, no absolute evidence indicates a precise time.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The data from the profile descriptions, photo interpretations, radiocarbon dating, and field mapping support the hypothesis that landforms in the study area developed under alternating fluvial and aeolian geomorphic processes. Prior to the Holocene, the dominant landforms on the Qt2 terrace were fluvial. The levee, well drained terrace tread, and backswamp positions were all present on the terrace. The ridge dune was present on the western edge of the terrace. Holocene aeolian activity buried the terrace surface with dunes and sand sheets. Aeolian sand engulfed the low-energy stream on the backswamp and created a series of depressions that periodically become wetlands. Pleistocene aeolian landforms present on higher terraces were also modified during the Holocene.

Ridge dunes are the initial deposition of sand from the Cimarron River at the edge of the floodplain. When the river downcuts and creates a terrace, the ridge dunes are preserved along the terrace escarpment and on the terrace tread. Subsequent remobilization during later arid periods modifies the dune forms. This conclusion is supported by analysis of the dune forms, topography, and relative dating techniques.

This report contains the first detailed mapping of terraces along the Cimarron River in western Oklahoma. The Cimarron River has numerous terraces, but reports from eastern and central Oklahoma indicate the Cimarron River has four to six terraces. This research establishes that the Cimarron River has eight terraces in the study area, and several more at higher elevations. Each of the terraces has sandhills associated with it on the proximal side. The presence of these sandhills shows that the process of sand blowing out of the channel onto the flood plain has been one of the normal processes in this basin for a large part of its history.

Soil development and weathering are important indicators of age. Proper recognition of these indicators requires careful examination of aeolian sediments. In western Oklahoma, leaching of calcium carbonate, development of structure, and destruction of cross-bedding are indicators of the weathering interval in recent aeolian sands. The modern classification system, Soil Taxonomy, fails to discriminate between these young soils. In buried soils, biological indicators such as color, structure, pores, root channels, fungal mycelia, and worm casts must be described to establish past relationships.

The relative dating scheme developed in this study establishes the age relationships between the terraces and sand dunes. The changes in weathering, soils, and surface morphology are sufficient evidence to delineate groups of dunes based on age.

The two study sites have received a mantle of aeolian sand, over at least three depositional events. Radiocarbon dates bracket times of stability in the landscape. The surface of the Qt2 terrace at the Hanor farm has a conventional C14 age of 10,410 years BP. The date signifies the earliest aeolian deposition could begin. Buried surface horizons in the dunes record two late-Holocene events on the Qt2 terrace. Sand was mobilized after stable periods dated at 1,730 years BP and 1,250 years BP.

Recommendations

The relative age relationships of the dunes and sandhills, even though supported by the evidence presented, needs to be established by quantitative studies that will corroborate the evidence and establish absolute dates for the deposition of dunes and terraces. Studies of resistant minerals that weather slowly could provide data for these sediments that may range in age to mid-Pleistocene. The older and higher dunes are the most problematic, because they have undergone rejuvenation several times at least, and weathered under several climates. This research could accompany studies of the adjoining terrace surfaces. The older terrace surfaces also appear to be altered by loess deposition.

This study establishes a partial chronology for the mobilization of sand in the Holocene. The radiocarbon dates on buried soil horizons establish maximum limiting dates for aeolian activity. The limited number of dates leaves gaps in the chronology. Using another technique, such as optically stimulated luminescence to date the aeolian sands directly, would provide a higher resolution of the dates of aeolian activity. The younger sands could also be dated to develop the chronology of the last few hundred years. These dates will also allow a correlation between soil development and absolute dates in this geographic region on Holocene aeolian sands. This correlation would be useful on the Canadian and Salt Fork of the Arkansas Rivers, where similar landforms and soils are present.

Additional mapping of Cimarron River terraces is needed to establish the total number of terraces on the north side of the river. The terraces need to be dated and correlated with other drainage systems, if possible. Several of the terraces may reflect a decay function in the basin following a major event. The higher terraces may have volcanic ash deposits that might correlate with the time markers of Carter, et al. (1990).

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APPENDIX A.

Scientific and Common Names of Plants in the Study Area

SCIENTIFIC NAME	COMMON NAME
Andropogon gerardii	Big bluestem
Andropogon hallii	Sand bluestem
Aristida purpurascens	Arrowfeather threeawn
Artemisia Filifolia	Sand sagebrush
Aster ericoides	Heath aster
Bouteloua curtipendula	sideoats grama
Bouteloua gracilis	Blue grama
Calamovilfa gigantea	Big sandreed
Celtis occidentalis	hackberry
Celtis reticulata	netleaf hackberry
Cephalanthus occidentalis	Buttonbush
Cornus drummondi	Roughleaf dogwood
Cyperus schweinitzii	Schweinitz flatsedge
Dalea enneandra	Bigtop dalea
Desmanthus illinoensis	Illinois bundleflower
Echinochloa crus-galli	Barnyardgrass
Eragrostis Trichodes	Sand lovegrass
Juniperus virginiana	red cedar
Lespedeza spp.	Lespedeza
Panicum Anceps	Beaked panicum
Panicum capillare	witchgrass
Panicum scribnerium	Scribner panicum
Panicum virgatum	Switchgrass
Poa Arachnifera	Texas bluegrass
Polygonum pensylvanicum	Pennsylvania smartweed
Populus deltoidies	Eastern cottonwood
Prunus angustifolia	Chickasha plum
Quercus havardii	Havard oak
Quercus marilandica	blackjack oak
Quercus stellata	post oak
Rhus Trilobata	Skunkbush sumac
Salix negra	black willow
Schizachyrium scoparium	Little bluestem
Silphium laciniatum	Compassplant
Sorghastrum Nutans	Indiangrass
Spartina pectinata	Prairie cordgrass
Sporobolus asper	Tall dropseed
Sporobolus cryptandrus	Sand dropseed
Stillingia sylvatica	Queensdelight
Tamarix chinensis	Tamarisk
Tridens Flavus	Purpletop
Tripsacum dactyloides	Eastern gamagrass
Ulmus americana	American elm

APPENDIX B—SOIL PROFILE DESCRIPTIONS.

Descriptions of soil profiles.
All colors moist Munsell notation.

98-OK-093-1
Hanor Farm
Oct. 28, 1998
N 36° 11' 32.15"
W 098° 10' 42.77"
Water table—312 cm

A--0 to 20 cm; dark brown (7.5YR 3/2) loamy fine sand; moderate fine granular structure; pH 7.5; non-effervescent; clear smooth boundary.

B1--20 to 45 cm; brown (7.5YR 5/3) loamy fine sand; moderate medium prismatic structure parting to moderate fine subangular structure; common fine roots; common fine distinct strong brown 7.5YR 5/6 redox concentrations; pH 7.8; clear smooth boundary.

B2--45 to 99 cm; 10YR 6/4 loamy fine sand; common fine distinct 10YR 5/8 redox concentrations; moderate coarse prismatic structure parting to moderate fine subangular structure; pH 8.0; abrupt smooth boundary.

2Ab--99 to 109 cm; 10YR 4/2 loamy fine sand; moderate fine subangular structure; common fine roots; abrupt smooth boundary; seems to be a truncated horizon, only 10 cm of the surface remains.

2Bt1b--109 to 129 cm; 10YR 5/1 sandy clay loam; strong medium prismatic structure parting to strong fine and medium subangular structure; many fine distinct 7.5YR 4/6 redox concentrations; common fine roots; 10YR 3/1 redox depletions in root channels; few fine black bodies; many distinct clay films on ped faces; pH 8.0; clear smooth boundary.

2Bt2b--129 to 231 cm; 10YR 4/1 sandy clay loam to sandy clay; strong medium prismatic structure parting to strong fine blocky structure; few fine black bodies; many fine pores; 10YR 3/1 streaks of redox depletions in root channels; few fine calcium carbonate concretions; pH 8.2; few films of calcium carbonate in old root channels; few slickensides; many distinct clay films on ped faces; faces of the coarse prisms have film of clean sand grains along faces, very compact, 2mm thick; clear smooth boundary.

2Btk1b--231 to 279 cm; 10YR 4/1 sandy clay; strong medium and coarse prismatic structure; many fine calcium carbonate threads; thick sand films on large prism faces; common fine distinct 5Y 4/3 redox accumulations; pH 8.2; non-effervescent; few fine pores; clear smooth boundary.

2Btk2b--279 to 325 cm; 10YR 5/1 sandy clay loam; strong coarse prismatic structure parting to moderate medium subangular blocky structure; few medium distinct 2.5Y 4/6 redox accumulations; few distinct clay films; common very fine pores;

common very fine soft bodies of calcium carbonate; pH 8.2; clear smooth boundary.

2Bt3b--325 to 378 cm; 10YR 7/2 sandy clay loam; moderate coarse prismatic structure parting to moderate fine and medium subangular blocky structure; few fine distinct redox depletions; common distinct clay films on vertical ped faces; few medium distinct 10YR 6/6 redox accumulations; few 7.5YR 5/6 rhizospheres in old root channels; few very fine pores; pH 8.2; clear smooth boundary.

3BC1--378 to 472 cm; 2.5Y 7/2 loamy fine sand; weak coarse prismatic structure; common very fine pores; common fine faint 10YR 7/4 redox accumulations; few thin layers of fine sandy loam, 1.25 cm thick; pH 8.2; clear smooth boundary.

3C--472 to 610 cm; 2.5Y 7/2 stratified loamy fine sand; weak coarse prismatic structure; few strata of 10YR 6/6 fine sandy loam; very few effervescent spots; pH 8.2; includes a few strata of sandy clay loam 10 cm thick, 2.5Y 7/2, with common fine distinct 10YR 5/6 redox accumulations.

98-OK-093-2
Oct. 29, 1998
Hanor Farm
W 36° 11' 34.97"
N 098° 10' 37.86"
Water table--556 cm

A--0 to 10 cm; 10YR 4/2 loamy fine sand; moderate fine platy structure parting to weak fine granular structure; many fine roots; pH 8.0; few large pores; clear smooth boundary.

AC--10 to 46 cm; 10YR 5/3 loamy fine sand; moderate medium prismatic structure parting to weak medium subangular blocky structure; common fine roots; pH 8.0; abrupt smooth boundary.

Ab--46 to 56 cm; dark brown (7.5YR 3/2) loamy fine sand; moderate fine and medium subangular blocky structure; common fine roots; pH 7.3; abrupt smooth boundary.

AC1b--56 to 102 cm; 7.5YR 4/3 loamy fine sand; moderate coarse prismatic structure parting to moderate medium subangular blocky structure; common fine roots; krotovina filled with dark brown (7.5YR 3/2) loamy fine sand from above; pH 7.5; few medium pores; clear smooth boundary.

AC2b--102 to 142 cm; 7.5YR 5/4 loamy fine sand; moderate coarse prismatic structure parting to moderate fine and medium subangular blocky structure; few fine roots; common fine pores; slightly hard, soft; slightly brittle when dry; pH 7.0; abrupt smooth boundary.

E & Btb--142 to 193 cm; 7.5YR 5/4 loamy fine sand; 7.5YR 4/4 lamellae of fine sandy loam; weak coarse prismatic structure parting to moderate fine and medium subangular blocky structure; few fine roots; soft, loose; common fine pores; pH 7.0; clear smooth boundary.

Bwb--193 to 224 cm; 7.5YR 4/6 loamy very fine sand; moderate coarse prismatic structure parting to moderate fine subangular blocky structure; few fine roots; slightly hard, very friable; many very fine worm casts; common fine pores; pH 7.3; clear smooth boundary.

BCb--224 to 315 cm; 7.5YR 6/6 fine sand; moderate fine and medium subangular blocky structure; soft, loose; few fine faint 5YR 4/6 redox accumulations; few very fine pores; pH 7.3; few lamellae in lower part. The lower 10 cm is a boundary transition to a buried A horizon. It is stratified 7.5YR 4/6 loamy fine sand, dark brown (7.5YR 3/2) loamy fine sand, and 7.5YR 5/4 loamy fine sand; abrupt smooth boundary.

2A1b--315 to 340 cm; 7.5YR 4/2 loamy fine sand; moderate medium prismatic structure parting to moderate fine subangular blocky structure; slightly hard, very friable; pH 7.5; clear smooth boundary.

2A2b--340 to 358 cm; dark brown (7.5YR 3/2) loamy fine sand; moderate medium prismatic structure parting to moderate fine subangular blocky structure; slightly hard, very friable; pH 7.5; clear smooth boundary.

2ABt--358 to 368 cm; dark brown (7.5YR 3/2) fine sandy loam; moderate medium prismatic structure parting to moderate fine subangular blocky structure; hard, friable; few distinct clay films; some medium and coarse sand; few fine distinct 5YR 4/6 redox accumulations; few very fine pores; pH 7.5; clear smooth boundary.

2Btk1b--368 to 452 cm; 5YR 4/6 sandy clay loam; strong medium prismatic structure parting to moderate fine subangular blocky structure; common distinct 7.5YR 5/2 clay films; common fine soft bodies of calcium carbonate; few fine distinct 7.5YR 5/1 redox depletions in old root channels; pH 7.8; effervescent in spots; gradual smooth boundary.

2Btk2b--452 to 478 cm; 5YR 5/6 light sandy clay loam; moderate medium prismatic structure parting to moderate fine subangular blocky structure; hard, friable; common very coarse sand grains; common fine pores; common medium distinct 7.5YR 5/1 redox depletions; non-effervescent.

2BC--478 to 599 cm; 5YR 5/6 fine sandy loam; moderate medium prismatic structure parting to moderate fine subangular blocky structure; hard, friable; few distinct clay films; many fine pores; few very fine pores; common fine distinct 7.5YR 6/1 and 5YR 5/2 redox depletions in old root channels; pH 7.5; grading to fine sandy loam at about 559 cm and then to massive fine sandy loam at 599 cm.

3C1--599 to 747 cm; 5YR 4/6 loamy fine sand; massive; few medium distinct 7.5YR 6/2 redox depletions; pH 8.0; abrupt smooth boundary.

3C2--747 to 792 cm; 2.5Y 7/2 fine sandy loam; massive; common fine distinct 7.5YR 5/6 redox accumulations; noneffervescent; pH 8.0.

98-OK-093-3
Oct. 30, 1998
Hanor Farm
W 36° 11' 43.63"
N 098° 10' 44.15"
Water table—270 cm

A--0 to 25 cm; 10YR 4/2 loamy fine sand; weak medium subangular blocky structure parting to weak fine granular structure; soft, loose; many fine roots; pH 7.5; clear smooth boundary.

Bw--25 to 86 cm; 7.5YR 4/2 loamy fine sand; moderate coarse prismatic structure parting to weak fine and medium subangular blocky structure; few fine distinct 7.5YR 5/8 redox concentrations; soft, loose; common fine roots; few medium pores; common fine pores; pH 7.5; abrupt smooth boundary.

2A--86 to 97 cm; 10YR 3/2 fine sandy loam; hard, friable; moderate fine subangular blocky structure; many fine pores; few fine roots; pH 7.8; clear smooth boundary.

2Bt1--97 to 109 cm; coarsely mottled 7.5YR 4/6, 5YR 4/4, and 7.5YR 5/2 sandy clay loam; strong medium prismatic structure parting to moderate fine subangular blocky structure; hard, firm; many distinct dark brown (7.5YR 3/2) clay films on ped faces; common very fine black bodies; pH 7.5; clear smooth boundary.

2Bt2--109 to 178 cm; 10YR 5/2 sandy clay loam; strong medium and coarse prismatic structure parting to strong fine and medium subangular structure; many medium distinct 10YR 5/6 redox concentrations; many distinct 10YR 5/2 clay films on prism faces, thick with some clean sand grains; common medium and coarse sand grains, few fine calcium carbonate concretions; pH 8.0; clear smooth boundary.

2Btk--178 to 279 cm; 2.5Y 5/1 clay loam; strong medium prismatic structure parting to moderate fine subangular blocky structure; common medium distinct 10YR 5/4 redox concentrations; hard, firm; common films and a few concretions of calcium carbonate; many distinct N 7/0 clay films on ped faces; common fine pores; few medium pores; effervescent in spots; raining like hell; few fine black bodies; common intersecting slickensides; clear smooth boundary.

2BC--279 to 373 cm; 2.5Y 6/2 loam; weak medium prismatic structure parting to weak medium subangular blocky structure; hard, friable; few fine roots; many fine pores; few fine distinct 2.5Y 5/4 redox concentrations; few medium pores; few fine black bodies; non-effervescent; no clay films; few clean medium sand grains; still raining; pH 8.0.

98-OK-093-4
Oct. 11, 1998
Hanor Farm
N 36° 11' 28.98"
W 098° 10' 42.72"
Water table--168 cm.

Notes: This site is in a depression about 300' south of site 10-28-98. A small dune runs E-W between these sites.

The site has typical cover sands, described often, grading into coarsely mottled (7.5YR 5/6 & 5YR 5/2) sandy clay loam at 2.4 meters.

At 274 cm, encountered 2Ab.

2Ab--274 to 315 cm; 10YR 4/2 clay; saturated; very plastic, slightly sticky, extremely firm; difficult to remove from tube; structure not determined; sampled; common fine soft bodies of calcium carbonate; few medium calcium carbonate concretions; few medium roots; common slickensides; few fine distinct 10YR 4/6 redox concentrations; as the soil dries, strong very fine angular blocky structure is apparent; non-effervescent.

2Bw--315 to 376 cm; 10YR 6/2 sandy clay loam grading to fine sandy loam; non-effervescent.

11-16-98
98-OK-093-5
Hanor Farm
N 36° 11' 35.65"
W 098° 10' 46.70"

This position is on the summit of a blowout rim on fore-dune of large ridge to the west.
This site is on a longitudinal dune, west side of N-S depression. This dune runs N-S and is about 2.4 meters above the low area. It has very complex slopes, and blowouts are common.
Bearings; to irrigation well 1, 54o magnetic north.
to irrigation well 2, by center pivot, 193o magnetic north.
to pivot, 213o magnetic north.

Profile:

A,A2,AC--0 to 165 cm; 7.5YR 4/2-5/4-6/4 loamy fine sand.

C--135 to 330 cm; 7.5YR 6/6 loamy fine sand with lamellae (that could be developed on cross-bedding, but sample is too small to tell) of 5YR 6/4 loamy fine sand; weak coarse prismatic structure; weak fine subangular blocky structure in lamellae; lamellae are slightly brittle.

2Ab--330 to 356 cm; 7.5YR 4/4 loamy fine sand; pH 7.5; non-effervescent.

2Bt1b--356 to 381 cm; 7.5YR 5/8 sandy clay loam; moderate medium prismatic structure parting to moderate fine subangular blocky structure; few distinct clay films; few pockets of clean sand; pH 7.5.

2Bt2b--381 to 419 cm; (auger samples only from here on down); 2.5Y 5/2 sandy clay loam; common medium distinct 10YR 5/8 redox concentrations; few fine black bodies; few pockets of clean sand; non-effervescent; pH 7.5;

2Bt3b--419 to 584 cm; stratified 2.5Y 5/2 sandy clay loam and fine sandy loam; non-effervescent; pH 7.5.

2BC--584 to 762 cm; 10YR 7/4 fine sandy loam; massive; pH 7.8; non-effervescent.

98-OK-093-6
Hanor Farm
Nov. 20, 1998
N 36° 11' 23.16"
W 098° 10' 36.96"
On large dune as southeast edge of quarter, 75' W of northern-most blackjack oak on east side of dune.

A--0 to 25 cm; dark brown (7.5YR 3/2) loamy fine sand; moderate medium subangular blocky structure parting to weak fine granular structure; slightly hard, very friable; many fine roots; few medium pores; few fine pores; pH 7.5; clear smooth boundary.

AC1--25 to 40 cm; brown (7.5YR 4/3) loamy fine sand; moderate medium and fine subangular blocky structure; slightly hard, very friable; common fine roots; few fine pores; pH 7.5; clear smooth boundary.

AC2--40 to 142 cm; strong brown (7.5YR 5/6) loamy fine sand; moderate medium prismatic structure parting to weak fine and medium subangular blocky structure; slightly hard, very friable; few fine roots; few medium roots; few fine pores; few medium pores; pH 7.8; clear smooth boundary.

C--142 to 307 cm; brown (7.5YR 5/4) fine sand; weak coarse prismatic structure parting to weak fine platy structure; soft, loose; few fine roots; few medium roots; few fine pores; few brown (7.5YR 5/4) lamellae 0.3 to 0.6 cm thick; below 203 cm many very fine cross-bedding that appear as the soil dries; cross-bedding has color value ranging from 4 to 7 common pockets of clean sand; pH 7.8; clear smooth boundary.

2Ab--307 to 338 cm; brown (7.5YR 4/4) loamy fine sand; moderate medium subangular blocky structure parting to moderate medium platy structure; soft, very friable; no roots; common fine pores; common very fine pores; common pockets of clean sand grains; pH 7.8; clear smooth boundary.

2Btb--338 to 411 cm; yellowish red (5YR 4/6) heavy loamy fine sand; strong medium prismatic structure parting to moderate fine and medium subangular blocky structure; slightly hard, very friable; few medium roots, dead and partially decayed; many fine pores; few distinct clay films; common clay bridging between sand grains; few yellowish red (5YR 3/4) lamellae; few old worm casts; non-effervescent; pH 8.0; abrupt smooth boundary.

2BCb--411 to 475 cm; strong brown (7.5YR 4/6) loamy fine sand; moderate coarse prismatic structure parting to weak medium subangular blocky structure; slightly hard, very friable; no roots; few lamellae 0.6 cm thick of yellowish red (5YR 4/6) heavy loamy fine sand, having weak medium platy structure; common fine pores; non-effervescent; pH 8.0; abrupt smooth boundary.

3Btb--475 to 528 cm; brown (7.5YR 4/4) fine sandy loam; moderate coarse prismatic structure parting to moderate medium subangular blocky structure; slightly hard, very friable; no roots; many fine pores; few medium pores; common very fine pores; few clean sand grains; few distinct clay films; common clay bridging between sand grains; few darker lamellae 1.25 cm thick of dark brown (7.5YR 3/4) fine sandy loam; non-effervescent; pH 8.0; clear smooth boundary.

4Ab--528 to 559 cm; brown (7.5YR 4/3) loam; moderate fine and medium subangular blocky structure parting to weak medium granular structure; slightly hard, friable; no roots; common fine pores; many very fine pores; few clean sand grains; common old root channels; few old wormcasts; few strata of dark brown (7.5YR 3/2) loam; pH 8.0; non-effervescent; abrupt smooth boundary.

4AC--559 to 591 cm; stratified brown (7.5YR 5/4), dark brown (7.5YR 3/4), and strong brown (7.5YR 4/6) fine sandy loam; weak medium prismatic structure parting to weak medium subangular blocky structure; slightly hard, very friable; no roots; strata are 0.2 to 0.4 cm thick; many fine pores; few medium pores; common medium and coarse sand grains; few old worm casts; (layers in '4') this is a combination eolian/alluvial deposit; clear smooth boundary.

4C1--591 to 645 cm; yellowish red (5YR 5/6) loamy fine sand; weak coarse prismatic structure parting to weak medium subangular blocky structure grading to massive; soft, loose; no roots; few fine pores; non-effervescent; pH 8.0; clear smooth boundary.

4C2--645 to 665 cm; light yellowish brown (10YR 6/4) loamy fine sand; massive; stratified with very dark grayish brown (10YR 3/2) loam; massive; non-effervescent; pH 8.0; abrupt smooth boundary.

5Ab--665 to 693 cm; very dark grayish brown (10YR 3/2) silt loam; moderate medium and fine subangular blocky structure parting to weak medium granular structure; hard, friable; no roots; many fine pores; few medium pores; many old root channels; common worm casts; non-effervescent; pH 8.0; clear smooth boundary.

5Bt1--693 to 732 cm; very dark brown (10YR 2/2) silty clay; strong medium prismatic structure parting to strong fine subangular blocky structure; very hard, very firm; no roots; many fine root channels; common fine pores; few medium pores; few white fungal threads; common distinct clay films; non-effervescent; pH 8.0; clear smooth boundary.

5Bt2--732 to 782 cm; grayish brown (10YR 5/2) sandy clay loam; common medium distinct strong brown (7.5YR 5/8) redox accumulations; strong medium prismatic structure parting to moderate fine subangular blocky structure; hard, firm; common distinct clay films; few very dark grayish brown (10YR 3/2) ped faces; common fine pores; few medium pores; non-effervescent; pH 8.0; gradual smooth boundary.

5BC--782 to 817 cm; pinkish gray (10YR 6/2) fine sandy loam; slightly brittle; weak medium subangular blocky structure; hard, friable; few fine distinct strong brown (7.5YR 5/6) redox accumulations; few strong brown (7.5YR 5/8) rhizospheres in old root channels; few faint clay films; common fine pores; few very fine pores; many old root channels; non-effervescent; pH 8.0.

98-OK-093-7
Nov. 23, 1998
Hanor Farm
in NE corner of quarter
79 meters @334 ° north to pipeline crossing
58 ° bearing to the northeast corner of the quarter.

Notes: This profile is intended to represent the sand sheet mantled surface. It is about 2.4 meters above the low N-S depression. None of this area is without some sand sheet and this profile is no exception.

A--0 to 30 cm; dark grayish brown (10YR 4/2) loamy fine sand.

Bw--30 to 104 cm; yellowish brown (10YR 5/4) loamy fine sand.

2Ab--104 to 119 cm; brown (7.5YR 4/4) fine sandy loam; moderate fine subangular blocky structure parting to moderate very fine subangular blocky structure; few faces of dark brown (7.5YR 3/4) color; many fine pores; few worm casts.

2Bt1b--119 to 155 cm; reddish brown (5YR 4/4) fine sandy loam/sandy clay loam; strong medium prismatic structure parting to moderate medium and fine subangular blocky structure; common distinct clay films.

2Bt2b--155 to 193 cm; brown (7.5YR 5/4) loam; moderate medium prismatic structure parting to moderate fine subangular blocky structure; common medium distinct yellowish red (5YR 5/6) redox accumulations; few distinct clay films; common fine roots.

2BCb--193 to 231 cm; brown (7.5YR 4/4) loamy fine sand; weak medium prismatic structure; common fine distinct yellowish red (5YR 5/6) redox accumulations; common fine black bodies; few fine distinct pinkish gray (7.5YR 6/2) redox depletions.

3Ab--231 to 249 cm; dark grayish brown (10YR 4/2) silt loam; common fine distinct pinkish gray (10YR 6/2) redox depletions; common fine distinct yellowish brown (10YR 5/6) redox concentrations; few silt films; many fine pores...

3Bt1b--249 to 305 cm; very dark brown (10YR 2/2) silty clay; strong medium prismatic structure parting to strong medium and fine subangular blocky structure; many distinct clay films on ped faces; many fine pores...

3Bt2b--305 to 368 cm; dark gray (10YR 4/1) sandy clay loam; moderate medium prismatic structure parting to moderate fine subangular blocky structure; few distinct clay films; few medium distinct strong brown (7.5YR 5/6) redox accumulations...

3BC--368 to 508 cm; gray (10YR 5/1) fine sandy loam; few strata of sandy clay loam.

98-OK-093-8
Hanor Farm
Dec. 3, 1998
Site is in wheat field south of gravel road to the gene transfer center.
30 meters south of the center of the road.

17 ° bearing to telephone pole.
This site is straight south of the low area in section 20.

Ap--0 to 25 cm; dark brown (7.5YR 4/2) loamy fine sand; weak fine granular structure; soft, loose; common fine pores; pH 8.0; clear smooth boundary.

AC--25 to 191 cm; strong brown (7.5YR 5/6) loamy fine sand; weak medium prismatic structure parting to weak medium subangular blocky structure; at 76 cm is a zone of platy structure, it may be cross-bedding; few fine roots; few lamellae 0.3 cm to 0.6 cm thick, yellowish red (5YR 4/6); many fine pores; soft, loose; pH 8.0; abrupt smooth boundary.

2Ab--191 to 201 cm; brown (7.5YR 4/3) fine sandy loam; moderate medium prismatic structure parting to moderate fine subangular blocky structure; slightly hard, very friable; degraded-mixed with loamy fine sand from above, possibly by worms, bioturbation; many fingers of loamy fine sand; few fine faint yellowish red (5YR 4/6) redox accumulations; few fine black stains; many fine pores; few fine black bodies; pH 7.5; clear smooth boundary.

2Bt1b--201 to 244 cm; yellowish red (5YR 4/6) fine sandy loam; moderate medium prismatic structure parting to moderate fine subangular blocky structure; hard, friable; many distinct clay films on ped faces; many fine pores; few medium roots; few worm casts; few medium pores; pH 7.5; clear smooth boundary.

2Bt2b--244 to 363 cm; coarsely mottled strong brown (7.5YR 5/6) and yellowish red (5YR 4/6) fine sandy loam; moderate medium prismatic structure parting to moderate fine subangular blocky structure; hard, friable; common distinct clay films on faces of peds; common clean sand grains; many fine pores; common medium pores; common worm casts; slightly brittle; pH 7.5; clear smooth boundary.

2BCb--363 to 508 cm; strong brown (7.5YR 4/6) fine sandy loam, stratified with loamy fine sand; some stratifications are strong brown (7.5YR 4/6), a few are dark brown (7.5YR 3/2); water table at 394 cm; hole caved in below that; poor core below 4.6 meters, one strata of silt loam 15 cm thick, a few of coarse sandy loam; few old root channels in the form of rhizospheres; many fine stratifications.

3Bw1--508 to 731 cm; yellowish red (5YR 4/6) very fine sandy loam; weak fine subangular blocky structure; common fine pores; common fine black bodies; few medium sand grains.

3BW2--731 to 762 cm; yellowish red (5YR 4/6) loam; moderate fine subangular blocky structure; many fine pores that are old root channels; few distinct clay films.

3BC--762 to 884 cm; yellowish red (5YR 5/6) sandy clay loam; moderate medium prismatic structure parting to weak fine and medium subangular blocky structure; few strata of fine sandy loam; common medium distinct pinkish gray (7.5YR 6/2) redox depletions; common fine distinct yellowish brown (10YR 5/6) redox accumulations, mostly as vertical streaks; common fine pores.

98-OK-093-9
Hanor Farm
Dec. 9, 1998

It is 10.6 meters west of a mineral feeder and 100' at 218 ° bearing to the green water tank we located on the total station survey. This core has a well drained soil over fine sandy loam/sandy clay loam. No sign of any buried, wet areas, but a lot of buried surfaces nevertheless.

Ap--0 to 15 cm; dark brown (7.5YR 4/2) loamy fine sand; weak fine granular structure; clear smooth boundary.

A1--15 to 43 cm; dark brown (7.5YR 3/2) loamy fine sand; moderate medium subangular blocky structure parting to weak fine granular structure; clear smooth boundary.

Bw--43 to 107 cm; brown (7.5YR 5/4) loamy fine sand; moderate medium prismatic structure parting to moderate fine subangular blocky structure; many fine roots; soft, loose; many fine pores; clear smooth boundary.

BC1--107 to 150 cm; strong brown (7.5YR 5/6) loamy fine sand; moderate medium prismatic structure parting to weak fine subangular blocky structure; few fine roots; common fine pores; abrupt smooth boundary.

BC2--150 to 190 cm; strong brown (7.5YR 5/6) loamy fine sand; moderate medium prismatic structure parting to moderate medium subangular blocky structure; common fine pores; slightly brittle; common fine roots; common fine worm casts from horizon below (darker), I think that this horizon was bioturbated, worked by worms, after commencement of sand deposition.

2Ab1--190 to 218 cm; brown (7.5YR 4/4) fine sandy loam; moderate medium subangular blocky structure; has faces of brown (7.5YR 4/3); many fine pores; common worm casts; from 190 cm down medium and coarse sand grains are common; clear smooth boundary.

2Bt1b--218 to 246 cm; brown (7.5YR 4/3) sandy clay loam; moderate fine and medium subangular blocky structure; few distinct clay films on faces of peds; clay bridging between sand grains; common fine pores; common medium and coarse sand grains; clear smooth boundary.

2Bt2b--246 to 267 cm; brown (7.5YR 4/3) sandy clay loam; strong medium prismatic structure parting to moderate medium subangular blocky structure; many distinct clay films on ped faces; many fine pores, which are old root channels; few rhizospheres; few red mottles, and a moderately well drained appearance; gradual smooth boundary.

2Bt3b--267 to 335 cm; strong brown (7.5YR 4/6) fine sandy loam; strong medium prismatic structure parting to moderate medium subangular blocky structure; few fine roots; common distinct clay films on faces of peds, brown (7.5YR 4/3); many fine pores; few medium pores; common worm casts; abrupt smooth boundary.

3Ab--335 to 356 cm; strong brown (7.5YR 5/6) loamy fine sand; moderate medium prismatic structure parting to moderate fine and medium subangular blocky structure; common distinct clay films on faces of peds, few darker faces; many fine pores; common medium pores; few coarse pores, which are old root channels; this horizon is slightly brittle; has a few clean sand grains; clear smooth boundary.

3Btb--356 to 376 cm; yellowish red (5YR 4/6) heavy fine sandy loam; moderate medium prismatic structure parting to moderate medium subangular blocky structure; common distinct clay films on faces of peds, faces are darker; clay bridging between sand grains; old root channels have black, decayed roots; many fine pores; abrupt smooth boundary.

4Ab--376 to 396 cm; strong brown (7.5YR 4/6) loamy fine sand; moderate medium prismatic structure parting to moderate medium subangular blocky structure; many fine pores; many medium pores; many coarse pores; many old root channels; clear smooth boundary.

4Bt1--396 to 422 cm; red (2.5YR 4/6) crushed, red (2.5YR 5/6) cut face, sandy clay loam; still has coarse sand grains; many fine pores; many distinct clay films on ped faces; old root channels; common worm casts; clear smooth boundary.

4Bt2--422 to 508 cm; yellowish red (5YR 5/8) sandy clay loam; strong coarse prismatic structure parting to moderate fine and medium subangular blocky structure; many distinct clay films on ped faces, faces are darker; pockets of clean sand grains on ped faces and in old root channels; some old root channels have decayed roots.

4BC--508 to 569 cm; yellowish red (5YR 5/8) fine sandy loam; moderate medium prismatic structure parting to weak fine and medium subangular blocky structure; few fine pores; common old root channels.

4C--569 to 914 cm; yellowish red (5YR 4/6) fine sandy loam; water table at 584 cm; nearly massive weak fine subangular blocky structure; common fine black stains; a few strata of silty clay loam; this horizon was augured.

98-OK-093-10
Hanor Farm
Jan. 20, 1999

On east edge of farm, 11.5 paces west of fence, 11.5 paces at 332 ° to a bare depression, which is about 152 meters north of the main gate. This location is about 0.5 meters higher than the lowest part of the nearby depression, on the south side of the depression. If the low, buried stream channel is here, the sediments below should show it.

Water table--175 cm

A1--0 to 18 cm; very dark grayish brown (10YR 3/2) loamy fine sand; moderate fine granular structure; many fine roots; clear smooth boundary.

A2--18 to 41 cm; very dark grayish brown (10YR 3/2) loamy fine sand; weak medium subangular blocky structure; common fine roots; few fine redox depletions; clear smooth boundary.

2A1--41 to 53 cm; yellowish brown (10YR 5/4) loamy fine sand; clear smooth boundary.

2Bt--53 to 91 cm; yellowish red (5YR 5/6) fine sandy loam; moderate medium subangular blocky structure; common distinct clay films on faces of peds; few fine roots; gradual smooth boundary.

3A--91 to 117 cm; brown (7.5YR 5/4) loamy fine sand; weak medium subangular blocky structure; few fine roots; clear smooth boundary.

3Bt--117 to 173 cm; yellowish red (5YR 4/6) clay loam; moderate medium prismatic structure parting to moderate fine subangular blocky structure; few fine roots; many distinct clay films on ped faces; clear smooth boundary.

4A--173 to 213 cm; yellowish red (5YR 5/6) fine sandy loam; moderate fine and medium subangular blocky structure; few rhizospheres; many fine pores; clear smooth boundary.

4Bt--213 to 264 cm; yellowish red (5YR 4/6) sandy clay loam; moderate medium prismatic structure parting to moderate fine and medium subangular blocky structure; many fine pores; common distinct clay films on faces of peds; gradual smooth boundary.

4BC--264 to 304 cm; yellowish red (5YR 4/6) loam and very fine sandy loam.

4C--304 to 610 cm; very saturated, unable to get a good sample, but texture is loam and fine sandy loam, yellowish red (5YR 5/6); comparable to commonly seen terrace material in lower parts of terrace, correlates.

This is a well-drained profile with the exception of the 33-66 cm layer, and the sediments here do not correlate with the surface topography, even though this is a depression, it is not a part of the terrace backswamp.

January 27, 1999
98-OK-093-11
Hanor Farm.
Location 33.5 meters at 38 ° to the south end of the cattle guard of the main gate.
The site is an interdune position, just east of a longitudinal dune that runs N-S.
The aeolian sand sheet here is only 104 cm thick, overlying well drained profile of fine sandy loam, loam, and very fine sandy loam.
Water table at about 3.6 meters. The underlying material from 3.6 to 4.9 meters is saturated fine sandy loam and loamy fine sand.

98-OK-093-12
Feb. 8, 1999
Hanor Farm.
Location: 204 ° bearing to the high hill, 84o bearing to the irrigation well. About 183 meters south of the north fence, on high N-S ridge on west side of the study site. North and a little west of the pig house.
Here I am looking for continuation of terrace surface, and any cross-bedded sands.
This dune was mapped Nobscot, but only because it had oak savannah vegetation. This is part of the terminal dune (apparently proximal to the river) covering the Qt2 terrace.

A--0 to 10 cm; dark brown (7.5YR 4/2) fine sand; weak fine granular structure; loose, loose; many fine roots; clear smooth boundary.

E--10 to 51 cm; light yellowish brown (10YR 6/4) fine sand; weak coarse subangular blocky structure; loose, loose; common fine roots; gradual smooth boundary.

E&Bt--51 to 152 cm; 90 percent light yellowish brown (10YR 6/4) fine sand, and 10 percent strong brown (7.5YR 5/6) loamy fine sand in the form of lamellas 0.3 to 1.25 cm thick; weak fine platy structure and weak coarse subangular blocky structure; soft, loose; few coarse bedding planes; the Bt lamellae decrease with depth; as soil dries the cross-bedding and platy structure becomes evident; diffuse smooth boundary.

C1--152 to 366 cm; reddish yellow (7.5YR 6/6) fine sand; massive, single grained; loose, loose; all is bedded, some evident cross-bedding; very low angle dune here, but very regular bedding, same thickness, 0.2 cm; the last core depth is 365 cm; augured to 1280 cm.

C2--366 to 609 cm; reddish yellow (7.5YR 6/6) fine sand; same as above.

C3--609 to 670 cm; light brown (7.5YR 6/4) fine sand; about 10 percent streaks of yellowish brown (10YR 5/6) fine sand.

C4--670 to 731 cm; strong brown (7.5YR 5/6) fine sandy loam.

C5--731 to 914 cm; coarsely mottled yellowish brown (10YR 5/6), very pale brown (10YR 7/4), and light gray (10YR 7/2) fine sandy loam; water table at about 792 cm.

C6--914 to 1158 cm; coarsely mottled, 70 percent yellowish red (5YR 5/6) and 30 percent very pale brown (10YR 7/3) fine sandy loam; yellowish red (5YR 5/6) color increasing with depth.

C7--1158 to 1250 cm; coarsely mottled, 70 percent yellowish red (5YR 5/6) and 30 percent very pale brown (10YR 7/3) sandy clay loam.

C8--1250 to 1280 cm; dark grayish brown (10YR 4/2) clay loam; common fine distinct strong brown (7.5YR 5/8) redox accumulations; common medium distinct pinkish gray (10YR 6/2) redox depletions.

98-OK-093-13
Hanor Farm
Feb. 10, 1999

Location: south of entrance road, about 244 meters, 240 ° to south center pivot, 62 ° to green tank on ridge south of lone oak tree.

Only went 305 cm deep.

This site is lower topographically, but was in the well drained position on the stream terrace. No clearly defined surface horizon buried at this spot, but may have been destroyed; it would not have had to have been, by necessity, preserved.

A--0 to 38 cm; dark grayish brown (10YR 4/2) loamy fine sand; weak fine granular structure; soft, loose; many fine roots; clear smooth boundary.

AC--38 to 66 cm; brown (7.5YR 5/4) loamy fine sand; weak medium subangular blocky structure; common fine roots; common fine pores; abrupt smooth boundary.

Abt--66 to 94 cm; brown (7.5YR 4/4) fine sandy loam; moderate medium prismatic structure parting to moderate fine subangular blocky structure; common fine roots; common fine pores; (could this be a Bt horizon?) clear smooth boundary.

Eb&Btb--94 to 157 cm; 70 percent yellowish brown (10YR 5/4) loamy fine sand, and 30 percent strong brown (7.5YR 5/6) fine sandy loam; the Bt material is in irregular chunks; moderate medium prismatic structure parting to weak medium subangular blocky structure; many fine pores; gradual smooth boundary.

Btb1--157 to 213 cm; red (2.5YR 5/6) heavy fine sandy loam; common medium distinct very pale brown (10YR 7/3) redox depletions as vertical streaks along ped faces; moderate medium prismatic structure parting to moderate fine subangular blocky structure; hard, friable; many fine pores; few black bodies; few distinct clay films on faces of peds; gradual smooth boundary.

Btb2--213 to 249 cm; red (2.5YR 4/6) sandy clay loam; common fine distinct light brown (7.5YR 6/4) redox depletions as vertical streaks along ped faces; moderate medium prismatic structure parting to moderate fine and medium subangular blocky structure; hard, firm; few fine black bodies; few distinct clay films on faces of peds; common old root channels; many fine pores; gradual smooth boundary.

Bb--249 to 330 cm; red (2.5YR 5/6) fine sandy loam to loam; few fine distinct pale brown (10YR 6/3) redox depletions; weak coarse prismatic structure parting to moderate fine subangular blocky structure; saturated; hard, friable; common black stains; few fine black bodies; many fine pores; lower part breaks out in bedding planes 0.6 cm to 1.25 cm thick like platy structure; many old root channels 0.2 to 0.4 cm diameter.

98-OK-073-1
Hajak Ranch
Sept. 14, 1998
N 36° 08' 31.54"
W 098° 09' 19.75"
Water table--91 cm

A--0 to 33 cm; dark brown (7.5YR 3/3) loamy fine sand; weak medium subangular blocky structure parting to weak fine granular structure; clear smooth boundary.

AC--33 to 79 cm; brown (7.5YR 4/4) loamy fine sand; moderate medium subangular blocky structure; clear smooth boundary.

Ab--79 to 127 cm; dark brown (7.5YR 3/3) loamy fine sand; moderate medium subangular blocky structure parting to moderate fine subangular blocky structure; common worm casts; common fine pores; gradual smooth boundary.

ABb--127 to 152 cm; light brown (7.5YR 6/4) loamy fine sand; few fine distinct strong brown (7.5YR 5/6) redox accumulations; moderate medium subangular blocky structure; common fine pores; gradual smooth boundary.

C1--152 to 203 cm; reddish yellow (10YR 6/6) fine sand; common fine distinct reddish yellow (5YR 6/6) redox accumulations; weak medium subangular blocky structure parting to single grained; common fine black bodies; common medium black bodies; few fine soft bodies of calcium carbonate; gradual smooth boundary.

C2--203 to 269 cm; reddish brown (5YR 5/4) loam; common medium distinct pinkish gray (10YR 6/2) redox depletions; moderate medium prismatic structure parting to moderate fine and medium subangular blocky structure; common fine pores; gradual smooth boundary.

C3--269 to 335 cm; stratified very pale brown (10YR 7/4) fine sand and brown (7.5YR 4/4) very fine sandy loam; few fine faint pinkish gray (10YR 6/2) redox depletions; common medium black bodies; gradual smooth boundary.

2Ab--335 to 427 cm; dark grayish brown (10YR 4/2) clay loam; common medium distinct strong brown (7.5YR 5/6) redox accumulations; moderate medium prismatic structure parting to moderate fine subangular blocky structure; few fine pores; common very fine pores, some partially filled with calcium carbonate; few fine black bodies; clear smooth boundary.

2Btb--427 to 533 cm; yellowish red (5YR 5/6) sandy clay loam; many medium distinct pinkish gray (10YR 6/2) redox depletions; weak coarse prismatic structure parting to weak medium subangular blocky structure; common fine pores; clear smooth boundary.

2C--533 to 579 cm; strong brown (7.5YR 5/6) stratified sand and fine sand; common medium distinct pinkish gray (10YR 6/2) redox depletions; massive; few clay balls; clear smooth boundary.

3A--579 to 610 cm; yellowish red (5YR 4/6) fine sandy loam; common medium distinct gray (10YR 6/1) redox depletions; moderate medium prismatic structure parting to weak medium subangular blocky structure; few medium pores; few fine black bodies; clear smooth boundary.

3Bt1--610 to 671 cm; pinkish gray (10YR 6/2) sandy clay loam; common medium distinct brown (7.5YR 5/4) redox accumulations; weak medium prismatic structure parting to weak fine subangular blocky structure; many fine black bodies; gradual smooth boundary.

3Bt2--671 to 762 cm; yellowish red (5YR 5/6) sandy clay loam; pinkish gray (7.5YR 6/2) redox depletions; weak medium prismatic structure parting to weak fine subangular blocky structure; black stains in old root channels; common fine black bodies in lower part; gradual smooth boundary.

3BC1--762 to 792 cm; brown (7.5YR 5/4) fine sandy loam; few medium distinct yellowish red (5YR 5/6) redox accumulations; gradual smooth boundary.

3BC2--792 to 884 cm; yellowish red (5YR 5/6) loam; common medium distinct pinkish gray (10YR 6/2) redox depletions; massive; few old roots; few black stains in old root channels; common very fine pores; few fine pores.

98-OK-073-2
Hajek Ranch
Sept. 20, 1998"
N 36° 08' 38.81"
W098° 09' 15.52
Water table--427 cm

A1--0 to 30 cm; dark brown (7.5YR 3/2) loamy fine sand; moderate fine platy structure parting to moderate fine subangular blocky structure; many fine roots; clear smooth boundary.

A2--30 to 61 cm; dark brown (7.5YR 4/2) loamy fine sand; moderate medium subangular blocky structure parting to single grained; common fine roots; gradual smooth boundary.

AC--61 to 107 cm; brown (7.5YR 4/4) loamy fine sand; moderate medium subangular blocky structure; common fine roots; common fine pores; gradual smooth boundary.

C--107 to 137 cm; yellowish brown (10YR 5/4) loamy fine sand; weak medium subangular blocky structure parting to massive; few fine pores; clear smooth boundary.

Bb--137 to 213 cm; strong brown (7.5YR 4/6) loamy fine sand; moderate coarse prismatic structure parting to moderate medium prismatic structure; common fine pores; gradual smooth boundary.

C1--213 to 305 cm; light yellowish brown (10YR 6/4) fine sand; massive; faint cross-bedding; gradual smooth boundary.

C2--305 to 335 cm; pale brown (10YR 6/3) fine sand; massive.

2Ab--335 to 351 cm; reddish brown (5YR 4/3) fine sandy loam; moderate medium prismatic structure parting to moderate fine subangular blocky structure; clear smooth boundary.

2Btb1--351 to 427 cm; yellowish red (5YR 4/6) sandy clay loam; moderate medium prismatic structure parting to moderate fine subangular blocky structure; common fine pores; few fine calcium carbonate films in pores; many distinct reddish brown (5YR 4/3) clay films on ped faces; gradual smooth boundary.

2Btb2--427 to 488 cm; strong brown (7.5YR 5/6) sandy clay loam; common fine distinct brown (10YR 5/3) redox depletions; moderate fine prismatic structure parting to moderate fine and medium subangular blocky structure; many distinct dark brown (7.5YR 4/2) clay films on ped faces; few calcium carbonate films in pores; many fine pores; few coarse pores; gradual smooth boundary.

2C1--488 to 610 cm; yellowish red (5YR 4/6) loam; massive; few fine concretions of calcium carbonate; common black streaks; gradual smooth boundary.

2C2--610 to 701 cm; brown (7.5YR 4/4) loam; moderate coarse prismatic structure; many very fine black bodies; clear smooth boundary.

3Ab--701 to 732 cm; dark grayish brown (10YR 4/2) clay loam; many fine and medium concretions of calcium carbonate.

3B--732 to 914 cm; yellowish red (5YR 5/6) loam; few fine concretions of calcium carbonate.

3C--914 to 1097 cm; yellowish red (5YR 4/6) loam; massive.

98-OK-073-3
Hajak Ranch
Sept. 17, 1998
N 36° 08' 36.21"
W 98° 09' 19.01"

A--0 to 30 cm; dark brown (7.5YR 3/4) loamy fine sand; weak medium subangular blocky structure parting to weak very fine granular structure; many fine roots; few worm casts; few fine pores; pH 6.8; clear smooth boundary.

AC1--30 to 91 cm; brown (7.5YR 5/4) fine sand; moderate coarse prismatic structure parting to weak medium subangular blocky structure; common fine roots; few worm casts; few very fine pores; few fine pores; pH 7.5; gradual smooth boundary.

AC2--91 to 254 cm; brown (7.5YR 5/4) fine sand; weak coarse prismatic structure parting to weak medium subangular blocky structure; few fine roots; many clean sand grains; common very fine pores; pH 7.5; diffuse smooth boundary.

C1--254 to 330 cm; strong brown (7.5YR 5/6) fine sand; weak coarse prismatic structure parting to single grained; few fine roots; faint cross-bedding; pH 8.0; non-effervescent; leached; diffuse smooth boundary.

C2--330 to 457 cm; strong brown (7.5YR 5/6) fine sand; single grained; many very fine cross-bedding; photo at 417 cm; pH 8.0; clear smooth boundary.

Ab--457 to 495 cm; dark brown (7.5YR 4/2) loamy fine sand; common medium faint strong brown (7.5YR 4/6) redox accumulations; weak medium subangular blocky structure parting to weak fine subangular blocky structure; soft, very friable; common fine pores; few clean sand grains; few old worm casts; few medium pores; few dark organic streaks-old roots; horizon sampled; pH 7.5; non-effervescent; clear smooth boundary. SAMPLE 99-OK-073-1

B1b--495 to 554 cm; brown (7.5YR 5/4) fine sand; few fine distinct strong brown (7.5YR 5/6) rhizospheres; weak medium subangular blocky structure parting to weak fine subangular blocky structure; slight platy structure that may be weathered cross-bedding, tilted; common clean sand grains; common fine pores; few medium pores; pH 7.5; non-effervescent; gradual smooth boundary.

B2b--554 to 589 cm; light brown (7.5YR 6/4) fine sand; common fine faint pink (7.5YR 7/4) vertical streaks of bleached sand grains; few fine distinct yellowish red (5YR 5/6) redox concentrations; weak medium subangular blocky structure parting to weak fine subangular blocky structure; many fine pores; common medium pores; few coarse pores; few old root channels; pH 7.5; non-effervescent; gradual smooth boundary.

B3b--589 to 614 cm; yellowish red (5YR 5/6) loamy fine sand; common medium distinct pinkish gray (5YR 7/2) vertical redox depletions, that are old root channels; moderate coarse prismatic structure parting to moderate medium subangular blocky structure; soft, very friable; many fine pores; common medium pores;

common coarse pores; slightly brittle; common clean sand grains; pH 7.5; non-effervescent; gradual smooth boundary, grading through fine sandy loam.

2Btb--614 to 655 cm; coarsely mottled brown (7.5YR 4/4) and light gray (10YR 7/2) clay loam; hard, firm; moderate medium prismatic structure parting to moderate fine subangular blocky structure; many distinct clay films on ped faces; few fine black bodies; many fine pores; many medium pores; few very fine concretions of calcium carbonate; few fine gravel; many old root channels; pH 7.8; non-effervescent; clear smooth boundary.

2Btkb--655 to 711 cm; coarsely mottled brown (7.5YR 4/4) and light gray (10YR 7/2) clay loam; hard, firm; moderate medium prismatic structure parting to moderate fine subangular blocky structure; many distinct clay films on ped faces; few fine black bodies; many fine pores; many medium pores; many very fine concretions of calcium carbonate; few fine concretions of calcium carbonate; common pores filled with films of calcium carbonate; few fine gravel; many old root channels; pH 8.0; non-effervescent.

98-OK-073-4
Hajek Ranch
Sept. 25, 1998
Pit on stream bank.
Water table--325 cm
N 36° 08' 36.50"
W 098° 09' 20.26"
Notes: Profile has overblown A, A1, AC, Ab, Cb1, Cb2.

A1--0 to 10 cm; very dark grayish brown (10YR 3/2) loamy fine sand; strong medium subangular blocky structure parting to moderate fine platy structure; hard, very friable; many fine roots; common fine worm casts; repels water for a time; pH 7.0; non-effervescent; clear smooth boundary.

A2--10 to 46 cm; dark brown (7.5YR 4/2) fine sand; strong coarse prismatic structure parting to moderate coarse subangular blocky structure; hard, very friable; many fine roots; common worm casts; few fine concretions of calcium carbonate; few snail shells; pH 7.0; non-effervescent; gradual wavy boundary.

AC--46 to 91 cm; brown (7.5YR 4/4) fine sand; moderate coarse prismatic structure parting to moderate coarse subangular blocky structure; slightly hard, very friable; few fine roots; few medium roots; few fine pores; few medium pores; many worm casts filled with A material; common fine concretions of calcium carbonate, few snail shells; pH 7.8; non-effervescent; clear smooth boundary.

Ab--91 to 112 cm; brown (7.5YR 4/3) fine sand; weak coarse subangular blocky structure parting to single grained; slightly hard, very friable; common fine pores; few medium pores; common fine roots; common inclusions of above horizon mixed in; few krotovina; pH 7.8; non-effervescent; clear wavy boundary.

ACb--112 to 198 cm; reddish yellow (7.5YR 6/6) fine sand; weak coarse prismatic structure parting to single grained; soft, loose; few fine roots; common fine pores; few medium pores; few fine black streaks of organic matter (old roots); pH 8.0; non-effervescent; gradual wavy boundary.

Cb--198 to 254 cm; very pale brown (10YR 7/3) fine sand; few fine distinct strong brown (7.5YR 5/8) redox accumulations and rhizospheres; few fine distinct yellowish red (5YR 5/8) rhizospheres; weak coarse prismatic structure parting to single grained; slightly hard, very friable; few krotovina of mixed material, 8 cm in diameter, averaging fine sandy loam, with some dark grayish brown (10YR 4/2) material; no visible cross-bedding in pit, could be weathered out; few medium root channels filled with dark brown (7.5YR 4/2) loamy fine sand; few very fine black bodies; pH 8.0; non-effervescent; abrupt wavy boundary.

2Ab--254 to 264 cm; reddish brown (5YR 4/4) fine sandy loam; few medium distinct brown (7.5YR 5/2) redox depletions; weak medium subangular blocky structure parting to weak fine subangular blocky structure; slightly hard, very friable; few medium pores; common fine pores; common worm casts or old root channels filled with material from above; pH 8.0; non-effervescent; clear wavy boundary.

2Bt1b--264 to 287 cm; dark grayish brown (10YR 4/2) heavy sandy clay loam; common fine distinct strong brown (7.5YR 5/6) redox accumulations; common medium faint grayish brown (10YR 5/2) redox depletions; few medium distinct gray (10YR 6/1) redox depletions only along root channels; moderate medium subangular blocky structure parting to strong fine subangular blocky structure; hard, firm; common fine black bodies; horizon is slightly brittle; few roots; many fine pores; few very fine pores; common distinct clay films on faces of peds; few clean sand grains; pH 8.0; non-effervescent; clear smooth boundary.

2Bt2b--287 to 310 cm; brown (7.5YR 5/4) fine sandy loam; moderate medium subangular blocky structure parting to moderate fine subangular blocky structure; common fine faint strong brown (7.5YR 5/8) redox accumulations; common fine distinct yellowish red (5YR 4/6) redox accumulations; common medium distinct grayish brown (10YR 5/2) redox depletions; few distinct clay films on faces of peds; many fine pores; few medium pores; few very fine black bodies; pH 8.0; non-effervescent; clear smooth boundary.

2Cb--310 to 340 cm; brown (7.5YR 5/4) loamy fine sand; massive; pH 8.0; non-effervescent; water table in this horizon.

340 to 417 cm; coarsely mottled gray (10YR 6/1), grayish brown (10YR 5/2), and strong brown (7.5YR 4/6) fine sandy loam.

417 to 457 cm; coarsely mottled grayish brown (10YR 5/2) and brown (7.5YR 4/4) sandy clay loam.

457 to 610 cm; grayish brown (10YR 5/2) sandy clay loam; total depth 610 cm.

98-OK-073-5
Hajek Ranch
Sept. 30, 1998
N 36 ° 08' 39.23"
W 098 ° 09' 19.01"
Water table--356 cm
Notes: Interdune position just west of site 8-20-98.

A--0 to 20 cm; dark brown (7.5YR 3/2) loamy fine sand; moderate fine platy structure in the upper 8 cm, moderate fine subangular blocky structure below; hard, very friable; common fine roots; poorly sorted, mostly fine sand, some very fine sand few medium sand grains, no coarse, pH 7.5; non-effervescent; clear smooth boundary.

AC1--20 to 76 cm; dark brown (7.5YR 3/3) loamy fine sand; moderate coarse prismatic structure parting to moderate coarse and medium subangular blocky structure; hard, very friable; common fine roots; common fine pores; few worm casts; poorly sorted, mostly fine sand, some very fine sand few medium sand grains, no coarse, pH 7.5; non-effervescent; clear smooth boundary.

AC2--76 to 97 cm; brown (10YR 4/3) loamy fine sand; weak coarse prismatic structure parting to weak coarse subangular blocky structure; slightly hard, loose; few fine roots; common very fine pores; few worm casts; few poorly sorted, mostly fine sand, some very fine sand few medium sand grains, no coarse, clean sand grains; pH 7.5; non-effervescent; clear smooth boundary.

C--97 to 157 cm; light yellowish brown (10YR 6/4) fine sand; soft, loose; few fine roots; few very fine pores; poorly sorted, mostly fine sand, some very fine sand few medium sand grains, no coarse; few faint cross-bedding observed in fresh sample; pH 7.5; non-effervescent; clear smooth boundary.

2Ab--157 to 175 cm; reddish brown (5YR 4/4) fine sandy loam; moderate fine and medium subangular blocky structure; hard, friable; no roots; common worm casts, filled with lighter material from above; few faint clay films (could be a remnant of AB horizon); common very fine pores; pH 7.5; non-effervescent; clear smooth boundary.

2Bt1b--175 to 203 cm; brown (7.5YR 5/4) sandy clay loam; common fine distinct pinkish gray (7.5YR 6/2) redox depletions; common fine distinct reddish yellow (7.5YR 6/6) redox accumulations; moderate medium prismatic structure parting to strong medium and fine subangular blocky structure; hard, firm; many distinct dark brown (7.5YR 4/2) clay films on ped faces; common fine black stains in old root channels; common fine pores; pH 8.0; non-effervescent; gradual smooth boundary.

2Bt2b--203 to 229 cm; brown (7.5YR 4/4) loam; common fine distinct brown (7.5YR 5/2) redox depletions along root channels; moderate medium prismatic structure parting to moderate medium and fine subangular blocky structure; hard, friable; common distinct brown (7.5YR 5/4) clay films on faces of peds; few clean sand grains in old root channels; few black stains; common fine pores; few medium pores; common coarse pores; pH 8.0; non-effervescent; gradual smooth boundary.

2Bt3b--229 to 305 cm; brown (7.5YR 4/4) loam; common fine distinct pinkish gray (7.5YR 6/2) redox depletions along root channels; moderate medium prismatic structure parting to moderate fine subangular blocky structure; hard, friable; few distinct brown (7.5YR 4/4) clay films on faces of peds; common very fine pores; common fine pores; less clay than above; pH 7.8; non-effervescent; gradual smooth boundary.

2BC--305 to 518 cm; yellowish red (5YR 4/6) fine sandy loam; common fine distinct pink (7.5YR 7/3) redox depletions; moderate medium prismatic structure parting to moderate fine and medium subangular blocky structure; slightly hard, friable; few fine roots; few very fine pores; few fine pores; structure becomes obscure below water table; mottles tend to run along ped faces and old root channels; pH 8.0; effervescent in spots at the top, becoming effervescent continuous and strongly effervescent below 396 cm; clear smooth boundary.

2C--518 to 548 cm; yellowish red (5YR 4/6) loam to sandy clay loam; few medium distinct pinkish gray (7.5YR 6/2) redox depletions; massive (from augur); few fine roots; few fine gravels; few medium concretions of calcium carbonate; common fine concretions of calcium carbonate; pH 8.0; strongly effervescent; clear smooth boundary.

2C2--548 to 914 cm; stratified yellowish red (5YR 4/6) 75% coarse loamy sand and 25% clay; the clay strata are up to 25 cm thick, and have a few soft shale fragments (local origin); coarse loamy sand has up to 5% fine gravel; clay has a few medium concretions of calcium carbonate; at 914 cm formation became too coarse to get a sample; strongly effervescent; pH 8.0.

98-OK-073-6
Sept. 1, 1998
Hajek Ranch
N 36 ° 08' 39.96"
W 098 ° 09' 13.21"
Water table--175 cm
Next to creek at north boundary of section 10.

Profile:

A--0 to 15 cm; very dark grayish brown (10YR 3/2) loam; common fine distinct pinkish gray (10YR 6/2) redox depletions; moderate fine subangular blocky structure parting to moderate medium granular structure; hard, friable; many fine roots; common fine pores; pH 8.0; effervescent; clear smooth boundary.

C1--15 to 41 cm; brown (10YR 5/3) loamy fine sand; few fine distinct yellowish brown (10YR 5/6) redox accumulations; moderate medium and fine subangular blocky structure; many fine bedding planes; many fine roots; common worm casts; pH 8.0; effervescent; clear smooth boundary.

C2--41 to 69 cm; brown (10YR 5/3) fine sand; common medium distinct yellowish brown (10YR 5/6) redox accumulations; single grained; common fine roots; common worm casts; faint stratifications; pH 8.0; effervescent; abrupt smooth boundary.

2Ab--69 to 97 cm; very dark grayish brown (10YR 3/2) loamy fine sand; common fine distinct yellowish brown (10YR 5/6) redox accumulations; moderate medium prismatic structure parting to moderate medium subangular blocky structure; common worm casts, some filled with lighter material from above; common fine pores; pH 8.0; effervescent; clear smooth boundary.

2Btk1b--97 to 155 cm; strong brown (7.5YR 4/6) clay loam; few fine faint grayish brown (10YR 5/2) redox depletions; few medium distinct strong brown (7.5YR 5/8) redox accumulations in lower part; strong medium prismatic structure parting to strong fine subangular blocky structure; hard, firm; many distinct dark brown (7.5YR 4/2) clay films on ped faces; common fine roots; common fine pores; few very fine pores; common fine concretions of calcium carbonate; pH 8.0; effervescent in spots; gradual smooth boundary.

2Btkb2--155 to 206 cm; brown (7.5YR 4/3) clay loam; many coarse distinct gray (10YR 5/1) redox depletions, vertically aligned; common fine distinct yellowish brown (10YR 5/6) redox accumulations; moderate medium prismatic structure parting to moderate medium and fine subangular blocky structure; hard, firm; common fine roots; common distinct dark brown (7.5YR 4/2) clay films on faces of peds; few fine pores; few very fine pores; few medium pores; common medium black bodies; common fine concretions of calcium carbonate; pH 8.0; effervescent in spots; clear smooth boundary.

2BC1b--206 to 254 cm; coarsely mottled brown (7.5YR 4/3) and yellowish red (5YR 4/6) loam; very soft, poor sample; pH 8.0; effervescent in spots.

2BC2b--254 to 335 cm; yellowish red (5YR 4/6) loam; common fine distinct gray (10YR 5/1) redox depletions in old root channels; moderate medium prismatic structure parting to moderate coarse subangular blocky structure; hard, friable; few very fine pores; common black streaks; few worm casts; pH 8.0; non-effervescent; at this depth core is lost and have to augur - will describe samples at specific depths.

366 cm; yellowish red (5YR 5/6) fine sandy loam; pH 8.0.

465 cm; yellowish red (5YR 5/6) loamy fine sand; pH 8.0.

488 cm; yellowish red (5YR 5/6) loamy fine sand; common medium distinct pinkish gray (5YR 6/2) redox depletions; pH 8.0.

610 cm; yellowish red (5YR 4/6) fine sandy loam and very fine sandy loam; pH 8.0; strongly effervescent.

640 to 701 cm; yellowish red (5YR 4/6) clay loam and silty clay loam; common very fine concretions of calcium carbonate; pH 8.0; strongly effervescent.

853 cm; yellowish red (5YR 4/6) very fine sandy loam; pH 8.0; non-effervescent.

945 cm; yellowish red (5YR 4/6) fine sandy loam; many coarse sand grains; pH 8.0; non-effervescent.

1113 cm; reddish brown (5YR 4/3) fine sandy loam; pH 8.0; effervescent.

1158 cm; grayish brown (10YR 5/2) fine sandy loam; pH 8.0; non-effervescent.

98-OK-073-7
Hajek Ranch
Sept. 30, 1998
N 36 ° 08' 39.23"
W 098 ° 09' 16.81"
Water table--284 cm
Interdune, west side of creek.

A--0 to 25 cm; dark brown (7.5YR 3/2) heavy loamy fine sand; moderate fine subangular blocky structure parting to weak medium granular structure; slightly hard, very friable; many fine roots; common very fine pores; common worm casts; clear smooth boundary.

Bw1--25 to 56 cm; brown (7.5YR 4/3) loamy fine sand; few medium faint strong brown (7.5YR 5/6) redox accumulations; weak medium prismatic structure parting to moderate fine subangular blocky structure; slightly hard, very friable; common very fine pores; few medium pores; few worm casts; clear smooth boundary.

Bw2--56 to 97 cm; brown (7.5YR 4/3) loamy fine sand; common fine faint strong brown (7.5YR 5/6) redox accumulations; moderate coarse prismatic structure parting to moderate medium and fine subangular blocky structure; hard, very friable; brittle when dry; few fine roots; common fine pores; common medium pores; few very fine pores; few clean sand grains;

Ab--97 to 132 cm; brown (10YR 5/3) fine sand to loamy fine sand; few fine faint strong brown (7.5YR 5/6) redox accumulations; weak medium and fine subangular blocky structure; hard, very friable; brittle when dry; few fine roots; few fine pores; few very fine pores; clear smooth boundary.

Bwb--132 to 160 cm; yellowish brown (10YR 5/4) loamy fine sand; common medium faint grayish brown (10YR 5/2) redox depletions; moderate medium prismatic structure parting to moderate fine subangular blocky structure; some clay bridging; few faint clay films on faces of peds; common fine pores; few very fine pores; few clean sand grains; clear smooth boundary.

2Ab--160 to 173 cm; brown (7.5YR 5/4) fine sandy loam; common fine faint brown (7.5YR 5/2) redox depletions; moderate coarse prismatic structure parting to moderate medium and fine subangular blocky structure; hard, friable; few fine roots; common fine pores; few medium pores; few worm casts; few very fine concretions of calcium carbonate; few very fine black bodies; pH 7.8; effervescent; clear smooth boundary.

2Bt1b--173 to 188 cm; brown (7.5YR 4/4) fine sandy loam; moderate coarse prismatic structure parting to moderate fine and medium subangular blocky structure; hard, friable; common coarse sand grains; few fine roots; few worm casts; common fine pores; common very fine pores; few medium pores; few distinct dark brown (7.5YR 4/2) clay films on faces of peds; common fine concretions of calcium carbonate; pH 8.0; effervescent; clear smooth boundary.

2Bt2b--188 to 213 cm; finely mottled brown (7.5YR 5/4), brown (7.5YR 5/3), and strong brown (7.5YR 5/6) sandy clay loam; few fine distinct grayish brown (10YR 5/2) redox depletions on ped faces; moderate coarse prismatic structure parting to moderate fine subangular blocky structure; hard, friable; few worm casts; few medium pores; common fine pores; common very fine pores; common distinct clay films on faces of peds; few clean sand grains; pH 8.0; effervescent; gradual smooth boundary.

2Bt3b--213 to 279 cm; brown (10YR 4/3) clay loam; common medium distinct yellowish brown (10YR 5/6) redox accumulations; strong coarse prismatic structure parting to strong fine subangular blocky structure; hard, firm; few fine roots; few medium roots; common fine pores; common very fine pores; common medium pores; many distinct grayish brown (10YR 5/2) clay films on ped faces; few medium concretions of calcium carbonate; common very fine soft bodies of calcium carbonate; discontinuously effervescent, ranging from non-effervescent to strongly effervescent; gradual smooth boundary.

2Bt4b--279 to 345 cm; brown (7.5YR 5/4) clay loam; common medium distinct reddish yellow (7.5YR 6/6) redox accumulations; strong coarse prismatic structure parting to strong medium subangular blocky structure; hard, firm; few medium pores; few very fine pores; many fine pores; common distinct clay films on faces of peds; many old root channels, most coated with films of calcium carbonate; patchy strongly effervescent on faces of peds; non-effervescent with few effervescent spots in interior of peds; few medium black bodies; pH 8.0; gradual smooth boundary.

2Bt5b--345 to 424 cm; brown (7.5YR 4/4) loam; common medium faint brown (7.5YR 5/3) redox depletions; moderate coarse prismatic structure parting to moderate medium and fine subangular blocky structure; hard, friable; few medium pores; many fine pores; common very fine pores; common films of calcium carbonate in pores; strongly effervescent in pores; few distinct clay films on faces of peds; , effervescent in spots; common coarse sand grains; one 5 cm krotovina of dark grayish brown (10YR 4/2) clay loam.

424 to 470 cm; sample very soft, ruined and lost.

2BC1b--470 to 508 cm; yellowish red (5YR 5/6) sandy clay loam; few fine distinct brown (7.5YR 5/2) redox depletions; moderate coarse prismatic structure parting to moderate medium subangular blocky structure; hard, firm; common fine pores; common very fine pores; common fine black bodies; pH 8.0; non-effervescent; clear smooth boundary.

2BC2b--508 to 541 cm; yellowish red (5YR 5/6) fine sandy loam; common medium distinct pinkish gray (7.5YR 6/2) redox depletions; moderate coarse prismatic structure parting to moderate medium subangular blocky structure; hard, friable; common medium black bodies; few old roots; common fine pores; few very fine pores; pH 8.0; non-effervescent; abrupt smooth boundary.

3BC1--541 to 609 cm; light yellowish brown (2.5Y 6/3) sandy clay loam; common medium distinct light brown (7.5YR 6/4) redox accumulations; weak coarse prismatic structure parting to moderate medium subangular blocky structure; hard, firm; many fine pores; few medium pores; common fine black bodies, some spherical, some dendritic; few reddish yellow (5YR 6/6) bodies up to 5 cm diameter; at 582 cm a zone of many fine concretions of calcium carbonate, and violently effervescent in this zone; no visible clay films; common coarse sand grains; pH 8.0; non-effervescent; clear smooth boundary.

3BC2--609 to 693 cm; pale brown (10YR 6/3) fine sandy loam; few fine distinct strong brown (7.5YR 4/6) redox accumulations; moderate coarse prismatic structure parting to moderate medium subangular blocky structure; hard, friable; few fine black bodies; few old roots that are black and rotten; common fine pores; common very fine pores; pH 8.0; non-effervescent; gradual smooth boundary.

3BC3--693 to 746 cm; yellowish red (5YR 4/6) heavy fine sandy loam; 5 percent fine gravel; common medium distinct light brown (7.5YR 6/3) redox depletions; moderate coarse prismatic structure parting to moderate medium subangular blocky structure; few medium concretions of calcium carbonate; few bedding planes of lighter fine sandy loam; pH 8.0; effervescent in spots; clear smooth boundary.

3BC4--746 to 782 cm; yellowish red (5YR 5/6) fine sandy loam; moderate coarse prismatic structure parting to moderate fine subangular blocky structure; few large concretions of calcium carbonate; few large disseminated masses of soft calcium carbonate; common fine pores; few fine black bodies; few quartz gravels.

98-OK-073-8
Hajek Ranch
Oct. 6, 1998
N 36 ° 08' 30.11"
W 098 ° 09' 24.05"
Water table--290 cm

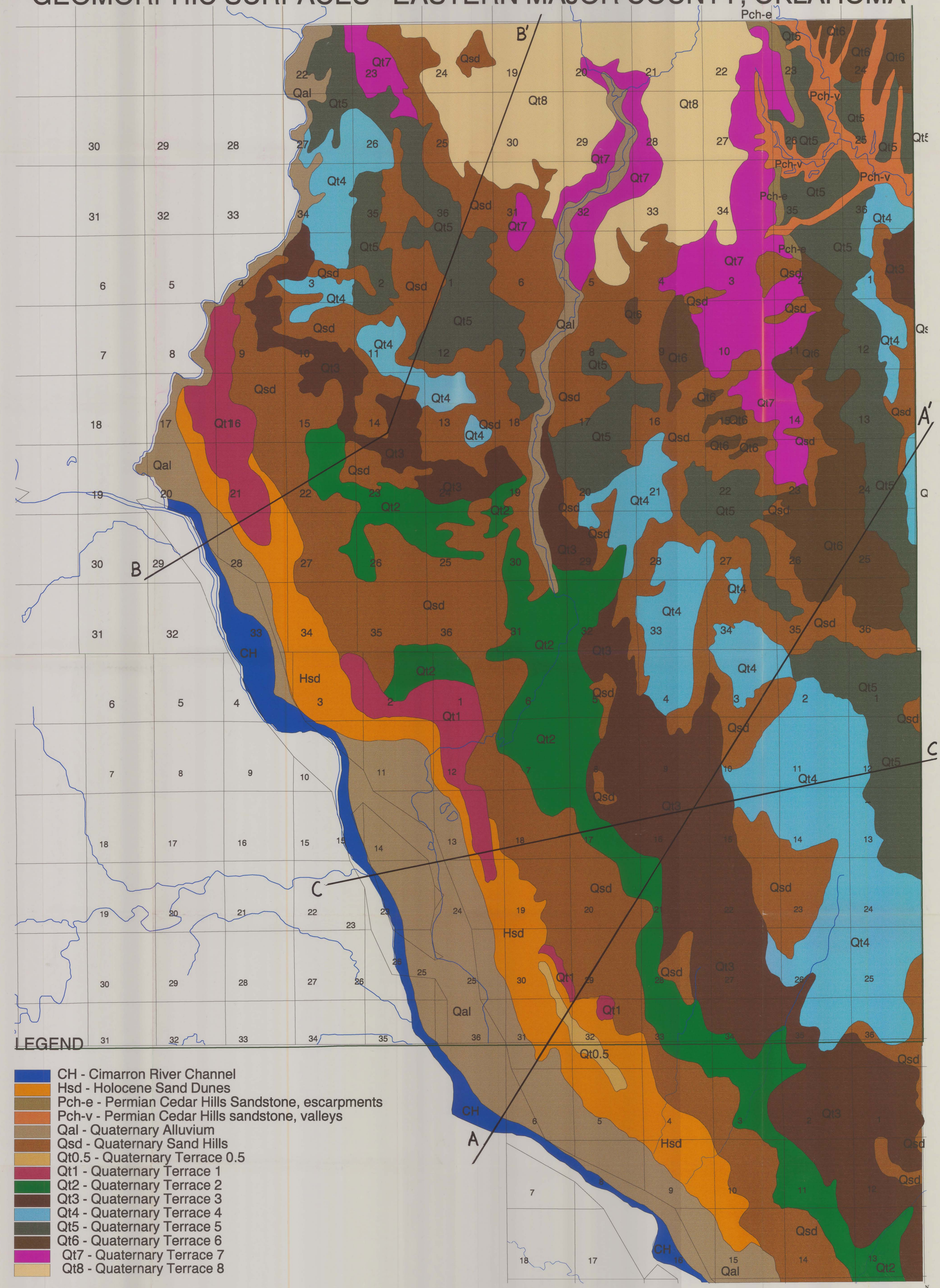
Core, south of last site.
15 meters east of section line, 30 meters north of creek.
Notes: Across creek from 8-25-98 creek bank location, almost identical to 8-25-98 location. Horizon sequence and depth to buried A is within 10 cm of correspondence. At depths below 6 meters yellowish red (5YR 4/6) fine sandy loam is encountered, similar to other sites.

At 12 meters, red (2.5YR 5/6) silty clay is encountered.

No other remarkable features.

Figures Three and Eight.

GEOMORPHIC SURFACES - EASTERN MAJOR COUNTY, OKLAHOMA

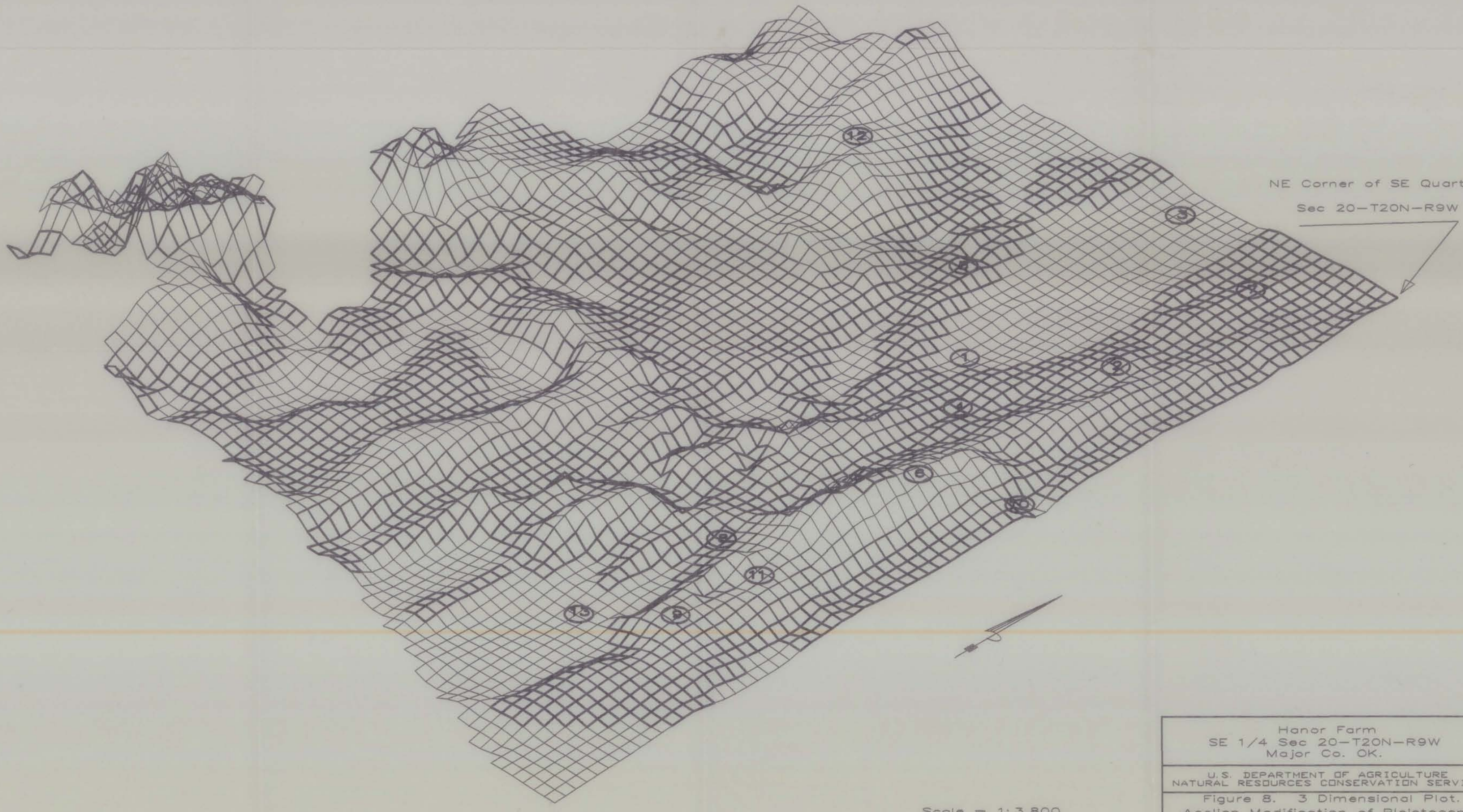


LEGEND

- 🟦 CH - Cimarron River Channel
- 🟧 Hsd - Holocene Sand Dunes
- 🟫 Pch-e - Permian Cedar Hills Sandstone, escarpments
- 🟧 Pch-v - Permian Cedar Hills sandstone, valleys
- 🟫 Qal - Quaternary Alluvium
- 🟫 Qsd - Quaternary Sand Hills
- 🟨 Qt0.5 - Quaternary Terrace 0.5
- 🟥 Qt1 - Quaternary Terrace 1
- 🟩 Qt2 - Quaternary Terrace 2
- 🟫 Qt3 - Quaternary Terrace 3
- 🟦 Qt4 - Quaternary Terrace 4
- ⬛ Qt5 - Quaternary Terrace 5
- 🟫 Qt6 - Quaternary Terrace 6
- 🟪 Qt7 - Quaternary Terrace 7
- 🟨 Qt8 - Quaternary Terrace 8

NAD83 GRS80 UTM14
USDA NRCS STILLWATER   OKLAHOMA GIS SECTION October 1999
Geomorphic Mapping by Gregory F. Scott

AEOLIAN MODIFICATION OF PLEISTOCENE TERRACES ALONG THE CIMARRON RIVER IN MAJOR COUNTY, OKLAHOMA: FIGURE 3.



Hanor Farm
SE 1/4 Sec 20—T20N—R9W
Major Co. OK.

U.S. DEPARTMENT OF AGRICULTURE
NATURAL RESOURCES CONSERVATION SERVICE

Figure 8. 3 Dimensional Plot.
Aeolian Modification of Pleistocene
Terraces Along the Cimarron River in
Major County, OK. Gregory F. Scott

VITA

Gregory Fisher Scott

Candidate for the Degree of

Master of Science

Thesis: AEOLIAN MODIFICATION OF PLEISTOCENE TERRACES ALONG THE CIMARRON RIVER IN MAJOR COUNTY, OKLAHOMA

Major Field: Environmental Science - Geology

Biographical:

Personal Data: Born in Oklahoma City, Oklahoma, on July 6, 1954, the son of Arthur W. and Betty D. Scott.

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Experience: Employed by Oklahoma State University, Department of Agronomy as an undergraduate assistant, 1972 to 1976. Employed by the USDA-Natural Resources Conservation Service as a soil scientist, 1976 to present.

Professional Memberships: Soil Science Society of America, Geological Society of America, Professional Soil Scientists Association of Oklahoma, American Geophysical Union.